

## THE ECOLOGY OF SHRUBS IN BRYCE CANYON NATIONAL PARK

WITH SPECIAL REFERENCE TO PURSHIA TRIDENTATA<sup>1</sup>K. T. Harper and Hayle Buchanan<sup>2</sup>

## ABSTRACT

Shrubs contribute more cover than either forbs or graminoids in the forests of Bryce Canyon National Park. Purshia tridentata reaches maximum abundance in the ponderosa pine forests and declines steadily with increasing elevation. Purshia is the major understory species in the low elevation forests. The study covers mortality and establishment rates in six forest types over a 21 year period.

## INTRODUCTION

Bryce Canyon National Park is in Garfield and Kane Counties, southcentral Utah. Elevation ranges from 7,915 ft (2,412 m) at park headquarters to 9,105 ft (2,777 m) at Rainbow Point, the highest spot in the park. Geology in the area is dominated by the rather soft Wasatch limestone that has eroded along the edges of the plateau to produce spectacular pink pinnacles and badlands that are the major scenic attractions of the park. Precipitation at headquarters averages about 15.9 inches (40 cm) annually (Eubank and Brough 1979). Precipitation is about equally distributed throughout the year with 25 percent in the January to March period, 22 percent in April to June, 33 percent in July to September, and 20 percent in the October to December interval. Mean annual temperature averaged 41.0°F (5°C) for the 1916-75 interval: January temperatures averaged 21.6°F (-5°C), while July had an average temperature of 62.9°F (17°C) (Eubank and Brough 1979). Deep snowpacks accumulate on the plateau in winter: April 1 water content of snowpacks at headquarters averaged 4.3 inches (11 cm), while water content of snowpacks at Rainbow Point averaged 8.7 inches (22 cm) (Whaley and Lytton 1979).

Although total annual precipitation is unknown for any location other than at headquarters, two general studies relate precipitation to elevation in Utah mountains. Lull and Ellison (1950) showed that annual precipitation in Ephraim Canyon on the Wasatch Plateau (central Utah) increased about 4.9 inches/1,000 ft (12.5 cm/305 m) rise in elevation. Harper and others (1981) reported a 3.0 inches (7.6 cm) increase in precipitation per 1,000 ft (305 m) rise in elevation in the Uinta Mountains of northeastern Utah. Assuming that the relationship between elevation and precipitation at Bryce Canyon National Park is similar to that observed elsewhere in the state, annual precipitation at Rainbow Point probably averages somewhere between 19.5 and 21.8 inches (49.5 and 55.4 cm).

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## OBJECTIVES

The principle objective of this paper is to document the density of Purshia tridentata (bitterbrush) in various forest types within Bryce Canyon National Park for the intervals 1957-59 and 1978-80. The data base permits us to describe mortality and establishment rates for that species in six forest types over a 21 year period. We also provide information on associated shrubs, because such data should help managers to put the bitterbrush data into proper ecological perspective.

## METHODS

Our report is based on 223 permanently marked study plots sampled in the summers of 1957-59 by Buchanan (1960) and sampled again in 1978-80. At each study plot, a 10.76 ft<sup>2</sup> (1.0 m<sup>2</sup>) quadrat was established to sample herbs and shrubs. Trees and tree reproductions at each plot were sampled using the quarter method of Cottam and Curtis (1956). A marking peg at each 10.76 ft<sup>2</sup> quadrat was used as the point from which quarter method distances were measured. All perennial plants in each quadrat were mapped onto gridded paper using a metal frame with 16 equal-sized subsections. About one-third of the study plots were photographed in the initial and again in the later sample.

The sampling points were spaced approximately 300 ft (91 m) apart on a transect that ran along the top of the plateau and nearly the entire length of the park. Direction of the transect was occasionally altered as it encountered park boundaries or edges of the plateau. Compass bearings along each leg of the transect were recorded; distance between plots was measured with a surveyor's chain. The transect began near Rainbow Point and terminated near the park boundary about 1 mile (1.61 km) north of Fairyland View point and some 3 miles (4.83 km) northeast of headquarters. In addition to vegetational characteristics, slope steepness and direction of slope exposure were also recorded at each sampling point. Elevations at sampling points were taken from topographical maps.

