Crater Lake National Park

Botrychium pumicola
2009 Research Report and Monitoring Plan

Botrychium pumicola showing mature sporangia.
August 13, 2009. Photo by Janelle Cossey.

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The Crater Lake moonwort or pumice grapefern (*Botrychium pumicola*) is a rare pteridophyte fern, which occurs in Crater Lake National Park, Deschutes and Winema National Forests, and Prineville District of the Bureau of Land Management of central Oregon (Figure 4) and Shastina Cone in the Shasta-Trinity National Forest of California. It is a former Federal Category 1 Candidate for listing as Threatened and a former Federal Species of Concern, currently listed as Threatened by the State of Oregon and is on the U.S. Forest Service Sensitive Species List (USDA Forest Service 2008). *B. pumicola* populations occur on pumice and/or volcanic rubble substrates on exposed, high elevation ridges (alpine/sub-alpine populations) and lodgepole pine frost-pocket basins at lower elevations (montane populations). Historic sightings within Crater Lake National Park have been documented in sub-alpine habitat on Llao Rock, Cloudcap, Dutton Ridge, Skell Head and Grotto Cove. Due to previous inconsistent survey methodologies within Crater Lake National Park, resource managers have been unable to determine the status of known populations. It is also unclear why the plant is absent from suitable habitat in alpine pumice fields that appear to meet the requirements of the species. This research provides baseline data using systematic monitoring protocols, and investigates the factors affecting the abundance and distribution of sub-alpine/alpine populations of *B. pumicola* for informed management decisions regarding this unique taxon.

This was a summer of discovery regarding the ecology of *Botrychium pumicola*, (Crater Lake moonwort, pumice moonwort). I have been fortunate to work with an expert in the genus *Botrychium* and to visit the re-discovered population of *B. pumicola* on Shastina cone, a parasitic eruption on the western flank of Mt. Shasta, California. It has been a pleasure to locate and document all the known populations of *B. pumicola* within Crater Lake National Park and to discover several new populations. For the first time, the Park has well documented and mapped occurrence information for this interesting taxon. Certain assumptions and conclusions about *B. pumicola* have been falsified as new knowledge has been gathered over the summer by myself and other researchers. For example, through my research it is clear that *B. pumicola* is not restricted to pumice substrates or precluded from occurring on east aspects with up to 30% slope. This species can no longer be referred to as an Oregon endemic due to the re-discovered population on Shastina cone. This report summarizes my field notes for site visits to *B. pumicola* populations in Crater Lake National Park, Deschutes National Forest and Shasta-Trinity National Forest. I also describe my methodology for field data collection and a preliminary monitoring plan for *B. pumicola* populations at Crater Lake National Park which will be fully implemented in 2010.

I would like to thank the Crater Lake Natural History Association for funding this research. I am also very grateful to my field assistants Eric Andersen, Kathryn Williams, Wendy Wayne, Keith Roe, Eunice Roe and Janelle Cossey for their invaluable help locating and counting *B. pumicola* plants, and assisting with plant identification, photography, and data collection for countless hours out on the hot, dry, exposed pumice fields of Crater Lake's caldera rim.

STUDY SITES - Crater Lake National Park

Grotto Cove
UTM: 4756486 N, 0577679 E, +/- 9ft. NAD 83 Zone 10.
Date of site visits: 6/22/09, 7/7/09, 7/28/09, 7/30/09, 8/6/09.
Elevation: 2096 meters (6876 feet)
Slope: 5%
Aspect: 12 degrees N-NE.
Total *B. pumicola*: 13 (7 at upper site, 6 at lower site)
Plots sampled: 5 BoPu, 5 Paired
Soil Temperature Range: 23.3 c – 25.1c
Most common plant associates: *Carex breweri, Phlox hoodii, Lupinus Lepidus*
B. pumicola trophophore length: 1.5 – 4cm, sporophore length: 1.5-4cm.

