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Establishment and Survival of the Endangered Blowout Penstemon

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ESTABLISHMENT AND SURVIVAL OF THE ENDANGERED BLOWOUT PENSTEMON

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Abstract. *Blowout penstemon* (Penstemon haydenii *S. Wats.) is the rarest plant endemic to the Great Plains and is the only officially endangered plant species in Nebraska. The endangered species recovery plan calls for an increase in viable populations from five to ten and an increase in plant numbers from about 6,000 to 15,000. Research conducted on survival of greenhouse grown seedlings transplanted at three sites in the Nebraska Sandhills showed that transplanting seedlings was feasible. Greatest survival was obtained when blowout penstemon seedlings were transplanted into blowoutgrass* [Redfieldia flexuosa *(Thurb.) Vasey*] *communities in blowout depressions. Plants were not long lived, but they produced seed for continuation of the species. Their relatively short life span may be directly related to the temporary aspect of suitable habitat in blowouts.*

Long-term Survival of the Endangered Blowout Penstemon

Blowout penstemon (*Penstemon haydenii* S. Wats.) is the rarest plant native to the Great Plains (Stubbendieck et al. 1989) and is restricted to only a few blowouts, sites of active wind erosion, in the Nebraska Sandhills (Stubbendieck et al. 1989). It is the only plant species in Nebraska officially classified as endangered and protected under the Federal Endangered Species Act (U.S. Fish and Wildlife Service 1987; Jobman 1989). Blowout penstemon

Figure 1. Blowout penstemon in the sandhills.

was apparently first collected by the explorer and geologist Ferdinand V. Hayden along the North Loup River in 1857 (Sutherland 1988). Raymond Pool (1914) stated that it was one of the most common plants in blowouts in the Nebraska Sandhills. However, populations declined rapidly until it was thought to be extinct by mid-century. It was rediscovered in 1968 (Sutherland 1988).

Blowout penstemon is a perennial forb with ascending stems reaching from 20 to 50 cm in height (Fig. 1). Its compact, cylindrical inflorescences of milky blue to lavender (rarely white) flowers are strikingly attractive, and the flowers possess a distinctive fragrance (Great Plains Flora Association 1986). Blowout penstemon reproduces by short rhizomes and stems rooting at the nodes (Fig. 2). Naturally occurring seedlings are relatively rare because of a combination of a thick seed coat, a chemical inhibitor within the seed, and a germination zone that rapidly dries before seedlings become established (Stubbendieck et al. 1983; Stubbendieck and Weedon 1984). Of over 20,000

Figure 2. Blowout penstemon (*Penstemon haydenii*) S. Wats.

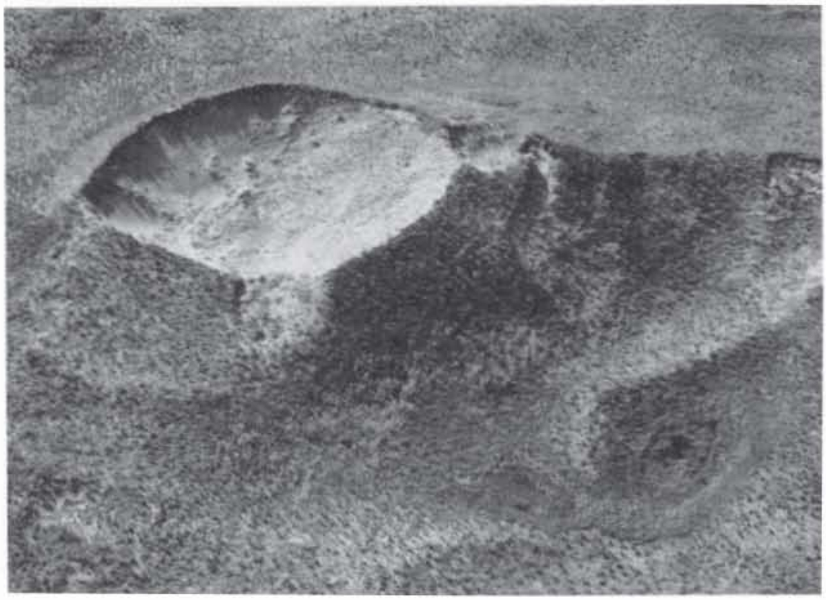


Figure 3. Sandhills blowout viewed from the windward to the leeward direction.

seeds planted in several direct seeding experiments, fewer than 5 emerged, and none became established (Flessner unpublished data).