After data from the second sample were in hand, individual sampling points were assigned to one of six general forest types based on composition of the tree layer at each point. Finally, several sampling points within each forest type were randomly chosen for analysis for soil depth and other characteristics: those samples were taken in summer of 1981. Soil depth was estimated with a thin (0.39 inch, 1.0 cm) diameter steel rod fitted with a handle at right angles to its length. The sharpened, 3.28 ft (1 m) long rod was pushed into the soil until it struck material that the worker could not penetrate. Five depth samples were taken at each point, one at the center and one in each corner of the 10.76 ft<sup>2</sup> quadrat. Twelve subsamples of the surface 6 inches (1.52 dm) soil (litter layer removed) were taken at each sampling point with a tube sampler. Subsamples were uniformly distributed within the area delimited by the four trees sampled by the quarter method; subsamples were composited for analyses.

## RESULTS

We recognized the following forest types at Bryce Canyon: Pinus ponderosa - Juniperus scopulorum (PIPO-JUSC), Pinus ponderosa - Pseudotsuga menziesii (PIPO-PSME), Pinus ponderosa - Abies concolor (PIPO-ABCO), Pinus flexilis (PIFL), Pseudotsuga menziesii - Abies concolor (PSME-ABCO), and Abies concolor (ABCO). Pinus ponderosa - Juniperus scopulorum forest dominated gently rolling, lower elevation sites, while Abies concolor was either the dominant or a successional aggressive species on higher elevation sites. Such sites also tended to be on steeper slopes than those that supported PIPO-JUSC forests (table 1).

Table 1.--General environmental conditions in six forest types at Bryce Canyon National Park. Forest types are identified by major tree dominants. Abbreviations used for trees in this and subsequent tables are as follows: Abies concolor (ABCO, white fir), Juniperus scopulorum (JUSC, Rocky Mt. Juniper), Pinus flexilis (PIFL, limber pine), Pinus ponderosa (PIPO, ponderosa pine), and Pseudotsuga menziesii (PSME, Douglas fir). All values reported are based on the sample sizes reported at the bottom of the table except for soil depth, which was based on sample sizes of 14, 7, 14, 28, 11, and 12 (left to right among forest types). The same letter in superscripts denotes means that do not differ significantly (P .05).

|                                           | Forest types       |                    |                    |                     |                    |                     |
|-------------------------------------------|--------------------|--------------------|--------------------|---------------------|--------------------|---------------------|
|                                           | PIPO-<br>JUSC      | PIPO-<br>PSME      | PIFL               | PSME-<br>ABCO       | ABCO               | PIPO-<br>ABCO       |
| Ave. elevation (m)                        | 2,437 <sup>a</sup> | 2,519 <sup>b</sup> | 2,600 <sup>c</sup> | 2,626 <sup>cd</sup> | 2,640 <sup>d</sup> | 2,651 <sup>de</sup> |
| Ave. slope (%)                            | 13.6 <sup>a</sup>  | 24.6 <sup>bc</sup> | 26.3 <sup>b</sup>  | 18.4 <sup>d</sup>   | 18.0 <sup>d</sup>  | 17.7 <sup>acd</sup> |
| Ave. exposure <sup>1</sup>                | 1.2 <sup>ade</sup> | 0.8 <sup>bc</sup>  | 0.7 <sup>b</sup>   | 1.0 <sup>ac</sup>   | 1.5 <sup>d</sup>   | 0.9 <sup>ce</sup>   |
| Ave. soil depth (cm)                      | 36.5 <sup>a</sup>  | 25.1 <sup>bc</sup> | 34.5 <sup>a</sup>  | 31.1 <sup>ab</sup>  | 39.5 <sup>a</sup>  | 21.6 <sup>c</sup>   |
| Biotic characteristics in 1980 and (1959) |                    |                    |                    |                     |                    |                     |
| Trees/ha                                  | 178 ( 84)          | 163 (101)          | 312 (221)          | 676 (300)           | 682 (436)          | 262 (138)           |
| Saplings/ha                               | 155 (102)          | 256 (114)          | 448 (191)          | 961 (516)           | 1,281 (680)        | 646 (202)           |
| Living cover (understory)                 |                    |                    |                    |                     |                    |                     |
| Forbs (%)                                 | 11.6 (11.9)        | 3.0 (5.0)          | 3.5 (3.0)          | 4.8 (5.8)           | 3.0 (3.0)          | 7.5 (8.0)           |
| Grasses (%)                               | 4.7 (5.3)          | 2.0 (4.0)          | 1.0 (1.0)          | 2.5 (4.1)           | 2.0 (3.5)          | 3.0 (7.0)           |
| Shrubs (%)                                | 11.7 (13.7)        | 12.0 (17.0)        | 13.5 (22.0)        | 8.0 (17.3)          | 3.0 (5.5)          | 12.5 (21.0)         |
| Total understory cover (%)                | 28.0 (30.9)        | 17.0 (26.0)        | 18.0 (26.0)        | 15.3 (27.2)         | 8.0 (12.0)         | 23.0 (36.0)         |
| No. plots/type                            | 72                 | 16                 | 29                 | 72                  | 19                 | 15                  |

