EFFECTS OF FIRE ON ALPINE PLANT COMMUNITIES IN THE NORTH CASCADES, WASHINGTON[1]

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Abstract. Alpine heath and krummholz communities were studied on Sourdough Ridge at 1,900 m, 29 years after fire. Fire effects are observable in structure and compositional details (species presence, frequency, and coverage) of these communities and in acidity and humus form of the soils. Unburned krummholz stands are dominated by *Abies lasiocarpa* and *Tsuga mertensiana*, with *Phyllodoce empetriformis* and *Vaccinium deliciosum* as major understory species. Unburned heath communities are dominated by *V. deliciosum*, *P. empetriformis*, and *Cassiope mertensiana*. Of these species, only *V. deliciosum* persists as a frequent element on burned sites. Fire effects substantial and persistent increases in diversity of both krummholz and heath communities.

INTRODUCTION

The vegetation changes due to fire in alpine regions of the western United States are not well documented. In contrast to the large alpine areas in the Rocky Mountains, areas supporting developed alpine plant communities are not extensive on Pacific Coast mountains (Franklin and Dyrness 1969). Most of the Alpine Zone of the Pacific Coast is occupied by glaciers, snowfields, bare rocks, and talus slopes. The only comprehensive vegetation studies in these alpine regions were done by Archer (1963) in the Coast Range of southwestern British Columbia and Bliss (1969) in the Olympic Mountains of Washington.

In the North Cascades a 29-year-old burn on an alpine ridge was studied during the summer of 1969. The fire originated in the continuous forest below and swept upslope, cutting a swath approximately 250 m wide through the alpine vegetation. On either side of the burn undisturbed plant communities provided a comparison for the study of pyric succession. Most of the study area shows a floristic affinity more alpine than subalpine. Trees occur only in dwarfed, krummholz form. We have therefore classified this area as alpine, recognizing its proximity to the upper Subalpine Zone.

DESCRIPTION OF AREA

Physiography and geology

The study area is located on Sourdough Ridge on the eastern flank of the Picket Range in North Cascades National Park, Washington (Fig. 1). It lies about 25 km south of the Canadian border and 48 km east of Mt. Baker. This part of the North Cascades is characterized by steep, rugged peaks ranging from 2,000 to 3,200 m elevation, with floors of major river valleys at 200–400 m. The topography is dominated by landforms associated with Pleistocene and Recent glaciation. Sourdough Ridge extends northwest-southeast about 10 km between Elephant Butte and Sourdough Lookout. Many northeast slopes form precipitous cirque headwalls, the ridgetop is somewhat narrow, and southwest slopes average 30°–35°. The alpine vegetation is situated on southwest-facing slopes near the ridge crest at elevations ranging from 1,830 to 1,980 m.

Bedrock in this portion of the Picket Range consists principally of pre-Upper Jurassic metamorphics, with Skagit Gneiss predominating. The Sourdough Ridge soils are essentially residual. However, the presence of 6,600-year-old volcanic ash from the Mazama eruption in bog and tarn sediments and in some colluvial deposits in the area suggests that there may be a substantial, though morphologically imperceptible, volcanic ash component in the soil parent material on the ridge.

Climate

The Mt. Baker weather station (elevation 1,296 m, 40 km west of the study area) provides the best available records indicative of mountain climate in the area. At that station mean annual precipitation is 279 cm, most of which occurs in fall and winter. Average summer (June, July, August) precipitation averages 29 cm. Mean annual temperature is 4.5°C, and the July mean is 12.2°C. The climate of the study area is assumed to resemble that of the Mt. Baker station, but may be somewhat cooler and drier because of higher elevation and high mountain masses to the west (Fig. 1).