Blowouts are one of the most striking features of the Sandhills. They are the result of wind erosion and originate on the upper, exposed slopes of dunes when the vegetative cover is removed or disturbed (Stubbendieck et al. 1989). Historically, concentrations of grazing animals and repeated fires caused the disturbance (Pool 1914). Over the period of a few years to a few decades, an embryonic blowout develops into a full scale, active blowout. Sand is blown from the exposed windward side of the slope and deposited onto the leeward side. As the erosion becomes more active and the blowout deepens, roots of the prairie vegetation are exposed, and soon whole plants blow away. As the crater deepens, the sand on the sides slides into the depression. The sharp, steep edges caused by the sliding sand help to catch the wind and cause increased turbulence

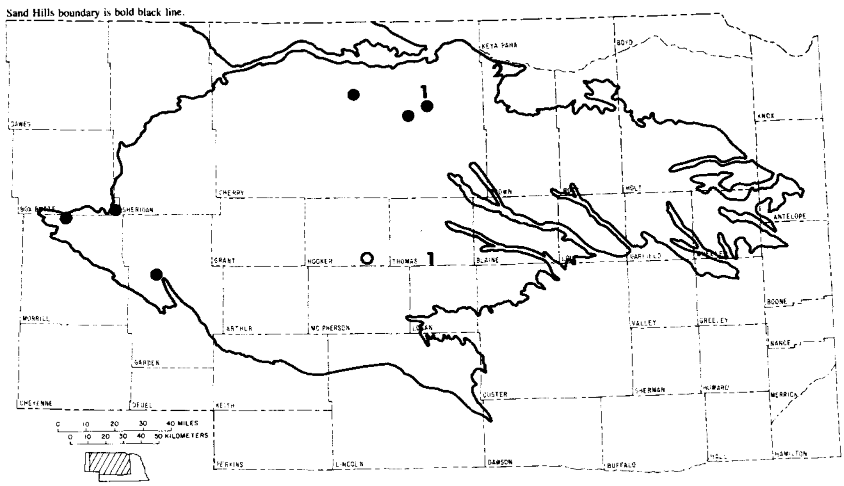
breaking more sand particles free. The loose sand is quickly blown out and deposited on the leeward side of the crater (Pool 1914).

The northwest inner slope of an active blowout generally has a gradient of about 30 degrees. It has the longest slope and is never directly exposed to the wind. The opposite side is usually much steeper, sometimes nearly perpendicular, because sand continually rolls down and is blown out over the side. The leeward side of the hill, the area of sand deposition, usually has a gradient of about 60 degrees. This slope is usually vegetated by perennial grass species that can yearly grow up through 0.2-0.7 meters of deposited sand (Pool 1914).

Nebraska Sandhills blowouts are irregularly conical or rounded depressions of varying depth and diameter (Fig. 3). They usually occur on the northwest sides of upper slopes and hills. The northwest side of the rim is usually lower than the southeast rim. Sand is continually deposited in a southeasterly direction building a rim. A blowout is dynamic. The area of active wind erosion continually moves across the landscape at the speed of a few meters a year. Succession constantly occurs on the windward side. A blowout may exist for decades before it reaches maturity. When the blowing sand is deposited in a deep valley or lake, and no longer accumulates on the leeward side, it is considered mature (Pool 1914). The leeward side then is lowered as the wind blows through the hilltop. The steep front slope is eliminated, which suspends the wind turbulence and the erosion force of the wind.

