Species Status Assessment Report for Texas Trailing Phlox (*Phlox nivalis* subspecies *texensis*)

Photo: Suzzanne Chapman, Mercer Arboretum and Nature Center

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Throughout this document, the first use of scientific and technical terms are underscored with dashed lines; these terms are in the glossary in Appendix A.

EXECUTIVE SUMMARY

Texas trailing phlox (*Phlox nivalis* ssp. *texensis*) is a herbaceous perennial and member of the family Polemoniaceae. Seven extant populations occur in Texas on private, public, and state-owned lands within Hardin, Tyler, and Polk counties. Extant populations, both natural and ex-situ populations (two reintroductions, one introduction), are distributed across the Big Thicket region of the East Texas Pineywoods. This fire-dependent species, often associated with long leaf pine (*Pinus palustris*) dominated uplands, was listed as endangered in 1991. Known threats to the species included low population numbers coupled with a limited geographic distribution, lack of regulatory protections, and habitat disturbance. Housing developments, silvicultural practices, fire suppression, herbicide exposure, and industry construction have all contributed to habitat loss for this sensitive species. Additional stressors include off-road vehicle use, illegal dumping, burning of debris, and commercial take of plants.

To evaluate the current and future biological status of Texas trailing phlox, we considered the species' viability as characterized by its resiliency, redundancy, and representation (3R's). These three factors can provide an assessment and a framework to support all functions of the U.S. Fish and Wildlife Service's (Service) Endangered Species Program, including recovery planning strategies (i.e. recovery plans, site specific management plans, 5-Year Status Reviews, etc.).

Populations were considered to have high resiliency when they: contained at least 600 individuals, exhibited plant separation less than 2 kilometers (1.24 miles), contained canopy cover between 5-25 percent, limited shrub layer cover to 10-25 percent, maintained litter depths of 3-5 centimeters, and received an annual precipitation rate of 48-60 inches (121.9-152.4 centimeters). Frequent fire exposure (every 1-2 years) serves as a critical component to sustaining healthy individual plants within the longleaf pine ecosystem, as well as other native vegetation associated with the Pineywoods. Using all of these factors, seven extant populations were ranked either low or moderate in current resiliency.

Redundancy measures the risk to a species from natural or catastrophic events. For the Texas trailing phlox, we measured redundancy as an adequate number of resilient populations that provided an exchange of genetic material and foraging opportunities for pollinators. Due to the low or moderate resilience rankings of most populations, the few number of extant populations, and that these populations are distributed throughout a restricted range, we estimated that both connectivity for pollinating species and exchange of genetic material is limited. Therefore, we rank the overall redundancy of Texas trailing phlox as low.

The measure of representation describes the ability of a species to adapt to changing environmental conditions over time. We lacked genetic studies specific to Texas trailing phlox examining variability within and among its' populations. Further genetic analysis of Texas trailing phlox could determine to what extent, if any, the impact of range contraction contributes to the loss of the genetic variability. Due to an absence of genetic information informing our measure of representation, we used ecological diversity as a surrogate for genetic diversity. We

assumed no ecological or niche diversity at any of the specific sites therefore, the representation of Texas trailing phlox is extremely low.

We forecasted three plausible future scenarios associated with resiliency, redundancy, and representation for Texas trailing phlox. Each scenario examines oil and gas development (a stressor), coupled with prescribed burning (a conservation benefit). These are the most significant aspects impacting the species at all life stages (seedbank, plant, habitat), and are likely to continue into the future. Future conservation benefits attributed to prescribed burning were projected for 30 succeeding years. We selected this timeframe to evaluate what is likely to occur over three generations of the plant. We assessed the effects that oil and gas development activity (including related activities, e.g. maintenance) would have on the Texas trailing phlox at all populations. We examined multiple oil and gas activity data sets during our analysis with the goal of identifying historic trends that we could project into the future (10 years). Developed scenarios incorporated the ongoing stressor and conservation benefit at current levels, as well as increasing and decreasing levels.

- Scenario 1: We assumed the best possible conditions over the 30 year time period. Over time, almost all populations would remain stable in the presence of both oil and gas development and prescribed burning, with both Sandylands and Campbell units of the Big Thicket region remaining healthy.

- Scenario 2: This scenario assumed that current oil and gas development and prescribed burning conditions would continue over the next 10 years and 30 years, respectively. Risks from oil and gas activity would increase in this region, resulting in increased land being cleared/maintained for well construction and maintenance activities. We anticipate a reduction in habitat quality and quantity, thus affecting Texas trailing phlox resiliency. Most populations are expected to remain stable or decline over time.

- Scenario 3: We assumed that risks from oil and gas activity would increase at a more considerable rate in this region, primarily due to the steady increase in crude oil production within the State and that Southeast Texas has become a dedicated distribution center for oil and gas (Dick 2019, pp. 1-3). This scenario also assumes that prescribed burning would only occur sporadically or not at all at a population. Expected results include severely fragmented habitat, disturbed soils from new well pad and road construction, and increased herbicide use to limit vegetation within right-of-ways. Since we know that a high population resiliency depends on a certain percent of open canopy cover, a lack of fire activity would reduce canopy openness and canopy structure would be the least optimal, thereby shading out the Texas trailing phlox, thus reducing its survivability. Most populations would be expected to decline over time, with the Tyler County population expected to become extirpated. We foresee that even with some increased level of management, impacts from oil and gas could remain insurmountable despite these conservation efforts.

The Service does not anticipate that Scenario 1 is probable. We foresee that future conditions will likely remain at levels described in Scenario 2, but could slip into Scenario 3 if conservation activities decrease in the presence of accelerated oil and gas activity.

Table of Contents

CHAPTER 1 - Introduction and Species Biology

1.1 Species Status Assessment – Background and Need

Texas trailing phlox (*Phlox nivalis* ssp. *texensis*) is a nonwoody herbaceous perennial found only in the open pine forests of the Pineywoods ecoregion of East Texas. The species is a rare endemic, with populations only known from Hardin, Tyler, and Polk counties. It was federally listed as endangered on September 30, 1991 (56 FR 49636) and listed by Texas Parks and Wildlife Department (TPWD) as endangered on March 30, 1993 (Poole *et al.* 2007, p. 374).

At the time of its listing, Texas trailing phlox was known from only two sites, one each in Tyler and Hardin counties (U.S. Fish and Wildlife Service (USFWS) 1995, p. 4). The Hardin County site, with 250 plants, was presumed to be the only genetically and reproductively viable population (USFWS 1995, p. 4). However, through management and monitoring efforts from The Nature Conservancy (TNC) and the National Park Service's Big Thicket National Preserve (BTNP), these original natural populations occurring on their properties have flourished. In addition, reintroductions at the BTNP have increased plant abundance and several previously unknown natural populations have been located on adjacent Campbell Timber lands in Hardin County.

This Species Status Assessment (SSA) is a comprehensive review of the Texas trailing phlox and will provide the biological basis for the USFWS's recommendations in the 5-year review. The Service is required under Sections 4(c)(2)(A) and 4(c)(2)(B) of the Endangered Species Act (Act) to conduct a review of all species included under the Act at least once every five years. The Service initiated the 5-year review for the Texas trailing phlox on March 29, 2010 (75 FR 15454). The 5-year review was completed on August 30, 2018. Additionally, the SSA will be a basis to guide future actions and documents, which may include revised recovery plans, 5-year reviews, Section 7 consultations, and management plans. The SSA will be updated to reflect new information should it become available.

The SSA framework (Figure 1.1.1) summarizes the information assembled and reviewed by the Service, incorporating the best scientific and commercial data, to conduct an in-depth review of a species' biology and threats, evaluate its biological status, and assess the resources and conditions needed to maintain long-term viability. For the purpose of this assessment, we define the viability of the Texas trailing phlox as its ability to sustain populations in the wild into the future. Using the SSA framework, we consider what the species needs to maintain viability through an assessment of its resiliency, redundancy, and representation.

- **Resiliency** – describes the ability of populations to withstand stochastic events (arising from random factors). We can measure resiliency based on metrics of population health; for example, birth versus death rates and population size. Highly resilient populations are better able to withstand disturbances such as random fluctuations in birth rates (demographic stochasticity), variations in rainfall (environmental stochasticity), or the effects of anthropogenic activities.

