Population Trends of *Penstemon haydenii* (blowout beardtongue) – Extensive Monitoring in 2015-2017
Final Report
Carbon County, Wyoming

Prepared for
Bureau of Land Management – Rawlins Field Office and State Office

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ABSTRACT

This report presents monitoring results for *Penstemon haydenii* (blowout beardtongue) from the third and final year of extensive monitoring at all dunes supporting high numbers in Wyoming. It provides a three-year compilation of annual trends and a comparison with an earlier three-year period of monitoring a decade ago. The overall objective was to document population trends in all of the blowouts on public land that have ever had high numbers (i.e., census records of more than 300 established plants, a metric cited in the first recovery plan). We documented the following:

1) *Penstemon haydenii* numbers declined in recent years at all monitored dunes during the recent 2015-2017 period compared to the 2004-2006 period.
2) *Penstemon haydenii* numbers showed an uptick for 2017 numbers at most monitored dunes in an annual comparison with 2015 and 2016 numbers.

This monitoring study was designed to address established plants, the only life history stage that has reliably been found in most years. Objectives were expanded to address unprecedented germination levels in recent years, and results from this phase of study temper the decadal decline among established *Penstemon haydenii* plants.

Pilot work on seedling trends to date indicates that seedling distribution is highly localized compared to the extent of established plants, that there is high mortality, and that there are differing rates of mortality and survival over short distances that may be significant in answering the question whether the recent germination episode is adequate to compensate for the decadal trends.

ACKNOWLEDGEMENTS

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INTRODUCTION

Penstemon haydenii Wats. (blowout beardtongue[1]) was listed as an Endangered species in 1987 under the Endangered Species Act (ESA; USDI Fish and Wildlife Service 1987; FWS) when it was regarded as endemic to the Nebraska Sandhills. A recovery plan was prepared for *P. haydenii* (Fritz et al. 1992) that set recovery objectives based on a minimum population numbers (300 plants) at a minimum number of populations where it is naturally reproducing and self-sustaining over time. Long-term monitoring has been conducted in Nebraska to gauge progress in meeting recovery goals (e.g., Stubbendieck and Kottas 2004).

In 1996, *P. haydenii* was discovered below Bradley Peak in Carbon County of southcentral Wyoming by Frank Blomquist (Bureau of Land Management; BLM) who photographed the species. Vouchers were collected in 1999 (Roderick et al. 1999, Taylor 2000, Fertig 2000, 2001). Information on *P. haydenii* distribution and trend were scant in Wyoming to address status and recovery needs. This prompted surveys in Wyoming dune fields starting in 2000 (Fertig 2001, Heidel 2005, Heidel 2012) and extensive monitoring from 2004-2006 (Heidel 2007) following the same monitoring conventions used in Nebraska. We found that plant numbers differed significantly from one year to the next, so annual monitoring for a minimum number of consecutive years seemed to represent the best approach at gleaning overall trends. After the 3-year monitoring project, scaled back monitoring ensued (2007, 2009-2013) to census at least one dune per year as rudimentary gauge of trends.

In 2012, *P. haydenii* was addressed in a 5-year review (USDI Fish & Wildlife Service 2012). The review called for a recovery plan update incorporating the most current status information and refining recovery criteria. It also identified current population numbers and research to:

> "… include objective, measurable criteria which address all listing factors and which, when met, will result in a determination that the species be downlisted and eventually removed from the Federal List of Endangered and Threatened Plants. Recovery criteria should include population growth rates over time and documentation of populations dispersing to unoccupied habitat" (USDI Fish & Wildlife Service 2012)."

Thus, the central purpose of this three-year project was to obtain current population and trend data by replicating extensive monitoring of *P. haydenii* plants in 2015-2017 at each dune on public lands that has ever had 300 plants. This includes all of the five dunes that were monitored earlier (2004-2006), plus one dune that was not found until 2011. This monitoring work represents baseline monitoring as needed to understand population trends and set meaningful recovery objectives in the sense of Elzinga et al. (1998). This third-year report builds on and compiles data from the two prior interim reports (Heidel 2016, 2017).

[1] *Penstemon haydenii* has been referred to by the common name "blowout penstemon" in all prior WYNDD reports and data products. The common name for it in the PLANTS database is blowout beardtongue, consistent with conventions being used by Flora of North America, so this new common name is now being treated as the accepted common name in Wyoming.

STUDY AREA

Dune location

Penstemon haydenii is present at the east end of the Ferris Dunes of northwestern Carbon County, Wyoming (Figure 1).

