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# Physical Characteristics of Some Northern California Brush Fuels

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**Cover:** Snowbrush (*Ceanothus velutinus* Dougl.), a major brush fuel in northern California, grows on the lower slopes of Mount Shasta.

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Brush species make up much of the fuel load in forested wildlands. Basic physical and chemical characteristics of these species influence ease of ignition, rate of fire spread, burning time, and fire intensity. Quantitative knowledge of the variations in brush characteristics is essential to progress in fire control and effective use of fire in wildland management. Five shrub species common to northern California brush fuels were analyzed in this study—greenleaf manzanita, snowbrush, mountain whitethorn, chinkapin, and bitter cherry. Quantitative data on ash content, fuel density, solvent extractives, surface-to-volume ratios, heating values, fuel loading by size classes of material, relative amounts of dead and living fuels, vertical distribution of fuel elements, and amount of litter fuel are provided.

*Retrieval Terms:* fuel characteristics, fuel loading, brush fuels, wildland fuels

Thermal energy from burning fuel provides the basic driving force for the fire phenomena observed in wildland fire. The physical characteristics of the wildland fuel array and of the fuel elements in the array determine the amount of energy available and the rate at which it is released as the fuel burns. Fuels such as small twigs and foliage, for example, release their energy quickly. But large logs usually burn slowly, and may require hours to release all of their potential energy.

In varying degree, fuel characteristics influence ease of ignition, rate of spread, burning time, and fire intensity. Quantitative knowledge of the variations in fuel characteristics and the effect of the variations on fire behavior, therefore, are essential to progress in wildland fire control and for effective use of fire as a wildland management tool. How variations in most fuel characteristics affect fire behavior is known in a general way. But few explicit relationships have been established, particularly for combinations of fuel characteristics as they appear naturally. Procedures for estimating fuel characteristics are not well developed: knowledge of the characteristics and range of variation for many of the common wildland fuels is scant.

In spring and early summer, living material in the brush has a high moisture content and a brushfield will burn slowly, if at all. But as the dry summer typical of interior northern California progresses, the brush becomes dormant and its moisture content drops drastically. It then becomes highly flammable and a major fire hazard.

Brush fuels cover extensive areas of the foothills and mountains of northern California. The fuel type consists of numerous species, most of which are evergreen. Large areas of a single species are not uncommon, but a mixture of two to several species is found more frequently. The fuel type is a climax vegetative cover for many sites, often a natural understory in open stands of coniferous timber. Many of the brushfields, however, result from shrub species taking over a site when extensive areas of timber are removed by logging or fire. Because of the competition from dense brush, natural regeneration of timber species is slow, and may not take place at all unless the brush is removed. Regeneration is especially slow when logging is followed by fire, or when an area burns more than once.

This report describes the results of a study of the physical characteristics of five northern California brush species—greenleaf manzanita (*Arctostaphylos patula* Green), snowbrush (*Ceanothus velutinus* Dougl.), chinkapin (*Castanopsis sempervirens* [Kell.] Dudl.), mountain whitethorn (*Ceanothus cordulatus* Kell.), and bitter cherry (*Prunus emarginata* Dougl. ex Eaton). Data concerning the various fuel bed characteristics were collected from 28 mil-acre (0.0004-ha) plots between 1936 and 1939 as part of an early study of the rate of fire spread in northern California brush. The study site, on the lower eastern slopes of Mt. Shasta in Shasta County, is at an elevation of 4000 to 6000 ft (1200 to 1800 m). The original study was concerned primarily with fuel loading by size class of material, proportion of live and dead material, and vertical distribution of the fuel. In 1974, additional material was collected from the study area for laboratory determination of heating values, density, ash content, and amount of solvent extractives in the various fuel categories.

## SPECIES CHARACTERISTICS

### *Greenleaf Manzanita*

Greenleaf manzanita is a widely branching shrub with crooked, stout branches and branchlets. Shrub height usually varies between 3 and 8 ft (0.9 and 2.4 m), with occasional taller specimens on good sites. It is one of the most prevalent shrub species in the northern California brush fuel type, and the principal species in the study area. Greenleaf manzanita frequently grows in extensive pure stands, and often is the most abundant species in mixed brush stands.

### *Snowbrush*

Snowbrush usually grows as a rounded shrub with several to many stems from the base. The shrub ordinarily reaches a height of 3 to 6 ft (0.9 to 1.8 m), but occasionally may grow to 12 ft (3.7 m). Because the foliage is waxy and often sticky, the shrub is sometimes called sticky laurel or mountain balm. Snowbrush frequently is found in extensive pure stands at elevations above 5000 ft (1524 m), and often grows in mixture with greenleaf manzanita.

### *Chinkapin*

Chinkapin is a spreading shrub with many flexible stems from the base, and long and flexible branchlets. The main stems often are almost prostrate for a considerable distance from the base and, consequently, shrub height is variable, ranging from 1 to 8 ft (0.3 to 2.4 m). Foliage is often sparse. Chinkapin frequently grows in mixture with greenleaf manzanita and snowbrush. It may also be found in pure stands, but such stands are less extensive than those of greenleaf manzanita or snowbrush.

