



Status of *Penstemon haydenii*
(Blowout Penstemon) in Wyoming
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Abstract

Penstemon haydenii (Blowout Penstemon) is federally designated as an Endangered plant species. It was first recognized as part of the Wyoming flora in 1999. Systematic surveys were started in 2000 and completed in the Ferris and Killpecker dune fields in 2011, filling gaps among all prior surveys. A monitoring study was conducted in 2004-2006 with supplementary monitoring in more recent years. Publications on pollination biology and an initial report on seed ecology on *P. haydenii* in Wyoming have since been completed. Conservation measures are underway. This report represents a compilation, expanded treatment, and updated assessment of *P. haydenii* status that incorporates all previous work in Wyoming.

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Cover photo: *Penstemon haydenii* and its habitat in Wyoming. By B. Heidel.

Acknowledgements

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The monitoring of *Penstemon haydenii* at Bradley Peak in 2011 was conducted with the help of Frank Blomquist, Bureau of Land Management (BLM), Emma Stewart, Susan Chamberlain, Hans Hallman, and Mark Bellis (U.S. Fish & Wildlife Service); and by a cadre of other biologists in prior years.

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This study represents a continuation, expansion and revision of Wyoming work on *Penstemon haydenii* started by Walter Fertig (WYNDD), including his surveys, historical recount, reports, and models. Valuable Nebraska perspective was garnered in accompanying Dr. James Stubbendieck and Dr. Kay Kottas in Nebraska fieldtrips to their *P. haydenii* study sites in 2007, and in surveying it in the Sandhills when working for the Midwest Regional Office of the Nature Conservancy in 1981. However, this report does not represent Nebraska status of *P. haydenii*.

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OVERVIEW

Penstemon haydenii Wats. (Blowout Penstemon) was proposed for listing as Endangered under the Endangered Species Act when it was considered to be endemic to the Nebraska Sandhills (U.S. Fish and Wildlife Service 1986). It was designated the following year, (U.S. Fish and Wildlife Service 1987). In 1996 it was discovered at Bradley Peak in Carbon County, Wyoming by Frank Blomquist, and later vouchered by Blomquist and botanist colleagues there in 1999 (Fertig 2000). The designation status of every plant species listed under the Endangered Species Act applies throughout the species' ranges, so *P. haydenii* was automatically recognized as Endangered in Wyoming.

This report represents the culmination of surveys, compilation of monitoring, and synthesis of other available information to date on *Penstemon haydenii* in Wyoming. Knowledge of *P. haydenii* distribution and population size in the state has grown incrementally since its 1999 discovery, with concerted surveys in 2000 and 2003-2004, monitoring in 2003-2005, limited survey and monitoring in more recent years, and research in other facets of species' biology. Finally in 2011, surveys were conducted to fill any survey gaps in the Ferris Dune Field surveys and to conduct extensive Killpecker Dune Field surveys. The first part of this report covers the culmination of *P. haydenii* surveys that took place in 2011 in the two largest dune fields of Wyoming. The second part represents a synthesis of all previous status and monitoring reports in the state, incorporating information from more recent surveys, research and protection measures.

Penstemon haydenii is Wyoming's only Endangered plant species.¹ It is also the only Endangered or Threatened plant species in the state that has a recovery plan (Fritz et al. 1992). However, this plan addressed the species' habitat conditions and management considerations in Nebraska, which differ significantly from those in Wyoming. Thus, the secondary objective of this report is to consolidate information on its habitat conditions, management considerations and all other available biological information in Wyoming. This information on *P. haydenii* status in Wyoming has also been sought for reference by other *P. haydenii* researchers, and by the U.S. Fish and Wildlife Service in undertaking a 5-year review (initiated in 2008, currently in progress). The second part of the report has the most complete status information on *P. haydenii* in Wyoming. It replaces prior *P. haydenii* survey and monitoring reports and other information and communications provided by Wyoming Natural Diversity Database (WYNDD; Fertig 2000, 2001; Heidel 2005a, 2007, plus all annual updates and personal communications).

¹ Ute ladies tresses (*Spiranthes diluvialis*), Colorado butterfly plant (*Gaura neomexicana* ssp. *coloradensis*) and Desert yellowhead (*Yermo xanthocephalus*) are in Wyoming and listed as Threatened.

PART 1 – 2011 SURVEYS OF *PENSTEMON HAYDENII*

INTRODUCTION

Surveys of *Penstemon haydenii* in Wyoming have used multiple working hypotheses as to what constitutes potential habitat. The 2011 surveys represent the culmination. The framework for past surveys, methods, and survey extent are presented in this introduction as context for 2011 survey methods and results.

The *Penstemon haydenii* setting at Bradley Peak in the Ferris Dune Field, and at all Nebraska sites (Nebraska Sandhills), have eolian (wind-borne) sand deposits reworked into choppy dunes containing blowout features. Unlike the Nebraska Sandhills, the Bradley Peak site of *P. haydenii* site is at much higher elevation. Therefore, ensuing surveys were conducted by Walter Fertig in 2000 at similar high-elevation wind-blown sand deposits of south-central Wyoming as determined using GIS layers of suitable geology (Quaternary sand dunes in Love and Christiansen 1984) and of similar elevation (2195-2255 m). The survey met with success when Fertig and Blomquist discovered a new Ferris Dune population of *P. haydenii* on July 7 on the south slopes of Bear Mountain at the eastern end of the Ferris Dunes. On a return trip on 26 July, Blomquist and Fertig located an additional occupied blowout on the nearby north slope of adjacent Junk Hill and a large population on the sandy apron connecting the north side of Junk Hill and the south flank of Bear Mountain (Fertig 2001; Appendix A). Surveys were expanded into in the semi-contiguous Seminoe Dune Field (south of Table Mountain/Cheyenne Ridge continuing south of the Seminoe Mountains/ID Ridge) and in two separate areas: the “Sand Hills”, a small dune field northeast of Baggs, and initial surveys in the Killpecker Dune Field, the largest dune field in the state. No additional *P. haydenii* populations were found in these other dune fields. The 2000 surveys were based on the first potential distribution model for *P. haydenii* (Fertig 2001; Appendix C). A later potential distribution model was produced that represented an extrapolation of known distribution around the two known Ferris Dune populations (Fertig and Thurston 2003), delimiting an area that was restricted to part of the Ferris Dunes in the northwestern corner of Carbon County, WY.

The first two *Penstemon haydenii* potential distribution models were based on the assumption that the species does not occur below 2195 m in Wyoming, though it occurs no higher than 1160 m in Nebraska, and there are Wyoming dune fields that lie between Nebraska and Wyoming populations at intermediate elevations. These intervening dune fields were surveyed in 2004-2005, focusing on the Casper Dune Field and secondarily on the Torrington Dune Field. The potential distribution model for these surveys was expanded mainly by eliminating elevation constraints. Expanded criteria were added to ensure completeness in identifying eolian sand deposits, including associated soils (Quaternary sands, Psamment soil order in Munn and Arneson 1998), and vegetation (Short Grama Prairie land cover in Wyoming GAP analysis (Merrill et al. 1996, Driese et al. 1997), in addition to the original geology layer. This third potential distribution model (Heidel 2005a; Appendix A) was projected onto digital orthophotos to systematically search for blowout features.

As a result of 2004-2005 surveys, one new *Penstemon haydenii* population was found in a new area of the Ferris Dunes but no new populations were found in the dune fields lying between Nebraska and Wyoming populations. It was inferred and later concluded that the Casper Dunes despite having

large blowout features were not suitable, and that the Torrington Dunes, with their relatively small blowout features, generally did not have early-succession vegetation but more closely resemble Nebraska settings (Heidel 2005a). Surveys in the latter were limited by public access, and suitability could not be thoroughly gauged.

Application of the revised *Penstemon haydenii* potential distribution model has been evaluated in other areas of the state, specifically addressing whether Campbell County has potential habitat. Aerial photointerpretation was done to determine that Campbell County has no blowout features and therefore, no potential habitat (Heidel and Handley 2010). After completion of 2004-2005 surveys, plus unpublished 2003 surveys to a small dune area north of Tipton, all eolian sand deposit areas in Wyoming, with or without dune blowouts, had partial if not complete surveys.

Additional Ferris Dune subpopulations were documented in 2006 surveys of *Penstemon haydenii* surveys incidental to monitoring work (Heidel 2007). After all of the above-mentioned surveys, the question was raised whether we were confident that all potential habitat for *P. haydenii* on public lands had been surveyed. The short answer was no. This was the impetus for systematic 2011 surveys in the Ferris and Seminoe Dunes, in which prior cumulative survey results were pooled to identify and fill gaps. All unsurveyed blowout features were identified, as located within the area of Quaternary sand (Figure 1).

The 2011 *Penstemon haydenii* survey work was further expanded to include the Killpecker Dunes. The Killpecker Dunes are the largest dune field in Wyoming, and lie upwind of the Ferris Dune Field. The geologist who documented the geology of the Killpecker Dunes (Ahlbrandt 1973), conveyed information that he had seen a *Penstemon* plant resembling *P. haydenii* in the study area (Ahlbrandt pers. commun.). Limited surveys for *P. haydenii* had been conducted there in 2000 (Fertig 2001). A project was also getting underway to survey *Elymus simplex* var. *luxurians* (long-awned dune wild-rye), a state endemic known from the Killpecker Dunes. The latter, or the type variety of *E. s. var. simplex*, has been collected in the Ferris Dunes. Thus, the proposed project plan was expanded to survey both *P. haydenii* and *E. s. var. luxurians* across the Ferris and Killpecker Dunes ensuring systematic coverage for both plants in both areas.

METHODS

The 2011 surveys for *Penstemon haydenii* covered the two largest dune fields in Wyoming (Figure 1, Table 1). In the Ferris Dunes, all known *P. haydenii* population boundaries were projected onto digital aerial photos, and past surveys were represented as sections that have been covered, and all unsurveyed blowout features on public lands were made targets for survey. This was done in ArcMap at a scale ranging from 1:3000-1:10,000, looking for the concave depressions and associated bordering vegetation rims characteristic of blowouts, whether or not associated with wetland habitat.

In most of the Killpecker Dunes, there are not blowout features but large blocks and bands of open sand forming transverse dunes rather than parabolic dunes. We originally tried to identify survey point targets for *Penstemon haydenii* in the Killpecker Dunes but in the absence of discrete

blowouts, ultimately aimed to traverse topographic gradients in every section having open upland sand habitat, while also surveying the potential wetland habitat of *Elymus simplex* var. *luxurians*.

All blowout features originally identified as priorities for *Penstemon haydenii* survey were marked on digital orthophotographs using 2009 National Agriculture Imagery Program (NAIP) black and white imagery, printed out at the scale of quarter-quadrangle maps to match that of 1:24,000 U.S.G.S. topographic maps for reference in the field. They were printed out as quarter-quadrangle areas onto 8 ½" x 11" pages showing known distribution of *P. haydenii*, flagged blowouts for survey, and past survey efforts. They were also formatted with other reference information (section lines, quad map boundaries, and private property tracts). This scale of aerial photograph is very close to that of U.S.G.S. topographic maps (7.5') and they were carried together for reference in executing surveys. In advance of fieldwork, access permission was secured from private landowners to isolated public land parcels in the Ferris Dunes, and all survey work was coordinated with the lease holders. There were 15 quarter-quadrangle maps considered in Ferris Dunes surveys (12 warranted survey) and 28 in Killpecker Dunes surveys (all warranted survey). A total of 256 sections were surveyed in the Ferris and Killpecker Dunes in 2011, additions to the 73 sections previously surveyed where absent.

The survey work was preceded by a census of *Penstemon haydenii* at Bradley Peak, an exercise that trained the survey team to look for the distinguishing traits of *P. haydenii* flowering plants as well as of those in vegetative condition. It was conducted on 21 June 2011 at what is ordinarily the start of the flowering period when plants are most conspicuous, but which only had plants in bud during the late growing season of 2011.

Surveys for both *Penstemon haydenii* and *Elymus simplex* var. *luxurians* were conducted by 2-4 people working in tandem between 23 June – 27 July. An additional survey was conducted on 9 August. Datapoints were recorded on Global Positioning Systems (GPS) devices at every blowout that was visited in the Ferris Dunes. In the Killpecker Dunes, GPS points were only recorded at the discrete, surveyed wetlands, but essentially, *P. haydenii* was surveyed in all intervening upland habitat. The potential sand dune habitats were systematically surveyed by Bonnie Heidel, Emma Stewart, Susan Chamberlain and Hans Hallman. The *E. s.* var. *luxurians* occupies different habitat zones and has different distribution than *P. haydenii* so the results of survey for it are presented separately (Heidel 2012a).

Where *Penstemon haydenii* was found, a Wyoming plant species of concern survey form was filled out, GPS points were taken along the population perimeter, photographs were taken, and population numbers were censused. A collecting permit was secured from the U.S. Fish and Wildlife Service in advance of the field season. One of the three populations, nearest the Pathfinder Reservoir, had never had a voucher specimen collected because the population numbers and flowering levels had consistently been very low during all visits of prior years. In 2011, a new subpopulation was discovered for this population, and the new one had a comparatively high number of plants, including flowering plants, so it was documented by a voucher, deposited at the Rocky Mountain Herbarium (*Stewart 1*). After the field season, all survey results were entered into the central WYNDD database, with its Geographic Information System (GIS) platform.

Where *Penstemon haydenii* was surveyed but not found, survey routes were marked onto U.S.G.S. topographic maps (7.5') and digitized. To represent survey coverage at a glance, all sections with negative survey results were added into a spreadsheet and converted into an ArcMap theme of negative survey results for *P. haydenii*. An example of quarter-quad aerials marked by survey targets is presented in Appendix A. Survey routes are represented in Appendix B.

RESULTS

Penstemon haydenii was documented at three new subpopulations in 2011 within the Ferris Dunes, extensions of known populations. Complete population and subpopulation records and maps are presented in Appendix C, and aerial photographs of the three new subpopulations and GPS reference points are also included. Two of the new subpopulations extend the Bear Mountain - Junk Hill – Ferris population 1.5 miles farther west, now spanning 8.5 miles and 15 main blowouts. The third new subpopulation extends the Pathfinder Reservoir population 2.5 miles farther northeast, now spanning 3 miles and three blowouts. This represents an increase of 5% in the total number of *P. haydenii* subpopulations, and an increase in about 5% of total occupied habitat.

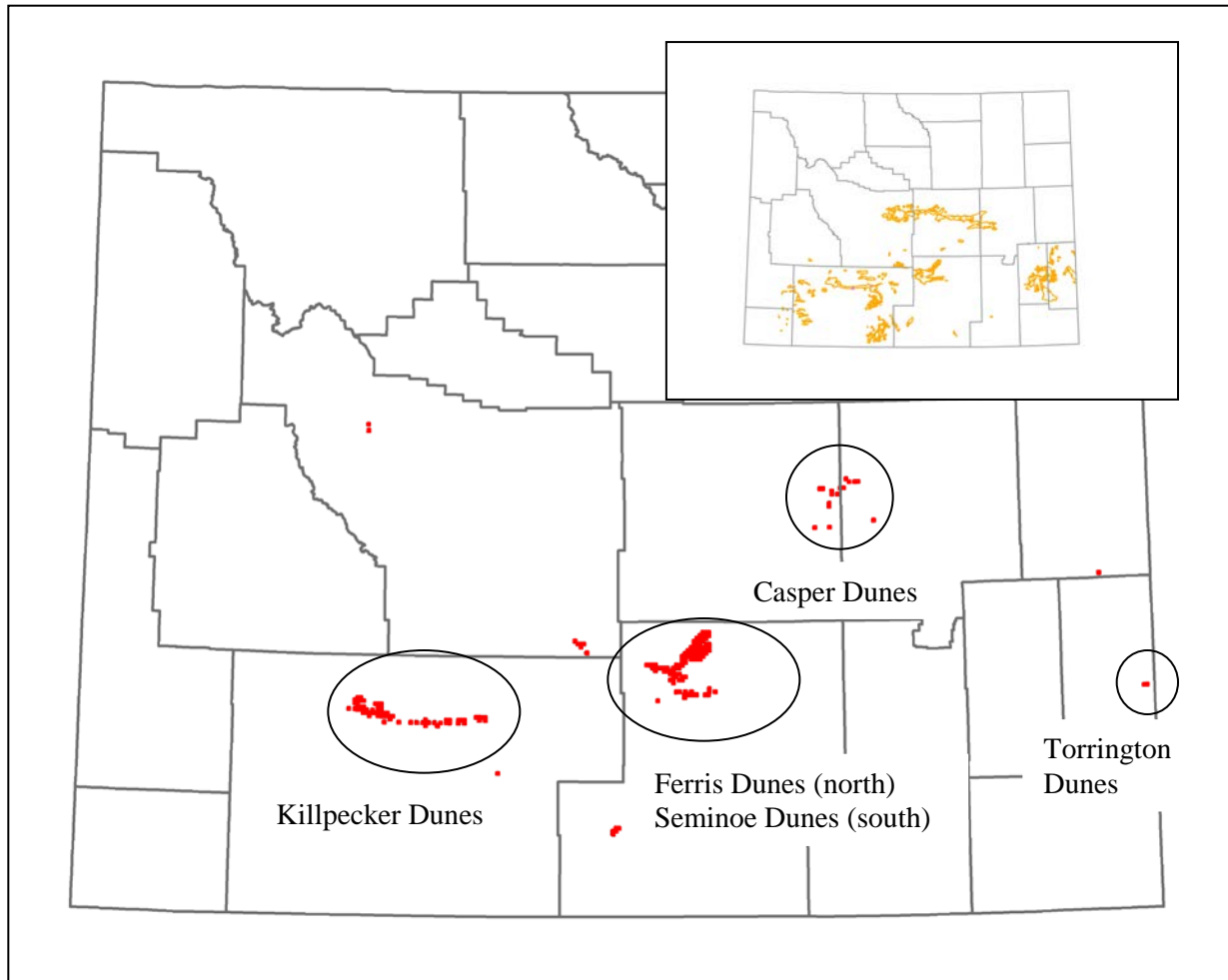
A total of 888 *Penstemon haydenii* plants were censused in the three new subpopulations. The two new subpopulations of the Bear Mountain - Junk Hill – Ferris population both had low numbers (36 and 83 plants total) and were made up nearly or entirely of vegetative plants. The Pathfinder Reservoir had 769 plants, of which 112 flowered in 2011, not including browsed plants. At the time of survey on 4 July, all reproductive plants were in fruit, and the only flowers that persisted were those on axillary shoots of browsed plants. The plant numbers in the additional populations represent an increase of 4-8% of the total number of *P. haydenii* plants, depending on whether these one-time tallies are integrated into the minimum or maximum tallies for other subpopulations.

