DISTRIBUTION, HABITAT, AND REPRODUCTIVE BIOLOGY OF *PHLOX OKLAHOMENSIS* (POLEMONIACEAE)

By

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1978

Submitted to the Faculty of the Graduate College
of Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
MASTER OF SCIENCE
May, 1983

DISTRIBUTION, HABITAT, AND REPRODUCTIVE BIOLOGY OF PHLOX OKLAHOMENSIS (POLEMONIACEAE)

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PREFACE

The biology of Phlox oklahomensis has been investigated to learn more about the taxon. Special consideration was given to the taxon's geographical distribution in Oklahoma, habitat requirements, and reproductive biology.

I thank Dr. R. J. Tyrl, my thesis adviser, for his time and effort throughout the project. Appreciation is given to Dr. R. M. Ahring and Dr. P. E. Richardson for advice and criticism during the study and preparation of this manuscript.

Thanks are also given to Dr. P. F. Nighswonger of Northwestern Oklahoma State University for his help in data collection during field studies, and to Mr. and Mrs. George Dyer and Mr. and Mrs. Rudy Bush of Freedom, Oklahoma, for use of their properties where I conducted much of my field research. Special thanks is given to Merry, my wife, for her encouragement throughout my studies, and for the typing of this manuscript.

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CHAPTER I

INTRODUCTION

Phlox oklahomensis Wherry (Figure 1) is a perennial herb which belongs to the tribe Polemonieae in the family Polemoniaceae (Grant, 1959). The genus *Phlox* comprises about 70 species. All species are distributed throughout most of North America; however one taxon, *P. borealis*, ranges into Eurasia. Two species of *Phlox* are endemic to the Great Plains region of North America (Grant, 1959). *P. oklahomensis* occupies a very limited geographical distribution and throughout a large part of its range is genetically isolated from other species of *Phlox*.

Phlox oklahomensis was first described by E. T. Wherry (1944). The holotype was collected 22 April 1929 in Woodward County near Mooreland, Oklahoma, by H. C. Benke (collection #5017). Initially, the taxon was known to occur in Woods and Woodward Counties in Oklahoma. Later, the taxon was reported in Kansas (Horr and McGregor, 1949, 1951) and in Texas (Correll and Johnston, 1970). Reports of *P. oklahomensis* occurring in northwestern Arkansas (Wherry, 1955) were later shown to be incorrect by Marsh in a 1960 biosystematic study of the relationship of *P. oklahomensis* and *P. bifida*.

Because of its restricted geographical distribution, *P. oklahomensis* was designated a threatened plant species (Ayensu and DeFilipps, 1978). Plants of the threatened category include taxa that are likely to become endangered within the foreseeable future

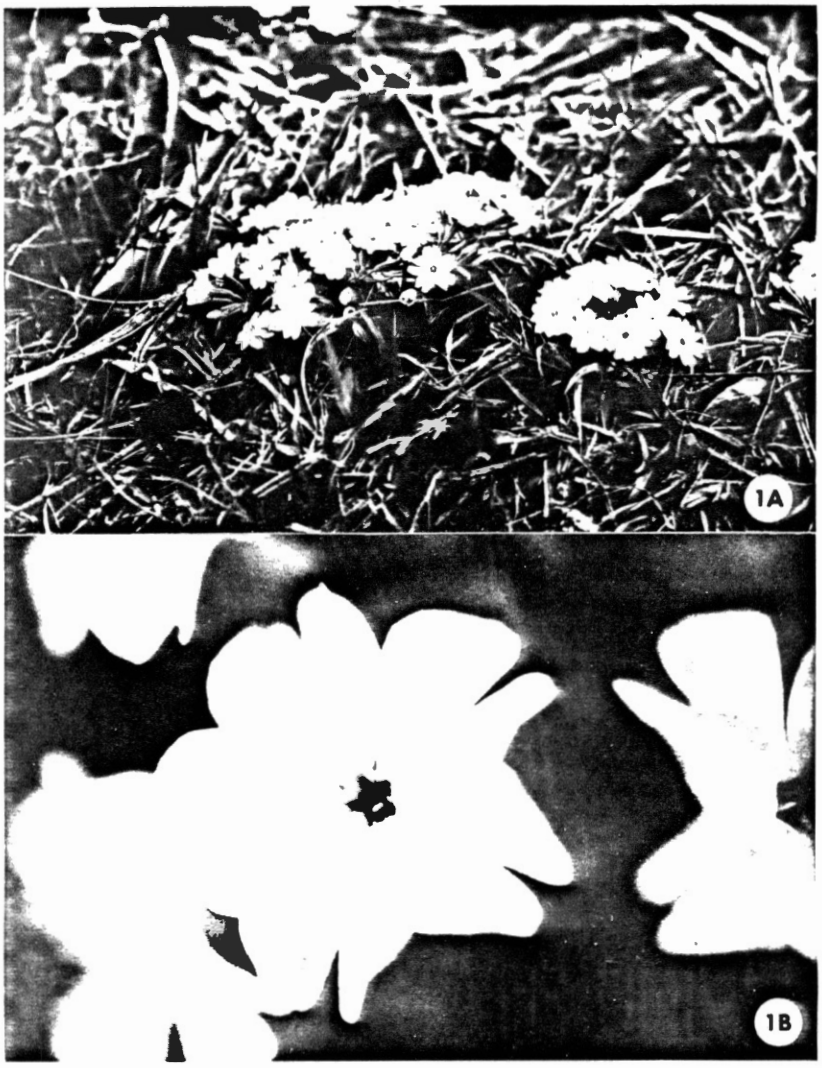

Figure 1. Phlox oklahomensis. 1A: Habit. 1B: Flower.

throughout all or a significant portion of their ranges. Factors such as habitat curtailment, a fragile or restricted habitat, or small population size usually place a species in the endangered category.

While the listing of P. oklahomensis as threatened by Ayensu and DeFilipps did not constitute an official or legal designation, it did indicate a need for information about the taxon. Although field surveys and status evaluations have been conducted (Tyrl et al., 1978; Zanoni et al., 1979, and Taylor and Taylor, 1980), a detailed study of the biology of the taxon seemed appropriate. Therefore, the objectives of this investigation were: 1) to determine the extent of its range; 2) to describe its habitat; 3) to describe its external morphology; and 4) to describe its reproductive biology.

CHAPTER II

MATERIALS AND METHODS

Field studies were initiated in 1980 with observations of distribution and habitat. Detailed investigations were conducted during the 1981 and 1982 growing seasons. These included studies of the taxon's distribution, habitat requirements, external and reproductive morphology, and reproductive biology. The last study encompassed an examination of chromosome number, pollen-size and distribution percentages, pollen viability, phenology, reproductive system, seed-size and distribution percentages, and seed germination requirements.

The geographical distribution of Phlox oklahomensis was established by field trips and examination of herbarium specimens deposited at the Field Museum of Natural History, Chicago, Illinois (F); Gray Herbarium, Cambridge, Massachusetts (GH); University of Kansas, Lawrence (KANU); Kansas State University, Manhattan (KSC); Lundell Herbarium, Austin, Texas (LL); University of Oklahoma, Norman (OKL); Oklahoma State University, Stillwater (OKLA); Herbarium of the Academy of Science Philadelphia, Philadelphia, Pennsylvania (PH); New York Botanical Garden, Bronx, New York (NY); and University of Texas, Austin, Texas (TEX).

Morphological variation among plants of individual populations and among populations was studied. Characters examined were: 1) leaf

length, 2) leaf width, 3) calyx length, 4) corolla blade (limb) length, 5) corolla blade (limb) width, 6) corolla tube length, 7) style length (including the stigmas), and 8) anther length.

Phenological patterns and habitat requirements were observed as populations were encountered.

Studies involving the reproductive biology of Phlox were conducted at three sites in Woods County, Oklahoma. The legal and physical descriptions of each site are given in Table I.

Plant chromosome numbers were obtained from root tips collected from germinating seedlings. Pretreatment methods and fixation were modifications of those used by Meyer (1943). Root tips were pretreated in 0.2% colchicine solution for two hours, fixed in Semmen's Carnoy (3:1:1, 100% ethanol:glacial acetic acid:chloroform), squashed on a microscope slide in alcoholic acetocarmine stain, and mounted in Hoyer's mounting medium. Pollen viability was determined at sites 1 and 2 on 3 April and 18 April 1982. At each site on each date one anther from five flowers buds from four plants was removed one to two days before anthesis. The anther was squashed onto a microscope slide in aniline blue in lactophenol. Aniline blue stained the viable pollen grains dark blue while non-viable grains stained faintly. From each microscope slide 100 pollen grains were scored and percentages were calculated by number.

Pollen size and distribution percentages were determined at sites 1 and 2 on 3 April and 18 April. At each site on each date, intact flowers were collected and transported to Stillwater for laboratory analysis. Pollen grains were removed from the anthers onto a watch glass and dispersed in deionized water with the aid of a Coulter Type

TABLE I

LEGAL AND PHYSICAL DESCRIPTIONS OF STUDY SITES
IN WOODS COUNTY, OKLAHOMA

	Site 1	Site 2	Site 3
Latitude and Longitude	36° 59' N Lat. by 99° 05' W Long.	36° 55' N Lat. by 98° 55' W Long.	36° 56' N Lat. by 99° 01' W Long.
Legal Description	R17W; T29N; Sec. 19	R16W; T28N; Sec. 9	R17W; T28N; Sec. 3
Location (name)	Dyer Ranch	Near Cora, OK	Bush Ranch
Geologic Formation	Ogallala	Flowerpot shale	Marlow
Soil Type	Potter fine sandy loam	Vernon very fine sandy loam	Vernon very fine sandy clay loam
Soil pH	6.9 - 7.0	6.9 - 7.1	6.9 - 7.1
Dominant Associated Species	Schizachyrium scoparium and Andropogon gerardii	Bouteloua sp.	Bouteloua sp.
Demography	Scattered individuals	Scattered individuals	Numerous plants
Exposure	Variable	Variable	Northwest
Slope (°)	1 - 5	0 - 20	6 - 15
Approximate Elevation (m)	576	539	579

II-A cationic dispersing agent. Pollen samples were counted and sized with a Coulter Counter Model Z-BI and Coulter Channelyzer unit. The instruments were calibrated using a 22.5 μm reference particle. Pollen sizes were calculated and distribution percentages were determined.