Grotto Cove is located approximately 10 meters north of the Grotto Cove/Palisades overlook. It is the easternmost and lowest elevation subalpine *B. pumicola* population in the Park. The substrate consists of white "popcorn" Mazama pumice varying in size from 1cm- 5cm mixed with various size gravel and silt. Associated plant cover is sparse. The site is surrounded on three sides by an open stand of wind-dwarfed *Pinus contorta* (lodgepole pine) with the lake precipice on the west side. The *B. pumicola* occur in a scattered distribution on the east (upper site) and west (lower site) side of a paved walkway which bisects the population. This path originates circa 1940 when the old rim road was re-routed and this overlook was largely abandoned after some light grading and planting of *P. contorta* and *Arctostaphylos patula* (greenleaf manzanita). During the Mission 66 era, the path was re-developed circa 1968 into the "Grotto Cove Nature Trail" which was created as a handicap accessible interpretive trail. Interpretive signs, placed on both sides of the path, explained the flora at the site. This nature trail was abandoned for unknown reasons by 1975. Because the paved path still exists, many visitors mistake it for a hiking route or path to an overlook, only to find that the path ends abruptly, at which point they continue on through the pumice. There is evidence of heavy disturbance from foot traffic in the lower site where visitors leave the paved walkway to get closer to the lake precipice. The history of this site is intriguing because there is no mention of *B. pumicola* at this site until 1995 when Dick Vander Schaaf from the Nature Conservancy documented the upper site. This is curious, given that other plants were highlighted along the former nature trail. One can only speculate that either *B. pumicola* was indeed at the site and overlooked or ignored (which seems unlikely given that the only known populations at the time were at Llao Rock and Cloud Cap, so a new discovery would likely have been noted), or that this is a relatively recent colonization by the species.

Grotto Cove Population – upper site.

Grotto Cove Population – lower site. Remains of rock wall visible at the site.

Volunteers assisting with data collection at Grotto Cove lower site.

Grotto Cove *B. pumicola* with pumice substrate

Entrance to Grotto Cove Nature Trail circa 1968.

Grotto Cove Nature Trail circa 1968.

Remains of rock wall and footpath of former Grotto Cove Nature Trail. 2009

Skell Head
UTM: 4755736 N, 0577706 E, +/- 8ft. NAD 83 Zone 10.
Date of site visits: 6/22/09, 7/13/09, 7/15/09
Elevation: 2180 meters (7152 feet)
Slope: 9%
Aspect: 250 degrees W-SW
Total *B. pumicola*: 37+
Plots samples: 5 BoPu, 5 Paired
Soil Temperature Range: 16.9 c - 20.1 c
Most common plant associates: *Erigeron elegantalus, Carex breweri, Achnatherum occidentale*.
B. pumicola trophophore length: 1-3 cm., sporophore length: .5 – 3.5 cm.

The Skell Head population is located approximately 200 meters north of the parking area for the Skell Head overlook. The substrate consists of white "popcorn" Mazama pumice varying in size from 1cm-5cm mixed with various size gravel and silt. Associated plant cover is sparse with a scattered distribution of *B. pumicola*. There are several clumps of 3-5 *B. pumicola* indicating vegetative reproduction via gemmae. The site is open and windswept with a stand of *Pinus albicaulis* (whitebark pine) directly to the east and the lake precipice to the west. There is little sign of disturbance by humans at this site. Deer scat was observed at the site but no signs of herbivory were observed.

Skell Head Population

Skell Head *B. pumicola* clump with pumice substrate

Cloud Cap Population 1
UTM: 4754095 N, 0577589 E, +/- 8 ft. NAD 83 Zone 10.
Date of visits: 6/23/09, 7/31/09, 8/6/09
Elevation: 2402 meters (7880 feet)
Slope: 22-36%
Aspect: 185-210 degrees S-SW
Total *B. pumicola*: 115+
Plots sampled: 5 BoPu, 5 Paired
Soil Temperature Range: 21.9 c -24.8 c.
Most common plant associates: *Antennaria rosea, Erigeron elegantalus, Carex breweri.*
B. pumicola trophophore length: 1-2cm, sporophore length: 1.5-3.5 cm.

The Cloud Cap population 1 is located 5 meters to the northwest of the Cloud Cap overlook parking area and covers an area of approximately one acre. The substrate consists of Mazama pumice varying in size from 1cm- 3 cm mixed with various size gravel and silt. There is less pumice at this location than Grotto Cove, Skell Head or Llao Rock and more dark gravel. In some areas of the population there is little to no pumice and only the dark gravel. Associated plant cover is moderate with a mostly scattered distribution of *B. pumicola*. There are several areas within the population that have higher densities of *B. pumicola* occurring along a north-south axis in line with the prevailing winds. Another population (Cloud Cap Population 2) is located approximately 15 meters to the south of Population 1, below the overlook rock wall. Both of these populations are subject to visitor impacts due to their proximity to a very busy overlook. Visitors often leave the parking area and overlook to walk on the fragile pumice fields below the rock wall. A popular social trail is located directly to the east of Population 1 and while most visitors appear to stay on the trail, there is evidence of foot traffic into the *B. pumicola* population. No signs of herbivory were observed at this site.

