Boechera pusilla (Small Rockcress; Fremont County Rockcress)

Final Monitoring Report (2015-2017)

and Status Report Update

Fremont County, Wyoming

Prepared for
Bureau of Land Management
Wyoming State Office and Rock Springs Field Office

By
Bonnie Heidel
Wyoming Natural Diversity Database
University of Wyoming
Dept. 3381, 1000 E. University Avenue
Laramie, WY 82071

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ABSTRACT

Boechera pusilla was designated sensitive by the Bureau of Land Management (BLM), and more recently recognized as a Candidate species (Category 1) by the U.S. Fish and Wildlife Service (FWS). It is known from one population throughout its range, and has been the subject of studies and protection measures. A monitoring study was set up in 1988 within part of the largest subpopulation. The 1988 monitoring was replicated in 2003 and 2004; then from 2008-2012, and most recently in 2015-2017. Monitoring results document oscillating trend among flowering plant numbers in the original monitoring plot with relatively high numbers in 2017 (81) relative to recent years, but no rebound to 1988 numbers. In addition, complete census was sought in all of the *B. pusilla* populations, tallying a total of 1340 plants (flowering + vegetative) in 2017. New surveys of *B. pusilla* were conducted and small subpopulation boundary edits were made. A closely-related taxon, *B. pendulina*, was documented as recurrent in surrounding sections, and the recent report of a "new" *B. pusilla* population was based on material that has been redetermined as *B. pendulina*. This report represents a culmination of monitoring work, reinforcing the interpretation that there has been major decline, though it does not provide an explanation.

ACKNOWLEDGEMENTS

Boechera pusilla monitoring work was supported as a joint project of the Bureau of Land Management (BLM) and the Wyoming Natural Diversity Database (WYNDD). This study draws heavily from the previous monitoring work of Hollis Marriott. This year's report drew from her 2017 fieldwork. Taxonomic consultation with Dr. Michael Windham is acknowledged with gratitude. The 2017 monitoring was conducted with the support of Chris Keefe and Jim Glennon, BLM, under a challenge cost-share agreement between BLM and WYNDD (most fieldwork charges under L12AC20036, and all other charges under L16AC00389).

Literature citation:

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INTRODUCTION

Boechera pusilla (Rollins) Dorn (syn. *Arabis pusilla*) (Small Rockcress; also called Fremont County Rockcress) was on the most current list of designated sensitive species prepared by the Bureau of Land Management (BLM) in Wyoming (2010). It is now recognized as a Candidate species (Category 1 species) for listing under the Endangered Species Act (USDI Fish and Wildlife Service; FWS 2011)[1]. It is known from only one population throughout its range, so is a species of very high Wyoming contribution rank having Global and State ranks of G1/S1 (Heidel 2012). The entire population is on land administered by BLM out of the BLM Rock Springs Field Office.

Four *Boechera pusilla* status reports have been produced (Marriott 1986, Dorn 1990, Heidel 2005, 2012). The primary purpose of this project was to conduct an additional year of monitoring *B. pusilla* as culmination to a monitoring period data (2015-2017). It marks the tenth year of monitoring since the 1988 establishment year. New survey objectives were added in 2017 to resolve pilot 2016 survey questions, focusing on similar habitat near Pine Creek or otherwise in the same township as currently known. Finally, we examined new sets of climate data to look for climate patterns that might parallel population patterns. As such, this report replaces the other dual-purpose status and monitoring reports (Heidel 2005, 2012) but incorporates data directly from them. A timeline that encapsulates species studies, status changes, and related reports is presented in Appendix A, summarizing the history mentioned in different sections of this report.

MONITORING

Study design

A definition for plant population monitoring, as presented by Elzinga et al. (1998) is: "We define monitoring as the collection and analysis of repeated observations or measurements to evaluate changes in conditions and progress toward meeting a management objective." For purpose of this report, monitoring refers to repeated data-collecting visits to specific plant populations or population segments and the ensuing data analysis, to document trends and help gauge population viability in keeping with BLM's mandate to manage for viable populations. In this case, the repeated visits have been made once a year. The past year's work also included a survey component. Survey refers to a systematic search for a species where there are no pre-existing records of its presence. Census refers to a tally of individual plants by some set of standards, whether conducted in a monitoring study or in a survey study.

A monitoring design was established for *Boechera pusilla* and carried out in 1988 and it involved complete census of flowering plants in a given plot area placed within a large subpopulation (Marriott 1988). The plot area covered 16 m x 25 m (400 m^2). The original monitoring was conducted by setting out the plot boundaries and then laying a 25 m measuring tape at 2 m intervals along the 16 m baseline, counting all flowering plants and categorizing

[1] Since the time that this report was prepared, the U.S. Fish and Wildlife Service determined that listing Boechera pusilla as Endangered or Threatened is not warranted (USFWS 2018).

them within 1 m of the tape, carried out by a two-person team. The 1988 researchers also mapped the entire subpopulation as almost fitting within a 50 m x 25 m area (1250 m^2), and proposed expanding the original monitoring plot to the 50 m x 25 m area, and then converting it into a random sampling design. Detailed photo documentation and notes accompanied the establishment record of 1988 monitoring and accompanying raw data. It was recommended for annual monitoring but did not get repeated.

A separate monitoring design for *Boechera pusilla* was set up and executed in 1993 as complete census (Amidon 1993). From a schematic diagram and description of its location, it was located in roughly the same subpopulation area as the 1988 monitoring plot. The monitoring was reported in English units and spanned an area of 40 ft x 100 ft (4000 ft^2; 371.6 m^2). A series of tapes were spaced 5 ft (~1.5 m) apart and referred to as transects. A one-page summary copied from agency files was available for reference. It was also recommended for annual monitoring but the location of the plot was not marked on the ground or archived with maps, so could not be repeated.

The same subpopulation of *Boechera pusilla* that was monitored in 1988 and 1993 was not targeted for monitoring again until 2003 (Heidel 2005). It was readily apparent that the species was no longer in high density as reported in 1988, and was not random in its distribution but occurred as patches that followed irregular outcrop features, arguing against a random sampling design. The schematic maps and photo records that accompanied the 1988 monitoring were available for reference. It was possible to precisely relocate the 16 m x 25 m original plot area (400 m^2) based on photographs, field notes and a field map, confirmed in person later by Marriott in 2016. Global Positioning System (GPS) coordinates are on record, augmented by photographs from each corner point were added in 2017 as reference (Appendix B).

Monitoring of *Boechera pusilla* has been repeated in ten different years since establishment in 1988 (Table 1). The first repeat visits to the original plot were in 2003 and 2004.

In 2003, I raised questions whether overall trend results might be masked by shifts in the ratio of flowering-to-nonflowering individuals. Therefore, the scope of monitoring was expanded by adding census of nonflowering (vegetative) plants. All plants with a flowering stem of the current year were tallied as a flowering plant, no matter the number of stems or whether or not they had mature fruit. All plants without flowering stems were tallied as nonflowering, though it is challenging to reliably discern vegetative plants. They can be smaller than the diameter of a dime, and examination of many plants under hand lens was routine. Though generally out in the open, they were sometimes difficult to spot. The vegetative plant forms a small rosette, with simple hairs at the leaf margin and often a reddish coloration that are different from the two other *Boechera* species in the immediate area (*B. microphylla* and *B. pendulocarpa*).

Sometimes short-lived plants are prone to shift in their local distribution pattern. Starting in 2008, this was addressed by expanding the scale to include the largest rectangle possible within subpopulation boundaries to 50 m x 25 m (1250 m^2) as had been proposed twenty years earlier. Thus, the 1988 design was replicated, expanded, the corner points were marked, and pursued as exhaustive monitoring within the original and expanded plots. Two 50 m tapes were run the length of the monitoring plot on opposite sides, and two other 25 m tapes were stretched

perpendicular at 1 m intervals to grid off the plot for conducting complete census. Rocks were used to anchor the tapes to prevent shifting with wind, and anchoring the lanes was required to get accurate tallies in even the slightest of breezes. The zero axis was in the northeastern corner, and a pair of 25 m tape measures laid across the width of the plot to divide it into 1 m bands, in which a 1 m² frame was placed to record plant numbers along the 25 m bands. The 1250 m² sample area is henceforth referred to as the expanded plot area and the original plot is nested within it.

The monitored subpopulation covers an area that is more or less oval in outline, so there are small extensions on all sides of the 50 m x 25 m rectangular monitoring plot. The counts in these peripheral areas are not incorporated in the running tally of plot data, though they were noted separately in 2009-2012 and 2016-2017 monitoring to be stored in master datasets for the rest of subpopulation and population data. In other words, all data that are referred to as monitoring data come from just the rectangular plot area, with permanent corner markers.

Table 1. *Boechera pusilla* monitoring overview (1988-2017)

Monitoring date	**Monitoring extent (400 m² or entire 1250 m²)**	**Inclusion of vegetative plants in addition to flowering plants**
20 Jun 1988	400 m²	No
6 Jun 2003	400 m²	Yes
15 Jun 2004	400 m²	Yes
2 Jun 2008	1250 m²	No
1 Jun 2009	1250 m²	Yes
31 May 2010	1250 m²	Yes
6 Jun 2011	1250 m²	Yes
31 May 2012	1250 m²	Yes
4 Aug 2015	1250 m²	Yes
6 Jun 2016	1250 m²	Yes
2 Jun 2017	1250 m²	Yes

In this report, the term "flowering plant" is used interchangeably with "fruiting plant" and "reproductive plant." The term "nonflowering plant" is used interchangeably with "vegetative plant." The timing of *Boechera pusilla* monitoring has been early in the growing season thinking that this is a key period to evaluate life history. All monitoring was conducted when plants had fruits (siliques), except 2011, a year in which a small number of plants were still in late flower. It was a late year and traces of snow persisted around the plot area. The timing of monitoring changed in 2015 when opportunistic plans for *B. pusilla* monitoring were made on a trial basis in early August. Flowering stem breakage was rare, and there were no signs of plants having died between early and late in the summer. So monitoring is still ideal in early summer, but conditions may be amenable for later monitoring in years of mild growing conditions.

In 1988, the year that monitoring was established, there were 671 flowering plants in the original plot area. In each of the later ten years of monitoring, flowering plant tallies have always been less than 25% of 1988 flowering plant numbers. In an effort to address all possible explanations,

consultation with Hollis Marriott was pursued in 2016. She revisited the monitoring site and surroundings on July 15-17. She confirmed that the plot is located as she had originally placed it (Marriott 2016).

The scope of monitoring was expanded in 2011 to include a second subpopulation area with high numbers of *Boechera pusilla* plants, re-censused in 2016 and 2017 (see circles on the study area map, Figure 5). Census in this second area was conducted by laying tapes across occupied habitat, without establishing permanent plot boundaries and baselines. This census, like to rest of monitoring, was conducted mainly on hands and knees, and vegetative plants were included in the tally. In 2016-2017, the monitoring objective was further expanded to completely re-census of all occupied habitat (Figure 5). All other subpopulations have plants in low numbers, so they were traversed on foot, without use of measuring tapes to divide subpopulations into lanes (as needed in high density to avoid both omission and redundancy in census).

