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Ecology of the Pumice Desert, Crater Lake National Park

The Pumice Desert is a conspicuous natural feature within Crater Lake National Park. This rather barren, flat area of about 5½ square miles contrasts sharply with the surrounding forests of lodgepole pine (*Pinus contorta*). Explanations for this opening along the park's North Entrance Road have not been available. Why has plant succession proceeded so slowly in this area? Why have lodgepole pines only recently begun to invade? Which environmental factors are responsible?

The study reported herein was carried out in 1962 to (1) describe the existing vegetation and (2) measure selected environmental factors—air temperature, evaporation stress, and precipitation and soil temperature, nutrient level, and moisture. These data and the insight they have provided into factors contributing to the existence and maintenance of the Pumice Desert are the subject of this paper.

Description of Study Area

Geology and Physiography. The Pumice Desert is a flat, rather homogeneous-appearing area (Figure 1), with a slight depression running east-west through the center. Scattered washes also cause minor topographic variations. The two bench marks in the area probably represent the highest and lowest elevations: 5962 and 6010 feet.

The pumice covering the Pumice Desert was ejected by ancient Mount Mazama (Williams, 1942). Later eruptions contained a great deal of gaseous material which flowed down the slopes as glowing avalanches. These avalanches eventually became the glassy dacite pumice and basic scoria deposits which filled the valleys and depressions around Mount Mazama. The depth of these deposits in the Pumice Desert may be as much as 200 feet (Williams, personal communication).

Climate. Climatic data for Crater Lake National Park are provided by a U.S. Weather Bureau station located at Park Headquarters, about 14 miles south of the Pumice Desert at 6475 feet elevation (Sternes, 1963). Winters are fairly mild with mean monthly temperatures in the high twenties. Summers are cool with mean monthly temperatures in the mid-fifties.

Records kept at Park Headquarters from 1931-1964 show the average annual precipitation to be 68.61 inches. However, summer rainfall is slight, and most of the annual precipitation comes as winter snow.

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Figure 1. Pumice Desert, looking north from permanently marked sampling plot. Metal stake extends two feet above ground.

Methods

Vegetation Analysis. Pumice Desert vegetation was sampled with 22 line transects, each 200 feet in length. Coverage data were taken on the basis of line interception. Density and frequency data were gathered on the area 10.9 feet on each side of the center line—a total of 0.1 acre for each transect. Nine of the 22 plots were permanently marked for future studies on successional progress in the area.

Climatic Analysis. Summer climatic conditions on the Pumice Desert were measured in 1965. A recording hygrothermograph placed in a slatted shelter set on the ground was used to obtain data on air temperature and humidity. Environmental evaporative stress, a parameter integrating the effects of relative humidity, wind, and radiation intensity, was estimated using Livingston black-and-white-bulb atmometer spheres. Rainfall was measured in a totalizing gage.

Soil temperatures were recorded on each of the 22 plots on four separate days during the summer. Measurements were taken with a Weston dial-type thermometer between 10:00 a.m. and 4:00 p.m. Temperatures were measured 7 inches above; at; and 7 inches below the soil surface at each end of the line transects.

Soil Analysis. Soil samples for chemical analysis were taken from ten sites: eight randomly selected from the 22 vegetation plots, and two others, hereafter referred to as numbers 9 and 10, from the narrow *Carex* and *Pinus* transition zone. Samples from the A horizon were analyzed in the Purdue University Soil Testing Laboratory. Extraction agents used were phenoldisulfonic acid for NO_3; AgCl for Cl; and $BaSO_4$ for SO_4. The Bray method was used to extract P, and all solutions were analyzed with a colorimeter. Potassium was extracted with 0.75 N HCl, then measured with a flame photometer. Soil reaction was determined with a glass electrode pH meter (Gohlke, 1961).

Calcium and magnesium exchange capacity was determined by the author with an atomic absorption spectrophotometer after extraction with 1 N $NH_4A\bar{c}$. Organic matter was determined by titration with $KMnO_4$ (Kohnke, 1963).

Estimates of field capacity and permanent wilting percent were obtained on additional soil samples from the same sites using the pressure plate and pressure membrane apparatus, respectively.

