Penstemon oklahomensis (Plantaginaceae) Habitat in Oklahoma

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We describe the habitat conditions of *Penstemon oklahomensis* thru analysis of biotic and abiotic conditions associated with *P. oklahomensis* populations in central Oklahoma. Biotic conditions included associated plant species, species richness, and evenness. Soil chemistry and texture were analyzed for the abiotic component, as well as, disturbance. *P. oklahomensis* habitat consisted of grassland areas with various levels of disturbance and plant species diversity. The most frequent associated species was a member of the Poaceae family. Soils were loam or sandy loam with low nitrogen. Due to the various mowing regimes of the sites evaluated, *P. oklahomensis* appears to tolerate this disturbance. Correlation between the numbers of individual *P. oklahomensis* plants present and the amount of thatch showed a trend of more individuals in plots with higher percent coverage of thatch.

Introduction

Penstemon oklahomensis Pennell (Plantaginaceae) is a regional endemic to the southern plains. Historically, the only known populations were located in Oklahoma (Pennell 1935), but a population was recently discovered in northeastern Texas (Holmes et al 2010). *P. oklahomensis* has been documented in 24 Oklahoma counties (Figure 1), all of which are centrally located in the Osage Plains of Oklahoma (Pennell 1935; Freeman 1981; Great Plains Flora Association 1986; Lindgren and Wilde 2003). Of the 13 species of *Penstemon* occurring in Oklahoma, only the distribution of *P. oklahomensis* is restricted to the state (Hoagland et al 2012; Nold 1999). As a result, it is tracked by the Oklahoma Natural Heritage Inventory, which has assigned it a conservation rank of G3 (either very rare and local throughout its range or found locally, even abundantly at some of its locations in a restricted range, or because of other factors making it vulnerable to extinction throughout its range), S3 (rare and local in Oklahoma, though it may be abundant at some of its locations) (Oklahoma Natural Heritage Inventory 2012).

The geographical range of *P. oklahomensis* coincides with the distribution of the Cross Timbers vegetation type. Within

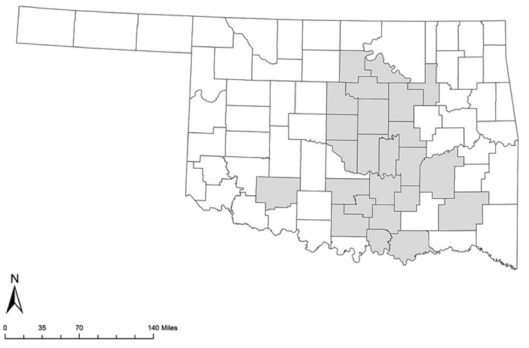

Figure 1. Known county distribution of *Penstemon oklahomensis* within Oklahoma at the beginning of this study, from Oklahoma Vascular Plants Database (Hoagland et. al. 2012).

that region, however, *P. oklahomensis* grows in grasslands and open woodlands. Central Oklahoma is where the Cross Timbers meets the transition from tall grass prairie to mixed grass prairie. The Cross Timbers area is a mix of woodland, savanna, and prairie. The dominant trees in the woodlands are *Quercus stellata* and *Q. marilandica*. Grasses found dispersed in the Cross Timbers are the same species that are found in tall grass prairies (Woods et al 2005). Tall grass prairie is characterized by tall perennial grasses, shorter grasses, and forbs, with the tall grasses dominating. Historically, the tall grass prairie was maintained by grazing bison and fire. Fire suppression and land use change have reduced the total area remaining in the tall grass prairie. Mixed grass prairie is similar to tall grass prairie except that mid-sized grasses are dominant and interspersed with short grasses. Tall grasses are present but much less frequent and abundant. Land use change has also reduced the area covered by mixed grass prairie (Woodward 2008).

The habitat of *P. oklahomensis* has been described as ranging from "sandy soil, prairies and open woods" (Pennell 1935) to "dry, red clay and sandy loam soils, woodland or prairie" (American Penstemon Society 2010). *P. oklahomensis* collections listed in the Oklahoma Vascular Plants Database (OVPD) have similar habitat descriptions ranging from areas of little disturbance to areas of high disturbance such as roadsides, hay meadows, and golf courses. Habitat descriptions also range from open woods to grassland prairies with a few mentioning Tallgrass prairie specifically. Soil descriptions of these same collections also vary from clay to rocky sandy soil (Hoagland et al 2012).