<sup>1</sup> Exposures are coded according to a scheme suggested by Beers and others (1966): in that scheme, southwesterly slopes receive a value of 0.0, while northeasterly slopes are assigned a value of 2.0. Generally speaking, the larger the value, the cooler the site, all other things being equal.

Purshia tridentata achieved maximum abundance in the PIPO-JUSC forests at the lowest elevations (table 2). Purshia tended to become less important as elevation increased; the species was either absent or performed poorly in forests where Abies concolor was capable of doing well. Although bitterbrush occurred in 20 percent of the study plots of the PIPO-ABCO forest type that occupies shallow soils at the highest elevations (table 1), the population there suffered 33 percent mortality over the 1959-80 period and was unable to establish any new plants (table 2).

Purshia population densities declined in all forest types over the study period (table 2). Average density loss for the five forest types that had bitterbrush in 1957-59 was 35.9 percent in 20 years. Density losses were low in the PIPO-JUSC forests (21.4 percent) and maximal in the PSME-ABCO community (100.0 percent). Mortality was high in the limber pine forests too, but there, recruitments equalled mortality to give zero change in density (table 2). In general, mortality increased and recruitments declined with elevation.

Table 2.--Density (individuals/10 m<sup>2</sup>) of various shrub and subshrub species in the forests of Bryce Canyon National Park in 1980. Additional parameters for Purshia tridentata populations are given at the bottom of the table. An asterisk denotes a species that retains the bulk of its foliage during the winter (evergreen).

| Species                                          | PIPO-<br>JUSC | PIPO-<br>PSME | PIFL  | PSME-<br>ABCO | ABCO | PIPO-<br>ABCO |
|--------------------------------------------------|---------------|---------------|-------|---------------|------|---------------|
| <u>Artemisia nova</u> *                          | 1.0           | .0            | .0    | .0            | .0   | .0            |
| <u>Arctostaphylos patula</u> *                   | 3.6           | 8.1           | 5.5   | 2.5           | .0   | 2.7           |
| <u>Berberis repens</u> *                         | 7.5           | 12.5          | 12.8  | 21.2          | 14.4 | 13.3          |
| <u>Ceanothus martini</u> *                       | .8            | 2.5           | 1.7   | .6            | .0   | .7            |
| <u>Chrysothamnus depressus</u> *                 | 16.7          | 3.8           | 5.9   | 4.2           | .0   | 25.3          |
| <u>Pachystima myrsinites</u> *                   | 2.2           | 7.5           | 7.2   | 11.8          | 15.9 | 28.7          |
| <u>Petradoria pumila</u>                         | .0            | .0            | .0    | .7            | .0   | 11.3          |
| <u>Purshia tridentata</u>                        | 6.1           | 1.9           | 1.4   | .0            | .0   | 1.3           |
| <u>Rosa woodsii</u>                              | .4            | .0            | 3.4   | .6            | .5   | 1.3           |
| <u>Symphoricarpos oreophilus</u>                 | .7            | 4.4           | 6.9   | 7.6           | 1.1  | 3.4           |
| <u>Tetradymia canescens</u> *                    | .8            | .0            | .0    | .0            | .0   | .0            |
| <u>Xanthocephalum sarothrae</u>                  | 2.8           | .0            | .3    | .0            | .0   | 4.7           |
| Other <u>Purshia</u> parameters                  |               |               |       |               |      |               |
| Frequency (% in m <sup>2</sup><br>quadrats 1959) | 40.3          | 25.0          | 17.2  | 6.9           | .0   | 20.0          |
| Mortality (% from 1959-80)                       | 39.3          | 50.0          | 100.0 | 100.0         |      | 33.3          |
| Recruits (No./10 m <sup>2</sup> )                | 1.4           | .6            | 1.4   | .0            | .0   | .0            |
| Density change (% from<br>1959-80)               | -21.4         | -25.0         | .0    | -100.0        |      | -33.3         |