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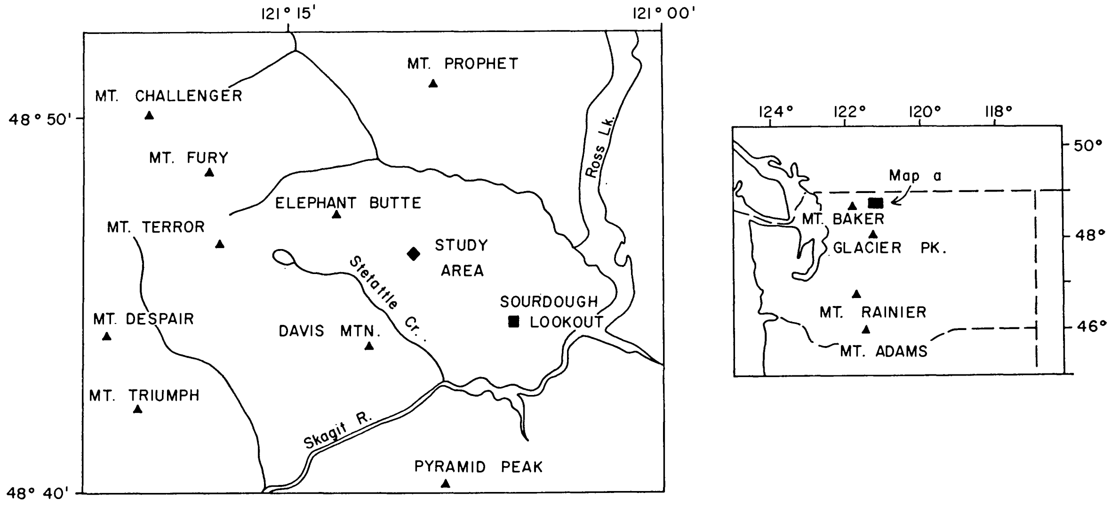

FIG. 1. Study area location in relation to nearby features (map a, left) and major peaks of the Cascade Mountains in Washington (map b, right).

In the vicinity of Sourdough Ridge, mesoclimate regimes influenced by topography and aspect are indicated by differences in late season snow cover. Across Stetattle Creek from the study area, hanging glaciers persist on the northeast face of Davis Mt. down to an elevation of 1,200 m. In contrast, the southwest-facing study area at about 1,900 m is probably snow-free by mid-June in most years. In mid-August 1969 considerable snow still persisted in some adjacent depressions with southeast or northwest aspect, while cornices and other wind-accumulated snow persisted at a few sites along the ridge crest. These areas of late snowmelt support little or no vegetation.

METHODS

Soils

Soils were sampled in each plant community on slopes of 6° or less and aspect of about S 30° W, on somewhat convex topography near the ridge top. Profile morphology was described, samples were air-dried and screened in the field, and stoniness was assessed gravimetrically with a spring balance. Laboratory analysis of the fine (< 2 mm) fraction included: particle-size distribution (hydrometer); pH (1:2 soil:water, glass electrode); total N (Kjeldahl); organic matter (Walkley-Black wet oxidation, to exclude charcoal from burned sites); and cation-exchange capacity (N CH_3COOK, pH 7). Analytical details are described by Jackson (1958).

Plant communities

Two stands were sampled in each of four communities: burned and unburned heath, and burned and unburned krummholz. The undisturbed stands were sampled within 30–40 m of the burned area. Rectangular plots, 20 by 50 cm, were systematically spaced at 1-m intervals in each stand. This size is considered adequate for vegetation of this type (Daubenmire 1968). Forty plots were sampled in all but one community, where size restricted the number to 30. Plot numbers were sufficient according to the "minimal area" criterion; sampling was terminated well after the plateau in the species plot curve was reached. Cover for all vascular plants, mosses, and lichens was estimated for each plot with the methods of Daubenmire (1959). Data from the two stands in each community type were pooled.

Nomenclature for the vascular plants follows Hitchcock, Cronquist, Ownbey, and Thompson (1955–69); moss nomenclature follows Lawton (1965) with the exception of *Ptilidium,* which follows Clark and Frye (1928). Lichen nomenclature is that of Hale and Culberson (1966).

RESULTS AND DISCUSSION

Soils

Typical soils, classified according to the Canadian system (National Soil Survey Committee 1968) are Lithic Humo-Ferric Podzols under unburned krummholz and Lithic Mini Ferro-Humic Podzols under unburned heath vegetation. In some areas under heath, B horizons are so weakly developed that soils are classed as Lithic Alpine Dystric Brunisols. In the current American system of classification, nearly all soils in the study area would be classed as Lithic Cryorthods.