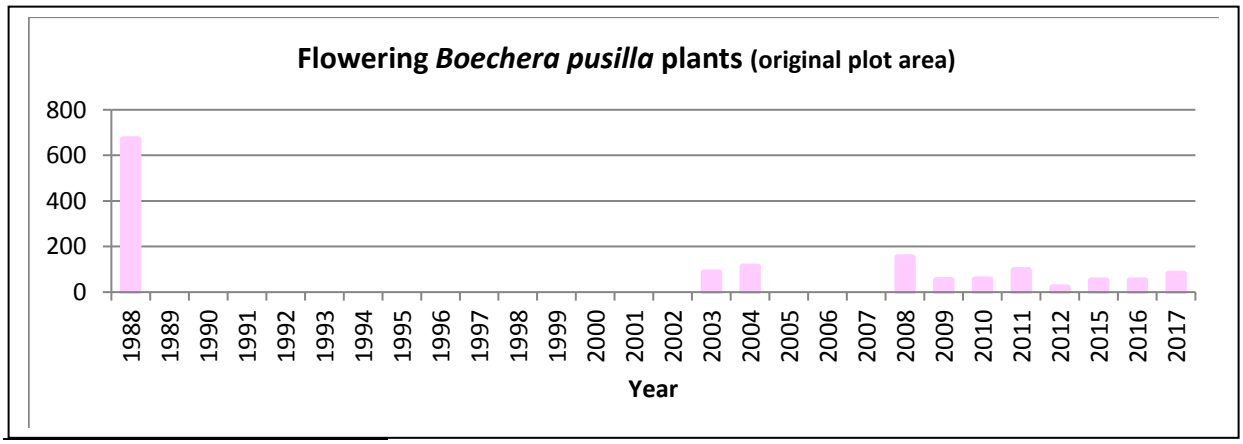
Monitoring results

The 2017 replication of 1988 monitoring shows that current *Boechera pusilla* flowering plant numbers (81 flowering plants) are about 12% of 1988 numbers (671 flowering plants). There has been no overall trend emerging from the ten years of data though there appears to be some level of oscillation (Table 2, Figure 1).

Table 2. Flowering *Boechera pusilla* plants over time

	400 m²	1250 m²
1988	671	
2003	87	
2004	112	
2008	152	400
2009	53	223
2010	56	238
2011	97	505
2012	21	213
2015	52	210
2016	52	316
2017	81	415

Figure 1. *Boechera pusilla* flowering plants in the original plot (400 m²) show small oscillation but not rebound to 1988 numbers[2],[3]

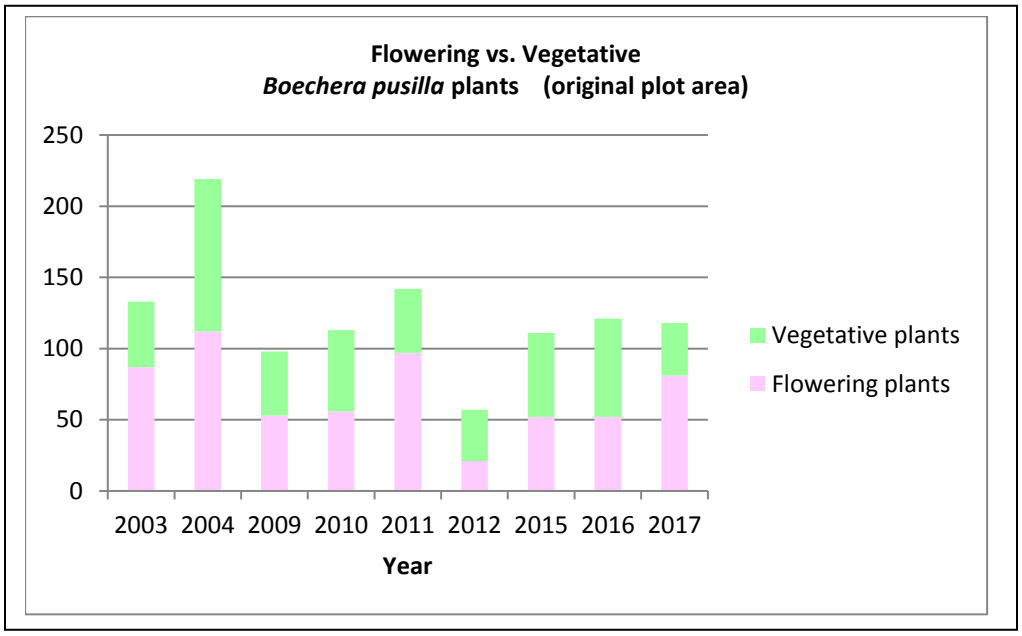


[2] Note that this is the only dataset and monitoring graph in the present report that compares the past 15 year period with the 1988 establishment report dataset, 30 years ago.

[3] All graphs in this report use pink to represent flowering plants and green to represent vegetative plants, in light or dark shades depending on whether they represent the original plot (light shade) or the expanded plot (dark shade).

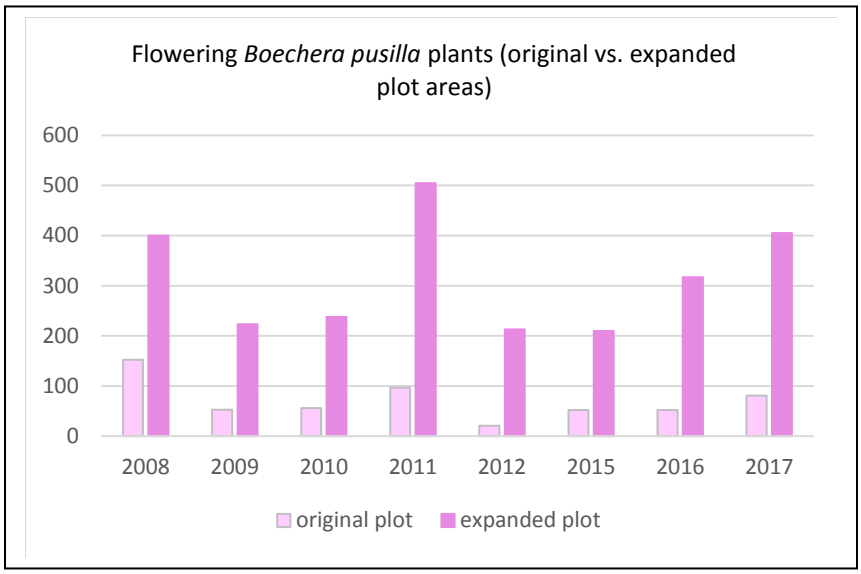
Addition of nonflowering plant census with flowering plant census indicates that nonflowering plant numbers may make up high proportions (50% or greater) of total plant numbers in both low-count years and in high-count years (Figure 2). Data also indicate that ratios between nonflowering and flowering plant numbers change between years and cannot be inferred from flowering plant counts. This indicates that the tally of all plants (flowering + vegetative) is a better representation of trends than either alone.

Figure 2. Flowering and nonflowering *Boechera pusilla* plants in the original plot (2003-2017) show that the vegetative plants can contribute ~30-70% of total plant numbers in any given year, and that vegetative plants may contribute significantly to total numbers in both low-count and high-count years



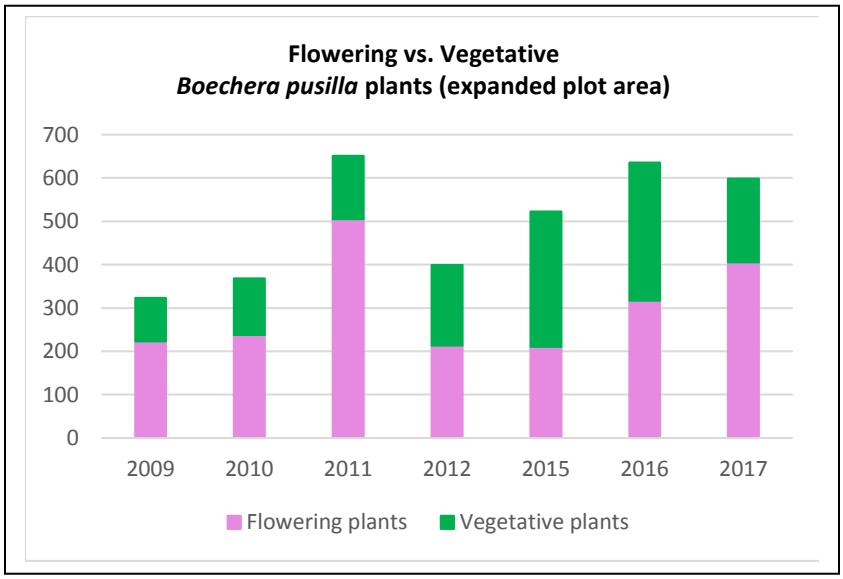
Examination of monitoring data for just flowering plants in the expanded plot versus the original plot indicates that the overall trends are analogous for any given interval between the original and expanded plot (Figure 3), refuting the idea that there might be shifts in locations for concentrated plant numbers over time. However, the expanded plot has not had flowering plant declines on par with declines in the original plot. The original plot declines up to 41% of peak numbers (2008-2017) compared to 14% declines of peak numbers in the expanded plot. It is possible that there might be some greater resiliency in portions of the expanded plot than in the original plot, keeping numbers from dropping as sharply.

Figure 3. *Boechera pusilla* flowering plants in the original and expanded plots (2008-2017; the dark pink corresponds with Table 2, second column) show that the trends in the original plot closely mirror the trends in the expanded plot



Finally, a composite graph of all flowering + vegetative plants in the expanded plot (2009-2017) shows variable ratios and overall parity in trends for each component. It does seem that vegetative plants make up a higher proportion of total plants in recent years (2012-2017) than in previous years (2009-2011).

Figure 4. Flowering and nonflowering *Boechera pusilla* plants in the expanded plot (2009-2017) show that the oscillating pattern of total monitoring plot numbers resembles that of just flowering plants, at the scale of both the original and expanded plots, and that vegetative plants comprise relatively high proportions of total plant numbers in recent years (2012-2017) compared to prior years (2009-2011)



Polygon-by-polygon monitoring results are summarized in Table 3 and detailed in Appendix C. In both 2011 and 2016, the two polygons with high numbers each had a magnitude more plants than any of the other polygons. This pattern shows every sign of being consistent between years. There are shifts between them. This underscores the benefit of the three-pronged approach using both original and expanded monitoring plots, and census throughout the rest of the population.