The principle shrubs associated with Purshia in those forest types where it performed best were Arctostaphylos patula, Berberis repens, Chrysothamnus depressus, and Xanthocephalum sarothrae. Other species such as Pachystima myrsinites, Rosa woodsii and Symphoricarpos oreophilus occurred infrequently with Purshia but achieved best development at higher elevations than that species (table 2).

Although Purshia is a winter deciduous species, most of the shrub individuals in these forests are evergreen. Over 70 percent of the shrub or subshrub individuals were evergreen in all six of the forest types (table 2). Of the shrub individuals, 95 percent were evergreen in the most dense (and presumably darkest) forest type (white fir). The success of so many evergreen shrub species in the understory of the Bryce Canyon forests suggests that the characteristic has some adaptive value there. We will return to the question of possible adaptiveness of evergreen leaves.

Over the 21 years of observation, average understory cover declined in all six of the forest types (table 1). The average decline across all forest types was 31.3 percent. Cover of all lifeform groups in the understory declined, but grasses and shrubs declined much more than forbs (table 1). Overall, forbs declined about 9 percent in relative terms, but grasses (39 percent) and shrubs (37 percent) declined over four times faster. Undoubtedly, the declines were strongly influenced by the great increases in forest density and attendant shading: in 21 years, density of trees and saplings roughly doubled on the average in Bryce Canyon forests (table 1). Nevertheless, photographs taken in the initial and the 1978-80 sample demonstrate that many shrub individuals died and left no replacements even in quadrats not overshadowed by trees or saplings.

Although Cowania, the other Rosaceous shrub focused in this symposium, did not occur in our samples, we have compared soil physical and chemical parameters in the forest zone of best development of Purshia in this study with similar parameters in stands that support Cowania mexicana var. stansburiana in central Utah (table 3). Purshia is shown to occur on deeper, better developed and more fertile soils than Cowania (table 3). The smaller rooting volume (soil depth) at Cowania sites would be expected to magnify the differences noted for Cowania and Purshia sites in respect to amounts of essential nutrients per unit weight of soil. Our field experience suggests that these results are probably broadly representative for habitats occupied by these species throughout Utah. Cowania is often on rocky outcrops or coarse gravels, while Purshia seems to prefer better developed soils. These closely related species thus appear to have diverged along at least edaphic and climatic gradients. Modern distribution patterns suggest that Purshia is more tolerant of cold winters and dry summers than Cowania.

#### DISCUSSION

Major changes have occurred in the Bryce Canyon National Park forests during the 21 years of our study. Forests have become more dense and natural succession has altered their composition. Those changes have been associated with less dramatic, but nevertheless large changes in the shrub layers of the forest understories. We have considered response of only Purshia tridentata here. The data provide many insights into ecological principles bearing on management of that species.

Our data show that bitterbrush in Bryce Canyon is most competitive at elevations below 8,200 ft (2,500 m). Although it did occur above those elevations at the park, it failed to perform well there: mortality was high -- an average of 71 percent above 8,200 ft as opposed to <sup>2</sup>39 percent below that elevation; and recruitments were low -- 1.30/100 ft<sup>2</sup> below and 0.46/100 ft<sup>2</sup> above 8,200 ft. Ream's (1963) data for species abundance in 25 northern Utah mountain communities support

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<sup>3</sup> Buchanan, H. and K. T. Harper. Successional dynamics of the forests of Bryce Canyon National Park, Utah. Unpublished manuscript.