### *Mountain Whitethorn*

Mountain whitethorn is a low, widely spreading shrub with smooth whitish bark and many short, rigid branchlets. Leaves are small and numerous. In the study area, shrub height ranged from 2 to 5 ft (0.6 to 1.5m). The species often grows in pure stands and frequently forms almost impenetrable thickets.

### *Bitter Cherry*

Bitter cherry is a deciduous shrub, usually 3 to 8 ft (0.9 to 2.4 m) tall. Long and slender branches grow from the main stem. Bitter cherry is most often a minor component of the northern California brush fuel type, but occasionally grows in small but dense thickets.

## FUEL ELEMENT CHARACTERISTICS

### *Ash Content*

The amount of ash or minerals in vegetation can affect how well the material burns. One study showed that unleached corn plants would not sustain flaming, but naturally leached plants burned readily (Broido and Nelson 1964). This difference was attributed to the ash and phosphorus content of the material. The unleashed plants contained 11.4 percent ash and 0.53 percent phosphorus. The leached plants contained 3.7 percent ash and 0.17 percent phosphorus. In two other studies, pyrolysis rate, volatile production, and other thermal characteristics of several species of plant material were found to be related to the effective mineral content of the material (Philpot 1968, 1970). Another study showed that the moisture content of living vegetation with high ash content tends to be higher than that with low ash content (Nord and Countryman 1971).

In this study, the ash contents of the brush species were determined for the foliage and for various sizes of dead and live woody material. Duplicate samples of 6 to 10 g were first dried in a vacuum desiccator for 48 h at 156°F (69° C) to determine the sample dry weight. The samples were then placed in a muffle furnace heated to 600° F (316° C), and kept at this temperature until they stopped smoking (about 2 h). The furnace temperature was then raised to 1100° F (593° C), and the samples processed at this temperature for 6 h. The samples were cooled, examined for complete ashing, and replaced in the furnace and dried for 60 minutes at 300° F (149° C). After a brief cooling period, the samples were removed from the furnace and weighed immediately. Percent ash in each sample was calculated from its final weight and its original dry weight.

Shrub foliage had the largest amount of ash and showed the greatest variation among species, ranging from 3.0 percent for chinkapin to 8.5 percent for bitter cherry:

| Species | Foliage ash content |
|---|---|
| | *Percent* |
| Chinkapin | 3.0 |
| Greenleaf manzanita | 3.9 |
| Snowbrush | 4.5 |
| Mountain whitethorn | 5.6 |
| Bitter cherry | 8.5 |

Ash content of the woody material was low and did not vary consistently among species or size class of material. Average ash content of the live woody material was 1.6 percent with a coefficient of variation of 25.2 percent. Ash content of the dead material was only slightly lower, averaging 1.4 percent. Variability of the dead fuel ash content was greater, however, with a coefficient of variation of 37.1 percent. The greater variation probably resulted from differences in the amount of weathering among individual samples rather than from variation among species or size of material.

### *Fuel Density*

Density—weight per unit volume—of the fuel elements substantially affects ease of ignition and rate of burning of wildland fuels. Fuels with low density, for example, can be ignited in a shorter time for a given amount of heat, or with less heat in the same time, than can fuels with high density. Rate of spread in small experimental fires decreased as fuel density increased (Fons 1946). The same effect was found also in laboratory crib fires burning rectangular sticks of white fir (Fons 1960).

Densities of the foliage and different size classes of woody material were determined for the five shrub species of this study on the basis of green volume and dry weight. Leaf dimensions of a random sample of 100 leaves from each species were used to measure volume of the foliage. The water displacement method, with 15 samples for each size class of each species, was used to determine volume of woody material. To obtain dry weights, the samples were oven-dried at 212°F (100° C).

Density of the foliage varied widely among species, and ranged from 5.6 lb per ft$^3$ (0.05 g/cm$^3$) for bitter cherry to 54.7 lb per ft$^3$ (0.88 g/cm$^3$) for greenleaf manzanita. Variation among species was considerably less for the living woody material, and density increased with size of material for all species *(table 1)*. Density of the dead woody fuel was highly variable, and was evidently strongly influenced by the relative amount of weathering and decay in individual samples. In general, however, density of the dead fuel appeared to be about 90 percent of that of living fuel.

Table 1—*Living fuel density, by species and fuel category*

| Species | Foliage | Woody fuel (inches diameter) ≤0.25 | 0.26 to 0.50 | 0.51 to 1.00 | >1.00 |
|---|---|---|---|---|---|
| | | | *lb/ft$^3$* | | |
| Greenleaf manzanita | 54.7 | 38.9 | 41.3 | 44.5 | 46.4 |
| Chinkapin | 39.9 | 29.2 | 29.9 | 31.4 | [1] |
| Mountain whitethorn | 21.1 | 37.0 | 37.2 | 37.7 | 39.1 |
| Bitter cherry | 5.6 | 32.1 | 32.9 | 34.6 | 38.5 |

[1] No data

## Solvent Extractives

Waxes, oils, terpenes, and fats are usually found in wildland fuels. These substances have a higher thermal energy content than other plant constituents and, when present in significant quantities, can affect ease of ignition and amount and rate of energy release from the fuel. Pilot ignition time for both ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) and sphagnum moss (*Sphagnum* sp.) powder was increased by the removal of extractives (Mutch 1964). Guava (*Psidium guajava* L.) leaves treated with herbicide had less solvent extractives and burned more slowly than untreated leaves (Philpot and Mutch 1968). The burning rate of aspen (*Populus tremuloides* Michx.) leaves extracted with ether was slower than for untreated leaves (Philpot 1969a). Material extracted from chamise (*Adenostoma fasciculatum*) had a heating value two to three times that of unextracted material (Philpot 1969b).

