Structural Changes in Chamise (*Adenostoma fasciculatum*) along a Fire-induced Age Gradient

PHILIP W. RUNDEL AND DAVID J. PARSONS

Abstract

Chamise (*Adenostoma fasciculatum*) undergoes major structural changes in above-ground biomass along a gradient of increasing stand age since fire. Shrub growth in volume and biomass is rapid through 16 years but levels off in older stands. In this early phase of linear biomass increase, net above-ground productivity has a mean of 430 $g \cdot yr^{-1}$ for each shrub, or 60 $g \cdot m^{-2}$ yr^{-1} over the period of 2–16 years stand age. Individual shrubs at 37 years in Sequoia in the southern Sierra Nevada have more than twice the biomass and four times the annual above-ground productivity of chamise of similar age in the San Gabriel Mountains of Los Angeles County. Between 16 and 37 years, shrub senescence increases with no increase in above-ground biomass and a sharp reduction of available photosynthetic surface area. Total stand biomass continues increasing with stand age up to 37 years as shrub biomass increases, with a maximum at approximately 15,000 $kg \cdot ha^{-1}$. Fine fuels less than 10 mm comprise more than 500 $g \cdot m^{-2}$ in all chamise canopy ages, providing an important structural element of flammability.

The characteristic evergreen shrub or chaparral vegetation of central and southern California is a classic example of a fire-type community (Hanes 1977; Biswell 1974). Occurring in both pure and mixed stands throughout most of the state's foothill zone, chamise (*Adenostoma fasciculatum* H. & A.) is the single most common chaparral species (Hanes 1965, 1977). Physical characteristics which are well adapted to rapid rates of energy release (Countryman and Philpot 1970) combine with typical hot and dry summers, volatile ether extractives, and low fuel moistures to make chamise an especially flammable fuel type. Its wide distribution and frequent proximity to developed and urban areas has made chamise the subject of growing management concern as well as scientific investigation (Parsons 1976; Hanes 1977).

Following fire, chamise characteristically resprouts from a root crown as well as germinating from heat-treated seeds (Christensen and Muller 1975). In most cases the sprouts form the basis of a rejuvenated stand which rapidly matures to the point where within about 15 years the fuel loading (weight per unit area) is thought to be able to again support a moderately intense fire (Philpot 1973). During the past century fire suppression policies have greatly reduced fire frequencies in most chaparral areas. As a result there now exist large areas of overmature chamise chaparral which constitute highly flammable, potentially catastrophic fuel accumulations as well as being of little value as browse of wildlife.

This report provides a detailed analysis of structural changes in chamise following different periods since fire. Such information is of value in understanding the concept of senescence as it applies to shrub growth as well as adaptations of chamise to periodic burning. Analysis of growth patterns,