Table 3. *Boechera pusilla* census results, by polygon (2011-2017)

Polygon no.	**Polygon location**	**2011 census**	**2016 census**	**2017 census**
1	Oval polygon encompassing original + expanded monitoring plot (Easternmost polygon)	615	681	688
2	Second polygon with high numbers (NW¼)	726	925	537
3	Largest polygon, south of creek (SW¼)	No census	35	50
4	Expanded polygon, south of creek (SW¼)	No census	Not relocated	11
5	Small polygon bordering 2-track	25	9	27
6	Polygon west of second circled polygon (NW¼)	No census	19	22
7	Northernmost in a pair of points within one large outcrop	No census	Not relocated	8
8	Northernmost in a pair of points within one large outcrop	No census	Not relocated	1
9	Southern point above trees	No census	No census	8
10	Southwestern-most in a set of points within one large outcrop among trees	No census	No census	7
11	Small polygon east of creek beside knoll	No census	No census	8
TOTAL			1669	1367

In the limited time allocated for 2016 work, plants were not relocated at the three smallest polygons. Searches were not exhaustive.

In the expanded time allocated for 2017 work, plants were found at the three smallest polygons, and two more small polygons were located close by. Note: there is extensive outcrop habitat between these five locations. Though plants have not been found in intervening habitat, it is possible that suitable habitat lies between them and that they should be mapped as a single large polygonal area.

Furthermore, boundaries were expanded for one other polygon, and an additional small polygon was located. The latter is in the most rugged of settings among known polygons, it appears to correspond with a location marked onto maps by Robert Dorn (1990), and therefore it is inferred that the locale was overlooked in 2003-2004 surveys. By this convention of mapping, there are eleven polygons (Table 3), though five of them are all on the same semi-contiguous outcrop.

Monitoring discussion

The Category 1 designation of *Boechera pusilla* by FWS (2011) was based in some measure on trend information, placing a premium on acquiring and interpreting the most current information. The most fundamental conclusion is that there has been a persisting major decline between 1988 flowering plant numbers and more recent years. This decline is not explained by shifting ratios between flowering and nonflowering plants, or by shifts in plant distribution within the

monitored subpopulation. Dorn (1990) postulated that population size "Probably varies considerably from year to year depending on climate conditions."

Despite major decline, the monitored subpopulation still supports numbers similar to the 1988 tally of 671 flowering plants IF nonflowering plants are included in tallies, IF the expanded plot were considered rather than the much smaller original plot, and IF the top tallies (e.g., 2016 had 681 plants) were used for comparison. Results are also tempered somewhat by the fact that the species is not restricted to the one subpopulation where monitoring was started. There is exactly one other subpopulation that has had tallies of the same magnitude – sometimes greater, sometimes less than - the originally monitored subpopulation.

Alternate explanations for the documented decline in the original monitoring plot are presented in this section, and discussed as hypotheses with their respective pro- and con- arguments.

1. The 1988 results reflect highly anomalous population numbers rather than a reference point for interpreting overall population trend and comparison with the past 15 years.
2. Trends in weather or climate over the past 30 years show fundamental shift in the first 15 years compared to the past 15 years driving population trend.
3. There is some other key aspect of species' biology or species' habitat - as yet undetermined - that is subject to decadal changes, steady-state changes, or compounding effects.

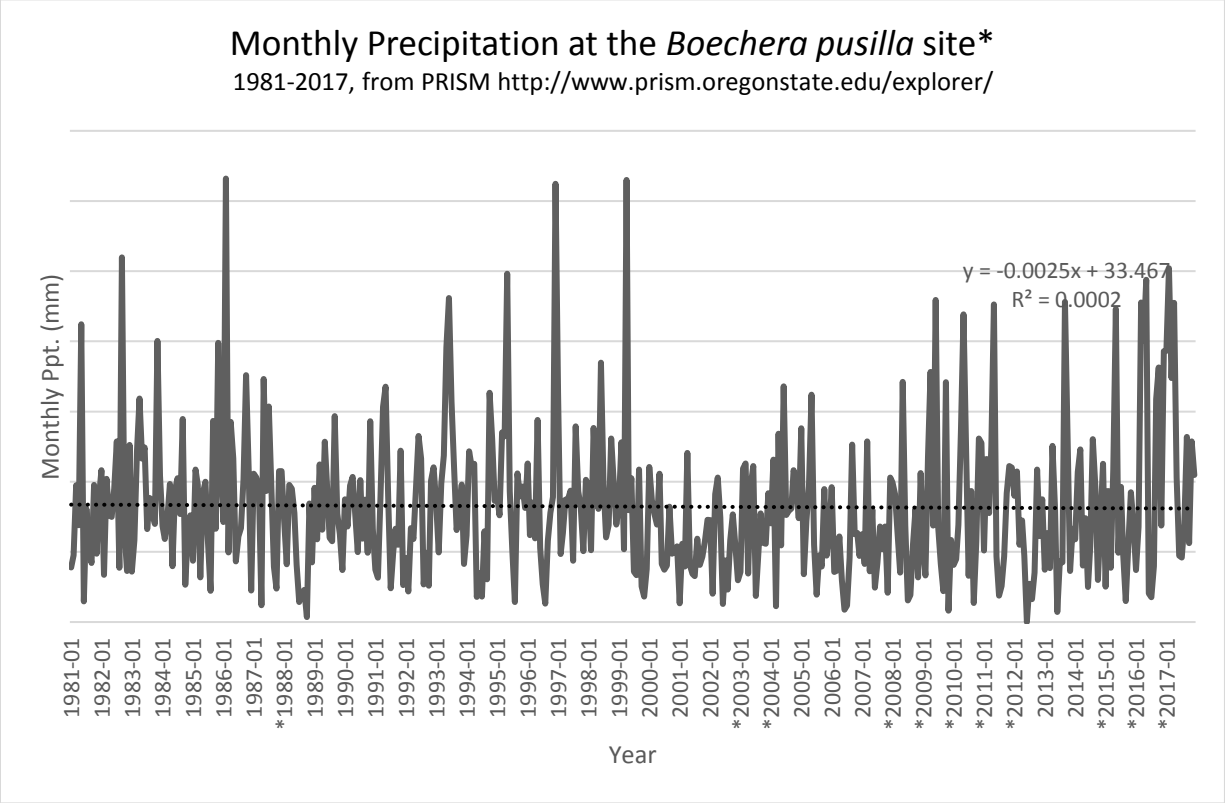
The three potential explanations (above), and their strengths and weaknesses are discussed further as hypotheses (below).

Hypothesis 1 - The 1988 monitoring report (Marriott 1988) determined that there were 671 flowering *Boechera pusilla* plants in the original plot (400 m^2) and estimated total population numbers at 800-1000. Ten years of monitoring data (over a 15-year period) are at least a magnitude larger a dataset than the one-time 1988 establishment report dataset, and the original establishment report data point is an outlier compared to recent data. It may not be possible to rigorously compare the recent dataset with a single point decades ago or determine whether or not the original point is anomalous.

Arguing against this, the 1993 pilot monitoring (Amidon 1993), though not georeferenced, appeared to overlap if not encompass the 1988 monitoring. It appears as though the 1993 plot area was almost twice as big (8000 ft^2; or about 740 m^2) as the 1988 plot area, and it documented 517 flowering *Boechera pusilla* plants. In other words, there was a relatively high number of flowering plants documented five years after the first monitoring, representing another data point with high numbers in decades past. So the 1993 data would argue against dismissing 1988 as anomalous.

Hypothesis 2 – Thirty-seven years of climate data were obtained from the Prism Climate Group (http://www.prism.oregonstate.edu/) for monthly precipitation at the *Boechera pusilla* site, consisting of a 2.5 arc-min (4 KM2) gridded data set for United States climate coverage. The graphed data show a flat trend at the *B. pusilla* site using linear regression (Figure 5). A polynomial trend line was also projected onto the same graph, and it showed a dip for the drought years (about 2000-2006), and rebounds in more recent years. Arguing against these schematic relations, *B. pusilla* population numbers have been stable since 1988 or rebounded.

Figure 5. Monthly precipitation at the *Boechera pusilla* site (1981-2017)



*Asterisks mark the years in which *Boechera pusilla* monitoring was conducted.

It is possible that only a portion of monthly precipitation data dictates over species' trends, if, for example fall precipitation is crucial for seedling germination and establishment. If this were the case, and if established plants take at least two years to flower, then trends may reflect climate conditions of two years prior. By this hypothesis, the 1988 census results could be influenced by the very high precipitation levels of 1986. It is also possible that other meteorological data such as monthly temperature might be relevant, independently or in combination with precipitation. So this hypothesis, that precipitation dictates or otherwise influences species' trends, is plausible only if there is a subset of precipitation data that is relevant, a lag in species' response, or else multi-factor considerations (e.g., adverse back-to-back precipitation extremes in "yo-yo years").

Hypothesis 3 – The third hypothesis is a catch-all or continuation of the above that we don't know some key piece of life history or interactions between the life history of *Boechera pusilla* and its environmental drivers. The growing season of the original monitoring year in 1988 did not start dry, but it was the year of Yellowstone National Park fires when there was little if any precipitation and hot temperatures in the rest of months that year. Such conditions might have been associated with low germination and high plant mortality for *B. pusilla*. This is supported by the inference that *B. pusilla* once had a prevalence of robust plants such that it was characterized as long-lived. Demographic monitoring would be needed to evaluate the merit of this specific hypothesis.

SPECIES STATUS UPDATE

The following pages provide results of recent surveys and expanded *Boechera pusilla* information. Plant species status reports and updates to them have been prepared by WYNDD as the most complete (unabridged) compilation of biological information pertaining to the conservation status of a species, as needed to evaluate its conservation needs and potentially to manage it. The structure and content of such reports are modeled after prototypes created for plants soon after passage of the Endangered Species Act, with some customized approaches for other agencies, with structural revision and elaborations as new information resources became available. There have also been format alterations in the case of this dual-purpose report that addresses culmination of species' monitoring and updates to status.

Classification

Scientific name
Boechera pusilla (Rollins) Dorn

History of the species
Boechera pusilla was first collected near South Pass in Fremont County, Wyoming by Reed and Kathryn Rollins in 1981. It was described and named by Rollins as *Arabis pusilla* (Rollins 1982); the species epithet "*pusilla*" refers to its small size. It is been recognized in the state flora under this name (Dorn 1988, 1992), later transferred to the *Boechera* genus and recognized as *B. pusilla* in the current state flora (Dorn 2001), likewise recognized by this name in the current Rocky Mountain Herbarium checklist for Wyoming (Hartman and Nelson 2018), and by this name in the *Flora of North America* (FNA; Al-Shehbaz and Windham 2010).

Synonyms
Arabis pusilla Rollins

Common name
In all reports and other information compilations (Marriott 1998, Dorn 1990, Fertig et al. 1994), Wyoming botanists have referred to *Boechera pusilla* as "Small rockcress." About ten years later, national databases including the Biota of North America (BONAP) and the PLANTS database came on-line, and posted the common name as "Fremont County rockcress".

Family
Mustard Family (Brassicaceae)

Size of genus
A total of 111 species of *Boechera* are recognized in FNA (Al-Shehbaz and Windham 2010, Kiefer and Koch 2016), of which 26 are in Wyoming (Rocky Mountain Herbarium 2018).

