Oklahoma Native Plant Record
Volume 22, May 2024

ASSESSMENT OF OKLAHOMA PHLOX (*PHLOX OKLAHOMENSIS*: POLEMONIACEAE) IN THE GYPSUM HILLS OF NORTHWESTERN OKLAHOMA AND SOUTHERN KANSAS

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Keywords: distribution range, census

ABSTRACT

Phlox oklahomensis Wherry, Oklahoma phlox, occurs within the tall grass prairie of the southern Flint Hills of Kansas, and other populations occur within the southern mixed grass prairie of the Gypsum Hills of northwestern Oklahoma and southern Kansas. The first census of Oklahoma phlox in northwestern Oklahoma and southern Kansas was conducted over a three-year period (1980-1982). The second and third censuses occurred approximately 20 years after the first census, in 2002 and 2003. Since the 1980s two major wildfires and several droughts have occurred throughout its distribution range. The goals of this research were to compare the 1980-1982 census and the 2002 and 2003 censuses of Oklahoma phlox to censuses conducted in 2020 and 2021 and assess the current status of the species. In addition, we used a geographic information system (GIS) to identify factors that influence the likelihood of finding Oklahoma phlox in the region. The final census found that the occurrence of Oklahoma phlox has not changed significantly over the last 40 years. Populations thrive in areas where the fire interval is >5 years, and it commonly occurs on the upper elevations of the landscape on hilltops and/or ridges where the slope is > 7%. Although plants were observed on all landscape exposures, populations occur more frequently on west and northwest facing slopes. The authors recommend an S3 ranking for Oklahoma phlox.

INTRODUCTION

Oklahoma phlox (Figure 1), *Phlox oklahomensis* Wherry, was described in 1944 by E. T. Wherry from plant materials collected approximately 21 km (13 miles) north of Mooreland, Oklahoma (Woodward County) by H. C. Benke #5017, holotype (F, Field Museum of Natural History, Chicago, IL), on 22 April 1929. *Phlox oklahomensis* is a perennial herb that grows up to 15 cm high with a lavender, pink, or white corolla with a notch at the tip of each lobe. Its leaves are linear-lanceolate, opposite, and up to 2 cm long (Wherry 1955). It is classified in the tribe Polemonieae of the family Polemoniaceae. Populations of Oklahoma phlox are reported to occur in Butler, Chautauqua, Comanche, Cowley, and Elk counties of Kansas and in Woods and Woodward counties of Oklahoma (Springer and Tyrl 1989).

Figure 1 *Phlox oklahomensis* Wherry from Woods County, Oklahoma. Photographs by Tim Springer.

The distribution of Oklahoma phlox is not continuous, e.g., populations of *P. oklahomensis* occur within the tall grass prairie of the southern Flint Hills of Kansas and other populations occur within the southern mixed grass prairie of the Gypsum Hills of northwestern Oklahoma and adjacent Kansas. Wherry (1955) hypothesized that populations of *P. oklahomensis* of the Gypsum Hills were once continuous with populations of the Flint Hills, and that intermediate populations have been destroyed due to farming and land misuse. Ayensu and DeFilipps (1970) published their inventory of endangered and threatened plants of the United States and listed Oklahoma phlox as a threatened plant species due to its restricted geographical distribution. However, in 1980 the U.S. Fish and Wildlife Service reclassified *P. oklahomensis* as a Category 3C species, i.e., 'Taxa that have proven to be more abundant or widespread than was previously believed and/or those that are not subject to any identifiable threat. Should further research or changes in land use indicate significant decline in any of these taxa, they may be re-evaluated for possible inclusion in Categories 1 or 2 of endangered or threatened.' These listings did, however, justify the need for comprehensive research of *P. oklahomensis*.

A census of Oklahoma phlox populations was conducted over a three-year period (1980-1982) in the Gypsum Hills of northwestern Oklahoma and adjacent Kansas using land survey sections to determine its distribution (Springer 1983).