- **Representation** – describes the ability of a species to adapt to changing environmental conditions. Representation can be measured by the breadth of genetic or environmental diversity within and among populations and gauges the probability that a species is capable of adapting to environmental changes. The more representation, or diversity, a species has, the more it is capable of adapting to changes (natural or human caused) in its environment. In the absence of species-specific genetic and ecological diversity information, we evaluate representation based on the extent and variability of habitat characteristics across the geographical range.

- **Redundancy** – describes the ability of a species to withstand catastrophic events. Measured by the number of populations, their resiliency, and their distribution (and connectivity), redundancy gauges the probability that the species has a margin of safety to withstand or can bounce back from catastrophic events (such as a rare destructive natural event or episode involving many populations).

In summary, this review is not a decision-making document, rather the most inclusive scientific review of the available information related to the Texas trailing phlox, its biology, and conservation. It does not provide nor pre-determine the Service's recommendations or decisions. All decisions will be made separately after reviewing this document, along with supporting analyses, other relevant scientific information, and all applicable laws, regulations, and policies.

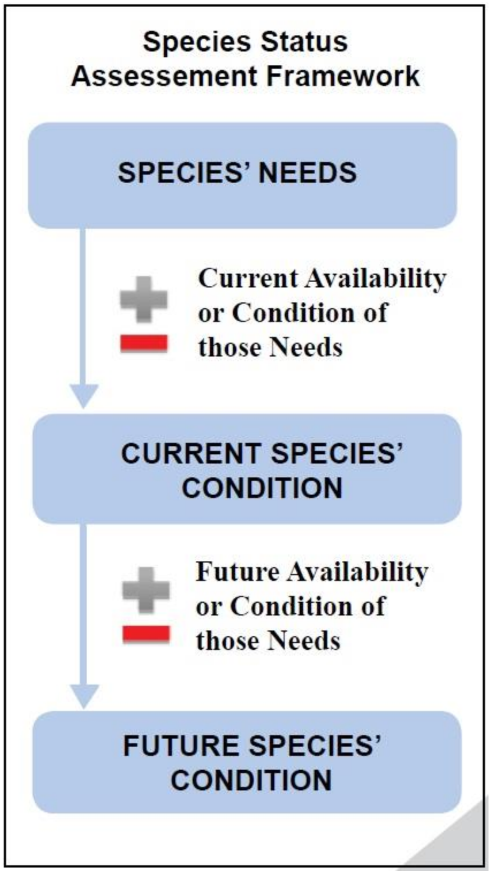


Figure 1.1.1. Species Status Assessment Framework.

1.2 Texas Trailing Phlox – Life History and Morphology

The following description of the Texas trailing phlox is adapted from the description by Poole *et al*. (2007, p. 374); USFWS (1995, p. 1); and, Wherry (1955, p. 24):

> Texas trailing phlox, as the name implies, is often trailing or decumbent and clumped (seldom matted) in form. Texas trailing phlox has flowering shoots, lax, erect, 10-30 centimeters (cm) long, pubescent, hairs inconspicuously glandular. Leaves are opposite, simple, sessile, persistent, very dense on lateral shoots, linear-subulate and canaliculated on sterile shoots or linear-lanceolate and essentially flat on fertile shoots. Leaves are 2.5-

30 millimeters (mm) long and 1-3 mm wide, apex spine-tipped, margins with stiff hairs. Older stems have smaller and darker green leaves, which typically lie directly on the grounds surface. Younger stems produce the flowers, are more or less erect, and have longer, slightly wide, and lighter-green leaves. Flowers are in small cymes, usually with 3-6 flowers terminal (typically) on the tallest stems (Figure 1.2.1). The pedicels are slender, glandular-pubescent, and 3 – 25 mm long. The calyx is glandular-pubescent, 6-10 mm long and fused below with 5 narrow, spine-tipped lobes, about equal to the tubes in length. The corolla is rotate and fused below in to a tube 11 – 17 mm long. Each of the 5 lobes is 11 – 12 mm long, 7 mm wide and usually notched at the apex. Texas trailing phlox corolla color has been noted to range from pink, rose-pink, bluish, lavender or purplish, often with deep-hued eye-striae. White flowering is rare and has only been observed once at the Tyler County site in 1997 (Carr 1997, p. 1). Like other phlox species, the ovary contains three ovules. Ellipsoid, rugulose seeds produce achene-like fruit.

Figure 1.2.1. A and B - Texas trailing phlox at Big Thicket National Preserve (credit: Andrew Bennett); C - Close-up of single flowering plant at Mercer Botanic Gardens (credit: Suzanne Chapman); and, D - arrow pointing to a developed fruit on a plant at Big Sandy Creek unit, Big Thicket National Preserve, April 2017 (credit: Andrew Bennett).

Its creeping, subshrub habit; potentially basally woody stems (the plant itself is not woody); styles that are shorter than its sepals; and, the subulate leaves distinguish the Texas trailing phlox from all the other Phlox in Texas (Poole *et al.* 2007, p. 374). Much study and research have involved distinguishing the members of the Eastern-mat forming *Phloxes* that include *P. oklahomensis*, *P. subulata*, *P. bifida*, and our species, *P. nivalis* ssp. *texensis* (Locklear 2011, pp. 45-46).

The Texas trailing phlox can be confused with several other plants, as the "vegetative plants of Texas trailing phlox look similar to those of *Loeflingia squarrosa* (spreading pygmyleaf). However, as an annual, *L. squarrosa* has fewer leaves per stem and is usually smaller in size than Texas trailing phlox" (USFWS 1995, p. 2). Seedlings of *Juniperus virginiana* (eastern red cedar) can appear as single stems of Texas trailing phlox, but a juniper seedling will become woody, develop darker green leaves, and produce fewer leaves than Texas trailing phlox. Similar colors and blooming periods of *Verbena canadensis* (homestead purple verbena) can cause misidentification when seen only from a distance.

1.3 Taxonomy and Genetic Diversity

The Texas trailing phlox is a member of the family Polemoniaceae (Grant 1959, Porter and Johnson 2000; in Fehlberg *et al.* 2008, p. 116), which encompasses nearly 70 species distributed throughout most of North America (Springer 1983, p. 1). Locklear (2011, p. 17) provides a thorough botanical history of the genus *Phlox* dating back to the earliest scientific encounters with the species by John Banister in 1678. Since 1678, there has been a long history of nomenclature concerns and divisions within the genus (Gray 1970, 1878, 1886, in Grant 2001, p. 25). The following is a chronological account of the prominent taxonomic descriptions and divisions within the genus:

> The earliest scientific encounters with *Phlox* came from Englishman John Banister in 1678. Banister drew *P. pilosa* and *P. subulata* in 1680, providing the first *Phlox* illustrations (Locklear 2011, p. 17). Efforts to collect and illustrate other *Phlox* species continued into the 1700's and 1800's. See Locklear for more detail (2011, pp. 17-18).
>
> Carl Linnaeus first described all nine *Phlox* taxa in his *Species Plantarum* in 1753; his botanical nomenclature and descriptions are internationally accepted and still recognized today (Locklear 2011, p. 19).
>
> Asa Gray was the first North American to publish the collections and descriptions of *Phlox* in 1870. In this publication, he listed 27 species, 11 varieties, and one formae of *Phlox* (Grant 2001; Locklear 2011 p. 25). Additionally Gray split *Phlox* into subgenera or sections, including the subdivisions *Latifoliae*/*Perennes*, *Subulatae*/*Suffruticuloso-perennantes*, *Occidentales*, and *Phlox drummondii* (Grant 2001, p. 26).
>
> Gustav A. Peter, in1897, divided *Phlox* into six main groups: *Drummondianae*, *Reptantes*, *Paniculatae*, *Divaricatae*, *Subulatae*, and *Pulvinatae* (Grant 2001, p. 26). These groups included both eastern and western members of the genus, assigning them to

sections. However, according to Wherry 1955 (p. 8), these groups should be treated as subsections.

Between 1898 and 1938, Aven Nelson, through his collections and descriptions, named 15 species, one subspecies, and one variety of *Phlox*. Only three of his species have withstood taxonomic criticism and remain valid today (Locklear 2011, p. 26).

In 1907, August Brand divided *Phlox* into two subgenera, Microphlox and Macrophlox (Grant 2001, p. 27). Using herbarium specimens, Brand listed 48 species, 17 subspecies, 37 varieties, and seven subvarieties of *Phlox*; however, again only one new species is still recognized today (Locklear 2011, p. 28).