No studies have attempted to describe the habitat conditions of *P. oklahomensis*. Thus, the objective of this study was to gather field data for an analysis of biotic and abiotic conditions associated with *P. oklahomensis* populations in central Oklahoma. To assess these conditions the following questions were posed: 1) What is the soil chemistry and texture of *P. oklahomensis* habitats? 2) What other plant species are associated with *P. oklahomensis*? 3) Is there a common plant associate between populations?

METHODS

Study Sites

All populations studied were located in central Oklahoma. The climate of Oklahoma is continental and experiences temperature extremes. The average annual precipitation follows a northwest to southeast gradient with precipitation increasing from the northwest to the southeast along with the decrease in elevation (Johnson and Duchon 1995). The geology of central Oklahoma is of Permian origin with red sandstones and shales dominating (Johnson and Luza 2008); the area is also known as the Central Redbed Plains (Curtis and Ham 1972). The soils are predominately mollisols; deep, fertile soils that develop under prairie vegetation (Gurevitch et al 2006) that usually have a pH equal to or greater than 7.0 (Johnson and Luza 2008).

There are three known *P. oklahomensis* populations located in Norman, OK, on the University of Oklahoma campus. Two of the campus locations are mowed regularly and provided the opportunity to observe how *P. oklahomensis* responses to frequent disturbance. The third campus location is located behind the Sam Noble Natural History Museum (35°11'N, 97°26'W) and is mowed only once a year. This was the primary observation site as it contains the largest of the campus populations. There are also three known populations located at Tinker Air Force Base, in Midwest City, OK. Two of these populations are on the Air Force Base proper and the third is just off-base on land leased by the Air Force. The population located at the southern end of the base has the largest population and is relatively undisturbed by base operations and was the primary base site for observations and data collection. The second on base population is much smaller and used

regularly for base operations. The third site, just off-base, is used extensively for training exercises and numerous Air Force personnel and civilians use off-road vehicles for recreational purposes in the area. Observation and field data collection from this area was limited because of these activities.

Additional study sites were located and selected using the Oklahoma Vascular Plants Database (Hoagland et al 2012), the Oklahoma Natural Heritage Inventory (Oklahoma Natural Heritage Inventory 2012), and other sources as appropriate. Two new populations were evaluated as well. The previously undocumented *P. oklahomensis* populations discovered had a representative specimen collected and deposited in Robert Bebb Herbarium, located at the University of Oklahoma, Norman, OK. These specimens were added to the Oklahoma Vascular Plants Database and the Oklahoma Natural Heritage Inventory database.

Once located, a 1 m^2 quadrat was centered over the population. Data were collected from the plots in the spring while *P. oklahomensis* was in flower. Eight plots were established in 2011 and four more in 2012, for a total of twelve plots. In each plot, the total number of *P. oklahomensis* individuals was counted. For each plot, it was recorded whether they were in a reproductive stage (e.g. plants with buds only or buds and open flowers) or vegetative stage (rosettes without inflorescences). The number of inflorescences per individual plant was counted.

All additional plant species present in the quadrat were identified and percent cover visually estimated in increments of 5%. Species that were present in the plots but did not contribute more than 1% were assigned a value of 1% meaning they were merely present. The cover of bare ground and thatch (defined as dead plant material from the previous growing season) were likewise visually estimated. Any pollinators observed in *P. oklahomensis* flowers were collected and identified if possible.

Soil samples were collected from each plot using a soil core. Five soil cores were taken from within each plot; one at each corner and one from the center. This was then blended into a composite sample and sent to the Soil, Water and Forage Analytical Laboratory at Oklahoma State University (www.soiltesting.okstate.edu) and analyzed for pH, nitrogen (N), phosphorous (P), potassium (K), and soil texture.