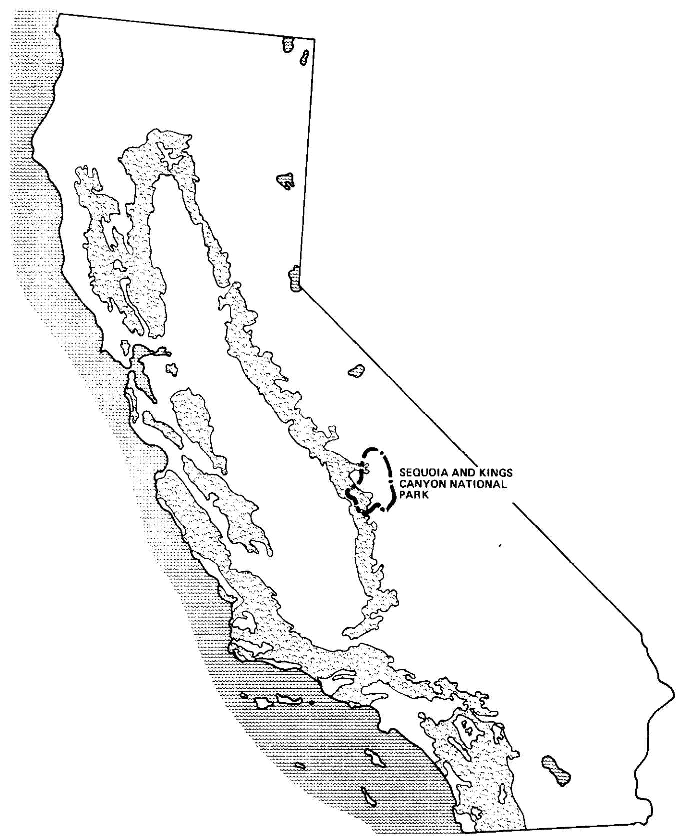

Fig. 1. *Location of research area in Sequoia National Park. The Distribution of chaparral vegetation within California is shown by the textured area. Adapted from Bentley (1967).*

Authors are associate professor, Department of Ecology and Evolutionary Biology, University of California, Irvine 92717; and research scientist, Sequoia and Kings Canyon National Parks, Three Rivers, California 93271.
The authors greatly acknowledge the assistance of Gail Baker, Sue MacLeod, and Steve DeBenedetti in carrying out this study. Funding was provided by the National Park Service and by a National Science Foundation Grant.
Manuscript received May 1, 1978.

productivity and biomass distribution directly relate to potential flammability and thus may eventually provide a key to predicting burning characteristics.

Study Area and Methods

The study area is located within the low elevation foothills of Sequoia National Park in the southern Sierra Nevada of California (Fig. 1). Past fires in this area have occurred almost exclusively during the dry season (summer or fall) and have been of moderate to high intensity. Specific study sites are located within stands of nearly pure chamise along a fire induced age gradient. The sites, located on southerly exposures of moderate slope between 750 and 900 m in elevation, have respectively experienced 2,6,16,37 and something over 60 years since last being burned. Each site is characterized by a predominance of chamise with only the youngest sites showing even a moderate abundance of any other woody species. Previous work at these same sites has documented an increase in woody cover and height as well as litter accumulation with increasing time since fire (Parsons 1976).

The climate of the study area is characterized by an annual precipitation of about 70 cm which falls mainly as winter rain. The summers are hot and dry with daytime temperatures often exceeding 40°C. The soils are generally a shallow, sandy loam of granitic origin. Extensive soil sampling throughout the study area shows little variation in soil type (unpublished data).

At each study site three to five typical shrubs were selected for analysis. Since "typical" shrubs were selected for analysis in each stand as the best means of sampling biomass distribution, no attempt has been made to provide statistical interpretation of the data. Shrub dimensions and biomass are quite consistent in the 2-, 6- and 16-year stands, but somewhat variable in the 37- and over 60-year stands. All above-ground biomass was sampled in 30 cm canopy height increments. Mean diameter of the shrub at each height increment was recorded. Shrub dimensions were used to calculate biomass data for unit area of canopy cover. Biomass samples were divided into leaves and stems with the latter subdivided into 0−5, 5−10, 10−20, 20−30, and 30+mm diameter classes.

Oven-dry weights of each fraction were determined in the laboratory, and leaf and stem surface areas calculated following procedures in Countryman and Philpot (1970). For leaves this method calculates leaf surface area on a geometrical model of an individual leaf as a cone and two frustulums. Biomass data include both living and dead stems, but exclude standing dead branches predating the last fire.

Results and Discussion

Structural characteristics of chamise shrubs along a gradient of stand age since fire show a rapid early growth leveling off beyond 16 years (Table 1). Shrub volumes increase rapidly up through our 16 year stand, but only moderate canopy diameter and height changes occur beyond this age (Fig. 2). Total shrub above-ground biomass (for an individual shrub) increases linearly for 15−20 years with a mean annual increment of 430 $g \cdot yr^{-1}$ (Fig. 3). Between our 16 and 37 year stands, the slope of annual growth decreases gradually in a nonlinear manner to a biomass peak of 8,900 g. Overmature stands greater than 60 years in age have a reduced biomass, apparently due to death and breakage of individual branches. On a unit area basis, net annual above-ground productivity approaches linearity from 2 to 16 years, with a slope of approximately 60 $g \cdot m^{-2} yr^{-1}$. From 16 years on, above-ground biomass remains relatively steady at about 1,400 $g \cdot m^{-2}$ (Table 1).