Some physical and chemical properties of the soils are listed in Table 1. Coarse fragments (> 2 mm) amount to 20–30% of the A horizons and 45–70% in the lowest B horizons over bedrock. In the finer fraction, textural class is either sandy loam or loamy sand for all horizons sampled, and clay

TABLE 1. Soil properties on unburned and burned krummholz and heath sites

Site	Humus form	Horizon	Depth (cm)	Color	Coarse fragments (%)	< 2-mm Fraction Sand (%)	Silt (%)	Clay (%)	pH	Cation-exchange capacity (meq/100 g)	N (%)	Organic matter (%)	C/N
Unburned krummholz	Thin mor	Ahe	0–5	7.5YR4/2	25	84	10	6	4.42	28	0.20	11.9	34
		Bfh	5–39	5YR4/6	45	87	6	7	4.92	27	0.16	7.3	26
		R	39+										
Burned krummholz	Mull-like moder	Ah	0–3	10YR2/2	20	86	4	10	4.82	46	0.73	17.3	14
		Ae	3–6	7.5YR6/3	20	91	4	5	4.97	15	0.08	4.0	29
		Bf1	6–31	10YR4/4	50	92	2	6	5.38	19	0.10	3.2	19
		Bf2	31–39	10YR4/4	75	93	3	4	5.20	11	0.05	3.5	41
		R	39+										
Unburned heath	Raw moder	Ah	0–4	10YR3/3	30	92	7	1	5.38	31	0.47	15.2	19
		Bhf	4–28	7.5YR3/4	60	92	3	5	5.33	25	0.26	10.1	23
		R	28+										
Burned heath	Mull-like moder	Ah	0–13	10YR4/2	30	75	21	4	6.08	27	0.23	10.0	25
		Bhf1	13–23	10YR4/4	50	76	17	7	5.88	36	0.23	11.9	30
		Bhf2	23–34	10YR4/6	60	82	10	8	5.90	47	0.23	14.2	36
		R	34+										

content ranges from 1% to 10%. High and low clay contents in A horizons of burned and heath soils may reflect localized surface erosion and deposition.

The organic matter component of these soils is considered especially important because of limited water and nutrient retention by the shallow, coarse-textured mineral component. Organic matter content of the < 2-mm fraction ranges from 3% to 17%. Cation-exchange capacity of this fraction ranges from 11 to 47 meq/100 g and is closely related to organic matter content. Humus forms reflect vegetation and stand history, with thin mor under undisturbed krummholz, raw moder under undisturbed heath vegetation, and mull-like moder on burned sites.

Nitrogen content of the < 2-mm fraction varies considerably, ranging from 0.05% in a Bf horizon to 0.73% in the thin Ah horizon of the burned krummholz site. Carbon-to-nitrogen ratios range from 14 to 41. On burned and heath sites, the carbon-to-nitrogen ratio is high in the deepest B horizon, presumably because of poorly decomposed residues of roots that proliferated over the bedrock surface. As in typical forest soils, the carbon-to-nitrogen ratio under undisturbed krummholz is high in the A horizon.

Soil pH is lower under krummholz than under heath vegetation, and lower on unburned than on burned sites. This is generally true of both A and B horizons. Soon after fire, A horizon pH levels were doubtless much higher in burned areas, but current pH differences appear too small to effect substantial ecological differences between sites.

Textural uniformity and the similar ranges of soil depth and drainage class on all sites suggest that no primary edaphic factor universally accounts for the predisturbance distribution of krummholz and heath vegetation in the area. Of all soil properties examined, pH shows the largest and most consistent analytical differences between burned and unburned sites; humus form shows the most obvious morphological differences.

Plant communities

Plant cover and frequency in the four plant communities are summarized in Table 2. The undisturbed heath and krummholz communities are similar to those noted in the Alpine Zone from British Columbia to Oregon (McAvoy 1931, van Vechten 1960, Archer 1963, Douglas 1969, 1970).

The unburned heath community is dominated by scattered clumps of *Phyllodoce empetriformis, Cassiope mertensiana* var. *mertensiana,* and *Vaccinium deliciosum.* These species contribute 51% of a total coverage of 91%. Other important components, usually occurring between the heath clumps, are *Antennaria lanata, Pedicularis racemosa* var. *racemosa, Phlox diffusa* var. *longistylis, Dicranum fuscescens,* and *Cladonia subsquamosa.* The unburned krummholz stands have a solid overstory of *Abies lasiocarpa, Tsuga mertensiana,* and *Chamaecyparis nootkatensis.* The understory cover is high (52%), considering the density of the canopy above. *Vaccinium deliciosum* and *Phyllodoce empetriformis* are the dominant plants, but *Cassiope mertensiana* is virtually absent. *Dicranum fuscescens* is an important moss in this community.

