

FINAL REPORT
AN INVENTORY AND MONITORING PROGRAM OF
THE VEGETATION IN THE BREAKS,
BRYCE CANYON NATIONAL PARK, UTAH

VOLUME I

INTRODUCTION
PROGRAM DETAILS
DATA AND DISCUSSION

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I. INTRODUCTION

With the probable advent of anthropogenic climate change in the next 5-20 years (cf. Abrahamson 1989), long-term monitoring of biotic ecosystems will become critical. Only through such monitoring can we directly measure and understand the effects climate change will have on natural and anthropogenic ecosystems. Furthermore, resource managers on public lands in the U.S. will require hard data in order to make informed decisions on resources on lands under their management during a climate change regime.

The National Park Service has prepared initial statements on the feasibility of climate change studies on the Colorado Plateau (National Park Service 1990). These kinds of studies have yet to be initiated on the Plateau. Until such time as region-wide interdisciplinary monitoring programs are established, individual national parks, and Forest Service and BLM districts, on the Plateau, must take the initiative and begin local monitoring programs.

In 1991, the resource management division of Bryce Canyon National Park (henceforth BRCA) requested funds from the BRCA Natural History Association to initiate a monitoring program on the vegetation in the BRCA breaks. Resource personnel felt that, since the breaks was one of the most heavily visited natural features in the region, as well as being world famous, any changes that could affect its visual scenic character need to be anticipated and understood. The BRCA breaks are an ideal system to study the effects of climate change on vegetation. Because of the harsh conditions, including nutrient poor soils, high erosion

rates, and drought conditions, many plant species are near their tolerance limits. Any changes in climate, that in turn could bring about changes in soil moisture levels or erosion rates, may have a rapid effect on the vegetation in the breaks. In particular, conditions in the breaks are ideal for the study of tree responses to climate change, for the reasons noted in Fritts (1976) and Spence (1990).

In this report, a protocol as well as preliminary results for a long-term vegetation monitoring program in the BRCA breaks are presented. Although primarily designed to monitor changes in the vegetation due to natural physical and biotic factors, the effects of human use, especially trampling, can also be detected by this program. As human use will probably increase in the breaks, the preliminary data presented in this report will provide a useful benchmark for comparisons against future changes. This report is the first of two parts. The protocol, sites, physical descriptions, understory and shrub cover, and tree density, health, and needle lengths, will be presented in Part I. Part II will present tree-ring analyses for selected tree species in the breaks, detailed analyses of climate variation in the park, and develop a dendroclimatological model to predict tree response to climate change.

II. PREVIOUS WORK

1. Bryce Canyon vegetation research.

The flora of BRCA is well known and large, with 458 species

reported (Buchanan & Graybosch 1981; Spence & Buchanan 1992). Several rare species, endemic to south-central Utah, are found in the park, and many occur in the breaks. Some research has been done in the forests on the Paunsagunt Plateau in and to the west of the park (Buchanan 1960, 1971; Harper & Buchanan 1983; Stein 1989; Roberts et al. 1991; Van Pelt et al. 1992), but only one study has focused on the BRCA breaks (Graybosch & Buchanan 1983). Four main vegetation types (habitat types or floristic associations) were recognized in this study, Pinus ponderosa-Arctostaphylos patula, P. ponderosa-Pseudotsuga menziesii, mixed conifer, and Pinus longaeva. Some of these were divided into phases depending on subdominants. In addition, clay slopes and talus were recognized as a fifth "psuedo-type". The distribution of 11 rare species was discussed in the area of the main breaks amphitheater. One of the most important finds of this work was the recognition that the bristlecone pine vegetation in the breaks is at the lowest elevation known for this species throughout its range (cf. Bailey 1970; Hiebert & Hamrick 1984). This vegetation was also found to include many of the rare species in the park.

2. Climate-vegetation monitoring.

Monitoring the effects of climate change on vegetation is not a single, well focused, area of research. A variety of techniques can be used, drawn mostly from standard vegetation survey methods or dendroclimatology. Techniques can range from simple transect estimates of plant frequency and cover (eg., Halvorson et al. 1988) to sophisticated analyses of individual tree response to

microclimate (eg., Fritts 1969). In general, monitoring techniques should conform to several criteria:

1. Observations should be made on permanent plots or permanently marked individuals, to control for site to site variation,
2. Techniques should be kept as simple as possible, especially with respect to equipment that may or may not be available,
3. Methods of reading or recording data should be as objective as possible, to control for observer error between censuses,
4. Kinds of data and species studied should be appropriate to the questions being asked.

This last criterion is particularly important, and often difficult to meet. One problem is that plant responses are integrated, often synergistic, combinations of the effects of many factors, such as climate, soil, nutrient status, genetics, and the biotic environment. Even in a reductionist framework, a particular plant response, eg., to climate, is a function of threshold values related to structure, physiology and the particular climatic variable (Woodward 1987). For example, short-term fluctuations (ie., a few minutes in duration) in temperature microclimate, induced by changes in cloud cover or sudden gusts of wind, effect particular structures and processes at the cellular level (ie., cell respiration and photosynthesis, stomatal aperture), but not plant survival, reproduction, or geographic distribution. On the

other hand, major climatic events, such as the El Nino, can alter all plant responses from the cellular to the geographic level. A mid-scale approach is taken in this monitoring program, where meso-scale climate (monthly, yearly, and 10-year averages of temperature and precipitation in the breaks) are related to changes in plant cover, frequency, growth (in trees), health, and reproduction.

The best studied area of plant response to climate in western North America is dendroclimatology, the study of tree responses to climate (Fritts 1976). Although tree ring width and density are the most sensitive tools, other kinds of observation, on tree health and growth can be made. In this study, tree health, as assessed by mistletoe and disease infection, and needle drought, are monitored in addition to reproductive and tree ring data. Needle length variation was also chosen for monitoring, as many studies have indicated a relationship between needle length and climate variation in conifer species (eg., Tausch and West 1987; Armstrong et al. 1988). Reproduction is also sensitive to climate in many species (eg., Floyd 1987). Best species for monitoring include arid-adapted conifers in the genera Pinus and Juniperus (cf. Spence 1990).

Cover, frequency, and reproduction of understory and shrub species are generally easy to census, and are variables that should respond to climate change. If climate changes in a linear fashion, some species should increase in cover and frequency, while others should decrease. Reproductive status should also

change for many species, with some ceasing to flower and fruit, while other, sterile, species begin to. These responses are based on the widely corroborated premises that, 1) species have threshold values, which determine functional responses to the environment, and 2) that they may not be at their optima in most parts of their range (Cain 1944; Woodward 1987; Tilman 1988).

Relatively little published information is available on monitoring programs in western U.S. national parks (Davis 1989; van Riper et al. 1991). After studying the available literature on techniques and programs, methods were selected to conform to standard ecological census techniques (see Mueller-Dombois and Ellenberg 1974; Greig-Smith 1983), and to the criteria noted earlier as much as possible. The methodology is presented in section IV.

III. PHYSICAL DESCRIPTION OF THE BREAKS

The Bryce Canyon breaks result from rapid headwall erosion of the Claron Formation, a freshwater lacustrine and fluvial formation of probable Eocene age (Bowers 1991). Two informal, weakly differentiated, members can be found in this formation, the white limestone and the pink limestone members. All transects are either located on the Claron formation, or on quaternary colluvium derived largely from it or overlying it. However, the mixed conifer transect in Bryce Canyon may have some colluvial input from the Wahweap formation.

Topographically, the breaks consists of badland-like

formations, with steep slopes dropping off relatively flat ridge crests. Erosion is rapid, because of the relatively soft rocks of the Claron limestone. Major processes include winter freeze-thaw activity, and summer sheetwash erosion. Retreat rates have been calculated at one meter per 150-200 years. The soils of the breaks are young, and generally thin except where Quaternary deposits have accumulated. Because of the porous nature of the limestone, soils and other surface deposits are well drained. Slopes with high clay concentrations, in particular, generally resist water penetration, and are consequently dry at depth.

The climate of Bryce Canyon is semi-arid and continental, with cold winters and rather cool summers. Precipitation is weakly bimodal, with winter (December-March) and summer (June-September) peaks (Figure 1). Spring (April-May) and fall (October-November) tend to be drier. Summary data (visitor center, elevation 2413 m) from the long term average (1916-1975; Eubank & Brough 1979) and the 1981-1990 period, are listed in Table 1. Compared with the long term average, 1981-1990 appears to be warmer (except for lower July average highs), with a shift in precipitation to higher summer and lower winter totals (Figures 1-4). However, yearly means for average temperature and precipitation are very similar for the two periods.

As the transects are at lower elevations than the visitor center weather station, lapse rate calculations for transect locations are needed. In addition to temperature and precipitation data, various indices have been devised by combining the two in

biologically meaningful ways. An exhaustive survey can be found in Tuhkanen (1980). Two climatic indices are used in this report, de Martonne's and Bailey's.

Indices combining temperature and precipitation are useful, as the two are strongly inter-correlated and because plants respond to both factors simultaneously. Of the many different combined indices, de Martonne's aridity index was selected because of its simplicity and good correlation with biological activity (Tuhkanen 1980). This index (H) uses average temperature and precipitation as follows:

$$H = \text{precipitation} / (\text{temperature} + 10)$$

where precipitation is in millimeters and temperature in degrees celsius. The higher the value, the less arid the climate, and in general the more water available for biological activity (at least above 0 C°). Monthly values can be calculated by the equation:

$$\text{Monthly } H = \text{monthly precipitation} * 12 / (\text{monthly } T + 10)$$

Monthly values of H for 1916-1975 and 1981-1990 are plotted in Figure 5.

A widely used index examining temperature variation is that of Bailey (1960), who developed an index describing the continentality of a region based upon temperature ranges. This temperateness index (M) is:

$$M = 161.7 - 41 \log_{10} [(WM - 10)^2 + (CM - 18)^2]$$

where WM is average temperature for the warmest month, and CM is average temperature for the coldest month of the year in degrees celsius. The greater the value of M, the greater the

temperateness. A score of 0 would indicate conditions similar to the south pole, while a score of 100 would be a good description of some versions of heaven.