The amount of material that could be extracted with acetone as a solvent was determined for the foliage and woody material of different sizes for the shrub species of this study. First ground in a Wiley mill with a 20-mesh sieve, duplicate samples of each category of material were dried in a vacuum desiccator for 48 h at 140° F (60° C) to obtain their dry weight. The samples were then distilled for 6 h by reflux distillation, allowed to soak overnight in the solvent, and then distilled for an additional 2 h. The processed material was dried for 48 h in the vacuum desiccator to drive off the acetone and to obtain the dry weight of the material. Amount of extractives was taken as the difference in the dry weights of the extracted and original material.

Except for whitethorn, foliage of the shrubs had more extractive material than did living woody fuels (*table 2*). For whitethorn, however, extractive content of the foliage was less than that of the smallest size category of the living woody material. Amount of extractives in the woody fuel tended to decrease with size of material for all species.

Dead fuel was found to have considerably less in amount of extractives than living material, and the amount varied erratically among species and size categories (*table 3*). The lower extractive content is probably the result of natural leaching and the variability in the soundness of the material—individual samples differed in the degree of weathering and incipient decay.

Table 2—*Solvent extractives in living fuels, by species and fuel category*

| Species | Foliage | Woody fuel (inches diameter) | | | |
|---|---|---|---|---|---|
| | | ≤0.25 | 0.26 to 0.50 | 0.51 to 1.00 | >1.00 |
| | *Percent* | | | | |
| Greenleaf manzanita | 16.9 | 6.2 | 4.2 | 3.6 | 3.4 |
| Snowbrush | 18.3 | 6.0 | 4.2 | 3.3 | 2.6 |
| Mountain whitethorn | 7.7 | 8.5 | 6.8 | 5.7 | 4.6 |
| Chinkapin | 26.2 | 6.2 | 4.2 | 3.1 | [1] |
| Bitter cherry | 14.9 | 6.5 | 6.1 | 4.8 | 4.92 |

[1] No data

Table 3—*Solvent extractives in dead fuels, by species and fuel category*

| Species | Woody fuel (inches diameter) | | | |
|---|---|---|---|---|
| | ≤0.25 | 0.26 to 0.50 | 0.51 to 1.00 | >1.00 |
| | *Percent* | | | |
| Greenleaf manzanita | 2.6 | 1.2 | 1.4 | 1.9 |
| Mountain whitethorn | 1.5 | 0.6 | 0.8 | 1.2 |
| Chinkapin | 4.4 | 1.4 | 2.9 | [1] |
| Bitter cherry | 1.0 | 0.5 | 1.7 | 2.7 |

[1] No data

## Surface-to-Volume Ratio

The ratio of the surface area of a piece of fuel to its volume strongly influences the combustion and flammability characteristics of the fuel. If an unburned piece of fuel is placed in a fire, heat is transferred to the fuel surface by all three methods of heat transfer—radiation, convection, and conduction. But the heat received by the fuel surface can be transferred to the interior of the fuel only by conduction, and all of the heat must go through the surface layer. The greater the surface area in relation to the fuel volume, therefore, the faster the fuel will be heated. For dead fuels, moisture gained or lost must go through the surface also. The rate at which the fuel changes in moisture content, therefore, is also affected by the surface-to-volume ratio of the fuel.

Rate of fire spread has been found to increase linearly with increase in the surface-to-volume ratio in small experimental fires for a range of ratios of 1.3 to 12 $ft^2$ per $ft^3$ (Fons 1946). Rate of spread was also found to be directly proportional to the surface-to-volume ratio in small crib fires of rectangular sticks (Fons 1960).

Investigation of the effect of various fuel parameters on ignition time of dead fuels in a muffle furnace showed that ignition time decreased with increasing surface-to-volume ratio for a range of temperatures from 850° to 1300° F (454° to 593° C) (Fons 1950). The data indicated, however, that the surface-to-volume ratio had a lesser effect as the furnace temperature increased.