This census created a baseline for future monitoring of the species. Approximately 20 years after the first census, second and third censuses of Oklahoma phlox were conducted in 2002 and 2003, respectively (Springer and Tyrl 2003). Since 1982 two major wildfires and several droughts have occurred over the range of Oklahoma phlox in the Gypsum Hills of northwestern Oklahoma and adjacent Kansas; therefore we undertook a fourth and fifth census of the species in 2020 and 2021. The goals of this research were 1) to compare the censuses of *P. oklahomensis* to previous censuses; 2) assess the status of the species; and 3) identify factors that appear to influence the likelihood of finding Oklahoma phlox within the region.

METHODS

In previous censuses, land survey sections adjacent to public roads were visually surveyed to determine the presence or absence of Oklahoma phlox (Springer and Tyrl 1989, 2003). This was accomplished by driving public roadways of Woods and Woodward counties, Oklahoma, and Comanche County, Kansas. If a phlox population occurred within a land survey section, the section was counted. In April 2020 and 2021, we conducted similar censuses of Oklahoma phlox in northwestern Oklahoma and adjacent southern Kansas, except that we used a smartphone global positioning system (GPS) application to determine the coordinates of each Oklahoma phlox population encountered. These GPS locations were converted to land survey sections using Earth Point© Tools for Google Earth (Earth Point© 2021) and summarized to land survey sections. Areas previously visited were reexamined and, to determine a more accurate distribution of Oklahoma phlox, areas of similar soil types and habitats were examined outside its known distribution range. The relative abundance of phlox plants was noted but was not quantified for populations. GPS data calculated the length of survey route as 523.6 km in April 2020 and 2021. Since GPS data were not used in the three previous censuses, lengths of survey routes are unknown. In 2020 and 2021 the part of the survey route that was uncultivated on both sides of the roadway was 380.3 km. The route where cultivation had occurred on one side of the roadway was 89.0 km and the remaining 54.3 km was cultivated on both sides. The "cultivated" classification was based on the 2020 cropland data layer (USDA-NASS 2021) and photo interpretation of the most recent satellite data available on Google Maps in 2021.

For 2020 and 2021 data, we assembled elevation, soil, and fire history geospatial datasets for the study area into a geographic information system (GIS) to identify factors that may influence the distribution of the species. Soil mapping spatial data for each county were obtained from the USDA-NRCS, Web Soil Survey (Soil Survey Staff, USDA-NRCS 2022). The various soil mapping units encountered were grouped by component composition irrespective of slope or other phase characteristics. One hundred and one unique soil map units were encountered by sampling the survey route and the units were combined to form 37 soil mapping unit groups based on component composition. All single component soil mapping units (i.e., soil mapping units with only one named soil series or miscellaneous land type, such as rock outcrop) with the same named component were grouped together even though they may have a different map unit symbol because they were mapped in a different county or have a different slope class or other phase characteristic. For complex soil mapping units with only two components, the grouped units shared the same composition but in different proportions and, as above, with different phase characteristics. Soil map units composed of three components were included in the same group if at least one component was in common with all other members of the group. The fire history data were the monitoring trends in burn severity (MTBS) dataset described in Picotte et al. (2020) that covers the period 1984 through 2020. Based on the first author's observations, there was no evidence of fire anywhere along the survey route in 2021 and we feel confident the 1984 to 2020 MTBS dataset can also be used to represent 2021 along the survey route as well. We utilized the fire polygons layer from the MTBS. The elevation dataset (DEM) used was the 30-m national elevation dataset available to download for each county from the USDA-NRCS, Geospatial Data Gateway (2022). The DEM was used to derive additional geospatial datasets including slope, slope aspect, and topographic position indexes (TPIs) at four scales. The slope and aspect rasters were calculated in the database using the st_slope and st_aspect functions in the POSTGIS extension for PostgreSQL. For the TPIs we wrote our own procedures in the R language to implement the TPI method given in De Reu et al. (2013) and Weiss (2001). The topographic position index characterizes a location's elevation in relationship to the average elevation of the surrounding landscape, where the surrounding landscape is defined as the area covered by an annulus centered on the location. The annulus has an outside radius given as the scale radius and the inside radius is defined as the outside radius minus the band width. The radiuses used for the four TPI scales were 2000 m, 1000 m, 300 m, and 150 m (67, 33, 10, and 5 DEM cells away) and the band width was always 60 m (2 cell widths). A TPI near zero signifies the site is on a plain that may or may not be sloping; a large positive TPI, depending on the scale, implies the site is on a mound (local scale), hill, ridge, or interfluve (regional scale); and a large negative TPI signifies the site is in a gully (local scale), swale, or large valley (regional scale).