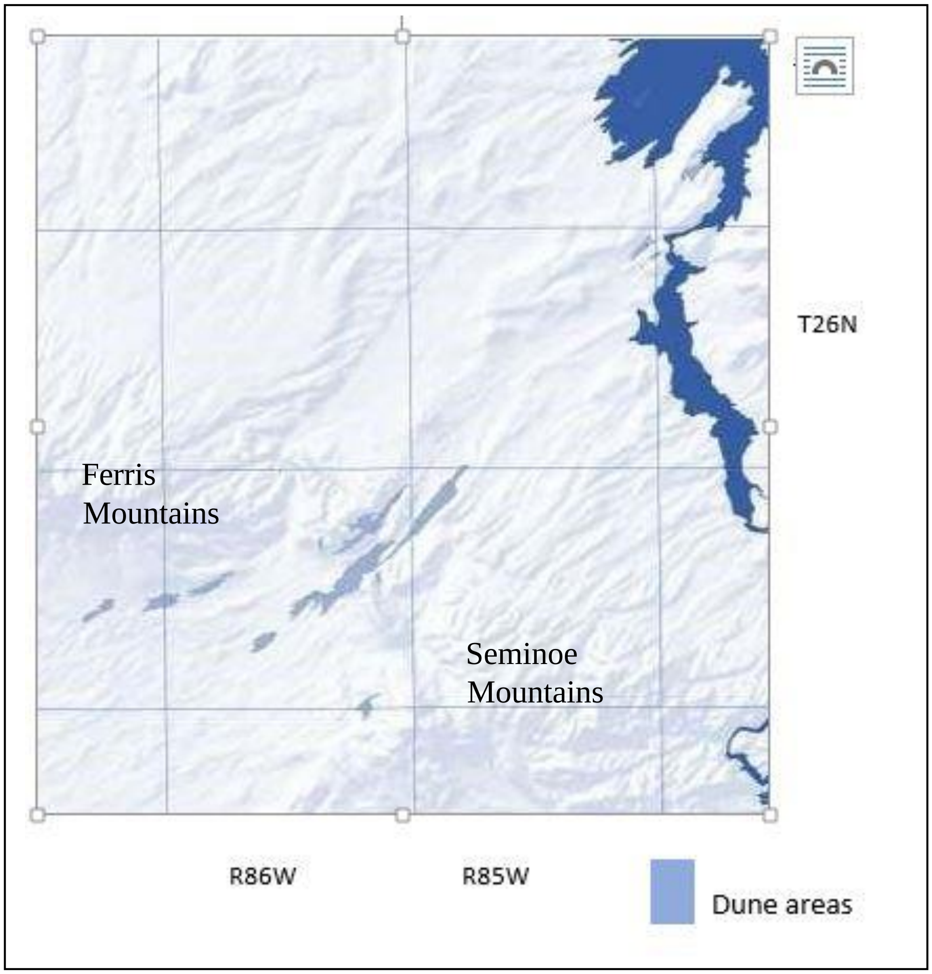

Figure 1. Sand dune areas supporting *Penstemon haydenii* in Wyoming[2]

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[2] This map of occupied sand dune areas is a composite of active sand dunes from 1946-2015. They migrate over time such that this compendium merges the distinctions that are evident at any given time between dune areas in the central set. It is addressed in Heidel et al. 2014 and 2018[4]. Note that in the 2016 report and all prior years of monitoring results, the Bear Mountain – Junk Hill – Ferris population complex was described as having 15 dune areas but since that time, we merged Bear Mountain East and Bear Mountain West based on the fact that they had been just one continuous dune area in 1946 imagery.

There are 22 occupied dunes[3]. Six dunes with highest numbers were addressed in 2015-2017 monitoring (see Table 1). The six dunes represent all dunes on public lands that have or once had over 300 plants in Wyoming. The areas of occupied habitat that were censused are shown in Appendix A. Four are on BLM lands; the other two are on state and Bureau of Reclamation (BOR) lands.

Table 1. Monitoring priorities among dunes occupied by *Penstemon haydenii* in Wyoming[4]

Dune Name	Population Name	Priority? (>300 plants)	First Discovery	Agency/ Ownership[3]
Bradley Peak	Bradley Peak	Yes	1996	BLM
Junk Hill Main	Bear Mtn-Junk Hill-Ferris	Yes	2000	BLM / R2
Junk Hill West 1	Bear Mtn-Junk Hill-Ferris	No – mostly pvt	2004	BLM / R1
Junk Hill West 2	Bear Mtn-Junk Hill-Ferris	Yes	2004	BLM / R1
Junk Hill West 3	Bear Mtn-Junk Hill-Ferris	Yes	2004	BLM / R1
Junk Hill West 4	Bear Mtn-Junk Hill-Ferris	-	2004	BLM
Junk Hill West 5	Bear Mtn-Junk Hill-Ferris	No – mostly pvt	2011	BLM / R1
Bear Mt Valley	Bear Mtn-Junk Hill-Ferris	-	2000	State
Junk Hill Upper Outlier	Bear Mtn-Junk Hill-Ferris	-	2000	BLM
Bear Mt [East+West][4]	Bear Mtn-Junk Hill-Ferris	Yes	2000	State/R2
Bear Mt Outlier	Bear Mtn-Junk Hill-Ferris	-	2002	BLM
Ferris 1	Bear Mtn-Junk Hill-Ferris	-	2005	BLM/R2
Ferris 2	Bear Mtn-Junk Hill-Ferris	-	2005	BLM
Ferris 3	Bear Mtn-Junk Hill-Ferris	-	2005	BLM
Ferris 4	Bear Mtn-Junk Hill-Ferris	-	2011	BLM
Ferris 5	Bear Mtn-Junk Hill-Ferris	-	2016	R2
Ferris 6	Bear Mtn-Junk Hill-Ferris	-	2016	R2
Ferris 7	Bear Mtn-Junk Hill-Ferris	-	2016	R2
Ferris 8	Bear Mtn-Junk Hill-Ferris	-	2016	R2
Pathfinder Reservoir	Pathfinder	Yes	2011	BOR
Pathfinder South	Pathfinder	-	2004	BOR
Pathfinder North	Pathfinder	-	2004	State

[3] In this report, the word "dune" refers to a discrete area of open sand with habitat occupied by *Penstemon haydenii*. Some are in clusters that might signify populations or population complexes.
[4] BOR refers to Bureau of Reclamation lands. State refers to State Trust lands. R1 refers to private property of Ranch 1, surveyed in 2015. R2 refers to private property of Ranch 2, surveyed in 2016.

Dune dynamics

In this report, the word "dune" refers to a discrete area of open sand with habitat occupied by *Penstemon haydenii*. Some are in clusters that might signify a large population or population complex. There are occupied and unoccupied zones within any given dune, there are many dunes in the vicinity that are not occupied, dunes migrate and change, and that there are many variations on dune morphology and landscape position. These include climbing and falling dunes, and isolated dunes or dune series.

Analysis of all major occupied dune areas has been conducted using aerial images from 14 acquisition dates over 70 years that were scanned, orthorectified and used to digitize potential habitat (Heidel et al. 2018). We found out that all dunes currently containing *Penstemon haydenii* subpopulations were present in 1946. The 2012 and 2015 active dune areas (all dunes combined) were about 14% lower than the 70-year mean, indicating a possible but modest loss of habitat. This decadal loss of habitat is not nearly as severe as that seen for the Nebraska population of *P. haydenii* where complete loss has been documented. Dunes migrated downwind, with the fastest dune migrating 18 m/yr. The faster migrating dunes had lower subpopulations sizes. Dune size was not correlated with dune migration rate.

A composite map of active dune areas since the 1940s shows the 70-year extent of dunes and their confluence over time (Figure 1). The Bradley Peak Dune population, where *P. haydenii* was first discovered, is a single isolated dune. The Pathfinder Dune population is comprised of three dunes occupied by *P. haydenii*, only one of which has high numbers warranting monitoring. The third population, the Bear Mountain – Junk Hill – Ferris dune complex is a population complex (metapopulation) that spans across almost nine miles, with 18 occupied dune areas that are all active, on the same wind currents, and close to one another for pollinator and seed dispersal connectivity. For purposes of the monitoring study, they are treated as separate regardless of historical confluence or proximity to one another. We note that in 2015, one more dune area with high numbers of plants was discovered on private land, but it is excluded from consideration because of private ownership. In total, six discrete dune areas on public land have, or once had, over 300 *P. haydenii* plants. These six dunes have much more than half of the total number of *P. haydenii* plants of all 22 occupied dunes combined.