Statistical Analysis

Species richness (e.g. the number of species present), evenness (E; equation 1), and Simpson's Diversity Index (D; equation 2) were calculated for each plot using PC-Ord ver. 5 (Gleneden Beach, OR). Evenness is a measure of how abundance is distributed among species at a site. A site with a high evenness score would be one where each species has almost equal abundance values. Sites with low evenness are those where one or two species account for the majority of abundance. In this study, percent cover is the measure of abundance. A high D value indicates high species diversity. This index of diversity, rather than Shannon's Index of Diversity, was selected because it is a robust diversity measure and because of the small number of plant species encountered (n = 55) during plot evaluation. Simpson's Index is better suited for samples smaller than 1,000 species (Magurran 2004).

$$E = \frac{D}{S} \qquad \text{[equation 1]}$$

$$D = 1 - \Sigma p_i^2 \qquad \text{[equation 2]}$$

Correlation was run to test for relationships between the total number of individual *Penstemon oklahomensis* plants per plot with soil nutrients and pH. The correlation was run a second time including the percent coverage of thatch and bare ground within each plot. SPSS ver 18. (SPSS Inc., Chicago, IL) was used for statistical analysis.

RESULTS

Twelve populations were visited in the central to the southwestern portion of the known *P. oklahomensis* range (Table 1). Habitat at eight of these sites was described as open fields, meaning an open area of grassland with very few trees present. The open field sites in Oklahoma County are not mowed but have been mowed in the past. The open field sites in Cleveland County are mowed regularly; plot 6 is mowed once annually in late fall, and plots 7, 8, and 9 are mowed approximately every other week during the growing season. The other four plots were located along highways; the Oklahoma Department of Transportation mows these areas a minimum of twice annually (Montgomery et al 2010).

A total of 55 species were identified during plot evaluation, six of which were not native to North America (Table 2). None of these taxa had a relative frequency greater than 33%, so little fidelity was exhibited by co-occurring species. The highest frequencies at the family level were for Asteraceae (58%), Fabaceae (92%), and Poaceae (100%). Thatch was found in 78% of the plots. The mean cover of thatch from these nine plots was 25% (STD = 14.1). Bare ground was detected in seven plots and mean cover was 17.8% (STD = 12.2).

Species richness ranged from 4-18 (avg. = 8.6, STD = 4.7).Evenness between plots varied from a value of 0.286 to 0.963 (avg. = 0.670, STD = 0.189). Simpson's diversity scores ranged from 0.235 to 0.881 (avg. = 0.616, STD = 0.199). Although plot 1 had the lowest E and D scores, the species richness was close to average. This is most likely due to the high abundance of *Vulpia* spp. Plot 6 had the highest evenness value; although the low species richness lowered the value of D. Plot four had the highest species richness, and correspondingly high values for D (0.881) and E (0.833).

The percent canopy cover of *P. oklahomensis* within each plot ranged from 5% to 15% (avg. = 7.9%). At least one member of the Poaceae family (Grass family) was associated with all plots. The other most frequently encountered features in the plots were thatch and bare ground. The percent cover of thatch ranged from 0% to 50% with an average of 16.5%. Bare ground cover ranged from 0% to 40% with an average of 12.9% (Table 1). A list of the associated species found in plots and the percent canopy cover of each is listed in Table 2.

The number of individual *P. oklahomensis* varied from one individual to 26 individuals in a plot. Five of the plots had 100% of the individuals in the reproductive stage. The majority of individual plants in the reproductive stage were in all but two plots. These two plots, however, had been mowed just prior to sampling. The plots located along highways had more buds and open flowers than plots located in fields (Table 3).

The soil texture class results were split evenly with six plots having loam soil and six plots having sandy loam soil. Soil pH of the plots was found to range from 5.5 to 7.6. Nitrogen (N) was consistently low; 0.5 to 3.0 ppm. Phosphorus (P) ranged from 2.0 to 13.0 ppm and potassium (K) ranged from 99.5 to 219.0 ppm (Table 4).

Correlation analysis of the number of individual *P. oklahomensis* with soil nutrients showed a strong positive relationship with potassium (Figure 2b; $r = 0.709$, $p = 0.01$). There was no significant relationship with the other soil nutrient variables (Figures 2 & 3). Adding percent thatch and percent bare ground to the analysis showed a positive relationship with percent thatch (Figure 4a; $r = 0.666$, $p = 0.018$). The number of individuals was negatively correlated with the percent of bare ground present (Figure 4b; $r = -0.043$, $p = 0.894$).