Cloud Cap Population 1

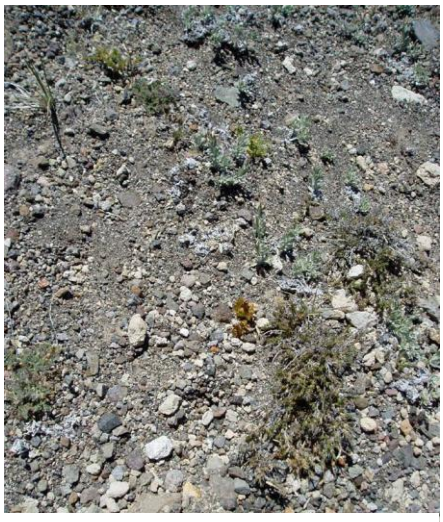
Cloud Cap *B. pumicola* with dark gravel substrate

Cloud Cap Population 2
UTM (corner stakes): NE corner 4753993 N, 0577614 E. NW corner 4753991 N, 0577613 E.
SW corner 4753978 N, 0577614 E. SE corner 4753984 N, 0577620 E. all +/- 8ft.
Date of visits: 6/23/09, 8/19/09
Elevation: 2393 meters (7851 feet)
Slope: 31%
Aspect: 250 degrees S-SW

Total *B. pumicola*: 21+
Plots sampled: plots not sampled.
Soil Temperature Range: 22.5 c.
Most common plant associates: *Eriogonum umbellatum, Erigeron elegantalus, Carex breweri.*
B. pumicola trophophore length: not measured.

This population occurs approximately 10 meters below the overlook rock wall. Associated plant cover is moderate with a mostly scattered distribution of *B. pumicola*. The substrate is very similar to Cloud Cap Population 1. Suitable habitat exists to the east, west and south of this population, however the plants are restricted to a small area where they occur along a north-south axis in line with the prevailing winds. 12 inch galvanized metal stakes were placed at the four corners of the population to test if this type of marker will be suitable for pumice soils. There is heavy foot traffic through this lower population where visitors go over the rock wall and walk down to a precipitous outcrop over the lake. Interpretive signs and "do not enter" signs and seasonal fencing should be installed to protect both populations at Cloud Cap.

Cloud Cap Population 2 below overlook wall.



Cloud Cap Population 2 senescing *B. pumicola*.

Llao Rock Population 1
UTM: 4758192 N, 0570364 E, +/- 9 ft. NAD 83 zone 10.
Date of visits: 7/19/09, 7/23/09.
Elevation: 2444 meters (8018 feet)
Slope: 11%
Aspect: 250 degrees W-SW
Total *B. pumicola*: 257+
Plots sampled: 10 BoPu, 10 Paired
Soil Temperature Range: 16.9 c – 18.6 c.
Most common plant associates: *Raillardella argentea,Carex breweri, Agoseris sp.*
B. pumicola trophophore length: 1-4cm, sporophore length: 1.5-5 cm.

Llao Rock Population 1 is located at the western end of the rolling terrain summit of Llao Rock. The substrate consists of white "popcorn" Mazama pumice varying in size from 1cm- 5cm mixed with various size gravel and silt. Soil excavation here revealed much more buildup of organic matter than the other Crater Lake sites which may be a factor leading to the high density and frequency of *B. pumicola* at this site. Associated plant cover is dense with a very dense distribution of *B. pumicola*. There are several clumps of 3-5 *B. pumicola* indicating vegetative reproduction via gemmae. The site is open and windswept with clumps of 1-3 of *Pinus albicaulis* (whitebark pine) scattered along the southern and western edge of the population. To the south is a very steep caldera precipice. Human foot traffic is minimal although occasional hikers reach the site via the west and north, however there is little sign of disturbance by humans at this site. Elk and deer scat were observed below the site but no signs of herbivory were observed. This is one of four populations on Llao Rock. Population 2 is located approximately 20 meters to the east. Population 3 is located approximately 10 meters from Population 2 on the northwest flank of Llao Rock. *B. lanceolatum* also occurs in Population 1 and 3 but is unmistakable with its yellow-green, shiny cast and lanceolate pinnae. A fourth population occurs about 50 meters down the northwest flank. These will need to be fully surveyed in 2010. A galvanized metal stake was placed in the center of this population which should be removed and four corner stakes installed to reduce trampling in this very dense population.