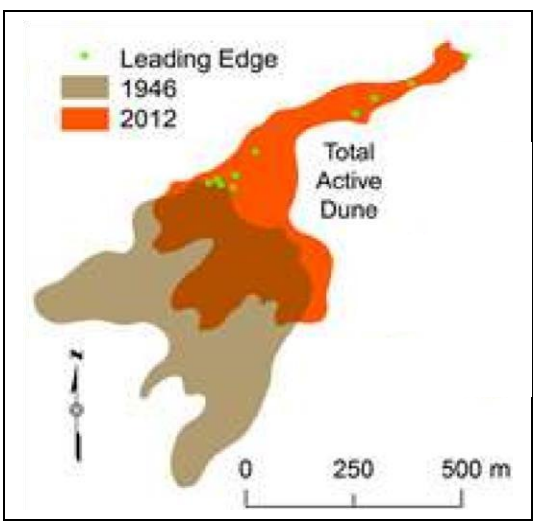


Figure 2. Bradley Peak Dune location

Climate

Climate data provide valuable context for the recent monitoring work, and has not previously been reported with monitoring results. Peak precipitation is early in the growing season, with the highest values averaging 5 cm in May, and to a lesser extent in April and June (Figure 1, 1980-2010; PRISM).

Mean annual precipitation in the Ferris Dunes is 28.8 cm (1946-2015; PRISM). In an expanded evaluation of PRISM data for the same locale (1947-2015), only three months in the past 49 years had monthly precipitation less than 0.1 cm, and two of those three extremely subnormal periods were shortly before the recent monitoring interval. The two were in June of 2013, which had 0.069 cm; and in June of 2012, which had 0.088 cm. At the other end of the spectrum, only four months in the past 49 years have had monthly precipitation over 10.0 cm, and the highest one was at the start of the current monitoring phase in May of 2015, which had 12.58 cm. In other words, meteorological conditions have been highly dynamic, in keeping with dune movement dynamics (Heidel et al. 2018), even though the management framework has remained the same over the course of monitoring. Some of the extremes in dynamic conditions, both high and low extremes, occurred at the start or shortly before the recent monitoring period.

Wind also directly affects erosion. Wind speeds and directions were monitored for a full year at two anemometers located upwind and downwind in the Ferris Dunes. They were collected as part of geological research (Gaylord 1984), and analyzed against the measurements of mean quartz grain size making up the dunes. It was determined that minimum wind speeds of 4.7 m/second were necessary to maintain particle movement (saltation or suspension). Those anemometer readings pegged winter months as prime for dune movement. It is hypothesized that the arid growing season conditions of 2012 and 2013 lead to drops in subsurface moisture, conducive to episodes of major winter dune erosion and sand movement in the ensuing winter months of 2013-2014. Periods of major sand movement may expose a buried seedbank of *P. haydenii*, bring it closer to the surface, or bury it deeper.

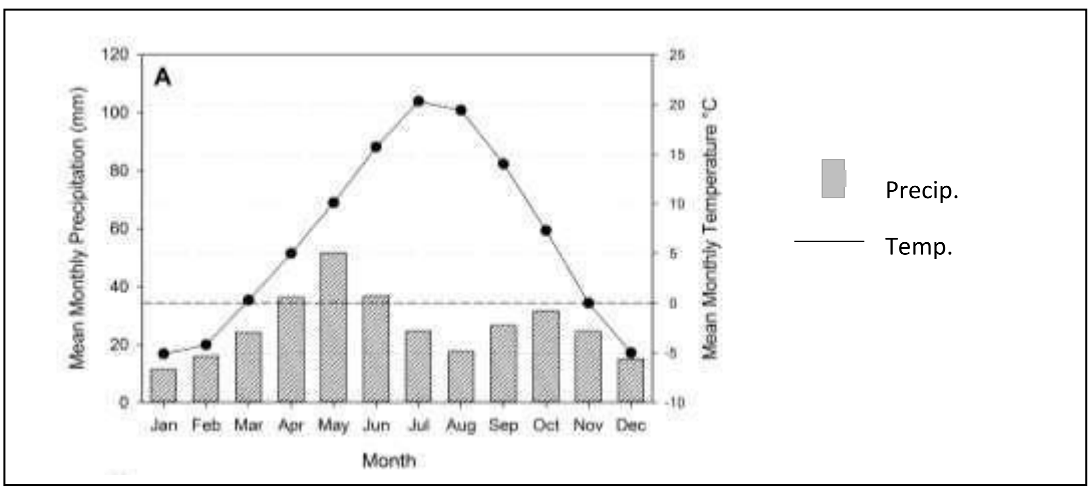


Figure 3. Climogram showing monthly mean precipitation and mean temperature averages for the period 1980-2010 in the Ferris Dunes (Bear Mountain; data from http://www.prism.oregonstate.edu/explorer/). (From Tilini et al. 2017).

The forces and influences of both wind and water are greatly modified by microhabitat conditions over short distances. Dunes are partitioned into zones that include the blowout bowl, blowout rim, side slopes, and lee slope; and there are different expressions of them and microrelief patterns from dune to dune. Furthermore, the zonation itself is subject to change. For example, Tilini et al. (2017) found that *P. haydenii* plants at much the same elevation along a 400 m transect experienced annual rates of burial and erosion ranging from 20 cm burial to -40 cm erosion within just one year (2013).

BACKGROUND INFORMATION

The first step in preparing for any plant species monitoring study is to compile all available information on the species (Elzinga et al. 1998). The most recent *Penstemon haydenii* status report (Heidel 2012) presents an overview of all that was known about the species in Wyoming up to that time including pollination research by others (Tepedino 2006, Hawk and Tepedino 2007). Later, the interim monitoring reports for 2015 and 2016 presented new *P. haydenii* life history information (Heidel 2016, 2017) including the first report of episodic seed germination, and the first reports that the species survives sand burial and forms successively higher root crowns as older ones are buried. This also corroborates the conventions used in census, to delimit individuals using 15 cm demarcation.