In order to determine the nature of the reproductive system of P. oklahomensis, the capacity for autogamy (self pollination--pollen from the flower is deposited onto the stigmas of that flower), allogamy (cross pollination--pollen from a flower is deposited onto the stigmas of another flower), and agamospermy (apomixis--asexual reproduction) were tested at site 3 using standard techniques (Radford et al., 1974). Because of the floral morphology, flowers were not tested for anemophily (wind pollination). In studying each reproductive mode, 25 flowers at approximately the same stage of development were tested. Flowers were chosen at random throughout the population from at least five plants. Pedicels were tagged with colored tape. Methods used for each study are summarized below:

CONTROL (natural pollination)--flower buds were tagged and left undisturbed through flowering and fruiting.

AGAMOSPERMY--flower buds were emasculated and plants were covered with nylon cages.

AUTOGAMY--Natural: flower buds were tagged and plants were covered with nylon cages. Artificial: partially open flowers, approximately one day old, were manually self-pollinated and plants were covered with nylon cages.

ALLOGAMY--partially open flowers, approximately one day old, were manually cross-pollinated and plants were covered with nylon cages. Reciprocal crosses were not performed.

The mature capsules were collected three weeks later, dissected, and the number of seeds counted in order to determine natural fruit and seed set.

At sites 1 and 2, seed size and distribution percentages were determined. Prior to dehiscence and seed dispersal, approximately 1,500 capsules were collected at each site in 1981 and 1982. Seed were extracted using a light abrasive action on a rub-board and cleaned to pure seed. Seed were separated into five seed size classes with a South Dakota seed blower Model B using air valve openings of 25, 30, 35, 40, and 45 degrees. Seed size was determined by dividing the milligram weight of each class by the number of seed in the class. Percent distribution was calculated by dividing the number of seed in each class by the total number of seed sized.

Germination experiments were conducted on seed of the 35 degree seed class harvested in 1981 to determine requirements for germination. Seed from sites 1 and 2 were germinated in a 20° C constant dark environment on substrates moistened with either H_2O or 0.2% KNO_3. One experiment involved predrying (heat treatment) at 65° C for 0, 8, 24, 48, and 96 hours. A second experiment consisted of a moist prechill (H_2O or 0.2% KNO_3) at 0-5° C for 0, 1, 2, and 4 weeks prior to germination at 20° C.

In addition, studies were conducted to determine the relationship of seed size to germination. This study utilized four seed classes, a control (i.e., bulk seed not separated into size classes), and the 30, 35, and 40 degree seed classes. Seed collected and divided into classes from both field sites in 1981 and 1982 were studied. The germination conditions were the same as in the preliminary studies, except that

prior to germination seed were subjected to a moist prechill at 0-5° C for two weeks in either H_2O or KNO_3, depending upon the treatment.

All germination experiments were conducted as a completely randomized block statistical design with four replications.

CHAPTER III

RESULTS AND DISCUSSION

Distribution

Phlox oklahomensis is restricted to Kansas and Oklahoma. Populations occur in the southern Flint Hills region of Kansas, Butler, Chautauqua, Cowley, and Elk Counties, and in northwestern Oklahoma, Woods and Woodward Counties, and in Comanche County, Kansas (Figure 2). Numerous populations were discovered in these two areas. They are represented by approximately 60 herbarium specimens (Appendix A). Prior to this investigation, the species was represented by only 40 sheets. This paucity of specimens indicates a lack of early spring collecting in the region. The taxon occurs in 56, 19, and 4 sections of Woods, Woodward, and Comanche Counties, respectively (Figure 3; Appendix B). Searches in adjoining counties with similar habitats were conducted without success. Wherry (1955) suspected that populations of the Flint Hills region of Kansas were once continuous with those in northwestern Oklahoma and western Kansas, but that farming, ranching, and land misuse eliminated the intervening populations.

The taxon's association with specific geologic formations is quite apparent. In northwestern Oklahoma and adjacent western Kansas the distribution of P. oklahomensis closely coincides with Tertiary deposits (Ogallala formation). In these areas the Ogallala formation directly overlays the Rush Springs and Marlow formations of the Whitehorse group

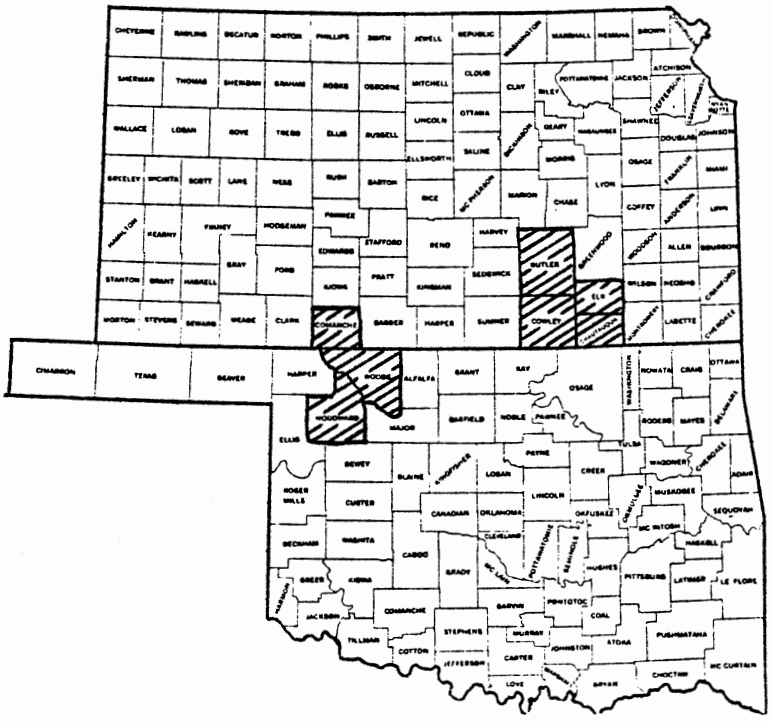

Figure 2. County Distribution of Phlox oklahomensis.

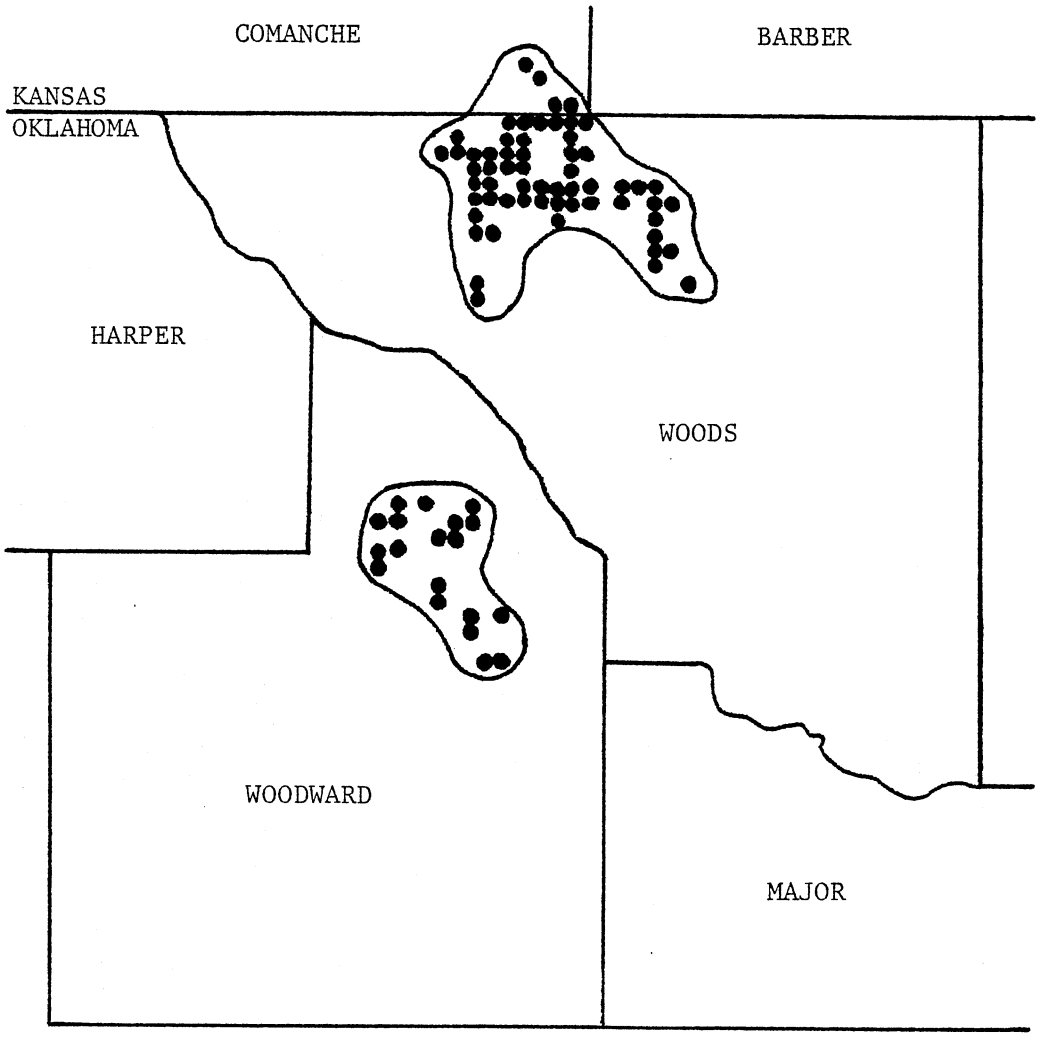

Figure 3. Sectional Distribution of Known Populations of Phlox oklahomensis in Northwestern Oklahoma and Adjacent Kansas.

upon which P. oklahomensis also occurs (Fay, 1965). The Rush Springs formation is characterized by shale, gypsum, and dolomite. The Marlow formation is sandstone. In the Flint Hills region of Kansas it is associated with the Chase and Council Grove groups (Foley, 1964). These groups are primarily limestone formations.