Pollinators and Pests

One *Diabroticina undecimpunctata* (Spotted Cucumber Beetle) was observed eating the corolla of a *P. oklahomensis* plant near plot 6. Beetles from the Dermestidae family were observed in the open anthers of numerous

Table 1. Location, sample date, species richness, evenness, Simpson's Diversity Index (D), percent cover of *Penstemon oklahomensis*, percent cover of thatch, percent cover of bare ground, land use, and if mowed data for each plot.

Plot	County	Coordinates	Sample Date	Species Richness	Evenness	(D)	% PEOK Cover	% Thatch	% Bare Ground	Land Use	Mowed
1	McClain	34 54′N, 97 21′W	29-Apr-11	8	0.286	0.235	5	0	0	Highway	Yes
2	Oklahoma	35 23′N, 97 22′W	11-May-11	14	0.665	0.728	5	0	0	Field	No
3	Oklahoma	35 23′N, 97 22′W	11-May-11	14	0.883	0.873	5	25	0	Field	No
4	Oklahoma	35 23′N, 97 22′W	11-May-11	18	0.833	0.881	5	10	0	Field	No
5	Oklahoma	35 26′N, 97 22′W	11-May-11	11	0.682	0.721	5	0	25	Field	No
6	Cleveland	35 11′N, 97 26′W	18-May-11	5	0.963	0.776	10	50	0	Field	Yes
7	Cleveland	35 10′N, 97 26′W	19-May-11	4	0.674	0.515	10	30	20	Field	Yes
8	Cleveland	35 11′N, 97 26′W	19-May-11	4	0.545	0.397	10	30	5	Field	Yes
9	Cleveland	35 11′N, 97 26′W	11-Apr-12	7	0.528	0.504	10	40	5	Field	Yes
10	Grady	34 47′N, 97 58′W	16-Apr-12	4	0.814	0.643	10	20	40	Highway	Yes
11	Stephens	34 36′N, 97 58′W	16-Apr-12	8	0.683	0.683	5	10	15	Highway	Yes
12	Garvin	34 47′N, 97 18′W	16-Apr-12	6	0.487	0.441	15	10	15	Highway	Yes

Table 2. Cover data summary for 12 plots containing individuals of P. oklahomensis. Freq = frequency, RF = relative frequency, Mcov = mean percent cover, STDcov = standard deviation for percent cover, Nativity indicates whether taxon is native to North America or introduced from another continent.

Species	Freq	RF	Mcov	STDCov	Nativity
Achillea millefolium	3	25	0.67	1.44	Native
Ambrosia psilostachya	3	25	0.92	1.93	Native
Ammoselinum spp.	1	8.3	0.08	0.29	Native
Amorpha spp.	2	16.7	0.17	0.39	Native
Andropogon virginicus	2	16.7	3.33	11.55	Native
Antennaria spp.	1	8.3	0.08	0.29	Native
Apiaceae spp.	1	8.3	0.08	0.29	NA
Arenaria serpyllifolia	1	8.3	0.08	0.29	Non-native
Artemisia spp.	1	8.3	0.08	0.29	Native
Asclepias viridiflora	1	8.3	0.08	0.29	Native
Aster spp.	3	25	0.25	0.45	Native
Bromus spp.	2	16.7	3.75	8.82	Non-native
Calylophus spp.	1	8.3	0.08	0.29	Native
Capsella bursa-pastoris	1	8.3	0.08	0.29	Non-native
Carex spp.	2	16.7	0.17	0.39	Native
Cirsium spp.	1	8.3	0.08	0.29	NA?
Coelorachis cylindrica	1	8.3	0.42	1.44	Native
Coreopsis spp.	2	16.7	0.5	1.45	Native
Dalea spp.	2	16.7	0.17	0.39	Native
Dichanthelium spp.	1	8.3	0.08	0.29	Native
Eleocharis erythropoda	1	8.3	0.92	2.87	Native
Eragrostis spp.	2	16.7	0	0	Native
Erigeron philadelphicus	2	16.7	0.92	2.87	Native
Fimbristylis spp.	2	16.7	0.17	0.39	Native
Galium texense	1	8.3	0.08	0.29	Native
Lespedeza capitata	3	25	1	2.86	Native
Linum spp.	1	8.3	0.08	0.29	Native
Lupinus texensis	1	8.3	2.92	10.1	Native/Planted
Mimosa nuttallii	3	25	0.58	1.44	Native
Oenothera spp.	0	0	0	0	Native
Oxalis stricta	3	25	0.25	0.45	Native
Oxalis violacea	1	8.3	0.08	0.29	Native
Panicum spp.	1	8.3	0.08	0.29	Native
Panicum virgatum	4	33.3	10.83	17.3	Native
Pediomelum spp.	1	8.3	0.08	0.29	Native
Penstemon laxiflorus	1	8.3	0.42	1.44	Native
Penstemon oklahomensis	12	100	7.92	3.34	Native
Plantago spp.	3	25	0.92	1.93	Native
Psoralidium tenuiflorum	1	8.3	0.08	0.29	Native
Rubus spp.	1	8.3	0.08	0.29	Native
Ruellia humilis	1	8.3	0.08	0.29	Native
Salvia azurea	1	8.3	0.08	0.29	Native
Schizachyrium scoparium	3	25	3.33	7.49	Native
Scleria spp.	1	8.3	1.25	4.33	Native
Setaria spp.	1	8.3	0.08	0.29	Native
Sisyrinchium angustifolium	3	25	0.25	0.45	Native
Solidago radula	1	8.3	0.42	1.44	Native
Solidago spp.	1	8.3	0.08	0.29	Native
Sorghastrum nutans	3	25	3.75	7.72	Native
Sporobolus spp.	2	16.7	0.17	0.39	Native
Symphyotrichum ericoides var. ericoides	1	8.3	0.09	0.3	Native
Trifolium spp.	2	16.7	0.17	0.39	Non-native
Tripogon spicatus	1	8.3	0.08	0.29	?
Ulmus pumila	2	16.7	0.5	1.45	Non-native
Unknown Grass	1	8.3	5	17.32	NA
Vicia sativa	2	16.7	0.17	0.39	Non-native
Viola tricolor	0	0	0	0	
Vulpia spp.	2	16.7	7.08	21.58	NA
Yucca spp.	1	8.3	0.83	2.89	Native
Bare Ground	7	58.3	10.42	12.87	
Thatch	9	75	18.75	16.53	