Blowout penstemon is successional in nature. It is an early colonizer in blowouts and declines when other vegetation becomes well established (Weedon et al. 1982). Active wind erosion is necessary to maintain blowout penstemon populations (Stubbendieck et al. 1989). Its change in status from common to rare may be related to natural occurrences and to changes in management. Wildfire control and improved range management practices have greatly decreased the habitat of blowout penstemon, thus greatly reducing plant numbers (Stubbendieck et al. 1989).

The drought of the 1930s negatively influenced many prairie species (Weaver 1954). Even though habitat may have increased, the drought may have caused a decline in blowout penstemon populations because of inadequate moisture, since these plants are highly susceptible to competition for moisture (Stubbendieck 1986). As blowouts stabilize, habitat improves for many rodents. Some of these rodents apparently feed on the relatively large blowout penstemon seeds, greatly reducing the seed bank. Recently, severe damage from unidentified stem boring insects has caused considerable plant loss (Fritz et al. 1992). Extensive searches since 1979 have led to locating seven



● Natural populations, ○ Natural population lost in 1990,
1 Experiment 1 Transplant Sites, 2 Experiment 2 Transplant Site.

Figure 4. Locations of natural and transplanted populations of blowout penstemon.

population complexes in five Nebraska counties (Fritz et al. 1992). One of the seven populations was lost in 1990 and another decreased to only five plants in 1992. Numbers of individuals in the five other populations (Fig. 4) vary from over 2000 to fewer than fifty, and population numbers fluctuate widely from one year to the next (Hardy et al. 1989).

Numbers of blowout penstemon plants and locations of populations must be increased if the species is to meet goals for recovery as outlined in the recovery plan (Fritz et al. 1992). Direct seeding has been unsuccessful, and naturally occurring seedlings are rarely found. Since seedlings have been grown successfully in the greenhouse (Flessner 1988), a useful approach is to start them in the greenhouse and transplant them into their natural habitat. Research in the early 1980s solved the problem of low germination rates and techniques were

developed for greenhouse production of seedlings (Stubbendieck et al. 1982a; Stubbendieck et al. 1983; Stubbendieck and Weedon 1984).

The overall objective of this research was to determine if greenhouse grown blowout penstemon seedlings could be successfully transplanted into natural habitat. Success would be determined by rate of survival over time. The initial specific objective was to determine survival rates of plants placed in different geomorphic locations in blowouts. A subsequent objective was to determine in which plant community transplants should be placed for greatest survival.

Methods

Experiment 1, Geomorphic Position

Blowout penstemon seeds were collected in late August 1982 from a natural population in a single blowout about 30 km south of Valentine in Cherry County, Nebraska. Seeds were removed from air-dried fruiting stalks, separated in an air column into heavy and light fractions, and stored in plastic vials at 3-4 C. In January, 1983, seeds in the heavy fraction were placed under running tap water for 24 hours to remove a water soluble, natural inhibitor and followed by hand scarification with a razor blade (Stubbendieck et al. 1982a, 1982b). Four scarified seeds were immediately planted at a depth of 1 cm in seedling tubes (4 cm in diameter and 20 cm long) containing pure, washed, steamed (120 C, 120 min) sand. These tubes were used because roots are able to extend to the bottom of the tubes. Therefore, roots can be placed in contact with moist soil at time of transplanting. Also, seeding tubes require minimum greenhouse space. Seedlings emerged in 5 to 10 days. The natural photoperiod was extended to 14 hours. Greenhouse temperatures ranged between 25 and 30 C. Two weeks following emergence, seedlings were thinned to one per tube. Seedlings were fertilized weekly with 75 ppm of nitrogen [0.26 M $Ca(NO_3)_2$ solution] and 75 ppm of phosphorus [0.24 M NaH_2PO_4 solution] were applied until the soil was saturated. Seedlings were sprayed with a combination insecticide/fungicide weekly and watered as needed.