Standard lapse rates for temperature against elevation have been calculated for the region. Betancourt (1984) calculated a rate of $-0.45^{\circ}\text{C}/100\text{ m}$ increase for southeastern Utah, but noted that climate data above 2100 was lacking, and the lapse rate was inaccurate above this elevation. A lapse rate of $-0.59^{\circ}\text{C}/100\text{ m}$ was noted for the nearby San Juan Mountains of Colorado, a more realistic figure for mountain climates. Both are lower than the standard $-0.65^{\circ}\text{C}/100\text{ m}$ in climate textbooks. In this study, the San Juan lapse rate is used over Betancourt's because of the incorporation of high elevation data.

Lull and Ellison (1950) calculated an increase in precipitation of $41\text{ mm}/100\text{ m}$ increase in elevation in central Utah, in an area likely to be similar to Bryce Canyon in overall climate. As data are lacking from the Bryce Canyon area, this rate is used.

Betancourt (1984) noted that average lapse rates concealed some seasonal variation. In southeastern Utah, precipitation increases more rapidly with elevation in winter compared to summer, while temperature decreases more rapidly with elevation in summer compared with winter. Hence values used in this report are likely to slightly underestimate summer temperatures and overestimate summer precipitation in the breaks.

IV. METHODS AND MATERIALS

1. Site selection

After initial surveys in June and July of 1991, sites were selected in and around Bryce Canyon and Campbell Canyon for monitoring. The Pinus longaeva (PILO), P. ponderosa/Arctostaphylos patula (PIPO), and P. ponderosa-Pseudotsuga menziesii (MC) communities were selected for detailed study. An oak-mountain mahogany community on Boat Mesa was also studied, and the results will be reported at a future date. The mixed conifer community was rejected based on several criteria, including small areal extent, high site to site variability, uneven topography, and proximity to heavily used trails. In this report the P. ponderosa-P. menziesii community is termed the mixed conifer community for convenience, and it should be noted that this is not the same as the mixed conifer community in Graybosch and Buchanan (1983), which is a riparian Picea pungens community.

Criteria for site selection varied depending on community. For P. longaeva sites, areas were selected on relatively flat ridge crests, with P. longaeva in the vicinity. For the two forest communities, sites were selected on slopes. The presence and abundance of P. menziesii was used in placing a site into one of the forest communities. Sites were evaluated for community type using criteria in Graybosch and Buchanan (1983). Important criteria for selecting all sites included; relatively distant from areas of heavy human use, lack of fire or windfall disturbance, relatively uniform topography, ease of re-location, and uniformity

of both understory and overstory vegetation.

2. Site location and transect and plot design

Eight transects were established, four in the PILO community, and two each in the PIPO and MC communities. Each transect consisted of three 10 m X 10 m plots, placed roughly equidistantly, along a specified compass azimuth (note: all compass readings in this report are magnetic, and not corrected for true north). Distances between plots varied from 50-100 m depending on topography. Plots were selected subjectively, based on homogeneity criteria, and subject to the constraint that at least one adult tree was included in the plot. Plot corners were marked with rebar, flagged, and cairned. A diagram of a standard plot, with details on quadrats, intercept lines, soil depth measurement, bearing, etc., is shown in Figure 6.

3. Site physical description

For each plot, the following data were recorded; map reference and coordinates, elevation, aspect, slope, bedrock geology, substrate texture and type, vegetation, and evidence of past events such as fire, animal activity, or disturbance. A sample plot description sheet is shown in appendix A.

4. Soil depth

A 10 m tape measure was placed through the middle of the plot along the transect bearing. At one meter intervals, from 1.0 m to 10.0 m, a 60 cm soil probe was inserted into the ground, and depth recorded to the nearest centimeter. Depths of 60 cm were recorded as 60+ unless a clear barrier to the probed tip was encountered at

exactly 60 cm. For calculations of average depth, 60+ was converted to 61 cm, leading to a possible slight underestimate of soil depth. A sample plot soil depth sheet is shown in appendix A.

5. Understory data

Along the two edges of each plot along the transect bearing, 10 quadrats were placed at 1 m intervals, from 0.4 to 9.4 m, for a total of 20 quadrats per plot. The quadrat size used was 20 cm X 50 cm, which is suitable for low herbaceous vegetation (Grieg-Smith 1983). Total area read was 2.0 m² per plot. A nested frequency design (see Smith et. al. 1987) was used, with the quadrat divided into three areas of increasing size, 250 cm², 500 cm², and 1000 cm² (see Figure 6). The quadrat was placed inside the plot edge, with the 20 cm side aligned along the edge (eg., from 0.4 to 0.6 m, etc.). Placement was such that the smallest of the nested plots was closest to both the plot edge and the corner at which the first quadrat was read (see Figure 6).

Cover was estimated visually for litter, soil, rock, native ungulate sign (dung and prints), human sign (footprints, litter), and all herbaceous and low shrub species rooted in the quadrat frame, using the Daubenmire scale (Daubenmire 1970):

<u>Interval</u>	<u>Midpoint</u>
1 = >0-5%	2.5%
2 = 5-25%	15.0%
3 = 25-50%	37.5%
4 = 50-75%	62.5%

5 = 75-95%	85.0%
6 = 95-100%	97.5%

For total cover estimates in plots, the midpoints of the intervals were used. This scale was used because it reduces variation among observers, as observers are less likely to derive different estimates in the same quadrat with this scale than with a finer scale (cf. West and Hatton 1990).

Frequency was recorded for plants rooted inside the three nested quadrats using the technique in Smith et al. (1987). A score of 1, 2 or 3 was recorded for each species depending on whether it occurred in the largest, mid-sized, or smallest nested quadrat respectively. Total frequency can vary from 0 to 300% for each species. The nested quadrat method was chosen because of the much greater range of values obtained (0-300% rather than 0-100%), allowing for more sensitive and detailed analysis of trends in frequency over time.

Reproductive status for each species was determined by noting the presence of flowers and/or fruits within the quadrat. Sample understory data sheets can be found in appendix A.

6. Shrub data

The line-intercept method (cf. Mueller-Dombois and Ellenberg 1974) was used to record tall shrub data (see appendix B for distinction between low and tall shrubs). A 10 m tape measure was placed along both edges, as well as the middle of each plot (where soil depth was recorded), along the transect bearing (see Figure 6). A total of 3000 cm were measured for each plot. Shrubs under

this line were recorded to the nearest cm by species. A "filling-in" technique was not used in this study because of its subjective nature. As the canopy of some shrubs, such as Arctostaphylos patula, can be very open, not using this "filling-in" technique will result in a slight to moderate over-estimate of shrub cover.

For each transect species-segment, health and reproductive status was assessed. The presence of flowers and/or fruits was noted for each species-segment. Health was assessed by a three point scale based on leaves:

- 1 = >50% of leaves under tape diseased, dead or dying,
browsed, or with insect feeding sign,
- 2 = 10-50% of leaves under tape diseased, dead or
dying, browsed, or with insect feeding sign,
- 3 = <10% of leaves under tape diseased, dead or dying,
browsed, or with insect feeding sign.

Damage types used were drought (brown or dead intact leaves), nutrient deficiency (yellowing of leaves), disease (signs of lesions or fungal infection), browsed (entire leaves removed or cropped), or insect feeding (marginal patches chewed or holes in leaves). Appendix A includes a sample shrub cover data sheet.

7. Tree data

All trees located in each plot were mapped and measured for diameter at ground level, reproductive status, mistletoe infection, limb death, and drought status. Diameter at ground level (dgl) was used because it provides a more accurate measure of basal area. In those cases where roots were exposed, diameter

was measured directly above the root level. Reproductive status was noted by the presence of female cones. Mistletoe infection and limb death were determined using the scale developed by Hawksworth (1977). This technique consists of dividing the crown into thirds and assessing each third as follows:

No branches dead or infected	=	0
<50% of branches dead or infected	=	1
>50% of branches dead or infected	=	2

A branch was defined as a relatively large offshoot of the main tree stem. The scores for each third of the tree are added, for a total score of 0 to 6. Drought was determined by browning or death of needles in the same way, but only for living crown (ie., if the top third of a tree was dead only the other 2/3 of the crown was assessed, for a score ranging from 0-4). For saplings (see below), the crown was divided into half (total possible score = 0-4), while for seedlings only one assessment was made (total possible score = 0-2). Tree size-age definitions were as follows:

adult=	dgl > 10.0 cm,
Sapling	= dgl = 2.5-10.0 cm,
seedling	= dgl < 2.5 cm.

A sample tree data sheet can be found in Appendix A.

8. Tree needle data

Five selected adults of each common tree species in or around each plot were chosen for needle length estimates. The species selected were Pinus longaeva and P. ponderosa. These species were selected because studies on pines have noted a strong relationship

between needle length and water status of the tree (Fritts 1969; Tausch and West 1987; Armstrong et al. 1988), with shorter needles in drier and/or colder years and longer needles in wetter and/or warmer years at montane-subalpine elevations. For each tree, ten branches were sampled at random, by walking around the tree, stopping at random points, and selecting one of a group of branches without looking at it. Obviously diseased or damaged branches were rejected. For P. ponderosa, three fascicles were collected from each branch, one just behind (but not including) the current year's growth, one midway between the branch tip and oldest needles, and one in the last group of needles. This will select needles of approximately 2, 3-4 and 4-5 years of age in P. ponderosa. The same method was used in P. longaeva except that the last needle fascicles were selected at a point corresponding to or as close to the ten year position as could be determined, based on counts of growth scars. Thus needles of ca. 2-3 years, 4-7, and 8-10 years were selected. Current years (1991) needles were not included because they had not fully extended during the sampling period (August-September). The needles for each tree were placed in a plastic bag, mixed, and 10 fascicles randomly selected. The longest needle in each fascicle, from fascicle base to tip, was measured to the nearest millimeter. A preliminary analysis indicated little difference in needle lengths between 2-needled and 3-needled fascicles in P. ponderosa, so both were used as collected. A sample data form is included on the tree data form in appendix A.