Llao Rock Population 1

Llao Rock Population 1 *B. pumicola* clump

Llao Rock Population 1 *B. lanceolatum* in upper section of population with lower density of *B. pumicola.*

Llao Rock Population 2
UTM (corners marked with metal stakes): NW 4758191 N, 0570497 E. SW 4758173 N, 0570487 E. NE 4758173 N, 0570572 E, SE 4758148 N 0570561 E. +/- 7-8ft. NAD 83 zone 10.
Date of visits: 8/13/09, 8/14/09.
Elevation: 2446 meters (8024 feet)
Slope: >5-28%
Aspect: 110 - 290 degrees SE, SW, NW
Total *B. pumicola*: 1000+
Plots sampled: 10 BoPu, 10 Paired
Soil Temperature Range: 9.5 c – 11.1 c.
Most common plant associates: *Raillardella argentea,Carex breweri, Elymus elymoides.*
B. pumicola trophophore length: 1.5 – 4.5 cm, sporophore length: 1.5-8 cm.

Llao Rock Population 2 is located at the eastern end of the rolling terrain summit of Llao Rock. This is the largest population in the Park with over 1000 plants. The substrate consists of white "popcorn" Mazama pumice varying in size from 1cm- 5cm mixed with various size gravel and silt. Soil excavation here revealed even more buildup of organic matter than Llao Rock Population 1 and the other Crater Lake sites which may be a factor leading to the high density and frequency of *B. pumicola* at this site. Associated plant cover, especially *Raillardella argentea*, is dense with a very dense distribution of *B. pumicola*. There are several clumps of 3-5 *B. pumicola* indicating vegetative reproduction via gemmae. This population also has the tallest *B. pumicola* of all other Crater Lake sites with the maximum sporophore length of 8 cm. The site is open and windswept with a clump of 10 *Pinus albicaulis* (whitebark pine) along the eastern edge of the population and 3 other *P. albicaulis* along the northern edge. To the south is the very steep caldera precipice. Human foot traffic is minimal although occasional hikers reach the site via the west and north, however there is little sign of disturbance by humans at this site. Elk and deer scat were observed below the site but no signs of herbivory were observed. Llao Rock Population 4 is located approximately 50 meters down slope on the northwest flank of Llao Rock. Population 3, approximately 10 meters down slope from Population 2 was discovered by Don Farrar PhD, a *Botrychium* researcher from Iowa State University on 8/13/09 during his visit to Crater Lake to observe and participate in my research.

Llao Rock Population 2

Llao Rock Population 2 *B. pumicola* with 8 cm. sporophore showing sporangia.

Llao Rock Population 2 showing high density of *Raillardella argentea* and *B. pumicola*.

Dutton Ridge
UTM: 4750307 N, 0574711 E. +/- 7ft. NAD 83 zone 10.
Date of visit: 6/24/09, 8/17/09.
Elevation: 2468 meters (8100 feet)
Slope: 14%
Aspect: 190 degrees S-SW
Total *B. pumicola*: 2
Plots sampled: 1BoPu, 1 Paired
Soil Temperature: 15.6 c.
Most common plant associates: *Achnatherum occidentale, Raillardella argentea, Carex breweri.*
B. pumicola trophophore length: 1.5 cm, sporophore length: 1.5 cm.

The Dutton Ridge population consists of two *B. pumicola*. On my second visit to the site I was unable to locate the plant seen on 6/24/09 which I believe to be different from the one observed on 8/17/09. This site is located approximately 10 meters below the summit in open, windswept "popcorn" pumice substrate similar to Llao Rock. The density of associated plant species is sparse. Interestingly this is the only other Crater Lake population where *Raillardella argentea* occurs (in much lower density than Llao Rock), however the density of *B. pumicola* is surprisingly low. The site is bordered on the southern side by a stand of *Pinus albicaulis* with other *P. albicaulis* scattered around the site. Further investigation of soil chemistry and nutrients and presence or absence of mychorrizal fungi is necessary to speculate as to the reasons for this small population. A galvanized metal stake was installed 20 cm N of the *B. pumicola* plant in a group of *Carex breweri* and *Lupinus lepidus*. The plant is located in between two solitary yellow-flagged *Pinus albicaulis* on a compass bearing of 216 degrees. The first flagged *P. albicaulis* is 1 m tall and is located 2.5 meters from the *B. pumicola*. The second *P. albicaulis* is 2 meters tall and is located 6 meters from the *B. pumicola*.