After these datasets were assembled, the layers were sampled at all points where phlox sites were recorded in 2020 and 2021 and at a set of 1000 random points. The random points were selected from within a 30 m buffer along that portion of the survey route where at least one side of the route was not cultivated (i.e., everything except the 54.3 km cultivated on both sides). The sampling was done using R software by intersecting the points with the attribute layers and appending the attribute information to the points.

The attribute data for the sites where phlox was observed in 2020 and 2021 were compared with the attribute data for the random sites to determine whether phlox sites differ from random sites and, if so, how they differ. For each attribute, a table was constructed with the counts of each attribute value associated with phlox sites, and the expectation was derived from the counts of each attribute value associated with the set of random points. A χ^2 analysis was done for each table to determine if the overall distribution differed between the phlox sites and the random sites and, if the test was significant, two by two tables were constructed to test whether each attribute value was observed less often, more often, or about as often as expected by chance at phlox sites.

The data from the 2020 and 2021 surveys are published on Ag Data Commons (https://doi.org/10.15482/USDA.ADC/1529120). Included in this dataset are three KML format files and a data dictionary describing the tabular variables found in the other three files in CSV format. One KML format file contains the geographic coordinates, soil, fire history, and topographic characteristics of each location where phlox populations were observed along the survey route in each year and another file contains the same for a set of 1000 random points along the survey route. The last KML format file gives the geometry of the survey route and whether the segment was cultivated on either side of the route in 2020 and 2021.

RESULTS AND DISCUSSION

It has been 40 years since the first census of Oklahoma phlox in northwestern Oklahoma and adjacent Kansas. Over that period, short- and long-term droughts have occurred in the region, the driest years occurring in 2011-2012 (Weather records from the Southern Plains Range Research Station, USDA Agricultural Research Service, Woodward, Oklahoma). Wildfires have occurred in the known range of Oklahoma phlox in Woods County, Oklahoma and Comanche County, Kansas in February 1996 and again in March 2016, and consecutive wildfires over parts of the known range of *P. oklahomensis* in Woodward County, Oklahoma in March 2017 and April 2018.

Five censuses of Oklahoma phlox have been conducted in which public roadways were driven and surveyed visually (as far as the eye could see) to determine the presence or absence of Oklahoma phlox. The first census occurred over a three-year period, 1980-1982, the second occurred in 2002, the third in 2003, the fourth in 2020, and the fifth in 2021. The first census verified the presence of Oklahoma phlox in 56 and 19 survey sections in Woods and Woodward counties, Oklahoma, respectively, and four sections in Comanche County, Kansas (Springer 1983). The number of survey sections averaged over the 2002 and 2003 censuses was 51.0 and 27.5 survey sections for Woods and Woodward counties of Oklahoma, respectively, and 4.5 sections in Comanche County of Kansas (Springer and Tyrl 2003). Similarly, the number of survey sections averaged over the 2020 and 2021 censuses was 45.0 and 33.5 for Woods and Woodward counties of Oklahoma, respectively, and 7.0 sections in Comanche County of Kansas (Table 1). Combining the data over the last two censuses, the total number of phlox observation sites was 529 in 99 land survey sections. Thirty-one

Table 1 Land survey sections containing one or more populations of *Phlox oklahomensis* Wherry in censuses conducted in 1980−1982, 2002, 2003, 2020, and 2021.