Soil samples for determining field moisture content were taken in early August. Single flat, north-facing, and south-facing sites were randomly selected from the original 22 vegetation sample plots. Eighteen soil samples were taken at each site—6 at a depth of 1″ to 2″, 6 at a depth of 4″ to 6″, and 6 at a depth of 8″ to 10″. Moisture content was calculated as percent of dry weight.

All laboratory tests were duplicated.

Results

Vegetation. The vegetation of the Pumice Desert is sparse, both in numbers of species and in total quantity (Table 1). Only 14 of 570 plant species listed in the "Plants of Crater Lake National Park" (Applegate, 1939) were found on the desert. Average density of plant specimens was only 0.6 individuals per square foot and plant coverage averaged only 4.49 percent.

The most abundant species were not always evenly distributed. *Carex breweri* had the highest average density, but over half of the specimens were found in a single plot. Most species were fairly well distributed, although a few occurred in only a few sites.

TABLE 1. Density, frequency, and coverage of plants. Density is number of plants per 0.1 acre plot; frequency is percent of the 22 plots in which each species occurred; and cover is percent of total length of the line transect covered by the canopy of each species.

	Total specimens number	Density number	Frequency percent	Average cover percent
Arabis playsperma Gray.	115	5.2	45.5	[1] —
Arenaria pumicola Cov.	8,000	363.6	90.9	0.39
Aster shastensis var. *eradiatus* Gray.	1,349	61.3	81.8	0.07
Carex breweri Boott.	18,769	853.1	81.8	0.95
Carex halliana Bail.	1,568	71.3	9.1	0.05
Eriogonum marifolium T. & G.	9,671	439.6	100.0	1.19
Hulsea nana Gray.	22	1.0	9.1	—
Lomatium martindalei C. & R.	1,844	83.8	81.8	0.14
Pinus contorta var. *marrayana* (Balf.) Engl.	3	.1	9.1	—
Polygonum newberryi Small.	2,955	134.4	90.9	0.72
Sitanion hystrix J. G. Sm.	13	.6	18.1	—
Spraguea umbellata Torr.	5,968	271.3	100.0	0.20
Stipa californica Merr. & Davy.	4,152	188.7	77.2	0.75
Viola purpurea var. *venosa* (Wats.) Brain.	2,341	106.4	81.8	.03
Total	56,771			
Average per 0.1 acre		2,580.5		4.49

[1] A dash (—) indicates cover less than 0.01 percent.

Carex halliana was found only in a narrow transition zone between the desert and surrounding lodgepole pine forest. *Hulsea nana* was found mainly on the low central portion of the Pumice Desert in association with open wash areas. This central area was poorest in number of species, supporting *Carex breweri, Polygonum newberryi, Spraguea umbellata*, and *Eriogonum marifolium* almost exclusively.

Many plant species growing on the Pumice Desert have adaptational features generally shared by desert and alpine plants (Bliss, 1962). *Eriogonum marifolium, S. umbellata,* and *Arabis playsperma* have thick leathery leaves, while those of *Arenaria pumicola* are reduced to needle-like structures. Leaves of *Aster shastensis* var. *eradiatus* are small, sessile and narrow. Desiccation of *S. umbellata* is further reduced by its prostrate form, the leaves lying in a tight rosette. *Eriogonum marifolium* and *Hulsea nana* both have dense coverings of hair. These hairs not only reduce wind friction, but may also reflect visible light during the day and reduce heating. At night they may trap heat, retarding reradiation and cooling.

Polygonum newberryi appears especially adapted to the Pumice Desert. The shoots are well developed in mid-June, emerging as the snow melts. The 6-inch shoots store water for the growing season. The loss of water from leaves collected from 24 plants averaged 341 percent on a dry weight basis. The root system is also very extensive with thick tubers extending over 3 feet into the soil and finer roots extending even deeper.

Phenologic records showed that all species complete their life cycles well within the short summer (Table 2). Most break dormancy, flower, and fruit in a few weeks. Although there was still some snow on the Pumice Desert on June 4,[2] it had entirely melted by June 13. By this time two species were already flowering (Table 2). In most instances, species attained their peak blooming period directly after the first observation, the long flowering period resulting from only a few specimens still blooming. Much of the *Spraguea, Viola, Arenaria, Polygonum, Aster,* and *Lomatium* had shed their seeds by the first of August, the vegetative portions becoming dry and brown.