Seedlings were transplanted into blowouts in the Nebraska Sandhills in Cherry and Thomas counties (Fig. 4) on May 1, 1983. The Cherry County site was the same blowout from which seeds were harvested in 1982. The Thomas County site was 32 km southwest of Halsey and contained no blowout penstemon. Soil at both sites was Valentine fine sand (mixed, mesic, Typic Ustipsamment). It formed in sediments derived from sandstone or other sand bodies that are

wind-deposited. It contains little organic matter, has moderate water-holding capacity, and is excessively drained (U.S. Department of Agriculture 1956, 1965; Elder 1969). Both sites exhibited rolling topography, and both blowouts faced northwest. Yearly rainfall at the sites averaged 589 and 509 mm in Cherry County and Thomas County, respectively (U.S. Department of Agriculture 1956, 1965).

Seedlings planted in three blowout locations (depression, leeward rim, and depositional slope) at each site corresponded with locations where natural, blowout penstemon plants were most commonly found. Each of four replications consisted of 33 plants transplanted into three rows with a spacing of 45 cm between rows and between plants. Numbers of plants exhibiting live, above ground tissue were recorded during the second week of August each year from 1983 through 1991. The measured response, Y_{ij}, was the number of surviving plants in each block, yielding the model:

$$Y_{ij} = \mu + T_j + \phi_i + \varepsilon_{ij}$$

where μ is the overall mean effect, T_j is the year effect, ϕ_i is the community or block effect, and ε_{ij} is the random error component. Data were subjected to PROC DISCRIM (SAS Institute 1985) analysis to test for ability to use the pooled covariance matrix. PROC GLM with the repeated option (SAS Institute 1985) was used to process the data. Mauchly's criterion test for symmetry of the variance-covariance matrix was completed, as was a multi-variate test for interaction with the time component. The Huynh-Feldt and Greenhouse-Geisser adjusted F-tests were also conducted for interaction with time (Crowder and Hand 1990).

Experiment 2, Plant Communities

Placement of transplants of blowout penstemon in Experiment 1 did not include consideration of plant community in which the transplants were placed. Within two years after initiating Experiment 1, it became evident that the plant community in which transplants were placed directly influenced survival and that this variable should be examined. A site on the Niobrara Valley Preserve, about 15 km north of Johnstown, Nebraska (Fig. 4), was selected for this experiment. Soils were similar to those of the other two research sites. Average annual precipitation was 556 mm (U.S. Department of Agriculture 1938). A 4

ha fenced blowout undergoing plant succession with several plant communities was chosen for the transplant site.

Plant communities in the blowout depression could be readily divided into four categories. The bare soil category was an area of actively moving sand. The few, scattered plants present in these areas were not effective in controlling sand movement. The blowoutgrass community contained blowoutgrass [*Redfieldia flexuosa* (Thurb.) Vasey] in nearly pure stands with a basal cover of less than 1%. The annual plant community was comprised of primarily plains sunflower (*Helianthus petiolaris* Nutt.), cristatella [*Polanisia jamesii* (T.&G.) Iltis], winged pigweed [*Cycloloma atriplicifolium* (Spreng.) Coult.], and sandbur [*Cenchrus longispinus* (Hack.) Fern.]. Basal cover was about 3%. The Sandhills Prairie occupied stabilized areas where the plant community had advanced through succession to near climax. Dominant species in the Sandhills Prairie were sand bluestem [*Andropogon gerardii* var. *paucipilus* (Nash) Fern.], little bluestem [*Schizachyrium scoparium* (Michx.) Nash], switchgrass (*Panicum virgatum* L.), and prairie sandreed [*Calamovilfa longifolia* (Hook.) Scribn.].

Seeds of blowout penstemon were collected in Cherry County in 1984. Seedlings were grown in the greenhouse and transplanted into the blowout in 1985. Methods used to produce transplants were identical to those in Experiment 1. Four replications of 33 seedlings each were placed in bare sand and the three plant communities. Survival was determined in the second week of August of each year from 1985 through 1991.