	Number of Sections with Populations		
	Oklahoma		Kansas
Survey Years	Woods Co.	Woodward Co.	Comanche Co.
1980−1982	56	19	4
2002	34	16	2
2003	68	39	7
2020	39	26	7
2021	51	41	7

percent of the 529 observation sites were identified in 2020 and 69% were identified in 2021 (some observation sites may be common to both years). Thus, the data suggest that the number of land survey sections has not drastically changed over the 40-year period (Table 1). The low census counts in 2002 and 2020 can be explained by below average fall and winter precipitation in 2001-2002 and again in 2019-2020. Springer et al. (2013) suggested that the variation in the number of sections found among years was correlated with fall and winter precipitation, i.e., when below average fall and winter precipitation occurs, fewer phlox populations are observed, and conversely when above average fall and winter precipitation occurs, more populations are observed. Thus, abundant fall and winter precipitation is important in the life cycle of Oklahoma phlox.

Based on the 38-year burn history, the distribution of the number of burns during this time period differed between phlox sites and randomly selected sites ($\chi^2 = 35.4$, df = 3, $P < 0.0001$). Oklahoma phlox was less likely to occur on unburned areas or areas burned three times over the 38-year period (Figure 2). Phlox was observed only once in an area that received three wildfires over the 38-year period; however, eight observations would have been expected by chance. There were 240 observations of phlox on unburned areas. This was 82% of what was expected. Where fire occurred once or twice during the period of record, significantly more phlox observations occurred than expected by chance (149 and 139 observations and 1.2 and 1.4 times as many as expected by chance, respectively).

We also defined phlox populations along the survey route according to the year from last burn (areas not burned during the 38-year period were classified as burned before 1984). Populations of phlox were not proportionately distributed among each of the years from last burned classes ($\chi^2 = 428.1$, df = 6, $P < 0.0001$, Figure 3). As expected, phlox observations in areas burned before 1984, 55.6% of the survey route, were underrepresented. This is

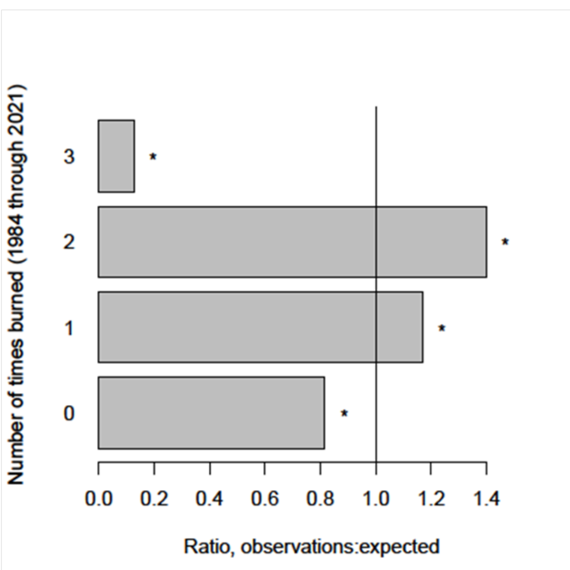

Figure 2 The ratio of the number of sites where *Phlox oklahomensis* Wherry was observed to the number of sites expected by chance for each area along the survey route with a different number of burns in the previous 37 years (1984 to 2021).

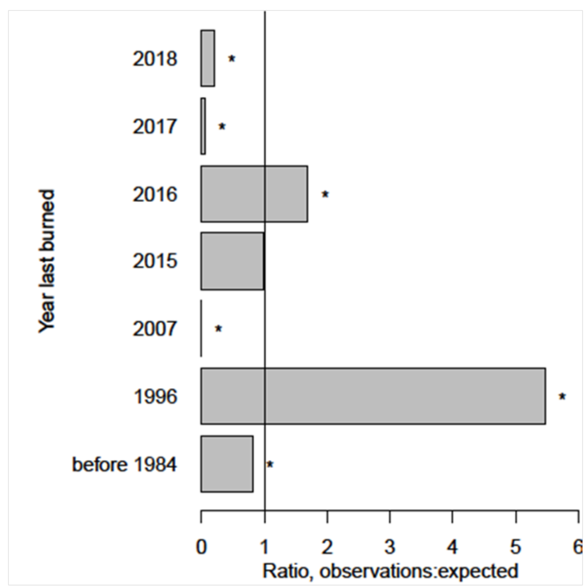

Figure 3 The ratio of the number of sites where *Phlox oklahomensis* Wherry was observed to the number of sites expected by chance for each area along the survey route with a different year last burned.