Basic information on *Penstemon haydenii* has also been greatly expanded by two seed ecology papers that came out after the status report (Tilini et al. 2016, 2017) that indicate *P. haydenii* forms a seedbank, and that deeply-buried seeds remain dormant whereas shallowly-buried seeds have the potential to germinate after cold stratification and sufficient moisture. In addition, a study of dune migration data analysis (Heidel et al. 2014) has been re-analyzed with inclusion of 2015 data (Heidel et al. 2018). In recent years there has also been completion of surveys for *P. haydenii* on private land, as submitted to USFWS with the compiled positive and negative results of 2015-2016 surveys on private land (Heidel 2017). Now that surveys have been completed across the dune landscape, we can begin to understand how the total number of *P. haydenii* plants and acreage of occupied habitat that is split between lands administered by the BLM, the Bureau of Reclamation (BOR) and State Trust lands, in addition to two different landowners. Related to this report, a highlight of *P. haydenii* monitoring results was represented in a poster entitled "Decadal trends of an endangered sand dune species" in the 2017 Natural Areas Conference (10-11 Oct 2017, Fort Collins, CO) focusing on a comparison of 2005-2006 data with 20152016 data. The original status report and all subsequent information about the species expand the knowledge base as context for interpreting the 2015-2017 monitoring results.

One of the most far-reaching of recent *Penstemon haydenii* studies were taxonomic investigations that compared morphology and genetics of Nebraska and Wyoming populations (Freeman 2015). Results to date suggest morphological differences but not genetics differences.

METHODS

Census

The 2017 *Penstemon haydenii* monitoring work was conducted as complete census of species' numbers at all six dunes on public lands in Wyoming that have had more than 300 plants. Census was conducted at the six dunes in 2017 by teams of one to four people, between 19 – 28 June. It marked the third year in what was to be a minimum of three consecutive years of monitoring. Enlarged annotated maps of population boundaries were superimposed on aerial photos that were carried into the field for each of the six dunes; as presented in Appendix A.

The 2015-2017 methods follow 2004-2006 methods, consistent with Nebraska conventions for censusing established plants. The full history of *P. haydenii* monitoring in Wyoming is presented in Appendix B. Monitoring involved pacing the habitat in series of traverses across discrete segments of occupied dune counting all individuals. Census required consistency in distinguishing individuals. In census of *P. haydenii*, any stems that were within about 15 cm apart were inferred to be part of the same individual. This threshold was relaxed slightly if stems were slightly further apart but buried and appeared to converge belowground (Heidel 2007). This threshold was corroborated in digging trials in which underground connectivity was sought among individuals of 15-100 cm apart. No evidence of rhizomes or other connectivity were found in 20 samples made in three dunes (reported in Heidel 2016). It is inferred that reports of the species having rhizomes can be attributed to buried rootcrowns and stems made prostrate by erosion that were subsequent buried. Census work attentiveness was required to avoid omitting plants and avoid counting plants twice in the parallel routes.

Work was generally conducted during flowering for ease of locating plants and distinguishing them from nonflowering plants. Separate tallies were kept for flowering (reproductive) vs. nonflowering (vegetative) plants as rudimentary gauge of fecundity and population reproduction levels that year. A single plant may produce 1-many stems that are all flowering, all nonflowering, or more often, a combination. For purposes of this census, plants with any flowering stalks were recorded as flowering plants. A third tally was kept of browsed plants (except for 2004 tallies). This was originally intended to evaluate the effects of herbivory on fecundity and population reproduction levels, but in extreme cases of heavy browse, it was not possible to differentiate whether or not the plant once had a capacity to flower. For purposes of this census, plants with any stalks browsed, regardless of whether there were also intact flowering or nonflowering stems, were recorded as browsed plants. In general, the timing of monitoring was conducted before livestock were brought into the pastures, so that the herbivory tallies represented the influences of elk, antelope and mule deer, listed in order from most to least common observed tracks and direct wildlife observations. Some years we did witness livestock (cattle) within the pastures but rarely found cattle tracks or other sign in occupied habitat.

In 2004, a demographic monitoring study for *Penstemon haydenii* was initiated to provide context and detail for census monitoring. It failed in its original objectives (Heidel 2007). Permanent belt transects were set up in small areas of occupied habitat with high densities of established plants (unknown ages). No new plants appeared, so the main results were documenting rates of local declining numbers. Starting by 2015, germination levels flourished. Seed biology studies became available and, with unique dispersal traits of species' seeds, provide evidence that the wind dispersal of seeds takes them away from parent plants, that seeds are often buried, and that they can remain dormant in seed banks. This is consistent with the ineffectiveness of earlier demographic monitoring set up around established plants.

Seedling and first-year plants

Seedling sampling was added to monitoring study design in 2015 to address an unanticipated phenomena, the appearance of abundant seedlings for the first time on record. A subsampling along transects and traverse estimates were used because they can be in high densities of 216 seedlings per m², and are easily trampled and their substrate destabilized. They can be over a magnitude smaller than established plants, so they are not as readily spotted. On Bear Mountain, they overlapped with established plants, but everywhere else they were isolated from established plants and restricted to blowout bowls. It is not known if the suitable microclimate for germination is restricted to bowls, the wind-borne seeds naturally accumulate in bowls, or some combination of characteristics such as concentrated sand deposition and erosion makes the bowls best-suited for germination.

True seedlings have cotyledons and are generally about 2 cm tall. In 2004 I saw what I thought were seedlings in the Junk Hill West series of dunes, having very slender stems and a few pairs of leaves but generally ~10 cm tall. In some cases, they were almost eroded out, exposing most of the root system. They were seen again by Blomquist in the same area in 2005. Also in 2005, Blomquist located an extension of the Bear Mountain population that had young plants of mixed stature. In 2015 we saw true seedlings, growing side-by-side with the larger class of plants, now interpreted to represent first-year plants. The latter appear to still be in the process of becoming established, i.e., forming a root system that reaches well below the drying zone of the soil profile. Reference sets of seedling and first-year plant photos are presented in Appendix C to represent every category of plant and variation among them.
The high density of seedlings precluded complete counts. To address seedlings and first-year plants, two permanent belt transects within high density areas of seedlings totaling 17.5 m^2 were established in 2015, reread in 2016 and we attempted repeated readings in 2017. The seedlings tended to be oriented in a narrow band so the belts were only 0.5 m wide. The seedlings tended to be in a straight band so the belts were set within continuous occupied habitat of 25 m x 0.5 m and 10 m x 0.5 m. The coordinates for each seedling or first-year plant were recorded to track its survival. Outside of the belt transects, we tried to get estimates in blowout bowl settings. The two transects have different placement within two different blowout bowls. We obtained three years of data from Transect 1 but the two rebars marking endpoints of Transect 2 were pulled out at some time between the 2016 and 2017 monitoring times so it was not possible to precisely relocate the second transect and get a third year of data from it.