The krummholz tree form attests to the severity of the environment on this alpine ridge; however, the existence of a more favorable microenvironment beneath the krummholz canopy is indicated by the presence of *Cryptogramma crispa* var. *acrostichoides,*

TABLE 2. Percentage frequency and cover of plants in the alpine plant communities of Sourdough Ridge (T (trace) indicates cover of less than 0.5%)

	Krummholz				Heath			
	Unburned		Burned		Unburned		Burned	
Species	Cover	Fre-quency	Cover	Fre-quency	Cover	Fre-quency	Cover	Fre-quency
Trees								
Abies lasiocarpa	55		—		—		—	
Tsuga mertensiana	38		—		—		—	
Chamaecyparis nootkatensis	8		—		—		—	
Pinus albicaulis	T		—		—		—	
Shrubs and herbs								
Vaccinium deliciosum	21	75	6	40	12	75	9	53
Phyllodoce empetriformis	12	54	T	2	25	68	4	20
Arnica latifolia var. *latifolia*	3	19	1	9	T	2	T	1
Luetkea pectinata	1	14	7	25	1	26	2	14
Pedicularis racemosa var. *racemosa*	1	12	—	—	6	28	—	—
Mitella breweri	1	11	—	—	—	—	—	—
Cassiope mertensiana var. *mertensiana*	1	8	—	—	14	46	—	—
Carex rossii	1	8	1	11	1	29	3	27
Viola spp.	T	9	—	—	—	—	—	—
Deschampsia atropurpurea var. *latifolia*	T	6	4	43	T	2	1	14
Luzula wahlenbergii	T	5	T	9	—	—	—	—
Epilobium alpinum var. *alpinum*	T	4	T	5	—	—	—	—
Luzula campestris var. *multiflora*	T	1	—	—	T	2	—	—
Sorbus sitchensis var. *grayi*	T	1	—	—	—	—	—	—
Ribes howellii	T	1	—	—	—	—	—	—
Phlox diffusa var. *longistylis*	T	1	—	—	3	36	2	11
Penstemon davidsonii var. *menziesii*	T	1	T	2	—	—	T	11
Cryptogramma crispa var. *acrostichoides*	T	1	—	—	—	—	—	—
Polystichum munitum var. *munitum*	T	1	—	—	—	—	—	—
Penstemon procerus var. *tolmiei*	—	—	8	40	T	6	T	1
Trisetum spicatum	—	—	3	46	—	—	3	30
Antennaria alpina var. *media*	—	—	3	25	—	—	T	3
Epilobium angustifolium	—	—	2	29	—	—	T	3
Poa sandbergii	—	—	2	20	—	—	7	33
Hieracium gracile	—	—	1	36	T	15	1	23
Erigeron peregrinus ssp. *callianthemus* var. *scaposus*	—	—	1	10	T	4	1	4
Vaccinium membranaceum	—	—	1	6	—	—	—	—
Lupinus latifolius var. *subalpinus*	—	—	1	4	T	5	1	10
Juncus parryi	—	—	1	4	1	15	2	14
Pinus albicaulis	—	—	1	1	—	—	—	—
Erigeron aureus	—	—	T	4	—	—	T	4
Agoseris aurantiaca var. *aurantiaca*	—	—	1	4	T	5	1	10
Salix spp.	—	—	T	4	—	—	—	—
Carex spectabilis	—	—	T	2	—	—	—	—
Carex phaeocephala	—	—	T	2	—	—	—	—
Heuchera glabra	—	—	T	1	—	—	—	—
Oxyria digyna	—	—	T	1	—	—	—	—
Saxifraga bronchialis var. *austromontana*	—	—	T	1	—	—	—	—
Carex nigricans	—	—	T	1	—	—	—	—
Antennaria lanata	—	—	T	1	7	70	—	—
Antennaria racemosa	—	—	T	1	—	—	—	—
Arctostaphylos uva-ursi	—	—	T	1	T	1	1	4
Juniperus communis var. *montana*	—	—	T	1	—	—	—	—
Tsuga mertensiana	—	—	T	1	—	—	—	—
Agrostis scabra	—	—	T	1	—	—	1	6
Arenaria capillaris var. *americana*	—	—	—	—	1	29	—	—
Lycopodium sitchense	—	—	—	—	1	22	T	1
Abies lasiocarpa	—	—	—	—	T	1	—	—
Empetrum nigrum	—	—	—	—	—	—	1	3
Saxifraga ferruginea var. *macounii*	—	—	—	—	—	—	T	3
Phleum alpinum	—	—	—	—	—	—	T	1
Sibbaldia procumbens	—	—	—	—	—	—	T	1
Anaphalis margaritacea	—	—	—	—	—	—	T	1