identical to the result shown above for areas that were not burned but, irrespective of how many times burned, only in areas last burned in 2015 (4.0% of the survey route) are phlox sites represented in proportion to chance expectation. The areas last burned in 2007 (1.0% of the survey), 2017 (7.3% of survey), and 2018 (9.9% of survey) have significantly fewer phlox sites than expected, and the areas last burned in 2016 (19.4% of the route) and especially in 1996 (2.8% of the route) had significantly more phlox observations than expected by chance. The areas last burned in 2016 had approximately 70% more phlox sites than expected, and areas last burned in 1996 had nearly 5.5 times as many phlox sites as expected by chance. Thus, prescribed fires would be beneficial to Oklahoma phlox in areas where fires have not occurred over a long period of time. However, a high frequency of prescribed fires may reduce the number of individuals in a phlox population.

We also considered each sampling year separately and defined fire history in terms of years since last burned in the sampling year. Areas sampled in 2020 with 24 years since last burned and correspondingly areas sampled in 2021 with 25 years since last burned had more phlox observations than would be expected by chance (Figure 4). In 2020, all other years since last burned, except four years since last burned, had fewer phlox observations than expected by chance. In 2020, the four years since last burned had more than expected, but in 2021 the corresponding areas with five years since last burned had phlox observations in proportion to what was expected by chance. Also in 2021, the six years since last burned areas had phlox observations in proportion to what was expected by chance and areas with the other four levels of years since last burned (3, 4, 14, and 37 years) had fewer phlox sites observed than expected by chance. Therefore, it may take five to six years for phlox populations to fully recover after a wildfire, although long durations

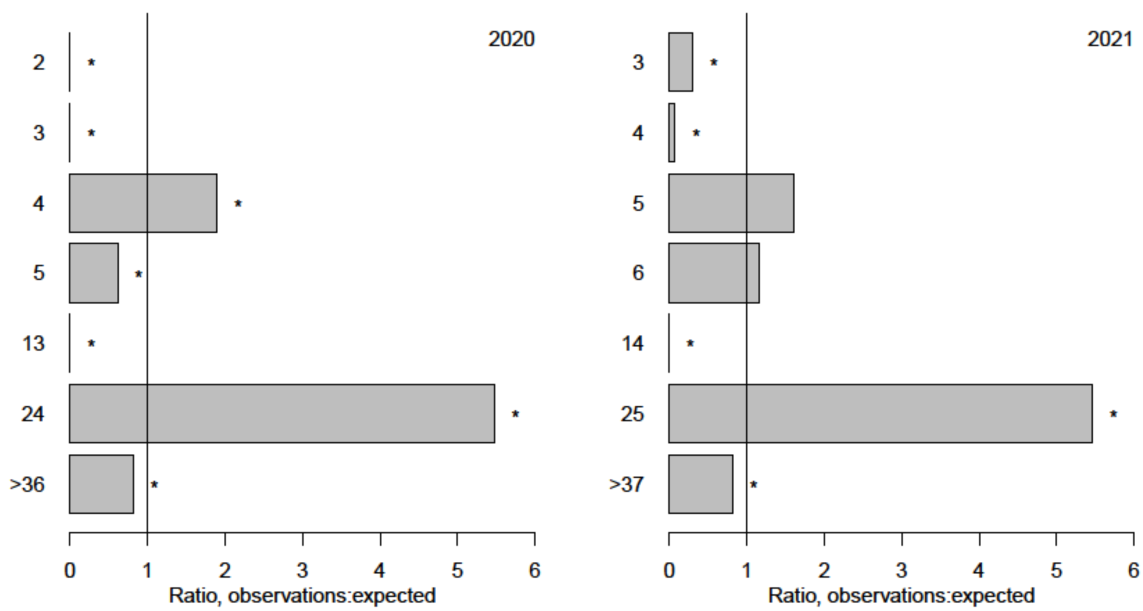

Figure 4 The ratio of the number of sites where *Phlox oklahomensis* was observed to the number of sites expected by chance for each area having a different number of years since last burned for surveys completed along the route in 2020 and 2021.

without fire significantly reduced the number of phlox populations encountered along the survey route, as evidenced by the data where sites were unburned for 36 or 37 years (Figure 4). This may be due to the accumulative effects of eastern red cedar (*Juniperus virginiana* L.) growth or the growth of other woody plant species. Thus, a 10-to-15-year burn cycle may be the best management practice for Oklahoma phlox.