Table 3.--Soil characteristics in the ponderosa pine-juniper forest type at Bryce Canyon National Park and in the Cowania mexicana var. stansburiana community in central Utah (data from Price and Brotherson, in press). Means of each value are followed by their standard deviation. The same letter in superscript denotes means for any given parameter that do not differ significantly (P .05)

|                                           | <u>Purshia</u><br>(PIPO-JUSC type) |         | <u>Cowania</u>     |         |
|-------------------------------------------|------------------------------------|---------|--------------------|---------|
| Soil depth (dm) <sup>1</sup>              | 3.65 <sup>a</sup>                  | ± 1.04  | 1.79 <sup>b</sup>  | ± 0.74  |
| Soil texture                              |                                    |         |                    |         |
| Sand (%)                                  | 36.3 <sup>a</sup>                  | ± 7.5   | 53.6 <sup>b</sup>  | ± 13.9  |
| Silt (%)                                  | 33.1 <sup>a</sup>                  | ± 7.3   | 27.9 <sup>a</sup>  | ± 8.5   |
| Clay (%)                                  | 30.6 <sup>a</sup>                  | ± 4.2   | 18.3 <sup>b</sup>  | ± 7.5   |
| pH                                        | 8.2 <sup>a</sup>                   | ± 0.1   | 7.7 <sup>b</sup>   | ± 0.4   |
| "Available" phosphorus (ppm) <sup>2</sup> | 10.2 <sup>a</sup>                  | ± 14.6  | 12.8 <sup>a</sup>  | ± 3.8   |
| Exchangeable                              |                                    |         |                    |         |
| Calcium (%)                               | .91 <sup>a</sup>                   | ± 0.23  | 0.58 <sup>b</sup>  | ± 0.09  |
| Magnesium (%)                             | .08 <sup>a</sup>                   | ± 0.02  | 0.02 <sup>b</sup>  | ± 0.01  |
| Potassium (ppm)                           | 242.0 <sup>a</sup>                 | ± 161.0 | 176.0 <sup>a</sup> | ± 102.0 |
| Sodium (ppm)                              | 50.0 <sup>a</sup>                  | ± 16.0  | 97.0 <sup>a</sup>  | ± 121.0 |
| Sample Size                               | 8                                  |         | 10                 |         |

<sup>1</sup>Actually soil penetrability with a thin probe. Sample size for this parameter at Bryce Canyon was 14.

<sup>2</sup>On Bryce Canyon soils, phosphorus was extracted with 0.2 N acetic acid, while in the Cowania study, the extractant was sodium bicarbonate. The former extractant usually frees more phosphorus than the latter on common soil samples.

our observations at Bryce Canyon. He found Purshia in greatest abundance below 6,250 ft (1,900 m) and lacking completely as a significant member of the vegetation above 7,400 ft. Since Ream's (1963) data were taken about 4° farther north, one would expect the species to perform best at lower elevations there than at Bryce Canyon.

Our data suggest that bitterbrush's ability to establish in marginal habitats must be heavily influenced by ephemeral, local conditions. Although the species had once established itself above 7,400 ft at Bryce Canyon, high mortality and poor reproduction suggest that it will not persist in those forest types. Since there is little evidence for significant climatic changes in the Bryce Canyon area during the past half century (McNulty 1947), we conclude that establishment of the species at the higher elevation sites must have been favored by past disruptions of the vegetative cover. Data summarized elsewhere suggest that ground fires and abusive grazing by domestic livestock in the early part of this century probably kept forests at Bryce open and less dark than at present.

Others have earlier noted the decline of bitterbrush populations across Utah. As early as 1947, McNulty (1947) described a widespread failure of bitterbrush stands to reproduce in the state. McNulty (1947) blamed the poor reproductive success exclusively on overuse by grazing animals. Our data implicate another cause (community succession) for population declines in bitterbrush populations, even though ungulate grazers may also have been involved.