These data from above-ground biomass of individual shrubs

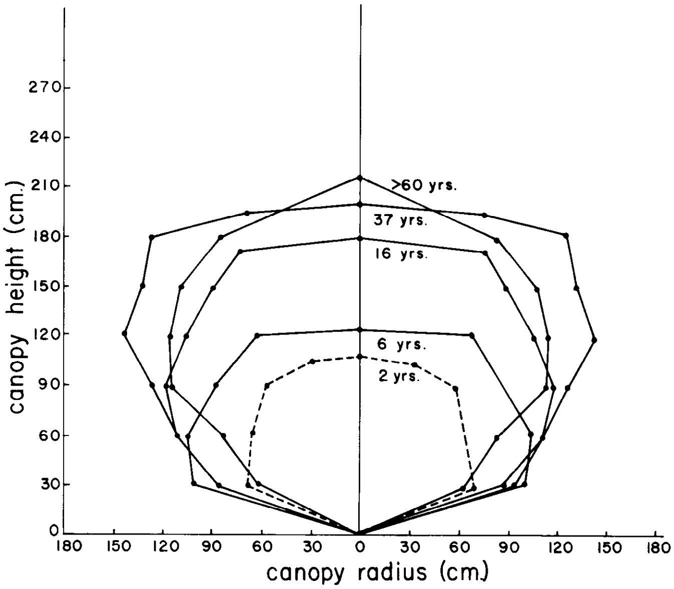

Fig. 2. *Cross-section of mean canopy dimensions of* Adenostoma fasciculatum *along a gradient of stand age since fire.*

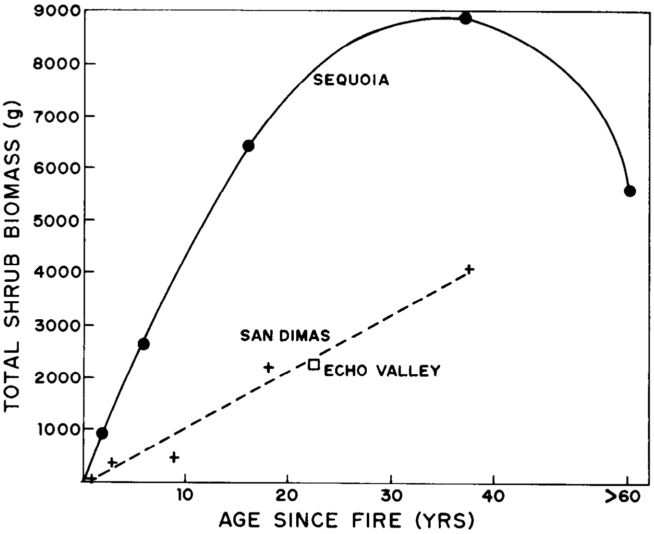

Fig. 3. *Above-ground biomass changes of individual* Adenostoma fasciculatum *along a gradient of stand age since fire for Sequoia National Park, San Dimas, and Echo Valley. San Dimas data adapted from Specht (1969), Echo Valley data from Mooney, et al. (1977).*

Table 1. Structural characteristics of *Adenostoma fasciculatum* shrubs along a gradient of stand age since fire.