The random sites and phlox population sites were found on a total of 37 unique soil mapping unit groups and Oklahoma phlox was observed in most of these groups (25) in proportion to the chance expectation, but phlox was found less than expected in seven soil mapping unit groups and more than expected in five soil mapping unit groups ($\chi^2 = 464.1$, df = 36, $P < 0.0001$). The 12 soil map units with phlox observations either significantly more or less than expected are plotted in Figure 5 as the observed:expected ratio.

The elevations above sea level for the phlox sites and randomly selected sites along the survey ranged from 456 m to 656 m. The elevation of the phlox sites averaged 591 m which was significantly greater than the randomly selected sites (539 m, $P < 0.0001$). The observed slopes in the dataset ranged from < 0.25% to 37.0%. Sites where phlox was observed averaged 7.2% slope which was significantly steeper than the average for the randomly selected sites along the survey route (5.6%, $P < 0.0001$). When we reclassified slope into six slope classes, phlox was less likely to be observed on slopes of <5% compared with that of chance, phlox was equally likely to occur on slopes of 5 to 7%, and phlox was expected to occur more often where slopes were >7% (Figure 6). Springer and Tyrl (1989) reported that *P. oklahomensis* was observed near rocky outcrops where competition from plants and accessibility to livestock is reduced. Furthermore, steep slopes are not conducive to human activity.

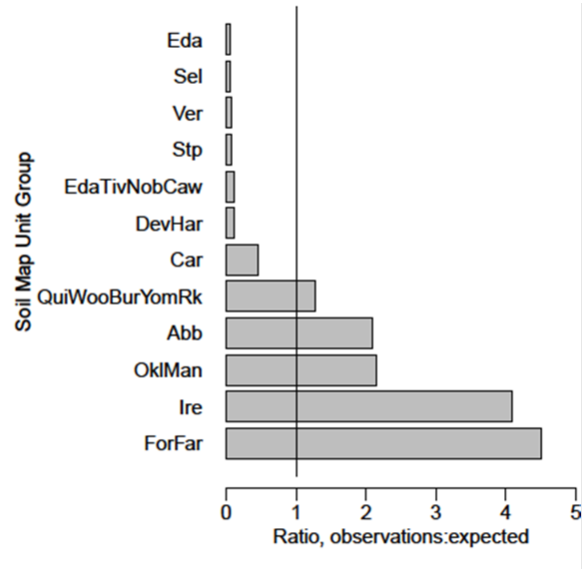

Figure 5 The ratio of the number of sites where *Phlox oklahomensis* Wherry was observed to the number of sites expected by chance for each area having a different soil map unit group. Shown in this figure are only the map unit groups where the number observed differs significantly from the expectation. Of the 37 groups encountered, seven had fewer and five had more Oklahoma phlox observation than expected by chance. The remaining 25 soil map unit groups had Oklahoma phlox observations in proportion to the expectation based on the area available. Eda, Eda soils; Sel, Selman soils; Ver, Vernon soils; Stp, St. Paul soils; EdaTivNobCaw, Eda-Tivoli-Nobscot-Carwile complex; DevHar, Devol-Harteman complex; Car, Carey soils; QuiWoodBurYomRk, Quinlan-Woodward-Burson-Yomont-Rocky outcrop soils; Abb, Abbie soils; OklMan, Oklark-Mansic soils; Ire, Irene soils; ForFar, Fortyone-Farry soils.