Surface-to-volume ratios of wildland fuels vary over a wide range. Cylindrical fuel ⅛ inch in diameter, for example, has a surface-to-volume ratio of 383 $ft^2$ per $ft^3$ (12.6 $cm^2/cm^3$), whereas the ratio for 1-inch diameter fuel is only 48 $ft^2$ per $ft^3$ (1.6 $cm^2/cm^3$). Because foliage is usually small in diameter, such as conifer needles, or thin and flat, as in hardwood leaves, the surface-to-volume ratio of this fuel category is usually large and varies greatly among plant species. Some surface-to-volume ratios reported for foliage of different species are:

| Species: | Surface-to-volume ratio ($ft^2/ft^3$) | Reference |
|---|---|---|
| White pine | 2700 | Rothermel and Anderson (1960) |
| Ponderosa pine | 1471 | Rothermel and Anderson (1960) |
| Juniper | 861 | Countryman (1967) |
| Pinyon pine | 848 | Countryman (1967) |
| Engelmann spruce | 1652 | Brown (1970) |
| Aspen | 4260 | Brown (1970) |
| Eucalyptus | 1883 | Brown (1970) |

Table 4—*Surface-to-volume ratios for brush, by species and fuel category*

| Species | Foliage | Woody fuel (inches diameter) ≤0.25 | 0.26 to 0.50 | 0.51 to 1.00 | >1.00 |
|---|---|---|---|---|---|
| | | | $ft^2/ft^3$ | | |
| Greenleaf manzanita | 1623 | 343 | 137 | 66 | 32 |
| Snowbrush | 1771 | 320 | 133 | 70 | 41 |
| Chinkapin | 1928 | 300 | 133 | 76 | [1] |
| Mountain whitethorn | 3232 | 320 | 123 | 71 | 44 |
| Bitter cherry | 3009 | 400 | 133 | 68 | 34 |

[1] No data

The shape of a piece of fuel is often irregular, and the fuel surface frequently has ridges, depressions, cracks, and pits that affect the amount of surface area. As a result, the determination of the true surface area of wildland fuel is difficult. Despite the difficulty of obtaining precise surface area, however, useful estimates can usually be calculated from measurements of the fuel dimensions and assumption of a geometrical shape, or combination of shapes, most closely approximating that of the fuel element.

Random samples of 100 leaves of each species were used to determine the surface-to-volume ratio of the foliage. Area of individual leaves was measured with a planimeter, and the volume calculated from the area and average thickness of each leaf. Woody fuel was assumed to be cylindrical in shape. Mean diameter of the material in each size category was estimated from random samples of each category. The samples contained 75 to 100 fuel pieces as removed from the shrub in the two smallest size categories, 35 to 50 pieces in the third size category, and 15 to 25 pieces in the largest category. The average of two diameter measurements taken at right angles at each end of the fuel piece was used to obtain the mean diameter of the piece. Surface-to-volume ratios for the foliage varied considerably, but the variation for the woody material was small, especially for the larger size categories (*table 4*).

## *Heating Value*

The heating value of wildland fuel determines the total potential thermal energy available and, consequently, is a major determinant of fire behavior. Heating values of the foliage and woody material for the species in this study were determined by the standard oxygen bomb calorimetry methods of the American Society for Testing and Materials (1966).

Heating values of the woody material varied little among species, with size of material, or between live and dead fuels (*table 5*). Heating values of the foliage, however, were somewhat greater than for the woody material.

Heating values of the extractives were obtained indirectly because the quantity of extractives obtained in the distillation process was too small to determine the values accurately. The heating value of fuel material after extraction was determined, and the heating value of the extractives calculated from the amount of extractives and the difference in the heating values of the extracted and original material.

As expected, heating values of the extractives from the foliage were higher than for the untreated material and also varied considerably among species:

| Species: | Foliage extractive heating value |
|---|---|
| | *Btu/lb* |
| Greenleaf manzanita | 11,701 |
| Snowbrush | 11,942 |
| Mountain whitethorn | 15,074 |
| Chinkapin | 10,502 |
| Bitter cherry | 13,712 |

# FUEL BED CHARACTERISTICS

Brush fuel in northern California is essentially two-layered. The most prominent layer is the standing fuel—foliage and both living and dead woody material—that is supported above the ground by the main stems or trunks of the shrubs. The second layer is the litter—a more or less compact layer of dead and often partially decomposed material—under the standing fuel.

Data descriptive of brush fuel bed characteristics were derived from measurements made in the original study of 28 mil-acre (0.0004-ha) plots. The measurements included brush height, dry weight of the standing fuel by size classes, vertical distribution of fuel by size classes, and amount of litter under the standing fuel. Not all of these measurements were made for every plot, however. Of the 28 plots, 9 contained only a single species each, and 19 had two or more species. The whitethorn stand sampled was about 20 years old, but the brush in the other plots ranged in age from 40 to 45 years. The areas for plot location were arbitrarily selected to represent the general range of characteristics observed in the brushfields covering the foothills of Mt. Shasta, California. The plots were spread over several square miles, and had an elevational range of about 2000 ft (610 m).