At least as important as the preceding results, there were 256 additional sections containing active sand erosion features in the Ferris and Killpecker Dunes that had negative survey results, in addition to the prior 73 sections surveyed. Together they represent the most active sand dunes in the state. Negative surveys are represented in Figure 1.

Report of a plant resembling *Penstemon haydenii* in the Killpecker Dunes came to the attention of Dr. Richard Scott who, in 2011, revisited the reported plant material and found Red Desert penstemon (*P. arenicola*). This species has been documented at least one other time incidental to previous *P. haydenii* surveys on stabilized dunes in 2000 (*Fertig 19183 RM*). The *P. arenicola* has at least superficial similarity to *P. haydenii*, is almost certain to be the material observed by Dr. Ahlbrandt, and might be considered in future studies of taxonomic relationships. This adds support to the conclusion that public lands in these two dune fields are thoroughly surveyed for *P. haydenii* and they are unlikely to have any additional subpopulations or populations.

Information from all sources, including consultants and others, has been compiled over time to represent every section in Wyoming that has a dune feature, plus a couple that don't, and which have ever been surveyed specifically for *Penstemon haydenii*. The 2011 negative surveys and those from all prior years have been converted to a shapefile (Figure 1). Surveys are summarized in Table 1.

Figure 1. *Penstemon haydenii* negative surveys in Wyoming (inset: Quaternary sand in Wyoming)



This map represents systematic surveys for *Penstemon haydenii* in all eolian sands (a subset of Quaternary sand deposits), only a fraction of which have choppy dune development and even fewer have blowout features or other active sand erosion features. The areas shown in red on this map represent 329 sections that have been surveyed where it is not present (2000-2011). They correspond to the negative survey results presented in Table 1.

Table 1. *Penstemon haydenii* negative surveys in Wyoming

Month/ Year	Surveyor	County/ BLM field office	Dune Field	U.S.G.S. topographic map (7.5')
June, July, August 2000	Fertig	Carbon/ Rawlins and Lander	Ferris, Killpecker, "Sand Hills" ne. of Baggs, Green Mtn outlier, Seminoe	Boars Tusk, Bradley Peak, Crooks Peak, Ferris, North Table Mountain, Ox Yoke Springs, Riddle Cut, Sagebrush Park, Seminoe Dam SW, Sulphur Springs, Wild Horse Mountain
July 2001	Fertig, Blomquist, Heidel	Carbon/ Rawlins	Ferris	Buzzard Ranch
June 2003	Heidel	Sweetwater/ Rock Springs	Tipton	Tipton
June 2004	Heidel	Carbon/ Rawlins	Ferris, Seminoe	Buzzard Ranch, Ferris, Lamont NE, Seminoe Dam SW
July, August 2004	Heidel	Converse, Natrona/ Casper	Casper	Beauchamp Reservoir, Gumbo Hill, McKenzie Flat, Pratts Soda Lakes
July 2005	Heidel	Converse, Goshen/ Casper	Casper outlier, Torrington	Hylton Ranch, Torrington SE
August, September 2005	Hnilacka	Fremont/ Lander	No dune field	Crow Heart, Crow Heart NW
June 2006	Parametrix	Carbon/ Rawlins	Ferris	Ferris
Sept 2007	LMFlora Consulting	Fremont/ Lander	Green Mtn outlier	Crooks Peak
Aug 2009	Heidel	Carbon/ Rawlins	"Sand Hills" ne. of Baggs	Willow Creek
Summer 2010	Harvey Consulting	Carbon/ Rawlins	Ferris	Buzzard Ranch, Seminoe Dam
June, July, August 2011	Heidel, Stewart, Chamberlain	Carbon/ Rawlins	Ferris, Seminoe	Bradley Peak, Ferris, Lamont NE, Riddle Cut, Seminoe Dam, Seminoe Dam SW, Wild Horse Mountain
July 2011	Heidel, Stewart, Hallman	Sweetwater/ Rock Springs	Killpecker	Black Rock Flat East, Black Rock Flat West, Black Rock North, Boars Tusk, Essex Mountain, Fifteenmile Spring, North Table Mountain, Ox Yoke Springs, Red Lake, Steamboat Mountain, White Rocks
Sept 2011	Heidel, Chamberlain	Niobrara/ Newcastle	Outlier	Reynolds Spring

As of 2011, there have been systematic surveys for *Penstemon haydenii* conducted across Wyoming in areas that span 33 U.S.G.S. topographic maps (7.5') that cover all reworked eolian sand deposits on public lands in the state. With the exception of the Torrington Dune Field, the majority of active sand features are on public land.

DISCUSSION

The habitat of *Penstemon haydenii* can be circumscribed by many attributes including geology, soils, elevation, topographic position, water availability, surface water features, distance from known populations, and succession. Ultimately, the habitat is only found in eolian sand deposits that have been reworked to form choppy dune systems where there are active blowout erosion features present, and specifically where such dune features intercept topographic barriers.

Habitat requirements of *Penstemon haydenii* as known and hypothesized are presented in detail in the species status section of this report. An understanding of habitat requirements is essential in considering the completeness of survey efforts to date. In the course of this study, there were no habitat zones or geographic areas ruled out within the two dune fields. Instead, surveys were pursued as an opportunity to explore the limits of what might constitute suitable habitat within the active erosion features of dune fields.

If loose sand substrate and hydrology were the only habitat requisites for *Penstemon haydenii*, one might expect hydrological conditions to be met in a range of other sandy conditions under varying precipitation levels and groundwater patterns. The information at hand is inadequate for evaluating cause and effect, but point to a plurality of environmental requirements as conditioned by species' biology, as detailed in the habitat description section.

The results of this report present refinements available to the U.S. Fish and Wildlife Service for determining necessary and sufficient criteria for Section 7 reviews and the environmental conditions that support *Penstemon haydenii* in Wyoming. Earlier information was assembled to inform the debate as whether other areas of the state can be ruled out because they lack dune fields (e.g., Heidel and Handley 2010). Not all wind-blown sand and open sand settings constitute suitable *P. haydenii* habitat. Dune fields are not the only settings for loose sand in the state, also found on rolling sand plains and sandstone erosion landscapes. Either of the latter may have pockets of open sand habitat under natural conditions and man-made disturbance. But only dune fields with active, persisting sand erosion have suitable habitat.

The need for complete *Penstemon haydenii* distribution information is all the greater as the Bureau of Land Management (BLM) updates the Biological Assessment for *P. haydenii* (Chamberlain 2011), as the U.S. Fish and Wildlife Service prepares a biological evaluation on that document, and as BLM develops a management plan for the Area of Conservation Concern (ACEC) established to maintain its habitat. The need for complete, current information has been evident in the 5-year review by U.S. Fish and Wildlife Service of *P. haydenii*. It is absolutely essential if a recovery plan is prepared to address Wyoming populations of *P. haydenii*.

The rest of 2011 survey results are reflected in the species information on the following pages, including population numbers and trends, habitat descriptions and trends, current management, and existing and potential threats. Additional details and supporting documentation are in the Appendix.

PART 2 – SPECIES INFORMATION

A highlight of all species information is presented in the state species abstract (Appendix D).

Classification

Scientific Name: *Penstemon haydenii* S. Watson (1891)

Watson originally spelled the specific epithet “*haydeni*”, but a second “*i*” was later added to make the name etymologically correct (Fritz et al. 1992).

Common Name: Blowout Penstemon, Hayden’s Penstemon, Blowout Beardtongue

Family: Scrophulariaceae (Figwort Family)

However, DNA sequence studies of the Scrophulariaceae have provided the basis for splitting the family into separate families. One of its segregates, including the *Penstemon* genus, has been placed in vastly enlarged Plantaginaceae (Plantain Family; Albach et al. 2005). This is the new treatment and convention that will be used in the *Flora of North America* (FNA). The FNA volume containing the *Penstemon* genus (Volume 17) will be published in the future.

Synonyms: None

Phylogenetic Relationships: The genus *Penstemon* contains nearly 250 species centered primarily in western North America (Cronquist et al. 1984). *Penstemon haydenii* belongs to section *Coerulei*, a group recognized by succulent and glaucous leaves, anthers that dehisce their entire length, and compact inflorescences of blue, violet, pink, or white flowers (Cronquist et al. 1984). *P. haydenii* is unique within this section in having fragrant flowers (Freeman 1986). *P. haydenii* has been thought to be most closely related to *P. grandiflorus* and *P. angustifolius*, and Freeman (1981) has hypothesized that *P. haydenii* may be of hybrid origin between these two taxa. It has the same diploid number of chromosomes ($n=8$) as the two related species (Freeman 1986).

Legal Status: *Penstemon haydenii* was placed on a notice of review for plants being considered for listing as endangered or threatened under the U.S. Endangered Species Act on 15 December 1980 (45 FR 82480). It was proposed for listing as Endangered on 29 April 1986 (U.S. Fish and Wildlife Service 1986) and designated on 1 October 1987 (U.S. Fish and Wildlife Service 1987). It is protected under state law in Nebraska, but receives no comparable protection in Wyoming.

Natural Heritage Rank: NatureServe (formerly the heritage division of The Nature Conservancy) and the network of natural heritage programs give *Penstemon haydenii* a rank of G1G2, indicating that the species is intermediate between “critically imperiled” and “imperiled” because of rarity throughout its range. The rank of “G1” is generally reserved for species with 5 occurrences or less, and the rank of “G2” is generally reserved for species with 6-20 occurrences, tempered by abundance, range extent, trends, and threats.

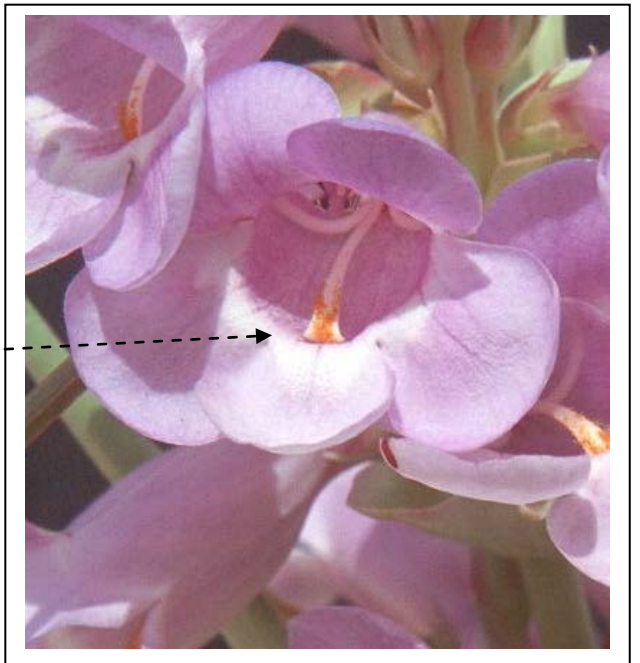
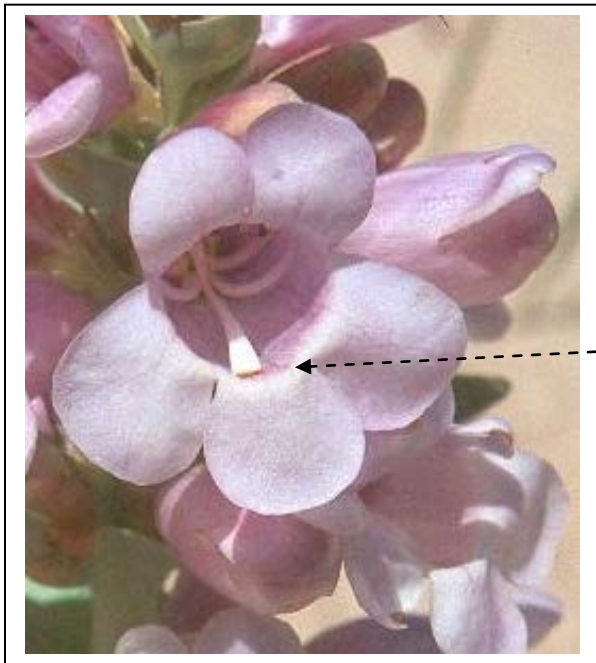
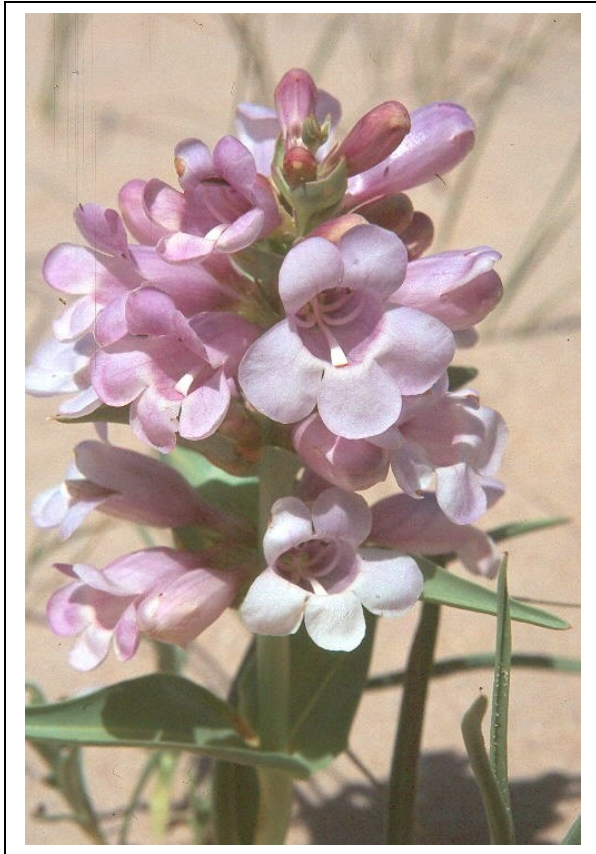
At the state level, it is ranked S1 (critically imperiled) in Nebraska (Nebraska Natural Heritage Program 1996) and in Wyoming (Heidel 2012b) based on number of occurrences and range extent.

Description: *Penstemon haydenii* is a perennial herb with one to many glabrous upright or decumbent stems arising from a branched caudex, rooting from buried nodes (Figures 1-3). Flowering and vegetative stems are usually less than 30 cm tall and have greenish-blue, waxy leaves. Flowering stems broad-based, clasping, waxy upper stem leaves 0.7-3 cm wide that taper abruptly to a narrow tip and narrow basal leaves, whereas vegetative stems just narrow, linear leaves 2.5-12 cm long and 0.3-1 cm wide. The inflorescence is 6-16 cm long with 3-6 (10) compact, leafy whorls of milky-blue to pale lavender flowers (rarely pinkish or white). Bracts of the inflorescence are broad and heart-shaped at the base and narrow to an elongate tip. Individual flowers are 23-25 (30) mm long with tubular, bi-lobed and faintly vanilla-scented corollas that are broadly dilated above the glabrous, linear sepals. Anther sacs are 1.8-2 mm long and glabrous. The sterile staminode is glabrous or hairy. Fruits are 13-16 mm long capsules, acute, with light-brown, disc-shaped seeds that have narrowly winged margins (Stubbendieck et al. 1982a, 1997; Freeman 1986; Fertig 2000, 2001; Heidel 2005a).

During 2004 fieldwork, *Penstemon haydenii* flower variation was noted that had not been previously recorded in taxonomic literature. Morphological variables included hairy and glabrous staminodes, nectar guidelines both present and absent, and occasionally, trichomes on the styles and inner corolla within the same subpopulation (Junk Hill Main and possibly others). In Freeman (1986), staminodes are described as consistently hairy and nectar guidelines are characterized as appearing among all flowers in early stages of maturation. The variation within the main Junk Hill subpopulation was documented and recorded (Heidel 2007; Appendix D) and is represented in the flower enlargements depicted in Figures 2-5. The hairy vs. glabrous staminode trait is usually consistent for all members of a species, and the latter is less common among *Penstemon* species than the former. This trait variability has also been reported for another Wyoming species, *P. caryi* (Fertig 2002). This variation may be significant in understanding species' pollination adaptations and taxonomic relations. Flower traits are conservative in most plant families, and the previously-undescribed variation in flower traits raised questions.

Pilot genetic study compared Nebraska and Wyoming plants of *Penstemon haydenii* using a nuclear ribosomal DNA marker in leaf tip samples. Preliminary results indicated no divergence between states (Szalanski 2001). However, the previously-unreported variability in flower traits prompted a re-evaluation of the genetic differences between species material from the two states, using samples from two populations of *P. haydenii* in Wyoming and three in Nebraska. The recent research found significant genetic differences between Nebraska and Wyoming material, at magnitudes of genetic difference that are equal or greater than differences between some other pairs of taxonomically recognized *Penstemon* species (Buerkle and Jenkins, in prep.) in which 37 additional *Penstemon* species were studied. They recommended further research into the taxonomic status of Wyoming material, research which is underway in the laboratory of Dr. Craig Freeman, *Penstemon* author in the future *Flora of North America* treatment.

Similar Species: *Penstemon grandiflorus* has ovate to spoon-shaped leaves (widest above the middle), non-aromatic corollas over 35 mm long, and fruits over 16 mm long. *P. angustifolius* var. *angustifolius* has non-aromatic corollas less than 25 mm long and narrowly lance-shaped stem leaves over 7 times as long as wide (rarely over 1 cm wide). *P. angustifolius* var. *caudatus* has non-aromatic corollas under 25 mm long and lance-shaped to ovate flowering bracts. (cont. p. 13)



Figures 2-5. *Penstemon haydenii* inflorescences and enlargements of flowers with glabrous and hairy staminodes. By B. Heidel.



P. arenicola has non-aromatic corollas, elliptic to oblanceolate leaves, 2.5-5(7) cm long and 4-11(15) mm wide (Cronquist et al. 1984, Freeman 1986; Dorn 2001).