Edgar T. Wherry's descriptions of *Phlox* in 1955 were novel in that he based his conclusions on combined accounts of herbarium specimens and extensive fieldwork. His 1955 monograph *The Genus Phlox* was pivotal in taxonomically describing and classifying 67 species and 57 subspecies. Wherry largely divided *Phlox* into three sections (Grant 2001, p. 27) based on style characters and habit: Section Protophlox, alpha-Phlox, and Microphlox (Wherry 1955, p. 8; Grant 2001, p. 27). In this classification, members of the genus *Phlox* are described as "habit upstanding to openly or rarely densely cespitose; leaves large- to medium- or exceptionally small-sized; inflorescence ample, rarely uniflorous; seeds 6-3.5 mm long, with a large to medium-sized embryo." Wherry acknowledges that his classification was rather polyphyletic, but that other attempts to arrange members were nonsensical (1955, p. 8).

More recently, Dr. Donald Levin and Dr. Carolyn Ferguson published extensive scientific research on the genus *Phlox*. Beginning in the 1960s, Levin published work related to evolution, hybridization, polyploidy, and breeding system of *Phlox* (Locklear 2011, p. 30). Ferguson's investigations center on laboratory findings to help clarify the taxonomic and genetic relationships among and between *Phlox* species.

Geographically, most accounts agree on a general division between *Phlox* species, characterizing them as either an eastern or western mat-forming phlox (Grant 2001, p. 28); *P. nivalis* ssp. *texensis* is considered an eastern mat-forming species (Ferguson *et al.* 1999, p. 622). To date, the USFWS (1995) and Wherry (1955, p. 24) recognize *P. nivalis* ssp. *texensis* as a valid taxon.

At the species level, there has been considerable study regarding the taxonomic relatedness and validity of *P. nivalis*, compared to *P. subulata* and *P. bifida*. All three species have woody, trailing stems. Older scientific accounts from Gray and Brand group the first two species (*P. nivalis* and *P. subulata*) together (Brand 1907, Gray 1870; in Grant 2001), while more recent accounts from Wherry, Fernald, Smith, and Levin grouped all three together (USFWS 1995). Meyer (1943, p. 199) determined that the chromosomes of *Phlox* are relatively large and few in number. Chromosome morphology can assist in identifying different plants or varieties within the same species (Meyer 1943, p. 209). Meyer (1943) found that the chromosome number of *P. nivalis* and its varieties are 14 (the 2N number), with some fragments (Meyer 1943; pp. 200, 203). Chromosomes of *P. nivalis* and *P. subulata* are very similar; other species have quite different length ratios (Meyer 1943, p. 216). Morphologically, *P. subulata* and *P. bifida* have long styles; while *P. nivalis* has short styles on its corolla (see Table 1.3.1). Also through molecular evidence (via internal transcribed spacer) by Ferguson *et al.* (1999, p. 626), her research showed that the 3 above-mentioned species and *P. oklahomensis*, form one monophyletic subgroup (Grant 2001, p. 28) and share common ancestry (Ferguson *et al.* 1999, p. 626).

The classification at the subspecies rank has also been investigated (Wherry 1955, p. 8; Bogler 1992, p. 2). For the Texas trailing phlox, Lundell (1942, p. 303) was the first to collect and describe the subspecies from Hardin County, Texas, in 1931 as "*Phlox nivalis* (Loddiges) subspecies *texensis* (Lundell). In 1945, this name was realigned as *P. texensis* (Lundell) Lundell. There are two subspecies recognized under *P. nivalis* (ssp. *texensis* and ssp. *nivalis*), with the primary difference between each being the presence or absence of minute glandular hairs (USFWS 1995, p. 3) (Table 1.3.1). Researchers have long hypothesized that *P. oklahomensis* and *P. nivalis* ssp. *texensis* are taxonomically related. In Texas, the Texas trailing phlox is most similar to the *P. oklahomensis*, however, they do have apparent differences (Table 1.3.1) (Wherry 1955; Bogler 1992, p. 2; USFWS 1995, pp. 3-4). Subspecies ranges could also be a distinction as populations of *P. nivalis* have been recorded in several Louisiana parishes. As genetic investigations are lacking, we do not know if these records in Louisiana are more closely related to the ssp. *texensis* in Texas or ssp. *nivalis* (Bogler 1992, p. 2).

Table 1.3.1. Differences in subspecies of *Phlox nivalis* (Wherry 1955, p. 8; USFWS 1995, p. 3).

Characters	*P. nivalis* ssp. *texensis*	*P. nivalis* ssp. *nivalis*	*P. oklahomensis*	*P. nivalis*	*P. subulata*	*P. bifida*
Plant	clump of spreading prostrate leafy sterile shoots which lengthen after anthesis, send up erect flowering shoots	compact clump of prostrate leafy sterile shoots, with erect flowers; latent axillary shoots abundant	sprawling, basally woody species; shoots 4-8 cm long with 5 nodes; flowering shoots have 3 or 4 sterile nodes; sterile shoots elongate and bear large leaves	woody, trailing	mat or densely persistent-leafy sterile shoots, sending up form many flowering nodes; woody, trailing stems	openly cespitose with persistent foliage, sending up flowering shoots 10-20 cm high with about 4 nodes; woody, trailing stems
Leaves	mostly subulate	subulate to linear-subulate, ciliate	linear to lanceolate, ciliate		linear to subulate	linear to narrowly elliptic or lanceolate
Pubescence; minute glandular hairs	minute glandular hairs	Absent	glandular-pubescent		fine-ciliate and the upper leaf pilose, the hairs glandless or in rare variants gland-tipped	upper leave portions pilose
Styles	free, 1-1.5 mm	1.5 to 3 mm long, free for 1 mm.	Unique styles as fairly high in corolla tube	short styles	long styles, 7-10 mm	long styles, 6-12 mm
Corolla tube	petal-blade variable but usually obovate and notched 1-3 mm	10-13 mm long; petal-blade usually obovate and about 11 by 7 mm, terminally entire	8-12 mm long; petal-blade variable but with terminal notch, yielding a "ten-point" star		8-15 mm long; petal-blade obovate with tip either entire or notched	9-14 mm long, petal-blade 10 by 7.5 mm, with notch 3-5 mm deep
Flower color	purple to lilac or rarely white; herb is pubescent with long fine hairs, some with minute glands	variable, purple to pink, near white (in type population) or pure white (albino), the tube and eye-striae often deep-hued	lilac, pink, or lavender, ranging to white; eye can bear pair of deep-hued striae at each blade-base.		flowers highly variable, predominantly purple, ranging to red or less frequent to violet-purple, lilac, pink, and white	lavender or rarely lilac to white, the blade-base sometimes being paired violet striae
Habitat	open pine-oak woods on sandy slopes	sandy slopes and flats, often in open pine woods	within grasses and shrubs in prairie soils and clays; on limestone outcrops		occupies areas of sterile soil on open rocky, gravel, and sandy slopes	rocky slopes and sand hills
Range	Endemic from Woodville to Kountze and Silsbee, Texas	Alabama to Florida, north to Virginia	only near Garland, near Dallas, Texas		northeastern provinces	disjunct in Midwestern states

Genetic analysis of Texas trailing phlox could assist in answering the questions of relatedness of individuals within a population and between individuals of separate populations; however, these investigations have not been conducted. There is much interest among state, local, federal, and nongovernmental organizations to complete this inter- and intra-genetic work on the species. While Traditional Section 6 funding has been used in the past to initiate projects, adequate funding has not been available or secured to conduct these important genetic studies to the level needed to answer these complicated questions. Understanding the genetic relatedness could clarify how we define a population and an individual plant. As more information becomes available, we will adapt our analyses.

Only the Integrated Taxonomic Information System (ITIS) has reviewed the current status of the Texas trailing phlox. The partnership of federal agencies that forms the ITIS, reviews and provides a scientific basis to justify taxonomic information of a species and its validity. The Flora of North America, another entity that reviews the taxonomic validity of species, has not reviewed the species. Given what information is known about the species, the lack of new information to inform the question of genetic relatedness, and that the Texas trailing phlox is an accepted taxonomic status in ITIS (ITIS online, 2018), we acknowledge that the species is a distinct and separate subspecies.

1.4 Life history – Growth, Phenology and Reproduction, Mortality

Growth

Texas trailing phlox is a perennial, evergreen species, actively growing with optimal precipitation and temperature (Figure 1.4.1). New growth from seedlings and vegetative plants is often seen in early spring, from late February to late April, and again in September and October when rainfall increases relative to summer months (USFWS 1995, p. 9). Each new stem growth produces a long rigid grass-like leaf, which lives throughout the winter. In the spring, flowering stems are produced from these vegetative parts (and adjacent root nodes) while the outer vegetative portions of the plant will die (Higgins 1895, p. 36).