All of the plots were square and fully covered with fuel. Plot centers in the selected areas were located by tossing a weighted

Table 5—*Heating values of brush, by species and fuel category*

| Species | Foliage | Woody fuel (inches diameter) ≤0.25 | 0.26 to 0.50 | 0.51 to 1.00 | >1.00 |
|---|---|---|---|---|---|
| | | | *Btu/lb* | | |
| Living fuel | | | | | |
| Greenleaf manzanita | 9076 | 8246 | 8212 | 8306 | 8320 |
| Snowbrush | 9081 | 8274 | 8274 | 8226 | 8230 |
| Mountain whitethorn | 8544 | 8340 | 8347 | 8335 | 8207 |
| Chinkapin | 8825 | 8494 | 8214 | 8202 | [1] |
| Bitter cherry | 8337 | 8261 | 8138 | 8171 | 8126 |
| Dead fuel | | | | | |
| Greenleaf manzanita | [1] | 8280 | 8367 | 8201 | 8429 |
| Snowbrush | [1] | 8374 | 8327 | 8255 | 8194 |
| Mountain whitethorn | [1] | 8296 | 8381 | 8258 | 8127 |
| Chinkapin | [1] | 8527 | [1] | [1] | [1] |
| Bitter cherry | [1] | 8025 | 8035 | 7975 | 7994 |

[1] No data

marker over the shoulder into the area. Eight-foot (2.4-m) iron rods were driven into the ground to mark the plot corners, and a wooden frame 6.6 ft (2 m) on a side fitted over the rods. The frame was moved down the rods and all material outside the frame removed to outline the plot dimensions in the vertical direction.

The brush within the plot boundaries was separated by fuel categories and bagged. The bagged material was then transported to the nearby laboratory for weighing. Duplicate samples of each fuel category were taken at the time of weighing for the moisture content determination needed to calculate dry weights.

## Standing Fuel Loading

Fuel loading—the weight of fuel per unit of area—largely determines the total potential thermal energy of the fuel bed. But fires in brush fuels ususally do not consume all of the potentially combustible material, except under extreme burning conditions. Living fuel is a major constituent of the standing fuel in brush, and because of its high moisture content does not burn well, or does not burn at all, by itself. The heat produced by the burning litter fuel and the dead material in the standing fuel is needed to dry the living material to the point where it will burn and add to the thermal energy output of the fire. The amount of dead fuel in the brush fuel bed, therefore, strongly influences the amount of thermal energy released and the rate at which it is produced when the brush fuel burns.

Brush fuels contain various sizes of fuel, ranging from foliage and small twigs to large main stems and trunks of shrubs. Because of their greater surface-to-volume ratio, small fuels ignite more easily and burn more rapidly than do large fuels. The relative quantities of fuels of different sizes in a brush fuel bed, therefore, are also major determinants of the amount of fuel that will burn and its rate of energy release.

## Single Species Plots

In the nine plots containing only one species each, both greenleaf manzanita and snowbrush had a considerable range in loading (*table 6*). This range possibly resulted from site differences because the plots were widely separated. The two whitethorn plots, taken from the same area, differed little in total loading.

Almost all of the foliage in the plots was living—only one greenleaf manzanita plot had any dead foliage at all. For the woody fuel, the amount of dead material exceeded that of the living in the smallest fuel size category for all species, and for all size categories for snowbrush (*table 7*). In both greenleaf manzanita and chinkapin, the proportion of living material tended to increase as the size of fuel increased, and for these species the total amount of living fuel exceeded that of the dead fuel.

Table 6—*Distribution of load on single-species plots, by species and fuel category*

| Species | Load | Foliage | Woody fuel (inches diameter) ≤0.25 | 0.26 to 0.50 | 0.51 to 1.00 | >1.00 |
|---|---|---|---|---|---|---|
| | *Tons/acre* | *Percent* | | | | |
| Greenleaf manzanita | 21.16 | 7.1 | 10.7 | 10.2 | 24.5 | 47.5 |
| Greenleaf manzanita | 45.01 | 7.1 | 20.5 | 12.6 | 21.8 | 38.0 |
| Greenleaf manzanita | 17.45 | 7.9 | 21.6 | 32.1 | 32.5 | 5.9 |
| Snowbrush | 40.91 | 5.5 | 24.4 | 21.1 | 49.0 | |
| Snowbrush | 38.51 | 3.1 | 18.9 | 30.5 | 36.5 | 11.8 |
| Snowbrush | 22.45 | 6.0 | 25.3 | 33.7 | 35.0 | |
| Mountain whitethorn | 23.75 | 4.7 | 39.5 | 32.9 | 22.9 | |
| Mountain whitethorn | 21.04 | 4.7 | 43.0 | 41.0 | 11.3 | |
| Chinkapin | 36.97 | 8.5 | 22.9 | 20.9 | 32.0 | 15.7 |

## Mixed Species Plots

The fuel loading of the mixed species plots varied widely, ranging from 11.43 to 41.22 tons per acre (25,600 to 92,400 kg/ha) *(table 8)*. Greenleaf manzanita was the predominant species in the plots, comprising more than 50 percent of the total fuel in all but three of the plots. Bitter cherry was a minor contributor to the fuel loading.