9. Photographic data.

Photographs were taken of each plot using a standard 35 mm camera and lens. A permanent photo point was established at each plot (see Figure 6), with as much as the plot in the frame as possible. Data recorded include locality, date, film, time of day, f-stop, lens size, speed, frame number, height of camera, weather conditions, and bearing and distance to plot. In most cases, Ektachrome 200 color slide film was used. A sample photo data sheet is shown in appendix A.

10. Data analysis and storage.

Summary data are presented in the results section, while individual plot data can be found on computer disk. Standard DBASE III+ format files were used to store data. Separate files were prepared for soil, understory, shrub, tree, needle length, site description, and photographic data.

Summary data is presented for transects in the results section. For calculations of average shrub and understory cover the quadrat and intercept data were averaged over the three plots per transect. Species reproduction was calculated as the percentage of quadrats or line intercept species-segments in which flowers and/or fruits were recorded. Tree health status data were grouped and averaged by transect and class (adult, sapling or seedling).

V. RESULTS

1. Site locations and physical characteristics.

Tables 2-3 summarize site physical features and climate. The four PILO transects are located on N-S trending ridge crests between Campbell and Bryce Canyons, centered around the Mormon Temple. The PIPO 1 transect is located on the slopes below PILO 1, on the north side of Bryce Canyon. MC 1 is also in this canyon, downstream, and on a NW facing slope. PIPO 2 is on the slope of Boat Mesa in Campbell Canyon, while MC 2 is located on a north facing slope directly below the Fairyland Trail near the rim. Locations are mapped in Figure 7, and complete details for locating plots, including plot and transect sketches, can be found in Volume II. Site physical data can be found in the DBASE III+ file SITEDESC.DBF.

2. Understory data.

Understory data for the transects across the three vegetation types is summarized in Tables 4 and 5. A total of 76 species of vascular plants was encountered in the 24 plots. These are listed in appendix B. Species richness varied from a high of 37 species on the PIPO-1 transect to 26 species on the PILO-1 transect. Individual plot richness varied from a low of 16 species to a high of 28 species. PILO plots were the richest, averaging 24.2 species, compared with MC plots (22.0), and PIPO plots (21.2).

Cover was lower in the PILO woodland, compared to the forest types. The most important understory species in this type were Eriogonum panguicense, Lesquerella rubicundula, Townsendia minima, and Linum kingii. The most important species in the PIPO type were Elymus salinus, Oenothera howardii, Carex rossii, and Stipa

comata. In the MC type, the most important species were Mahonia repens, Carex rossii, Elymus salinus, and Lithospermum multiflorum. Litter was dominant on the ground in the forest types, while rock was most common in the PILO type. No evidence of human activity was encountered in the quadrats in any of the plots. Native ungulate (deer) activity was moderate in the MC and PIPO types, but very light in the PILO type.

Reproduction varied from 0-100% among understory species. Most widespread or common species flowered, but a few, eg., Carex rossii, were rarely recorded as flowering. Many of the least commonly encountered species were non-reproductive.

Complete plot understory data can be found in the DBASE III+ file UNDERSTR.DBF.

3. Rare or geographically restricted species

Some species of forbs were categorized as rare or of limited distribution. Several are federal candidate species. Appendix C contains a listing of the eleven species included in this group as well as other rare species in or around the park. Rare species averaged 8.5 per PILO transect, 1.5 per PIPO transect, and 1.0 per MC transect. A strong concentration of rare species was observed in the PILO vegetation type. The only geographically rare species encountered in the forest plots were Cryptantha abata, Draba subalpina, Gentianella tortuosa, and Townsendia minima, and none were common.

Rare species dominated the understory in the PILO woodland, with 11/21 found in the park encountered in this type in this

study. Three of the four most important species are in this group. Most showed moderate to high reproduction, but Townsendia minima, Sphaeromeria capitata, and Penstemon bracteatus were rarely encountered with flowers or fruits in the quadrats.

4. Shrub data

Line intercept data for the shrub stratum in the three vegetation types is summarized in Tables 6 and 7 by transect. Arctostaphylos patula was the only commonly encountered species in the PILO type, while this species shared importance with Quercus gambelii and Symphoricarpos oreophilus in the forest types. Shrubs were rare in the PILO type, but generally were important components of the forest types.

Reproduction was rare in A. patula in the PILO type, and generally high in the forest types. The reverse was true for health status in this species, as it appeared healthier in the PILO type. The most common leaf damage types were drought and insect feeding. Other shrubs encountered in the forest types generally had low reproduction, while health status varied. Some species, especially Ceanothus martinii, were heavily browsed by deer, while other species, eg., Symphoricarpos oreophilus, had little sign of disease or browsing damage. Complete data can be found in the DBASE III+ file SHRUBCOV.DBF.

5. Tree data

Summary tree data for the transects can be found in Tables 8-12. Numbers of individuals in the adult, sapling and seedling classes are shown for each species in Tables 8 and 9, while health

status for the three classes are listed in Tables 10-12.

On the PILO transects, Pinus longaeva dominated most plots, but P. ponderosa was almost as important and occasionally assumed dominance. Pinus flexilis was generally present but in low numbers, while Juniperus scopulorum was rare. Trees per hectare varied from 633-1867/transect, while total basal area (cm²) varied from 2475-5524/transect. Figure 8 shows the size distribution for the most common species. For adults and saplings the same pattern occurs, with the ranking P. longaeva > P. ponderosa > P. flexilis. However, few P. longaeva seedlings were found, although the actual number may be higher because of difficulties in separating P. longaeva and P. flexilis seedlings. Far greater numbers of P. ponderosa and P. flexilis seedlings occurred than expected.

Size class numbers are summarized for the PIPO transects in Figure 9. Only two species, P. ponderosa and J. scopulorum, were common. P. ponderosa dominated the adult class, while J. scopulorum dominated the sapling and seedling classes. Total trees per hectare varied from 467-1400/transect, while total basal area (cm²) per hectare varied from 9812-15970/transect.

Figure 10 summarizes the size distributions on the MC transects. Three species were common, P. ponderosa, Pseudotsuga menziesii, and J. scopulorum. The size ranking for adults and saplings was the same, ranked P. ponderosa > P. menziesii > J. scopulorum. The seedling class was dominated, however, by P. menziesii. Total trees per hectare ranged from 1370-2100/transect, while total basal area (cm²) varied from 12248-13576/transect.

Tree status is summarized in Tables 10-12 for the three types. P. ponderosa was not infected by mistletoe in any plots, while all other species had at least some infection except for the seedling stage. Pseudotsuga menziesii (by A. douglasii) was the most heavily infected, while P. longaeva, P. flexilis (both by A. cyanocarpum), and Juniperus scopulorum (by P. juniperinum) showed lower rates.

Limb-death was highest in P. longaeva, and P. ponderosa in the PIPO and MC types. Despite heavy mistletoe infestation, Pseudotsuga menziesii showed relatively low limb-death rates. Most saplings and seedlings showed low rates of limb-death for most species, except for P. longaeva in the PILO type.

Needle drought damage was highest in the PILO type, with both P. longaeva and P. ponderosa showing extensive needle death. The exception is the seedling class in P. ponderosa, which was less affected. However, seedlings of this species showed extensive needle death in the PIPO type.

Reproduction varied from 50-100% in adults. Pinus ponderosa showed the highest rates in the PIPO type, and substantially lower rates in the MC and PILO types. Only P. longaeva saplings showed any reproduction, probably because of their much greater age compared to equivalent-sized individuals of the other species.

Needle length data are summarized in Table 13. For P. longaeva, similar values were obtained for all transects. Needle lengths vary more for P. ponderosa, both within and between vegetation types. In general, lengths were lowest for PILO

transects, compared with PIPO and MC transects.

Complete data can be found in the DBASE III+ file TREES.DBF, while needle length data can be found in the file NEEDLES.DBF.

VI. DISCUSSION

The main goal of the monitoring program is to detect changes in vegetation cover, frequency, reproduction, and health over moderate time intervals (eg., 10-50 years). In the event of directional change in climate, future censuses of the transects should document changes in some or all variables recorded, from needle length in conifers to changes in cover and reproduction of understory species. However, although the fact of change can often be demonstrated, the underlying cause(s) is more difficult to determine. Changes could result from climate change directly, or indirectly through the effects of climate change on other aspects of the breaks environment, such as soils or associated biota (eg., disease, herbivory). Untangling the complex interactions between climate, soils, biota, fire history, etc., are difficult and well beyond the scope of this program. Below, I will first discuss climate modeling and potential changes in climate at BRCA, then suggest a series of possible responses by the common woody species to the most likely change scenario.

Modeling the climate is extremely complex. Three different kinds of models have been used, energy balance, global circulation, and radiative-convective. All three sets of models agree on an increase in average temperature of from 1.5-4.5 °C

with a doubling of CO² content, expected in the next 50-60 years. Increases will be greater at higher latitudes. Recent estimates of increases have been near the higher end of this range. The most recent applications of these models to studies of past climate change has provided some confirmation of the predictions derived from them, because the predicted increase in temperature over the last 100 years (+0.5) is very close to the observed change. Ominously, of the 125 year period from 1861-1985, the three warmest years were 1980, 1981, and 1983 (Macdonald 1989).

Because of the limited resolution of most models (500 km grids in the more complex global circulation models) predictions of local or regional climate changes are difficult. Some predictions, however, have been made for the western and southwestern United States. Manabe & Wetherald (1987) predict a 50% reduction in spring soil moisture levels in the western U.S., and Revelle & Waggoner (1989) predict water flow reductions of 40-75% of the Colorado River and other rivers in the southwestern U.S. by 2150. In both cases, the suggested most likely climate change in western U.S. is increased temperature and a slight decrease in precipitation. This will bring about an intensification of the early summer drought, resulting from earlier snowmelt and higher rates of evapotranspiration.