Table 3. The total number of individual *P. oklahomensis* plants per plot, the percentage of plants in vegetative (rosette) stage, and the percentage of plants in the reproductive (buds and flowers) stage. The number of bolts, buds, and flowers found in each plot included along with mean, range, and standard deviation.

Plot	Total Individuals	% Rosettes	% Flowering	# Bolts	# Buds	# Flowers
1	11	0	100	15	17	69
2	9	11	89	5	0	20
3	1	0	100	3	50	5
4	4	0	100	5	5	9
5	3	0	100	4	7	5
6	26	31	69	0	0	0
7	16	88	12	0	0	0
8	17	82	18	0	0	0
9	17	18	82	14	223	13
10	12	50	50	6	73	66
11	9	0	100	12	84	51
12	17	29	71	21	126	213
Mean	11.9	25.8	74.3	7.1	48.8	37.6
Range	1 - 26	0 - 88	12 - 100	0 -21	0 - 223	0 - 213
Std.Dev.	7.21	31.99	31.99	6.84	68.98	60.93

Table 4. Soil nutrients and texture results for established plots.

Plot	N (ppm)	P (ppm)	K (ppm)	pH	% Sand	% Silt	% Clay	Class
1	3.0	9.5	217.5	7.4	35.0	45.0	20.0	Loam
2	1.5	6.0	126.5	5.5	38.8	42.5	18.8	Loam
3	1.5	7.0	137.5	5.7	30.0	46.2	23.8	Loam
4	2.5	5.5	119.0	6.2	35.0	42.5	22.5	Loam
5	1.5	4.5	99.5	5.7	62.5	25.0	12.5	Sandy Loam
6	1.0	13.0	205.5	6.3	58.8	30.0	11.3	Sandy Loam
7	0.5	3.0	180.5	6.3	62.5	25.0	12.5	Sandy Loam
8	1.0	5.0	199.5	6.0	36.3	45.0	18.8	Loam
9	1.0	5.5	213.5	6.2	35.0	47.5	17.5	Loam
10	1.0	2.0	219.0	6.5	65.0	20.0	15.0	Sandy Loam
11	1.0	7.0	154.5	7.6	71.2	16.2	12.5	Sandy Loam
12	1.0	7.5	159.0	6.1	65.0	22.5	12.5	Sandy Loam
Mean	1.4	6.3	169.3	6.3	49.6	34.0	16.5	
Range	0.5 - 3.0	2.0 - 13.0	99.5 -219.0	5.5 - 7.6	30.0 - 71.2	16.2 - 47.5	11.3 - 23.8	
Std. Dev.	0.7	2.9	42.3	0.6	15.6	11.8	4.3	