The average quantity of fuel in the three smallest size categories of the woody fuel did not vary greatly. Woody fuel

Table 7—*Distribution of dead fuel on single species plots, by species, fuel category, and plot average*

| Species | Foliage | Woody fuel (inches diameter) ≤0.25 | 0.26 to 0.50 | 0.51 to 1.00 | >1.00 | Plot average |
|---|---|---|---|---|---|---|
| | Category load *(percent)* | | | | | *Percent* |
| Greenleaf manzanita | 5.6 | 60.7 | 44.1 | 27.3 | 32.4 | 33.5 |
| Greenleaf manzanita | | 63.4 | 52.4 | 35.3 | | 27.3 |
| Greenleaf manzanita | | 61.6 | 66.0 | 40.6 | | 47.7 |
| Snowbrush | | 69.7 | 63.0 | 67.6 | | 63.4 |
| Snowbrush | | 63.0 | 61.6 | 61.6 | 76.3 | 61.7 |
| Snowbrush | | 61.3 | 61.1 | 58.0 | | 56.4 |
| Mountain whitethorn | | 57.5 | 48.6 | 88.7 | | 59.0 |
| Mountain whitethorn | | 63.5 | 45.4 | 100.0 | | 57.3 |
| Chinkapin | | 55.9 | 49.3 | 19.1 | | 34.7 |

larger than 1 inch (2.54 cm) in diameter accounted for almost 30 percent of the load, and the foliage 8.5 percent:

| Fuel category | Average percent of load | Standard deviation |
|---|---|---|
| Foliage: | 8.5 | 1.9 |
| Woody fuel: | | |
| ≤ 0.25 inch diam. | 20.6 | 4.9 |
| 0.26 to 0.50 inch diam. | 18.2 | 5.6 |
| 0.51 to 1.00 inch diam. | 22.8 | 5.5 |
| > 1.00 inch diam. | 29.8 | 11.1 |

All of the foliage was living in the mixed species plots, but only 43 to 44 percent of the woody fuel in the three smallest size categories was living material (*fig. 1*). In the largest size category, living fuel again dominated, averaging 75 percent of the weight of the fuel in the category.

The distribution of living and dead material among the three major species followed the same general pattern as the single species plots. Greenleaf manzanita had the most living fuel and snowbrush the least, with chinkapin intermediate between the two (*fig. 2*).

Table 8—*Standing fuel loading for mixed species plots, by plot number and species*

| Plot number | Tons per acre | Species: Greenleaf manzanita | Snowbrush | Chinkapin | Bitter cherry |
|---|---|---|---|---|---|
| | | Load *(percent)* | | | |
| 10 | 18.19 | 94.5 | 5.5 | | |
| 11 | 19.25 | 80.9 | 19.1 | | |
| 12 | 23.28 | 63.3 | 36.7 | | |
| 13 | 28.20 | | 78.9 | 21.1 | |
| 14 | 37.37 | 82.6 | 9.6 | 7.8 | |
| 15 | 36.00 | 79.5 | 11.5 | 9.0 | |
| 16 | 11.43 | 49.8 | 45.0 | 5.2 | |
| 17 | 22.85 | 74.8 | 18.2 | 7.0 | |
| 18 | 21.98 | 87.6 | 0.4 | 12.0 | |
| 19 | 26.03 | 58.2 | 20.8 | 21.0 | |
| 20 | 22.43 | 27.3 | 42.4 | 30.3 | |
| 21 | 27.44 | 61.1 | 27.8 | 11.1 | |
| 22 | 41.22 | 69.6 | 6.3 | 24.1 | |
| 23 | 25.52 | 96.3 | 1.2 | 2.5 | |
| 24 | 32.73 | 76.1 | 18.9 | 5.0 | |
| 25 | 28.57 | 91.1 | 6.5 | 2.4 | |
| 26 | 32.45 | 96.3 | 1.8 | | 1.9 |
| 27 | 33.46 | 87.5 | 12.0 | | 0.5 |
| 28 | 22.23 | 68.4 | 23.2 | | 1.2 |

## Vertical Distribution of Fuel

The vertical distribution of fuel by categories was measured in 10 of the mil-acre (0.0004-ha) plots. Eight of these plots were of mixed species and two were of a single species each—greenleaf manzanita and snowbrush. The shrubs in four of the mixed species plots were between 4 and 5 ft (1.2 and 1.5 m) tall, and between 5 and 6 ft (1.5 and 1.8 m) in the other four plots. Shrub height for the single species plots was between 4 and 5 ft (1.2 and 1.5 m).

The plots were divided into horizontal sections, measured from the litter surface. The first section was 2 ft (0.6 m) in height, and the remaining sections 1 ft (0.3 m) each. Because the shrubs were not all exactly 5 ft (1.5 m) or 6 ft (1.8 m) tall, the topmost section was not always filled with fuel. In a plot with brush 4.5 ft (1.4 m) tall, for example, fuel would be found only in the first one-half of the top section.