The Colorado Plateau is very sensitive to climate changes, as it lies between dominant winter and summer air systems. In winter, cold polar air pushes south to the northern fringes of the plateau, bringing winter storms and snow. During the summer, the

monsoons penetrate onto the southeastern part of the plateau (Mitchell 1976). If either of these fronts change, by moving north or south, dramatic changes in precipitation are likely. Betancourt (1984) and Neilson & Wullstein (1983) provide a useful analysis of climate in the region. Based on climatological and paleoecological work, they suggest that a warming trend involving the plateau would bring about, 1) increased summer precipitation, with the peak shifting from August to July, and 2) decreased winter precipitation, as the polar jet is forced further north by high-pressure doming from the south brought about by increased temperatures. This I will call climate change model 1. Other models can be envisioned, using various combinations of increased and/or decreased summer and winter precipitation. Interestingly, at least three predictions of model 1 appear to be borne out by the climatological analysis presented in Table 1 and Figures 1-5. Precipitation has shifted over the last 10 years, compared to the 1916-1975 average, to an increased summer and decreased winter pattern, the peak has begun to move towards July, although August remains wetter (see Figure 1), and soil drought has intensified in the May-June period (Figure 5). The next ten years will be critical in deciding whether this climate shift is permanent.

Before discussion the possible responses of species in the breaks to climate changes, a few interesting biological features noted in this study should be discussed.

Although P. longaeva, P. flexilis, Pseudotsuga menziesii, and J. scopulorum were all infected by mistletoe species, it was

interesting to note that P. ponderosa was not. This is in contrast to the extensive infestation by Arceuthobium vaginatum of ponderosa above the rim. It is not known why A. cyanocarpum was not found on the transects. Lack of the appropriate bird disperser in the breaks may have something to do with this, although the principal vector of this mistletoe is not known at BRCA and needs to be determined.

The PILO transects were vegetationally similar, but the two transects for both the PIPO and MC types showed striking differences. This is particularly evident with the MC transects. MC 1 has a dense understory of Quercus gambelii while MC 2 lacked the oak entirely. Hence, observations on the responses of vegetation and particular species to climate change may show variability related to the transect.

A remarkable concentration of rare species occurred along the PILO transects, supporting the observations of Graybosch & Buchanan (1983). They first pointed out the importance and unusual features of the vegetation and flora in the bristlecone woodland in the breaks. The distribution of this community is probably quite limited. The Red Canyon area to the northwest of the park is most similar, and scattered sites on Claron limestone probably occur in other areas of the Paunsaugunt Plateau. Some species also occur at Cedar Breaks, but differences probably exist because of the higher elevation there. Because of the concentration of rare species, and its limited distribution, special consideration should be given to this vegetation in resource management

decisions.

Another important feature of this study was the documentation of the lack of human disturbance in the breaks. Although prints were visible on ridge crests and slopes away from the trails in the breaks, none occurred in the 480 quadrats and were rarely seen in the plots. This may change, however, as visitation increases and if the social or demographic structure of the population changes, perhaps resulting in a greater tendency to explore off trail areas in the national parks. Future censuses of the plots should be able to detect increases in such activities, by prints as well as trampling or other damage to plants.

The responses to climate change of selected woody species found in this study are listed in Table 14. For many species, little is known about their possible responses. For these, general ecology and distribution in the region were used to determine possible responses. If the species was at its lowest limits in the breaks (more common at higher elevations), I assumed that warmer conditions would cause an upward contraction of the distribution. If the species was at its highest limits in the breaks, I assumed that increased temperatures would bring about an expansion. For a few well studied species, especially P. longaeva and P. ponderosa, enough is known for more firm conclusions to be drawn.

Response to climate change may be detected by many variables recorded in the plots. For understory species, these include changes in cover, frequency, or flowering. For shrubs, changes in cover, death of individuals, leaf health, and reproduction. For

trees, changes limb-death rates, mistletoe infection, needle status, seedling survival and germination, numbers of individuals, or death of individuals.

Bristlecone pine is at its lowest limits in the breaks. Other studies have indicated that this species is limited by several factors, most important of which appears to be competition with other conifers and intensity of late spring-early summer drought. Bristlecone does not respond well to late summer rains, and seems to be more sensitive to early season (winter) variations in precipitation. Fritts (1969) noted that in the White Mountains spring and early summer drought (April-June) was strongly limiting. Hiebert & Hamrick (1984) noted that bristlecone pine was restricted to poor sites by competition with more shade-tolerant, faster growing, conifers. Based on these considerations, it is highly likely that this species will begin to decline in the breaks under the climate change model 1. This results from the increase in early summer drought noted for the breaks, and the probably increase in ponderosa pine, a superior competitor, if summer precipitation increases. However, Hiebert & Hamrick (1984) noted an downslope increase over the last few hundred years in their study of this species. This may be the result of wetter conditions during the Little Ice Age (ca. 1600-1900), but more work needs to be done on this phenomenon.

Ponderosa pine is a Madrean species, closely related to P. engelmannii, P. leiophylla, and P. strobiformis of the Mexican mountains. One of the most important limiting factors for this

species is summer rainfall. Seedling establishment and reproduction, at least in the southwest, requires a relatively wet summer season. At upper limits, ponderosa pine is probably limited by winter frosts and winter needle drought. Ponderosa should increase in the upper parts of breaks under climate model 1.

Arctostaphylos patula, whose distribution is correlated with ponderosa pine, should respond in a similar fashion. However, winter kill by cold temperatures resulting from low snow cover may limit this shrub's increase.

Other species responses are noted in Table 14, and need not be repeated here. For many of them, only suggestions can be made. Future work on the ecology of these species and censuses of the transects may improve our understanding of their responses to climate change.

It is recommended that the transects be censused at ten year intervals. Intervals less than this are probably too short to detect extensive changes in long-lived woody species. Intervals longer than this will detect change, but may be too late from the management perspective, as extensive irreversible changes may have already occurred. A ten year interval will detect change but will also provide some flexibility for making management decisions.

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VIII. LITERATURE CITED

- Abrahamson, D.E. 1989. The challenge of global warming. Island Press, Covelo, California.
- Albee, B.J., L.M. Schultz, & S. Goodrich. 1988. Atlas of the vascular plants of Utah. Utah Mus. Nat. History, Occ. Pap. No. 7. Salt Lake City.
- Armstrong, J.K, K. Williams, L.F. Huenneke, & H.A. Mooney. 1988. Topographic position effects on growth depression of California Sierra Nevada pines during the 1982-83 El Nino. Arctic and Alpine Res. 20: 352-357.
- Bailey, D.K. 1970. Phytogeography and taxonomy of Pinus section Balfourianae. Annals Missouri Bot. Garden 57: 210-249.
- Bailey, H.P. 1960. A method of determining the warmth and temperateness of climate. Geografiska Annaler 42: 1- 16.
- Betancourt, J.L. 1984. Late quaternary plant zonation and climate in southeastern Utah. Great Basin Natur. 44: 1-35.

- Bowers, W.E. 1991. Geologic map of Bryce Canyon National Park and vicinity, southwestern Utah. USDI U.S. Geol. Survey, Misc. Investigations Ser. Map I-2108.
- Buchanan, H. 1960. The plant ecology of Bryce Canyon National Park, Utah. Unpubl. Ph.D. thesis, University of Utah.
- Buchanan, H. 1971. Changing conditions in the forests of Bryce Canyon National Park, Utah. Proc. Utah Acad. Sci., Arts and Letters 48: 31-36.
- Buchanan, H. & R.A. Graybosch. 1981. Revised checklist of the vascular plants of Bryce Canyon National Park, Utah. Great Basin Natur. 41: 109-120.
- Cain, S.A. 1944. Foundations of plant geography. Hafner Publ., New York.
- Daubenmire, R.F. 1970. Steppe vegetation of Washington. Wash. Agric. Exp. Sta. Tech. Bull. 62: 1-131.
- Davis, G.E. 1989. Design of a long-term ecological monitoring program for Channel Islands National Park, California. Nat. Areas J. 9: 80-89.
- Eubank, M.E. & R.C. Brough. 1979. Utah weather. Horizon Publisher's, Bountiful, Utah.
- Floyd, M.E. 1987. The significance of variability in cone production in Pinus edulis. pp. 58-64 In: Proceedings-- Pinyon-juniper conference. USDA Forest Service Int. Sta. Gen. Tech. Rep. INT-215.
- Fritts, H.C. 1969. Bristlecone pine in the White Mountains of California: Growth and ring-width characteristics. Papers of

- the Lab. Tree-ring Res. 4, University of Arizona, Tuscon.
- Fritts, H.C. 1976. Tree rings and climate. Academic Press, London.
- Graybosch, R.A. & H. Buchanan. 1983. Vegetative types and endemic plants of the Bryce Canyon breaks. Great Basin Natur. 43: 701- 712.
- Grieg-Smith, P. 1983. Quantitative plant ecology, 3rd Ed. California Univ. Press, Berkeley.
- Halvorson, W.L., S.D. Veirs Jr., R.A. Clark & D.D. Borgais. 1988. Terrestrial vegetation monitoring handbook, Channel Islands Nat. Park, California. National Park Service, Ventura, California.
- Harper, K.T. & H. Buchanan. 1983. The ecology of shrubs in Bryce Canyon National Park with special reference to Pushia tridentata. pp. 91-98 In: Proceedings-research and management of bitterbrush and cliffrose in western North America. USDA Forest Ser., Intm. Res. Sta. Gen. Tech. Rep. INT-152.
- Hawksworth, F.G. 1977. The 6-class dwarf mistletoe rating system. USDA Forest Ser. Rocky Mountain For. & Range Expt. Sta. Gen. Tech. Rep. RM-48.
- Hiebert, R.D. & J.L. Hamrick. 1984. An ecological study of bristlecone pine (Pinus longaeva) in Utah and eastern Nevada. Great Basin Natur. 44: 487-494.
- Lull, H.L. & L. Ellison. 1950. Precipitation in relation to altitude in central Utah. Ecology 31: 479-484.
- MacDonald, G. 1989. Scientific basis for the greenhouse effect. pp. 123-145 In: Abrahamson, D.E. 1989. The challenge of global

- warming. Island Press, Covelo, California.
- Manabe, S. & R.T. Wetherald. 1987. Large-scale changes of soil wetness induced by an increase in atmospheric carbon dioxide. J. Atmos. Sci. 44: 1211-1235.
- Mitchell, V.L. 1976. The regionalization of climate in the western United States. J. Applied Meteorol. 15: 920-927.
- Mueller-Dombois, D. & H. Ellenberg. 1974. Aims and methods of vegetation ecology. John Wiley & Sons, New York.
- National Park Service. 1990. Interest and capability statement, global climate change proposal, Colorado Plateau. Unpubl. report to the National Park Service, Rocky Mountain Region, Lakewood, Colorado.
- Neilson, R.P. & L.H. Wullstein. 1983. Biogeography of two southwest American oaks in relation to atmospheric dynamics. J. Biogeog. 10: 275-297,
- Revelle, R.R. & P.E. Waggoner. 1989. Effects of climate change on water supplies in the western United States. pp. 151-160 In: Abrahamson, D.E. 1989. The challenge of global warming. Island Press, Covelo, California.
- Roberts, D.W., D.W. Wight & G.P. Hallsten. 1991. Plant community distribution and dynamics in Bryce Canyon National Park. Draft final report to the National Park Service, Bryce Canyon National Park, Bryce Canyon.
- Smith, S.D., S.C. Bunting & M. Hironaka. 1987. Evaluation of the improvement in sensitivity of nested frequency plots to vegetational change by summation. Great Basin Natur. 47: 299-

307.