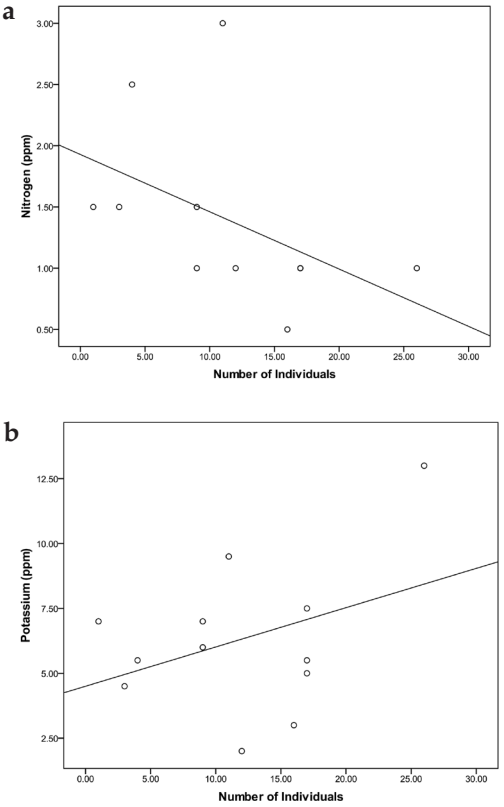

Figure 2. Scatterplots of nitrogen (a; r = -0.474, p = 0.119, R^2 = 0.225) and potassium (b; r = 0.375, p = 0.230, R^2 = 0.141) compared to the number of individual *Penstemon oklahomensis* plants per plot.

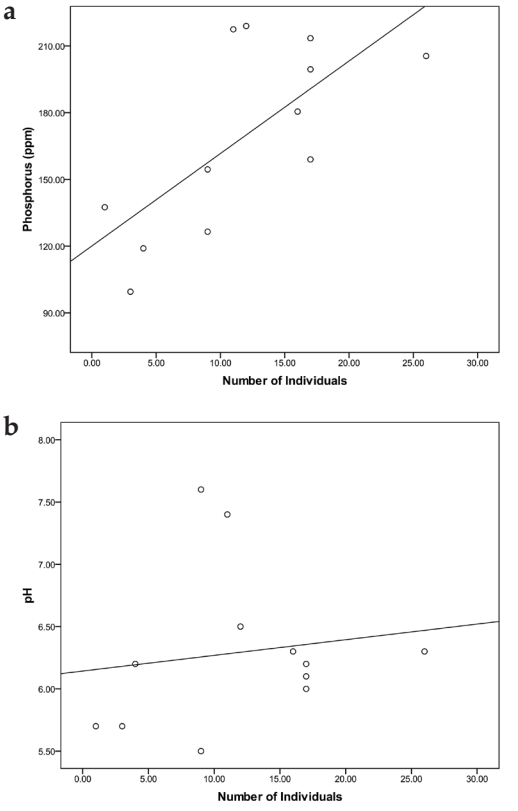

Figure 3. Scatterplots of phosphorus (a; r = 0.709, p = 0.010, R^2 = 0.503) and pH (b; r = 0.142, p = 0.659, R^2 = 0.020) compared to the number of individual *Penstemon oklahomensis* plants per plot.

P. oklahomensis flowers in the same field as plot 6 was located. Bees from the Halictidae family were observed pollinating flowers near plot 7. Within plots 7, 8, and 9, most of the *P. oklahomensis* plants were infested by species of the family Aphididae.

DISCUSSION

This study found that *P. oklahomensis* habitat consists mainly of grassland areas with various levels of disturbance and diversity. Most of the sites visited are mowed once or more annually with two sites mowed more frequently. This suggests that *P. oklahomensis* populations tolerate this type of disturbance and may even benefit from it. Mowing can disperse seeds and the thatch that is left may provide a suitable microhabitat for existing *P. oklahomensis* rosettes and new seedlings. Previous studies have found higher soil moisture (Rice and Penfound 1954) and higher forb seedling survival and establishment (Williams et al 2007) in grassland plots with thatch left after mowing.