None of the above-mentioned similar species are in the Ferris Dunes. There have not been reports of other *Penstemon* species sympatric with *P. haydenii* in Wyoming until 2004 when *P. subglaber* was noted in secondary dune habitat east of Junk Hill. This species is more common in the Seminoe Mountains, where it was collected for voucher. It has discrete basal leaves, lacks the glaucous appearance of *P. haydenii*, and has conspicuously dark flower color by comparison, and may only occur as an accidental in loose sand habitat. The only other species of *Penstemon* species observed in the surrounding landscape are *P. eriantherus* and *P. laricifolius*.

Figure 6. *Penstemon haydenii*, an exceptionally robust plant in flower at Bradley Peak. 2 July 1999. By Walter Fertig.



Figure 7. *Penstemon haydenii*, an exceptionally robust plant in flower at Bradley Peak. 2 July 1999. By Walter Fertig.

Three other states recorded in *Penstemon haydenii* monitoring



Figure 8. *Penstemon haydenii* seedling, west of Junk Hill, 30 June 2004. Rarely observed in monitoring. By B. Heidel.



Figure 9. *Penstemon haydenii* vegetative plant, Junk Hill, 24 June 2004. Prevalent condition in most subpopulations. By B. Heidel.



Figure 10. Browsed *Penstemon haydenii* plant, west of Pathfinder Reservoir, 25 June 2004. This is an example of severe browse. This plant probably would have flowered had it not been browsed. By B. Heidel.



Figure 11. *Penstemon haydenii*, with adventitious root development under wind erosion, on Junk Hill, 24 June 2004. By B. Heidel



Figure 12. *Penstemon haydenii* underground root branching and breakage point between two stems, on Bear Mountain East. 25 June 2002, By B. Heidel.

Geographic Range: *Penstemon haydenii* is a regional endemic of the Nebraska Sand Hills (referred to as “Sandhills” in Nebraska), the largest sand dune system in North America, located in north-central Nebraska (Stokes and Swinehart 1997, Forman et al. 2001). The Nebraska Sandhills cover about 5 million ha (approximately 12.4 million ac) in parts of over 20 counties. The Wyoming populations of *P. haydenii* are in the Ferris Dunes of northwestern Carbon County, separated from the Nebraska Sandhills by about 282 km (175 mi). The Ferris Dunes cover an area less than 124,000 ha (50,000 ac); over two orders of magnitude smaller than the Nebraska Sandhills (circled in Figure 13). Reports from Kansas (Coulter and Nelson 1909) are considered erroneous.

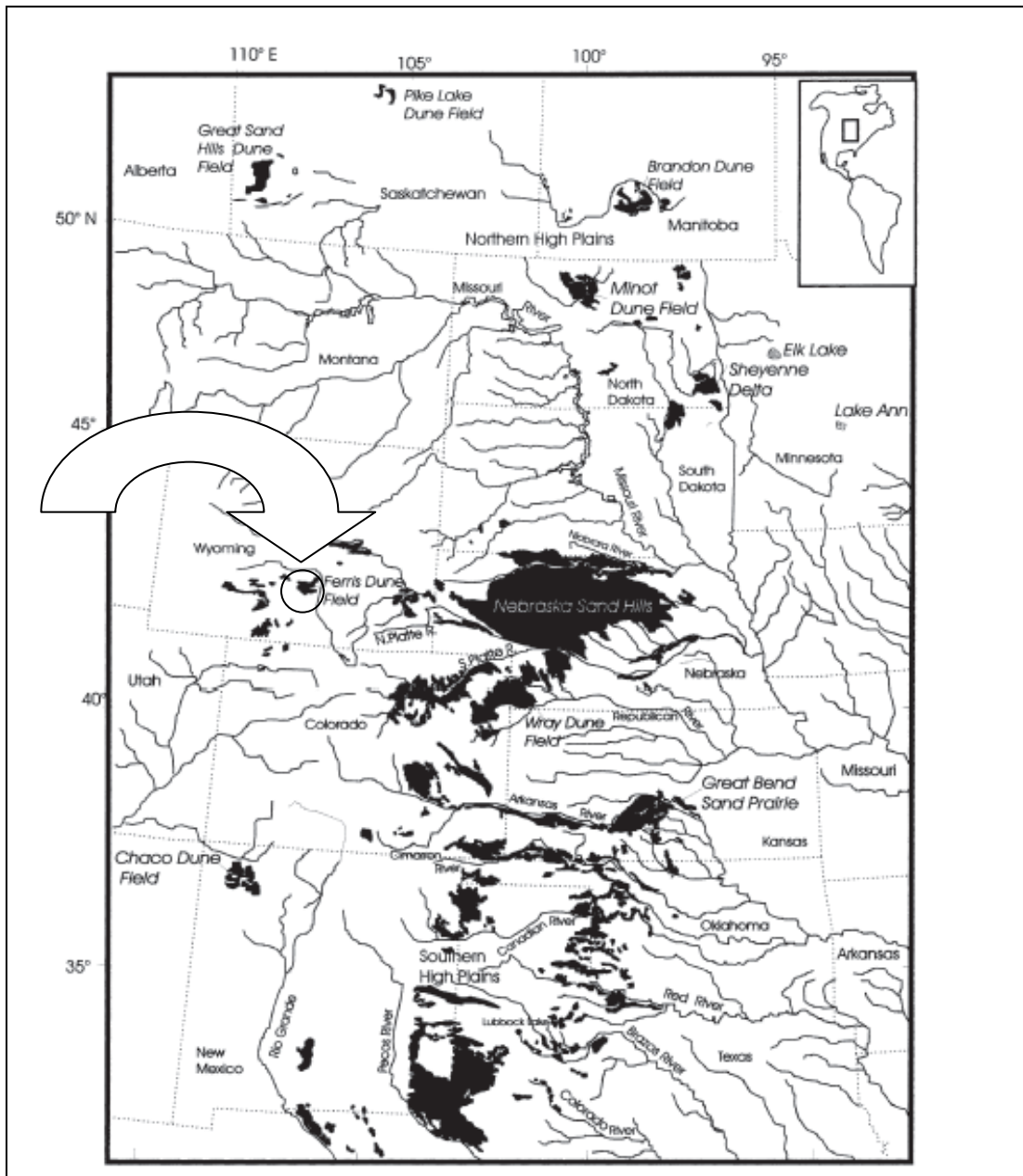


Figure 13. The Great Plains of North America with presently stabilized dune fields in black. [Figure 1 in Forman et al. (2001) derived from Ostercamp et al. (1987) and Muhs and Wolfe (1999)]

The Ferris Dunes are an irregularly shaped area of dune sand that blankets the downwind end of the Great Divide Basin, a closed basin (Stokes and Gaylord 1993). The three *Penstemon haydenii* populations are present in downwind portions of the Ferris Dunes, including the flank of Bradley Peak (western Seminoe Mountains), on the south side of Bear Mountain and north side of Junk Hill (eastern end of the Ferris Mountains), and at foothills of the Pedro Mountains where they extend on the west side of Pathfinder Reservoir (Figure 14, Appendix C and D; Dorn 2001, Taylor 2000, Fertig 2001, Heidel 2005a). They represent places where sand deposits intercept topographic barriers, and are only a small fraction of the Ferris Dunes. The occupied habitat spans an area of approximately 50 mi² (less than 13,000 ha; less than 31,000 ac).

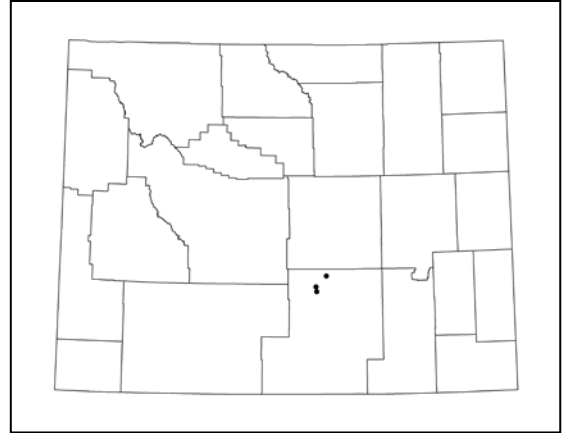


Figure 14. Distribution of *Penstemon haydenii* in Carbon County, Wyoming

Interpretation of this unusual *Penstemon haydenii* distribution pattern is further complicated and inextricably linked with its history of discovery. It was first recognized as a distinct species by Sereno Watson (1891) based on a flowering specimen collected by Herbert J. Webber along the Dismal River in Thomas County, Nebraska in 1891 (Pennell 1920, Sutherland 1988). At that time, the species was known from only one other record, a specimen collected by Ferdinand V. Hayden or expedition members during “one of his early surveys” and originally identified as *P. acuminatus* (a species now known to be endemic to the Columbia River Basin) (Watson 1891; Cronquist et al. 1984). It was deposited at Grays Herbarium. Watson attributed the Hayden collection to “the Laramie Mountains of Wyoming”. Pennell (1920) first noted that this specimen was possibly misidentified. Later, Pennell (1935) reported on duplicates of Hayden’s specimen at the Missouri Botanical Garden from “Loup Fork”, in the Nebraska Sandhills, and presumed that these specimens and the Grays Herbarium specimen were from the same Nebraska area. For the next 64 years, *P. haydenii* was presumed to be endemic to Nebraska (Sutherland 1988, Stubbendieck et al. 1997, Fritz et al. 1992).

In June 1996, Frank Blomquist of the Bureau of Land Management (BLM) Rawlins Field Office discovered a population of *Penstemon haydenii* on public lands at the west end of the Seminoe Mountains in northwestern Carbon County, Wyoming. The identity of this species was not confirmed until July 1999, when Blomquist and University of Wyoming botanists Amy Roderick Taylor, B. Ernie Nelson, Courtney Ladenburger, and Walter Fertig revisited the site and secured mature voucher material. These specimens were verified as *Penstemon haydenii* by Dr. Noel Holmgren of the New York Botanical Garden and Dr. James Stubbendieck of the University of Nebraska (Fertig 1999, 2000; Jennings and Sexson 2000). The species is recognized in the current Wyoming flora (Dorn 2001).

Expanded surveys for *Penstemon haydenii* by Fertig and Blomquist in 2000 documented a new population in the Bear Mountain – Junk Hill area. Fertig (2001) noted: “The discovery of the Bear Mountain population forced a reassessment of the disputed Ferdinand V. Hayden collection

reported by Watson (1891) for Wyoming. Much of the confusion regarding Hayden's whereabouts stems from the assumption of Pennell (1920, 1935) that the *P. haydenii* collections from the Missouri Botanical Garden and Gray Herbarium are duplicates, when in fact, they probably represent different collections separated by 20 years and several hundred miles. Two unnumbered Hayden collections that are true duplicates are deposited at the Missouri Botanical Garden and are labeled "*Penstemon acuminatus* or *fendleri*" from the "Sand Hills, Loup Fork" by George Engelmann. These specimens were probably collected by Hayden during the 1856-1857 G.K. Warren expeditions through the Nebraska Sandhills (Warren 1858), and are thought to represent the oldest collections (Sutherland 1988). Hayden was responsible for the botany during this survey, with Engelmann providing identifications (Pound and Clements 1898). By contrast, the Gray Herbarium specimen is labeled "*Penstemon acuminatus*" as determined by Asa Gray, who was the botanist in charge of determinations for Hayden's 1877 expedition in Wyoming (Hayden 1879).

In August 1877, Hayden's party traveled from Casper to Rawlins through "Sandy Creek Pass" in the "Seminoe Hills" (now called the Ferris Mountains). This route would have taken them through the low divide between the main massif of the Ferris Mountains and Bear Mountain (an unimproved county road goes through the pass today). In his *Eleventh Annual Report* of 1879, Hayden describes dunes near Sandy Creek Pass where "fine sand is blown up upon the hillsides for a distance of 500 to 600 feet" (Hayden 1879, p 138) and where "[l]ooking back upon the hills, the sand was found to reach up about 400 feet along their slopes" (Hayden 1879, p 32) (Figure 5). Since Hayden's party consisted largely of geologists, it is plausible that members of the group would have explored these dunes. According to Robert Dorn (2000), who studied the journal entries, the *Penstemon haydenii* specimen was probably collected by one of Hayden's assistants on 28 August and the location data for the specimen label ("Laramie Mountains") could have easily been garbled (similar problems with incorrect labels have been noted on other Hayden collections). The phenology of the specimen (post fruiting) is consistent with a late season collection. Although it cannot be proven definitively, Hayden was clearly at the Loup Fork in 1857 and Sandy Creek Pass in 1877 and could have made separate herbarium collections at both sites, which were later incorrectly assumed to represent just the former locality. If Hayden did collect his namesake plant in Wyoming in 1877 (pre-dating statehood), allegations that this species was introduced to Wyoming from Nebraska become even less tenable (Fertig 2000, 2001). It only took 119 years to discover *P. haydenii* in Wyoming a second time.

Habitat: *Penstemon haydenii* is associated with sparsely vegetated, early successional, shifting sand dunes with crater-like depressions created by wind erosion called blowouts. In Wyoming, *P. haydenii* is found primarily on the rim and lee slopes of blowouts, or the rim and steep facies of slip-face slopes. Occupied habitat spans elevations of 1786-2270 m (5860-7440 ft).

Penstemon haydenii is located in the Ferris Dunes of the Great Divide Basin, a closed drainage landscape where topographic barriers at the downwind end intercept wind-borne sand and in places, funnel it between breaks in topography (Gaylord and Dawson 1987). They lie downwind of Quaternary Lake Wamsutter (Grasso and Marrs 1993). The accumulated sand has been reworked by the wind to the choppy dunes of the Ferris and Seminoe Dune Fields. The Ferris Dune Field, the larger of the two, has been active as recently as 8800-8100 and 4300-4000 years B.P (Stokes and Gaylord 1993).

The Ferris Dunes cover >300 km² (116 mi²) with up to 40 m (13 ft) depth of predominantly stabilized parabolic dunes (Stokes and Gaylord 1993). Less than 15% of the total surface has actively migrating dunes. Parabolic dunes are horseshoe-shaped mounds of sand with convex noses trailed by elongated upwind arms anchored by vegetation and the shallow water table. The blowout is in the center of the horseshoe-shape, and gentle lee slopes cover the nose. Parabolic dunes are essentially migrating blowout bowls. According to Livingstone and Warren (1996), they "... are usually formed on a framework of larger dunes that has been stabilized by vegetation, after either a change in climate or sand supply."

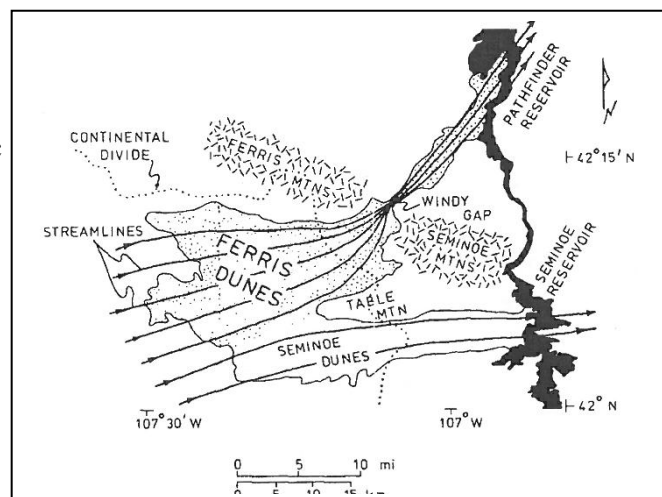
Parabolic dunes are distorted at gaps in topography, but they are not linear dunes as misstated in an earlier report (Heidel 2007). The funneling affect causes much of the aeolian load to drop upwind, accumulating near the gap (Stokes and Gaylord 1993) and funneling the wind like a nozzle (Gaylord and Dawson 1987). Downwind from the gap are the largest sand drift deposits and what might be called slip-face deposits for lack of a better term. They are epitomized in the Junk Hill Main blowout and the Bear Mountain set of blowouts, respectively. They differ from the primarily transverse dune system of the Killpecker Dunes (Ahlbrandt 1973), that only have the slightest development of parabolic dunes at their far western end.

Wind patterns in the Ferris Dunes are described by Gaylord and Dawson (1987):

"Heightened winds in the Ferris Dunes are most common from September to May (Dawson and Marwitz 1982). Records from continuously recording anemometers (4-m height) at two sites within the Ferris Dunes from 1976 to 1979 (Martner and Marwitz 1982) reveal yearly average winds of 4.1 and 4.6 m/s, respectively. Mean daily temperatures recorded at a nearby monitoring station are near or below freezing from late October to early March and average only 6 °C throughout the year (Becker and Alyea 1965). As a result, dune sands commonly are snow-covered, frozen, and relatively immobile during these months. However, from March to June and from September to November, when winter atmospheric conditions and heightened winds are still prominent, substantial eolian activity occurs."

Prevailing winds are out of the west-southwest. Where the blowouts form in a series parallel to the wind, they are staggered and non-overlapping. Where the blowouts form a series perpendicular to the wind, as at Bradley Peak, they are contiguous and form a single blowout complex laid out like stairsteps. There is a wind funnel affect at the gap between the Ferris and Seminole Mountains as represented in Figure 15.

Figure 15. Location map of Ferris dune field showing principal topographic and geographic features (from Gaylord and Dawson 1987).



Penstemon haydenii is found in a range of dune slopes and topographic positions in Wyoming. Unlike the Nebraska Sandhills, it often occurs outside of the blowout bowl rather than inside. This is because the blowout bowl is usually open on one side, and subject to the full force of winds that scour and bury. It is usually found on the rim and often more numerous on lee slopes immediately downwind from the blowout rim. A simplified diagram of blowout habitat is shown in Figure 16.

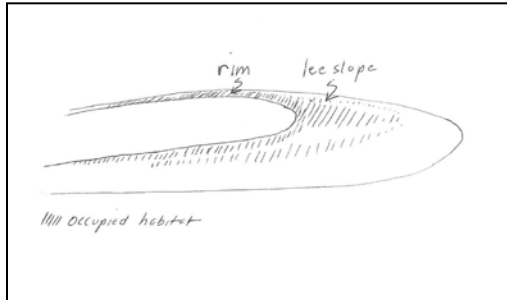


Figure 16. Typical parabolic dune blowout and occupied *Penstemon haydenii* habitat. By B. Heidel.