These observations suggest P. oklahomensis may have originated in the Rocky Mountains and become established in Oklahoma and Kansas during the Pliocene. Studies have shown the Ogallala formation to have extended much further east than it is presently known (Goss et al., 1972). In Kansas Tertiary deposits are as far east as McPherson.

Phlox oklahomensis was reported by Correll and Johnston (1970) to also occur in Dallas County, Texas. This report is based on one herbarium specimen. Attempts to relocate the population in 1980 and 1981 were unsuccessful. Dr. William Mahler of the SMU Herbarium was also unable to locate the taxon in this area in 1980 (Taylor and Taylor, 1980). Further, the area is quite different geologically and ecologically from habitats occupied in western Oklahoma and Kansas. Subsequent examination of the herbarium specimen, upon which the distributional report is based, revealed that the plant is P. bifida var. induta Shinners (Shinners, 1961), not P. oklahomensis. Phlox bifida is a species found in several disjunct areas in eastern and midwestern states and occurs on rocky slopes and sandy hills. Wherry (1955) and Marsh (1960) described several varieties primarily on the basis of floral characters. Plants of var. induta have dense, flattened, translucent, non-glandular pilose hairs on the pedicels and calyx. Plants of P. oklahomensis, however, possess both glandular and non-glandular pilose hairs which are shorter than those of induta.

Habitat

Phlox oklahomensis has adapted to a grassland (prairie) ecosystem, and populations thrive in areas of low to moderate grazing. In late winter and early spring when *P. oklahomensis* is actively growing, flowering, and producing seed, most of the native vegetation of the area is dormant.

Throughout its range in northwestern Oklahoma and adjacent Kansas the area is dissected with many small canyons and drainage basins. Similar habitats occur in the southern Flint Hills region of Kansas; however, in this region the topography is also interrupted with surfacing limestone (outcrops). In the Flint Hills region, populations generally were observed near the limestone outcrops. The restriction of plants to the outcrop area is possibly related to the increasing frequency of spring fire as man manages the tall grass prairies. Around outcrops fire intensity is lower due to reduced vegetation and wind shadowing. Burning usually occurs in April when *P. oklahomensis* is flowering most profusely; thus, yearly burning is interrupting seed production and may be having detrimental effects on vegetative growth as well. In northwestern Oklahoma and adjacent Kansas, burning is not used as a management practice.

In open areas where the topography is gently rolling hills with slopes ranging from 0-15 percent, *P. oklahomensis* is primarily found in association with *Andropogon gerardii*, *Schizachyrium scoparium*, *Bouteloua curtipendula*, *B. gracilis*, and *B. hirsuta*. In these areas grasses are dominant. In canyons and drainage basins it is primarily associated with

the grasses previously mentioned, and Juniperus virginiana, Prunus angustifolia, Ulmus americana, and Yucca glauca.

Other species which make up the late winter and early spring flora of the region are listed in Table II. Some of these species are occasionally encountered with P. oklahomensis, but for the most part they occur as small scattered populations throughout the region.

Although P. oklahomensis has been observed growing in clay and silt loam soils, plants appear to prefer a very fine sandy loam. Soils tested were low in nitrogen (NO_3^-) and had a relatively neutral pH (Table I). Throughout its range, P. oklahomensis occurs on well drained grassland soils that have weathered from calcareous shales. Plants have been observed on all exposures, but are more abundant on the cooler north-facing slopes.

Morphology and Phenology

Phlox oklahomensis is a perennial and grows from 5.0 to 20.0 cm tall. It has sub-remote nodes and finely pilose internodes. The sparsely pilose leaves are linear to lanceolate up to 30.0 (50.0) mm long and 3.0 (5.0) mm wide (Table III). The inflorescence is 3 to 9 flowered, the rachis and pedicels have hairs which vary from fine-glandular to glandless. Pedicel lengths vary from 8.0 to 20.0 mm. The sepals are 6.0 to 13.0 mm long and are united 3/8 to 5/8 of their length. The corolla tube is 7.0 to 15.0 mm long with variable petal blades averaging 8.0 mm long by 6.0 mm wide. In large populations, variation was observed in the size and shape of the corolla blades (limbs). They were occasionally very small with the flowers being approximately one-half their normal size, or they were pointed. Each petal blade terminates in a

TABLE II

SPECIES LIST OF THE LATE WINTER AND EARLY SPRING FLORA OCCURRING IN NORTHWESTERN OKLAHOMA AND ADJACENT KANSAS AND THE FLINT HILLS OF SOUTH CENTRAL KANSAS

Species Encountered with *Phlox oklahomensis*	Other Species
Allium drummondii	*Aesculus glabra* var. *sargentii*
Androstephium caeruleum	*Antennaria neglecta*
Anemone caroliniana	*Astragalus missouriensis*
Castilleja citrina	*Ceanothus herbaceus*
Castilleja sessiliflora	*Draba reptans*
Cymopterus acaulis	*Erythronium mesochoreum*
Euphorbia spathulata	*Lesquerella gordonii*
Linum lewisii	*Lithospermum arvense*
Lomatium foeniculaceum	*Ribes odoratum*
Nemastylis geminiflora	*Senecio plattensis*
Oxalis violacea	*Verbena canadensis*
Tragopogon pratensis	
Townsendia exscapa	

TABLE III

VARIATION IN MORPHOLOGICAL CHARACTERS OF PHLOX OKLAHOMENSIS FROM FOUR POPULATIONS (APPENDIX C) AND VARIOUS HERBARIUM SPECIMENS

Population	Number of Observations	Leaf Length			Leaf Width			Corolla Limb Length			Corolla Limb Width		
		Mean	Range	Standard Deviation	Mean	Range	Standard Deviation	Mean	Range	Standard Deviation	Mean	Range	Standard Deviation
		(millimeters)											
1	25	27.9	19-40	7.2	2.7	2.5-3.5	0.6	8.0	6-10	1.2	7.8	5-11	1.4
2	20	27.3	22-39	6.6	2.4	1.5-3.0	0.6	7.6	5-10	1.2	8.0	5-11	1.8
3	20	25.5	22-39	7.2	2.6	2.0-3.0	0.4	8.1	7-9	0.8	8.0	7-9	0.6
4	10	25.1	18-30	4.0	2.0	1.5-2.0	0.2	7.4	6-9	0.8	7.2	7-8	0.4
Herbarium Specimens	16	18.2	18-30	5.8	2.0	1.4-2.6	0.4	6.3	5-7	0.9	6.2	5-7	0.8

Population	Number of Observations	Corolla Tube Length			Calyx Length			Stigma-Style Length			Anther Length		
		Mean	Range	Standard Deviation	Mean	Range	Standard Deviation	Mean	Range	Standard Deviation	Mean	Range	Standard Deviation
		(millimeters)											
1	25	12.6	11-15	0.9	9.0	6-12	1.6	1.9	1.0-3.0	9.7	1.1	1-2	0.3
2	20	10.4	7-13	1.5	9.5	6-13	1.9	2.3	1.0-3.0	0.7	1.2	1-2	0.3
3	20	10.2	7-13	1.6	8.1	6-11	1.2	2.3	1.5-3.0	0.5	1.3	1-2	0.4
4	10	9.7	9-11	0.7	8.9	8-10	0.9	1.8	1.5-2.5	0.3	1.5	1-2	0.5
Herbarium Specimens	16	---	---	---	7.2	6-9	1.2	---	---	---	---	---	---

notch 1.0 to 4.0 mm deep which yields a "ten-point star" according to Wherry (1955). The styles are 1.5 to 3.0 mm long and are united 3/8 to 5/8 of their length. The corolla is usually white in color, but other color shades such as blue, light blue, and lavender have been observed. A pair of deep-hued straie was reported to occasionally occur at the base of each corolla blade (Wherry, 1955); however, they were not observed in plants examined in this study.

Little variation was found in the morphological characters examined (Table III). With a few exceptions, the character measurements agreed with those reported by Wherry (1944) in his original description of the taxon.

Phenological observations of P. oklahomensis revealed that flower bud formation begins in late February and continues through March. The three or four flower buds are protected from the environment prior to opening by appressed bracts and leaves. In late March, flowering begins and continues through early May. Flowering is at its peak in mid-April. The inflorescence is a simple cyme. The opening of the corolla occurs usually at night. The contorted corolla limbs untwist and separate until the limbs are fully extended. Once the corolla is open it remains open. The anthers dehisce longitudinally in the morning after the corolla has opened. Three to four weeks after pollination and fertilization, the capsules are mature. Upon drying, the capsule quickly separates along three sutures and catapults its seed outward, occasionally up to 2 meters away. This phenomenon has also been reported for Phlox drummondii (Halsted, 1901). As the capsule splits the sound is equivalent to that produced by kernels of popcorn exploding.

Reproductive Biology

Analysis of root tip chromosomes from plants collected at sites 1 and 2 revealed a mitotic number of 14 which is characteristic of the genus (Grant, 1959) (Figure 4).

Pollen grains are spherical and sculptured with echniate spines. Grains range in size from 18 to 33 microns (Figure 5). The populations exhibited similar distributions of pollen size. Slight differences in size were found within a population over time. Larger pollen appears to be produced later in the season. Thus, pollen grain formation is possibly temperature sensitive, and larger pollen is produced as a result of the seasonal increases in temperature.