Phylogenetic relationships
Arabis had once been treated as a synonym of *Boechera* (e.g., Rollins 1993) and they have many morphological similarities. More recently, FNA authors determined that similarities are due to evolutionary convergence rather than shared ancestry (Al-Shehbaz and Windham 2010). The

Boechera genus is restricted to North America and Greenland, whereas the *Arabis* genus is mainly an Old World genus (Al-Shehbaz 2003). The rationale and implications for this change in Wyoming have been highlighted by Dorn (2002).

FNA authors (Al-Shehbaz and Windham 2010) state that "The taxonomic complexity of *Arabis*, in the broad sense, is legendary. When the genus is split, most of the problematic taxa come to reside in *Boechera*. A rare confluence of hybridization, apomixis and polyploidy makes this one of the most difficult genera in the North American flora." In spite of the complexity, or because of it, the genus *Boechera* is receiving attention as a model system for studying ecological, evolutionary, and related genetic characteristics of numerous species in the same genus at a continental scale (Rushworth et al. 2011). There is work underway to determine the embryology, karology, and modes of reproduction in every *Boechera* species that exists (Dobes et al. 2006), and an on-line database of chromosome counts and literature is maintained. This work is expected to shed light on taxonomic relations and insights into speciation.

Recently a definitive genetic study was published on adaptive radiation in the *Boechera* genus (Kiefer and Koch 2012). The majority of the 111 species in the genus were subject to phylogenetic reconstruction and network analysis, including *B. pusilla*. The researchers tried to identify ITS types inside and outside major lineages. The genus-wide picture provides evidence of enormous reticulate evolution in the genus, supporting prior interpretations for *B. pusilla* as apomictic triploid of alloploid origin, though leaving unresolved its placement in major lineages. The FNA authors also discuss the distinctions between the primary products of divergent evolution, the sexual diploids, and the secondary products of reticulate evolution, the apomictic species such as *B. pusilla*, most of which are inferred to be polyploids (Al-Shehbaz and Windham 2010).

Rollins (1982) and Dorn (1990) postulated that *Boechera pusilla* is closely related to *B. demissa* var. *languida* (syn. *B. languida*; nodding rockcress), *B. pendulina* var. *russeola* (treated as *B. pendulina* in FNA; Daggett rockcress), and *B. oxylobula* (Glenwood Springs rockcress), a Colorado species. On the other hand, Al-Shehbaz and Windham (2010) state that morphological evidence suggests that *B. pusilla* is an apomictic species that arose through hybridization between *B. lemmonii* and *B. pendulina*. Elsewhere they note that apomictic species in the genus appear to be of relatively recent origin and generally have not migrated beyond regions where their parents are sympatric.

Michael Windham (Duke University) has microsatellite analyses from four *Boechera pusilla* plant specimens to date, including the holotype, one of the isotypes, and a cytogenetic voucher collected in 1999. There was minimal genetic variability in this sample, and all work done so far indicates that the species is an apomictic triploid with genomes derived from *B. pendulina*, *B. lemmonii*, and (probably) *B. oxylobula* (Windham pers. commun. 2012. Sampling was expanded in 2017, related genetics datasets have been posted (Li et al. 2017) and results pending.

Present legal or other formal status

U.S. Fish & Wildlife Service

Boechera pusilla was placed on the list of Candidate species by FWS in 1985. It was petitioned for listing in 1996. Based on protections in the BLM Green River Range Management Plan,

Area of Critical Environmental Concern establishment in 1997 and mineral withdrawal in 1998, FWS removed it from the list of Candidates in 2001 (FWS 2004). It was again petitioned to list in 2007. The Service issued a 12-month finding that it potentially warrants protection under the ESA (FWS 2011) which made it a Candidate species (Category 1 species) though listing was precluded by higher priority work. Most recently, FWS determined that listing was not warranted (FWS 2018).

Agency status

Boechera pusilla was on the first and on the most current list of sensitive species designated by the Bureau of Land Management (BLM) in Wyoming (2001, 2010). Its subsequent designation as a Candidate species automatically pre-empts its BLM designation.

Natural heritage rank

Boechera pusilla is known from only one population throughout its range, so is a species of very high Wyoming contribution rank having Global and State ranks of G1/S1 (Heidel 2012). These pair of rankings do not have any legal or regulatory status in Wyoming.

Description

General description

Boechera pusilla is a perennial herb with one-to-several slender, decumbent flowering stems 5-17 cm long. The plant has a cluster of linear, erect basal leaves with relatively sparse, simple, biforked or triforked spreading hairs. Flowering stems generally have 2-5 widely-spaced stem leaves, usually without auricles. Flowers are small, white to lavender and four-petaled. The fruits are linear siliques that spread at right angles from the decumbent stems on short pedicels 3-5 mm, usually secund. The fruits are relatively short: mostly 2.2-3.3 cm long and 1.5- 2 mm wide (Rollins 1982, 1993; Dorn 2001; Fertig et al. 1994; Al-Shehbaz and Windham 2010).

Technical description

The following text is reprinted from the description of Al-Shehbaz and Windham (2010) though some characteristics may warrant closer inspection as set off by brackets []. *Many of the characteristics are evaluated further by Marriott (2017; Table 5.)*

Perennials; [long-lived; (cespitose)]; apomictic; [caudex often woody]. Stems usually 2-6 [per caudex branch], arising from margin of rosette near ground surface, 0.5-2 dm, glabrous or sparsely pubescent proximally, trichomes simple and short-stalked, 2-rayed, to 0.2 mm, glabrous distally. Basal leaves: blade linear-oblanceolate, 1-2.5 mm wide, margins entire, ciliate along petiole, trichomes (simple), 0.4-0.7 mm, surfaces usually sparsely pubescent, rarely glabrous, trichomes short-stalked, 2- or 3-rayed, 0.1-0.4 mm. Cauline leaves [3-5], not concealing stem; blade auricles 0-0.2 mm, surfaces of distalmost leaves usually glabrous or, rarely, margins sparsely ciliate. Racemes [6-13 flowered], unbranched. Fruiting pedicels horizontal to divaricate-descending, straight or slightly curved downward, [2-3 mm], glabrous. Flowers divaricate-ascending at anthesis, sepals glabrous or sparsely pubescent, trichome spreading, 2-rayed; petals white to lavender, 4-5 x 1.5-1.8 mm, glabrous; pollen spheroid. Fruits horizontal or divaricate-descending, not appressed to rachis, [secund], straight, edges parallel, 1.6-3.2 cm x 1.5-2 mm; valves glabrous; ovules 20-32 per ovary; style 0.1-0.4 mm. Seeds uniseriate, 1.2-1.5 x 0.8-0.9 mm; not winged or with distal wing 0.05-0.1 mm wide. The following page of images represents key characteristics of the species (Fig. 6-11).

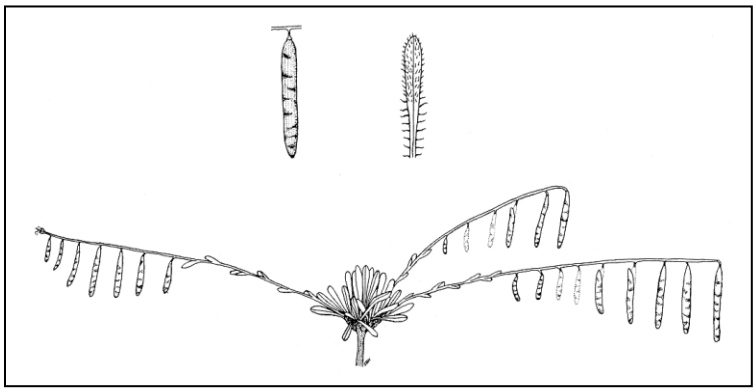
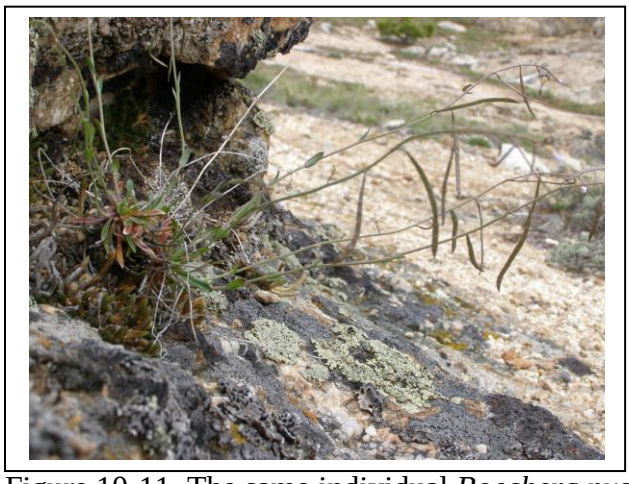


Figure 6. *Boechera pusilla*, illustration by Isobel Nichols, from Fertig et al. 1994

Figure 7. *Boechera pusilla* flower

Figure 8. One vegetative *Boechera pusilla* plant with an "old" and three "new" rosettes.

Figure 9. The flowering stalks of *Boechera pusilla* become more one-sided and prostrate as they mature.



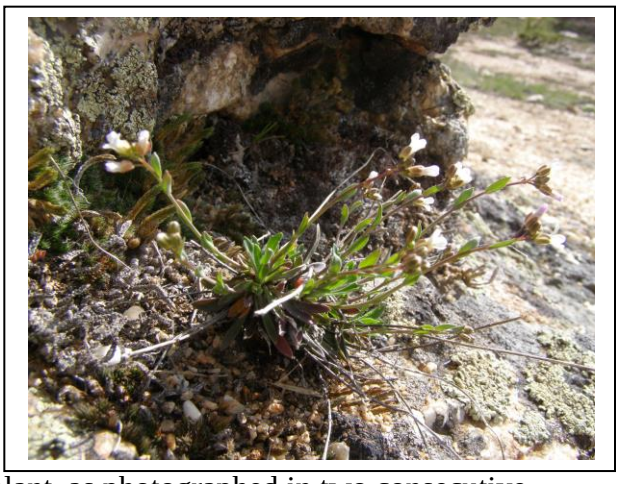


Figure 10-11. The same individual *Boechera pusilla* plant, as photographed in two consecutive years (Fig. 10, left – 31 May 2010 in fruit; and Fig. 11, right – 6 June 2011 in flower).

Similar Species

There are a striking number of different *Boechera* species in and near the South Pass area. One is common in parts of the *B. pusilla* population, *B. pendulocarpa*. It is most readily distinguished by the gray color of its leaves and stems, associated with dense hairs, compared with the bright green, sparse hairs of *B. pusilla*. Two other *Boechera* species are sympatric with, but rare in, occupied *B. pusilla* habitat: *B. microphylla* and *B. grahamii*.

Collections were made of all *Boechera* in the habitat and the vicinity incidental to surveys (Marriott 1986, Heidel 2005) to ensure that all species similarities and differences are addressed. The Rocky Mountain Herbarium (RM) on-line specimen database (2008) was also queried for species in the area. A table of characteristic was expanded from Heidel (2005) that represents *B. pusilla*, three overlapping species, four other species in the same or surrounding sections, and one species in nearby townships. The current comparison incorporates specimen reviews and verifications of all RM collections in the genus provided by Al-Shehbaz. Marriott (1986; Table A) presented the first concise table of distinguishing characteristics between *B. pusilla* and putative parent species. The comparative table has been updated with all current nomenclature, and replaced with all species in the area (Table 4).