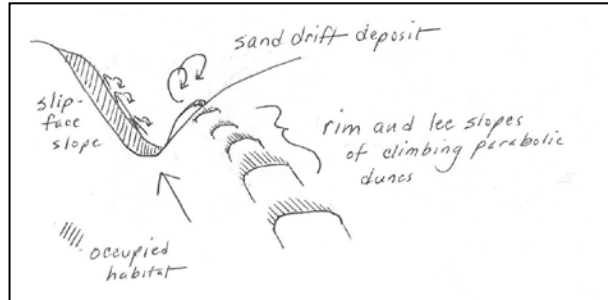


Figure 17. Schematic diagram of diverse *Penstemon haydenii* blowout habitat on Junk Hill and Bear Mountain, in a series of climbing parabolic dunes, slip-face slopes and sand drift deposits, looking downwind. By B. Heidel.

The dune morphology reflects the confining influence of the surrounding mountains on the prevailing winds. The symmetrical horseshoe shape of the parabolic dune is potentially distorted by topographic barriers over which the dunes climb, fall, or skirt, depending on the wind direction as compared to topographic orientation. Another schematic diagram of parabolic dune series, sand drift deposits and slip-face slopes is presented as a stylized representation of the different *Penstemon haydenii* habitats around Bear Mountain and Junk Hill (Figure 17), with arrows indicating direction of sand movement. There are all sorts of variations on these patterns, having to do with the orientation and rise or fall of topography compared to wind direction. Sand drift deposits form in deflation zones and slip-face slopes of steep sand form where oblique winds deposit sand against topographic barriers. The steepest of *P. haydenii* microhabitats develop where the dunes form steep slip-faces, which sometimes have high concentrations of *P. haydenii* (e.g., Bradley Peak, Bear Mountain). Slopes range from 1-5% in blowout craters, rims and crests, to well over 60% on Bear Mountain and Bradley Peak. Typical habitat shots are presented of the Junk Hill Main subpopulation lee slope (Figure 18) and rim (Figure 19). The steep slip-face of Bradley Peak as it overlooks the Ferris Dunes is on the cover of this report, and that of Bear Mountain East subpopulation is shown in Figure 6. Localized small mounds like miniature dunes are found around *Artemisia cana*, and are marginal habitat, sporadically occupied in the vicinity of primary habitat (Figure 20).

The Ferris Dune soils consist of fine psamments derived from wind-blown Quaternary alluvium (Love and Christiansen 1985; Munn and Arnesen 1998). A small set of soil samples were collected for analysis and characterization by the author, including a profile pair from Bradley Peak (a) 0-15cm; b) 15-30 cm) and one from Bear Mountain West (0-15 cm); (Table 2). They were collected in June and August of 2010, and stored at room temperature until tests were run at the University of Wyoming Soils Testing Laboratory for texture, nutrient, pH and ion measurements (Table 2). The particle sizes are coarse and relatively uniform, with almost no profile development, except for

what seemed to be a lower pH at the surface compared to subsurface (Bradley Peak a and b) but with no difference in clay fraction. The soils are nutrient-poor.

Table 2. Soil properties in *Penstemon haydenii* habitat

	Bradley Pk - a	Bradley Pk – b	Bear Mtn
Sand %	97	97	95
Silt %	1	1	0
Clay %	2	2	5
Dry color	2.5yr	2.5yr	2.5yr
Wet color	5y	5y	5y
pH	6.5	7.3	7.3
EC dS/m	0.2	0.2	0.1
CEC CMOLES/kg	2.4	2.4	1.0
Organic matter % LOI	0.2	0.2	0.1
Carbon %	0.04	0.05	0.02
Nitrogen %	0.006	0.008	0.003
PO4P mg/kg	0.01	<0.01	0.01
Soluble Ca meq/l	0.06	0.08	0.04
Soluble Mg meq/l	0.03	0.02	0.01
Soluble NA meq/l	0.1	0.06	0.1
SAR	0.2	0.1	0.3

Fertig (2001) postulated that the absence of *Penstemon haydenii* from the dunes in the broad valley between the Ferris and Seminole mountains may be related to unavailability of soil moisture during the growing season. He suggested that the primary source of moisture throughout the valley dunes may be wind-blown snow and ice trapped in layers of insulating sand during winter. Accordingly, low spring and summer precipitation, coupled with high evapotranspiration rates and the natural porosity of the dunes, kept the low elevation dunes too dry to support *P. haydenii* populations. Thus, only those dunes perched on the flanks of mountain slopes may receive enough supplemental moisture from local springs, subirrigated conditions or additional runoff to maintain this species.

Soil moisture comparisons have not been made between dunes that are occupied or unoccupied by *Penstemon haydenii*. The Ferris Dunes in general are characterized as having a high water table (Stokes and Gaylord 1993) and wetlands are associated with most dunes. Within *P. haydenii* habitat, it has been noted that the subsurface remains moist only 10 cm below bare, essentially unvegetated sand even when soil pits were dug in June 2002, a dry year. Other factors that differ between dunes in the broad valley settings and on the valley margins besides hydrology may include wind patterns and wind pattern complexity, sand movement patterns and movement complexity, vegetation patterns, vegetation succession and successional complexity.

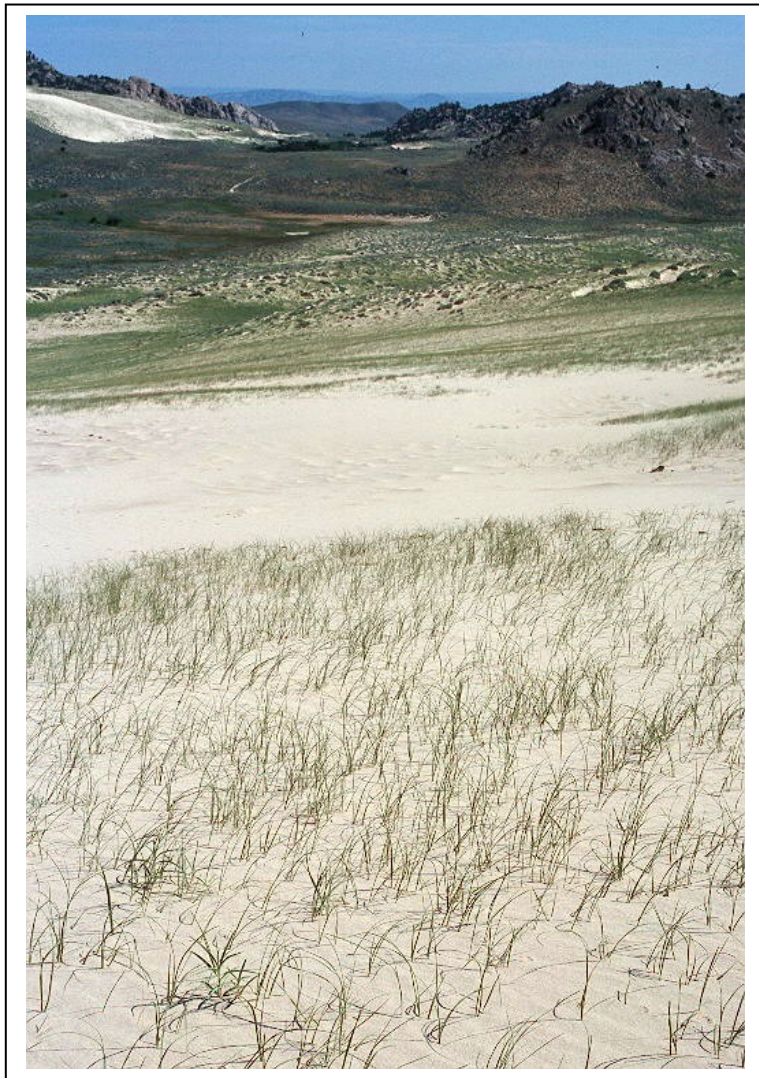


Figure 18. *Penstemon haydenii* habitat with *Redfieldia flexuosa* on gentle lee slope of Junk Hill Main subpopulation (Bear Mountain in background). Note vegetative *P. haydenii* plants. By B. Heidel.



Figure 19. Blowout rim habitat with entangled roots of *Psoralidium lanceolatum* and *Penstemon haydenii*. BLM photo by F. Blomquist.



Figure 20. Miniature “dunes” form around *Artemisia cana*, at fringes of big dunes, marginal habitat for *Penstemon haydenii*. By B. Heidel.



Figure 21. Overview of the most extensive subpopulation of *Penstemon haydenii* (Junk Hill; background), a sand drift deposit, viewed from the small, perched dunes that fill a side-valley on Bear Mountain (foreground). By B. Heidel.

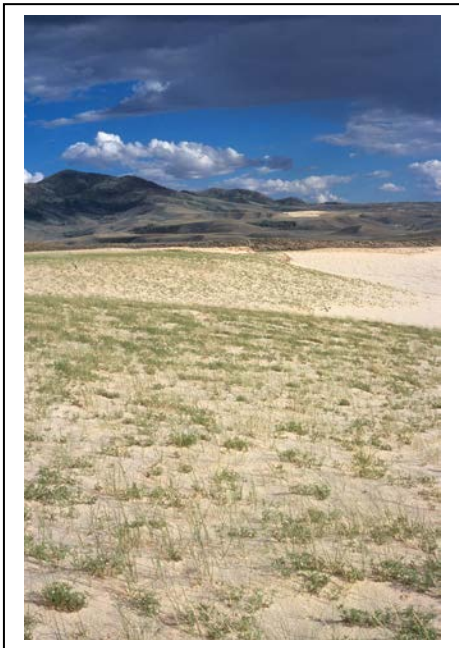


Figure 22. Gentle climbing dunes west of Junk Hill (foreground); Bradley Peak (background) with *Penstemon haydenii*. By B. Heidel.

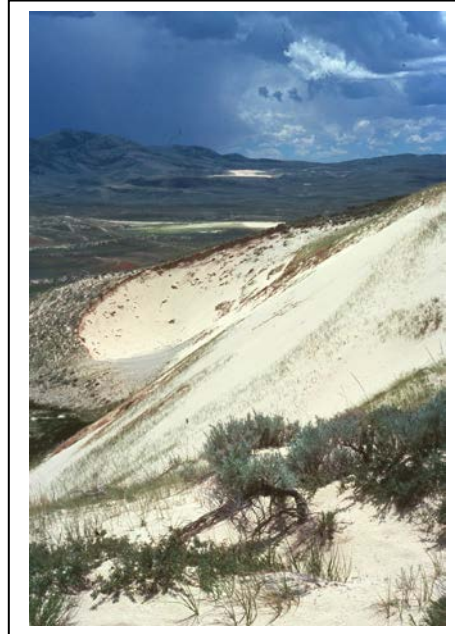


Figure 23. Another view from the side-valley (foreground); Bradley Peak (background), and dunes west of Junk Hill (middle) with *Penstemon haydenii*. By B. Heidel.



Figure 24. Falling parabolic dune with *Penstemon haydenii* (Pathfinder – South subpopulation), occupying bowl ridge and lee slopes (arrows). By B. Heidel.



Figure 25. Falling parabolic dune with *Penstemon haydenii* (Pathfinder – North subpopulation), occupying bowl ridge and lee slopes (arrows). 4 July 2011. By B. Heidel.



Figure 26. Blowout bowl habitat of *Penstemon haydenii* (Junk Hill West Dune #5), where also present on the rim and lee slope.

The nearest climate station is at Seminoe Dam, but the Rawlins Airport is almost as close and is in an intermontane basin setting at 2053 m (6736 ft elev) that corresponds closer to the Ferris Dunes elevation and setting. Mean annual precipitation is 23.4 cm (9.2 in) with peak precipitation coming in April and May. Mean annual temperature is 6° C (42.8° F). Mean maximum and minimum temperatures in January are -10.7° C (12.7° F) and -0.6° C (30.9° F), and mean maximum and minimum temperatures in July are 10.8° C (51.4° F) and 28.7° C (83.7° F; USDI NOAA 2006).

The vegetation of *Penstemon haydenii* habitat is sparse (often less than 5%) and made up of sand-loving species. Fertig (2001) said:

“...On unstable, windward slopes, Blowout *Penstemon* may be found in communities of blowout grass (*Redfieldia flexuosa*), lemon scurf-pea (*Psoralidium lanceolatum*), and thickspike wheatgrass (*Elymus lanceolatus* var. *lanceolatus*) with less than 5% vegetative cover (Table 2). Populations on more stable, lee slopes occur in similar communities with vegetative cover reaching 15-40%. Occasionally, populations may be found on choppy dunes associated with silver sagebrush (*Artemisia cana*) and thickspike wheatgrass, or on barren slopes above small stands of chokecherry (*Prunus virginiana*) and stinging nettle (*Urtica dioica*) associated with seep springs.”

The following observations are added to this characterization. Dune colonization as found in *Penstemon haydenii* habitat is often pioneered by *Redfieldia flexuosa* (Figure 13). To a lesser extent, early-succession settings may also be dominated by other grasses like *Achnatherum hymenoides* (syn. *Oryzopsis hymenoides*), and locally, by *Elymus lanceolatus*. *Psoralidium lanceolatum* occurs throughout dune landscapes, including occupied habitat, but where it most abundant, *P. haydenii* is usually not present. It is not known whether the nitrogen-fixing capacity of

P. lanceolatum affects habitat suitability. *P. haydenii* is usually absent from settings with 15-40% cover, and is only locally associated with *Artemisia cana* on semi-vegetated sand mounds (Junk Hill; Figure 15). It is also associated with *Prunus virginiana* with or without *Urtica dioica* on the lower fringes of steep slip-face dune slopes above springs in parts of two populations.

The species associated with *Penstemon haydenii* listed by Fertig (2001) are presented in Table 3 (with modifications). There are relatively few associated species, except for those in trace amounts or in peripheral zones that have greater vegetation development than most occupied *P. haydenii* habitat. The most common grasses are *Achnatherum hymenoides* and *Redfieldia flexuosa* (consistently present); and *Elymus lanceolatus* (locally dominant in places). The most common forb, more common than all others combined, is *Psoralidium lanceolatum*. A greatly-expanded list of plant species collected and observed in the Ferris Dunes landscape is presented in Appendix E, cross-referenced by their phenology and pollination regime as potentially relating to *P. haydenii* pollination biology.

Table 3. Species commonly associated with *Penstemon haydenii* in Wyoming

Scientific Name	Common Name	Growth Form
<i>Achnatherum hymenoides</i> (<i>Oryzopsis hymenoides</i>)	Indian ricegrass	Perennial graminoid
<i>Artemisia cana</i>	Silver sagebrush	Shrub
<i>Astragalus ceramicus</i> var. <i>filifolius</i>	Painted milkvetch	Perennial forb
<i>Calamovilfa longifolia</i>	Prairie sandreed	Perennial graminoid
<i>Chenopodium subglabrum</i>	Smooth goosefoot	Annual forb
<i>Cirsium canescens</i>	Platte thistle	Perennial forb
<i>Elymus lanceolatus</i> var. <i>lanceolatus</i>	Thickspike wheatgrass	Perennial graminoid
<i>Eremogone nuttallii</i> (<i>Arenaria nuttallii</i>)	Nuttall's sandwort	Perennial forb
<i>Lygodesmia juncea</i>	Rush-like skeletonweed	Perennial forb
<i>Machaeranthera canescens</i>	Hoary aster	Perennial forb
<i>Phacelia hastata</i>	Silverleaf phacelia	Perennial forb
<i>Psoralidium lanceolatum</i>	Lemon scurf-pea	Perennial forb
<i>Redfieldia flexuosa</i>	Blowout grass	Perennial graminoid
<i>Rumex venosus</i>	Veiny dock	Perennial forb
<i>Senecio spartioides</i> var. <i>spartioides</i>	Broom groundsel	Perennial forb
<i>Thermopsis rhombifolia</i>	Round-leaved golden-pea	Perennial forb

Searches for *Elymus simplex* var. *luxurians* turned up only the type variety at a couple locales (Heidel 2012a).

The vegetation structure and dominant species of *Penstemon haydenii* habitat have similarities between Nebraska and Wyoming, but a large number of associated species found in Nebraska are not present at the Wyoming sites. These species include *Cycloloma atriplicifolia* (Ringwing), *Physalis heterophylla* (Clammy groundcherry), *Polanisia trachysperma* (Clammyweed), *Muhlenbergia cuspidata* (Plains muhly), *M. pungens* (Sandhill muhly), *Eragrostis trichodes* (Sand lovegrass) and *Yucca* (*Yucca glauca*) (Fritz et al. 1992). A few of the associated Nebraska species

that are absent from *P. haydenii* habitat in Carbon County, Wyoming, were noted during survey of the Casper dune fields, including *C. atriplicifolia*, *M. cuspidata*, *P. trachysperma*, and *Y. glauca*.

It is interesting that there are dunes in the broad, level center of the Ferris Dunes where there is identical vegetation to that in occupied habitat of *Penstemon haydenii*. However, these dunes seem to have conditions that favor skewed vegetation patterns of stabilization on one hand, or loose, unconsolidated sand on the other. The tension between stabilization and destabilization in the broad valley seems to favor the extremes rather than the intermediate states of flux, resulting in scarcer intermediate states, less vegetation mosaic, and less continuity between intermediate states.

The apparent absence of *Penstemon haydenii* from the Casper dune fields calls for consideration. There are zones in the active dunes of Casper dune fields with the identical vegetation attributes as occupied habitat of *P. haydenii*. However, the active blowouts in the Casper dune field seem to have unidirectional forces, low complexity of successional vegetation, absence of dunes in active series, and no dunes in settings of topographic interception.

Population Size and Trends: Rangewide, *Penstemon haydenii* is currently known from 10 extant indigenous populations in Nebraska and 22 extant transplanted populations in Nebraska (some in the vicinity of indigenous population sites; Kottas 2008). By contrast, Wyoming only has three extant populations, comprised of 19 subpopulations that correspond with discrete blowout areas having limited or no suitable habitat between one another. Each of the three Wyoming populations (also referred to as occurrences) is part of a dune complex, and some have multiple blowouts that represent discrete population segments (hereafter referred to as blowout subpopulations). A summary of *P. haydenii* locations in Wyoming is summarized in Table 4. This represents a final tally, updating those in Fertig (2001) who reported 8 subpopulations (dividing subpopulations finer than current treatment), and the Heidel report (2007) of 16 subpopulations.