TABLE 2. Phenology of selected pumice desert flora, 1965.

	Floral Bud Formation		Flowering		Fruiting	
	Date observed					
	First	Last	First	Last	First	Last
Arenaria pumicola	—	—	June 13	July 24	June 28	Aug. 2
Aster shastensis var. *eradiatus*	July 8	July 24	July 24	July 28	July 30	Aug. 2
Eriogonum marifolium	June 24	July 8	June 24	Aug. 22	July 24	Aug. 2
Hulsea nana	June 28	July 2	July 3	Aug. 22	July 24	Aug. 12
Lomatium martindalei	June 13	—	June 17	June 28	June 24	July 30
Polygonum newberryi	June 13	July 3	June 24	June 29	July 2	July 8
Spraguea umbellata	June 13	June 22	June 24	July 22	July 24	July 30
Viola purpurea var. *venosa*	—	—	June 13	July 3	June 24	July 24

Increment borings were taken from lodgepole pines growing along the northern fringe of the Pumice Desert. The oldest tree found along the desert fringe, 181 years in age, had attained a diameter of 9 inches at breast height. In contrast, a sample of 27

[2] Personal communication from Assistant Park Naturalist Glenn Kaye.

pines growing on a 100-acre section of the desert averaged only 22.4 years in age.

Climate. Greater summer temperature extremes were recorded on the Pumice Desert than at Park Headquarters (Table 3). Recorded maxima were higher and minima were lower. For instance, between June 18 and August 31, Park Headquarters recorded nine minimum temperatures below 32°F; the Pumice Desert recorded 21. The lack of vegetation on the Pumice Desert probably contributed to these differences. Vegetative cover slows the rate of ground heating during the day and retards reradiation of ground heat during the night. It also supplies water vapor, which has similar effects, to the air.

During the summers of 1964 and 1965 snow had disappeared from the study area during the first week in June. Snow melt could not contribute directly to soil moisture throughout the summer. Rather the vegetation must rely on water stored in the soil and rainfall. Precipitation on the Pumice Desert was 2.97 inches between mid-June and September (Table 3). This was less than reported at Park Headquarters (3.73 inches), possibly due to the difference in elevation. Precipitation at Park Headquarters in June was below normal while that in August was far above normal in 1965. During the month of July twice as much rain fell on the Pumice Desert than at Park Headquarters.

TABLE 3. Climatic comparison of the Pumice Desert and Park Headquarters during the summer of 1965; summer temperatures were close to average but August had more and June less rainfall than usual

	Average Maxima (F°)	Average Minima (F°)	Average Mean (F°)	Precipitation (inches)
June				
Park Headquarters	60	34	46	0.86
Average (1930-64)	59	34	47	2.51
June 18-30				
Park Headquarters	59	34	46	0.24
Pumice Desert	72	33	52	0.00
July				
Park Headquarters	68	40	54	0.80
Pumice Desert	78	35	56	1.56
Average (1930-64)	70	42	56	.63
August				
Park Headquarters	64	40	52	2.69
Pumice Desert	72	35	54	1.41
Average (1930-64)	70	42	56	.74

The average daily water loss from the Livingston atmometers, an index of environmental evaporative stress, was 43.3 mls for the white and 54.2 mls for the black bulb. These values are comparable to those obtained in Arizona desert areas (Livingston, 1923) and on New Mexican lava fields (Lindsey, 1951).

Substrate. Soil temperatures are important since they affect moisture, aeration, and plant metabolism. Soil surface temperatures corresponded well with air temperature on cloudy days. However, they fluctuated greatly on sunny days because the soil absorbed a great deal of heat. For example, on July 24 soil temperatures taken at the

22 plot areas over a 6-hour period averaged 102°F, while air temperature did not exceed 83° during this time. Evaporation of water from the soil would have had a cooling effect, but large surface pores prevent the rise of capillary water.