Fire is an integral component of the longleaf pine ecosystem, and integral to the growth pattern of the Texas trailing phlox. Lightning–caused fires are the natural triggers for growth that sweep through the habitat (USFWS 1993, p. 108), from mid- to late-summer (Lorio 1986, p. 268). Above ground plant parts are typically destroyed by fire, but underground parts are typically undamaged. New growth is apparent on shoots within 2 weeks after a spring burn. Fires occurring in April may cause plants to sprout and bloom again in May of the same year. However, plants burned during drier parts of year may not respond as quickly with new sprouts (Corlies and Warnock 1992).

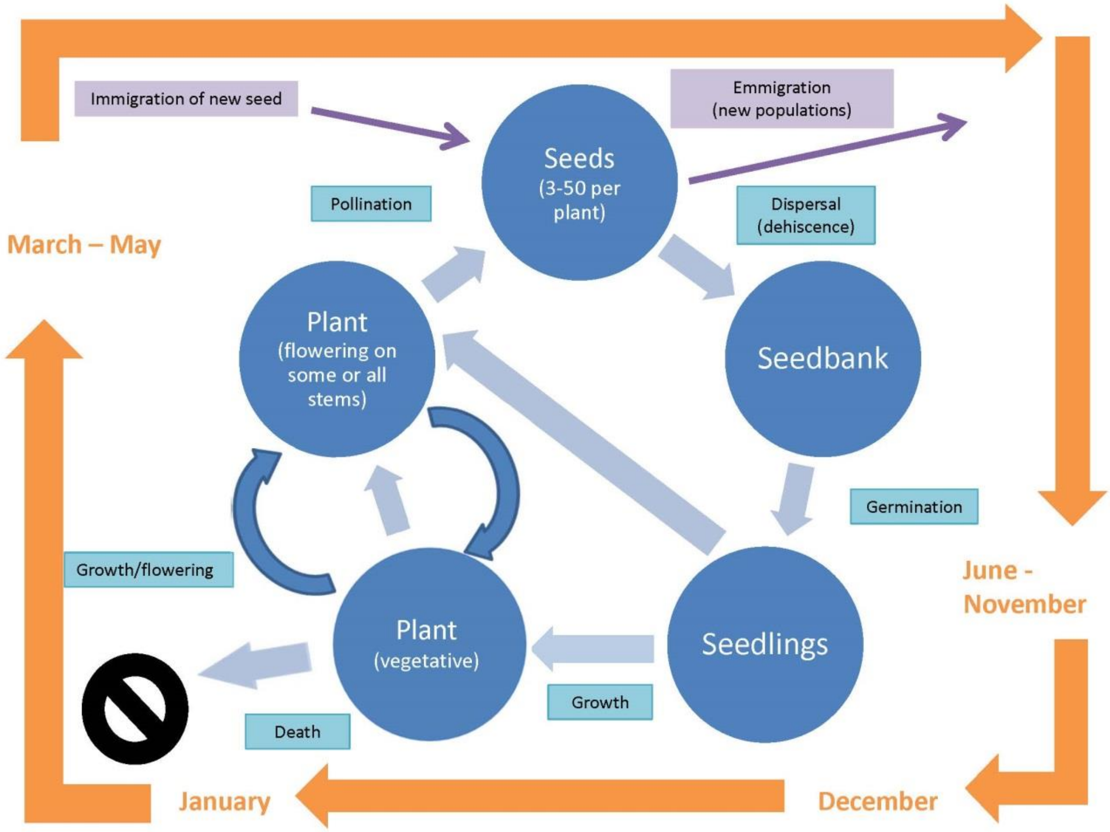


Figure 1.4.1. Life cycle of the Texas trailing phlox.

Phenology

Flowering of Texas trailing phlox generally begins in February with peak flowering occuring between late March and early April (Poole *et al.* 2007, p. 375; Ajilvsgi 1979, p. 241; U.S. National Park Service (NPS) 2015, p. 2), sometimes extending into May. Flowering can also occur sporadically in other parts of the year in response to precipitation and management (i.e. prescribed burning) (M. Buckingham, pers. comm. 2019a). Winter prescribed burns can delay flowering (NPS 2015, p. 2). Individual plants may produce between 3 and 50 flowers, depending on the size of the plant. Individual flowers can last 1-4 days and can continue to be produced over a period of 1-5 weeks (Corlies and Warnock 1992; TPWD 1997, p. 1; Maxey and Warnock 1996, p. 10) (see Figure 1.4.1). Texas trailing phlox petal color usually ranges from light- or rose-pink to bluish lavender, lilac, or purple, often with deep-hued eye-striae (Wherry 1955, p. 24; USFWS 1995, p. 2). As with other members in the genus *Phlox*, Texas trailing phlox can show rare cases of albinism (Wherry 1955, p. 24). This rare white petal color has been observed in a single Texas trailing phlox population from Tyler County, Texas (Carr 1997, p. 1). Texas trailing phlox plants exude a faint fragrance (Wherry 1955, p. 24).

Floral Biology
Studies on floral biology specific to the Texas trailing phlox have not been conducted. Bohorquez-Restrepo (2015), Hawke (2011), Locklear (2011), Levin (1972), and Majetic *et al.* (2014), have all investigated the effects of flowering color on other members of the genus *Phlox* and its effect on biological processes. In general, pollinators can discern between flower color, outline, size, and floral scent, and can learn to avoid plants that no longer provide a good supply of pollen or nectar (Levin and Anderson 1970, p. 456). Grant (1949, 1963) hypothesized that *Phlox* pollinators may demonstrate species fidelity, in discriminating the extent and shape of the corolla notch, with pollinator's discriminating between entire lobed corollas and other lobed forms. Lepidopteran pollinators of phlox (primarily butterflies in eastern species) display a moderate degree of flower-constancy, and when actively feeding, will typically move between neighboring plants of the same species (Levin and Kerster 1967). Pollen movements are generally over short distances, the average being 3-6 feet depending on population density. Therefore, lapses in pollinator loyalty are most likely to occur in colonies where species are interspersed, rather than contiguous or discontinuous (Levin 1967, p. 1125).

Levin and Kerster (1967) studied the natural selection for reproductive isolation in Phlox. They determined that the genus *Phlox* has a high level of variability in color phases, from red-pink to white and that the frequency of a population containing both pigmented and non-pigmented color phases, range from less than 1-10 percent, depending on taxon (p. 679). White corollas are rarely seen in species similar to *P. nivalis* ssp. *texensis*. Phlox are typically obligate outcrossers and interfertile (Levin and Kerster 1967, p. 680). Proximity to and overlapping of Phlox species can impact the color phase during blooming. This can affect pollinators as it appears that color divergence aids pollinators in flower discrimination and conserves its reproductive potential (p. 685).

Reproduction
Little is known about the reproduction of Texas trailing phlox. Their populations are small and consist of few scattered, inconspicuous individuals (Mahler 1980, p. 3). For this reason, asexual reproduction may be very important for recruitment (Parker and Warnock 1993, p. 19). However, the frequency at which asexual reproduction occurs for Texas trailing phlox is unknown. Underground connections between plants are quite extensive (USFWS 1995, p. 2). Largely, the Phlox breeding systems have been investigated by Dr. Levin and students at the University of Texas at Austin, focusing on the genetic consequences of inbreeding, outcrossing, hybridization, immigration, and gene flow of perennials (i.e. *P. divaricata*) and annuals (Bogler 1992, p. 4; Levin 1977). Both intra- and inter-specific hybridization (Levin and Schaal 1970; Schlichting and Levin 1986) and polyploidization (Levy and Levin 1971) have been investigated. Self-sterility in *Phlox* species is due to self-incompatibility. Widespread in the Polemoniaceae family, self-incompatibility is caused by early-acting inbreeding depression (in Ruane *et al.* 2015, p. 1660). The inbreeding depression can influence the genetic integrity of a population and individuals.

Pollination
Texas trailing phlox is a perennial species, occurring mostly as an outcrossing species pollinated by moths and butterflies (Bogler 1992, p. 5). However, it is not known whether flowers are obligate or facultative outcrossers (Maxey and Warnock 1996, p. 10; USFWS 1995, p. 9).