Table 4. Location of *Penstemon haydenii* in Carbon County, Wyoming

Population name	Occurrence number	No. of blowout subpopulations	Location
Bradley Peak	001	1	West end of Seminoe Mountains
Bear Mountain-Junk Hill-Ferris	002	15	East end of Ferris Mountains; confluent with northwest end of Seminoe Mountains
Pathfinder	003	3	West outliers of Pedro Mountains
TOTAL		19	

The occurrence names and numbers used for *Penstemon haydenii* throughout this report represent habitat-based delimitation as a preliminary standard for treating populations or population complexes, without the benefit of additional information on genetics, dispersal, and pollination distances to date. The populations each represent occupied habitats separated by over 3 km of unsuitable habitat and are named by the nearest landmark. The three populations are also on three different wind streams and associated dune series. Names have been added for each of the discrete blowout subpopulations, including numbers to differentiate those in a series.

Boundaries of each *Penstemon haydenii* blowout subpopulation were digitized using geographic positioning system (GPS) points recorded in the field and superimposed on digital aerial photography in ArcView and later ArcMap to draw polygon boundaries. GPS points were collected the first time that the blowout subpopulation was documented, while recognizing that both the blowout and the species' distribution are subject to shifts over time (discussed further below). A map of each population with each blowout subpopulation labeled is presented in Appendix E. Bradley Peak is comprised of three contiguous blowouts, and while they represent different zones of occupied and unoccupied bare sand, they functionally comprise an uninterrupted area of likely genetic exchange.

All of the 2011 subpopulations had patchy rather than continuous occupied habitat zones, so they have been mapped in detail as a series of small polygons rather than a single polygon. There have also been isolated clusters of fewer than 10 plants that have been mapped as polygons in the past, but these are not included in current subpopulation tallies. Outliers in low numbers are more appropriate to represent as points rather than polygons.

Penstemon haydenii was considered locally abundant in the Nebraska Sandhills in the early 20th century (Pool 1914), but by the 1940s was thought to be extinct (Fritz et al. 1992). Although the species was rediscovered in 1968, it remained extremely uncommon in west-central Nebraska (Lichvar 1982) and was listed as Endangered under the U.S. Endangered Species Act (USDI Fish and Wildlife Service 1987). The exact reason for this decline is not known, although wildfire control, severe drought, improvements in range management (leading to reduced blowout production), leveling of sand dunes, and outbreaks of pyralid moths have all been identified as potential causes (Fritz et al. 1992).

The original recovery plan for *Penstemon haydenii* (Fritz et al. 1992) had quantitative goals for defining recovery that included the numbers of populations and their size. Recovery was defined by minimal species numbers (15,000), population numbers with a minimum of 300 individuals (10), and associated protection and management. Long-term studies in Nebraska suggest that population size may fluctuate annually, depending on recruitment success and mortality (Flessner and Stubbendieck 1992) so the duration of these numbers adds another variable. The first two survey visits to the Bradley Peak population were made by Fertig in 1999 and 2000, and patterns of local losses between 1999-2000 were thought to be drought-related mortality (Fertig 2001). This and the reported fluctuations of *P. haydenii* numbers in Nebraska placed a premium on collecting population size information and accompanying trends information in Wyoming, to assess the contribution of Wyoming populations in helping achieve the recovery goals.

Fertig (2000, 2001) presented *Penstemon haydenii* population size information based on estimates, noting:

“Permanent monitoring plots were not established due to the difficulty in placing permanent markers in deep, shifting sand and in setting up measuring tapes for transect grids under conditions of persistent strong winds. Alternative monitoring methodologies, such as permanent photo points or a complete population census, will be pursued in the future.”

Starting in 2004, each blowout subpopulation of *Penstemon haydenii* was censused by traversing each part of the occupied habitat, by one or more people walking a series of parallel census lines and counting. Plants were tallied as to whether they had any flowering stems (reproductive), nonflowering stems (vegetative), or browsed stems. We could not be certain in many cases whether or not a given browsed stem once had the potential to be reproductive. The levels of browse also varied, sometimes only a single stem on a multi-stemmed plant was browsed, sometimes only the tip of a stem was browsed, or sometimes all stems and most or all leaves were browsed severely. Flowering stems that were browsed often had most or all of the flowers browsed, so the browsed category is taken as some indication of loss in reproductive potential. Extensive monitoring continued through 2006 (Heidel 2007), with scaled-back monitoring of no more than one subpopulation censused per year in most years until the 2011 field season (2007, 2009-2011).

The parallel paths walked in censusing *Penstemon haydenii* were spaced close or far depending on plant density, viewing and habitat slope. In areas of high density and/or on steep slope, census took place on only one side of the census line. When census involved more than one person in a given area of habitat, census-takers started at opposite ends, or else walked parallel lines and pointed to plants situated near the boundary between parallel census bands as a signal to indicate the plants had been counted. All of the blowout subpopulations take significant time to access and even more time to census. The blowout population covering the largest area, Junk Hill Main, is almost 60 acres, and was the hardest to cover completely in one day, and two years had incomplete survey that did not cover 100% of occupied habitat of this subpopulation. But they were presumed to cover over 95% of occupied habitat on Junk Hill Main. Annotated aerial photographs showing population boundaries were carried into the field for reference and one or more people previously familiar with the blowout subpopulation lead census in subsequent years. Early counts of the Bear Mountain East subpopulation omitted part of occupied habitat in early censuses, an area that contained many plants when added to census in later years. Therefore, the earliest count is not included in identifying minimum/maximum values.

In the course of *Penstemon haydenii* census, all stem clusters were taken to represent a single individual if they were located within a 15 cm diameter. This was expanded slightly if there was evidence of stem burial by sand. This was consistent with Nebraska methods and was also based on exploratory digging in 2002, looking for underground connectivity between stems at different distances from one another (Figure 12). There has been discussion as to whether or not *P. haydenii* reproduces vegetatively. We found two stems within 15 cm of each other that had a severed rhizome between them, indicating at least a repair capacity if not a propensity to reproduce vegetatively. The fact that stems were not seen in lines or cluster patterns of vegetative reproduction, and that there were usually no plants present at intermediate distances from one another (20-50 cm intervals) except under high density, supported this convention of tallying.

Table 5. Population information for *Penstemon haydenii* in Wyoming (2004-2011)²

Occurrence No.	Subpopulation name	No. of annual censuses	Min. census	Max. census	Size ha (ac)
001	Bradley Pk	4	452	776	6.9 (17.1) ³
002	Bear Mt E	4	3358	6317	12.9 (31.9)
002	Bear Mt W	3	622	831	5.0 (12.3)
002	Bear Mt E Out	2	52	87	13.8 (34.2)
002	Bear Mt Valley	1	24	(24)	1.1 (2.8)
002	Ferris 1	1	55	(55)	6.6 (16.4)
002	Ferris 2	1	30	(30)	2.1 (5.1)
002	Ferris 3	1	83	(83)	1.2 (3.1)
002	Ferris 4	1	79	(79)	1.8 (4.4)⁴
002	Junk Hill Main	5	1267*	4816	22.7 (56.2)
002	Junk Hill W1	1	431	(431)	0.1 (0.3)
002	Junk Hill W2	2	1811	2593	1.9 (4.8)
002	Junk Hill W3	2	1648	3646	7.8 (19.2)
002	Junk Hill W4	1	86	(86)	2.7 (6.8)
002	Junk Hill W5	1	36	(36)	0.3 (0.5)⁵
002	Junk Hill Upper	1	60	(60)	0.4 (0.9)
003	Pathfinder S	2	48	80	0.8 (1.9)
003	Pathfinder Middle	1	46	(46)	0.7 (1.6)
003	Pathfinder N	1	769	(769)	1.0 (2.6)⁶
TOTALS			10,957	20,845	89.8 (222.1)

² Subpopulations that were discovered in 2011 surveys are bold-faced. Census figures from incomplete censuses in 2002 and 2004 are excluded.

³ Bradley Peak had a second small outlying subpopulation of 0.3 ha that was originally documented as having over 20 plants in 1999 but which has not persisted in subsequent years.

⁴ Further divided into four separate areas.

⁵ Further divided into two separate areas.

⁶ Further divided into three separate areas.

Penstemon haydenii subpopulation census numbers at minimum/maximum values

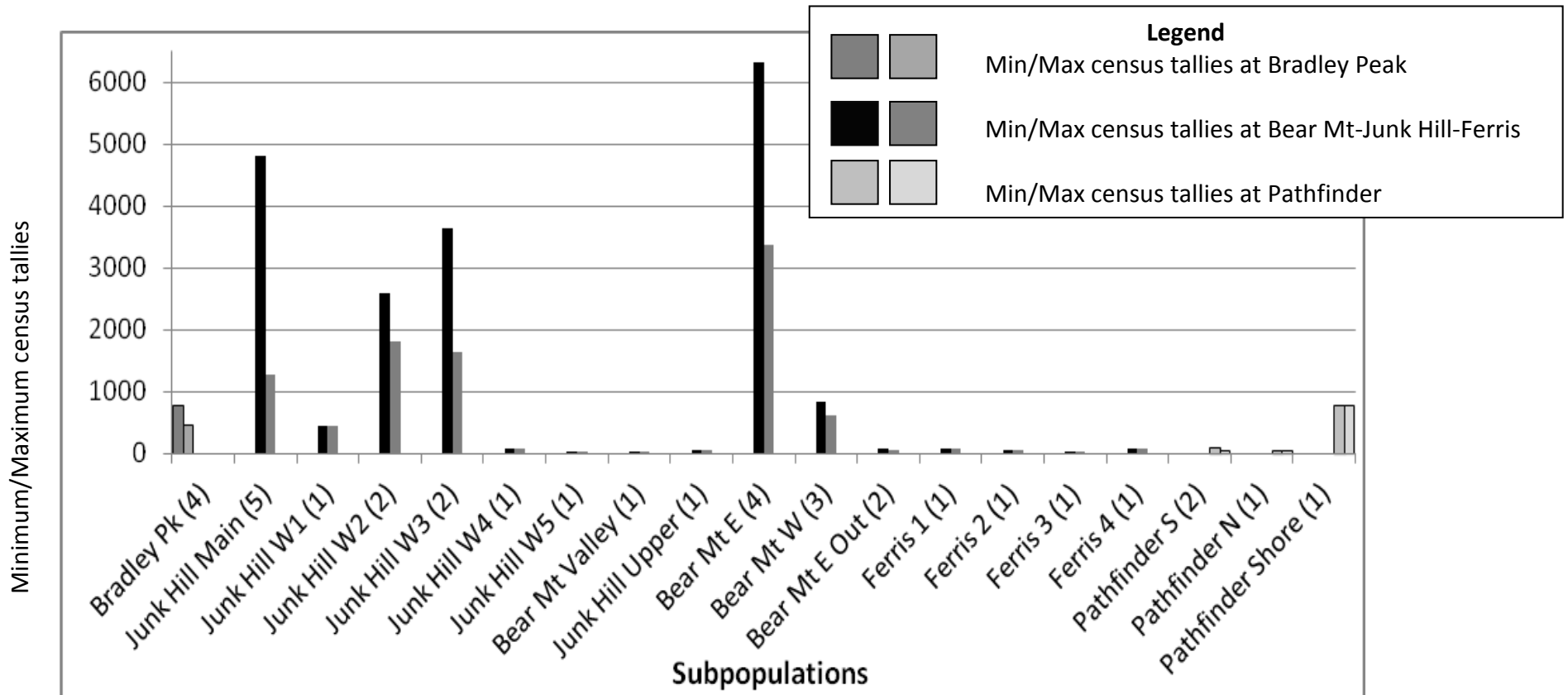


Figure 28. *Penstemon haydenii* census results – maximum/minimum subpopulation values⁷

⁷ The number in parentheses after the subpopulation name represents the number of years that complete census has been conducted for the subpopulation.

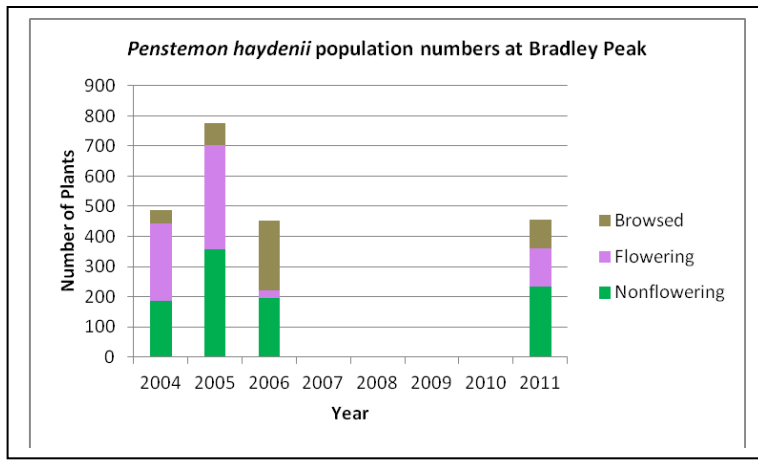


Figure 29. *Penstemon haydenii* population numbers at Bradley Peak

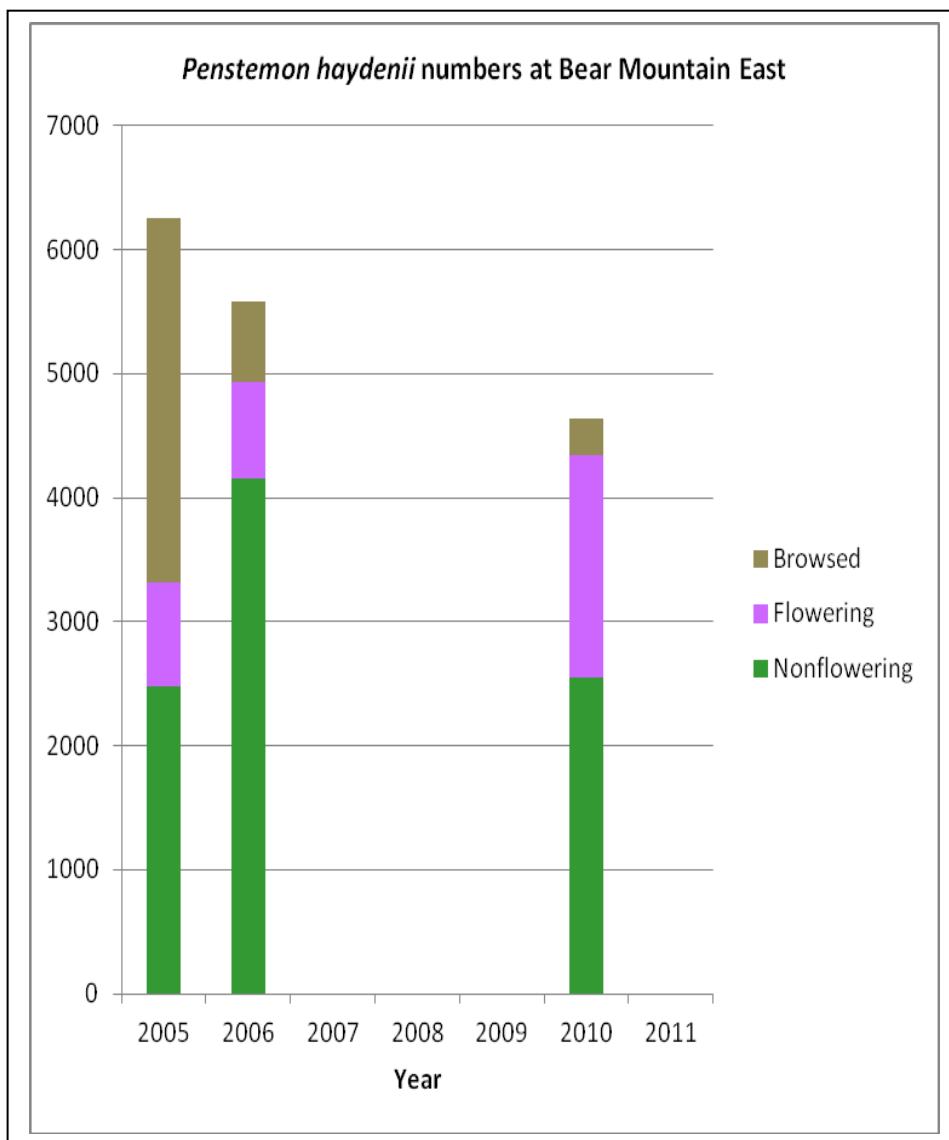


Figure 30. *Penstemon haydenii* population numbers at Bear Mountain East

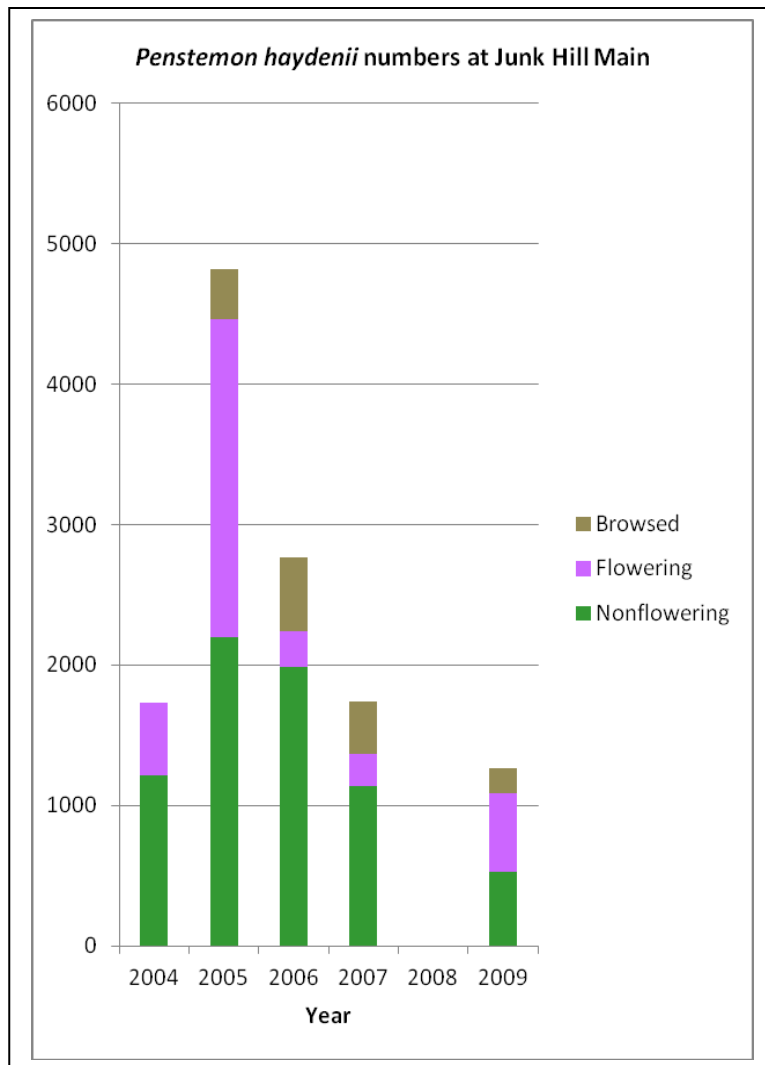


Figure 31. *Penstemon haydenii* population numbers at Junk Hill Main

The original goal was to document *Penstemon haydenii* population trends in all subpopulations having 300 plants or more, a number used to define large populations/subpopulations in the recovery plan (Fritz et al. 1992). A bar graph of census data for all known subpopulations was in the final monitoring report (Heidel 2007; Figure 2). The one consistent pattern is that all *P. haydenii* subpopulations with 2005 census data had higher numbers that year than in preceding or following years. This means that the sample size was not suited for determining trend. Moreover, monitoring started before completion of surveying in 2011, and there are now eight subpopulations that have been documented as ever having 300 plants or more. Half of the eight have only one or two censuses, inadequate for trend analysis.