RESULTS

Census

Mean *Penstemon haydenii* plant numbers in 2015-2017 showed a positive trend most dunes. The 2017 results in particular marked or reinforced a pattern of change within recent years that may be an uptick in trends if not a major turning point and rebound in trends. By comparison, the 2004-2006 census data did not exhibit an overall trend but a spike in numbers at most dunes in 2005, the middle year. The 2015 tally of *P. haydenii* plants counted in the six monitored dunes was 5,009 (Heidel 2016). In 2016, the total number of *P. haydenii* plants counted in the same six dunes dropped down slightly to 4,819 (Heidel 2017). The 2017 tally of *P. haydenii* plants was 8,883.

At the decadenal scale, comparison of mean *Penstemon haydenii* plant numbers in 2004-2006 with those in 2015-2017 shows major decline in each of the five dunes (Figure 2, Table 2). The mean number of plants per dune in the early period (2004-2006) was 3024 plants and the mean number of plants per dune in the recent period (2015-2017) was at 1028 plants; i.e., almost a threefold difference. The levels of decline ranged from 62% – 83% within the five separate dunes in comparing mean values of the recent period with the previous period.

The 2015-2017 census results are further addressed on the next page in data subsets – by category of plant stage, and by dune.

Table 2. *Penstemon haydenii* trends at dunes with high numbers

	Bradley Pk	Junk Hill Main	JH 2 W	JH 3 W	Bear Mt Total	Pathfinder
2004	488	1729				
2005	776	4816	2593	3646	6975	
2006	452	2770	1811	1648	6206	
2007		1739				
2008						
2009		1267				
2010						
2011	457					769
2012		662				
2013	185					
2014						
2015	170	810	156	527	2256	1110
2016	283	726	472	756	1456	1126
2017	217	1231	488	1764	4102	1081

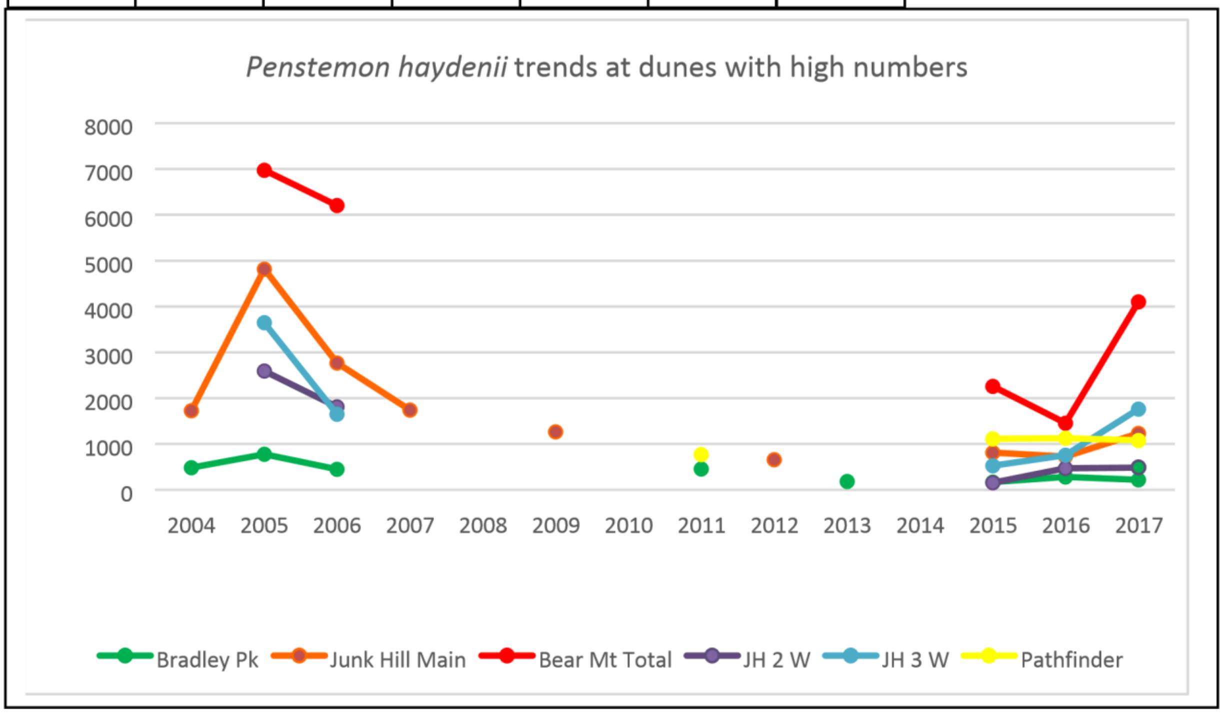


Figure 4. *Penstemon haydenii* trends
(Mean no. of plants/dune in 2004-2006=3024; mean no. of plants/dune in 2015-2017=1028)

Flowering and herbivory levels

The majority of established *Penstemon haydenii* plants in any of the monitored dunes in any year were usually vegetative. Reproduction levels are much lower than the tallied totals (Table 3 and Figure insets). Flowering levels ranged from 1-54% of plants among dunes in any given year (2005-2006, 20152017). A comparison of annual average flowering level per dune showed a range of from 11-33%. In absolute numbers, Bear Mountain Dune has consistently had more flowering plants (total) than the other five monitored dunes in each year of monitoring. It has also had relatively high if not highest proportions of flowering plants in all of the five monitoring years.

The relative numbers and proportion of flowering and browsed plants also showed differences between dunes, and between years (Table 3). In absolute numbers, Bear Mountain Dune and Junk Hill Main Dune have consistently had the highest tallies of browsed plants, but it has been mainly Bradley Peak Dune and Junk Hill Main Dune that have had the highest proportions of browsed plants.

In recent years (2015-2017), there were about twice as many flowering plants as browsed plants each year. By comparison, there were almost four times as many flowering plants as browsed plants in 2005, and slightly more browsed plants than flowering plants in 2006. In other words, the proportional browse levels have gone up as population numbers have gone down.

What do the data show for the impact of browsing on reproductive output of *Penstemon haydenii*? We have not conducted browse studies but observations suggest that browsers favor flowering plants over vegetative plants, though vegetative plants are definitely browsed. It also seemed as though the species was most heavily browsed in 2006 as perhaps the driest of the six monitoring years when flowering levels were also very low. Flowering plants have stouter stems, they might be more succulent, or be more nutritious in other ways. Apart from any selectivity, there appeared to be an opportunistic element in browse pattern based at least in part by the direction of traverse across occupied habitat. Without data on specificity or level of flower removal due to browse, we can treat the question with hypothetical assumptions that if all of wildlife browsing were on flowering plants, and if browsers consumed an average of 50% of reproductive potential, then browse levels would curtail between 14-35% of total reproductive output. Browsed conditions were not addressed in Nebraska monitoring.