Pollinators specifically include carpenter bees (*Xylocopa* spp.) (M. Quinn, pers. comm. 2008), Nessus sphinx moth (*Amphion floridensis*) (G. Grant, pers. comm. 2017), and Tiger swallowtail butterfly (*Papilio glaucus*) (G. Grant, pers. comm. 2014), but may also include a variety of flies, bees, and butterflies (TPWD 1997, p. 1; USFWS 1995, p. 9; Maxey and Warnock 1996, p. 10). Poole *et al.* (2000, p. 3) notes that there is the potential of large terrestrial arthropods to act as pollinators.

We lack information about effective pollinators. The Tiger swallowtail butterfly is a generalist pollinator in this habitat community and therefore, does not significantly contribute to the population structure (i.e. reproductive success and fitness) of the Texas trailing phlox (Dr. L. Gilbert, pers. comm. 2018). Individual *P. glaucus* butterflies move many kilometers in their life and hundreds of meters between flowers to feed on nectar, typically settling in to a patch of flowers between periods of host plant searches or mate seeking. According to Dr. Lawrence Gilbert, the key to understanding gene flow and the population structure (reproductive success, fitness) in Texas trailing phlox could reside with the pipevine swallowtail (*Battus philenor*) (pers. comm. 2018). The pipevine swallowtail's host plants (Aristolochia) occupy the same meadow habitat as does the Texas trailing phlox. There is often an overlap between larval and adult hosts as the pipevine swallowtails have been observed laying eggs on host plants while neighboring Texas trailing phlox plants were blooming (A. Bennett, pers. comm. 2019). The pipevine swallowtail might also be a more reliable pollinator as they fly lower in the forest canopy versus the Tiger swallowtail butterfly. Additionally, *B. philenor* has been observed nectaring on Texas trailing phlox (M. Buckingham, pers. comm. 2019b) but we cannot confirm their effectiveness as a pollinator of Texas trailing phlox as a pollination study has not been conducted.

Seed Biology

Like other *Phlox* species, each ovary in Texas trailing phlox contains three ovules. Seed set in the Texas trailing phlox is low, as rarely does more than 1 seed per fruit develop (Corlies and Warnock 1992; NPS 2015, p. 2; Ruane *et al.* 2014, p. 888). Although seed set in natural populations of *P. pilosa* is about 40 percent (Levin and Kerster 1967), this information is unknown for the Texas trailing phlox. Only one instance of fruit development has been observed. There are reports of seeds being both dehiscent (NPS 2015, p. 2) and indehiscent (USFWS 1995, p. 2; Maxey and Warnock 1996, p. 37). Taxonomically-speaking, *P. oklahomensis* is similar, however Springer noted that *P. oklahomensis* is autogamous, with floral morphology not characteristic of anemophily, and insect visitation is rare (Springer 1983, p. 24). Unlike Texas trailing phlox, *P. oklahomensis* flowers usually open at night, and cooler nighttime temperatures within its geographic range in Oklahoma, cause little insect visitation. Dehiscence has been noted in *P. oklahomensis* (Halsted 1901, in Springer 1983, p. 18; Levin and Kerster 1968, p. 130), where dried seed capsules quickly separate and catapult seeds upwards of 1 - 5 m away. Since Texas trailing phlox flowers have been observed opened during the day and insects have been noted, the species might be less reliant on dehiscence for seed dispersal (unlike *P. oklahomensis*) but its seed dispersal methods remain unknown. Seed germination has not been observed, but most likely occurs during the autumn or winter (Parker and Warnock 1993, p. 19). Seed size in *P. oklahomensis* ranges from 50-150 milligrams (mg) per 100 seeds (Springer 1983, p. 25); seed size specifically in Texas trailing phlox is unknown. Seed and seedling biology are also largely unknown. Maturation of seeds is unknown for Texas trailing phlox, however seeds of the *P. hirsuta* require 35-45 days to ripen after pollination (Ruane *et al.* 2015, p. 1660). Seed dormancy requirements and length of seed viability are unknown (USFWS 1995, p. 10). Table 1.4.1 and Figure 1.4.1 describes the timeline of the Texas trailing phlox lifecycle.

Table 1.4.1. Lifecycle of Texas trailing phlox (Parker and Warnock 1993, Springer 1983, USFWS 1995, M. Buckingham pers. comm. 2019).

Life stage	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Leafing & Budding		X	X									
Flowering		X	X	X	X	X						
Seed Germination	X								X	X	X	X
Dormant	X										X	X

Predation or Herbivory
Deer and other animals browse the Texas trailing phlox (USFWS 1995, p. 10), but it is unknown which floral parts are eaten. *P. oklahomensis* has appressed bracts and leaves which protect the flower buds from the environment; this could also protect it from herbivory (Springer 1983, p. 18). Largely, the sepals, bracts, and leaves of plants provide protection to vulnerable reproductive structures within developing flowers. The sepals on both the *P. oklahomensis* and Texas trailing phlox are somewhat united by a membrane during part of the flower's development. This partial coverage protects the developing reproductive structures. Hairs on both the *P. oklahomensis* and Texas trailing phlox also function to repel herbivores, insulate, cushion, and retain/repel moisture. However, hairs are unlikely to deter mammalian herbivores or insects with large jaws (i.e. grasshoppers) (A. Tiller, pers. comm. 2018). Ruane *et al.* (2014, p. 889) noted that in *P. hirsuta* in California, mammalian herbivores (i.e. rabbit, hares, and/or deer) consumed reproductive structures after peak flowering, but before fruits ripened. Severed stems on *P. hirsuta* plants had evidence of mammalian granivory. Ruane *et al.* (2014, p. 890) noted florivory from beetles to a variety of floral organs, including petals, stamens, stigmas, and styles on *P. hirsuta*. Observations of other insect florivory and granivory on *Phlox* species has been noted. The Phlox plant bug, *Lopidea davisi*, can be detrimental to *Phlox* species as it feeds on leaves, stem terminals, flowers, and seeds (Missouri Botanical Garden, online 2018). Interactions with potential herbivores and dispersers on Texas trailing phlox has only been noted by Benson and Ferguson. J. Benson (pers. comm. 2017) photographed leafcutter ants (*Atta texana*) carrying floral buds and stem materials away from Texas trailing phlox plants. C. Ferguson (pers. comm. 2018) states that mammals are not likely seed dispersers.

Longevity and Mortality
Given optimal conditions, the Texas trailing phlox may live for 6 years or more (Maxey and Warnock 1996, p. 37). Anecdotal survey records suggest that Texas trailing phlox can persist longer than 6 years as the species is a longer-living perennial. For example, individuals planted in 2007 are still thriving at the Hancock site in Tyler County (R. Bounds, pers. comm. 2018). Therefore, we estimate that the average lifespan of the Texas trailing phlox is around 10 years.

1.5 Resource Needs (Habitat) of Individuals
Texas trailing phlox occurs in the East Texas region (Diggs *et al.* 2006, p. 2) known within the Texas ecoregion of the Pineywoods (described by Gould *et al.* 1960; USFWS 1995, p. 6; Poole

et al. 2007, pp. 5-7; NPS 2015, p. 2). More discretely, most natural Texas trailing phlox populations are concentrated in an area known as the Big Thicket (Watson 1797, in Poole *et al.* 2007, p. 5). Often referred to as the "biological crossroads of North America", the Big Thicket is the junction of highly varied habitats; from swamps, wooded uplands, and arid sandylands (Ajilvsgi 1979). Plants growing in droughty soils of sandylands and longleaf pine uplands in the Big Thicket have adaptations such as hairs and hairy surfaces, waxy cuticles, recessed stomata, small leaves, deep roots systems, tubers, and succulent stems and leaves; which help retain moisture and prevent wind drying and radiation (Ajilvsgi 1979, p. 21).

Normal weather patterns for the Big Thicket are warm and wet. Average annual precipitation is well-distributed throughout the year, receiving between 48 in (121 cm) and 60 in (152 cm) of rain (USFWS 1995, p. 6; Diggs *et al.* 2006, p. 169). The lower portion of the Big Thicket receives the most rain, with almost 60 in (152.4 cm) annually (Ajilvsgi l1979, p. 7). Since the region is accustomed to large amounts of precipitation, droughts or extended dry periods impact the plants and their habitats. Climate change and potential effects to Texas trailing phlox is discussed in Chapter 5 of the SSA.