Penstemon haydenii is most conspicuous when it is in flower, one of the main reasons that census has been timed in early summer. Browse levels increase over the growing season, and keeping the same period between years maintains consistency in gauging browse levels. Livestock do not enter

the allotment until this time or later. Strong winds bearing sand have been rare at this time, and the rains and temperatures extremes generally moderate.

The census of large *Penstemon haydenii* subpopulations was extended beyond 2006 at three subpopulations (Figures 29-31). These subpopulations all had peak numbers in 2005. The greatest subsequent declines in numbers were at Junk Hill Main (having the gentlest slopes) and the least subsequent decline has been at Bear Mountain East (having the steepest slopes). It is hypothesized that habitat destabilization and associated decline in plant numbers is greatest on the gentler-sloping dune settings, having the highest migration rate or instability, compared to the steep dune settings. If there is subirrigated moisture in the dune settings, it is possible that moisture levels drop in gentle settings more readily than they do on steep slope settings.

The *Penstemon haydenii* census results show that flowering levels were high in 2005 for all three subpopulations, the same year as the spike in numbers. Flowering levels can approach levels of 50%, but vary from year-to-year and site-to-site. Flowering rates were often lowest in the smallest subpopulations, and there were no flowering plants found in the two smaller of the newly-discovered 2011 subpopulations. Browse levels were phenomenally high in 2005 at Bear Mountain East, approaching a level of 50%, and constrained flowering activity. Browsing has consistently been present in all years at all subpopulations.

Climate data were compiled for trend interpretation context, focusing on monthly average precipitation (Figure 32), based on the Rawlins Airport. The climate data for this NOAA station had gaps at critical intervals, including all of 2004, and whole months of data missing from 2001, 2003, 2005 and 2006. The years that had missing months of data are represented by “?” in Figure 29 and the values of monthly means were inserted as approximations. It seems as though 2005 was a near-average annual precipitation year (av. 9.2 in) and had the highest precipitation levels among a series of below-average precipitation years (Table 5, Figure 32, USDI NOAA 2007).

In any case, the main years of *Penstemon haydenii* census (2004-2006) appear to be within a drought period, as indicated by the Palmer Drought Severity index. Figure 33 shows the drought index pattern on the Lower Platte watershed, contiguous with the Upper Platte watershed that encompasses the study area, and which has the longest-running record in Wyoming. The 2000-2007 period is the longest uninterrupted drought interval since 1895 (USDI NOAA 2009).

Barr (1946) believed that the tendency to bloom profusely in certain years makes the plant vulnerable to weather conditions and local extinctions. We found that flowering was much more stable than seed germination and establishment. It is hypothesized that the 2005 spike in *Penstemon haydenii* population numbers reflects a multi-decadal peak in numbers that corresponds with a turning point from habitat stabilization to renewed destabilization. This is evaluated further in light of demographic information and habitat trend information in the report sections that follow. By this hypothesis, 2005 numbers reflect an infrequent phenomenon, and population trends are driven by mortality and recruitment levels associated with landscape-scale habitat trends.

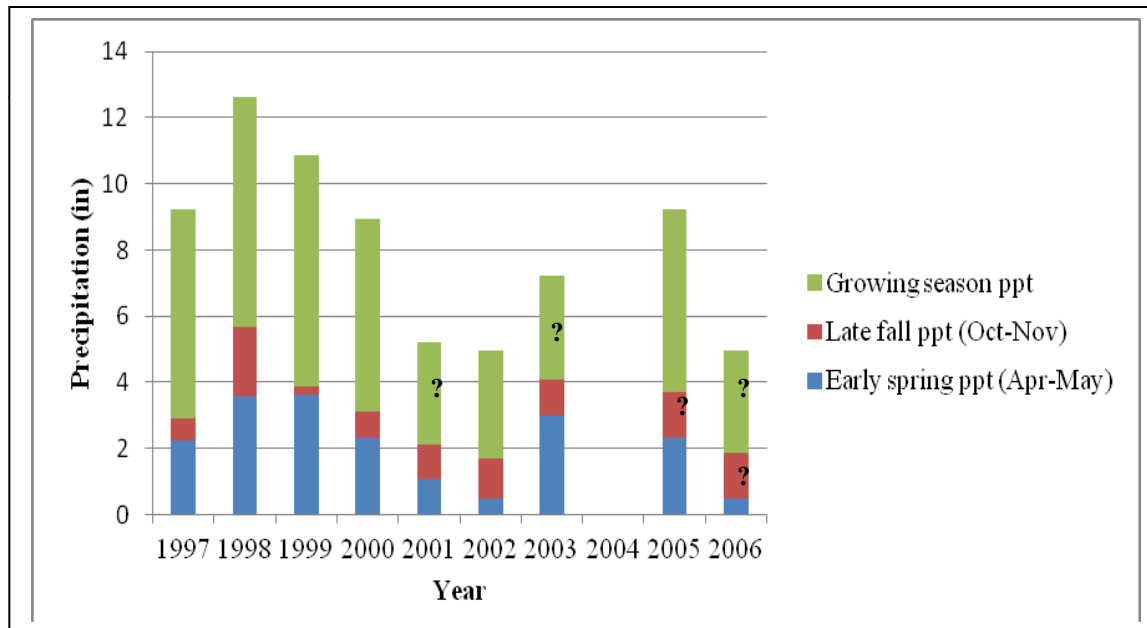


Figure 32. Annual precipitation at Rawlins FAA Airport (Station 487533; USDI NOAA 2006)

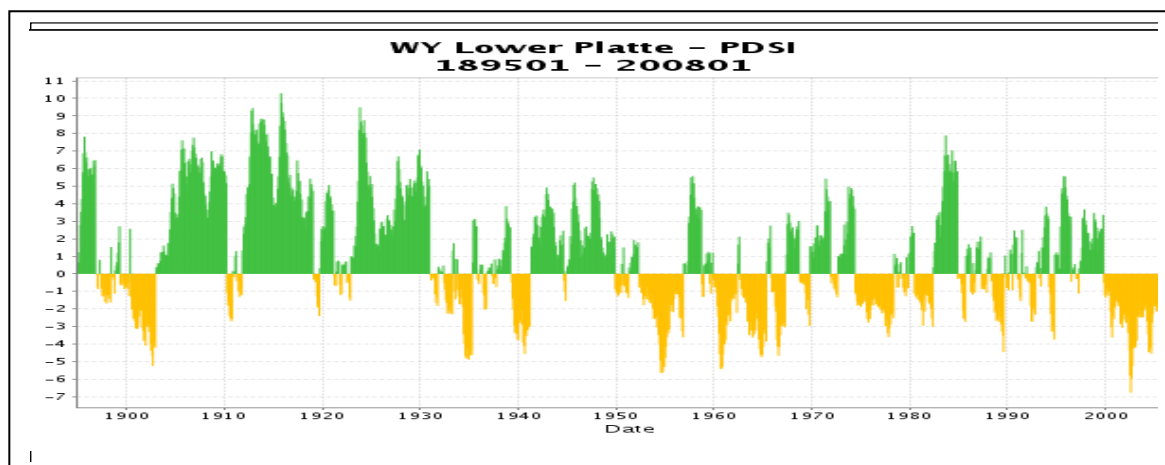


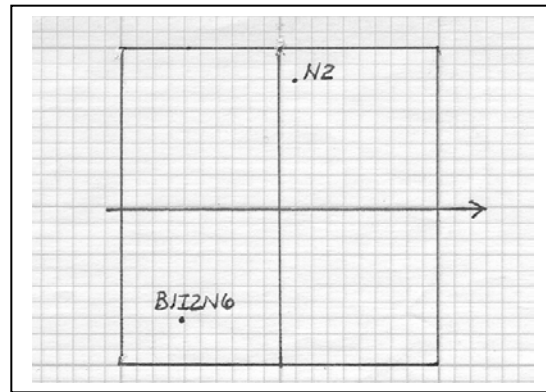
Figure 33. Palmer Drought Severity Index for the Lower Platte Watershed, southeastern Wyoming (1895-2007)

In the past, all demographic information and life history information for *Penstemon haydenii* was based on greenhouse information (Barr 1951, Flessner and Stubbendieck 1989, Lamphere 1999), experimental transplant experiments (Stubbendieck et al. 1993), and field observations. Therefore, pilot demographic monitoring was set up concurrent with census in Wyoming to get life history information and whatever other context might be available in tracking individual plants over time (2004-2006). It was not known if permanent monitoring in shifting dunes is feasible, as noted by Fertig (2001). The permanent monitoring included two permanent belt 50 m belt transects (2 m wide) set up at Junk Hill Main in 2003, and in one permanent 25 m belt transect (2 m wide) set up at Bradley Peak in 2004. Ends were marked by 1 m rebar and recorded as GPS points and compass

bearing. The endpoints were also used as photopoints. Data were collected in a 1 m² frame constructed of PVC pipe and joints marked in 10 cm intervals. Locations of all plants were mapped on graph paper by 10 cm-interval coordinates (estimating to 5 cm if there was more than 1 plant in a 20 cm x 20 cm area). A schematic diagram of the belt transect is presented in Figure 27.

The status of each stem making up the plant was recorded as to whether it was a flowering inflorescence (I), nonflowering (N), or was browsed (B). The latter could be the hardest to spot and were recorded first. The plot data were transcribed in the office onto excel spreadsheets to track individual plants over time based on coordinates, and identifying any disparities between years as tentative recruitment or mortality by size class and reproductive class.

Figure 27. Schematic diagram of permanent belt transect and data recording conventions. Four plots are diagramed to the right. Two of the four plots have plants, including a plant with 2 nonflowering stems, and a plant with 1 browsed, 2 flowering inflorescence stems, and 6 nonflowering stems.



The belt-transects were placed in areas of relatively high *Penstemon haydenii* density, including the blowout rim (Bradley and Junk Hill Main) and immediately downwind from the blowout on the lee slope (Junk Hill Main). There was no problem relocating rebar endpoints between years except that in the last year of monitoring (2006), one of the three transects (Junk Hill Main – 1; the transect downwind of the blowout) lost 5 m (10%) of habitat to expansion of the blowout. Its 2006 belt transect was re-read by laying a line from the remaining endpoint based on compass direction of the line.

The age of *Penstemon haydenii* plants was unknown at the start of demographic monitoring, and there is no reliable indication of plant age as indicated by size or number of stems. Plants were placed into size class categories (1 stem, 2-4 stems, 5-10 stems, and 11+ stems) and reproductive classes (flowering, nonflowering, browsed) for stage-based transition analysis. No seedlings were observed. The single-stemmed plants had the highest mortality levels of all size classes. Of the 189 plants present in Junk Hill Main belt transects in 2003, at least 71 persisted through 2006 (38%). Since plants were at least a year old at the start of monitoring, if the monitoring period were representative, then the mean longevity would be less than four years old. However, of the 189 original plants, 174 had more than a single stem and would be expected to be at least two years old if not older, and the majority had 5 or more stems. The monitoring period also represented a drought period. From the information at hand, this suggests that mean longevity of established plants exceeds 5 years. Demographic work is warranted only when there are seedlings present.

This was not set up as a study of the affects of browse on *Penstemon haydenii*, but the small dataset can be used for preliminary comparison of the fate of browsed vs. unbrowsed plants of different size classes and of different monitoring intervals (2004-2005 vs. 2005-2006). Mortality rates between browsed and unbrowsed plants differed little between years, and increase in size and flowering level trends differed more between years than between whether or not a plant had been browsed in the prior year. Browse did not appear to be a cause of mortality in and of itself. But a portion of the plants that had browsed stems had the stems browsed to stubs (see Figure 10). This may make them vulnerable to burial, and explain the high mortality in 2006 of the highly browsed plants in 2005. It was determined by Kottas (2008) that plants subject to clipping treatment to simulate grazing/browsing had no significant differences compared to unclipped plants in their plant survival and flowering stem numbers after either the first or second growing season.

There was no 2005 spike in *Penstemon haydenii* numbers in the demographic belt transects, only a steady decline, possibly indicating that local trends are independent of overall subpopulation trends. This suggests that nonrandom subsampling does not represent the subpopulation as a whole. Since the species distribution is nonrandom, this also indicates that random sampling is at least as unlikely to represent the subpopulation as a whole. This is interpreted to indicate that there are no known sampling techniques to substitute for census.

Penstemon haydenii plants in the two transects at Junk Hill Main were both subject to burial. We found that the plant persisted in the growing season when buried and a vestige of stem remained aboveground. But we didn't measure burial phenomena and it may have contributed to mortality in the plots. In any case, there were large areas outside the transect where deep burial occurred in 2006, and no surviving plants emerged from the center of the deep burial areas in subsequent years. This modifies previous statements that *P. haydenii* can recover from sand burial (Barr 1944), suggesting that it cannot recover from complete, prolonged burial.

Censusing the eight largest *Penstemon haydenii* subpopulations would require a minimum of five full days by two people. There have not been tests of replicability to assign a margin of error. Half of the work force in most of the past years has included first-time participants. If we assume that monitoring needs to exceed the mean average lifespan of established plants, then it needs to span more than five years. The scope of prior monitoring - three subpopulations for three consecutive years - would have to be quadrupled if the goal were to assess trends by the original recovery standards. There has been no precedent for this scale of Threatened and Endangered plant monitoring work in Wyoming, in terms of extent and duration combined.

Demographic monitoring of *Penstemon haydenii* was also pursued in a total of eleven Nebraska populations, including both indigenous and transplanted ones, in a three-year, four-part research program that also addressed seed longevity and germination, grazing effects, and floral herbivory and fungal disease (Kottas 2008). Only one of six indigenous and two of five transplanted populations had positive growth rates. The youngest stage of life history, from juvenile to established plant, was the most influential in determining growth rates. Habitat parameters were documented in the effort to sort the influence of habitat trends from population trends. The possibility that there are cycles of increasing and decreasing growth rates was postulated, requiring longer monitoring intervals to sort trends of a few years from those of several years (Kottas 2008).

In summary, Wyoming's *Penstemon haydenii* population numbers appear to have peaked in 2005. It remains to be determined whether the subsequent decline has plateaued or continues to decline. Population trends may mirror habitat trends. The dune habitat was extensively destabilized in 2006, signifying both new potential habitat and lost occupied habitat as discussed below.

Habitat Trends: *Penstemon haydenii* habitat in Wyoming is subject to change simultaneously with population numbers at different scales of change. The largest-scale habitat alterations observed since 1999 occurred in 2006 at the culmination of monitoring, and right after peak population numbers in 2005.

Different forms of *Penstemon haydenii* habitat change were observed incidental to species' monitoring. In 2006, rims of blowouts breached that previously were semi-continuously vegetated and held together by root masses of lemon scurfpea (*Psoralidium lanceolatum*), only to be eroded out or buried. As a result of breached rims, many blowout bowls filled in with several meters of sand. The slip-face slope of the Bradley Peak became more unstable, depositing sands downwind and doubling the length of the open sand zone (Appendix E). The blowout at Junk Hill Main that was about 2 m upwind from the belt transect when the transect was set up in 2003 eroded out 5 m of the transect in 2006. At the same time, wetland habitats associated with dunes were drier in 2006 than ever before observed (Appendix G). Either drought had a lag affect in its manifestation, or there were a combination of conditions that made 2006 particularly destabilizing.

The blowout crater is often one of the most unstable microhabitats for *Penstemon haydenii* but this is almost the only zone where seedlings have been observed as censused in 2004 (Figure 8). A bare blowout crater on Bradley Peak that had seedlings in 2004 was semi-vegetated in 1999, as documented in photographs, and in later years was completely buried again in sand. This suggests that seedling germination is episodic, seedling establishment is also episodic, and that the former does not guarantee the latter.

In the absence of any other information on population trends, information on habitat trends was compiled using two sources. First, the geologic record offers clues. The stratigraphy of the Ferris Dunes has been documented and periods of eolian activity identified (Stokes and Gaylord 1993). It is summarized by Forman et al. (2001):

“The record from the Ferris dune field shows that two major eolian episodes occurrence from ca. 8.2 to 7.4 cal. ka⁸ and from ca. 4.3 to 4.0 cal. ka. There is evidence of sporadic eolian activity between ca. 6.5 and 5.5 cal ka. Periods of relative landscape stability existed from ca. 7.4 to 6.7 cal. ka and from ca. 5.3 to 5.0 cal. ka. At least one episode of dune remobilization occurred after 2.0 ca. ka.”

Comparison of dune activity records as well as loess deposition records in the Great Plains shows that the two most recent periods of eolian activity in the Nebraska Sandhills and in the Ferris Dunes were close if not overlapping (Figure 13 in Forman et al. 2001). These Holocene episodes of activity do not reflect dune origin and earlier Pleistocene activity, but only suggest that dune activity is episodic, and there was some level of dune synchrony in Nebraska and Wyoming as they might relate to species' origin.