Dutton Ridge Population

Park Biological Technician with single Dutton Ridge *B. pumicola*

Dutton Ridge *B. pumicola* in pumice substrate.

Deschutes National Forest Sites

<u>The Dome – Newberry Volcanic National Monument</u>

Date of visit: 7/11/09.
Elevation: 2193 meters (7194 feet)
Slope: 18%
Aspect: 18 degrees W
Total *B. pumicola*: 75
Plots sampled: 5 BoPu, 5 Paired
Soil Temperature Range: 18 c – 26.5 c.
Most common plant associates: *Phlox hoodii*, *Castilleja applegatei*, *Achillia millefolium*
B. pumicola trophophore length: 1 – 3.5 cm, sporophore length: .5-3.5 cm.

The Dome is a horseshoe shaped volcanic cinder cone with a layer of "popcorn" pumice outfall from the Newberry caldera collapse. The substrate looks similar to that of Grotto Cove with the exception of the pumice source being from Newberry volcano, not Mt. Mazama. There is a mix of Newberry pumice and various size gravel and silt and a very different suite of plant associates than at Crater Lake. The *B. pumicola* population is on the southwest bend in the "horseshoe" in an area of approximately ¼ acre. The site is open and windswept with scattered *Pinus albicaulis*.

The Dome population

Dome *B. pumicola* in mixed pumice and gravel substrate near *Pinus albicaulis*.

Broken Top SE

Date of visit: 8/10/09.
Elevation: 2316-2333 meters (7598-7654 feet)
Slope: 20%
Aspect: 140- 82 degrees S-SE
Total *B. pumicola*: 636
Plots sampled: 5 BoPu, 5 Paired
Soil Temperature Range: 18.1 c – 23 c.
Most common plant associates: *Achillia millefolium*, *Penstamon davidsonii*
B. pumicola trophophore length: 1 – 5.5 cm, sporophore length: .5-7 cm.

Broken Top SE is one of two *B. pumicola* populations on Broken Top. This site is accessed via the Todd Lakes basin and is located near Ball Butte on the SE flank of Broken Top. This site has an unusual mix of pumice, gravel and hard packed soil substrate, the latter having very little associated plant cover but the most robust *B. pumicola* of all sites visited. There are scattered *Pinus albicaulis* throughout the site. The population is found on what appears to be a terminal moraine of past glacial activity and extends across the trail that bisects the population. Interestingly there are no *B. pumicola* on the slope above or directly below the population, only in the more reddish/brown substrate. One explanation may be the relative stability of the site allows for the connection of mychorrizal fungi between *B. pumicola* and an associated plant species. On the steeper slope above the population these connections may be routinely severed as the loose substrate moves throughout the year.

Broken Top SE population to left of trail on knob near *Pinus albicaulis*.

Broken Top SE population view towards Mt. Bachelor.

Broken Top SE substrate of volcanic rock with mixed pumice and gravel.

Broken Top SE large *B. pumicola* clump in hard packed soil typical of this site.

Mt. Bachelor

Date of visit: 8/11/09.
Elevation: 2761 meters (9058 feet)
Slope: >5- 35%
Aspect: 129 – 127 degrees E-SE and S-SE
Total *B. pumicola*: 372
Plots sampled: 5 BoPu, 5 Paired
Soil Temperature Range: 10.3 c – 16.6 c.
Most common plant associates: *Penstamon davidsonii, Carex breweri*
B. pumicola trophophore length: 1.5 – 6 cm, sporophore length: 1-6.5 cm.

This population is located on the very summit of Mt. Bachelor in open, windswept volcanic rubble from the Mt. Bachelor eruptions. The *B. pumicola* are found in between large to medium sized rocks in pockets of small amounts of Sisters pumice and mixed gravel and silt. Associated plant cover is sparse. The *B. pumicola* are found nestled in micro sites with other plants where some soil development has occurred. This site is resembles the Mt. Shasta site, however there is more soil development, plant cover and *B. pumicola* are scattered throughout the site, unlike Mt. Shasta where they are only found nestled in rock shelters. A hikers trail leads directly to the site so the Mt. Bachelor ski resort is required by the US Forest Service to place rope fencing and signs to deter hiker impacts on the population. This seems to be quite effective in protecting the plants.