Pollen viability averaged 81.3 percent. Statistical differences ($P<0.05$) in pollen viability were found between locations and dates (Figure 6); however, these differences are probably due to experimental error as the microscope slides were prepared in the field.

Fruit and seed set data obtained in the studies of the reproductive system indicate that P. oklahomensis is both allogamous and autogamous (Table IV). Plants tested for agamospermy had 8.3 percent fruit set and averaged 0.6 seeds per capsule. Apomixis, however, does not appear to play a role in the reproduction of the taxon and has not been reported in the family (Grant and Grant, 1965). The two fruits set are probably due to experimental error in the emasculation technique.

Fruits and seed failed to form when plants were caged and the flowers left undisturbed to test for natural autogamy. Plants artificially self-pollinated to test for the capacity of autogamy exhibited 37.5 percent fruit set and averaged 4.1 seeds per capsule. The insect-exclusion cages are believed to have reduced wind velocity necessary for

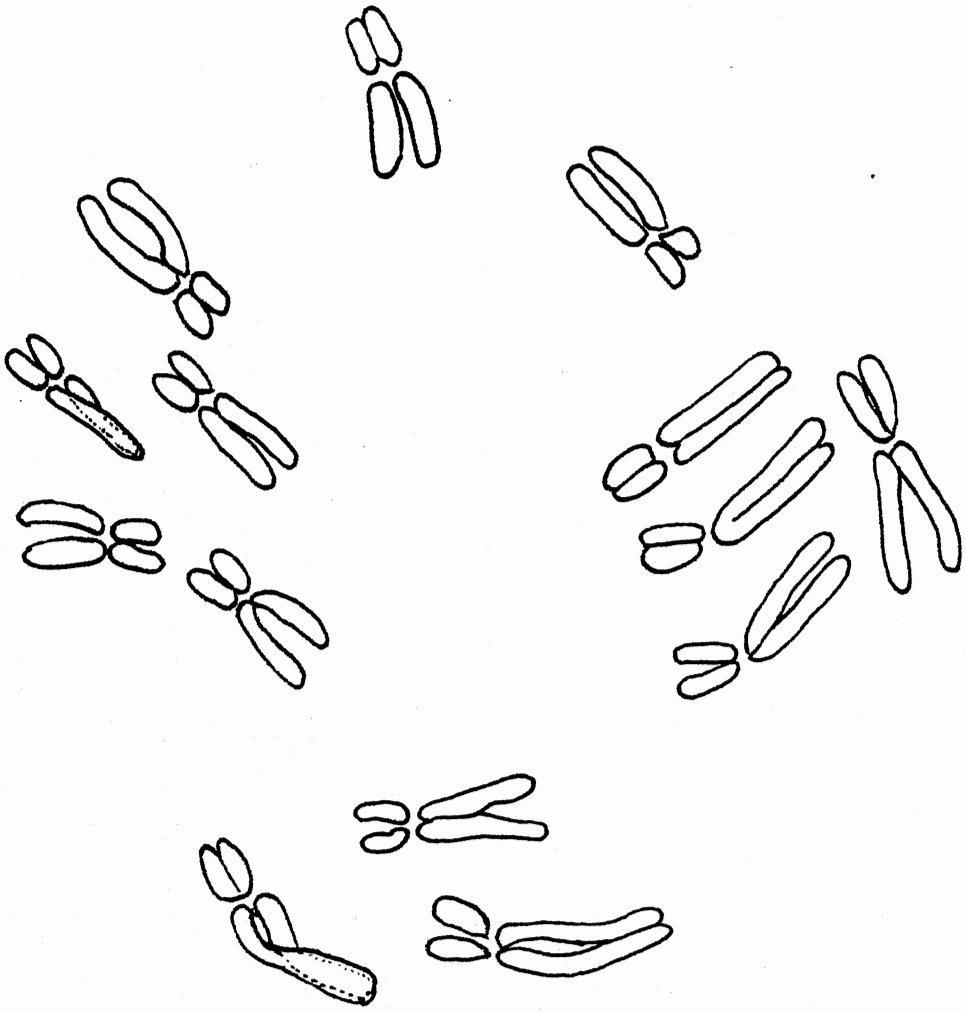

Figure 4. Drawing of Mitotic Metaphase Chromosomes of Phlox oklahomensis.

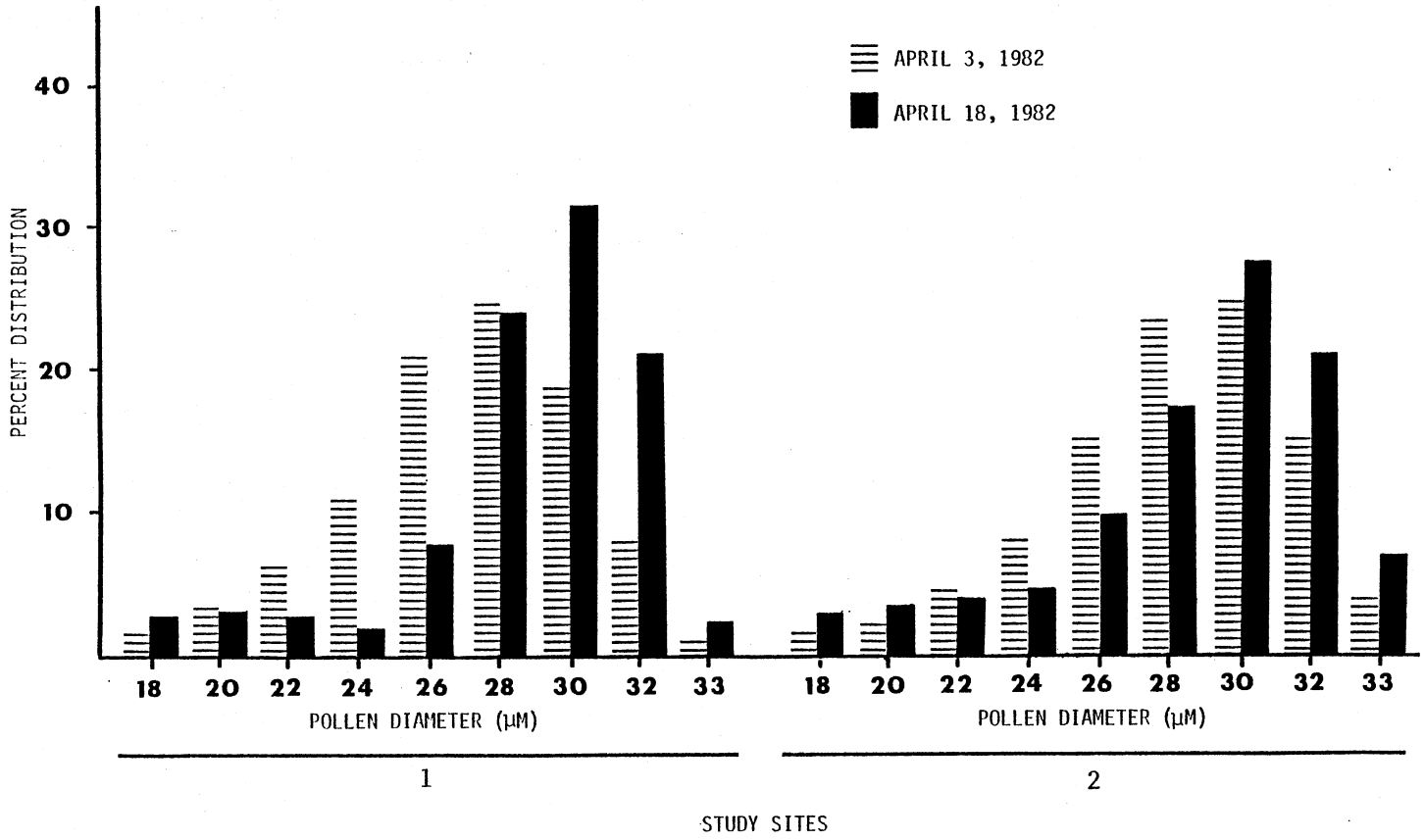

Figure 5. Average Percent Pollen Size Distribution of Phlox oklahomensis.

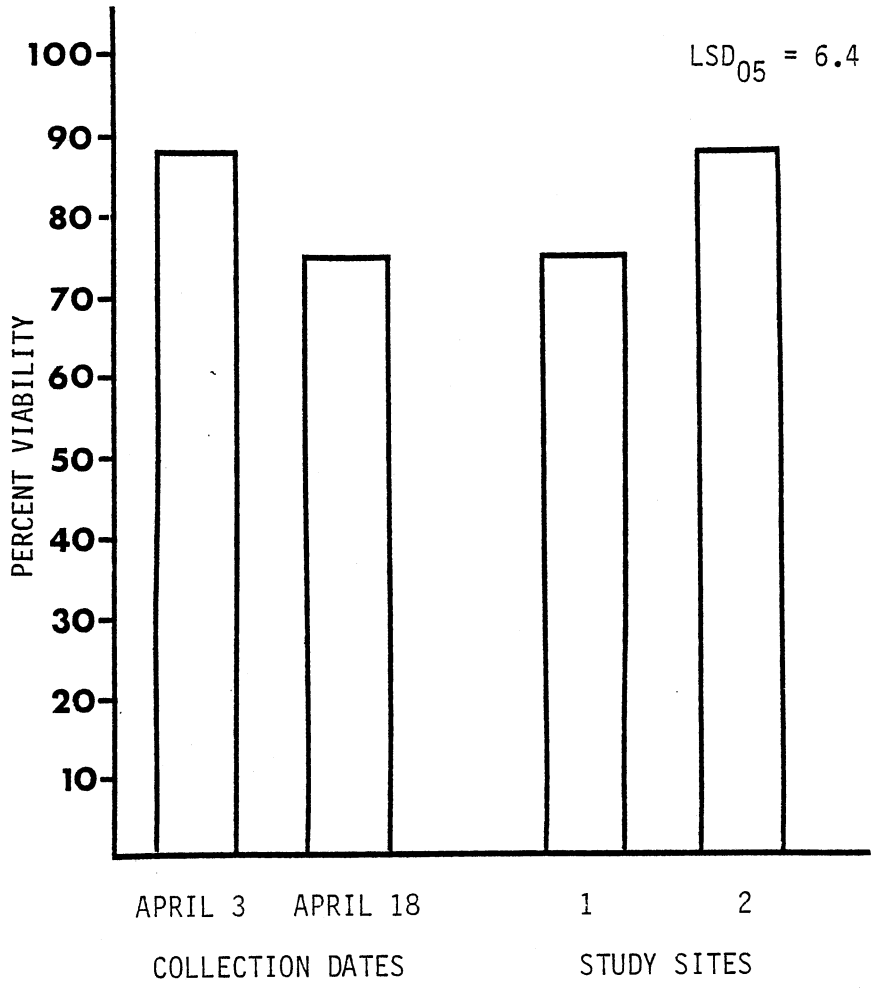

Figure 6. Average Percent Viable Pollen of Phlox oklahomensis.