We tested McNulty's (1947) hypothesis of grazing pressure (domestic and wild ungulates) as the cause for population decline in bitterbrush. Because domestic grazers have been excluded from the park since about 1937 (see footnote 3), we confined our attention to mule deer, the only hooved grazing animal remaining there. The data show (table 4) that deer herd sizes in the area have apparently declined throughout the period 1957-80. Harvest rates from other herd units of Utah for the period 1966-72 were 2.05, 2.63, 3.70, 5.48, and 8.56 animals/km<sup>2</sup> of summer range (North Book Cliffs, Pine Valley Mountains, Elk Ridge, LaSal Mountains, and Blue Mountain herd units respectively)<sup>4</sup>. In comparison, harvest rates for mule deer were 2.79 (unit 50) and 1.85 (unit 60) animals/km<sup>2</sup> of summer range/year from 1961 to 1965, a period of heavy harvests for our study areas. Therefore, deer populations were not unusually large during the period when bitterbrush populations were declining in the park. Declining hunter success through the years also suggests declining deer populations (table 4). Admittedly, such data are difficult to interpret because grazing stress is the result of an interaction between number of grazers and number of available plants per unit area. Nevertheless, it seems likely that grazing pressure alone is not responsible for the observed decline in bitterbrush populations at Bryce Canyon National Park.

Table 4.--Number of mule deer harvested from herd units that surround or lie close to and have habitats similar to those at Bryce Canyon National Park. Unit 50 (Antimony) lies due north of the Park, and unit 60 (Paunsagunt Plateau) includes but has most of its area to the west of the Park. Data are averaged by 5-year intervals for 1951-80 for both units. For a time, unit 60 was subdivided to produce 60B. We combined results for those subunits for the years of their existence. Percent hunter success in the regular season (special hunts ignored) is also reported for the same intervals used for harvest data). Data are from Utah Division of Wildlife Resources (1960-81) reports.

| Time interval | Herd unit |           |                  |           | Type of hunt                          |
|---------------|-----------|-----------|------------------|-----------|---------------------------------------|
|               | 50        |           | 60               |           |                                       |
|               | Harvest   | % success | Harvest          | % success |                                       |
| 1951-55       | 998       | 89.0      | 282              | NA        | Either sex                            |
| 1956-60       | 1631      | 70.4      | 1429             | 83.4      | Either sex                            |
| 1961-65       | 1619      | 67.2      | 1988             | 59.7      | Either sex                            |
| 1966-70       | 613       | 68.2      | 743              | 55.0      | Either sex                            |
| 1971-75       | 569       | 46.6      | 525              | 39.4      | Either sex 1971-73; buck only 1974 on |
| 1976-80       | 219       | 31.6      | 209 <sup>1</sup> | 24.8      | Buck only                             |

<sup>1</sup> area partially closed in 1980.  
NA = data not available.

Mooney and Gulmon's (1982) considerations relative to leaf duration have relevance to this study in two ways. Their work suggests that the prevalence of evergreen-leaved shrubs at Bryce Canyon may be related to the uniform distribution of precipitation throughout the year and/or to low availability of phosphorus, a

<sup>4</sup> Pederson, J. C. and K. T. Harper. Does summer range quality influence sex ratios among mule deer fawns in Utah? (In press).

critical element for plant growth (table 3). Also, full consideration of the comparative ecology of Purshia tridentata and Cowania mexicana var. stansburiana must include evaluation of the consequences of their difference in leaf duration. If Mooney and Gulmon's (1982) conclusions are broadly applicable, one would predict that bitterbrush (deciduous) should have higher photosynthetic rates and faster growth than its evergreen-leaved relative, Cowania. Their generalizations also suggest that the leaves of the former species should have higher protein levels and be more palatable to herbivores. Leaf duration may explain why bitterbrush has extended its range far into the summer-dry Great Basin and Pacific Northwest, while Cowania's range and abundance patterns are well correlated with the summer rain zone of the Southwest. Those observations conform to expectations suggested by the Mooney-Gulmon hypothesis relative to leaf duration: one would expect the evergreen species to perform best where the moisture supply was more uniform. The different edaphic preferences of these two shrubs also fit expectations for deciduous and evergreen taxa, with the evergreen species occurring where nutrients are more limiting.

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