Mt. Bachelor population with view towards three Sisters and Broken Top.

Mt. Bachelor population in summit rubble field.

Mt. Bachelor hiker trail with protective fence and sign.

Mt. Bachelor *B. pumicola* with *Penstamon davidsonii.*

Shasta-Trinity National Forest

Shastina Cone

Date of visit: 8/04/09.
Elevation: 2755 meters (9040 feet)
Slope: 15%
Aspect: 220 degrees SW
Total *B. pumicola*: 6
Most common plant associates: *Penstamon davidsonii, Carex breweri*
B. pumicola trophophore length: 1 – 4 cm, sporophore length: 1-4 cm.

This population is located on an exposed, very windy SW flank of Shastina Cone near the upper end of Diller Canyon. The substrate is predominately large to medium sized volcanic rubble from the Shastina eruptions mixed with some gravel and silt. There is no pumice at this site. Associated plants are very sparse and the site is scattered with clumps of *Pinus albicaulis* krummholtz. The *B. pumicola* are located in rock caves and crevices where a small amount of soil development has occurred and the plants are sheltered from the wind. This population was last seen by William Bridge Cooke in 1940 and has been discounted as being *B. pumicola* for over 50 years. The Jepson Manual places this sighting as a mistaken identification of *B. pinnatum* and indicates that *B. pumicola* does not occur in California. The re-discovery of *B. pumicola* occurred on 7/13/09 by Eric White and his staff from Shasta-Trinity National Forest. I was fortunate to accompany the second expedition along with Don Farrar, an expert in *Botrychium*, to the site to confirm the identity and locate 3 more plants in rock crevices near the first sightings. This adds a fascinating layer to the ecology of *B. pumicola* and opens up a new chapter on the evolution and distribution of the species in what was thought to be an Oregon endemic. Due to the small population I did not take a soil sample here. Soil development was only occurring around the plants and I felt the risk of disturbance and removal of underground gametophytes and juvenile sporophytes was too great to justify a soil sample.

Shastina population at end of valley in krummholtz *P. albicaulis*.

Shastina population below Shastina cone in rubble field.

Shastina *B. pumicola* habitat in rock shelters and crevices.

Largest Shastina *B. pumicola* in rock shelter.

Methods

Data collection occurred from June 22- August 28, 2009 at which time most plants were senesced. Each population (sampling universe) was located and delineated by temporary flag pins. Individual *Botrychium pumicola* plants were marked with pin flags by placing flags 5 cm from the plant. Five to ten randomly selected plots (1 meter square) within the sampling universe were selected from a random numbers table for sampling of occurrence variables (Table 1). Sites which matched the slope, aspect, elevation range and plant association criteria but lack *B. pumicola*, were be paired with a corresponding population at each site and sampled on the same day or the following day using the same methods listed above. If populations were too small for ten plots, then the sampling size was reduced and paired sites were delineated to match each known population size. Sampling occurred at the five known subalpine populations within Crater Lake National Park including Grotto Cove, Skell Head, Cloud Cap, Llao Rock and Dutton Ridge. Sampling also occurred at Deschutes National Forest subalpine sites including The Dome, Mt. Bachelor, and Broken Top. The Shastina Cone (Shasta-Trinity National Forest) site was visited but due to the difficult access, harsh conditions and small population size this site was not sampled, however it will be included in the discussion section for comparative purposes. Data were collected using GPS unit and field forms using techniques and equipment denoted in table 1. Data analysis will occur in Fall of 2009 with results available by April of 2010.

Table 1 Occurrence Variables

Occurrence variable	**Sampling technique**
Location (UTM's)	GPS – Garmin handheld unit
Elevation	GPS – Garmin handheld unit
Aspect	Silva Ranger compass
Slope	Suunto clinometer
Associated plant species	Identified by species and counted in each 1m plot. Density and frequency data collected for each.
Pumice size	1 kg sample collected for stratification in soil sieve.
Substrate type	Broad categories of each site based on USGS volcanic soil classifications.
Soil temperature	Reading taken at the root depth of one plant per plot using Taylor soil thermometer.
Soil transition/soil development	Will be noted for presence/absence during sampling for soil moisture.
Soil moisture, pH, Calcium, Nitrogen, Organic matter	Quart size zip lock bag sample taken from each population and paired plots to a depth of 10 cm. for analysis at OSU soil lab.
Mychorrizal Fungi and *B. pumicola* spore Presence/Absence	A tissue sample taken from the root of one associated plant per population placed in vial with 70% alcohol solution taken for analysis in lab. Another 1 kg sample of rock and soil taken to look for presence of fungal and *B. pumicola* spores.