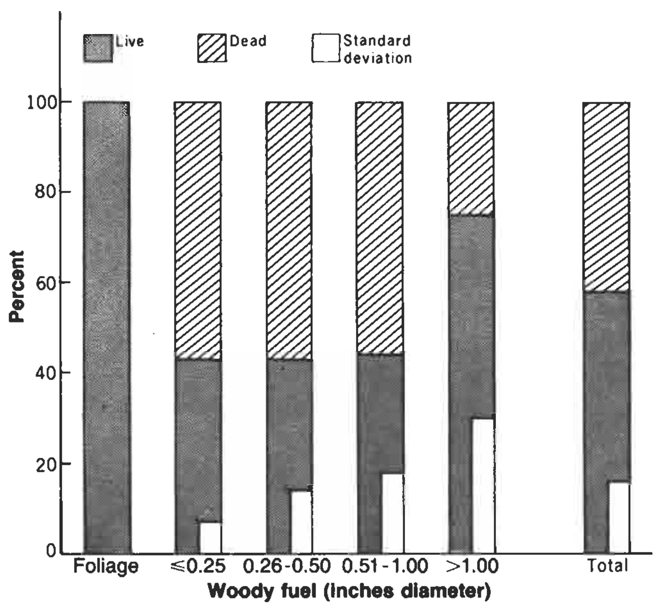


**Figure 1**—Percent foliage and woody fuel live and dead and standard deviation in the mixed species plots.

Vertical distribution of fuel by height sections and by category for the two groups of mixed species plots of different heights showed similar distribution patterns (*tables 9, 10*). Most of the foliage was in the upper sections, but the woody fuels were concentrated in the first section—almost three-fourths of the total fuel load was in this section. The amount of woody fuel in the other sections decreased with both height and size of fuel. Most of the dead fuel was also found in the first section.

Table 9—*Vertical distribution of fuel by plots, section height, fuel category, and percent total load*

| Section height (ft) | Foliage | Woody fuel (inches diameter): ≤0.25 | 0.26 to 0.50 | 0.51 to 1.00 | >1.00 | Percent total load |
|---|---|---|---|---|---|---|
| | Category load *(percent)* | | | | | |
| | | | **5-ft plots** | | | |
| 0 to 2 | 20.4 | 57.3 | 72.1 | 84.1 | 99.0 | 74.6 |
| 2 to 3 | 13.4 | 19.8 | 18.8 | 13.2 | 1.0 | 12.4 |
| 3 to 4 | 43.5 | 18.5 | 8.6 | 2.7 | | 10.0 |
| 4 to 5 | 22.7 | 4.4 | 0.5 | | | 3.0 |
| | | | **6-ft plots** | | | |
| 0 to 2 | 10.0 | 48.6 | 71.0 | 76.2 | 93.6 | 72.8 |
| 2 to 3 | 19.1 | 23.8 | 15.5 | 18.3 | 6.2 | 14.1 |
| 3 to 4 | 36.6 | 18.1 | 11.1 | 4.9 | 0.2 | 8.5 |
| 4 to 5 | 28.5 | 8.8 | 2.3 | 0.6 | | 4.0 |
| 5 to 6 | 5.8 | 1.2 | 0.1 | | | 0.6 |

Table 10—*Vertical distribution of dead fuel by plots, section height, fuel category, and percent total load*

| Section height (ft) | Foliage | Woody fuel (inches diameter) ≤0.25 | 0.26 to 0.50 | 0.51 to 1.00 | >1.00 | Percent total load |
|---|---|---|---|---|---|---|
| | Category load *(percent)* | | | | | |
| | **5-ft plots** | | | | | |
| 0 to 2 | | 80.8 | 97.6 | 100.0 | | 92.6 |
| 2 to 3 | | 15.4 | 2.4 | | 6.0 | |
| 3 to 4 | | 3.6 | | | | 1.3 |
| 4 to 5 | | 0.2 | | | | 0.1 |
| | **6-ft plots** | | | | | |
| 0 to 2 | 100.0 | 69.9 | 90.2 | 91.1 | 100.0 | 85.4 |
| 2 to 3 | | 19.8 | 5.9 | 7.1 | | 9.9 |
| 3 to 4 | | 7.6 | 2.8 | 0.7 | | 3.2 |
| 4 to 5 | | 2.2 | 1.0 | 1.1 | | 1.3 |
| 5 to 6 | | 0.5 | 0.1 | | | 0.2 |

Vertical distribution of fuel in the single species plots followed the general pattern of the mixed species plots (*tables 11, 12*). Both living and dead fuels for greenleaf manzanita, however, tended to be somewhat less concentrated in the first section than did snowbrush—almost all of the dead snowbrush was in the first section.

Little is known of the effect of vertical distribution of fuel on the behavior of fire. The heavy concentration of dead fuels near the ground surface that appears to be characteristic of northern California brush fuels, however, may be one of the primary reasons that the brush burns intensely when the dead fuels are dry in late summer and fall. These fuels are in a position that permits large amounts of heat to be transferred to the living material above them, thereby drying the living fuel sufficiently for it to burn and add to the energy output of the fire. Much of the standing fuel is also near the dead litter fuels, thereby augmenting the potential for high intensity fires when dead fuels are dry.