Age (yrs)	Above-ground biomass ($g \cdot m^{-2}$)	Leaf biomass ($g \cdot m^{-2}$)	Stem biomass ($g \cdot m^{-2}$)	% leaf biomass	% stem biomass	Leaf area index ($m^2 \cdot m^{-2}$)	Stem area index ($m^2 \cdot m^{-2}$)
2	593	232	361	39.1	60.9	1.79	0.45
6	793	200	593	25.2	74.8	1.53	0.61
16	1486	286	1200	19.2	80.8	2.20	0.84
37	1400	159	1241	11.4	88.6	1.23	0.73
760	1370	156	1214	11.4	88.6	1.22	0.63

and above-ground productivity for our stands at Sequoia National Park are considerably higher than values previously described for chamise in Southern California. At San Dimas in the San Gabriel Mountains, chamise shrubs in a 37 year old stand have a mean biomass of 4,100 g (Specht 1969), less than half the values in our stands of the same age. Our higher values of above-ground biomass of individual shrubs and productivity hypothetically are related to shortened summer drought periods in the Sierra Nevada resulting from more favorable ground water supplies. Chamise shrubs at San Dimas have a linear growth rate up to this age with a slope of 110 $g \cdot yr^{-1}$ (Specht 1969). At Echo Valley in San Diego County, chamise shrubs in a 22-year old stand average 1,726 $g \cdot m^{-2}$ with mean shrub dimensions of 1.16 m in height and 0.98 m diameter (Mooney et al. 1977). Mean shrub above-ground biomass at Echo Valley is 2,271 g.

While total above-ground biomass of chamise at Sequoia increases steadily in younger stands, the relative composition of leaves and stems in the biomass changes greatly. Leaf biomass per unit area remains high in younger stands, but drops in the two older stands (Table 1). Stem biomass increases rapidly in younger stands, but levels off after 16 years. Leaf biomass drops from 39% of total above-ground biomass in the two-year old stand to 11% in the oldest two age classes.

A good indication of relative shrub senescence can be seen in values of leaf area index (LAI) along the stand age gradient. Since chamise typically retains its leaves for only two growing seasons, LAI should be directly related to productivity. Values for LAI reach their highest point of 2.20 $m^2 \cdot m^{-2}$ in the 16-year old stand, then drop to only 1.23 and 1.22$m^2 \cdot m^{-2}$ in the oldest two stands (Table 1). This reduced LAI provides strong indirect evidence of morphological senescence in the two oldest stands and highest productivity at our 16-year stand. Since above-ground productivity shows no increase beyond 16 years (Table 1), the hypothetical increase of total productivity around this age may relate to increased root growth.

At Echo Valley in San Diego County, 22-year old chamise has comparable relative biomass of leaves and stems as our plants, with 17% leaves and 83% stems (Mooney et al. 1977). LAI for chamise at Echo Valley is high at 3.09$m^2 \cdot m^{-2}$.

Changing characteristics of gross shrub structure with age in chamise are associated with major changes of structural characteristics in indvidual canopy levels. Data on the distribution of leaf and stem components with 30 cm height levels in the canopy are presented in Table 2. In the two year old stand, more than 60% of the leaf and stem biomass is concentrated below 30 cm in the canopy with a LAI in this level of 1.09. At the 6-year age the greatest proportion of stem biomass remains in the lowest level, but the highest leaf biomass and LAI occur at 31-60 cm. Little biomass occurs above 90 cm. In the 16-year old stand biomass is well-distributed up to 120 cm. The highest stem biomass values in the canopy still occur below 30 cm, while leaf biomass peaks at 91-120 cm. LAI is relatively high and even from 31-150 cm. Leaf biomass is concentrated from 61-180 cm in the canopy of the 37-year-old stand. Values of LAI drop considerably at every level up to 150 cm, indicating a general stand senescense rather than a leaf drop limited to lower branches. These dramatic changes in leaf biomass and LAI between the 16 and 37 year stands indicate that leaf loss is not primarily due to shading effects in the canopy.

Table 2. Height distributions of leaf and stem surface area and biomass in the canopies of *Adenostoma fasciculatum* along a gradient of stand age since fire.