- Spence, J.R. 1990. Some comments on climate change on the Colorado Plateau, with preliminary suggestions for monitoring using plant species. Unpubl. report to the National Park Service, Capitol Reef National Park, Utah.
- Spence, J.R. & H. Buchanan. 1992. 1991 update, revised checklist of the vascular plants of Bryce Canyon National Park, Utah. Great Basin Natur. (submitted).
- Stein, S.J. 1989. Fire history of the Paunsaugunt Plateau in southern Utah. Great Basin Natur. 48: 58-63.
- Tausch, R.J. & N.E. West. 1987. Morphological variation / precipitation relationships of Great Basin single-needled pinyon. pp. 86-91 In: Proceedings--Pinyon-juniper conference. USDA Forest Service Int. Sta. Gen. Tech. Rep. INT-215.
- Tilman, D. 1988. Plant strategies and the dynamics of plant communities. Princeton University Press, Princeton.
- Tuhkanen, S. 1980. Climatic parameters and indices in plant geography. Acta Phytogeog. Suecica 67: 1-105.
- Van Pelt, N.S., C.D. Schelz, J.S. Tuhy, & J.R. Spence. 1992. Survey and analysis of relict plant communities within National Park Service units of the Colorado Plateau, Vol. II. Bryce Canyon N.P., Capitol Reef N.P., Cedar Breaks N.M., and Zion N.P. Draft report to the National Park Service, Rocky Mountain Region, Lakewood, Colorado.
- Van Riper III, C., T.J. Stohlgren, S.D. Veirs, Jr., & S.C. Hillyer. 1991. Examples of resource inventory and monitoring in

- national parks of California. USDI National Park Service, Washington, D.C.
- Welsh, S.A., N.D. Atwood, L.C. Higgins, & S. Goodrich. 1987. A Utah flora. Great Basin Natur. Mem. 9: 1-894.
- West, N.E. & T.J. Hatton. 1990. Relative influence of observer error and plot randomization on detection of vegetation change. Coenoses 5: 45-49.
- Woodward, F.I. 1987. Climate & plant distribution. Cambridge University Press, Cambridge.

IX. TABLES

- Table 1. Summary climate data for Bryce Canyon National Park.
- Table 2. Summary of PILO transect physical data.
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- Table 4. PILO transect understory data.
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- Table 10. Summary adult tree status.
- Table 11. Summary sapling tree status.
- Table 12. Summary seedling tree status.
- Table 13. Summary of tree needle lengths.
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Table 1. Summary of selected climate data for Bryce Canyon National Park, Utah. The climate station is located at the visitor center at an elevation of 2413 m. Precipitation values have been rounded to the nearest millimeter. Bailey's M and de Martonne's H are also listed.

	<u>1916-1975</u>	<u>Period</u> <u>1981-1990</u>
<u>Temperature</u> (°C)		
Yearly Average	5.0	5.3
January		
Average Low	-13.0	-12.2
Average High	2.0	2.7
July		
Average Low	7.6	8.3
Average High	27.0	23.8
<u>Precipitation</u> (mm)		
Yearly Average	403	425
Summer (June-September)	149	190
Winter (October-May)	254	235
<u>Bailey's M</u>	45.0	45.4
<u>de Martonne's H</u>	26.9	27.8
<u>Monthly</u>		

	<u>1916-1975</u>					<u>1981-1990</u>				
	Temperature		Precip			Temperature		Precip		
	High	Low	Aver	(mm)	H	High	Low	Aver	(mm)	H
January	2.0	-13.6	-5.8	31.0	88.6	2.7	-12.2	-4.7	26.8	60.7
February	3.7	-11.9	-4.1	35.0	71.2	3.7	-10.9	-3.6	23.9	44.8
March	6.7	-9.2	-1.2	38.3	52.2	6.5	-7.2	-0.3	44.5	55.1
April	11.9	-5.1	3.4	26.9	24.1	12.5	-3.8	4.3	22.3	18.7
May	17.7	-1.0	8.4	22.3	14.5	17.1	-0.2	8.4	23.1	15.1
June	23.3	3.1	13.2	17.5	9.1	23.8	4.9	14.4	11.8	5.8
July	26.8	7.4	17.2	33.3	14.7	25.8	8.3	17.1	60.7	26.9
August	25.1	6.7	16.1	56.9	26.2	24.5	6.8	15.7	61.5	28.7
September	21.8	2.2	11.9	41.1	22.5	20.4	3.2	11.8	55.6	30.6
October	15.2	-2.8	6.2	38.3	28.4	14.0	-2.8	5.6	38.5	29.6
November	7.3	-8.6	-0.7	27.2	35.1	6.3	-7.2	-0.4	31.8	39.8
December	2.9	-12.1	-4.6	35.3	78.4	2.2	-11.8	-4.8	24.2	55.8

Table 2. Summary of transect physical characteristics and climate for the PILO transects. Values for each transect are averages of the three plots. Soil depth is the average of 30 probes from the three plots.

	<u>PILO</u>			
	1	2	3	4
Elevation (m)	2320	2290	2290	2280
Aspect	----- more or less flat -----			
Slope (°)	----- <5° slope -----			
Bedrock	----- Claron Limestone -----			
Soil Depth (cm)	26.6	22.5	17.5	16.4
Average Yearly Temperature*	5.8	6.0	6.0	6.1
Average Yearly Precipitation*	387	375	375	370

*Based on 1981-1990 data, in °C and mm

Table 3. Summary of transect physical characteristics and climate for the PIPO and MC transects. Values for the transects are averages of the three plots. Soil depth is the average of 30 probes from the three plots.

	<u>PIPO</u>		<u>MC</u>	
	1	2	1	2
Elevation (m)	2220	2260	2200	2300
Aspect	S	SSE	NW	N
Slope (°)	15-17	10	<5	<5
Bedrock	----- Claron Limestone -----			
Soil Depth (cm)	24.3	36.3	23.4	35.3
Average Yearly Temperature*	6.4	6.2	6.6	6.0
Average Yearly Precipitation*	346	362	338	379

*Based on 1981-1990 data, in °C and mm

Table 4. Summary of cover, frequency, and reproduction for understory species on PULO transects: average cover (0-100%) / average frequency (0-300%) / average reproduction (0-100%). Plant species acronyms represent the first two letters of the genus and epithet (see appendix B). Species with an asterisk are either geographically restricted or federal candidate species. If a species had less than 0.1% cover, it was scored a t (trace).

	<u>Pilo 1</u>	<u>Pilo 2</u>	<u>Pilo 3</u>	<u>Pilo 4</u>
Litter	08.3/228/ -	11.5/287/ -	07.3/288/ -	15.4/298/ -
Soil	11.0/282/ -	34.7/285/ -	14.5/290/ -	09.8/242/ -
Rock	70.8/288/ -	51.1/300/ -	73.1/300/ -	67.8/290/ -
Nat. Ung.	-	-	-	00.1/010/ -
ERPA*	01.3/083/050	01.0/088/054	01.0/083/035	01.8/118/047
LERU*	00.8/058/060	01.0/107/068	01.6/178/077	01.4/155/074
TONI*	01.3/093/004	01.2/082/010	00.8/068/000	01.1/080/008
LIKI	t /003/000	00.9/078/059	01.4/087/052	01.5/117/059
IVSA	00.1/007/000	00.2/010/050	00.1/012/067	00.3/025/014
PEBR*	00.2/018/000	00.3/022/000	00.1/007/000	-
HYFI	00.4/020/020	00.3/027/000	00.2/013/000	00.3/012/000
CALA	00.1/007/000	00.1/003/000	00.2/020/000	t /005/000
AQSC*	00.1/005/050	-	00.1/005/050	00.1/008/100
HAAR	00.2/018/000	00.5/007/000	t /002/000	00.1/007/100
CYPU	00.2/018/000	00.2/018/000	00.3/025/014	t /003/000
MAGR	00.1/007/100	00.1/007/050	00.2/005/067	00.3/028/014
HYAC	00.3/030/014	01.0/080/004	00.8/057/000	00.3/012/000
PHPU	00.3/027/043	01.0/040/046	00.5/020/038	00.3/032/025
CARO	t /002/000	00.3/028/013	00.3/007/033	00.4/017/000
CRAB*	00.1/003/000	00.4/023/018	00.7/052/025	00.3/017/033
CIAR	t /002/000	t /002/000	00.1/007/000	t /002/000

PHCH	00.1/005/000	-	-	-
CARE*	-	00.2/013/050	00.1/013/067	00.1/012/067
ARFE	-	00.3/017/043	00.3/018/017	-
HAAC	-	00.3/017/033	00.1/010/000	00.8/048/007
SPCA*	-	00.7/027/000	00.4/020/020	00.1/010/000
ELSA	-	00.1/007/000	-	00.3/025/000
LOMI*	-	t /003/000	00.2/008/000	t /005/000
GETO*	-	t /002/100	00.1/007/067	00.1/003/050
DRSU*	-	t /002/000	-	-
OEHO	-	t /003/000	-	00.2/018/000
LIMU	-	-	00.3/005/100	-
ASCA	-	-	00.5/035/000	00.1/013/000

Table 5. Summary of cover, frequency, and reproduction for understory species on PIPO and MC transects: average cover (0-100%) / average frequency (0-300%) / average reproduction (0-100%). Plant species acronyms represent the first two letters of the genus and epithet (see appendix B). Species with an asterisk are either geographically restricted or federal candidate species. If a species had less than 0.1% cover, it was scored a t (trace).