The experiment was repeated in 1986 and 1987, but nearly all seedlings were lost to rodents within two weeks after transplanting. Trapping revealed high densities of kangaroo rats (*Dipodomys ordii*) and deer mice (*Peromyscus maniculatus*). The experiment was repeated in 1988. This time each replication of each treatment was fenced with woven wire with the lower portion buried 20 cm in the soil to exclude rodents. Statistical procedures were identical to those used in Experiment 1.

Results

Experiment 1

Analysis of the data from Thomas County (Table 1) showed that the pooled covariance matrices could be used in further analysis. Mauchly's criterion indicated that the hypothesis of compound symmetry existing for the data would be rejected ($P > 0.0001$). Further analysis of the data by the MANOVA test

TABLE 1

SURVIVAL (PERCENTAGE AND MEAN NUMBER) OF BLOWOUT PENSTEMON SEEDLINGS TRANSPLANTED INTO THREE LOCATIONS WITHIN BLOWOUTS IN THOMAS COUNTY, NEBRASKA

Location	Year								
	1983	1984	1985	1986	1987	1988	1989	1990	1991
	% N	% N	% N	% N	% N	% N	% N	% N	% N
Depression	85 (28.0)	79 (26.0)	41 (13.5)	19 (6.3)	7 (2.3)	4 (1.3)	0 (0.0)	0 (0.0)	0 (0.0)
Rim	42 (14.0)	28 (9.3)	18 (5.8)	5 (1.5)	1 (0.3)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Depositional Slope	53 (17.5)	47 (15.5)	25 (8.3)	14 (4.5)	2 (0.8)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
LSD (0.05)	(1.9)	(2.6)	(2.7)	(2.3)	(1.3)	(0.5)	–	–	–

criterion indicated a strong interaction with time (P > 0.0001), thus necessitating a return to the adjusted univariate analysis to explain what occurred at each point in time.

The univariate analysis revealed a highly significant difference between locations within the blowout on all dates (August 1983, 1984 (P > 0.0001), 1984 (P > 0.0004), 1986 (P > 0.0037), 1987 (P > 0.0199), and 1988 (P > 0.0002)] on which living plants were recorded. Least significant difference (LSD) and Waller-Duncan K-ratio mean separation tests were then performed, and they produced similar results. For the first two years of the study, 1983 and 1984, all communities were significantly different in number of surviving plants (Table 1). However, in 1985, 1987, and 1988, the depression location was significantly greater in number of surviving plants than at the other locations. In 1986, survival of plants in the rim location was significantly lower than in other

TABLE 2

SURVIVAL (PERCENTAGE AND MEAN NUMBER) OF BLOWOUT PENSTEMON SEEDLINGS TRANSPLANTED INTO THREE LOCATIONS WITHIN BLOWOUTS IN CHERRY COUNTY, NEBRASKA

	Year								
Location	1983	1984	1985	1986	1987	1988	1989	1990	1991
	% N	% N	% N	% N	% N	% N	% N	% N	% N
Depression	82 (27.0)	77 (25.3)	75 (24.8)	70 (23.0)	65 (21.3)	44 (14.5)	25 (8.3)	6 (2.0)	1 (0.3)
Rim	34 (11.3)	32 (10.5)	20 (6.5)	9 (3.0)	7 (2.3)	1 (0.3)	0 (0.0)	0 (0.0)	0 (0.0)
Depositional Slope	56 (18.5)	36 (12.0)	26 (8.5)	15 (5.0)	12 (4.0)	5 (1.8)	2 (0.5)	0 (0.0)	0 (0.0)
LSD (0.05)	(3.4)	(3.4)	(3.4)	(3.6)	(2.3)	(2.5)	(1.0)	(0.8)	(0.5)

locations within the blowout. By 1989, none of the original transplants remained alive, indicating that blowout penstemon is rather short lived.