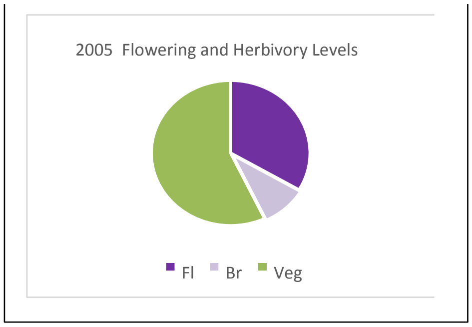
It would be interesting to compare the levels of flowering between Nebraska and Wyoming populations. It would also be interesting to investigate whether plants emerging from burial have the capacity to flower or are apt to remain vegetative. If there is more burial occurring in Wyoming than Nebraska, then this might be reflected in flowering level differences.

Table 3. *Penstemon haydenii* monitoring tallies for each dune, each year, by categories (Flowering, Browsed, Vegetative)[5] for 2005-2006 and 2015-2017

2005

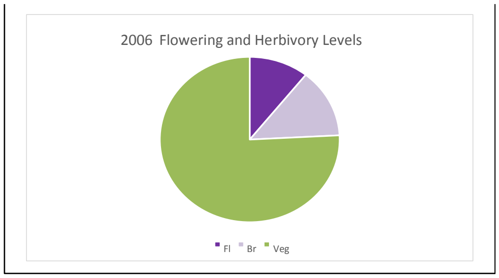
Fl Br Veg T % Fl %Br

	Fl	Br	Veg	Total	% Fl	% Br
Bradley Pk	348	72	356	776	54	17
Junk Hill Main	2273	349	2194	4816	54	13
JH 2 West	348	83	2162	2593	17	19
JH 3 West	688	322	2636	3646	28	32
Bear Mt	2858	997	3165	6975	41	14
TOTAL	**6167**	**1751**	**10,513**	**18,806**		



2006

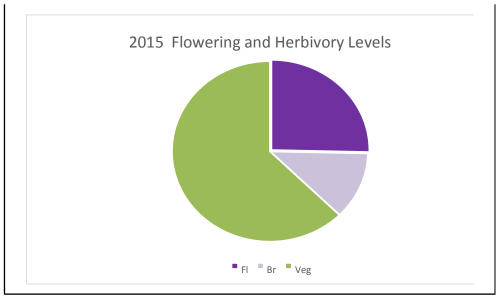
	Fl	Br	Veg	Total	% Fl	% Br
Bradley Pk	27	230	195	452	6	50
Junk Hill Main	259	529	1982	2770	9	19
JH 2 West	5	41	692	738	1	6
JH 3 West	27	24	1597	1648	2	2
Bear Mt	947	768	4491	6206	13	12
TOTAL	**1265**	**1592**	**8957**	**11,814**		



[5] The relative contributions of total flowering, browsed and vegetative plants each year are represented by pie diagrams (to right of tables). The 2004 census did not record tallies by category. In each table, the top two highest values of flowering and browsed plants numbers and proportions are highlighted in color.

2015

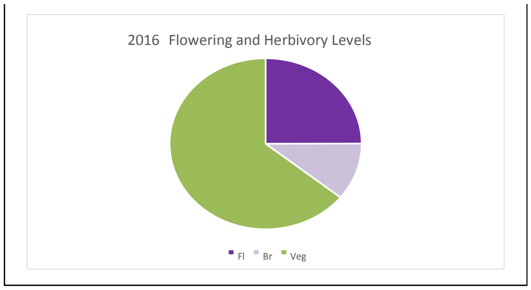
	Fl	Br	Veg	Total	% Fl	% Br
Bradley Pk	55	31	86	172	32	18
Junk Hill Main	228	347	235	810	28	43
JH 2 West	10	9	35	54	18	17
JH 3 West	6	35	697	738	1	5
Bear Mt	902	259	1792	2953	31	9
Bradley Pk	384	75	1066	1525	25	5
TOTAL	**1585**	**756**	**3911**	**6252**		



2016

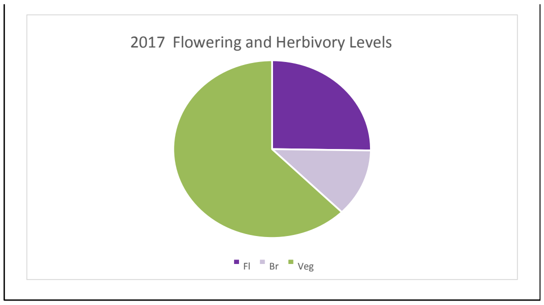
	Fl	Br	Veg	Total	% Fl	% Br
Bradley Pk	74	63	146	283	27	22
Junk Hill Main	42	300	384	726	6	41
JH 2 West	42	13	526	581	7	2
JH 3 West	36	20	700	756	5	3
Bear Mt	593	107	756	1456	41	7
Bradley Pk	443	31	652	1126	39	3

TOTAL 1230 534 3164 4928



2017

	Fl	Br	Veg	Total	% Fl	% Br
Bradley Pk	44	54	119	217	20	25
Junk Hill Main	209	452	570	1231	17	37
JH 2 West	10	44	434	488	2	9
JH 3 West	20	104	1640	1764	1	6
Bear Mt	1586	353	2163	4102	39	9
Bradley Pk	373	85	623	1081	34	8



TOTAL 2242 1092 5549 8883

Seedling and first-year plants

There are a couple important results coming out of monitoring seedlings and first-year plants (Tables 4 and 5). A tally of 1026 seedlings in Transect 1 for 2015 surpassed by magnitudes all reports of seedlings observed in prior years. Those prior reports from 2004-2005 were from the same two blowouts where seedlings were sampled in 2015-2016. They represent high densities, with a peak tally of 54 seedlings in a single 0.25 m^2 area as the highest recorded seedling density (216 seedlings/m^2 in Transect 1) and more seedlings in the 12.5 m^2 belt transect area than are found for established plants across many hectares of occupied habitat.

The second important results coming out of the sampling set up around seedlings is that survival rates are very low, from what we can tell by looking aboveground the next year. The seedlings of Transect 2, though present in low density compared with Transect 1, appeared to have had high survival rates. The 72 first-year plants of 2016 are interpreted to represent survival among the 83 seedlings of 2015.