	<u>Pipo 1</u>	<u>Pipo 2</u>	<u>MC 1</u>	<u>MC 2</u>
Litter	61.5/295/ -	52.8/300/ -	85.1/300/ -	84.2/300/ -
Soil	06.6/107/ -	18.9/255/ -	02.9/077/ -	04.2/107/ -
Rock	21.2/195/ -	18.2/223/ -	07.5/113/ -	03.6/110/ -
Nat. Ung.	00.5/043/ -	00.3/033/ -	00.3/015/ -	00.8/040/ -
ELSA	05.7/130/006	03.3/077/019	00.8/033/000	01.6/053/000
OEHO	01.0/047/000	01.0/078/000	00.4/038/000	-
STCO	01.9/027/062	-	-	-
CARO	00.1/008/000	01.7/052/000	02.0/065/000	01.8/043/000
MARE	00.1/008/033	00.1/010/000	02.1/103/000	00.7/042/000
MAGR	00.1/007/100	00.4/017/080	-	-
EUFE	00.1/007/100	00.4/042/020	-	-
LIPE	t /017/100	t /005/000	-	-
HEDR	00.1/006/050	-	-	-
ASCO	t /002/000	-	-	00.1/003/000
ERAL	t /005/000	-	-	-
LEER	t /002/100	-	-	-
STTE	t /005/100	-	t /002/000	-
CALA	-	00.6/018/000	-	-
HAAR	-	00.4/012/025	-	-
LIMU	-	00.4/015/050	01.3/042/055	00.3/020/080
CIAR	-	00.3/010/100	00.6/013/075	00.3/008/000

CRAB*	-	00.2/012/040	-	-
ASME	-	00.1/007/000	00.1/007/000	-
GUSA	-	00.1/005/050	-	-
HYFI	-	00.1/007/000	-	-
STHY	-	00.1/007/033	-	-
EUBR	-	t /003/000	-	t /005/000
CLCO	-	-	01.0/030/000	00.5/025/000
SOSP	-	-	00.4/017/000	00.2/012/000
SEMU	-	-	00.1/007/000	t /005/000
POFE	-	-	00.3/033/000	-
ELEL	-	-	00.1/010/000	-
ANPA	-	-	00.2/015/000	-
PHCH	-	-	t /005/000	-
CALI	-	-	00.1/005/000	-
ARDE	-	-	00.1/010/000	-
ARFE	-	-	-	t /003/100
DRSU*	-	-	-	t /003/000
ASMI	-	-	-	t /003/000

Table 6. Summary of shrub cover data for transects in the PILO community. Cover and reproduction are percentages of 100. Status is the health of individuals scored from 1-3.

<u>Species</u>	<u>Transect</u>			
	<u>Pilo 1</u>	<u>Pilo 2</u>	<u>Pilo 3</u>	<u>Pilo 4</u>
<u>Arctostaphylos patula</u>				
Cover	12.1	1.8	3.6	2.8
Reproduction	6.0	0	10.0	0
Status	2.9	3.0	2.7	3.0
<u>Juniperus communis</u>				
Cover	-	0.1	-	-
Reproduction	-	0	-	-
Status	-	2.0	-	-

Table 7. Summary of shrub cover data for transects in the PIP0 and MC communities. Cover and reproduction are percentages of 100. Status is the health of individuals scored from 1-3.

<u>Species</u>	<u>Transect</u>			
	<u>Pipo 1</u>	<u>Pipo 2</u>	<u>MC 1</u>	<u>MC 2</u>
<u>Arctostaphylos patula</u>				
Cover	4.2	22.9	10.6	24.7
Reproduction	49	40	57	43
Status	2.7	2.6	2.7	2.6
<u>Ceanothus martinii</u>				
Cover	1.7	-	0.9	3.6
Reproduction	30	-	18	36
Status	2.1	-	2.2	2.4
<u>Quercus gambelii</u>				
Cover	6.8	-	15.1	-
Reproduction	0	-	6	-
Status	2.8	-	2.5	-
<u>Purshia tridentata</u>				
Cover	-	1.0	-	0.2
Reproduction	-	0	-	0
Status	-	2.8	-	2.0
<u>Symphoricarpos oreophilus</u>				
Cover	-	-	5.1	1.3

Reproduction	-	-	0	0
Status	-	-	2.7	3.0
<u>Cercocarpus montanus</u>				
Cover	-	-	0.8	-
Reproduction	-	-	0	-
Status	-	-	2.0	-
<u>Juniperus communis</u>				
Cover	-	-	-	1.2
Reproduction	-	-	-	67
Status	-	-	-	2.7

Table 8. Summary tree data for PILO transects. Each transect consists of three 100m² plots. Basal area is in cm². Number of individuals in each age-class are listed. Seedlings were arbitrarily given a BA of 1 cm².

	<u>Pilo 1</u>	<u>Pilo 2</u>	<u>Pilo 3</u>	<u>Pilo 4</u>
<u>Basal Area (BA)</u>				
PILO	1399	460	1658	4417
PIPO	1103	843	1354	993
PIFL	85	1171	29	114
JUSC	707	1	0	0
<u>Adults</u>				
PILO	1	1	6	5
PIPO	2	1	3	2
PIFL	1	2	0	0
JUSC	1	0	0	0
<u>Saplings</u>				
PILO	1	6	5	2
PIPO	0	3	3	6
PIFL	0	3	1	3
JUSC	0	0	0	0
<u>Seedlings</u>				
PILO*	1	0	2	3
PIPO	12	11	22	14
PIFL*	0	10	12	21
JUSC	0	1	0	0
<u>Total Trees</u>				

PILO	3	7	13	10
PIPO	14	15	28	22
PIFL	1	15	13	24
JUSC	1	1	0	0

Summary

Total BA	3294	2475	3041	5524
Total trees	19	38	54	56
Trees/hectare	633	1267	1800	1867

*Seedlings of PILO and PIFL were very difficult to separate, so PIFL seedling numbers may be over-estimated and PILO seedling numbers under-estimated.

Table 9. Summary tree data for PIPO and MC transects. Each transect consists of three 100 m² plots. Basal area is in cm². Number of individuals in each age-class is listed. Seedlings were arbitrarily given a BA of 1 cm².

<u>Basal Area (BA)</u>	<u>Pipo 1</u>	<u>Pipo 2</u>	<u>MC 1</u>	<u>MC 2</u>
PSME	0	0	3020	1753
PIPO	14584	9299	8309	11334
PIFL	0	0	0	405
JUSC	906	513	919	84
PIED	480	0	0	0
<u>Adults</u>				
PSME	0	0	4	3
PIPO	8	3	4	9
PIFL	0	0	0	2
JUSC	1	0	2	1
PIED	1	0	0	0
<u>Saplings</u>				
PSME	0	0	7	2
PIPO	0	3	5	5
PIFL	0	0	0	2
JUSC	3	17	6	0
PIED	0	0	0	0
<u>Seedlings</u>				
PSME	0	0	21	9
PIPO	0	2	5	2
PIFL	0	0	0	2

JUSC	0	17	3	4
PIED	1	0	0	0
<u>Total Trees</u>				
PSME	0	0	38	14
PIPO	8	8	14	16
PIFL	0	0	0	6
JUSC	4	34	11	5
PIED	2	0	0	0
<u>Summary</u>				
Total BA	15970	9812	12248	13576
Total trees	14	42	63	41
Trees/hectare	467	1400	2100	1370

Table 10. Summary tree status data for adults in three communities. Average values for mistletoe, limb-death and needle drought are presented. Reproduction is the per cent of trees with female cones, with the smallest reproductive individual noted (diameter at ground level in cm). Jusc, Pied, and Pifl were too rare to include in the analyses.

<u>Species</u>	<u>Community</u>		
	<u>PILO</u>	<u>PIPO</u>	<u>MC</u>
<u>Pilo</u>			
Mistletoe	0.5	-	-
Limb-death	2.3	-	-
Needle drought	1.4	-	-
Reproduction	69%	-	-
Smallest ind.	10.5	-	-
<u>Pipo</u>			
Mistletoe	0	0	0
Limb-death	1.9	3.1	2.5
Needle drought	1.1	0.5	0.3
Reproduction	50%	100%	54%
Smallest ind.	22.8	37.5	34.5
<u>Psme</u>			
Mistletoe	-	-	1.3
Limb-death	-	-	0.6
Needle drought	-	-	0.3
Reproduction	-	-	57%
Smallest ind.	-	-	16.1

Table 11. Summary tree status data for saplings in three communities. Average values for mistletoe, limb-death and needle drought are presented. Reproduction is the per cent of trees with female cones, with the smallest reproductive individual noted (diameter at ground level in cm). No Pied saplings occurred in the plots, while PIFL was too rare to include.

<u>Species</u>	<u>Community</u>		
	<u>PILO</u>	<u>PIPO</u>	<u>MC</u>
<u>Pilo</u>			
Mistletoe	0.4	-	-
Limb-death	1.5	-	-
Needle drought	0.8	-	-
Reproduction	17%	-	-
Smallest individual	8.3	-	-
<u>Pipo</u>			
Mistletoe	0	0	0
Limb-death	0.7	0.3	0.4
Needle drought	0.8	0.7	0.4
Reproduction	0	0	0
Smallest individual	-	-	-
<u>Psme</u>			
Mistletoe	-	-	0.3
Limb-death	-	-	0
Needle drought	-	-	0
Reproduction	-	-	0
Smallest individual	-	-	-

<u>Jusc</u>			
Mistletoe	-	<0.1	0
Limb-death	-	0.2	0.2
Needle drought	-	0.3	0
Reproduction	-	0	0
Smallest individual	-	-	-

Table 12. Summary tree status data for seedlings in three communities. Average values for limb-death and needle drought are presented. No Pied seedlings occurred on the transects. No seedlings of any species were infected with mistletoe.