Age (yr)	Height in canopy (cm)	Leaf area index ($m^2 \cdot m^{-2}$)	Stem area index ($m^2 \cdot m^{-2}$)	Leaf biomass ($g \cdot m^{-2}$)	Stem biomass ($g \cdot m^{-2}$)	Total above-ground biomass ($g \cdot m^{-2}$)
2	0 – 30	1.09	0.29	141	247	388
	31 – 60	0.53	0.13	69	91	160
	61 – 90	0.14	0.03	18	20	38
	91 – 120	0.03	0.004	4	4	8
6	0 – 30	0.46	0.23	59	270	329
	31 – 60	0.54	0.23	71	202	273
	61 – 90	0.38	0.11	50	93	143
	91 – 120	0.13	0.03	17	26	43
	121 – 150	0.02	0.01	3	2	5
16	0 – 30	0.18	0.16	23	352	375
	31 – 60	0.49	0.21	64	330	394
	61 – 90	0.38	0.15	50	227	227
	91 – 120	0.68	0.19	88	203	291
	120 – 150	0.40	0.12	52	77	129
	151 – 180	0.07	0.01	10	10	20
37	0 – 30	0.02	0.09	3	292	295
	31 – 60	0.13	0.17	17	363	380
	61 – 90	0.30	0.19	39	281	320
	91 – 120	0.26	0.12	34	152	186
	121 – 150	0.22	0.08	29	83	112
	151 – 180	0.21	0.06	27	51	78
	181 – 210	0.09	0.02	12	18	30
60	0 – 30	0.02	0.10	3	360	363
	31 – 60	0.08	0.13	10	321	331
	61 – 90	0.18	0.11	23	201	224
	91 – 120	0.37	0.14	48	189	237
	121 – 150	0.30	0.09	38	89	127
	151 – 180	0.20	0.05	26	43	69
	181 – 210	0.06	0.01	7	8	15

Table 3. Size class distribution of above-ground biomass of *Adenostoma fasciculatum* in relation to stand coverage and age since last fire. All values are in kg·ha⁻¹.

Age	% coverage	Leaves	Stems (diameter class in mm) 0–5	5–10	10–20	20–30	30	Total above-ground biomass
2	20	464	556	156	11			1187
	40	928	1111	313	22			2374
	60	1392	1667	469	33			3561
	80	1855	2222	626	43			4746
	100	2319	2778	783	54			5934
6	20	399	642	406	137			1584
	40	798	1284	813	274			3169
	60	1197	1926	1219	411			4753
	80	1595	2569	1626	548			6338
	100	1994	3211	2032	685			7922
16	20	573	726	469	782	310	112	2972
	40	1145	1453	938	1565	619	224	5944
	60	1718	2179	1407	2347	929	336	8917
	80	2290	2906	1875	3130	1238	449	11889
	100	2863	3632	2344	3913	1548	561	14861
37	20	319	556	435	928	378	184	2800
	40	637	1113	870	1856	756	368	5599
	60	956	1669	1305	2784	1133	552	8399
	80	1274	2226	1739	3711	1511	736	11198
	100	1593	2783	2174	4639	1889	920	13998
	120	1912	3339	2609	5567	2267	1104	16798
	140	2230	3896	3044	6495	2645	1288	19597
	160	2548	4452	3479	7423	3022	1472	22397
60	20	313	420	288	1009	516	196	2742
	40	626	839	575	2017	1031	393	5481
	60	939	1259	863	3026	1547	589	8223
	80	1252	1678	1150	4034	2062	786	10962
	100	1565	2098	1437	5042	2578	982	13702
	120	1878	2518	1725	6051	3094	1178	16444
	140	2191	2937	2012	7059	3609	1375	19183
	160	2504	3357	2300	8068	4125	1571	21925

Instead, some physiological senescence with age may be responsible for the observed morphological changes.

On a stand basis the amount of chamise biomass can be calculated from our data for a range of values for canopy coverage (Table 3). While individual shrub biomass and canopy size increase with age, stand coverage concurrently increases. Parsons (1976) described vegetation structure of the four oldest stands described here, with total ground cover of chamise increasing steadily in a progression of 17, 74, 130, and 150% in these stands. Values above 100% result from overlap of canopies in the oldest stands. Calculating from our data for the same stands two years later, total chamise biomass would be 1,347 kg·hg⁻¹ at 6 years, 10,997 kg·ha⁻¹ at 16 years, 19,317 kg·ha⁻¹ at 37 years, and 20,553 kg·ha⁻¹ at over 60 years. Interpolating from Table 3 should allow estimation of biomass accumulation in other stands under similar growing conditions where stand age and chamise coverage are known.