Table 4. *Penstemon haydenii* sample results in Transect 1 (25 m x 0.5 m)

Year	Seedling tally	Seedling density (per m^2)	1rst -yr plant tally	1rst-yr plant density (per m^2)
2015	1026	82.1	8	0.64
2016	689	55.1	3	0.24
2017	369	29.5	0	0

Table 5. *Penstemon haydenii* sample results in Transect 2 (10 m x 0.5 m)

Year	Seedling tally	Seedling density (per m^2)	1rst-yr plant tally	1rst-yr plant density (per m^2)
2015	83	16.6	38	7.6
2016	3	0.6	72	14.4

These pilot seedling monitoring studies had limited success. One of the two belt transects could not be read in 2017 because the rebar marking its endpoints was pulled from the ground and removed. The other belt transect represented a zone of high recruitment but also had high burial. Further scouting in the area took place in 2017 and determined that there are zones of high recruitment that are not subject to high burial.

The pilot seedling monitoring data and observations indicate that seedling distribution is highly localized compared to the extent of established plants, that there is high mortality in the areas monitored, and that there are differing rates of mortality and survival over short distances that may be significant in answering the question whether the recent germination episode is adequate to compensate for the decadal trends. Expanded monitoring and possibly mapping of seedlings and first-year plants is needed to gauge whether they are adequate to perpetuate population numbers and distribution extent.

DISCUSSION

Overview

It was surprising that *Penstemon haydenii* numbers peaked in 2005 in the midst of drought, and equally surprising that *P. haydenii* numbers had plummeted when repeating the census of dunes in 2015, one of the mildest years since it was discovered in Wyoming (Heidel 2016). It is intuitive to expect that plants of arid habitat are moisture-dependent, so this pattern is counterintuitive. A possible explanation for this paradox is the tight coupling of *P. haydenii* trends to active dune habitat trends. An alternate explanation is that census results reflect a strong or stronger influence of prior years' weather conditions rather than current years. These two ideas are not mutually exclusive. To delve into results, it is appropriate to integrate results from a tandem study on dune migration (Heidel et al. 2018).

The decadenal decline of *Penstemon haydenii* may reflect large-scale sand deposition that buried established plants. If this is caused by a natural cycle of sand dune movement, then decline is to be expected. If such dune movement is outside the natural range of variability, reflecting shifts in climate, then the pattern of decline might be expected to continue. Recent annual population trends show modest increase in *Penstemon haydenii* numbers (2015-2017), albeit a much lower level of increase than the decadal decline. If the 2017 uptick reflects some combination of established plants becoming unburied and recruitment of new plants, then rebound is possible.

This hypothesis for explaining decadal decline is supported by observations. By 2006, the changes taking place on the landscape provided evidence that the habitat itself was changing over the course of monitoring. By 2006 in particular, the steep sand slope at Bradley Peak Dune had become less stable and wind erosion nearly doubled the length of the dune by eroding sand off of the slope and depositing it downwind (Figure 2). Wetlands in the same dune landscape were markedly dry and the discrete blowout rim features of most dunes were beginning to breach and bury or erode.

Two recent studies help quantify environmental changes that are occurring in occupied habitat, including local-scale burial and deposition (Tilini et al. 2017) and landscape-scale dune migration (Heidel et al. 2018). The magnitude and direction of recent changes taking place in the environment were not always evident, but there were patterns of blowout rims becoming further breached and buried, many blowout bowls filling but the giant blowout bowl on Bear Mountain expanding and new ones starting; and new sand deposits across the occupied habitat that lies downwind of the old blowout bowls. Therefore, the following census results reflect a species strongly influenced by its dynamic environment.

There was almost complete absence of seedlings observed during most years of census in almost all dunes until numerous seedlings were documented in 2015. Everything that we have learned since then suggests that seedling recruitment is episodic and localized. The seed ecology master thesis study out of Utah State (Tilini et al. 2016, 2017) reported that there were seedlings present along their Bear Mountain transects in 2013 that they excluded from their tallies. But Bear Mountain was not monitored by Wyoming biologists that year and the information didn't get conveyed. It is hypothesized that spring drought conditions of 2012 and 2013 exacerbated erosion to bring deep seedbanks close to the surface, then fostering germination later those same years, and mass germination in the wake of the high May 2015 precipitation levels.

It is worth pointing out that there is almost complete lack of plant mortality observed in the field. If the species can survive sand burial for some time and at some depth, then this raised the important possibility that we are missing buried plants during census. In 2013 we sought direct evidence of mortality to support population census numbers going up and down. There were almost no signs of dead plants except for occasional ones eroded out. Excavation trials were conducted that were recently summarized (Heidel 2016) and suggest that established plants may be alive 15 cm below the surface at the time of flowering. This indicates that it is not possible to distinguish mortality from survival belowground, a cryptic phase that confounds monitoring.

Comparing dunes

The dune with highest *Penstemon haydenii* numbers in early years of monitoring (20042006) was Bear Mountain Dune, and it has remained the dune with highest numbers in recent years (2015-2017). Likewise, the dune with lowest numbers in early years of monitoring, Bradley Peak Dune, has remained the dune with lowest numbers in recent years. These decadal patterns are consistent with *P. haydenii* being a long-lived perennial, and support the importance of maintaining dunes with high numbers.

The Bear Mountain Dune is significant in other ways. It is the dune with consistently high, if not highest proportions of its plant population flowering in any given year. It is centrally located among all 22 occupied dunes. In particular, it is located at and immediately below the Continental Divide, at a gap (called "Windy Pass" by some) that separates the Ferris and Seminoe Mountains, with particularly turbulent wind conditions. It spans over 1.5 mi (2.4 km), such that the upwind end of its subpopulation is likely to be a seed-and-sand source for its downwind end as for downwind dunes.

The discovery of the *Penstemon haydenii* at Pathfinder Reservoir Dune in 2011 was significant for several reasons that have subsequently come to light. This dune is "most different" from all the other monitored dunes in being at a distinctly lower elevation. It is particularly isolated from the rest of dunes with high numbers. The species there also have distinctly earlier phenology. It is at a dead-end in sand deposition, the farthest downwind for accumulating seeds and sand. Any seeds and sand that leave it are blown into the reservoir, entirely removed from the dune system.

Only eight of the dunes occupied by *Penstemon haydenii* have had seedling germination documented. They include the dunes west of (upwind from) Junk Hill, in addition to Bear Mountain and Pathfinder Reservoir dunes. From what we know, the majority of *P. haydenii* germination noted in monitored dunes has been concentrated in the blowout bowls, in localized patterns often resembling windrow patterns on a beach. These seedling distribution patterns together indicate that the seeds have blown in from upwind sources. This underscores the importance of the dune system collectively as fostering species' persistence at any given locale. This indicates that dunes in tight series might have greater collective species' viability than isolated dunes where wind-borne seeds are more likely to reach unsuitable habitat. It also raises question if the species can persist locally apart from turbulent crosswinds as found at Bear Mountain, or whether the upwind dune subpopulations are possibly "doomed." The previous dune migration study supports a landscape-scale management framework for *P. haydenii* and buffering of active dune areas upwind and downwind of populations to maintain dune succession processes and minimize system extremes in stabilization or destabilization.