Perhaps one of the most similar species to *Boechera pusilla* is *B. pendulina* (syn. *B. p.* var. *russeola*). As part of the 2017 study, all traits of both species were profiled from the most detailed literature (Al-Shehbaz and Windham 2010; Rollins 1993) and evaluated against individual specimens available at RM by Marriott (2017). Specimens included material collected in 2016. Of the five primary traits that distinguish the two according to the FNA treatment, none of the five are consistent for *B. pendulina* specimens in Wyoming, and do not encompass the range of values for specimens (Table 5). There is a closing remark in the FNA text that Wyoming material previously treated as *B. p.* var. *russeola* is a triploid apomict unlike *B. pendulina* as diploid elsewhere, and that further study is needed to determine whether they are in fact the same species. Marriott (2017) concluded that the FNA key is problematic in distinguishing between *B. pusilla* and *B. pendulina* in Wyoming and provided a set of *B. pendulina* photographs showing the species and its habitat (Appendix D).

Phenology

There are generalizations that *Boechera pusilla* flowers from May to mid-June. However, it was in fruit and finished flowering in June during eight of the nine monitoring years when visited early. Flowering during June was only found once in 2011, a year with a moist, late growing season when it was still in flower and early fruit on 6 June, indicating that there may be a phenology shift of three weeks or more between years depending on weather conditions. This was also the only year with extensive snow cover in adjoining woods. There was just one plant that still had flowers found in 2017 monitoring, which was also a late snowfall year.

The flowers are indeterminate, flowering from the base to the tip, with only slightly staggered phenology. Most flowering stems of the same plant are at similar phenological stages, but occasionally under moist conditions, a late flowering stem may be produced. Most plants in the same setting are at similar phenological stages, but different subpopulations may be at slightly different phases, as was observed in monitoring and in repeat visits of 2011.

Table 4. Characteristic features of *Boechera pusilla* and other *Boechera* species in the same area of the Wind River Range[4]

Species	Synonym	Proximity to *B. pusilla*	Basal leaf shape/ pubescence	Silique disposition	Silique dimensions	Pedicel length	Growth form
Boechera grahamii	*Arabis confinis; A. x divaricarpa; Boechera brachycarpa, B. drummondii, B. stricta*	Sympatric	Oblanceolate, sparsely to densely pubescent, trichomes 2-4 rayed	Divaricately ascending to descending, usually gently curved downward	3.5-9 cm long; 1-1.8 mm wide	6-12 mm	Solitary or few stems from simple caudex; biennial or perennial
Boechera pauciflora	*Arabis holboellii* var. *pinetorum and Boechera pinetorum* – misappl.	Vicinity	Oblanceolate; densely pubescent, trichomes 2-5 rayed	Horixontal, divaricate-descending or widely pendent, not second, curved	5.5-10.5 long; 1.5-2.2 wide	4-13 mm	Solitary or few stems from simple caudex; biennial or perennial
Boechera retrofacta	*Arabis holboellii* var. *secunda; Boechera holboelli* var. *secunda*	Vicinity	Oblanceolate, densely pubescent, trichomes 5-10 rayed	Straight-descending or at least sharply bent near base, sometimes ~secund, straight	3.5-9 cm long; 0.9-1.8 mm wide	7-12 mm	Solitary or few stems from simple caudex; biennial or perennial
Boechera languida	*Arabis demissa* var. *languida*	Vicinity	Linear oblanceolate to oblanceolate, densely pubescent; trichomes simple, 2-4 rayed	Pendent; straight to slightly curved	3-4.5 mm long; 1.8-2 mm wide	3-13	Few-several stems from a simple or branched caudex; perennial
Boechera lemmonii	*Arabis lemmonii*	Alpine species of nearby townships	Oblanceolate to obovate, densely to sparsely hairy, trichomes 3-9 rayed	Divaricately ascending to slightly descending, secund, straight or curved	2-4.4 cm long; 1.6-2.3 mm wide	2-6	One-many stems from woody caudex, somewhat cespitosa; perennial
Boechera microphylla	*Arabis microphylla*	Sympatric	Oblanceolate to linear-oblanceolate; densely pubescent, trichomes 4-8 rayed	Ascending to divaricately-ascending, not second	3-7 cm long; 1-1.5 mm wide	5-15mm	Usually many stems from a much-branched caudex; perennial
Boechera pendulina	*Arabis pendulina* var. *russeola*	Vicinity	Oblanceolate or obovate; pubescent, essentially all simple, trichomes 2-rayed	Widely pendent, not secund, curved to nearly straight	2-4 cm long; 1.5-2 mm wide	5-8 mm	Few-several stems from a simple or branched caudex; perennial
Boechera pendulocarpa	*Arabis holboellii var. pendulocarpa; Boechera exilis*	Among	Narrowly oblanceolate; densely hairy, trichomes 4-8 rayed	Erect to pendent, not secund, straight	2.5-3.8 long; 1.5-2.2 wide	3-8 mm	Solitary or few stems from branched caudex; perennial
Boechera pusilla	*Arabis pusilla*	-	Linear-lanceolate or linear-oblanceolate; sparsely pubescent, trichomes 2- to 3-rayed	Spreading at right angles to rachis, slightly ascending or descending, secund, straight	1-3.8 cm long; some fruits up to 2 mm wide	2-5 mm	Solitary or 2-6 stems per caudex branch, perennial

[4] Nomenclature follows Flora of North America (Al-Shehbaz and Windham 2010) and Rocky Mountain Herbarium (2018).

Table 5. Attributes of *Boechera pusilla* and *Boechera pendulina* from the literature, and from comparing specimens (Marriott 2017)

Source (literature or specimen)	caudex	stems	basal leaves	basal leaf pubescence	cauline leaves	fruiting pedicels	siliques	seeds	descriptive notes	other notes
FNA desc. 2010 ***B. pusilla***	often woody	2 - 6	linear-oblanc	ciliate along petiole, trichomes simple; surfaces usu sparsely pubescent, rarely glabrous, trichomes short stalked, 2 or 3 rayed	3-5, blade auricles 0-02. mm	horizontal to divaricate-descending, straight or slightly curved down, 2-5 mm	horizontal or divaricate-descending, secund, straight, edges parallel, 1.6-3.2 cm x 1.5-2 mm	uniseriate, not winged or with tiny distal wing		"Morphological evidence suggests pusilla is apomict that arose thru hybridization between lemmonii and pendulina"
FNA desc, 2010 ***B. pendulina***	often woody	2 - 6	oblanceolate to obovate	ciliate throughout, trichomes usu simple; surfaces pubescent, trichomes simple & short and long-stalked, 2 rayed	2-10 (13)	divaricate-ascending to horizontal, curved or angled down	widely pendant, not secund, curved to nearly straight, edges parallel, 2.2-4 cm x 1.2-2.1 mm	biseriate, usually not winged	diploid	"Typical collections are sexual diploids, whereas type of var. russeola is a triploid apomict; further study needed to determine if the two are conspecific."
Rollins desc. 1982 ***B. pusilla***	mostly unbranched	1-few, slender, slightly decumbent toward base	erect, linear to lin-oblanc, petiolate, acute to acuminate	sparsely pub with erect 2-3 branched hairs, rarely ciliate on margins with simple or forked hairs; petioles usu ciliate on margins with simple or forked hairs	3-5, usu remote, non auriculate	widely spreading, straight, 2-3 mm	widely spreading to slightly ascending; acuminate, nearly straight but with slightly undulating margins, 1-1.5 cm long, ca 2 mm wide	oblong, slighty compressed wingless or occ with slight distal margin, ca 2 mm x 1 mm	"very slender stems"; seeds in double row (not in description); of leaf hairs: "small, mostly forked or 3-branched, only a few along petiole margin are simple" pedicels "at right angles to infructescence rachis to slightly ascending	"Fremont Co., in cracks and crevices of huge metamorphic rocks" Rollins 81366 (holotype, GH; "isotypes to be distributed)
Rollins desc. 1982 ***B. pendulina***									more robust individuals than pusilla, with much longer, narrower siliques; pendulous siliques, arched pedicels	
Marriott 10322 ***B. pusilla***		2 - 10, slightly decumbent at base	generally erect; almost linear to oblanceolate; some old lvs	ciliate along petiole and margins with simple, 2-, 3-forked hairs (some tiny);	? - 4 (old stems hard to say)	curved down, a few horizontal	horizontal to widely pendant; not obviously secund; straight (two very slightly	maybe uniseriate		in RM reference collection; dupl. det. Rollins 1986; mostly dehisced fruit but not all (June 30)

			on one individ are broader	surfaces glabrous or sometimes with hairs like margin			curved?); to 1.8 mm wide;			
Johnston & Lucas 1689X ***B. pendulina***		1 - 10, slightly decumbent at base	generally erect; almost linear to oblanceolate	ciliate along petiole and margins with simple hairs; occasionally similar hairs on surface	on the order of 7 - 10	curving or arcing down, a few horizontal	widely pendant to descending; sometimes close to stem but pedicel not close; not secund; straight or slightly curved; to 2 mm wide		petiole and margin hairs noticeably coarser than in Marriott 10322	in RM reference collection; det. Rollins 1982; mature fruit (June 15; near hwy at South Pass)
Marriott 12581 ***B. pendulina***		3, slightly decumbent at base	generally erect; almost linear to oblanceolate	ciliate along petiole and margins with simple hairs; occasionally similar hairs on surface	3 - 4	curving or arcing down	widely pendant to descending; sometimes close to stem but pedicel not close; not secund; straight or slightly curved; to 1.8 mm wide		petiole and margin hairs noticeably coarser than in Marriott 10322	
Marriott 12583 ***B. pendulina***		4, decumbent at base	generally erect; almost linear to oblanceolate	ciliate along petiole and margins with simple hairs; occasionally similar hairs on surface	1 - 2 (or more? one broken stem)	curving or arcing down, a few horizontal	widely pendant to descending; sometimes close to stem but pedicel not close; not secund; straight or slightly curved; to 1.8 mm wide	possibly biseriate	petiole and margin hairs noticeably coarser than in Marriott 10322	
Marriott 12584 ***B. pendulina***		1 - 2, slightly decumbent at base	generally erect; almost linear to oblanceolate	ciliate along petiole and margins with simple hairs; occasionally similar hairs on surface	7 - 9	curving or arcing down, a few horizontal	widely pendant to descending; sometimes close to stem but pedicel not close; mostly secund; straight or slightly curved; to 1.9 mm wide		petiole and margin hairs noticeably coarser than in Marriott 10322	