TABLE IV

FRUIT AND SEED SET PER FLOWER IN EXPERIMENTAL STUDIES OF REPRODUCTIVE SYSTEM

Reproductive Mode Tested	Number of Flowers	Number of Fruit	Percent Fruit Set	Average Seed Set per Fruit
Control (open pollination)	27	22	81.4	4.3
Agamospermy	24	2	8.3	0.6
Autogamy				
Natural	30	0	0.0	0.0
Artificial	24	9	37.5	4.1
Allogamy	23	10	43.5	2.3

flower agitation to induce self-pollination, hence self-fertilization did not occur. Agitation of flowers by wind or insect visitors to effect selfing has been described in other taxa (Faegri and van der Pijl, 1971).

Cross-pollinated plants, in the test for allogamy, showed 43.5 percent fruit set and averaged 2.3 seed per capsule. Thus, P. oklahomensis is also cross-compatible.

Natural fruit set in the plants not manipulated or caged was 81.4 percent and seed averaged 4.3 per capsule. Although the percent fruit set in the control is approximately twice that obtained in the test for autogamy, the average number of seed set per capsule is similar. Because of the difficulty in working with small, delicate flowers like those of Phlox, the difference in fruit set could be due to inadequate pollination or dislocation of the ovary.

It is believed that P. oklahomensis' mode of reproduction is primarily autogamous. This is indicated by the crossing data. The observation that populations are morphologically very homogeneous is further evidence. As noted above, the floral morphology is not characteristic of anemophily, and insect visitation is rare. In three years of field observations, only one insect was observed visiting P. oklahomensis. At approximately 1500 hours CST, one clear-winged sphinx moth (Hemaris diffinis (Boisduval)) was observed. After collection and laboratory inspection it was found to be carrying pollen of P. oklahomensis. No other insects were observed visiting the plants. The lack of insect visitation is probably due to the mild spring days and very cool nights which are not conducive to insect activity. Self-pollination and hence self-fertilization would be highly likely even if insects visited

regularly. Due to the floral morphology, pollen would likely be transferred to the stigmas as the insect probes the flower (Wilson et al., 1971).

Seed and Seed Germination

Seed sizes and distribution percentages of seed classes are given in Table V. Size of P. oklahomensis seed ranges from about 50.0 to 150.0 mg per 100 seed. The percent distribution by seed size class was highly variable for locations and years, and displayed a unimodal distribution.

Test data to determine the germination requirements of P. oklahomensis are presented in Figures 7 and 8. A significant ($P<0.05$) decrease in germination was found to occur following predrying at 65° C and subsequent germination at 20° C in a constant dark environment. In general, substrates moistened with a 0.2% KNO_3 in water solution compared to water decreased germination of Phlox seed. A significant ($P<0.05$) increase in germination (emergence), regardless of the substrate moistening agent, occurred following a 2 and 4 week moist prechill treatment at 0-5° C and germination in a 20° C constant dark environment. At the end of the 28-day germination test period, seed subjected to a 4-week moist prechill duration showed a significantly ($P<0.05$) lower total germination in comparison to the 0 (control), 1, and 2 week moist prechill treatments. Also at the end of 28 days, no significant seed germination differences ($P<0.05$) were found between the control, 1, and 2-week prechill durations. These data suggest that P. oklahomensis requires a 2-week moist prechill treatment to stimulate and promote early

TABLE V

SEED SIZE AND SEED SIZE DISTRIBUTION OF PHLOX OKLAHOMENSIS BY SEED CLASS FOR LOCATIONS AND YEARS

Seed Class	Seed wt.-range (avg. mg wt./100 seed)	Percent Distribution (based on seed numbers) 1981 Site 1	1981 Site 2	1982 Site 1	1982 Site 2
25	49.2 - 62.9	4.46	3.71	32.59	12.84
30	69.0 - 77.7	24.08	15.64	34.19	27.21
35	92.2 - 96.3	47.48	42.21	23.25	35.39
40	114.0 - 116.5	22.86	36.11	8.75	33.33
45	137.0 - 152.2	1.18	2.33	1.22	3.14
Bulk lot (control)	73.1 - 93.3				

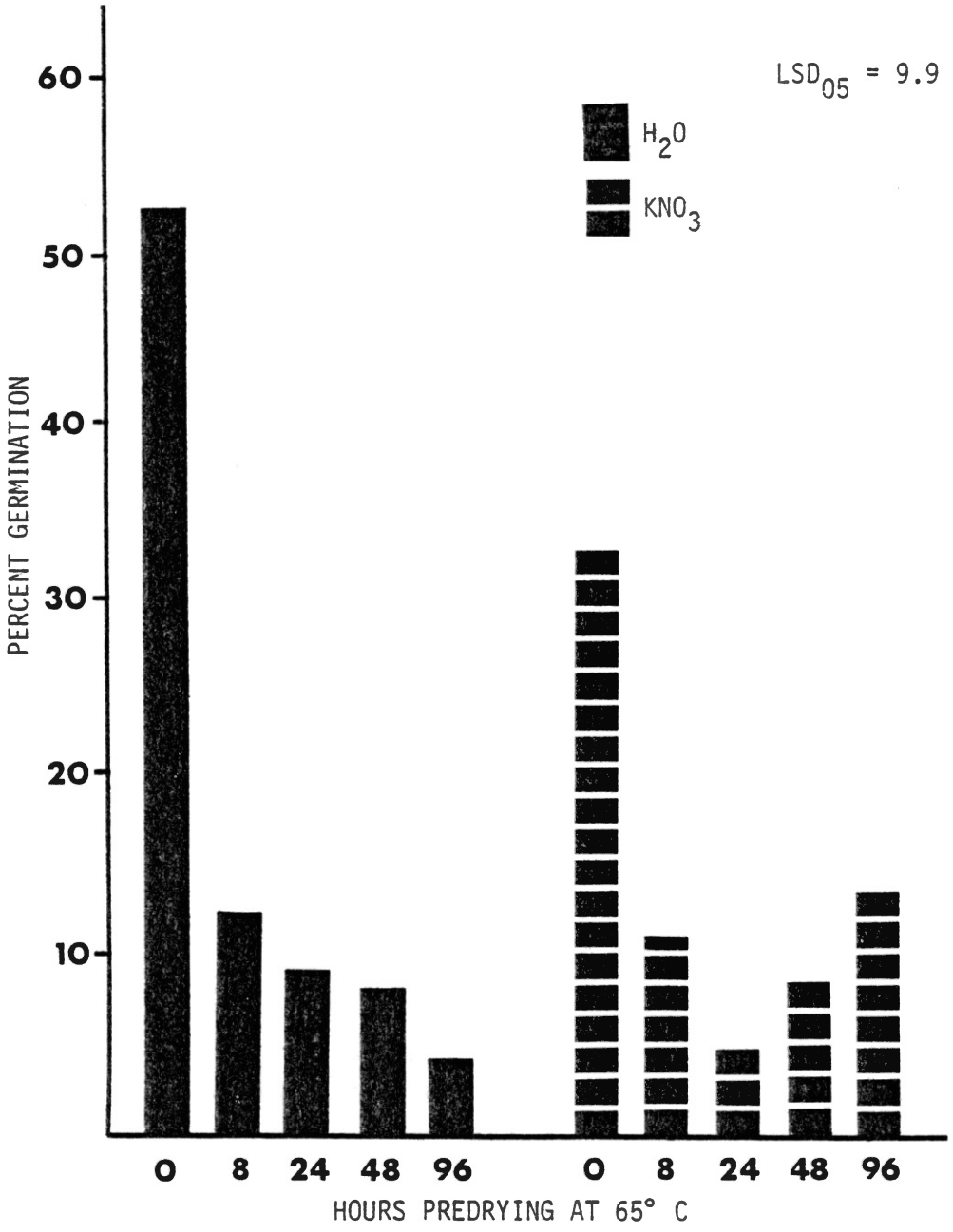

Figure 7. Average Percent Seed Germination of Phlox oklahomensis for Seed Predried at 65° C Prior to Germination.