Size class distribution of fuels is an important structural component of flammability. In chaparral fires where branches greater than 10 mm are seldom consumed, the high percentage of fine branch material in chamise adds considerably to its flammable characteristics. The relative biomass of individual size class components of chamise shown in Figure 4 demonstrates this pattern. Through 16 years more than half of the total shrub biomass is comprised of fine leaves and stems less than 10 mm diameter.

Even at greater ages, the relative amount of these fine size classes is much higher than comparable values for other chaparral shrub species (Rundel unpublished data). On a unit area basis, the biomass of fine fuel sizes remains high in all stand size classes. Leaf biomass and stem biomass at both the 0–5 mm and 5–10 mm size classes peaks at 16 years for our sample points with a total of 830 g·m⁻² (Fig. 5), but the total of

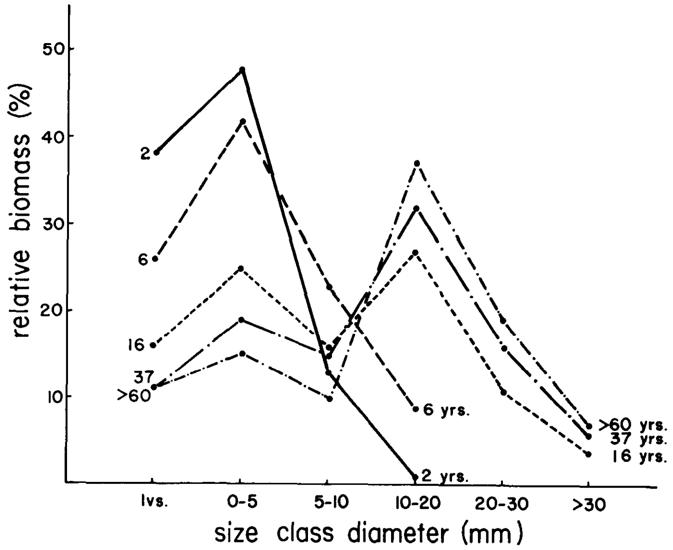

Fig. 4. *Relative biomass of shrub canopies of* Adenostoma fasciculatum *in relation to size class diameter of stem biomass. Data are shown for five stand ages.*

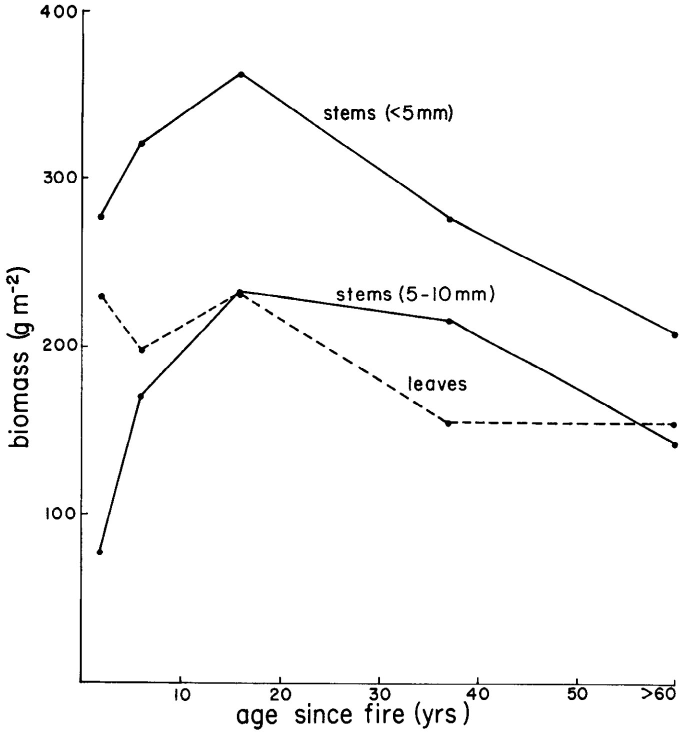

Fig. 5. *Biomass (g·m⁻²) of leaves, stems 0–5 mm, and stems 5–10 mm of* Adenostoma fasciculatum *along a gradient of stand age since fire.*