<u>Species</u>	<u>Community</u>		
	<u>PILO</u>	<u>PIPO</u>	<u>MC</u>
<u>Pilo</u>			
Limb-death	0	-	-
Needle drought	0.5	-	-
<u>Pipo</u>			
Limb-death	0	0	0
Needle drought	0.2	1.0	0.1
<u>Psme</u>			
Limb-death	-	-	0
Needle drought	-	-	0.3
<u>Pifl</u>			
Limb-death	0	-	-
Needle drought	0.5	-	-
<u>Jusc</u>			
Limb-death	0	0.3	0
Needle drought	0.5	0.6	0.3

Table 13. Average needle lengths (mm) for P. ponderosa and P. longaeva from the transects. Not enough adult P. longaeva occurred at plot 2 of PILO-4 transect to achieve the N=5 sample size.

<u>Transect</u>	<u>Species</u>			
	<u>P. ponderosa</u>		<u>P. longaeva</u>	
	<u>Plots</u> (N=50)	<u>Average</u> (N=150)	<u>Plots</u> (N=50)	<u>Average</u> (N=150)
Pilo-1	108.1/094.0/088.3	096.8	26.8/28.6/26.8	27.4
Pilo-2	091.3/098.5/105.1	098.3	28.3/27.4/26.1	27.3
Pilo-3	101.6/108.2/097.8	102.5	27.7/26.2/28.4	27.4
Pilo-4	100.4/110.6/104.9	105.3	27.6/ - /27.1	27.4
Pipo-1	111.1/104.9/115.2	110.4		
Pipo-2	113.4/105.7/097.5	105.5		
MC-1	103.9/117.8/120.2	114.0		
MC-2	112.4/110.0/088.6	103.7		

Table 14. Predicted species responses to climate change model I (warmer temperatures, reduced winter and increased summer precipitation). Species included are those woody plants that are well studied or common. Suggested responses that may be incorrect are in (). If the response is unknown, this is indicated by ?.

<u>Trees</u>	<u>Response</u>
<u>Juniperus osteosperma</u> :	+ Should increase because of warmer temperatures.
<u>J. scopulorum</u> :	? Response not known.
<u>Pinus edulis</u> :	(+) May move upslope into breaks because of warmer temperatures, but may be limited by Ponderosa increase.
<u>P. flexilis</u> :	(-) Should decrease because at lower limits in region.
<u>P. longaeva</u> :	- Should decrease because at lowest limits for species.
<u>P. ponderosa</u> :	+ Should increase, possibly dramatically.
<u>Pseudotsuga menziesii</u> :	(-) May decrease because of reduced winter precipitation, but increased summer rains may compensate.
<u>Shrubs</u>	
<u>Arctostaphylos patula</u> :	+ Should increase, although low winter precipitation may be limiting.

Ceanothus martinii: (-) May decrease.

Juniperus communis: - Should decrease because at lower limits in region.

Purshia tridentata: (+) Should increase, but specific requirements not well known.

Quercus gambelii: + Should increase because of warmer temperatures and increased summer rains.

Symphoricarpos oerophilus: - Should decrease because at lower limits in region.

X. FIGURES

Figure 1. Average monthly precipitation in millimeters at Bryce Canyon.

Figure 2. Average monthly temperature (°C) at Bryce Canyon.

Figure 3. Average monthly low temperature (°C) at Bryce Canyon.

Figure 4. Average monthly high temperature (°C) at Bryce Canyon.

Figure 5. Monthly values of de Martonne's H at Bryce Canyon. The straight lines at 20 and 10 represent change to semi-arid and arid conditions. The growing season (average monthly temperature above 0 °C) is shown by the vertical dashed lines at April and October.

Figure 6. Standard plot and quadrat design.

Figure 7. Map of Bryce and Campbell canyons showing transect locations.

Figure 8. Tree size-class distribution (number per class) in the PILO type.

Figure 9. Tree size-class distribution (number per class) in the PIPO type.

Figure 10. Tree size-class distribution (number per class) in the MC type.

XI. APPENDICES

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Appendix A: sample data sheets

Brickellia oblongifolia	BROB	000	000	000	000	001	000	000	000
Gutierrezia sarothrae	GUSA	000	000	000	000	100	010	000	000
Mahonia repens	MARE	000	000	000	000	111	101	111	111
<u>Forbs and Subshrubs</u>									
Antennaria parvifolia	ANPA	000	000	000	000	000	000	001	110
Apocynum androsaemifolium	APAN	000	000	000	000	000	000	111	000
Aquilegia scopulorum*	AQSC	110	101	101	110	000	000	000	000
Arabis demissa	ARDE	000	000	000	000	000	000	001	100
Arenaria fendleri	ARFE	000	010	000	000	000	000	000	100
Astragalus calycosus	ASCA	000	000	010	111	000	000	000	000
A. convallarius	ASCO	000	000	000	000	100	000	000	010
A. megacarpus	ASME	000	000	000	000	000	011	011	000
A. miser	ASMI	000	000	000	000	000	000	000	001
Calylophus lavandulifolius	CALA	111	111	111	100	011	111	000	000
Castilleja linariifolia	CALI	111	000	000	000	000	010	011	000
C. revealii*	CARE	000	011	111	111	000	000	000	000
Cirsium arizonicum	CIAR	101	111	110	111	101	111	111	111
Clematis columbiana	CLCO	000	000	000	000	000	000	111	111
Cordylanthus kingii	COKI	001	000	000	000	000	000	000	000
Cryptantha abata ¹ *	CRAB	111	001	111	111	111	111	001	000
Cymopterus purpureus	CYPU	100	111	101	011	010	000	000	000
Draba subalpina*	DRSU	000	010	000	000	000	000	000	110
Eriogonum alatum	ERAL	000	000	000	000	010	001	000	000
E. panguicense*	ERPA	111	111	111	111	000	000	000	000
Euphorbia brachycera	EUBR	000	000	000	000	000	001	100	101
E. fendleri	EUFE	000	000	000	000	111	101	000	000
Frasera speciosa	FRSP	000	000	000	000	000	000	010	001
Gentianella tortuosa*	GETO	000	000	000	110	000	000	000	000
Haplopappus acaulis	HAAC	000	101	111	111	000	000	000	000
H. armerioides	HAAR	111	111	110	001	101	111	000	000
Hedeoma drummondii	HEDR	000	000	000	000	010	000	000	000
Hymenopappus filifolius	HYFI	110	111	111	111	011	001	010	000
Hymenoxys acaulis	HYAC	011	111	111	111	100	000	000	000
Ivesia sabulosa	IVSA	111	101	111	110	000	000	000	000
Lesquerella intermedia	LEIN	010	000	000	000	000	000	000	000
L. rubicundula*	LERU	111	111	111	111	000	000	000	000
Leucelene ericoides	LEER	000	000	000	000	010	000	000	000
Linum kingii	LIKI	001	111	111	111	000	010	000	000
L. perenne	LIPE	000	000	000	000	011	011	000	000
Lithospermum multiflorum	LIMU	000	100	110	100	110	111	111	111
Lomatium minimum*	LOMI	000	011	101	101	000	000	000	000
Machaeranthera grindeli.	MAGR	111	101	111	111	001	111	000	000
Mimulus rubellus	MIRU	000	000	000	000	001	000	000	000
Oenothera howardii	OEHO	000	110	000	100	111	111	111	111
Pedicularis centranthera	PECE	000	010	000	000	010	000	000	001
Penstemon bracteatus*	PEBR	111	010	101	000	000	000	000	000
Phlox pulvinata	PHPU	011	111	111	111	000	000	000	000
Physaria chambersii	PHCH	011	000	000	001	001	000	001	000
Senecio multilobatus	SEMU	000	000	000	000	000	001	011	101
Solidago spathulata	SOSA	000	000	000	000	000	000	000	100
S. sparsiflora	SOSP	000	000	000	000	110	000	111	101

Sphaeromeria capitata*	SPCA	000	111	111	111	000	000	000	000
Stephanomeria tenuifolia	STTE	000	000	000	000	010	000	111	000
Townsendia minima*	TOMI	111	111	111	111	001	000	000	000

Graminoids

Carex rossii	CARO	111	111	111	111	111	111	111	111
Elymus elymoides	ELEL	000	000	000	000	000	000	011	000
E. salinus	ELSA	111	001	101	111	111	111	110	111
Poa fendleriana	POFE	000	000	000	000	000	000	011	000
Stipa comata	STCO	000	000	000	000	111	000	000	000
S. hymenoides	STHY	000	000	000	000	010	111	000	000

Parasites

Arceuthobium cyanocarpum	ARCY	000	011	100	001	000	000	000	000
A. douglasii	ARDO	000	000	000	000	000	000	011	100
Phorodendron juniperinum	PHJU	000	000	000	000	000	001	000	000

¹could include other Cryptantha species

*rare, federal candidate, or of restricted geographic distribution; see Appendix C.

1 = present, 0 = absent

Appendix C: Rare species

Species considered rare and found in the Bryce Canyon area (including surrounding forest land), are listed below. Listings are based on USDI Forest Service and U.S. Fish & Wildlife Service recommendations, my own observations, and distributional data found in the Utah Atlas (Albee et al. 1988). Currently, no endangered, threatened, or candidate C1 species are known from the park.

Species

1. Aquilegia scopulorum. Not ranked. This species is of local distribution in south-central Utah. In the breaks, it is conspicuous, widely distributed, by locally rare. Flowering is common.

2. Astragalus limnocharis. Ranked as a C2 sensitive species. Although reported from BRCA, no collections have been seen. Distributional data indicate it occurs just to the north of the park on the Claron Formation, so it probably occurs in the park, and should be searched for.

3. Castilleja revealii. Ranked (as C. parvula var. reavellii) as a C2 sensitive species. I continue to use C. revealii following the Intermountain Flora as no data is presented justifying reducing it to varietal status in Welsh et al. (1987). This species is found only on the Claron Formation in and around BRCA and Cedar Breaks. It is widely distributed in the breaks, commonly flowers, but is locally rare.