TABLE 2. (continued)

Species	Krummholz				Heath			
	Unburned		Burned		Unburned		Burned	
	Cover	Fre-quency	Cover	Fre-quency	Cover	Fre-quency	Cover	Fre-quency
Mosses								
Dicranum fuscescens	5	24	—	—	7	40	1	7
Lescuraea radicosa	2	18	—	—	—	—	—	—
Bryum sandbergii	2	12	—	—	—	—	—	—
Polytrichadelphus lyallii	T	6	T	15	T	2	—	—
Pohlia nutans	T	6	—	—	T	5	—	—
Polytrichum juniperinum	T	4	8	61	—	—	2	17
Polytrichum piliferum	T	2	4	34	2	22	14	64
Bryum creberrimum	T	2	2	49	T	6	1	43
Pohlia spp.	T	2	—	—	—	—	—	—
Dicranum spp.	T	1	—	—	—	—	—	—
Ptilidium californicum	T	1	—	—	—	—	—	—
Rhacomitrium sudeticum	T	1	T	1	T	1	T	1
Rhacomitrium canescens var. *ericoides*	—	—	T	2	T	5	T	6
Lichens								
Cladonia chlorophaea	T	4	—	—	T	8	T	6
Cladonia bellidiflora	T	1	—	—	2	49	T	6
Peltigera spp.	—	—	1	5	T	16	2	23
Peltigera canina var. *spuria* f. *sorediata*	—	—	T	1	—	—	—	—
Cladonia subsquamosa	—	—	—	—	4	56	1	7
Lecidea granulosa	—	—	—	—	2	45	1	11
Cetraria islandica	—	—	—	—	T	6	—	—
Stereocaulon alpinum	—	—	—	—	T	2	—	—
Cladonia mitis	—	—	—	—	—	—	T	3
Stereocaulon spp.	—	—	—	—	—	—	T	1

Luzula campestris var. *multiflora,* and *Polystichum munitum* var. *munitum,* species more common to lower elevations.

Floristically, the burned krumholz community is drastically different from the unburned krummholz community. The vascular plant species increase from 23 to 35 species. Since moss species decrease from 12 to six, the overall change is from 37 to 43 species, 27 of them different from those found in the undisturbed community. The tree species, except for two small, depauperate specimens of *Pinus albicaulis* and *Tsuga mertensiana,* were killed, and only dead trunks and branches remain. Little dominance is expressed by any individual species, the highest cover being contributed by *Penstemon procerus* var. *tolmiei* (8%) and *Polytrichum juniperinum* (8%). *Vaccinium deliciosum* has decreased in cover (21% to 6%), but appears able to withstand fire or reinvade much better than *Phyllodoce empetriformis,* which is extremely rare at present. A conspicuous feature of this burned site is the invasion of a number of grasses and sedges, especially *Trisetum spicatum* and *Poa sandbergii. Deschampsia atropurpurea* var. *latifolia,* infrequent in the original community, has notably increased in cover and frequency. Although moss species are few, moss cover is greater in the burned krummholz community, mainly because of increases in *Polytrichum juniperinum, P. piliferum,* and *Bryum creberrimum. Epilobium angustifolium,* a prolific pioneer species on burned areas at lower elevations, is also conspicuous in the disturbed krummholz community. However, it reaches only 20–25% of the height attained by lower elevation populations. *Luetkea pectinata,* another pioneer species, frequent in the Subalpine Zone of the North Cascades (Douglas 1970), is much more prominent in the burned than unburned krummholz community.

The burned heath community resembles the burned krummholz community, but also includes several species more characteristic of unburned heath. *Vaccinium deliciosum* and *Phyllodoce empetriformis* remain important after fire, though *Cassiope mertensiana* is eliminated. The cover and frequency of *Polytrichum piliferum* are increased. Species richness of lichens remains the same as in the unburned community, but frequency and cover are greatly reduced.