Table 11—*Vertical distribution of greenleaf manzanita fuel, by section height, fuel category, and percent total load*

| Section height (ft) | Foliage | Woody fuel (inches diameter) ≤0.25 | 0.26 to 0.50 | 0.51 to 1.00 | >1.00 | Percent total load |
|---|---|---|---|---|---|---|
| | Category load *(percent)* | | | | | |
| | **Greenleaf manzanita (live)** | | | | | |
| 0 to 2 | 15.6 | 58.3 | 79.9 | 91.2 | 100.0 | 75.0 |
| 2 to 3 | 34.3 | 23.1 | 15.5 | 7.8 | | 15.2 |
| 3 to 4 | 41.2 | 15.4 | 4.6 | 1.0 | | 8.4 |
| 4 to 5 | 8.8 | 3.2 | | | | 1.4 |
| | **Greenleaf manzanita (dead)** | | | | | |
| 0 to 2 | | 75.5 | 95.2 | 100.0 | | 91.0 |
| 2 to 3 | | 16.6 | 4.0 | | | 6.4 |
| 3 to 4 | | 6.9 | 0.8 | | | 2.3 |
| 4 to 5 | | 1.0 | | | | 0.3 |

## Litter Loading

Litter in this study included all of the dead organic material above mineral soil in the surface layer, and contained partially decomposed material as well as dead material deposited recently on the surface. Many of the mil-acre (0.0004-ha) plots also contained small amounts of sedge in the surface layer. This material adds to the living fuel in spring and to the dead surface fuel in the fall and winter.

Dry weight of the litter ranged from 3.02 to 22.13 tons per acre (6770 to 49,600 kg/ha), or from 14.4 to 54.1 percent of the amount of standing fuel in the individual plots (*table 13*). The data were insufficient to establish any definitive relationships between amount of litter and brush characteristics. From the data available, however, it appears unlikely that the amount of litter is closely associated with the amount of standing fuel. Plot 4, for example, had a standing fuel load of 40.91 tons per acre (91,690 kg/ha) and its litter load was 54.1 percent of the standing fuel load. But Plot 5 had a standing fuel load almost as great, with 38.51 tons per acre (86,310 kg/ha) and its litter load was only 16.4 percent of the standing fuel load.

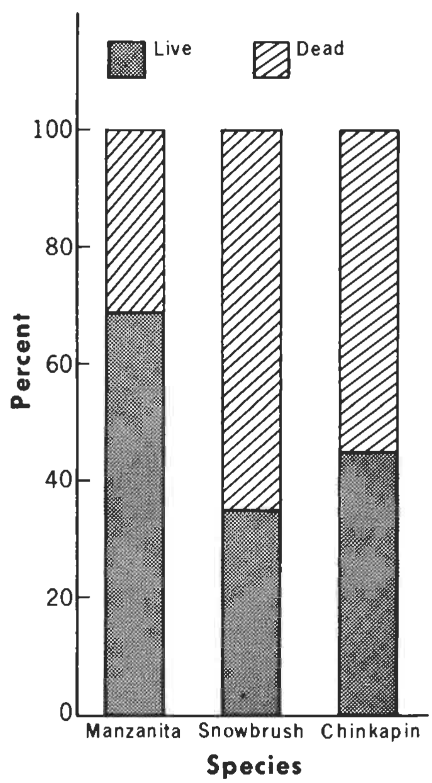


**Figure 2**—Percent live and dead material among the three major species—greenleaf manzanita, snowbrush, and chinkapin.

Table 12—*Vertical distribution of snowbrush fuel, by section height, fuel category, and percent total load*

| Section height (ft) | Foliage | Woody fuel (inches diameter) ≤0.25 | 0.26 to 0.50 | 0.51 to 1.00 | >1.00 | Percent total load |
|---|---|---|---|---|---|---|
| | Category load *(percent)* | | | | | |
| | **Snowbrush (live)** | | | | | |
| 0 to 2 | 5.4 | 60.8 | 90.8 | 100.0 | | 81.3 |
| 2 to 3 | 16.8 | 22.8 | 9.2 | | | 9.9 |
| 3 to 4 | 72.4 | 15.8 | | | | 8.3 |
| 4 to 5 | 5.4 | 0.6 | | | | 0.5 |
| | **Snowbrush (dead)** | | | | | |
| 0 to 2 | | 87.3 | 100.0 | 100.0 | | 96.5 |
| 2 to 3 | 11.2 | | | | | 3.1 |
| 3 to 4 | 1.5 | | | | | 0.4 |
| 4 to 5 | | | | | | |

Table 13—*Litter and sedge loading, by plots*

| Plot | Tons per acre: Litter | Tons per acre: Sedge | Percent of standing fuel load: Litter | Percent of standing fuel load: Sedge |
|---|---|---|---|---|
| 1 | 5.02 | 0.19 | 23.7 | 0.9 |
| 2 | 6.82 | | 15.2 | |
| 4 | 22.13 | .15 | 54.1 | .7 |
| 5 | 6.31 | | 16.4 | |
| 7 | 4.33 | | 18.2 | |
| 8 | 3.02 | | 14.4 | |
| 9 | 10.64 | | 28.8 | |
| 10 | 6.26 | .09 | 34.4 | .5 |
| 11 | 7.71 | .10 | 40.1 | .5 |
| 14 | 8.53 | .21 | 22.8 | .6 |
| 15 | 7.59 | .15 | 21.1 | .4 |
| 16 | 4.04 | .03 | 35.4 | .3 |
| 17 | 3.72 | .21 | 16.3 | .9 |
| 18 | 11.44 | .02 | 52.1 | .1 |
| 19 | 6.88 | .03 | 25.7 | .1 |
| 20 | 9.19 | .13 | 41.0 | .6 |
| 21 | 6.13 | .19 | 22.3 | .7 |

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