The Bradley Peak Dune population of *Penstemon haydenii* may be the one that is most at-risk of extirpation. It is the only one of the six that has not shown a rebound in recent years. Its highest tallies have usually come from a zone of steep slope that experienced large-scale erosion starting in 2006. Eroded sand blew downwind from this steep slope. This wind erosion doubled the length of active sand, but blew much of the loose sand into a trough. A trough setting may not be conducive to *P. haydenii* germination if the seed bank remains deeply buried in the deep trough depression. High levels of erosion are reducing other portions of the Bradley Peak Dune occupied habitat at the same time, and this dune is isolated from the seed input of any other dune. These comparisons underscore the importance of the dune system collectively, rather than focusing on or prioritizing any one dune or dune subsets over others.

Recommendations

There is a Species Status Assessment (SSA) process that was initiated by USFWS in 2015 when this monitoring study was getting underway. Results from this monitoring report has need to be incorporated for understanding species' viability. The results of this monitoring study, along with newlyavailable life history and habitat information, represent additions, elaborations and revisions for all three SSA components (needs, condition and viability) since start of the SSA process. It is appropriate to edit earlier SSA text with current needs and conditions, and with newly-framed viability questions. The mobility of habitat that has been documented emphasizes the need for landscape-scale management of *P.haydenii*.

The importance of habitat trends in shaping population trends is supported in this *Penstemon haydenii* monitoring report. Earlier dune migration studies indicate that active sand dune habitat has been continuously available to the species in Wyoming (Heidel et al. 2018), unlike Nebraska dune habitat. The extent of the landscapes and occupied habitat within them differ drastically between species' habitat of Nebraska and Wyoming, reflecting different scales and outcomes of succession. It may be constructive to convene Wyoming biologists at Nebraska habitat just as Nebraska biologists have convened at Wyoming habitat.

Now is also an appropriate time to consider the short-term and long-term plans for continued monitoring. We cannot distinguish an uptick from a rebound in *Penstemon haydenii* population numbers from just 2017 results unless complete census were conducted at six dunes for at least one more year. It would also be appropriate for all parties to discuss the prospects and circumstances in which the census of all six dunes might be considered, whether or not there are existing priorities for such monitoring, and if pursued, the terms and metrics for replicating census. The study requires personnel with a level of landscape familiarity and determination as well as agency/institutional commitments.

Two added lines of study are presented to interpret and determine species' trends.

1. The mapping of occupied habitat for most dunes was done as part of fieldwork in 2004-2006, as projected onto and following features of 2001 imagery. There have been changes to subpopulation outlines observed at all those dunes when revisited, with breaching and burial of blowout rims and the rest of occupied habitat. New imagery will show dune migration, but only field mapping can show species' distribution and document the extent of new sand deposits that had once been occupied. To date, no new colonization events have been shown in the areas of new sand deposition, and it remains to be seen whether seeds of the species lie buried awaiting some future erosion episode before germinating. Though it is not meaningful to record small outline changes on an annual basis, boundary changes over the course of a decade represent a much larger, measurable scale of change.

2. The seedling stage is the ideal stage for initiating demographic studies because the ages of seedlings are known, and a cohort of seedlings can be monitored to determine mean life expectancy. Demographic monitoring is an intensive form of monitoring that requires a sampling strategy. It remains to be seen whether recruitment levels and recruitment distribution patterns are

adequate to maintain viable species' numbers in any given active dune area, even though we have provided evidence for dune trends that are conducive to germination episodes. The pilot seedling studies to date have demonstrated that there are subtle suitability zones within a blowout bowl. We propose that an expanded number of transects be established and monitored for three years to capture trends within these zones for at least two dunes (Junk Hill #2 West and Junk Hill #3 West). It would also be appropriate to map the extent of seedlings in greater detail. The merit and feasibility of monitoring seedlings on the steep Bear Mountain Dune warrants consideration. The feasibility of monitoring plants at Pathfinder Reservoir Dune warrants discussion in light of heavy recreation use and occasional motorized vehicle traffic in the area.

Rebar from one of the two original seedling monitoring transects was removed in the past. Coordination with ranchers is needed for any new study involving more transects. Seedling monitoring to date has been limited to two gentle dunes of the Junk Hill West series. The seedlings observations to date indicate that they germinate in areas that are vastly smaller than those of currently occupied habitat, concentrated in parts of the blowout bowls. So it is not at all clear whether the recent germination phenomena could be expected to maintain numbers because they are so localized (magnitudes smaller than the area of occupied habitat), and any given locale is apt to change in suitability over time. Periodic surveys to check for new seedling locales may be warranted.

Original hypotheses

This project and other *Penstemon haydenii* study results since the most recent status report (Heidel 2012) have significantly revised our understanding of the species' life history, seed biology, population trends and habitat trends. It might be appropriate to update the existing status report with all of the new information. As stated earlier, the first step in preparing for any plant species monitoring study is to compile all available information on the species (Elzinga et al. 1998), and the latest information acquired has bearing in understanding species' status and trends.

One of the two hypotheses for this monitoring study was supported. The population size threshold of 300 plants was the numeric framework provided in the recovery plan (Fritz et al. 1992). The idea is based on Nebraska monitoring data and observations that dunes with high numbers tended to retain high numbers over time, and dunes with low numbers tended to remain low. This pattern has been supported with Wyoming monitoring data. The six dunes having high numbers of *Penstemon haydenii* plants harbored well over half of all *P. haydenii* plants as censused in 2004-2006 and as replicated in census of most dunes since. Data have been collected from dunes with low numbers in which low numbers persisted. Despite all of the year-to-year shifts for any given dune, the fact that most of these six had high numbers a decade apart, supports the idea that they have at least decadal significance in maintenance of numbers.

The other hypotheses behind this monitoring study was that *Penstemon haydenii* has the potential to have stable numbers over time. However, both the annual and decadal monitoring datasets suggest that it may not be appropriate to seek stable population numbers in an unstable habitat. Species' numbers oscillate due to episodic germination and to large-scale habitat dynamics that potentially bury seeds and established plants, or potential bring seeds close to the surface where germination conditions are suitable.

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