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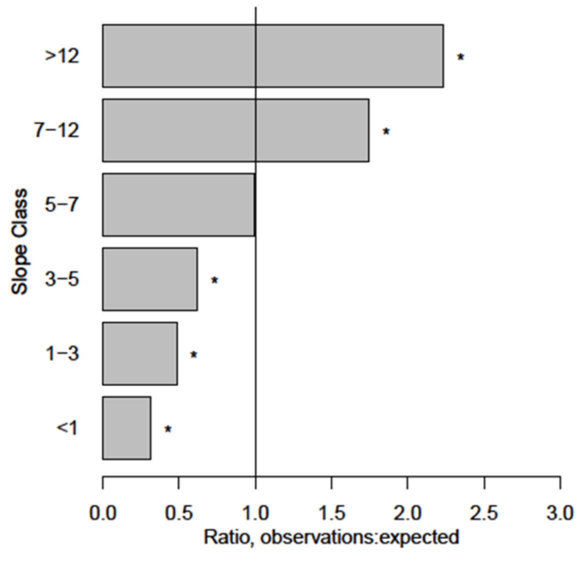

Figure 6. The ratio of the number of sites where *Phlox oklahomensis* Wherry was observed to the number of sites expected by chance for each area along the survey route with a different slope class.

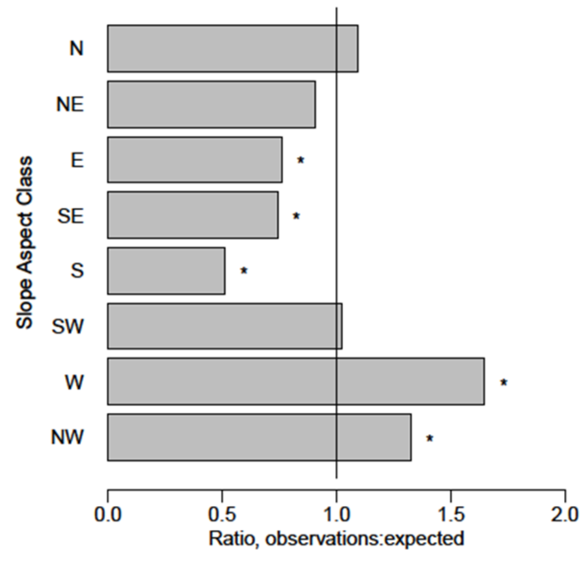

Figure 7. The ratio of the number of sites where *Phlox oklahomensis* Wherry was observed to the number of sites expected by chance for each area along the survey route with a different slope aspect class.

The mean slope aspect also differed between phlox observation sites (201°) and randomly selected sites (178°, $P < 0.0001$). To better understand the effect of slope aspect we reclassified aspect to one of the four cardinal or four primary intercardinal directions. It is clear from this analysis that E to S facing slopes have significantly fewer phlox observation sites than expected by chance and W to NW facing slopes have more phlox sites than expected by chance (Figure 7). The N to NE and SW facing slopes have phlox sites in proportion to the chance expectation. In contrast, Springer and Tyrl (1989) reported that plants were observed on all landscape exposures, but that plants preferred the cooler north-facing slopes.

Collectively the topographic position indexes at all four scales evaluated were greater at the phlox observation sites than the randomly selected sites along the survey route. The 150 m TPI averaged 2.1 for phlox sites compared with 0.7 for randomly selected sites ($P < 0.0001$). Likewise, the mean of the other three TPI scales was significantly greater for the phlox observation sites (300 m = 3.5, 1000 m = 7.3, and 2000 m = 11.0) than for the random sites (300 m = 1.2, 1000 m = 2.3, 2000 m = 4.1, for all TPI mean comparisons $P < 0.0001$). At each scale, the mode of the TPI distribution for random sites was near the means, but for the phlox observation sites the modes of the TPI distributions were greater than the means, and the greater the TPI scale the larger the difference between the mean and the mode (Figure 8). For comparison, a TPI near zero signifies a site of a flat or near continuous slope, a large positive TPI implies the site is on a hill or ridge, and a large negative TPI signifies the site is in a valley or gulley. Thus, Oklahoma phlox more commonly occurs on the upper elevations of the landscape on hills or ridges.