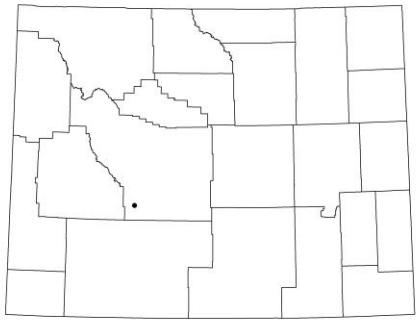
Marriott 12586 *B. pendulina*		1 - 2, slightly decumbent at base	generally erect; almost linear to oblanceolate	ciliate along petiole and margins with simple hairs; occasionally similar hairs on surface	1 - 3	curving or arcing down	horizontal to widely pendant; somewhat secund?; to 1.8 mm wide		petiole and margin hairs noticeably coarser than in Marriott 10322	
Marriott 12587 *B. pendulina*		2 or 3, slightly decumbent at base	generally erect; almost linear to oblanceolate	ciliate along petiole and margins with simple hairs; occasionally similar hairs on surface	3	curving or arcing down	widely pendant to descending; sometimes close to stem but pedicel not close; mostly secund; straight or slightly curved; to 1.8 mm wide		petiole and margin hairs noticeably coarser than in Marriott 10322	
Marriott 12578 (2016) *B. pendulina*		1, slightly decumbent at base	generally erect; almost linear to oblanceolate	ciliate along petiole and margins with simple hairs; occasionally similar hairs on surface	2	curving or arcing down	widely pendant to descending; not secund; straight or slightly curved; to 1.9 mm wide		petiole and margin hairs noticeably coarser than in Marriott 10322	
SUMMARY Range of values (*B. pendulina* specimens)		1-many; decumbent at base; 6.9 - 18 cm long	generally erect; almost linear to oblanceolate	ciliate along petiole and margins with simple hairs; typically glabrous on surface, occasionally similar hairs on surface	3-7	5-8 mm; there is usually consistency of curvature and angles within any given inflorescence	silique length x width: 2.4 - 4 x 1.3 - 2 cm, not secund			
SUMMARY range of values (*B. pusilla* specimens - including late June set)		1-many; decumbent at base; 6.2 - 17 cm long; almost never "woody" or long-lived	generally erect; almost linear to oblanceolate	ciliate along petiole sometimes extending around entire leaf margins, trichomes simple; surfaces usually sparsely pubescent, rarely glabrous, trichomes short stalked, 2 or 3 rayed	2-5	3-5 mm; variable on any given inflorescence; upper tend to ascend, lower tend to descend	silique length x width: 2.2 - 3.3 cm x 1.5 - 2.1 mm, not secund in the strict sense			

Geographic Range

Distribution

Boechera pusilla is a narrow endemic known from one location in Fremont County, Wyoming. It is located at the southern end of the Wind River Range in southwestern Fremont County (Figure 18). It is managed by the Bureau of Land Management Rock Springs Field Office, within the High Desert District. It lies midway between the towns of Lander and Farson along State Highway 28.

Figure 12. *Boechera pusilla* distribution in Wyoming



Boechera pusilla is mapped as spanning about 18.4 acres (7.45 ha), and comprised of 11 separate areas (referred to in this report as subpopulations) shown as discrete polygons (Figures 13 and 14). However, the largest area might be more accurately represented as a series of points rather than continuous occupied habitat. There is also a set of six polygons that might also be mapped as a single large area. The subpopulations as currently mapped are labelled 1-11 consistent with the tabulation monitoring results (Table 3). The population record is compiled in Appendix E.

Extant sites

Boechera pusilla is extant at the type locality, i.e., the one known location.

Historical sites

None

Unverified/undocumented reports

The previous monitoring report, an interim one (Heidel 2017), reported *Boechera pusilla* at a second location east of Highway 28. This has proven to be a location of *B. pendulina*, based on herbarium research and critical review of distinguishing characteristics (Table 5).

Sites where present status is not known

None

Extent of surveys in Wyoming

The 2016-2017 surveys focused on previously unsurveyed habitat in the same township as the *Boechera pusilla* population (T29N R101W) and townships to the immediate east and south (Appendix F; Figure 15).

Figure 13. *Boechera pusilla* population (USGS topographic basemap; 1 section = 1 mile)

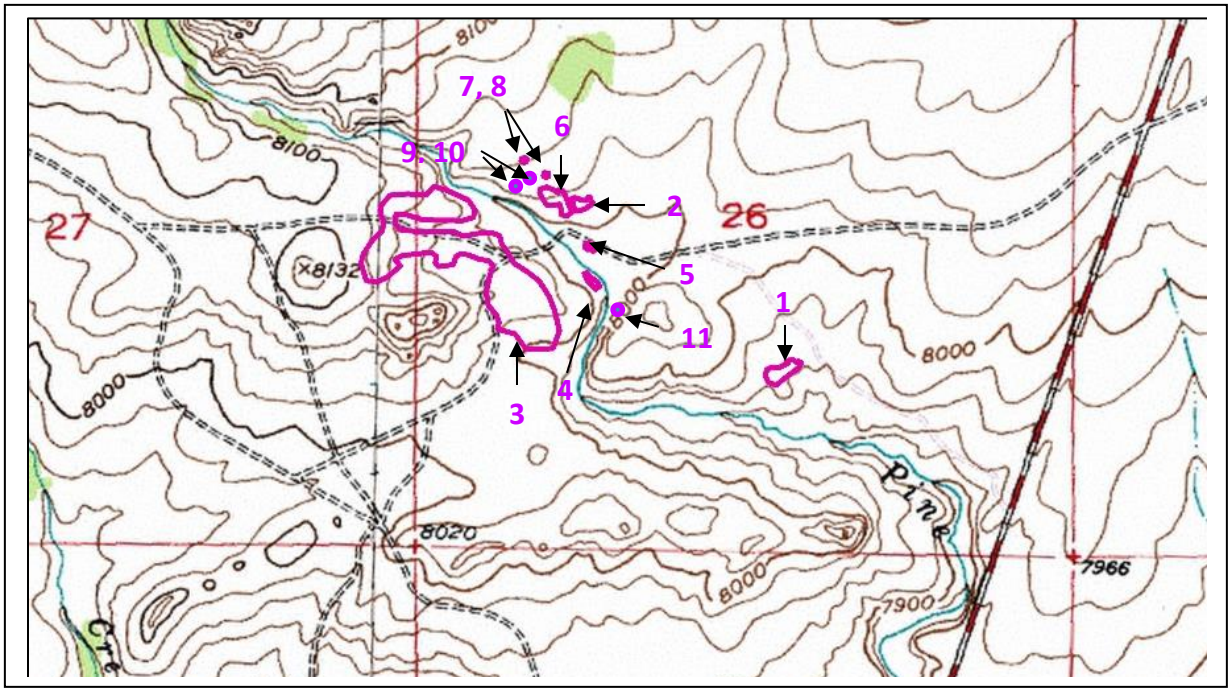
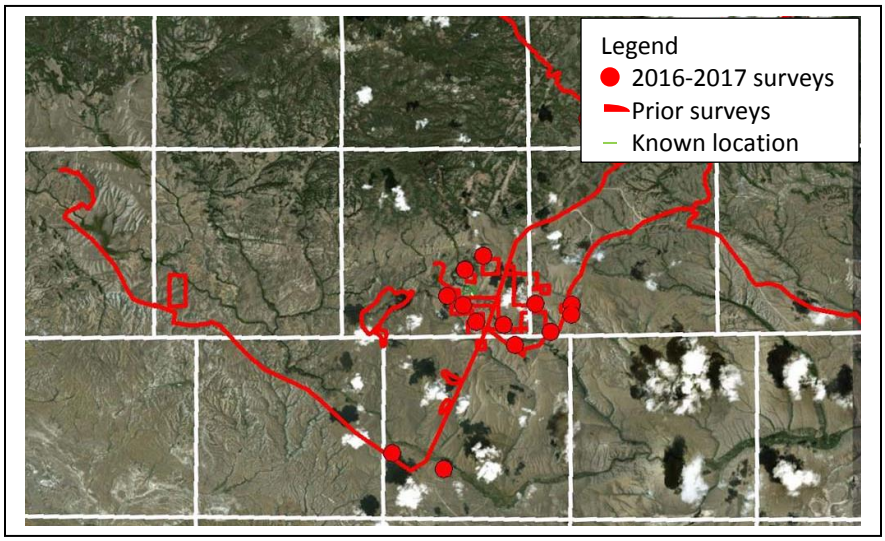


Figure 14. *Boechera pusilla* population (NAIP aerial imagery basemap)

Figure 15. Negative surveys for *Boechera pusilla* (each cell is 1 township = 6 miles)



Potential distribution in Wyoming

Potential distribution models were developed for *Boechera pusilla* by Fertig and Thurston (2003) and tested in 2003-2004 (Heidel 2005). A potential distribution model was developed by Andersen (Andersen et al. 2016) but noted that the low number of presence points constrained modeling. In 2017 surveys, aerial imagery was used to target bare areas with no prior record of surveys, prioritizing those close to Pine Creek (upstream and downstream) of the known population (Figure 15). The most detailed information is in a brief report, accompanying species determination notes, collection labels and survey forms for *B. pendulina* (Marriott 2017). All results were negative, though many new locations of the latter were documented.

Habitat

Boechera pusilla occurs on relatively barren gravelly soil pockets of exposed granite bedrock (Dorn 1990), including fractures, outcrop margins, gravel pavement, and to a lesser extent, very shallow gravelly soil overlying bedrock where sometimes subject to freeze-thaw activity. The low relief outcrops irregular surfaces. Elevation of the population as mapped ranges from 2425-2460 m (7960-8080 ft).

The first habitat description for *Boechera pusilla*, recorded on the collection label and in the Rollins publication (1982), described the setting as "cracks and crevices of huge metamorphosed rocks." However, the bedrock is igneous rather than metamorphic, essentially granitic material with phenocrysts (giant crystals) slowly cooled deep below the surface. The occupied habitat does not have major crevices because the outcrops have very little relief (Figures 16-22) but it does have fractures. The "huge" rocks in Rollins' habitat description may refer to nearby pluton landmarks (prominent knolls formed by solidification of molten magma deep within the earth) rather than the occupied habitat itself. The habitat description for *B. pusilla* was slightly modified in Al-Shehbaz and Windham (2010) as "cracks and crevices of granite outcrop."
The list of species directly associated with *Boechera pusilla* has been expanded from prior reports to over 60 species (Table 6), present on the same outcrop if not the same microhabitat. The moist 2011 and 2017 conditions and repeated visits have afforded opportunity to expand the

roster. This list includes many perennial montane species, a few intermontane annuals, and a couple of plains species at their upper range limits. This list is taken from field notes and collections at the monitored subpopulation. Some of the more common species in occupied habitat are widespread ones that include *Achnatherum hymenoides* (Indian ricegrass), *Erigeron compositus* (cut-leaved fleabane), and *Sedum lanceolatum* (lance-leaf stonecrop). The habitat is almost free of non-native species. *Taraxacum erythrospermum* (syn. *T. laevigatum*; red-seed dandelion) is present in the monitored subpopulation at low levels. In 2017, *Alyssum desertorum* (desert madwort) was locally common at one end of the other second *B. pusilla* subpopulation. Though it has probably been present all along in this locale, it was in conspicuously high numbers in 2017.