Several indices evaluate the similarity, diversity, and equitability of the four communities (Table 3). Although values reflect sampling procedures and somewhat arbitrary selection of index models, they do permit useful comparisons. To evaluate similarity two coefficients of community are used. The first (*CC*) is defined as the ratio of the number of species

TABLE 3. Indices of community similarity (*CC* and *C*), diversity (*H*), and equitability (*E*)

	Community[a] comparison			Community[a]			
Index	UK-BK	UH-BH	BK-BH	UK	UH	BK	BH
CC	0.21	0.49	0.44	—	—	—	—
C	0.05[b]	0.23	0.39	—	—	—	—
H	—	—	—	2.87	3.61	4.31	4.13
E	—	—	—	0.28	0.52	0.68	0.66

[a]U, B, K, and H refer to unburned, burned, krummholz, and heath, respectively.
[b]Assumes frequency equals cover for the four tree species in the UK community. The absolute value of *C* is little affected by assumptions concerning so few species.

shared by two samples to the total number of different species found in the two samples (Whittaker 1970). It varies from 0 (no species in common) to 1.0 (species lists identical). The second coefficient of community (*C*), which reflects dominance as well as presence, is calculated as $C = 2w/(a + b)$ (Oosting 1956). In this equation *a* and *b* are the sums of the quantitative values in the first and second samples, and *w* is the sum of the lower quantitative values calculated for those species common to both samples. The range of *C* is also 0 to 1.0. The quantitative values in this case are represented by prominence values, obtained by multiplying the cover of a species by the square root of its frequency, a modification of the procedure used by Beals (1960).

These indices show that the burned and unburned krummholz communities are markedly different ($CC = 0.21$, $C = 0.05$). Burned and unburned heath communities are more similar ($CC = 0.49$, $C = 0.23$). Burned heath and burned krummholz communities are also more similar ($CC = 0.44$, $C = 0.39$). Visual observations agree with the relative ranking of *C* values, i.e., burned heath and burned krummholz communities appear most similar. The seemingly anomalous ranking of *CC* values may reflect greater randomness of species occurrence (Kershaw 1964) on burned sites, rather than greater dissimilarity of burned communities.

Diversity is indicated by *H* values in Table 3, estimated as $\Sigma\ p_i \log_2 p_i$ (Shannon 1948), and calculated from tables by Lloyd, Zar, and Karr (1968). In this study p_i represents the fraction of total plant cover contributed by the *i*th species of a community. For this calculation, trace cover values in Table 2 were arbitrarily valued at 0.2%. Higher values of *H* indicate greater diversity. By this measure fire appears to increase diversity to comparable levels in both krummholz and heath communities. Undisturbed krummholz is the least diverse of the four communities.

Dominance is inversely related to equitability (*E*) of species distribution (Table 3), estimated as follows. Assuming that total plant cover is distributed among species according to the Macarthur broken stick model, the number of species needed to provide the known *H* value can be predicted. This is compared to the observed number of species in the sample, and the ratio of predicted to observed is a measure of the equitability (*E*) of the distribution (Lloyd and Ghelardi 1964). Equitability is greater in unburned krummholz ($E = 0.28$) than in burned krummholz ($E = 0.68$). This agrees with the visual impression that a krummholz community, dominated by a few species before fire, evinces no strong dominance pattern several years after burning. A similar, but much less pronounced trend appears in comparing the burned heath ($E = 0.66$) with the unburned heath community ($E = 0.52$).

The data suggest that although diversity may increase in the early stages of succession, dominance is established and diversity declines as a stable climax is approached. Goff and Zedler (1968), working in the upland forests of the western Great Lakes area, suggest a similar process after fire.

The effects of fire are observable after 29 years in the structure and compositional details (species presence, frequency, and coverage) of alpine heath and krummholz communities and in acidity and humus form of the associated soils. Community composition (Table 2) and mathematical indices (Table 3) show notable increases in species diversity and a marked decrease in dominance by a few species. Pioneer species adapted to transitory site conditions created by fire have occupied the site and will apparently persist for some time, particularly in burned krummholz stands where full recovery will have to await reestablishment of tree cover. The distinctive, persistent flora following fire makes a substantial contribution to the diversity of alpine areas.

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