⁸ Cal. ka means calibrated at about x number of 1000 years before present

Second, historic aerial photographs provide more recent information about dynamics of the Ferris Dunes. All available aerials from the study area were compiled from the Geology Library at the University of Wyoming, for direct comparison with NAIP imagery. The study area is completely covered by digital orthophotography from 1994 and 2009. There is partial aerial photo coverage for the study area that includes 1939, 1949, 1960 and 1977 imagery. All parts of the study have at least three aerial images (two digital images and one or more earlier images). Using this imagery, it might be possible to quantify the magnitude of change in open habitat, which appears as net loss in comparing 1994 or 2009 imagery with almost any prior image. It is easy to use for comparing changes in dune zonation and outline. One of the most graphic changes is the doubling of the length of loose sand at Bradley Peak between 1994-2009, which occurred at some time between the 2005 and 2006 census readings.

This historical aerial imagery sets are reprinted in Appendix E and suggest that all paired comparisons between the more recent digital imagery (1994, 2009) with that of any earlier aerials show decreases in net area of open sand. It is possible to quantify this change between 1994-2009 because the aerials are digital. It is possible to less precisely quantify changes between the recent and earlier aerial imagery if adjoining outcrops were used for geo-reference.

If the past decade is any indication, it might be more appropriate to think of *Penstemon haydenii* habitat as different entropy states, each dune with its own trends at any given time interval. These entropy states represent different levels of or balances between stabilization and destabilization. Ironically, the steeply-sloping occupied habitat has had some of the stablest population numbers in recent years, and this habitat may be less suited to migrating than the gently-sloping dune habitat.

Population Biology and Ecology: *Penstemon haydenii* plants are not evenly distributed across blowout habitat, but are generally found in sparse patches, bands and swathes that may correspond with habitat preferences, succession events, dispersal vectors, germination factors, mortality factors and chance. In Nebraska, density typically varies from 1 plant per square meter to 1-2 plants over several hundred meters (Fritz et al. 1992). In unusually favorable microsites in Wyoming, density can be 2-3 plants per square meter (Heidel 2005a). The numbers censused in Wyoming's *P. haydenii* subpopulations ranged from 24 plants to over 6000 plants. Demographic monitoring suggested that recruitment is episodic, and does not necessarily occur around parent plants.

Penstemon haydenii flowers from May to early July in Nebraska and produces fruits from mid-June to mid-July. Occasionally, flowering may re-occur from early August to early September (Fritz et al. 1992). Flowering in Wyoming occurs later than in Nebraska, from the middle of June often to early July. The earliest known flowering date start in Wyoming is 10 June (2004) when the first flowers were beginning to open (Blomquist pers. obs.). The latest known flowering date start in Wyoming is after 21 June (2011), when it was observed in bud and at least a few days from flowering, also at Bradley Peak. In addition, the lowest elevation population seems to flower up to a week earlier than the two higher populations, but this is based on limited observations. The latest known flowering date in Wyoming is 7 July (2000) when only one plants still had flowers at Bear Mountain. In summary, the start, peak and end of flowering can vary by up to two weeks between years. The duration of flowering has not been determined by repeat visits but appears to last for up

to three weeks at any given site. Browsed plants may sometimes produce late flowers on axillary shoots, extending the flowering period. The late flowering phenology in Wyoming compared to Nebraska is probably in response to drier and cooler climatic conditions and the shorter growing season.

Flowering of *Penstemon haydenii* is indeterminate (beginning at the base). Aborted flowers were noted at the tip of the inflorescence some years. The number of years that it takes for an established plant to produce flowers under natural conditions is not known. In Nebraska, 1-year transplants have been observed to flower the year after transplanting. Most greenhouse plants begin to bloom at 2-3 years of age (Flessner 1988a, b). No comparable information is available for plants in Wyoming.

Ratios of flowering to nonflowering *Penstemon haydenii* plants differ by subpopulations and between years. In 2005, a peak year of flowering, the ratio between flowering and nonflowering plants approached or exceeded 1:1 at several of the largest populations, and 2005 was consistently the best flowering year for all subpopulations except the heavily-browsed Bear Mountain East subpopulation.

Penstemon haydenii is one of only two self-incompatible species of *Penstemon* known thus far, so it is pollinator-dependent for sexual reproduction (Tepedino et al. 2006a, b). This changes prior interpretations that it is potentially self-fertile (Flessner and Stubbendieck 1992). Comparative pollination biology has been documented for it in the Nebraska Sandhills compared to that in the Wyoming Ferris Dunes, pointing to the same bee families (Apidae, Halictidae, Megachilidae); expanding on the work of Lawson et al. (1989). Over 20 different bee species were documented at both sites, all native, with mostly the same genera represented but only 7 of the same 45 bee species were present in both states. Visitation patterns were analyzed to determine pollinator importance, which differed significantly between Nebraska study sites as well as between states. Preliminary evidence was also found that flowers in Wyoming (but not Nebraska) experienced reproductive limitation. A plethora of other insect visitors were documented that, with the exception of a vespid wasp, had little or no role in pollination.

This guild of *Penstemon haydenii* pollinators may require many alternate pollen sources among flowering plants over the growing season, so a running list was compiled of vascular plant species in or adjoining *Penstemon haydenii* habitat, their phenology relative to *P. haydenii* flowering, and their pollination syndrome (Appendix F), as conducted incidental to monitoring in Wyoming. Caha et al. (1998) studied genetic variability in mitochondrial and chloroplast DNA from a subset of Nebraska populations of *Penstemon haydenii*. Although no difference could be detected in chloroplast DNA, at least 8 distinct markers were found in mitochondrial DNA, indicating a greater amount of genetic variability than would be expected in an inbreeding population. It was suggested that this variability could be due to high levels of gene flow between populations in the past. However, more recent documentation of it as an obligate outcrosser (Tepedino 2006a, b) points to pollination as vital to genetic variability. Pollination potentially compensates for limits to gene flow between today's isolated Nebraska populations. Intrapopulation genetic diversity may also be enhanced by the long-lived seed bank of this species, which allows new cohorts of seedlings to contain a mix of ages and genealogies (Caha et al. 1998).

There were no signs of symbiotic relations with *Penstemon haydenii*, and it is characterized as only marginally dependent on mycorrhizae (Flessner and Stubbendieck 1992), though nutrient levels are low (Table 2). The low mean infection levels were the basis that the authors characterized mycorrhizal relations as having limited bearing on viability of Blowout *Penstemon* in the Nebraska Sandhills.

In Nebraska, *Penstemon haydenii* plant size and reproductive success were examined to determine the average number of flowers per plant, the average proportion of flowers that produced fruit, the average number of fruits, and the average number of viable seeds per fruit (Tepedino et al. 2006a). By this measure, they determined that the average plant probably produces about 2000 seeds. This is an increase above earlier estimates that as many as 1500 seeds may be produced by each plant (Flessner and Stubbendieck 1992). *P. haydenii* inflorescences typically have over twice as many flowers in Nebraska as compared to Wyoming (Heidel pers. observation) so this indicates that the potential seed output in Wyoming would be less than 50% that in Nebraska.

Nebraska populations were further beset with insect floral herbivory, most likely due to grasshoppers, and fungal infection, ascribed to any of four pathogens (*Cercospora*, and possibly also *Fusarium*, *Rhizoctonia*, and *Alternaria*) that infect the inflorescences more than the leaves. Insect herbivory and disease have also been observed at high levels in Nebraska populations, but work to document loss levels by means of insecticide and fungicide treatments has not been successful to date (Kottas 2008). In Wyoming, specks of fungus infection on flowers were noted on flowers of *Penstemon haydenii* at Junk Hill Main in 2004, but had no apparent effect on flowering activity. Insect herbivory has not been noted.

Kangaroo mice and deer mice have been identified as consumers of *Penstemon haydenii* seed in Nebraska (Stubbendieck et al. 1993). Kottas (2008) has documented that seed predation can make the difference between 30% of viable seed remaining in the seed bank in the second spring after emplacement as compared to less than 1% remaining. Burial decreases the likelihood of predation. In Wyoming, mice sign were present in occupied Wyoming habitat. This was particularly evident as mice middens of sprouted seeds (possibly *Achnatherum hymenoides* seeds; Heidel 2004 personal observation).

In general, *Penstemon haydenii* seeds are released starting in late August and fall near the parent plant or are dispersed by wind or animals (Fritz et al. 1992; Stubbendieck et al. 1997). *P. haydenii* seeds have thick seed coats containing leachable chemical inhibitors. The seeds are often buried in shifting sand and can remain viable in the seedbank for 20 years (Stubbendieck et al. 1997). As noted above, Kottas (2008) reported that there is high seed predation that drastically reduces the potential seed bank. The winged seeds appear to be adapted for wind dispersal, with a pair of narrow, parallel wings forming almost a full circle like a tire hub. Winged seeds are uncommon among members of the *Penstemon* genus.

Prolonged wet conditions and abrasion are required for breaking dormancy and seed germination (Flessner 1988). Additional carryover mechanisms exist to regulate water uptake and germination of seeds, thus preventing the entire seed pool from germinating at once under seemingly favorable

conditions (Caha et al. 1998). Stubbendieck et al. (1982) found that scarification (especially removal of the radicle end of the seed) increased germination success from the normal 10% to 60%. Allowing seeds to imbibe water 12 to 24 hours prior to scarification improved germination success to 90-95% and may indicate the presence of a water-soluble inhibitor (Flessner 1988 a,b; Stubbendieck et al. 1982b). Nebraska researchers determined that seed germination is further enhanced by cold-moist stratification, a treatment that simulates overwintering conditions. Scarification under sulfuric acid treatment also greatly enhanced germination from levels of 4% to nearly 90% (Stubbendieck and Kottas 2007). Wind abrasion by sand particles may serve as the mechanical scarification.

Penstemon haydenii seeds have been collected on two occasions in Wyoming, first as part of pollination research (Tepedino 2006b), and more recently for seed biology research (Puckett and Meyer 2012). The former determined that average numbers of seeds/fruit ranged from 25.0-29.1 at Bear Mountain East and Junk Hill Main, respectively, when hand-pollinated between different plants. The number of seeds/fruit dropped to 15.9 in the absence of hand-pollination treatment, when left to natural pollinators at Bear Mountain East. This was taken as preliminary evidence that the species may be pollinator-limited in Wyoming.

The latter study collected two seed lots from Bear Mountain East, one when not fully mature on 9 August, and the other when ripened in the capsule and the capsules were beginning to shatter on 27 August. Both seed lots had base levels of viability at 90%. Germination levels were measured after treatments (hand scarification, soaking, gibberilic acid) and showed levels of 66-82% (Puckett and Meyer 2012). Germination response to scarification in combination with cold stratification resulted in lowered seed germination levels, all below 10%, and the researchers concluded: “The seeds seem to be programmed not to germinate immediately under optimal conditions, and it is probable that *Penstemon haydenii* seeds never germinate to a high percentage over a short time interval” (Puckett and Meyer 2012). Last, seed response to acid scarification was tested, in light of results by Stubbendieck and Kottas (2007) who were able to stimulate germination in seeds from Nebraska populations of *P. haydenii* from untreated levels at 4% to nearly 90%. The results using the same methods on Wyoming seeds documented 28-36% germination that was increased by prolonging the acid scarification to levels of 40-68% germination. At this point in time, despite high seed viability of Wyoming seeds, there has not been a means of inducing high germination rates using much the same techniques as those used on seed from Nebraska populations. Seed germination experiments will continue.

Seedlings of *Penstemon haydenii* become established with the development of a taproot. Barr (1951) noted that established seedlings 10-14 cm (4-5 in) tall often have roots over 30 cm (1 ft) long. Nebraska researchers have reported that, under natural conditions, seedling establishment is exceedingly low due to high levels of insect and rodent predation, plant pathogens, and unfavorable climatic conditions (Caha et al. 1998). Good seedling establishment may only occur every 8-10 years (Stubbendieck et al. 1997).

Penstemon haydenii seedlings have been observed in 2003 and 2004 in Wyoming. The presence or vestige of the cotyledon was the primary indication of the seedling stage, and seedlings tended to have similar size and occupy similar zones on a local scale. There were less than 100 seedlings

found in 2004 when they were tallied. Almost all were restricted to the bottoms of blowout depressions, and the highest numbers were in the series of blowouts west of Junk Hill, and less at Bradley Peak. Photographs taken at Bradley Peak in 2000 (Figure 8, in Fertig 2001) show that this blowout crater that once had grass cover in 2000 had no grass cover in 2004 but supported 31 seedlings of *P. haydenii*. By early summer, seedlings generally had only 2-4 leaves besides those of the cotyledon (Figure 6), and plants were less than 4 cm tall. Seedlings were subject to erosion. There were also flushes of seedlings of *Psoralidium lanceolatum* found in dune blowouts during 2004 surveys, and they had overall similar stature and growth form but with slightly different leaf outline and a glandular-pocked surface. The local distribution of seedlings for the two species had little overlap within blowout craters. No survivorship of *P. haydenii* seedlings was found in subsequent years.

The growth rate of *Penstemon haydenii* seedlings is conditioned by nutrient levels, and high growth rates are prolonged by mechanical injury to the apical meristem, stimulating axillary shoots (Flessner and Stubbendieck 1989b). *P. haydenii* seedlings transplanted into blowout zones had a high initial mortality in all but the blowout depression settings, where median life-span of first-year survivors ranged from three years (Thomas County) to six years (Cherry County). The authors concluded that *P. haydenii* has an intermediate life span, with a complete cycle from seed deposition to plant death occurring within 5-10 years (Stubbendieck et al. 1993, Kottas 2008).

Statements have been made that *Penstemon haydenii* reproduces primarily by rhizomes (Fritz et al. 1992; citing Stubbendieck et al. 1983, 1984; Flessner and Stubbendieck 1989, and Stubbendieck and Weedon et al. 1982). Further research showed that vegetative reproduction is not important compared to sexual reproduction (Stubbendieck 2001). Instead, axillary root branching may be more of a survival adaptation to erosion, and root branches more a function of vigor rather than a reproduction mechanism. Observations of adventitious roots in the field indicated that they have a primary anchoring function (Figure 12). Observations of axillary root branching were made by excavating around flowering stems in close proximity to evaluate how to differentiate individuals when doing census. In the course of conducting census, it was considered whether any given plant has been subject to burial or excavation by wind, and whether the axis of flowering stems appeared to converge below ground. In general, flowering and nonflowering stems (ramets) that are not buried or eroded out, converging at a subterranean axis and within about 15 cm were interpreted to represent the same individual (genet). If vegetative reproduction were widespread, then some guidelines would have been needed to convey census counts of *P. haydenii* clumps to genet counts. In any case, we did not find evidence of long-distance connectivity in digging around plants (Figure 12).

Penstemon haydenii is also adapted to its environment in having a waxy cuticle over the epidermis. As Weedon et al. (1982) wrote: "The plants must be able to withstand the fury of the drying winds of late summer and the accompanying withering sandblasts." Even though it occupies highly exposed habitat and is subject to strong winds early in the growing season, there have never been signs of plant damage or desiccation noted during census.

Current Management: Wyoming populations of *Penstemon haydenii* occur on lands of the Bureau of Land Management Rawlins Field Office (BLM), the State of Wyoming, and the Bureau of

Reclamation. Each agency has its own management framework and mission. About 80% of all occupied habitat is on BLM-administered land, followed by state and Bureau of Reclamation lands (Figure 34). Likewise, roughly 60% of *P. haydenii* numbers are on BLM land. One of the largest subpopulations, Bear Mountain East, is mainly on state land.

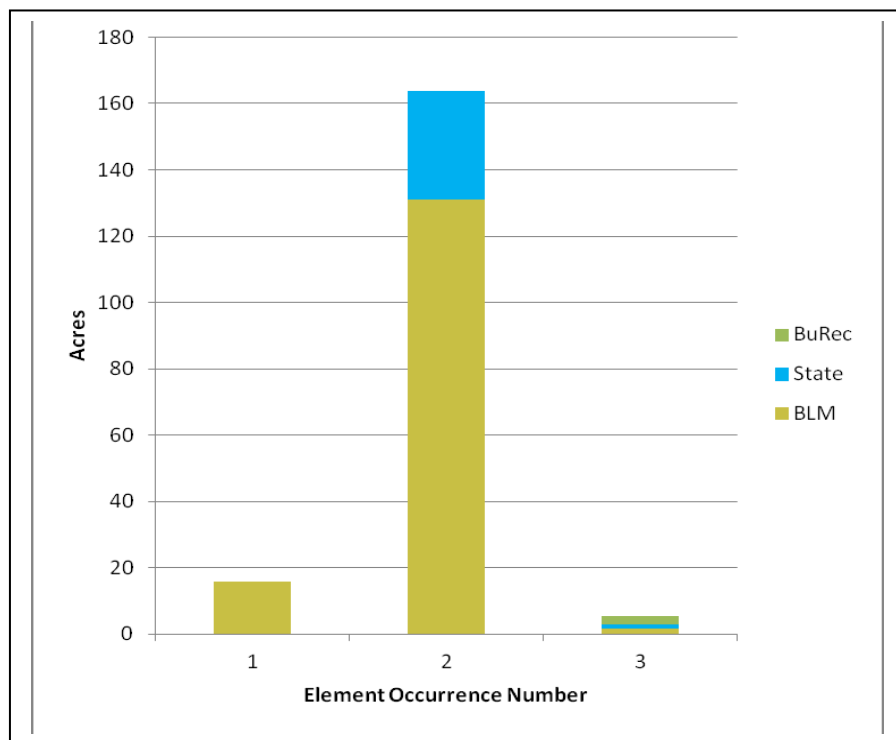


Figure 34. *Penstemon haydenii* occupied habitat area, by public land agency

An analysis of potential BLM management effects on *Penstemon haydenii* has been developed in a Biological Assessment (BA) document (Chamberlain 2011) to address all any overlapping resource matters and management actions:

- Cultural Resources
- Paleontological Resources
- Fire Management
- Forest Management
- Lands Program Management
- Livestock Grazing Management
- Minerals Management
- Recreation Management
- Soil, Water, and Air Management
- Visual Resource Management
- Wild Horse Management
- Wildlife Habitat and Fisheries Management

The purpose is to identify and circumvent potential conflicts. The BA awaits a Biological Evaluation by the U.S. Fish and Wildlife Service.

In 2007, BLM designated a 17,050 acre block of occupied and adjoining lands as Blowout Penstemon Area of Critical Environmental Concern (ACEC; USDI BLM 2007). The designation applies only to BLM lands and not any other public or private lands within boundaries. The course of management on BLM lands will be detailed in a management plan that will be prepared for the ACEC.