fine fuel biomass exceeds 500 $g \cdot m^{-2}$ at all ages. This indicates high potential flammability at all age classes. This factor combined with the increased total biomass and increased percentage of dead woody material within the shrub canopy for the older age classes (Parsons 1976) are important structural bases for the high fire danger commonly attributed to stands of mature chamise.

Conclusions

Too few data are currently available assessing fuel loading and fuel structural characteristics of the highly flammable chaparral areas of California. Such information is of critical importance, however, in providing land managers and fire control specialists with a basis for predicting potential flammability for natural stands of vegetation. Increasing interest in the reduction of fire hazards in chaparral areas through prescribed burning will require more data of this type to provide effective fire modelling (see Rothermel and Philpot 1973) and fire management.

The data presented here indicate that change in flammability resulting from increased stand age may result not only from increased above-ground biomass, but from alterations in the fuel size distribution as well. Structural comparisons of chamise from Sequoia National Park and from Southern California clearly indicate that considerable geographic variation in structure and productivity does occur within California. While the data presented here may be site specific to the southern Sierra Nevada, the methods used and concepts discussed are applicable to many other brushland communities. Additional empirical data on relative flammability of fuels and rates of fire spread will be required in the future to refine fire management programs to the desirable state of predictive accuracy.

Literature Cited

Bentley, J.R. 1967. Conversion of chaparral areas to grassland: techniques used in California. Agr. Handb. No. 328. U.S. Dep. Agr.

Biswell, H.H. 1974. Effects of fire on chaparral. *In:* Fire and Ecosystems. Edited by T.T. Kozlowski and C.E. Ahlgren. Academic Press, New York, p. 321-364.

Christensen, N.L., and C.H. Muller. 1975. Effects of fire on factors controlling plant growth in *Adenostoma* chaparral. Ecol. Monogr. 45: 29-55.

Countryman, C.M., and C.W. Philpot. 1970. Physical characteristics of chamise as a wildland fuel. Pacific SW Forest and Range Exp. Sta. Res. Pap. PSW-66. Berkeley, Calif. 16p.

Hanes, T.L. 1965. Ecological studies on two closely related chaparral shrubs in Southern California. Ecol. Monogr. 35: 213-235.

Hanes, T.L. 1977. Chaparral. *In:* Terrestrial Vegetation of California. Edited by M.G. Barbour and J. Major. Wiley & Sons, New York p. 417-470.

Mooney, H.A., J. Kummerow, A.W. Johnson, D.J. Parsons, S. Keeley, A. Hoffmann, R.I. Hays, J. Gilberto, and C. Chu. 1977. The producers-their resources and adaptive responses. *In:* Convergent Evolution in Chile and California. Edited by H.A. Mooney. Dowden, Hutchinson and Ross, Stroudsburg, Penn., p 85-143.

Parsons, D.J. 1976. The role of fire in natural communities: an example from the southern Sierra Nevada, California. Environ. Conserv. 3: 91-99.

Philpot, C.W. 1974. The changing role of fire on chaparral lands. *In:* Symposium on Living with the Chaparral. Edited by M. Rosenthal. Sierra Club, San Francisco, p 131-150.

Rothermel, R.C., and C.W. Philpot. 1973. Fire in wildland management: predicting changes in chaparral flammability. J. Forestry 71: 164-169.

Specht, R.L. 1969. A comparison of the sclerophyllous vegetation characteristic of mediterranean climates in France, California, and Southern Australia. II. Dry matter, energy, and nutrient accumulation. Aust. J. Bot. 17: 293-308.