The Pumice Desert soil is generally deficient in nutrients and in organic matter (Table 4). Low fertility levels are typical in soil developed from Mount Mazama pumice as, for example, under *Pinus ponderosa* and *Purshia tridentata, Ceanothus velutinus*, or *Arctostaphylos patula* communities east of Crater Lake (Youngberg and Dyrness, 1964, 1965) and Dyrness and Youngberg (1966). However, even these investigators recorded P, K, Ca, and Mg values consistently higher than those found in Pumice Desert soil. Pumice Desert samples were all taken from the A_1 horizon, but the data are most comparable to the C_1 and C_2 horizons of the Lapine soil series (Youngberg and Dyrness, 1965). These differences could be partially due to greater leaching of nutrients on the desert area since precipitation is greater than in the Lapine area to the east.

TABLE 4. Fertility status of Pumice Desert soils.

Soil Sample	NO_3 ppm	Cl ppm	SO_4 ppm	P ppm	K n.e./100g	Mg n.e./100g	Ca n.e./100g	pH	O.M. (reducible matter)
1	4.0	0	10	.3	.013	0.029	0.101	6.1	1.4
2	2.7	3	5	.5	.015	0.036	0.112	6.0	0.8
3	2.0	2	10	.1	.010	0.027	0.091	5.9	1.2
4	1.2	1	10	.1	.015	0.025	0.112	5.9	0.9
5	5.0	3	10	.3	.013	0.025	0.094	5.6	1.3
6	3.0	4	21	.1	.013	0.028	0.112	5.7	1.3
7	1.8	1	1	.1	.013	0.034	0.088	5.6	0.3
8	2.7	1	5	.1	.010	0.027	0.071	5.9	1.0
9	0.5	0	5	.0	.010	0.037	0.200	5.8	4.3
10	2.0	4	15	.3	.018	0.033	0.200	5.5	2.8

Organic matter percentages are low in the Pumice Desert soil, reflecting the sparse vegetation. Organic matter ranged from 0.3 to 4.3 percent, the higher value being found in the desert-forest transition zone dominated by *Carex*. Values for the C_1 and C_2 horizons of the Lapine soil series were 0.21 and 0.18 (Youngberg and Dyrness, 1965).

It appears that soil moisture was available for plant growth throughout the summer (Tables 5 and 6). Field moisture contents on August 2 were well within the range of available moisture as defined by the approximations of field capacity (pF 2.5) and

TABLE 5. Field moisture on August 2, 1962, as percent of oven-dry weight compared with moisture percent at standard tension points, pF 2.5 approximating field capacity and pF 4.15 approximating permanent wilting percent.

Site	Depth 1-2″	4-6″	8-10″	Tension pF 2.5	pF 4.15
	percent moisture			percent moisture	
Flat	1.0	14.2	12.7	20.4	2.7
North-facing slope	1.6	10.1	12.6	13.0	4.5
South-facing slope	1.8	8.6	9.2	14.4	4.0
Average[1]	1.5	10.9	11.5	15.9	3.7

[1] Average of 18 determinations at each depth.

TABLE 6. Field moisture on August 2, 1962, as percent on a volume basis compared with moisture percent at standard tension points, pF 2.5 approximating field capacity and pF 4.15 approximating permanent wilting percent.

Site	Depth 1-2″	Depth 4-6″	Depth 8-10″	Tension pF 2.5	Tension pF 4.15
	percent moisture			percent moisture	
Flat	1.2	17.0	15.2	24.5	3.2
North-facing slope	1.9	12.1	15.1	15.6	5.4
South-facing slope	2.2	10.3	11.0	17.3	4.8
Average[1]	1.8	13.1	13.8	19.1	4.4

[1] Average of 18 determinations at each depth.

permanent wilting percent (pF 4.15). Soil moisture in pumice soils may vary greatly when calculations based on soil weight and soil volumes are compared, due to differences in bulk densities. Youngberg and Dyrness (1964) state that bulk densities are generally less than 1.0 g/cc, their values ranging from 0.5 to 0.9 g/cc. However, Tidball[3] reports bulk densities of Crater Lake pumice soils ranging from .78 g/cc at the surface to 1.34 g/cc at depths of 6 feet. He attributed the change to an accumulation of organic matter. Pumice Desert soils had a bulk density averaging 1.2 and ranging from 1.0 g/cc in the desert-forest transition zone to 1.3 g/cc in a sandy wash area.[4] In both chemical and physical properties, Pumice Desert surface soils most closely resemble subsurface pumice soils examined elsewhere.