The first BLM planning document to address *Penstemon haydenii* was a conservation assessment, though it was prepared before survey was completed. It is not known if and when it might be updated. Maintenance of *P. haydenii* and its habitat is identified as a management priority under the current Rawlins Resource Management Plan (USDI Bureau of Land Management 2008).

All *Penstemon haydenii* populations are on lands that are part of large grazing allotments. The three agencies coordinate allotment planning, and the lands administered by the Bureau of Reclamation near Pathfinder Reservoir are managed by the BLM Rawlins Field Office. On both BLM and Bureau of Reclamation lands, *P. haydenii* is protected under the Endangered Species Act, and likewise in any federal actions. But is not protected on State Trust lands, where the highest general purpose is generating revenue for public schools. Insofar as current management on state lands is livestock grazing, this may be compatible with species' conservation. *P. haydenii* is not known from private land in Wyoming, but two of the new subpopulations are on BLM tracts encircled by private land. In another case, private tracts are encircled by BLM lands that support *P. haydenii*. While private land management may not directly affect *P. haydenii*, private lands are part of the same grazing allotments, access to them is controlled by private landowners, and the possibility of any developments on private land may affect public land management. The presence of private land in the vicinity of two *P. haydenii* populations, and the westward extension of the Bear Mountain - Junk Hill – Ferris population in particular, increase the possibility that *P. haydenii* may extend onto private tracts. This has not been investigated. One can only make qualified inferences from photointerpretation that nearly all major blowout features are on public lands rather than on private lands.

In Nebraska, *Penstemon haydenii* is protected at two sites of indigenous populations in the Valentine Lake and Crescent Lake national wildlife refuges and a transplanted population in the Samuel R. McKelvie National Forest (administered by Nebraska National Forest). Protected populations also occur at Ballard's Marsh Wildlife Management Area (managed by the Nebraska Game and Parks Commission) and The Nature Conservancy's Graves Ranch (Gerry Steinauer, personal communication; Stubbendieck and Kottas 2004, Kottas 2008). All other known populations are on private or state lands managed mainly for agriculture (Fritz et al. 1992).

Existing and Potential Threats: The following potential threats have been identified for this species, including changes to its habitat condition, grazing and trampling, over-collection, and surface-disturbing activities like mineral development, water resources development, ORV recreation, oil and gas leasing and associated infrastructure, and wind energy development and associated infrastructure. Some of these may operate directly on the species and others may operate indirectly on the habitat. Threats may be exerted directly or indirectly.

Changes to Habitat Condition: Historically, fire and grazing by bison and livestock helped maintain the blowout habitat of *Penstemon haydenii* by removing sand-stabilizing vegetation in Nebraska. The implementation of fire-control policies in the 1870s following white settlement, elimination of bison, initiation of soil conservation programs, and increased usage of rotational grazing systems have reduced the influence of wind erosion in maintaining early-succession habitat, resulting in the loss of *P. haydenii* habitat and a reduction in its population size in Nebraska (Fritz et al. 1992). The set of aerial photographs (Appendix E) suggest that there has been an overall trend of habitat stabilization over the past 30-70 years. Despite this overall trend, blowouts remain active at some level.

At the other extreme, extensive drought, such as the Dust Bowl drought of the 1930s, has been suspected as a cause of the serious decline of *Penstemon haydenii* in the Nebraska Sandhills early in the 20th century. While drought could create new habitat by killing grass cover and making sites more prone to erosion, *P. haydenii* may be vulnerable to prolonged water stress and sands that are too active for seedling establishment, and which cause deep seed burial. It is possible that Wyoming habitat is on this trajectory of increased destabilization. In any case, the Wyoming populations do not appear to be immediately threatened by habitat stabilization, at least not to the degree that they are in Wyoming.

Habitat quality at *Penstemon haydenii* sites could also be degraded in Wyoming by introduction of noxious weeds, exotic species in general, and native species that increase under disturbance. The low elevation Pathfinder population is weedier, whether because the conditions are milder, the levels of grazing use have historically been heavier closer to the reservoir, or the reservoir is a corridor for weed dissemination. Russian knapweed (*Centaurea repens*) recently got introduced at the base of the Bradley Peak population site and could become a major infestation, possibly even entering *P. haydenii* habitat. Cheatgrass (*Bromus tectorum*) is one of the more common non-native species in the Pathfinder population and has been observed to be spreading in some of the Bear Mountain subpopulations.

As previously discussed in under habitat trends, *Penstemon haydenii* population numbers may reflect the wind- and climate-driven patterns of vegetation stabilization and destabilization in Wyoming insofar as conditions increase or decrease available habitat and meet seed germination and seedling establishment requirements. Histories of bison use and fire frequency are not available for the Wyoming landscape. The Wyoming habitat trends appear to reflect predominantly natural patterns of change rather than management patterns of land use.

Livestock Trampling and Grazing: *Penstemon haydenii* is edible to cattle and horses, but is not preferred forage if other vegetation is available (Fritz et al. 1992). In Nebraska during non-drought conditions, grazing on *P. haydenii* is minor and confined mostly to occasional shoots. Such grazing can be stimulatory in breaking apical dominance (Fritz et al. 1992). When other forage is severely limited, as during drought conditions, severe grazing damage can occur (the entire above-ground portion of the plants may be eaten).

In theory, it is possible that the more arid habitat of *Penstemon haydenii* in Wyoming compared to Nebraska would be associated with greater grazing pressure. However, there have not been patterns

of herbivory, habitat alteration or livestock behavior observed to support this. The occupied habitat of *P. haydenii* lies within three large allotments. Cattle currently graze the allotments. Up until 2002, the allotment that included the Bradley Peak occurrence was grazed by sheep (Blomquist personal communication 2004). In Wyoming, the open sand dune setting of *P. haydenii* has limited livestock use except where it adjoins water sources such as ponds, spring seeps, and wetlands.

The sparsely-vegetated sand pioneer communities that support *Penstemon haydenii* are basically in excellent range condition because they receive little use. There is a shift toward “increaser” species (native species that increase under disturbance) at the Pathfinder blowouts. There is also a shift in species composition at the lower fringes of Bradley Peak associated with heavy use of the spring-fed meadows directly below. Due to the sparse distribution of *P. haydenii* and its shifting substrate, trampling damage is rarely significant on established plants (Fritz et al. 1992). However, cattle trampling can be particularly destructive to seedlings and transplants that are becoming established (Stubbeneick et al. 1982b). It is not known if any mineral or feed supplements are brought into the allotments with *P. haydenii* habitat. It would be important that any hay or other feed be certified as weed-free.

Reports of stem herbivory from grazing or browsing was noted in 2000, on nearly 10% of the *Penstemon haydenii* plants at Bear Mountain and Junk Hill in 2000 and on 60-80% of stems at Bradley Peak in July 2000. These include two of the steepest blowout settings that the species occupies and much of this herbivory was attributed to elk or mule deer based on the abundance of their tracks, rather than domestic stock, which seem to prefer the adjacent wet, grassy meadows to the barren dunes (Fertig 2001). Thus, ensuing censuses were conducted early or before any livestock were brought into the pasture, so that herbivory associated with wildlife browse could be addressed, as discussed in population trend information and below.

Wildlife Browse: Wildlife browse levels have ranged from 1-53% and are often proportionately higher in the larger subpopulations on *Penstemon haydenii* in Wyoming (Heidel 2007). There were some of the highest browse levels in 2005 at Bear Mountain East when population numbers spiked, indicating that it may be preferred forage. The Pathfinder population of *P. haydenii* is browsed by antelope, while the other populations are browsed by both elk and antelope, as based on direct observation, scats and tracks. Levels of browse have not been determined outside of the flowering period at the time of census, but it is fully expected that browse activity continues over the growing season. Broken stems have not been noted during the course of census, and only occasionally is the species eroded out by wildlife traffic across occupied habitat on steep terrain.

Over-collection: Many rare penstemon species are vulnerable to over-collection for seed or garden stock. Small populations near state highways are considered especially vulnerable to this threat in Nebraska. Specific site locations have been kept confidential to reduce the threats from overharvest (Fritz et al. 1992).

The Wyoming populations of *Penstemon haydenii* appear to be relatively isolated and inaccessible to protect them from over-collection at the present time. However, it is still appropriate that species' location be treated as sensitive. This sensitive status precludes posting of location data in reports and distribution of location data in data requests.

At the same time, outreach efforts have been undertaken to inform the Wyoming public about *Penstemon haydenii* and present the pro-active research in progress. These have included a poster of Threatened and Endangered plants in Wyoming (Bureau of Land Management and Wyoming Natural Diversity Database), a widely-distributed flyer (Heidel et al. 2008; printed and on-line), a popular article (Heidel 2005b) and small tours for educational purposes.

The rest of existing and potential threats relate to surface-disturbing activities. They are addressed separately by activity.

Oil and Gas Leasing: Oil and gas leasing occurs at the west end of the Bear Mountain – Junk Hill – Ferris occurrence near the Ferris townsite, including pumps, pumping stations, and a pipeline corridor. Addition of no-surface-occupancy stipulations would help provide safeguards if there were expansion in future. It is also at least remotely possible that drilling operations and recovery activity could affect local groundwater levels.

Wind Energy Development: The area between the Ferris and Seminoe Mountains was first identified as having persistent high winds of exceptional wind power potential by Kolm (1973) in a series of studies evaluating wind patterns, long-term climate change and wind-power potential from eolian landforms, precipitated by the 1970's oil embargo (summarized in Grasso and Marrs 1993). It functions as a natural wind funnel (Gaylord and Dawson 1987). It is an area of particularly high mean turbulent kinetic energy, responsible for sand deposition on steep slip-face slopes hundreds of feet high. In recent years, there have been wind energy permit applications that encompass *Penstemon haydenii* populations (Blomquist pers. commun.). Any alteration of on-site or upwind flow patterns, or related access development and construction, could affect the species and its habitat.

Mineral Claims: Sand quarrying may still occur southeast of the Seminoe Mountains near the Seminoe Road, a paved county road that provides access to Seminoe Reservoir and Seminoe Dam. Sand removed from the Seminoe Reservoir area has been used for golf courses, salt mix for road sanding in the towns of Sinclair and Rawlins, and at the City of Rawlins asphalt plant. Sand deposits in *Penstemon haydenii* habitats are distant from this activity and it seem impractical that they could be quarried due to the isolated location (7-15 miles from county roads), rugged terrain, and limited access. Changes to access could affect the economics of sand quarrying. There is not any information that compares the sand qualities of the Ferris Dunes with other sand sources in the state.

In the early 1980's, an individual came into the BLM Rawlins Field Office inquiring about sand from the Seminoe Road area for glass production. Tests revealed that the clay content of the samples made it unsuitable (Mark Newman, BLM Geologist personal communication to Frank Blomquist). It is not known whether the sand deposits in *Penstemon haydenii* habitat are suitable for these or other uses.

The Seminoe Mountains to the south of *Penstemon haydenii* populations have mineral deposits of iron, copper and gold (Hausel 1989). In addition, dune systems often contain wind-worked rock

(ventifacts), sometimes including chert. There are no mineral activities at present in the vicinity of occupied habitat.

Roads: The public road access to most parts of the three population sites is limited, via county and BLM roads. They all require walking 0.25-3 miles to access the blowouts. Vehicular travels on BLM lands are limited to existing roads, which helps maintain the dune habitats.

A road in the Ferris area marked as a county road on the BLM surface management map (Bairoil 1:100,000) but is deeply buried in sand and impassable. However, it could be the basis for claiming pre-existing use across the landscape. Essentially there are four separate dead-end roads to occupied habitat, and if there were any road developments between them, it would dramatically change access to occupied habitat.

Off-road Vehicles: The sand dune habitats of *Penstemon haydenii* in Nebraska are often popular for off-road vehicle (ORV) recreation, especially on public lands. Hill-climbing and other ORV activities may accelerate natural erosion in excess of plant colonization. Driving over the plants leads to high mortality (Fritz et al. 1992). This is particularly true for ORV when there are multiple ORV vehicles at the same time or repeated ORV use over time.

Most of the Wyoming *Penstemon haydenii* populations are relatively remote at present. The exception was at the newly-discovered Pathfinder subpopulation, where one or two sets of ORV tracks ran highmarks in tight circles up steep sand slopes. These particular tracks did not impact *P. haydenii*, but repeated use could accelerate erosion, and any increases in frequency or number of simultaneous uses is likely to be associated with greater extent, directly impacting the species by breaking plant stems or eroding them out. This particular subpopulation lies on Bureau of Reclamation lands.

Prior to 2011, three ORV incidents were noted (Heidel 2005a), at least two of which were straight tracks likely to have been set by leasees for range work that have limited affects. BLM and Bureau of Reclamation recreation planners should be made aware of the possible impacts to these populations from ORV use in all recreation and transportation planning.

Other Recreational Uses: The area is used by hunters and off-the-beaten-track tourists. Recreation use is light except at the subpopulation on Bureau of Reclamation land that is readily and routinely accessed by motorboat recreationists.

Water Development: Ponds and springs are present at the base of occupied *Penstemon haydenii* dunes at Bradley Peak, Bear Mountain and Junk Hill and one place appears to have been excavated as a stockpond. They are water sources for livestock. There are little or no prospects for farming using central pivot irrigation. Water developments may still potentially concentrate the levels of livestock grazing to directly or indirectly influence *P. haydenii* habitats.

Miscellaneous: Not all threats can be anticipated. Insect outbreaks were identified as potential threats to *Penstemon haydenii* in Nebraska, where it is preyed upon by spider mites, grasshoppers, penstemon aphids, and *Endothenia hebesana* (a seed predator) (Fritz et al. 1992). The most serious

pest is probably the larvae of pyralid moths, which bore into the stems and rootcrowns of *P. haydenii* to pupate and can cause 75% mortality (Stubbenieck et al. 1997). Fungal root rots can also cause death through wilting (Fritz et al. 1992). However, there have been no disease or pest outbreaks observed in Wyoming (1999-2011). The direct impact of herbicides on *P. haydenii* is not known, although the plant is probably vulnerable to broadleaf weed killers (Fritz et al. 1992). Due to the sparse cover of its habitat, herbicide application rates are minimal in Nebraska and are not known in Wyoming at present. The use of insecticides to combat range pests such as grasshoppers is a potential threat to the pollinators of this species (Tepedino 2006b).

U.S. Fish and Wildlife Service Recovery Plan: The U.S. Fish and Wildlife Service recovery plan for *Penstemon haydenii* (Fritz et al. 1992) promoted research into the life history and the management needs of this species in Nebraska for two decades. It spurred a major propagation-and-transplant program, reintroducing it into the historic range of the species across the Nebraska Sandhills. The primary goal of the recovery plan and contributing research was to reach stable populations having at least 15,000 individuals in 10 population groups (each with a minimum of 300 plants at the lowest ebb of a population cycle) in Nebraska. A minimum level of protection and management planning was also identified as needed for each of the target populations (Fritz et al. 1992).

The discovery of new *Penstemon haydenii* populations in Wyoming, well outside its presumed range, may be significant for the protection and future downlisting or de-listing of this species (Fertig 2000, 2001; Heidel 2005a) because the status of plant species is determined rangewide under the Endangered Species Act. This has spurred Wyoming surveys and research that might apply to recovery. The work conducted in Wyoming to date is represented by this report.

The existing *Penstemon haydenii* recovery plan does not represent *P. haydenii* biology, habitat biology and habitat conditions in Wyoming, or the specific research needs, protection needs and prospective recovery actions. This raises question if and how to incorporate *P. haydenii* information unique to Wyoming into recovery planning.

Regardless of recovery plan direction, the studies of *Penstemon haydenii* in Wyoming will help inform the Wyoming planning processes that are currently underway, including the updating of the statewide Biological Assessment for *P. haydenii* among the Threatened and Endangered species on BLM lands in Wyoming, the Biological Effects review of that document, and the development of management guidelines for the Blowout Penstemon Area of Critical Environmental Concern. These planning activities have major importance in ameliorating species' threats, setting the course for future recovery, and ultimately in determining species' status under the Endangered Species Act.

SUMMARY

Penstemon haydenii distribution in Wyoming is confined to the Ferris Dunes where parabolic dunes intercept topographic barriers. The biogeography of this species, previously considered endemic to Nebraska, is unusual. The circumstances of its discovery in Wyoming after listing and recovery

plan development are even more unusual, and the ESA implications are in early stages of being addressed.

Initially, the discovery of *Penstemon haydenii* in Wyoming raised the question whether the species may be more widespread and thus less imperiled than previously known (Fertig 2001). It has not proven to be widespread, though complete population census numbers at minimum/maximum values have documented population totals that ranged between over 10,000 - 20,000 plants. The high numbers appeared to represent a one-time spike in 2005, and the low numbers might plateau or decline further depending on the degree of occupied habitat destabilization currently underway.

Taxonomic research using genetic analysis techniques is the most far-reaching work that will shape species' status and impetus for continuation of *Penstemon haydenii* studies in Wyoming. The information needs that are spelled out in this report are contingent in one way or another on taxonomic research. The information needs include:

1. Seed germination and seed ecology research. There is little information on the earliest stages of life history for *Penstemon haydenii* in Wyoming, despite repeated visits. This research is underway.
2. Habitat trends. While the habitats of Nebraska populations are directly affected by management, Wyoming habitat trends are shaped mainly by climate. This is critical context and confounding factor in evaluating population trends. The framework for this research is laid out in the report and appendix.
3. Life history research. The pilot demographics study demonstrated the challenges of collecting life history information in the field. There might be a demographic monitoring plan contingency developed for rapid response if field visits were to document seedlings in any given year. Alternate approaches might be pursued including greenhouse research in tandem with common garden experiments of Nebraska and Wyoming plants.
4. Population trends. The definition of numeric goals in the recovery plan (Fritz et al. 1992) could be strengthened by addressing fluctuating population numbers and length of time standards. The three information needs above are important for evaluating overall population trends.

There is a strong case to make that the new *Penstemon haydenii* populations and subpopulations in Wyoming can contribute to rangewide recovery goals. However, there will not be *P. haydenii* recovery achieved in Wyoming until the framework for recovery is updated to include information from the state. The recovery standards may also warrant refinement.

In closing, *Penstemon haydenii* recovery is already advancing in Wyoming with incorporation of study results into agency guidelines and planning work underway. More than ever, there is an imperative for communication between states, coordination between agencies, and collaboration among all parties.

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