There are 244 frost-free days on average in this area, from early March through mid-December (Larkin and Bomar 1983). Storms are frequent in this area. Hurricanes Rita (2005), Ike (2008), and Harvey (2017) all affected the Big Thicket. Species here must be able to withstand or rebound from the high winds, heavy rainfall, saturated soils, and flooding that accompany these storms. These storms can however, mitigate drought conditions by the large amounts of rainfall that they bring (Nielsen-Gammon 2011, p. 10).

The vegetation of the Big Thicket, once described by Lundell (1942) as "pine land", has been/is influenced by the complex interactions of its habitat features, including geology (soils, hydrology, type of parent material), climate, succession, and fire (Diggs *et al.* 2006, p. 162). These features have shaped and shifted the vegetation associations found in this area over time. Historically, fire was a natural part of this habitat and used by Native Americans and early Euro-American settlers (Henderson 2006, p. 101). Anthropogenic fire continued into the early 1900's, and reports suggest further use of burning into the early 20th century (Henderson 2006, p. 103). Foster *et al.* (1917, in Henderson 2006, p. 103) even suggests that at least 75 percent of Tyler County burned each year in 1916. The Spanish colonial inhabitants also kept the forest of this region in pristine condition well into the 19th century by blocking settlement of its' interior regions (Frost 1993, p. 23).

The extent of the longleaf pine ecosystems across the South and Southeast U.S. have been greatly reduced. In pre-settlement times, the upland longleaf pine landscape once dominated this region, extending close to the Maryland state border (Frost 1993, p. 18). However, regenerative failure of longleaf pines to colonize natural stands, negative effects of feral livestock, and fire suppression and/or exclusion have reduced this habitat acreage to an estimated 3 percent of its original range (Stambaugh 2011, p. 1095; Frost 1993, p. 17; Landers *et al.* 1995; Jose *et al.* 2006). Frequent fires were historically an important disturbance feature within this ecosystem. Fire intensity and behavior, rather than seasonality or frequency, drive the ecosystem structure and species composition of the region (Oswald *et al.* 2018, p. 1). Oswald *et al.* (2018) found that fire occurrence within the longleaf ecosystem fosters a dense and diverse herbaceous layer with up to 300 species per hectare, many of which are currently rare or endangered. Natural populations of Texas trailing phlox occur in these open, fire-maintained pine and pine-hardwood woodlands (Poole *et al.* 2007, p. 375; USFWS 1995, pp. 6-7; NPS 2015, p. 2).

To maintain the longleaf pine ecosystem, the processes that maintained the ecosystem over long periods must be restored (Kaufmann *et al.* 1994). Appropriate fire-return intervals help to maintain the structure and composition of this ecosystem. Fire scar data within tree ring records can be difficult to estimate because of compounding biological process and factors but are invaluable in estimating historic fire regime patterns. Across the Eastern region of the U.S. in habitats east of the central grasslands to the Atlantic coast, sources suggest that historic fire-return intervals averaged less than 15 years (Henderson 2006, Huffman *et al.* 2004, Huffman 2006, Wade *et al.* 2000, in Knapp *et al.* 2009, p. 43) with fire-return intervals averaging 10.6 years in the Big Thicket (between 1668-1984) (Henderson 2006, p. 324). Jurney (2000, in Rideout *et al.* 2003, p. 263) states that historic fire-return intervals for the Village Creek area (an extirpated location for Texas trailing phlox) was 1-3 years but is now more than 20 years. Longleaf pine in Louisiana had an average fire-return interval between 0.5-12 years (Stambaugh *et al.* 2011, p. 1098).

Many plants of the southern pine ecosystems are well adapted to and require frequent burning. Numerous groundcover plants require growing season fires (conducted during late spring/early summer) for flowering and fruit and seed production (Platt *et al.* 1998, Streng *et al.* 1993, Walker 1993; in USFWS 2003, p. 69). Platt *et al.* (1988) showed that herbaceous plants exposed to growing season fires not only increased flower production, but also increased synchronicity of flowering, facilitating pollination and reducing risk of hybridization. The longleaf pine within this ecosystem depends on fire to remove competitive vegetation and maintain bare soil so seeds can germinate (Demers *et al.* 2010, p.1; Henderson 2006, p. 138) so often these burns help meet long-term management objectives. However, many fire adaptations in plants may not coincide with growing season burns. Plants carbohydrate reserves and growth and recovery, tender early-season plant tissues, and reduced reproductive capacity during this time period can be limited or reduced by these burn periods (Knapp *et al.* 2009, p. 5). Plants, including reproductive parts (i.e. flowers), can be destroyed or damaged during burns, thus terminating the opportunity for pollination to occur during that season. Timing of burns is critical to prevent impacts to the reproductive processes of these species. Texas trailing phlox responds well to fire and observations suggest that it also requires fire. Texas trailing phlox can rebound and reflower after growing season burns. We lack information that links fire to any biological or ecological function (e.g.. seed dispersal through dehiscence in pines) necessary to the Texas trailing phlox.

Fire is an important process to maintain optimal canopy structure. Maxey and Warnock (1996) investigated the impacts of management (i.e. prescribed burning, canopy thinning, and combined management) on Texas trailing phlox. They found that reproduction is best with an open canopy of pines (5-25 percent); less than 40 percent coverage of subcanopy pines (pines and hardwoods); and, less than 40 percent shrub coverage (Maxey and Warnock 1996, p. 37; see Table 1.5.2). Schwelling *et al.* (2000) used these results to predict suitable habitat for Texas trailing phlox within its known geographic range. The limiting factor for Texas trailing phlox growth at a site is the depth and degree of compaction of litter, not the type of litter. However, pine straw litter (versus hardwood leaves) helps to carry the fire of a prescribed burn, keeping the vegetation open among Texas trailing phlox habitat (Shilling and Mills 2010, p. 5). Litter must be sparse and/or not compacted at sites to allow for growth of Texas trailing phlox, litter depth is generally 3-5 cm (1.2 - 2.0 in), and coverage is usually 75-100 percent (USFWS 1995, p. 7). Hardwood and grass leaves tend to compact less than pine needles, although the Texas trailing phlox sites are usually dominated by pines as canopy trees. Brockway *et al*. (2005 pp. 4-6) describes the associated plant species of the longleaf pine forest ecosystem. Similar plant associates to the Texas trailing phlox identified by Ajilvsgi (1979), Mahler (1980), USFWS (1995), and the NPS (2015) are in Table 1.5.1 below.

Table 1.5.1. Plant Associates of Texas trailing phlox.

	Scientific Name	Common name	NPS 2015	USFWS 1995*	Ajilvsgi 1979	Mahler 1980
OVERSTORY	*Quercus incana*	blue jack, sand jack		x	x	
	Pinus palustris	longleaf pine	x	x	x	x
	Pinus elliottii	Slash pine		x		
	Pinus taeda	loblolly pine	x	x		x
	Pinus echinata	shortleaf pine	x			
	Quercus stellata	post oak	x	x		
	Carya texana	black hickory	x	x		x
	Quercus falcata	southern red oak		x		
	Liquidambar styraciflua	sweetgum				x
UNDERSTORY	*Quercus incana*	blue jack, sand jack		x		
	Quercus stellata	post oak		x		
	Sassafras albidum	sassafras		x		
	Ilex vomitoria	yaupon holly		x		x
	Carya texana	black hickory		x		
GROUNDCOVER	*Schizachyrium scoparium* var. *scoparium*	little bluestem	x			
	S. scoparium var. *divergens*	pinehill bluestem	x			
	Andropogon ternarius	split-beard bluestem	x			
	Sporobolus junceus	pineywoods dropseed	x			
SHRUBS	*Ilex vomitoria*	yaupon holly	x			
	Callicarpa americana	American beautyberry	x			
	Persea borbonia	redbay	x			
	Quercus incana	bluejack oak	x	x		
	Rhus copallina	Winged sumac		x		
	Ilex vomitoria	yaupon holly		x		
	Asminia parviflora	smallflower pawpaw		x		
	Carya texana	black hickory		x		
	Sassafras albidum	sassafras		x		
	Ascyrum hypericoides	St. Andrew’s Cross		x		
	Toxicodendron radicans	Eastern poison ivy		x		