The three most frequently mowed plots have been mowed during the height of flowering and still populations persist. The plots that were found to be most species rich were areas with no mowing disturbance while the plots with lower diversity experienced mowing disturbance and had higher percent cover of thatch left. The sites that were mowed had the same as, or higher, percent cover of *P. oklahomensis* plants present as the non-mowed sites. Species richness has been shown to decrease while the abundance of grasses increased in grassland plots with

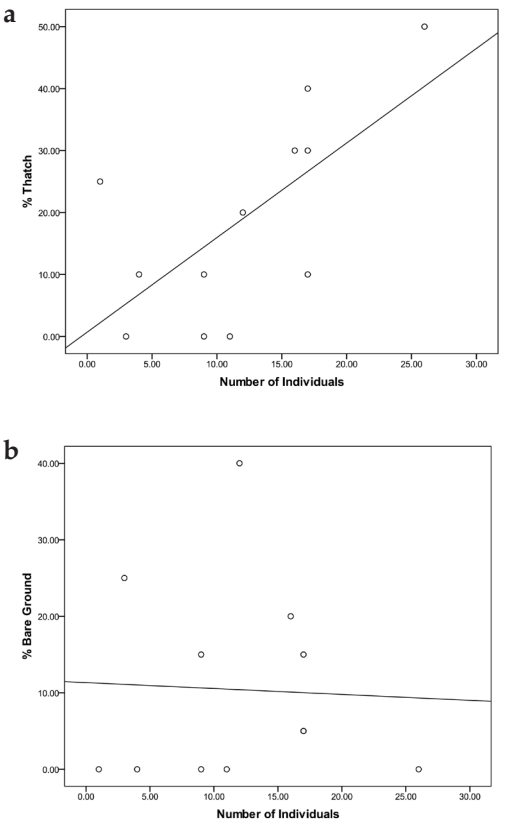

Figure 4. Scatterplots of percent thatch (a; r = -0.043, p = 0.894, R^2 = 0.443) and percent bare ground (b; r = 0.666, p = 0.018, R^2 = 0.002) compared to the number of individual *Penstemon oklahomensis* plants per plot.

thatch left after mowing (Rice and Penfound 1954). Conversely, mowed plots with the thatch removed, have been found to maintain species richness while reducing the abundance of grasses (Maron and Jefferies 2001).

The plots were evaluated during the known flowering period for this species which explains the large percentage of plants found in the reproductive stage versus the vegetative stage. While in the vegetative stage this species can be next to impossible to distinguish from *P. laxiflorus*, especially when both species are present in the same area. The key distinguishing feature between the two species is *P. laxiflorus* has purple nectar guides where *P. oklahomensis* does not.

Soil in *P. oklahomensis* habitats ranged from sandy loam to loam with overall low nitrogen levels. The number of individual plants was correlated with phosphorus levels; higher phosphorus plots had more individual plants present.

The most commonly encountered associated plant species was a member of the Poaceae family. The genera *Andropogon, Bromus, Panicum, Schizachyrium, Sorghastrum,* and *Vulpia* found most frequently. These six genera were also the most abundant species in the plots where present. More *P. oklahomensis* individuals found in a plot tended to correlate with a relatively high percent cover of thatch but was not correlated with the percent cover of bare ground. Bare ground could provide space for new *P. oklahomensis* seedlings due to little or no competition with other plant species, but this was not found in this study. Thatch possibly provides a more suitable germination site for *P. oklahomensis* seeds.

All of the *P. oklahomensis* populations evaluated in this study occurred in grassland habitat. The species diversity of the plots varied with the level of disturbance. Changes in species diversity over time could be monitored for changes in future studies. *P. oklahomensis* appears to tolerate and even benefit from some level of mowing disturbance. Some thatch accumulation in *P. oklahomensis* habitat appears to benefit populations, but thatch may reduce abundance if levels accumulate over time. Timing of mowing may not effect populations, but should be investigated in the future along with the effects of thatch accumulation and removal. Evaluation of *P. oklahomensis* populations in the remainder of its range should be conducted to determine if the trends found here are the same elsewhere in its distribution.

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