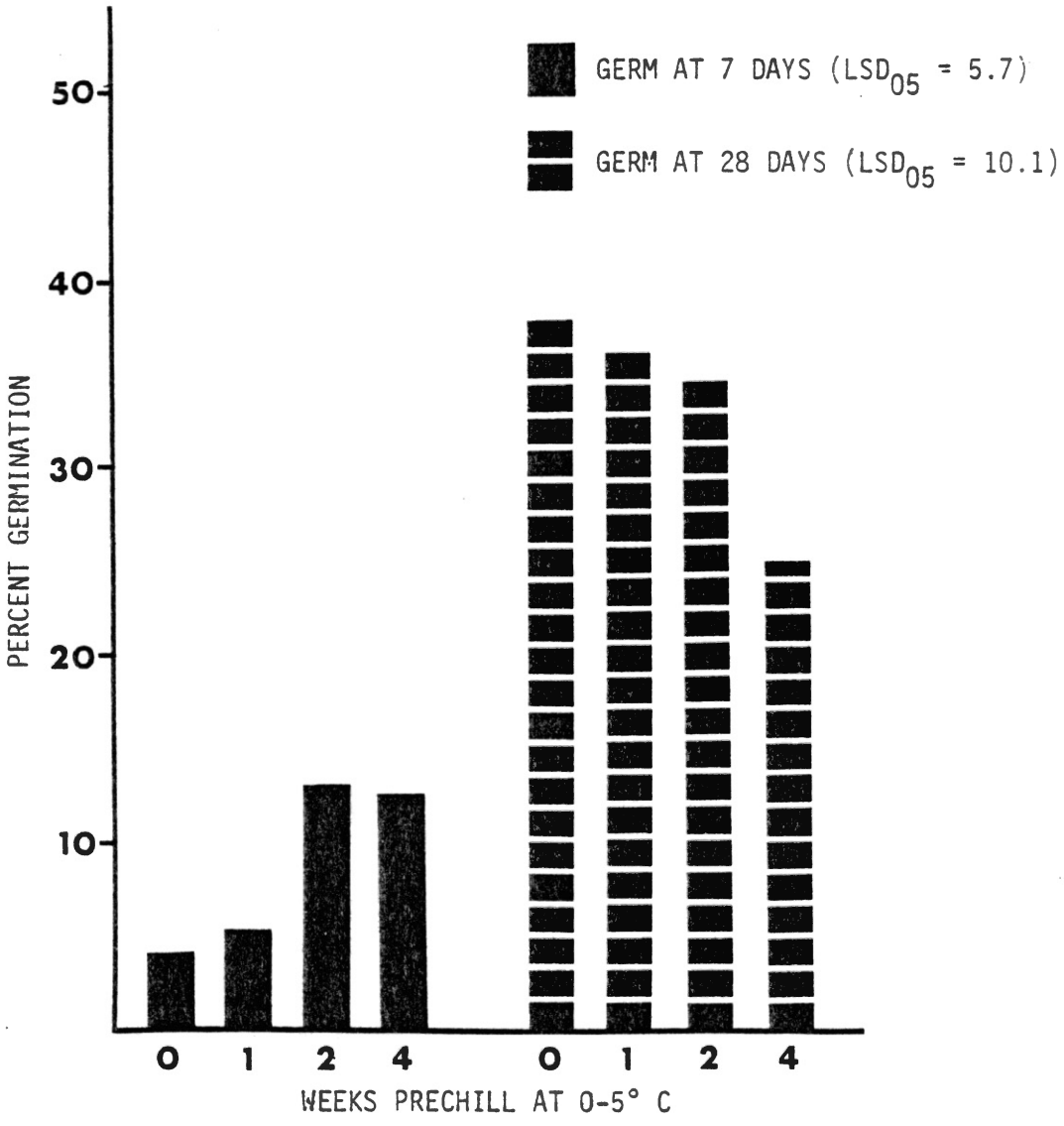

Figure 8. Average Seed Germination of Phlox oklahomensis at 7 and 28 Days for Seed Prechilled at 0-5° C Prior to Germination.

germination. Similar pregermination requirements have been found for Gilia capitata (Grant, 1949).

The studies to determine how germination is influenced by seed size showed a significant ($P<0.05$) four factor interaction between locations, substrate moistening agents, and years among seed classes (Figure 9). Germination differences among seed size classes were highly significant. The trend between locations and years among seed classes regardless of treatment is that the larger the seed the better the germination. In general, germination of 40 degree class seed is twice that of the 30 degree class. Differences in germination response between substrate moistening agents, e.g., 0.2% KNO_3 and H_2O, among seed classes, were also highly significant. The observed decrease in germination when KNO_3 in water is used as a moistening agent suggests a threshold antagonism. To see whether germination results using KNO_3 are due to the K^+ or NO_3^- ions would require a study on the effects of other salts, e.g., KCl, K_2SO_4, $(NH_4)_2SO_4$, KNO_3, $Ca(NO_3)_2$, and NH_4NO_3, in comparison to H_2O as substrate moistening agents. Although germination was significant between locations among seed size classes, germination of the control seed classes showed no differences. Germination in the control seed class, combined over years and substrate moistening agents, showed 26.3 and 27.5 percent germination for sites 1 and 2, respectively. Seed dormancy and age of seed at the time of germination usually account for the difference found between years. The data suggest a 2-week moist prechill prior to germination in a 20° C constant environment was not sufficient to break seed dormancy for seed harvested in 1982. In 1981 and 1982, germination at the end of a 21-day germination period was 39.5 and 32.9 percent, respectively. The firm seed remaining at the end of

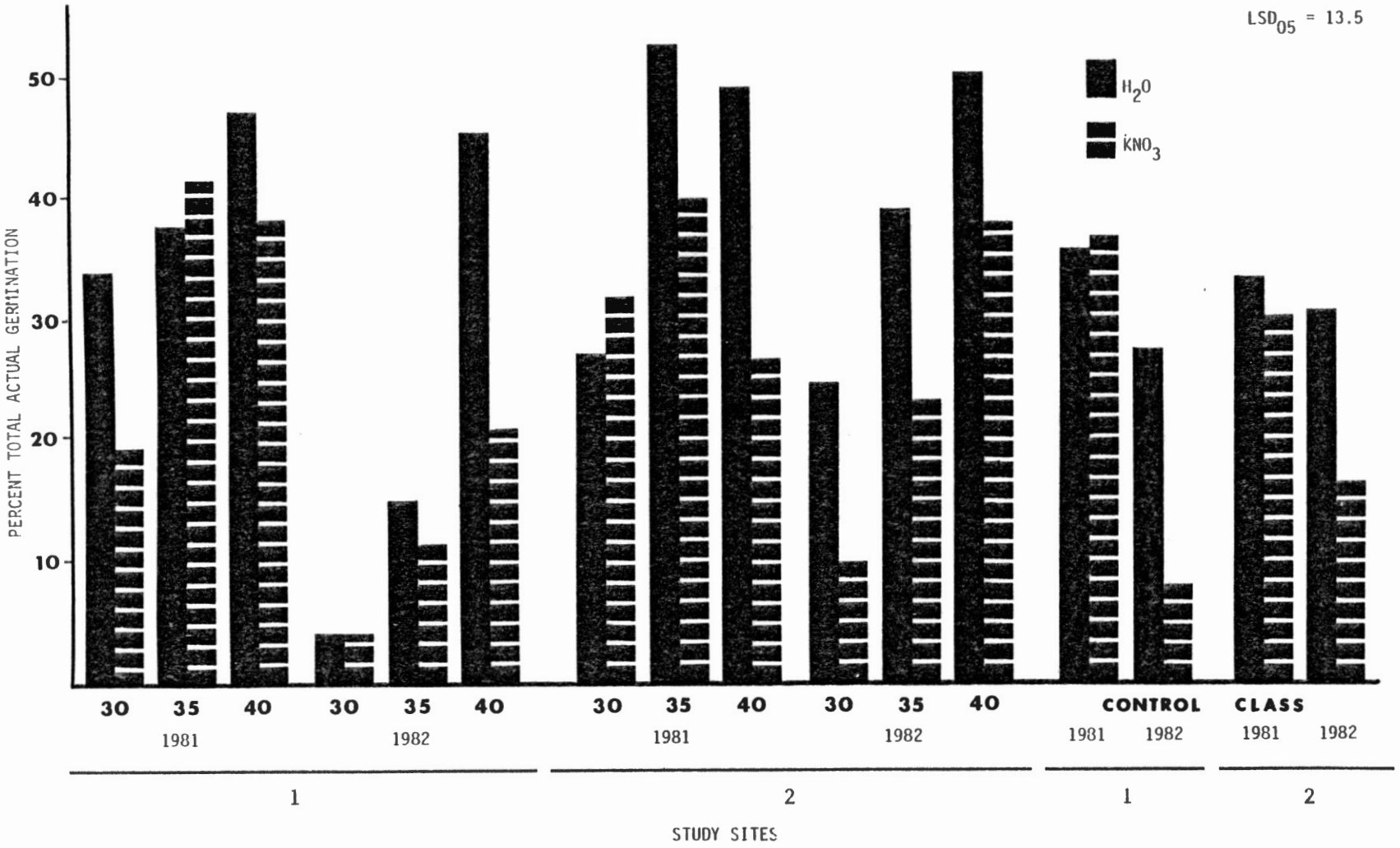

Figure 9. Average Percent Seed Germination of Phlox oklahomensis with Respect to Substrate Moistening Agents Between Locations and Years Among Seed Size Classes.

this same period was 36.9 and 43.8 percent for 1981 and 1982, respectively. Thus, the theoretical total viable seed, e.g., actual germination plus the firm seed remaining, was 76.4 and 76.6 percent for 1981 and 1982, respectively.

These tests suggest that P. oklahomensis has evolved with respect to its environment and seed dormancy brought on by hot dry temperatures can be broken by a moist prechill. Also, it appears that seed produced will not germinate completely from year to year, thus seed is always available to replenish the species.