Moisture stresses might still have occurred at the root surfaces. Water moves slowly in unsaturated soils, and sandy-textured materials inhibit upward capillary movement. Movement in unsaturated pumice soils, coarse-textured Regosols, is extremely slow. Hence, the possibility for development of high moisture stresses at the root-soil interface does exist. The dry surface layer of soil helped reduce evaporation from the subsurface soil. At no time during the summer did the soil feel dry below the surface 1 to 2 inches.

Discussion

Plants and their substrate develop together; they are dependent on each other as well as on the climate, which plays a leading role in the development of both. This interrelationship is clearly expressed on the Pumice Desert.

The present flora of the area seems well adapted to the short growing season. Plants complete their growth and reproductive cycles in a very short period of time. Although many dry up by the end of the summer, this is apparently due to the senescence of each individual and not wilting. The combination of widely fluctuating temperatures, low relative humidity, and high evaporative power of the air gives a clear picture of the dry climatic conditions under which existing flora must live and grow. This explains many of the morphological adaptations present in the flora since these same environmental conditions characterize true deserts and alpine areas. Only 14 of the 570 species in the park are sufficiently adapted to survive.

Lodgepole pines are just beginning to invade the Pumice Desert. The youth of trees

[3] Tidball, Ronald. 1965. A Study of Soil Development on Dated Pumice Deposits from Mount Mazama, Oregon. 235 pp. Ph.D. dissertation Univ. Calif.

[4] Mueller, Elizabeth. 1966. Introduction to the Ecology of the Pumice Desert, Crater Lake National Park, Oregon. 110 pp. M. S. dissertation, Purdue Univ.

on the desert indicates how recently this successional stage was initiated. Their average age was only 22 years; the oldest tree was less than 200 years old and was at the desert margin. The only dead trees found were seedlings. Most live seedlings were growing next to large pumice rocks, probably gaining shelter from the wind and sun.

The extreme temperatures encountered on the Pumice Desert, high and low, could be a major factor preventing the establishment of plants. High surface soil temperatures have little influence on plant roots which are buried and, therefore, protected from excessive heat. However, seedlings could be girdled at the soil surface by these same temperatures. Similarly, nighttime low temperatures and frosts could destroy many seedlings. The pumice soil would accentuate the problem of high daytime and low nighttime temperature extremes because of its very low thermal conductivity and volumetric heat capacity (Cochran, Boersma and Youngberg, 1967). In any case, a much smaller percentage of seed falling on the Pumice Desert, and subjected to temperature extremes, would be expected to germinate and grow successfully than in adjacent forested areas.

Although soil fertility was low, it was comparable to other high Cascade volcanic soils. Accumulated organic matter, also very low, indicates the degree of soil maturation and development, so it is not surprising that soil samples 9 and 10, taken from the transition area, had higher values. However, these organic matter percentages were still below those reported by Dyrness and Youngberg (1966). Mechanical analyses of Crater Lake pumice soils made by Tidball[5] compared with those made by the author[6] suggest that the Pumice Desert soils have a more youthful structure than those developed elsewhere from Mount Mazama pumice. As soil develops it supports a greater variety of life, which in turn contributes to soil maturation. Invasion of lodgepole pines from the surrounding forest shows this process is underway. However, it will continue to be very slow due to the severity and shortness of the growing season and the infertile soil.

Summary

The vegetation and environment of the Pumice Desert, a 5½ square mile area in Crater Lake National Park, were studied in 1965. Only 14 species with a density of 2580 plants per 0.1 acre were found in 22 linear 0.1 acre plots. Each species possessed one or more morphological adaptations for survival in alpine or desert environments. Lodgepole pine has only recently begun invading the area.

Widely fluctuating temperatures and high atmospheric evaporation rates characterize the short growing season. Surface soils heat to 20°F or more above air temperatures on sunny days. These severe climatic conditions probably retard invasion of the area by new seedlings.

Oregon pumice soils are generally considered infertile. However, Pumice Desert soils are even less developed than pumice soils previously studied and more nearly resemble unweathered parent material.

Many interacting factors combine to slow plant invasion and succession on the Pumice Desert. Chief among these are probably the severe climatic regime and infertile soil. Soil moisture does not appear to be a major limiting factor.

[5] See footnote 3.
[6] See footnote 4.

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