	Stillingia sylvatica	Queen's-delight		x		
	Callicarpa americana	American beautyberry		x		
HERBS	*Panicum anceps*	Beaked panigrass		x		
	Ambrosia psilostachya	Cuman ragweed		x		
	Berlandiera pumila	Soft greeneyes		x		
	Solidago odora	Anisescented goldenrod		x		
	Solidago rugosa	Wrinkleleaf goldenrod		x		
	Andropogon virginicus	Broomsedge bluestem		x		
	Eupatorium compositifolium	yankeeweed		x		
	Centrosema virginianum	Spurred butterfly pea		x		
	Fimbristylis autumnalis	Slender fimbry		x		
	Krigia virginica	Virginia dwarfdandelion		x		
	Rudbeckia hirta	blackeyed Susan		x		
	Tradescantia hirsutiflora	Hairyflower spiderwort		x		
	Euphorbia nutans	eyebane		x		
	Helianthemum carolinianum	Carolina frostweed		x		
	Hieracium gronovii	queendevil		x		
	Eryngium yuccifolium	rattlesnake master		x		
	Oxalis priceae	tufted yellow woodsorrel		x		
	Lespedeza hirta	hairy lespedeza		x		
	Hedyotis nigricans	diamondflowers		x		
	Silphium gracile	slender rosinweed		x		
	Tephrosia onobrychoides	multibloom hoarypea		x		
	Baptisia nuttalliana	Nuttall's wild indigo		x		
	Liatris elegans	pinkscale blazing star		x		
	Croton monanthogynus	Prairie tea		x		
	Stipa leucotricha	Texas wintergrass		x		
	Sisyrinchium rosulatum	Annual blue-eyed grass		x		
	Viola pedata	bird's foot violet				x

* = referenced by Poole *et al.* 2007 (p. 375)

Table 1.5.2. Key habitat characteristics for Texas Trailing Phlox (Parker and Warnock 1993, Maxey and Warnock 1996, and published in Schwelling *et al.* 2000).

Characteristic	**Poor**	**Tolerated**	**Optimal**
Percent Overstory Cover	>80 percent	25-80 percent	5-25 percent
Percent Understory Cover	not given	not given	25-70 percent
Percent Shrub Layer Cover	80-90 percent	25-40 percent	10-25 percent
Percent Ground Cover	not given	not given	25-70 percent
Slope	not given	not given	<5 percent
Soils	Deep sands	Deep sands	Deep sands
Elevation	not given	not given	9-75 m
Topography	not given	not given	Approx. level
Timing since last burn	>5 years	4-5 years	0-4 years

Texas trailing phlox occurs at elevations ranging from 9-75 meters (m) (USFWS 1995, p. 6), on level to slightly sloping ground (Maxey and Warnock 1996) with optimal slopes at most sites less than 5 percent (Maxey and Warnock 1996). Preferred soils are droughty sands, sandy clay loams, and loamy sands (Locklear 2011). Plants grow near edges of deep sands, underlain by clays 0.5-2 m below the surface (NPS 2015, p. 2). These soils are classified as xeric or subxeric, typically found in communities that are transitional between xeric and mesic (Locklear 2011). The Recovery Plan (USFWS 1995, pp. 6-7) describes the soils as, "sandy surface soil, coupled with moisture-bearing clays or sandy-clay soils. Sites are often on the sandy, drier and usually upslope side of transitional areas between sandy soils supporting longleaf pine woodland (*Pinus palustris*), and clay or sandy-clay soils supporting a mixed forest of hardwoods and pines, usually loblolly pine (*P. taeda)*." A record from 1998 (unknown, pers. comm.) notes that soils for the Big Sandy Unit in the Big Thicket National Preserve are mapped as Bowie fine sandy loam soils, however this series is not mentioned within the Natural Resource Conservation Service's (NRCS) mapped soil series for either Hardin, Tyler, or Polk counties (McEwen *et al.*1988, Wiedenfeld 2006, Steptoe 2008). Neither Watson (1982, pp. 16-17) or McLoed (1972, pp. 10-11) specifically mention Bowie fine sandy soils despite thouroughly describing the soils of the Big Sandy Unit. The specific soil series for Texas trailing phlox have not been mapped; however, one record indicates that soils could include the Bowie fine sandy loam (pers. comm. 1998).

CHAPTER 2 – Population-level Ecology

2.1 Geographic Range of the Genus

Wherry (1955, pp. 6-7) hypothesized about the geographic distribution of *Phlox*. Only one species, *P. sibirica*, succeeded in crossing the Bering Strait and entering Asia from the ancestral home in Keewatin Land (what is now Canada), during the late Cenozoic (Tertiary) Era. Before the Pleistocene ice sheet formed and vanished, which often occurred, many Phlox species were able to evolve and expand their ranges in all directions away from the Keewatin Land. Winter-hardy perennial plants like *Phlox* were able to withstand some of the harsh, low temperatures; melting of some of the ice and snow allowed the plants to migrate into new areas. Interglacial processes brought on moderate temperatures and decreased precipitation. Although, many Phlox species could not persist over this long period of warm, especially dry conditions and became extinct, some survived. The marked divergence in position, size, and shape of areas occupied by present-day *Phlox* taxa is thought to be the result of recurrent range-fluctuations.

Texas trailing phlox is a rare endemic of the Pineywood ecoregion of East Texas, with a restricted geographic range. It is only found in Hardin, Tyler, and Polk counties. The furthest populations are almost 66 kilometers (km) (41 miles (mi)) apart (RMS introduction - Tyler County and Campbell Easements – Polk County), with the closest distinct populations being about 2.2 km (1.36 mi) apart.

2.2 Population Distribution

The geographic location of plants has often been described by several interchangeable terms, including populations, sites, and locations. NatureServe (2002, p. 10) defines an Element of Occurrence (EO) record as an "area(s) of land or water in which a species or natural community is, or was, present." The Texas Natural Diversity Database (TXNDD) (part of TPWD) has adopted the use of EO records to track and describe the location of plants, animals, and habitats of conservation concern.

TXNDD has noted 26 EO records for the Texas trailing phlox (Table 2.2.1, Figure 2.2.1). Eula Whitehouse first collected the species in 1931 in Hardin County (USFWS 1995, p. 3; G. Yatskievych, pers. comm. 2017). This site represents EO 3 and is presumed extant (Table 2.2.1) (W. Ledbetter, pers. comm. 2018). When the Recovery Plan published in 1995, there were only two known sites in southeast Texas, including EO 3 (the type locality) and another site from Tyler County. However, it was likely that only the EO 3 was viable in a genetic or reproductive sense (USFWS 1995, p. 4). Since the 1995 publication of the final recovery plan, an additional 17 sites were observed in Hardin, Polk, and Tyler counties; however all of them are now considered extirpated. Locating these additional sites has been challenging since most records only contain vague location descriptions (Table 2.2.1). The USFWS is currently gathering location description information from known herbarium specimens to revisit the sites.

Currently, there are two ways (standards) to define a Texas trailing phlox population. The first, used by the USFWS in the Texas trailing phlox Recovery Plan, describes a natural population as a **"group of plants separated by a distance of at least 2 km (1.2 mi) from any other Texas trailing phlox plants, or is a group of at least 300 plants covering an area, at a maximum, of one 1 square kilometer"** (USFWS 1995, p. 13). To date, the USFWS recognizes that there are seven known extant populations in Hardin, Polk, and Tyler counties (Table 2.2.1), including five natural and three ex-situ sites (two reintroductions, one introduction).

The second standard used by TPWD's TXNDD describes a Texas trailing phlox population using a separation distance of 1.0 km (B. Gottfried, pers. comm. 2018). This distance is the default for the TXNDD where further information is lacking and is not the same as the separation distance used by the USFWS. In this SSA, we define a population using the USFWS's 1995 standard. Using the 2 km separation distance, it is assumed that there are areas of potential habitat between some of these designated populations that have not been surveyed for Texas trailing phlox. The lack of management actions over time could have made sites between extant populations less optimal (i.e. suitable habitat that does not have any prescribed burning). Additionally there is a lack of genetic studies and population structure information to confirm the relatedness of extant populations. Therefore, when additional surveys and genetic data are collected for the species, the definition of a population for this species may need to be revised.

The USFWS Recovery Plan contains a definition of a Texas trailing phlox plant. A "plant" is defined as a cluster of Texas trailing phlox stems with no above-ground connection to other groups of stems, and separated from other such groups by a distance of at least 5 decimeters (1.6 ft.) (USFWS 1995, p. 13). We used this standard when reviewing the resiliency of Texas trailing phlox at each site (i.e. the Minimum Viable Population (MVP)) and during surveys and monitoring for the species at its populations. It is important to consider the type of population when surveying and monitoring individuals. Planting patterns at an introduction may put plants in closer proximity than plants would naturally occur in a "natural" population; thus, the definition of how to define a "plant" in recovery terms needs to be clearly defined.