Long-term Monitoring Protocol

Designing a long-term monitoring protocol for *B. pumicola* is challenging due to the cryptic nature of the species including potential for dormancy, variability in distribution, variation in population size and fragile nature of the habitat. My goal is to establish long-term monitoring protocol for each *B. pumicola* population within Crater Lake National Park. Each known population was located and delineated by temporary flag pins. Galvanized metal stakes were installed at the four corners of the Cloud Cap 2, and Llao Rock 2 populations to test this method over the winter of 2009-2010. For each site, the entire population was mapped using a Garmin GPS unit. For the Crater Lake populations including Grotto Cove, Skell Head, Dutton Ridge, Cloud Cap and Llao Rock, a whole-census strategy should be used (Table 2). This should be conducted on a yearly basis to account for fluctuations in the population. This species goes through periods of dormancy where the plants will not emerge for 1-3 years, giving resource managers false population readings. At any given time up to 30% of the population may be underground

making monitoring all the more difficult. A yearly census over a minimum of five years will give an accurate estimate of population size.

For each population I recommend creating sub-plots for sampling of individual plants to gain information on the demography of the Crater Lake populations. Sub-plots were installed at Grotto Cove (four sub-plots) and Skell Head (five sub-plots) and were marked in the NE corner by an aluminum wire stake with plant tag. This information is critical in understanding the dormancy rate at each population. Since trophophore and sporophore size are correlated with age, these sub-plots will also provide an estimate of the comparative age of each population. They can also be used to follow the response of *B. pumicola* and associated plant species to climate change. If these aluminum wire tags overwinter successfully, the same method should be used to install sub-plots at all populations.

For the large population at Llao Rock (Llao Rock Population 2) I had previously recommended a sampling design using five 20-meter transects laid down within the sampling universe, spaced five meters apart. A one-meter plot was to be sampled on the east side of each transect at an interval of every five meters for a total of four plots per transect and twenty plots per site. Through my research and observing this type of monitoring being used in the Deschutes National Forest (at Sands Springs Pasture) I have found this type of sampling to be more damaging to the fragile pumice habitat than a whole-census. Walking back and forth to install transects and plots has more impact than placing pin flags and doing one sweep of the population. I have also observed and participated in whole-census monitoring of the Broken Top population which has over 600 plants and found this type of monitoring to be less resource intensive, taking two people only one day to complete. Therefore I recommend a whole-census strategy for all of the Crater Lake populations.

Two of the sites have visitor impact problems which must be addressed. The Grotto Cove site receives heavy foot traffic from visitors who mistake the old paved walkway as a trail, then deviate from the path into the *B. pumicola* population to get closer to the lake precipice. This old pavement should be removed and the population should be fenced in a similar fashion as the Mt. Bachelor population. The Cloud Cap population one and two are also receiving visitor impact via a social trail which runs along the eastern side of the population and via foot traffic below the overlook. The social trail continues to widen and erode and leads visitors up into the *B. pumicola* population where they leave the trail and walk down through the population back to the overlook. This social trail should be obliterated and appropriate signage installed to educate visitors about the fragile pumice habitat. Fencing is also recommended at this site since it receives heavy visitor use similar to the Mt. Bachelor population.

Table 2 Sub-Plot and Long-term Monitoring Data Collection

Field Data Collection Item	**Data Collection Method**
B. pumicola	Plants will be pin flagged and counted in each population (whole population census).
Tropophore length	Tagged plants measured in cm. in 1 meter square sub-plots. 1-5 per population depending on population size.
Sporophore presence/absence and length	Tagged plants measured in cm. in 1 meter square sub-plots. 1-5 per population depending on population size
Associated plant species	Identified and counted for density/frequency in 1 meter square sub-plots. 1-5 per population depending on population size.
Evidence of herbivory or trampling	Plant damage and footprints noted.