Table 6. Plant species associated with *Boechera pusilla*

Scientific Name	**Common Name**	**Growth Form**
Achnatherum hymenoides	Indian ricegrass	Perennial grass
Achnatherum pinetorum	Pine needlegrass	Perennial grass
Alyssum desertorum	Desert madwort	Annual herb
Androsace septentrionalis	Pygmy rock-jasmine	Annual herb
Antennaria dimorpha	Cushion pussytoes	Perennial herb
Antennaria parvifolia	Littleleaf pussytoes	Perennial herb
Artemisia arbuscula	Dwarf sagebrush	Shrub
Artemisia tridentata ssp. wyomingensis	Wyoming big sagebrush	Shrub
Artemisia tripartita var. rupicola	Three-tip sagebrush	Shrub
Balsamorrhiza incana	Hoary balsamroot	Perennial herb
Boechera grahamii	Graham rockcress	Perennial herb
Boechera microphylla	Small-leaf rockcress	Perennial herb
Boechera pendulocarpa	Drooping-fruit rockcress	Perennial herb
Bouteloua gracilis	Blue grama	Perennial graminoid
Camissonia scapoidea	Paiute suncup	Annual herb
Carex douglasii	Douglas' sedge	Perennial graminoid
Carex rossii	Ross' sedge	Perennial graminoid
Chaenactis douglasii	Douglas' dusty-maiden	Perennial herb
Collinsia parviflora	Blue-eyed Mary	Annual herb
Crepis modocensis	Siskiyou hawksbeard	Perennial herb
Cryptantha flavoculata	Miner's candle	Perennial herb
Cryptantha watsonii	Watson's cryptantha	Annual herb
Danthonia unispicata	Few-flower wild oatgrass	Perennial graminoid
Draba nemorosa	Woodland whitlow-grass	Perennial herb
Draba oligosperma	Few-seed whitlow-grass	Perennial herb
Elymus albicans	Montana wheatgrass	Perennial grass
Elymus elymoides	Bottlebrush squirreltail	Perennial graminoid
Elymus albicans	Bluebunch wheatgrass	Perennial grass
Eremogone congesta var. congesta	Ballhead sandwort	Perennial herb
Erigeron caespitosus	Tufted fleabane	Perennial herb
Erigeron compositus	Cut-leaved fleabane	Perennial herb

Eriogonum caespitoum	Matted wild-buckwheat	Perennial herb
Eriogonum ovalifolium var. purpureum	Cushion wild-buckwheat	Perennial herb
Eriogonum umbellatum	Sulfur-flower wild-buckwheat	Perennial herb
Eremogone hookeri	Hooker's sandwort	Perennial herb
Festuca idahonis	Idaho fescue	Perennial grass
Gymnosteris parvula	Small-flowered starlet	Annual herb
Hesperostipa comata	Needle-and-thread	Perennial grass
Ivesia gordonii	Ivesia	Perennial herb
Juniperus communis	Common juniper	Shrub
Lewisia pygmaea	Alpine lewisia	Perennial herb
Lithophragma tenellum	Prairie woodlandstar	Annual herb
Lupinus argenteus var. argenteus	Silvery lupine	Perennial herb
Navarretia breweri	Yellow pincushion-plant	Annual herb
Paronychia depressa	Spreading nailwort	Perennial herb
Penstemon humilis	Low beardtongue	Perennial herb
Phlox hoodii	Hood's phlox	Perennial herb
Phlox multiflora	Rocky mountain phlox	Perennial herb
Pinus flexilis	Limber pine	Tree
Poa fendleriana	Muttongrass	Perennial grass
Poa secunda	Curly bluegrass	Perennial grass
Potentilla pensylvanica	Pennsylvania cinquefoil	Perennial herb
Purshia tridentata	Bitterbrush	Shrub
Rhus trilobata	Fragrant sumac	Shrub
Ribes cereum	Wax currant	Shrub
Sedum lanceolatum	Lance-leaf stonecrop	Perennial herb
Selaginella densa	Dense spike-moss	Fern ally – perennial
Senecio integerrimus	Western groundsel	Perennial herb
Stenotus acaulis	Stemless mock goldenweed	Perennial herb
Taraxacum erythrospermum	Red-seed dandelion	Perennial herb
Trifolium gymnocarpon	Holly-leaf clover	Perennial herb

Vegetation cover is very patchy in occupied habitat of *Boechera pusilla* and the species is generally absent from areas of high cover (Figures 16-20). The question was raised whether associated plants might have greater competitive ability that could successionally encroach upon *B. pusilla* habitat, but the abrupt vegetation boundaries suggest this is not the case. The recent monitoring years provide no evidence of encroachment but do provide succession information anecdotes. One of the associated species that seems most problematic in the local successional picture is *Selaginella densa* (dense spike-moss). It is a colonizer in the same microhabitats as those occupied by *B. pusilla*. It appeared that *S. densa* plants had extensive dieback in or around 2008-2011. *Boechera pusilla* plants were sometimes seen growing in live *S. densa* mats, but at least as often noted in dead ones in 2010-2011 (Figure 18-19).

Figure 16. Three main microhabitats occupied by *Boechera pusilla*

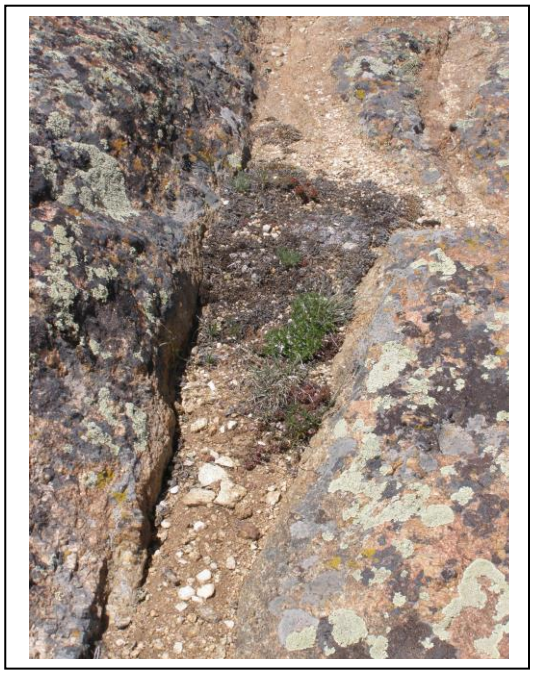


Figure 17. "Crevice habitat" where present in partially-filled outcrop fractures

Figures 18 and 19. Pavement habitat where present in the middle of a dead *Selaginella densa* mat (above) and dying mat (below)

Figure 20. *Boechera pusilla* also occupies shallow soils overlying bedrock, settings that border the outcrops and which are subject to frost heaving. The frost heaves may be present or absent from one year to the next.

Figure 21 (below). The landscape has sharp breaks in vegetated and unvegetated zones despite low relief , not only in occupied habitat, but also surroundings.

Figure 22 (above). Pools of water persisted on outcrops, and inundated some *B. pusilla* on gravel pavement for a day after a heavy rain event in 2017.

The processes that keep the rock outcrops unvegetated are not known, but the hard crystalline rock has virtually no water-holding capacity. This was evident in 2017 when ephemeral pools persisted on the gravel pavement of occupied *Boechera pusilla* habitat the day after heavy

evening downpours. Dorn (1990) suggested that it may be adapted to wide fluctuations in available moisture, as the limited soil layer goes through rapid drying and saturation flux. The restricted distribution of *B. pusilla* corresponds with the distribution of one of the larger expanses of pegmatite in the area (Heidel 2005). The outcrops are covered by an array of crustose lichens, but the lichens do not provide a colonization surface. Frost-heaving has been noted in gravelly shallow soils in and near occupied habitat, a process that may help maintain the abrupt break between vegetated and semi-barren conditions (Figure 15).

Further evaluation of climate conditions was pursued incidental to monitoring. Two climate datasets are available near *Boechera pusilla* habitat, the NOAA meteorological data from South Pass City (488385), and the SNOTEL monitoring data above South Pass (No. 775), as presented in prior reports. However, they are in different elevation zones or topographic positions. For purposes of characterizing climate, PRISM data (Figure 5) may be more appropriate.

Microclimate conditions of *Boechera pusilla* occupied habitat have not been documented but it is hypothesized that the pegmatite outcrops retard the temperature changes of the seasons, slow to heat early in the growing season, but radiating stored heat late in the growing season. It is hypothesized that *Selaginella densa* wicks the moisture that falls in light rainfall events, at least when it is alive, and helps slow moisture loss from evaporation whether it is dead or alive. There are also an expanded set of habitat photos from the monitoring plot (Appendix B).

The following physical habitat information draw almost exclusively from a combination of Marriott (1986) and Dorn (1990) in keeping with original headings.

Climate

Koppen climate classification – Cold steppe with winter drought

Regional macroclimate – The plants grow in an area with about 12 inches of mean annual precipitation based on nearest measurements at South Pass City (Marriott 1986). The mean maximum and minimum temperature in January are from 25 to 3 °F (-4 to -16 °C), and mean maximum and minimum temperature in July are from 76 to 42 °F (24 to 6 °C; in Dorn 1990). The number of growing degree days is at least in the range of 41-60 days or longer (after Curtis and Grimes 2004).

Physiographic and topographic characteristics (Dorn 1990)

The plants grow on exposed shallow soil pockets on granite outcrops with slopes generally from 0-10 degrees and all exposures. The bedrock is an early Precambrian intrusive igneous rock called the Louis Lake batholith and consists largely of gray homogeneous biotite-hornblende quartz diorite and granodiorite (Bayley 1973).

Edaphic factors (Dorn 1990)

Soils are poorly developed and derived from the parent material and the immediate surroundings. They tend to be very gravelly with a sandy to loamy base and very shallow with subirrigation occurring from extensive runoff from the exposed bedrock.

Dependence on dynamic aspects (Dorn 1990)
The plants are dependent on the barren substrate with little competition from other vegetation. They also may be adapted to wide fluctuations in moisture availability as the shallow soil dries out rapidly and then is saturated by subirrigation after each precipitation event.

Pollination
Boechera pusilla has been characterized as an apomictic species by Al-Shehbaz and Windham (2010). Some apomictic *Boechera* species have a mixed-mating system, i.e., both self-crossing and out-crossing, but limited information on *B. pusilla* pollination is available. The observation that fruit development starts before flowers senesce seems consistent with apomixis (Figure 23).