Analysis of data collected in Cherry County (Table 2) also showed that the covariance matrices could be pooled and be used in further analysis. Mauchly's criterion indicated that the hypothesis of compound symmetry existing for the data would be narrowly rejected (P > 0.04). Further analysis of the data by the MANOVA test criterion indicated a strong interaction with time (P > 0.0001). It was again necessary to use an adjusted univariate analysis to clarify what differences may or may not have existed at each point in time.

The univariate analysis revealed a highly significant difference between locations within the blowout on 8 of the 9 dates [August 1983, 1984, 1985, 1986, 1987, 1988, 1989 (P > 0.001), and 1990 (P > 0.0002)] with only one plant remaining in 1991. Least significant differences and Waller-Duncan K-ratio mean separation tests gave similar results. During the first year of the study,

TABLE 3

SURVIVAL (PERCENTAGE AND MEAN NUMBER) OF 1985 TRANSPLANTED BLOWOUT PENSTEMON PLANTS IN BARE SAND AND THREE PLANT COMMUNITIES OVER TIME

	Year						
Category	1985	1986	1987	1988	1989	1990	1991
	% N	% N	% N	% N	% N	% N	% N
Bare Sand	68 (22.3)	1 (0.3)	1 (0.3)	1 (0.3)	1 (0.3)	1 (0.3)	0 (0.0)
Blowoutgrass	86 (28.5)	68 (22.5)	65(21.3)	60(19.8)	51(16.8)	36(12.0)	33 (11.0)
Annuals	15 (5.0)	0 (0.0)	1 (0.3)	1 (0.3)	1 (0.3)	1 (0.3)	0 (0.0)
Sandhill Prairie	2 (0.8)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
LSD (0.05)	(2.8)	(1.1)	(1.8)	(2.4)	(3.1)	(5.2)	(5.0)

1983, all communities were significantly different in number of surviving plants. Numbers of plants surviving in the depression were significantly greater than at the other locations. The limited life span of blowout penstemon was clearly illustrated by these data.

Experiment 2

Survival of blowout penstemon transplanted into bare sand and three plant communities in 1985 (Table 3) showed that the covariance matrices could be pooled and used in further analysis. Mauchly's criterion indicated that the hypothesis of compound symmetry existing for the data should be rejected ($P > 0.0001$). Further analysis of the data by the MANOVA test criterion showed a strong interaction with time ($P > 0.0001$), again necessitating use of the adjusted univariate analysis.

TABLE 4

SURVIVAL (PERCENTAGE AND MEAN NUMBER) OF 1988 TRANSPLANTED BLOWOUT PENSTEMON PLANTS IN BARE SAND AND THREE PLANT COMMUNITIES OVER TIME

	Year							
Category	1988		1989		1990		1991	
	%	N	%	N	%	N	%	N
Bare Sand	57	(18.8)	21	(6.8)	17	(5.5)	12	(4.0)
Blowoutgrass	89	(29.3)	71	(23.3)	60	(19.8)	49	(16.3)
Annual	12	(4.0)	0	(0.0)	0	(0.0)	0	(0.0)
Sandhill Prairie	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)
LSD (0.05)		(5.8)		(3.2)		(3.1)		(3.4)

This process suggested a highly significant difference between communities on all 7 dates [August 1985, 1986, 1987, 1988, 1989 ($P > 0.001$), 1990 ($P > 0.0005$), and 1991 ($P > 0.0008$)]. Least significant differences and Waller-Duncan K-ratio mean separation tests gave similar results. In August, 1985, the first year of the study, numbers of surviving plants were different in all categories (Table 3). Plants surviving in the blowoutgrass community were greater than in the other communities for the duration of the experiment.