In summary, Oklahoma phlox is a hardy species. It has endured moderate to severe drought and untimely wildfires over the past 40 years. Land use in the Gypsum Hills has not changed significantly and consists

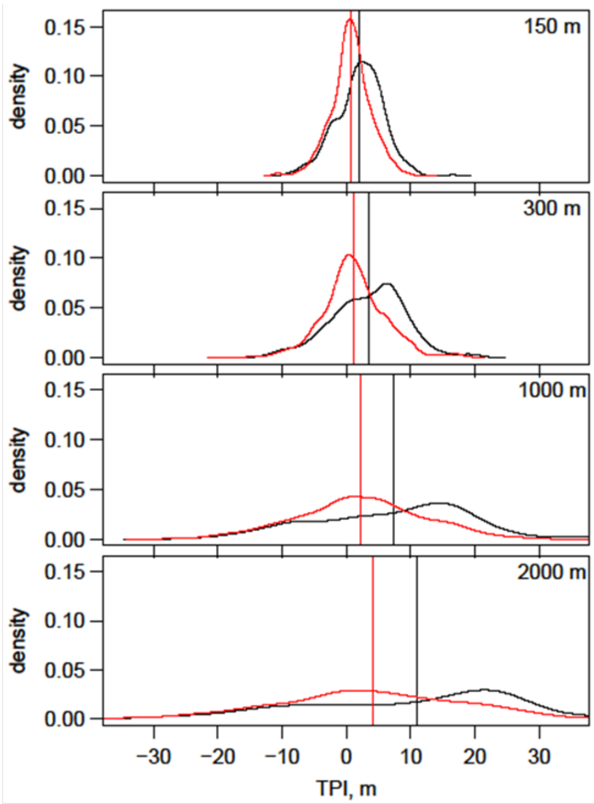

Figure 8 Distribution of the topographic position index (TPI, m) computed at 4 scales from 150 m to 2000 m for sites where *Phlox oklahomensis* Wherry was found (black curve) and random sites along the survey route (red curve). The means of the distributions are plotted as vertical lines on each panel and the mode is the peak of distributions.

primarily of cattle production (ranching). Much of the data collected through GIS agree with field observations; however, new data suggest a burn cycle of 10-to-15 years may be beneficial to the species' long-term survival. In addition, conducting a census in a single year may give false impressions of the species' status and stability, as shown by the data from 2001 and 2002 and again in 2020 and 2021. In each case fewer phlox observations were made in 2001 and 2020 compared with 2002 and 2021. Human activity that significantly disturbs the landscape is detrimental to the abundance of Oklahoma phlox.

Status of *Phlox oklahomensis* in 2021

The status of Oklahoma phlox has not changed significantly over the past 40 years. It was initially designated a Category 3C species by the U.S. Fish and Wildlife Service (1980 FR 45:82557). It is currently ranked as 'imperiled' (S2) at the state level (ONHI, 2017) and as 'vulnerable' (G3) at the global level (NatureServe 2023). The S2 designation states that the species is 'imperiled-at high risk of extinction due to very restricted range, very few populations (often 20 or fewer), steep declines, or other factors making it especially vulnerable to extirpation from the state,' and the G3 designation states that the species is 'vulnerable-at moderate risk of extinction or elimination due to a fairly restricted range, relatively few populations or occurrences, recent and widespread declines, threats, or other factors' (NatureServe 2023).

Woods County, Oklahoma appears to be the epicenter of the distribution range in the Gypsum Hills of northwestern Oklahoma and southern Kansas. Based on the censuses of 2020 and 2021 and the fact that populations appear to be stable over the past 40 years, and on close observations of several populations within this range, we suggest a change to the ONHI listing of S2 to an S3 ranking. The S3 ranking is like the G3 ranking and would align the state ranking with the global ranking.

ACKNOWLEDGMENTS

The first author thanks Dr. Paul F. Nighswonger (1923-2014), Department of Biology, Northwestern Oklahoma State University, Alva, and Dr. Ronald J. Tyrl (1943-), Department of Botany and Microbiology, Oklahoma State University, Stillwater. Both men recognized my interest in botany and invested much time to cultivate that interest and for that I am very grateful. The authors also thank Merry Springer for aiding in navigation and data collection over this two-year project.

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