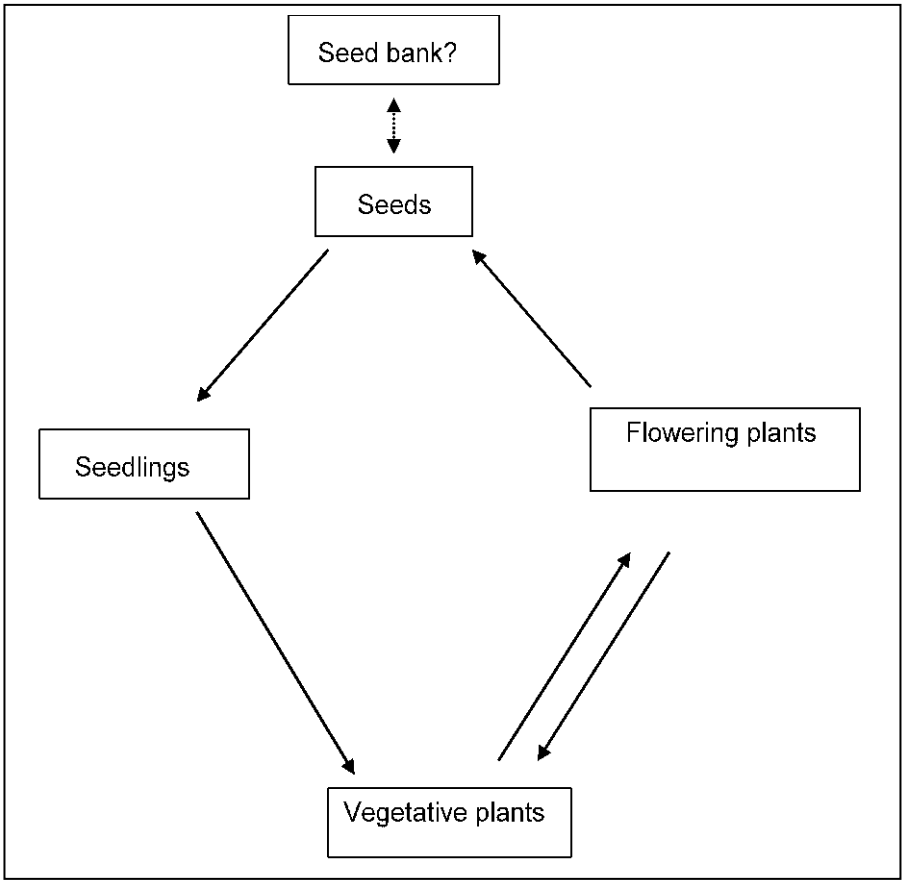
Figure 23. In most years of *Boechera pusilla* monitoring, terminal flowers on the inflorescence abort. Late flowers developed when conditions were moist and cool.

Population biology and demography

Life history
Boechera pusilla was called a "long-lived" perennial by FNA authors (Al-Shehbaz and Windham 2010) but this has not been documented and is not evident from review of herbarium specimens. There are individual plants in certain monitoring plot locations that have probably persisted for at least five years (see Figures 10-11), and similar specimens signify relatively large individuals. But it seems as though the majority of plants in any given monitoring year have had a single or at most two rosettes, consistent with a young age. A schematic life history diagram is presented in Figure 24. There is no data on mean or maximum life expectancy, average length of time to flowering, or seed ecology. The fact that vegetative plants comprised relatively high proportions of plants in both low-count and high-count years might indicate that plants can "revert" to vegetative conditions in years when conditions are not favorable for flowering stem production, and that establishment of new vegetative plants coincides with years of high counts.

Signs of dead and dying plants have rarely been noted in monitoring, suggesting that mortality is concentrated in other times of year.

Figure 24. *Boechera pusilla* life history[5]



Seeds are likely to germinate in fall. Seedlings have never been observed in the course of monitoring despite close inspection, but it is possible that the very small vegetative plants noted early in the growing season may have germinated in the previous fall. It has been grown in the greenhouse at the University of Wyoming, and the seeds were germinated without a cold treatment (Bill Higgins pers. commun. 2012), i.e., no dormancy requirement, consistent with fall germination. The seed does not have wings, and there are no known dispersal mechanisms, though wind and water have been suggested as possible vectors (Dorn 1990). The seed is 1.2-1.5 mm long (Al-Shehbaz and Windham 2010). It is not clear if *Boechera pusilla* forms a seed bank, i.e., dormant seeds that remain in underground storage until conditions are favorable. The paucity of soil development could limit formation of a seed bank if feasible.

[5] This diagram highlights presence/absence of the reproductive stage without having any data on the age-related life cycle.

Figure 25. One flowering *Boechera pusilla* plant (left arrow) and one very small vegetative plant (right arrow). The latter may have germinated in the previous fall (photographed 4 June 2017).

Demographic studies in the field or in the greenhouse have not been conducted to determine mean or maximum life expectancy of established plants. It is inferred that first-year plants produce a single cluster of basal leaves (rosette) and that plants can probably produce flowers by their second year. The slender flower stalks do not ordinarily persist between years, but vestiges have been observed on both flowering and vegetative plants of the current year. There is not a fixed ratio of vegetative to flowering plants.

Plants have been characterized as typically 2-6 stems with an average of 3.0 flowering stems per plant, and 10.4 fruits per plant (Marriott 1988). This is apt to be a high value for dry years if not for average years. Some flowering plants in the monitoring plot failed to produce any fruits whatsoever in 2003 (12 of 87 plants had flowering stalks with 100% aborted fruits). This could have been influenced by freezing conditions or drought. The flowering plant in Figure 25 has two flowering stems, one with six fertile fruits, but the other has only two maturing fruits and at least three pedicels of aborted fruits. It appears as though fruit abortion further reduces fecundity under stress. Observations suggest that fruit maturation, and not just flowering stalk numbers, vary greatly between years.

Likewise, plants seem to produce greater numbers of flowering stalks in wet years and fewer in dry years. Flowering plants in 2003 had a maximum of six flowering stems per plant and up to 28 fruits per plant. In 1988 there were up to 11 flowering stems per plant and up to 37 fruits per plant (Marriott 1988 raw data). In 2011 there was an average of 4.3 stems per plant in 2011. A few notably robust, many-stemmed plants were photographed in 2017 (Figure 26).

Figure 26. The largest of *Boechera pusilla* plants found in 2017 (below) had at least ten flowering stems and about 40 fruits

Population size and trends

The original 1988 monitoring documented 681 flowering plants in a small portion of one area, and a pilot 1993 monitoring in the same area came up with 517 flowering plant numbers, i.e., also a much higher number than has ever been recorded in the same area in later years (2003-2017). The peak tally is 91 flowering plants from virtually the same area as 1988 monitoring, from among ten years of data collecting. This is the basis for concluding that there has been major decline. Three alternate hypotheses were framed to explain the decline but do not provide robust answers to date. Results in the monitoring section of this report provide a silver lining to this conclusion. The population size has exceeded 1000 plants in each of the three years of extensive population monitoring (2011, 2016-2017; Table 3) by including vegetative plants with the tally of flowering plants, and by including a second large subpopulation with the one that was originally monitored.

Discussion

There is a Species Status Assessment (SSA) initiated in 2016 by FWS that will address the factors affecting species' viability (Reeves 2017). This section is a highlight from past WYNDD reports rather than a rendering of USFWS discussions and drafts that are works in progress.

Grazing

The original monitoring area lies within an exclosure representing a special management area designated for recreation use in 1978, and managed for such use (Dunder 1984). The rest of the population is part of grazing allotment, where the species occupies habitat that has limited use. Water sources are widely available in the pastures where the species is present and while some subpopulations are close to Pine Creek, they have little or no use by livestock. Salt block placement has not been noted near the population. Signs of stray cows entering the exclosure have been noted on rare occasions, without evidence of affecting the species.

The jack-legged fence was repaired recently where it intersects the closed-off road, and the original sign saying "Foot Travel Welcome" that had fallen has been replaced by a No Motorized Use sign. Some trees are dying in the area, and dead trees could fall onto the fence, or fire could burn the surroundings, putting the integrity of the wooden exclosure fence at risk.

Roads

The exclosure that curtails grazing also prevents traffic into this area and the rest of the population north of Pine Creek. There is little or no motorized traffic into that portion of the population located south of Pine Creek.

Recreational use

The Pine Creek area is a popular fishing area and readily accessible for primitive camping off of State Hwy 28. There was formerly a pit toilet by the creek, near the highway (Dunder 1984) that has since been removed. The only current access to the *B. pusilla* population is on foot.

Non-native species

Alyssum desertorum (desert madwort) was noted as abundant in one corner of a large subpopulation in 2017. There are no known noxious weeds or cheatgrass (*Bromus tectorum*) in the population, on the road into the area, or at area camping spots. Reduction of motorized vehicle use is consistent with reducing chances of spreading weeds.

Mining

Diamonds are sometimes associated with pegmatite. Gold and silver deposits have been mined in the Atlantic City and South Pass areas, and there was also localized placer mining in those areas. The exclosure has been withdrawn from surface mining, as addressed in a 1998 withdrawal.

Weather/climate

The 2003 and 2004 growing seasons had below-average monthly precipitation (Figure 5), among a series of dry years, and marked the start of recent *Boechera pusilla* monitoring. This was initially hypothesized as a factor in species' decline compared to the start of monitoring in 1988 (Heidel 2005). But there has not been a rebound in *B. pusilla* numbers despite rebounds in monthly precipitation since then.

Genetic isolation

There has never been any report of hybrids within the *Boechera pusilla* population despite its overlap with other species of *Boechera* and the proximity of additional species. The detailed

surveys for *B. pusilla* and comparisons conducted this year reinforce the distinction between it and the superficially similar *B. pendulina* and its habitat.

Gene conservation

In 2011, which was the first of recent years having high fruit production, seeds of *Boechera pusilla* were collected by WYNDD, submitted to Denver Botanic Garden, and conveyed for long-term storage at the National Center for Genetics Resource Preservation (NCGRP) of the USDA in Fort Collins. Viability results have not been obtained to date. Placement of a large seed collection in cold storage represents a safety net of sorts.

Other considerations

There is a Resource Management Plan update pending in the BLM Rock Springs Field Office. It would be appropriate to bring all past BLM decisions regarding *Boechera pusilla* into the pending document.

There is a Pine Creek Special Management exclosure, as designated in 1978. Marriott (1988) reported on its designation:

> "The exclosure includes about 88 acres popular with campers, anglers, hungers and travelers, and was established to prevent livestock conflict with recreational use. A fence was completed in 1982. The area is being managed for short-term camping and only minor improvements are planned. There was a management plan prepared for the exclosure (Dunder 1984) that would be appropriate to cite, with any other management considerations and policies that apply."

Later, in 1994, Barbara Amidon (Rock Springs BLM) initiated a Habitat Management Plan for this species, and helped secure Area of Critical Environmental Concern (ACEC) designation in 1997 for its occupied habitat, along with mineral withdrawal.

Recommendations

There are almost no records of BLM staff visiting the species and the exclosure since 1993. It is possible that it is regularly visited because "The exclosure fence is high priority for annual maintenance each spring following snowmelt to assure its integrity" (Dunder 1984). It might be helpful for two or more BLM natural resources staff to become familiar with locations of the two largest subpopulations on the ground, and for them to oversee these annual inspections, whether in person, by technicians or by interns, not only checking for exclosure integrity but also checking for any recreation use issues and weeds at recreation spots and population access points. WYNDD welcomes any form of species' observation information, any time.

The *Boechera pusilla* SSA was initiated by FWS in 2016 to address species' needs, conditions and viability. Distribution of this report is recommended to all parties involved, and discussion of report results would ideally flag any prospective changes to the three SSA components (needs, condition and viability) that are coming out of this study.

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