Survival counts of blowout penstemon transplanted in 1988 (Table 4) indicated that the covariance matrices could not be pooled. The within covariance matrix was therefore used in further analysis. Mauchly's criterion indicated that the hypothesis of compound symmetry existing for the data should be rejected ($P > 0.0001$). Further analysis of the data by the MANOVA test criterion indicated a strong interaction with time ($P > 0.0001$), thus

necessitating a return to the adjusted univariate analysis to clarify differences at each point in time.

The univariate analysis revealed a highly significant difference between categories on all four dates (August 1988, 1989, 1990, and 1991). Least significant differences and Waller-Duncan K-ratio mean separation tests showed that survival of blowout penstemon in the blowoutgrass community was significantly greater than survival in all other categories for all dates.

Discussion and Conclusions

This experiment demonstrated that greenhouse propagated blowout penstemon seedlings would survive transplanting in blowouts. Even though blowout penstemon plants occur naturally in all geomorphic positions in and immediately outside of blowouts, seedlings transplanted into the bowl-shaped depression were most successful (Tables 1 and 2). Blowout penstemon is successional in nature and apparently is unable to compete well with other vegetation (Weedon et al. 1982). Competition of the vegetation on the rim and on depositional slopes would be greater than in the depression.

Plants were placed in the depression in Experiment 1 without regard to plant community, except none were placed into the late successional Sandhills Prairie. It was observed, while collecting data during the first 2 years, that survival rate in the depressions was sensitive to plant community relationship. Therefore, Experiment 2 was initiated to determine the best transplanting site within the depression. Extremely low survival of blowout penstemon seedlings in the annual plant and Sandhill Prairie communities was probably due to competition for moisture. The blowoutgrass community had the highest long-term survival rate for blowout penstemon seedlings (Tables 3 and 4). Blowoutgrass does not grow in dense colonies, and is therefore not likely to be highly competitive. Essentially no competition from other plants occurred on bare sand. Even so, survival of seedlings by August of the second growing season was low. Often the wind removed sand to a depth greater than the transplanting depth in one season. The blowoutgrass community provided some stability to the sand allowing transplants to become established.

Blowout penstemon is rather short lived. We hypothesize that this is related to the temporary aspect of suitable habitat. Plants growing in depressions produce seeds which are moved by the wind out of the blowout. The seeds and sand are deposited in the blowoutgrass community where some germinate and establish. These plants are able to reproduce when the depression, the most

active site of wind erosion, moves into the area that the plants occupy. Due to little or no competition during this stage, the plants become robust, flower, and produce seed. The area in which the plants are rooted is stabilized by other plants when the blowout proceeds beyond in the leeward direction. The complete cycle from seed deposition to plant death may take only 5 to 10 years. Therefore, a longer life span in this dynamic system would be of no advantage to blowout penstemon. If blowouts are less active and move more slowly, the life span of blowout penstemon is not sufficient for it to be able to maintain itself. This hypothesis may help describe why blowout penstemon declined in the Nebraska Sandhills as the area became more stable because of improved range management practices. Also, it emphasizes the necessity of maintaining active wind erosion in selected locations to enable blowout penstemon to recover.

Due to its rather short life span, it is important that blowout penstemon plants quickly establish, flower, and produce seed. Occasionally, plants flowered and set seed one year following transplanting, however for most plants this occurred the second and subsequent years. As the seed bank builds and is replenished each year, the chances of a spring with the proper weather conditions for germination and establishment increase.

Plans for the recovery of blowout penstemon include increasing the number of plants from about 6,000 to 15,000 and increasing the viable populations from five to ten (Fritz et al. 1992). Seedling transplanting will be required because direct seeding has not been successful (Flessner 1988). Numbers of plants and populations can be successfully increased if seedlings are placed in blowoutgrass communities in blowout depressions. Relatively large and active blowouts should be carefully selected to minimize losses to rodents and to provide suitable habitat for blowout penstemon flowering and seed production. Hopefully, the complex set of conditions necessary for natural germination and seedling establishment will occur during the life span of the transplants to enable perpetuation of the population.

Acknowledgments

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