CHAPTER IV

SUMMARY

Phlox oklahomensis is a perennial herb endemic to Kansas and Oklahoma. Because of its restricted geographical distribution, *P. oklahomensis* was considered a candidate for designation as a threatened species in 1978 under the guidelines of the 1973 Threatened and Endangered Species Act. This indicated the need for information about its biology. Field studies in 1980-82 have generated information about the taxon's distribution, habitat requirements, and reproductive system. In northwestern Oklahoma and adjacent Kansas, and the southern Flint Hills of Kansas, the distribution of *P. oklahomensis* appears to coincide with Tertiary and limestone deposits, respectively. In both regions plants are usually associated with mid and tall prairie grasses. Plants are facultatively autogamous and rarely visited by insects. Seed dispersal is via an explosive dehiscence of the capsule, and seed are thrown as much as 2 m from the parent plant. Seed dormancy is induced by high temperatures and broken by moist, cold temperatures. *P. oklahomensis* is not threatened in northwestern Oklahoma and adjacent Kansas; however, populations may be declining in the southern Flint Hills of Kansas due to the current range management practice of spring burning.

BIBLIOGRAPHY

Ayensu, E. S. and R. H. DeFilipps. Endangered and Threatened Plants of the United States. Washington: Smithsonian Institution and World Wildlife Fund, Inc., 1978.

Correll, D. S. and M. C. Johnston. Manual of the Vascular Plants of Texas. Texas Research Foundation, Renner, Texas, 1970.

Fægri, K. and L. van der Pijl. The Principles of Pollination Ecology. Pergamon Press, Oxford, 5th ed., 1971, pg. 194.

Fay, R. O. Geology of Woods County. Norman: Oklahoma Geological Survey, Bulletin 106, 1965.

Foley, F. C. Geologic Map of Kansas. Lawrence: Kansas Geological Survey, M-1, 1964.

Goss, D. W., A. R. Ross, P. B. Allen, and J. W. Nancy. "Geomorphology of the Central Washita River Basin." Proc. Okla. Acad. Sci. 52 (1972), 145-149.

Grant, V. "Seed Germination in Gilia capitata and Its Relatives." Madrono 10 (1949), 87-93.

Grant, V. Natural History of the Phlox Family, Systematic Botany. Martinus Nijhoff, The Hague, 1959.

Grant, V. and K. Grant. Flower Pollination in the Phlox Family. New York, London: Columbia University Press, 1965.

Halsted, B. D. "Explosive Fruits." Torreya 1 (1901), 143-44.

Horr, W. H. and R. L. McGregor. "Kansas Plants New to Kansas Herbaria IV." Trans. Kans. Acad. Sci. 52 (1949), 346-349.

Horr, W. H. and R. L. McGregor. "Kansas Plants New for Kansas Herbaria VI: Including a New Form of Liatris punctata." Trans. Kans. Acad. Sci. 54 (1951), 212-217.

Marsh, D. L. "Relationship of Phlox oklahomensis to Phlox bifida Complex: Including a New Subspecies of Phlox bifida." Trans. Kans. Acad. Sci. 63 (1960), 12-19.

Meyer, J. R. "Colchicine-Feulgen Leaf Smear." Stain Tech. 18 (1943), 53-56.

Radford, A. E., W. C. Dickison, J. R. Massey, C. R. Bell, et al. Vascular Plant Systematics. New York: Harper and Row, 1974.

Shinners, L. H. "Phlox bifida var. induta (Polmoniaceae) a New Endemic in North Central Texas." Southw. Nat. 6 (1961), 50-51.

Taylor, R. J. and C. E. Taylor. Phlox oklahomensis - Status Report. Albuquerque: Endangered Species Office, Fish and Wildlife Service, 1980.

Tyrl, R. J., J. L. Gentry, P. G. Risser, and J. J. Crockett. Field Survey and Status Evaluation on Proposed and Candidate Endangered and Threatened Plant Species in Oklahoma. Albuquerque: United States Department of Interior, Fish and Wildlife Service, 1978.

Wherry, E. T. "Phlox oklahomensis." Notulae Naturae Acad. Nat. Sci. Phila. 146 (1944), 2.

Wherry, E. T. The Genus Phlox. Morris Arboretum Monograph, III, Philadelphia, 1955.

Wilson, C. L., W. L. Loomis, and T. A. Steeves. Botany. New York: Holt, Rinehart, and Winston, 5th ed., 1971, pg. 305.

Zanoni, T. A., J. L. Gentry, R. J. Tyrl, and P. G. Risser. Endangered and Threatened Plants of Oklahoma. Norman, Oklahoma: Department of Botany and Microbiology, University of Oklahoma, and Stillwater, Oklahoma: Department of General and Evolutionary Biology, Oklahoma State University, 1979.

APPENDIX A

HERBARIUM SPECIMENS

Kansas

Butler County

5½ miles south of Augusta; rocky prairie hillside, abundant; Andropogon gerardii dominant grass; 13 April 1950, R. L. McGregor, #4222 (GH, KANU, PH).

4 miles southeast of Douglas; rocky prairie, limestone surfacing on rocks, plants on shallow soil over surfacing rocks; 5 April 1954, R. L. McGregor, #9064 (KANU).

Chautauqua County

6 miles north of Cedarvale; prairie with limestone surfacing on slopes and ridges, found near limestone outcrops; 5 April 1954, R. L. McGregor, #9051 (KANU).

Cowley County

C. N. Gould (Phlox pilosa), 1896; P. oklahomensis, E. T. Wherry, 1946 (NY).

2½ miles east of Arkansas City along Highway 166; common in bluestem prairies, dry shallow loam over limestone, common, little else flowering; 12 April 1950, R. L. McGregor, #4211 (GH, KANU, OKLA, PH, NY, TEX).

1 mile south, 3 miles east of Arkansas City; growing in a small prairie in a clearing in mixed woodland; duplicate det. by Prof. Wherry, 13 April 1950; R. L. McGregor, #4212 (GH, KANU, PH).

4 miles north of Dexter; rocky prairie hillside, shallow soil over limestone rocks; 5 April 1954, R. L. McGregor, #9061 (KANU).

5 miles southeast of Dexter; bluestem prairie hay meadows, shallow soil over surfacing limestone, common in the area; 26 April 1956, R. L. McGregor, #11181 (GH, KANU).

20.1 miles east of Arkansas City; prairie along highway, common in local colonies; 9 April 1963, R. L. McGregor, #17458 (KANU, NY).

Cowley County State Lake; upland prairie north side of lake near fence; 13 April 1965, Steve Stephens, #1996 (KANU).

Cowley County State Lake; upland prairie, shortgrass north side of park near park fence; 13 April 1965, Steve Stephens, #2004 (KANU).

Cowley County State Lake; upland, shortgrass prairie, north side of lake, near north fence of park; 12 May 1966, Steve Stephens, #2988 (KANU).

12 miles east, 2 miles north of Arkansas City, Cowley County State Lake; upland prairie; 8 April 1967, Rudy G. Koch, #2876 (KSC, LL, OKLA).

5 miles south, 4 miles west of Dexter, Cowley County State Lake; upland, open prairie, limerock soil; 17 April 1967, Steve Stephens, #10417 (KANU).

5 miles south, 1 mile east of Dexter; upland prairie pasture, limerock soil; 17 April 1967, Steve Stephens, #10423 (KANU, NY).

4 miles south, 1½ miles west of Dexter; prairie roadside right-of-way, limerock soil, locally common, flowers blue to white; 30 March 1968, Steve Stephens, #19666 (GH, KANU, NY).

1 mile south of Dexter; prairie roadside right-of-way, dry rock limestone soil, abundant; 23 April 1969, Steve Stephens, #30100 (KANU, OKLA).

Roadside park 5 miles south of Dexter; rocky (limestone) prairie, rare, flower color light blue; 2 May 1970, Lawrence K. Magrath, #5124 (KANU).

2½ miles south, ¼ mile west of Dexter; ungrazed pasture associated with Andropogon gerardii and other tall grasses; 11 April 1982, Tim Springer, #501.

5 miles west of intersection U.S. 166 and KS 15, north of U.S. 166; scattered along highway right-of-way and adjacent pasture, associated with Andropogon gerardii and other tall grasses; 11 April 1982, Tim Springer, #502.

Comanche County

Grazed pasture, scattered on north-facing slopes along the Oklahoma-Kansas state line; sec. 14; T35S; R16W; 29 March 1981, Tim Springer, #402, with P. Nighswonger (KANU, OKL, NWOSU).

Open range, scattered along the bottom of a canyon adjacent to county road; sec. 15; T35S; R16W; 29 March 1981, Tim Springer, #404, with P. Nighswonger (KANU, OKL, OKLA).

Abundant along the west rim of northeast-southwest canyon; canyon adjacent to county road (open range); sec. 15: T35S; R16W; 29 March 1981, Tim Springer, #405, with P. Nighswonger (KANU, OKL, OKLA).

6 miles south, 15 miles east of Buttermilk; grazed pasture; sec. 5; T35S; R16W; 4 April 1981, Tim Springer, #409, with P. Nighswonger (KANU, OKL, NWOSU).

4 miles south, 14 miles east of Buttermilk; open range; sec. 32; T34S; R16W; 4 April 1981, Tim Springer, #410, with P. Nighswonger (KANU, OKL, NWOSU).

Elk County

3 miles southwest of Grenola; prairie pasture with limestone surfacing on slopes and ridges, plants on shallow soil near limestone; 5 April 1954, R. L. McGregor, #9052 (KANU).

Oklahoma

Woods County

About 4 miles east, 10½ miles north of Freedom, 5-3/4 miles south of Kansas line; in steep walled canyon, mostly at the base of north-facing slopes, grazed; 18 April 1971, P. Nighswonger, #793 (OKL, NWOSU).

14 miles west of Alva, on Highway 64, 6 miles north, 1 mile west, 1 mile north, ½ mile west; along south side of road; 19 April 1973, C. Rosendale, #8 (OKL).

14 miles west, 7 miles north of Alva; 16 April 1975, Tim Springer, #18 (OKL, OKLA, NWOSU).

4 miles east, 10½ miles north of Freedom; SW¼, sec. 8; T28N; R17W; 1 May 1978, R. Tyrl, #1587, with Crockett (OKLA).