4. Cryptantha abata. Not ranked. Locally distributed in south-central Utah. When sterile, this species cannot be distinguished from several other species, including C. ochroleuca. All fruiting material collected in the breaks during this study was this species. Common and locally important in the breaks.

5. C. compacta. Ranked as a C2 sensitive species. Reported from BRCA, but no collections have been seen. Inspection of distributional maps suggest it occurs just E of the park on forest service land, so it should be searched for on park land. The habitat is salt shrub and mixed desert shrub communities. It is close to and very difficult to distinguish from C. humilis

6. C. ochroleuca. Ranked as a C2 sensitive species. This species is difficult to distinguish from other low growing cryptanths, including C. abata, C. compacta, and C. humilis. Found in BRCA, it was not encountered on the transects, but sterile cryptanths, identified as C. abata in this study, may have included this species.

7. Draba subalpina. Originally a C3 species, this draba has been dropped from the list. However, it is locally distributed in south-central Utah. Most common in forested communities and clearings on the Paunsaugunt Plateau, it was only occasionally encountered in the breaks.

8. Eriogonum aretioides. Ranked a C2 sensitive species. Although reported from BRCA, no collections have been seen. It occurs on the Claron Formation outside the park, however, so it should be searched for.

9. Eriogonum panguicense. Originally ranked as a C3 species, but not considered sensitive. It is locally distributed in south-central Utah and is the most abundant forb throughout much of the breaks. Commonly flowering.

10. Gentianella tortuosa. Not ranked. Locally distributed from southeastern Nevada, south-central Utah, and western Colorado, this species occurs as scattered populations on limestones. Common in the breaks and abundantly flowering. In the past this species has been incorrectly called G. tenella in the park.

11. Haplopappus zionis. Ranked as a C2 sensitive species. Locally distributed on Claron Limestone from Zion National Park and Cedar Breaks, to Bryce Canyon. Reported from the park by Hallsten & Roberts (1988), and accepted by Spence & Buchanan (1992) although the specimen was not seen. Found at elevations near and above the rim, this species may also occur in the breaks.

12. Heterotheca jonesii. Ranked as a C2 sensitive species. The habitat of this species is sandstone, and it is not likely to occur in the breaks. It has been found in the NE part of the park

at low elevations.

13. Hymenoxys depressa. Ranked as a C2 sensitive species. Although reported from BRCA, no collections have been seen. The species occurs on forest service land to the west, however, so it probably will be found in the park. The habitat is shallow clay-loam soils in sagebrush meadows in exposed sites, above 2400 m.

14. Lesquerella rubicundula. Originally listed as a C3 species, but removed because of its abundance. This species is locally distributed in south-central Utah, and is one of the most widespread and common species in the breaks. Commonly flowering.

15. Lomatium minimum. Originally ranked C1, this species has been recently found to be more widespread than previously thought. No longer considered sensitive. It is locally distributed on the Claron Formation in south-central and southwestern Utah. Locally common but patchy in the breaks. Occasionally flowering.

16. Oxytropis jonesii. Originally considered a C3 species, this has been placed under the common widespread O. oreophila.

17. Pedimelum pariense. Ranked as a C2 sensitive species. Scattered along the Paunsaugunt rim from BRCA southwest, on Claron limestone. This species is found along the rim, but was not seen in the breaks along the transects.

18. Penstemon bracteatus. Ranked as a C2 sensitive species. Found on the Claron Formation in BRCA and surrounding forest lands. Local in the breaks, where it seems to favor the steeper slopes. Rarely found on the transects. Flowering moderate. This is a good candidate for C1 listing, in my opinion.

19. Silene pettersonii. Ranked as a C2 sensitive species. Scattered in central Utah, generally on Claron and Wasatch limestone. Common in Red Canyon, this species was not seen on the transects.

20. Sphaeromeria capitata. Not ranked, but considered sensitive by the USDI Forest Service. So far, only known from the area around Red Canyon and the park. It is disjunct from the main populations in Montana and Wyoming. In the park it went under the name Tanacetum nuttallii, which was mis-applied as that name belongs in synonymy under Sphaeromeria argentea. Rare and local on windswept ridges in the breaks, this species is associated with extreme PILO sites. Flowering and fruiting was moderately common, but patchy.

21. Townsendia minima. Originally ranked a C2 species, it has been dropped because of nomenclatural changes and also because it is considered common. I continue to use T. minima over T. montana var. minima because Welsh et al. (1987) provide no justification or data for the transfer. Locally distributed in south-central Utah

but common. This is one of the most important species in the breaks, and commonly flowers.

FINAL REPORT

**AN INVENTORY AND MONITORING PROGRAM OF
THE VEGETATION IN THE BREAKS,
BRYCE CANYON NATIONAL PARK, UTAH**

VOLUME II

**TRANSECT LOCATIONS
PLOT LOCATIONS
TREE MAPS**

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Submitted to

Bryce Canyon National Park
and the
Bryce Canyon Natural History Association

February 10, 1992

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I. TRANSECT LOCATIONS.

Refer to the map in Figure 7 for transect locations. Below, brief directions for finding each transect are noted. The major organizing feature is the ridge separating Campbell and Bryce canyons. This is the prominent ridge that joins Bristlecone Point to the rim. Midway along this ridge is a prominent high known as the Mormon Temple and Seals Castle. Note the patch of ponderosa-douglas fir on the north and northeast slopes of this feature. The four PILO transects are on N-S trending ridges around this feature, three to the north and one to the south.

1. PILO 1 transect.

Located S of the Temple on the prominent ridge directly east of the horse trail as it descends towards Bryce Canyon. From the outcrops at the N end of this ridge, plot 3 is 44.8 m to the south along a 170° bearing. Then follow the directions noted on the transect map. The transects and quadrats are read from N to S on all plots. Plot 1 is directly opposite the horse trail on the other side of the obvious gully.

2. PILO 2 transect.

Located on the north side of Mormon Temple. It is on the middle of three prominent ridges trending N-S looking north and

northeast from the slopes of the Temple. The ridge bends sharply to the west at its north end. Walk the prominent ridge crest towards Bristlecone Point. The proper ridge is the second major one along this crest. At the beginning, an odd band of small rocks occurs at the base of the slope of the ridge, ca. 15 m below crest. Go beyond this and walk ca. 70 paces (roughly 70 m) on a 335° bearing to a small point. Plot 1 is ca. 310° and about 10 m downslope. The transects and quadrats are read S to N on all plots.

3. PILO 3 transect.

Located on the farthest E ridge that is at roughly the same elevation as the ridges transects 2 and 4 are on. This ridge is distinctive because it forks, and a large, prominent ponderosa pine is situated on the fork trending NE. From the ridgecrest connecting Bristlecone Point with the Mormon Temple, E of transect 2, go downslope towards the proper ridge to a very large, mostly dead, bristlecone (55 cm dgl). Only one branch is alive (1991!). Starting at 2 m to the west of this tree, walk 60 m on a 30° bearing to the SW corner of plot 1. The transects and quadrats are read S to N on all plots.

4. PILO 4 transect.

This transect is on the ridge closest to and just NE of Mormon Temple. Beware, as there is a smaller ridge here as well, just to the E. Note some prominent outcrops on the northwest ridge of the Temple. These are obvious from the beginning of the transect. Walk down from the woodland towards a large twisted, very prominent, bristlecone snag. A smaller living bristlecone next to it is flagged. From here, walk ca. 30 m N along the ridge to a small reddish point, easily visible from the tree. About 25 m to the N is plot 1. The transects and quadrats are read S to N on all plots.

5. PIPO 1 transect.

From the horse trail descending into Bryce Canyon, walk eastward, crossing the entrance to the gully separating the horse trail from the ridge that PILO 1 transect is on, towards the south facing slopes below this ridge. A very large boulder on this slope is prominent. The NW corner of plot 1 is 4 m to the south. The transects and quadrats are read W to E on all plots.

6. PIPO 2 transect.

See directions for finding MC 2 transect. From the three prominent ponderosa's, walk through the open woodland in a N trending direction, staying roughly level on the slope, towards a set of prominent outcrops. The distance is about 1 km, or less. Climb up between these outcrops and look downslope to the N. Note

the very tall ponderosa below you. Head towards this tree and keep going past it on a 20° bearing. Cross the streambed, and go upslope. Plot 1 is near and under some large ponderosa's on the eastern edge of the open shrubby slope. The transects and quadrats are read W to E on all plots.

7. MC 1 transect.

Go E along the trail in the bottom of Bryce Canyon towards Tropic and the park boundary. Where this trail crosses the prominent streambed of the canyon the S, turn and go up this streambed about 100 m. Two large ponderosa trees can be seen in the streambed, ca. 1,5 m apart. From between these trees, walk a 150° bearing up on to the bank and through the woods. Go ca. 50-60 m. You should see a very large ponderosa near you. The NW corner of plot 3 is just S of this tree. The transects and quadrats are read S to N on all plots.

8. MC 2 transect.

Walk ca. 1 minute down the Fairyland trail from where it branches with the rim trail to small divide. Go down the obvious gully on the N side. Near the mouth (end) of this gully are three prominent ponderosa's lined up, the westernmost is a giant. The middle of the three has a distinctly curved trunk. From these trees, look on a $270-280^\circ$ bearing, beyond some trees and snags, to the second of two prominent snags, ca. 30-40 m (they may have fallen?). At the base of this snag is a small juniper, flagged. Just beyond the snag is an old fallen log. Plot 3 is 66 m on a 230° bearing from the base of this snag. From the three trees, also start N for PIPO 2 transect (see above). Transects and quadrats are read from W to E on all plots.

II. TRANSECT AND PLOT MAPS.

Following are sketch maps for each transect and plot. They are organized in the following sequence:

- Transect sketch
- Plot 1 location sketch
- Plot 1 needle tree location sketch
- Plot 1 tree map
- Plot 2 location sketch, etc.

in the following order:

- PILO 1
- PILO 2
- PILO 3
- PILO 4

PIPO 1
PIPO 2
MC 1
MC 2

Note that, inadvertantly, no plot location sketch for plot 3 of
PILO 2 transect was prepared.