2 miles west of Highway 14 junction on U.S. Highway 64, 10 miles north, ½ mile west; on county roads at creek bridge; SW¼, sec. 4; T28N; R16W; 1 May 1978, R. Tyrl, #1589, with Crockett (OKLA).

2 miles west of OK 14 junction on U.S. 64, 9½ miles north on county road; SE¼, sec. 9; T28N; R16W; 1 May 1978, R. Tyrl, #1590, with Crockett (OKLA).

9 miles north, 3/4 mile west of Cora; near bridge, grazed; sec. 4; T28N; R16W; 29 March 1981, Tim Springer, #399, with P. Nighswonger (OKL, OKLA, NWOSU).

9 miles north, 6 miles east of Camp Houston; ungrazed knoll of tertiary material; sec. 3; T28N; R17W; 29 March 1981, Tim Springer, #400, with P. Nighswonger (KANU, OKL, NWOSU).

Open range, along county road just south of the state line (Dyer Ranch); sec. 16; T35N; R16W; 29 March 1981, Tim Springer, #406, with P. Nighswonger (KANU, OKL, NWOSU).

About 10 miles north, 1 mile east of Camp Houston (Noble Ranch); secs. 25 & 36; T29N; R18W; 29 March 1981, Tim Springer, #407, with P. Nighswonger (OKL, OKLA, NWOSU).

About 1-3 / 4 miles north of Camp Houston; in grazed pasnure, associated with Andropogon gerardii and Bouteloua curtipendula; sec. 3; T27N; R18W; 4 April 1982, Tim Springer, #499.

West of Buzzard triangulation station adjacent to county road before entrance to Ware's Ranch, associated with little bluestem; sec. 21; T29N; R18W; 16 April 1982, Tim Springer, #503.

SW¼, sec. 29: T29N; R18W, along county road; associated with Andropogon spp. and other tall grasses; 16 April 1982, Tim Springer, #504.

5 miles east, 9 miles north of Camp Houston; Bush Ranch, associated with Bouteloua spp.; sec. 3; T28N; R17W; 18 April 1982, Tim Springer, #505.

Woodward County

13 miles north of Mooreland; along Highway 50; 22 April 1929, Benke, #5017, HOLOTYPE (F).

13 miles north of Mooreland; along Highway 50; 22 April 1929, Benke, #5017, Arithmotype (PH).

13 miles north of Mooreland; along Highway 50; 22 April 1929, Benke, #5017, Clasotype (PH).

Rocky slope near Waynoka; 24 March 1935, Helen Long (OKLA, PH).

Woodward County, Woodward; from SCS office via E. T. Wherry, 1945 (KSC).

Rocky slopes and prairie northern part of Woodward County; 26 March 1945, J. E. Engleman (OKL, PH).

On shallow soil, over crystalline limestone in gullies and broken land; 10 miles north of Mooreland; 10 April 1948, S. L. Glowenke, #10644, fragrance spicy, flowers pale violet with limb of corolla deeper; TOPOTYPE (PH).

11 miles north-northeast of Mooreland; by road, sparse-grassy rim of a break, orange-brown clay; 10 April 1948, E. T. Wherry (PH).

14 miles north of Mooreland; by road (Highway 50), north grassy slope toward a break, orange-brown clay well above limestone; 10 April 1948, E. T. Wherry (PH).

13 miles north of Mooreland; by road (Highway 50), north plains at edge of a break, yellow sandy loam over limestone; 10 April 1948, E. T. Wherry (PH).

11 miles southwest of Freedom; along Highway right-of-way; rare; 15 April 1977, Tim Springer, #141 (OKL, OKLA).

11 miles southwest of Freedom, along roadside, abundant; 8 April 1978, Tim Springer, #226 (KANU, NWOSU).

Slopes of Nigger Mountain, adjacent to old Mooreland-Alva road, about 8 miles south of Alabaster Caverns; NE¼, sec. 3; T24N; R19W; 1 May 1978, R. Tyrl, #1591, with Crockett (OKLA).

0.3 miles sounh of Slicker Creek bridge, Highway 50; NE¼, sec. 24; T25N; R19W; 1 May 1978, R. Tyle, #1592, with Crockett (OKLA).

About 13 miles north of Mooreland, along Highway 50; 25 April 1980, J. Taylor, #28779 (DUR).

11 miles north, 1½ miles west of Mooreland; on north-facing slope of greater than 30 , grazed; 12 April 1980, Tim Springer, #339, winh L. Loomis.

11 miles southwest of Freedom; along fence and grazed wheat pasture; sec. 13; T25N; R19W; 28 March 1981, Tim Springer, #397, with D. J. Huddleston (KANU, OKL, NWOSU).

8½ miles north, 3 miles east of Mooreland; grazed rangeland; sec. 17; T24N; R18W; 11 April 1981, Tim Springer, #413 (KANU, OKL, OKLA, NWOSU).

8 miles north, 6½ miles east of Mooreland; ungrazed county roadside; sec. 24; T24N; R18W; 12 April 1981, Tim Springer, #414 (OKL, OKLA, NWOSU).

APPENDIX B

COUNTY SECTIONS IN NORTHWESTERN OKLAHOMA AND ADJACENT KANSAS WHERE POPULATIONS OF *PHLOX OKLAHOMENSIS* HAVE BEEN OBSERVED

Comanche County, Kansas

R 16 W; T 34 S; Sec 32

R 16 W; T 35 S; Sec 4
R 16 W; T 35 S; Sec 14
R 16 W; T 35 S; Sec 15

Woods County, Oklahoma

R 16 W; T 27 N; Sec 2
R 16 W; T 27 N; Sec 12

R 16 W; T 28 N; Sec 4
R 16 W; T 28 N; Sec 6
R 16 W; T 28 N; Sec 7
R 16 W; T 28 N; Sec 9
R 16 W; T 28 N; Sec 10
R 16 W; T 28 N; Sec 16
R 16 W; T 28 N; Sec 21
R 16 W; T 28 N; Sec 27
R 16 W; T 28 N; Sec 28
R 16 W; T 28 N; Sec 33

R 17 W; T 28 N; Sec 2
R 17 W; T 28 N; Sec 3
R 17 W; T 28 N; Sec 4
R 17 W; T 28 N; Sec 5
R 17 W; T 28 N; Sec 6
R 17 W; T 28 N; Sec 7
R 17 W; T 28 N; Sec 8
R 17 W; T 28 N; Sec 9
R 17 W; T 28 N; Sec 10
R 17 W; T 28 N; Sec 11
R 17 W; T 28 N; Sec 16

Woods County, continued

R 17 W; T 29 N; Sec 14
R 17 W; T 29 N; Sec 15
R 17 W; T 29 N; Sec 16
R 17 W; T 29 N; Sec 17
R 17 W; T 29 N; Sec 18
R 17 W; T 29 N; Sec 19
R 17 W; T 29 N; Sec 22
R 17 W; T 29 N; Sec 26
R 17 W; T 29 N; Sec 27
R 17 W; T 29 N; Sec 30
R 17 W; T 29 N; Sec 31
R 17 W; T 29 N; Sec 34

R 18 W; T 27 N; Sec 3
R 18 W; T 27 N; Sec 10

R 18 W; T 28 N; Sec 2
R 18 W; T 28 N; Sec 3
R 18 W; T 28 N; Sec 10
R 18 W; T 28 N; Sec 11
R 18 W; T 28 N; Sec 12
R 18 W; T 28 N; Sec 15
R 18 W; T 28 N; Sec 22
R 18 W; T 28 N; Sec 23

R 18 W; T 29 N; Sec 13
R 18 W; T 29 N; Sec 21
R 18 W; T 29 N; Sec 24
R 18 W; T 29 N; Sec 25
R 18 W; T 29 N; Sec 26
R 18 W; T 29 N; Sec 27
R 18 W; T 29 N; Sec 28
R 18 W; T 29 N; Sec 29
R 18 W; T 29 N; Sec 34
R 18 W; T 29 N; Sec 35
R 18 W; T 29 N; Sec 36

Woodward County, Oklahoma

R 18 W; T 23 N; Sec 1
R 18 W; T 23 N; Sec 2

R 18 W; T 24 N; Sec 8
R 18 W; T 24 N; Sec 17
R 18 W; T 24 N; Sec 22
R 18 W; T 24 N; Sec 24
R 18 W; T 24 N; Sec 27

Woodward County, continued

R 18 W; T 25 N; Sec 14
R 18 W; T 25 N; Sec 17
R 18 W; T 25 N; Sec 22
R 18 W; T 25 N; Sec 23
R 18 W; T 25 N; Sec 26
R 18 W; T 25 N; Sec 27
R 18 W; T 25 N; Sec 28

R 19 W; T 24 N; Sec 3

R 19 W; T 25 N; Sec 13
R 19 W; T 25 N; Sec 23
R 19 W; T 25 N; Sec 24
R 19 W; T 25 N; Sec 35

APPENDIX C

LOCATIONS OF POPULATIONS USED FOR STUDY OF MORPHOLOGICAL CHARACTERS

Population	Longitude and Latitude	Legal Description	Location
1	36° 55' N. Lat. by 98° 55' W. Long.	R16W; T28N; Sec. 9	Woods County, 8 miles N. of Cora, Oklahoma (grazed native range pasture)
2	36° 47' N. Lat. by 99° 06' W. Long	R18W; T28N; Sec. 2	Woods County, 9 miles N. of Camp Houston, Oklahoma (grazed native range pasture)
3	36° 55' N. Lat by 99° 02' W. Long.	R17W; T28N; Sec. 9	Woods County, 4 miles E., 7 miles N. of Camp Houston, Oklahoma (in bottom of canyon, grazed native range pasture)
4	36° 38' N. Lat. by 99° 05' W. Long	R19W; T25N; Sec. 13	Woodward County, 11 miles S.W. of Freedom, Oklahoma, near the Slicker Creek bridge along State Highway 50

VITA

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Master of Science

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