The following information briefly describes the locations and status of the known populations of the Texas trailing phlox. Additional information on these populations is listed in table 2.2.1:

The Nature Conservancy's (TNC) Roy E. Larsen Sandyland Sanctuary - extant

This property was donated in 1977 and in 1978 to The Nature Conservancy (TNC) by Temple-Eastex, Inc. and then Gulf States Utilities Company, respectively (TNC 2018, p. 1). There are several extant EOs recorded on Roy E. Larsen Sandyland Sanctuary (hereafter referred to as the "Sandylands") in Hardin County, including EOs 3, 5, and 13 (Table 2.2.1). The TXNDD combined EOs 5 and 13 for monitoring purposes. Based on the population definition above, we consider these EOs as a single population for the purpose of this SSA. TNC continues to manage their land to conserve the longleaf pine savanna.

Timber Conservation Lands - extant

EO records 22 and 23 occur on land compartments found adjacent to and southeast of the Sandylands, all of which is owned by the Sandylands but which has historically been leased by timber companies. As of May 2018, TexMark Timberlands Treasury (TTL) was leasing the land, and prior to that land was leased by Campbell Timber (Campbell). We will refer to this site throughout the document as "timber conservation lands" to encompass historical and current management. These two timber conservation land compartments (#00376, #00377) include natural populations of Texas trailing phlox (Keith 2015). USFWS and Campbell Timber staff visited both compartments in March 2018. Plant estimates were recorded within compartment #00376 (Figure 3) (Table 2.2.1). These two Texas trailing phlox sites are within 1 km of each other and therefore, we consider as a single population. The populations on the timber conservation lands and those on the Sandylands are separated by 2.2 km (1.36 mi) and therefore are considered separate populations; however, it is likely that there is suitable habitat between these sites and/or species may be genetically similar. However, we do not have genetic studies at this time to support this claim. Plant estimates by Maxey and Warnock (1993) note that fewer than 200 plants, compared with the 500 plants, were observed in 1996 (1996, p. 9).

Big Thicket National Preserve – Big Sandy Creek Unit and EO 17 - extant

The National Park Service (NPS) has two natural EO records and two reintroduced populations, all of which occur within the Big Thicket National Preserve (BTNP) near Kountze, Texas. Both natural populations (EO's 17 and 21) are extant, occurring along roadsides (Table 2.2.1) in Polk County and adjacent to state-owned lands (Texas Department of Transportation (TxDOT)). BTNP, TNC, NPS, and other Texas trailing phlox partners reintroduced plants into the Big Sandy (BS) Creek Unit of BTNP in 2001 and have monitored the plants since the reintroduction (Table 2.1.1). EO 17 and the BS reintroduction are within 0.5 km (0.31 mi) of each other and, therefore, we define each as a single population. EO 17 is approximately 4 km (2.49 mi) from EO 21, therefore, we consider both natural populations as separate populations and thus analyze each separately in this SSA analysis.

Big Thicket National Preserve – Turkey Creek Unit – extant

The NPS and partners reintroduced plants into the BTNP Turkey Creek (TC) Unit in 1995 and have monitored the plants since the reintroduction (Table 2.2.1). Plant material for the TC reintroduction originated from cuttings of plants at the Sandylands, with assistance by Mercer Arboretum and Nature Center (Mercer) (Maxey and Warnock 1996, p 8).

Big Thicket National Preserve – EOs 10, 11, and 12 - extirpated

In the past TXNDD recorded several additional EOs 10, 11, and 12 in BTNP, however, they are considered extirpated (Table 2.2.1). These populations were located approximately 37 km (22.99 mi) from EO 17 and EO 21.

Resource Management Services

Land owned and managed by Resource Management Services (RMS), LLC in Tyler County includes a natural population of Texas trailing phlox (EO 9). First observed in April 1997, this population is unique, as it is the only observation of white flowering corollas (flowers) on the Texas trailing phlox to date.

Hancock Timber lands

Another Texas trailing phlox site was reintroduced into Tyler County in December of 2007 on Hancock Timber (referred to as "Hancock") private lands. The Stephen F. Austin State University's (SFA) Pineywood Native Plant Center provided 125 plants derived from wild stock from the Sandylands, for the reintroduction. These plants were planted in five separate plots on Hancock property, all within 1 km of each other. Therefore, we consider this a single population, as all the plants come from the same maternal stock. The natural site in Tyler

County (RMS, EO 9) is located about 36.5 km (22.68 mi) and therefore is analyzed separately in our SSA analysis.

Table 2.2.1. Element of Occurrence (EO) Records for the Texas trailing phlox (*Phlox nivalis* ssp. *texensis*) (TXNDD 2018; species experts). Population status abbreviations are as follows: Extant (E); Population is extant but unverifiable (E-UV); Historic (H); or Unknown (U). A population lacking information to help determine the status or one with a questionable status is denoted with a question mark (?).

Pop #	EO #	First Observer; Observation	Last Observer; Observation	County	Site Description	Voucher	Population Size and Observations	Status	Ownership
1	17	Maxey; 1998	Buckingham, Bennett; 2017	Polk	Big Thicket NP, Big Sandy Creek Unit - junction with Sunflower Road	None	**Natural population**. Site first observed on April 8, 1998, where two plants were found both in flower and with several buds (TXNDD 2018). The first plant had nine stems and the second plant had 15 stems (B. Carr, pers. comm. 1998). Site revisited on April 10, 1998 (TXNDD 2018). The site is known as the "beetle spot". In both 2005 and 2006, Big Thicket National Park (BTNP) staff found six plants. BTNP staff refer to site as "BSN1". In Spring of 2006 found five plants (J. Singhurst updates, in W. Ledbetter, pers. comm. 2006). Staff from BTNP observed plants between 2009 and 2013 with seven, 10, 11, five, and five plants, respectively (A. Bennet, pers. comm. 2018). February 17, 2017: Site was in bad need of a burn, with dense leaf litter and heavy encroachment by *Ilex vomitoria* and other woody species. Four plants observed, all at existing stakes but none were flowering. Plants were long and spindly due to lack of sunlight. Survey by BTNP staff found six plants in 2017 (A. Bennett, pers. comm. 2018). TxDOT and BTNP did not detect any plants at most of the existing stakes during two separate surveys in 2018 (M. Buckingham, pers. comm. 2018; A. Bennett, pers. comm. 2018).	E	Federal

1				Hardin	Big Thicket National Preserve, Big Sandy (BS) Unit		**Introduced.** Formal plantings occurred in February 2003 and 2005. Four sites were selected, each containing one cluster of 1-4 plots. Plots included – BS 1, 2, 3: North of Sunflower Road; BS 4-6: Near ROW of FM 1276; BS 7-10: near intersection of FM 1276 and Hendrix Rd; BS 12: North of Lilly Road. Re-planting occurred at some plots in February 2006. Most monitoring began the year following the planting; however, in plots BS 7-12, monitoring occurred 1-2 year after planting. Mortality in plots BS 1-6, ranged from 24-61% within six months of planting. All of these plots were at or near zero plants by 2014. For plots BS 7-12, mortality was very high, reaching nearly 100% within two years of first planting. Plant survival was much higher after second planting in these plots, but by 2015, they had all declined (NPS 2015).	E	Federal and State
2	21	Maxey; 1995	Miller and Buckinghman ; 2018	Polk	Big Thicket NP, Big Sandy Creek Unit - FM 1276 on both sides		**Natural population**. On March 23, 1995, observed 2 plants (or clumps) found in BS Unit in Fire Management Unit (FMU) 1401. There was a fire in July 1993 – either plants and/or a supply of seeds were already there (TXNDD 2018; Davis 1995). A herbarium specimen was collected from this FMU in 1995 (TXNDD 2018). Since April 2003, additional populations have been found on more interior parts of the BTNP (K. Nemec, pers. comm. 2003). BTNP staff found eight plants in 2003 and nine plants in 2004 (A. Bennett, pers. comm. 2018). While trimming on	E	Federal and State

							ROW, TxDOT found 15 new plants on March 23, 2005 (W. Ledbetter, pers. comm. 2005); BTNP also observed 15 plants in 2005 (A. Bennett, pers. comm. 2018). On January 10, 2006, Phlox Working Group searched for plants and habitat (W. Ledbetter, pers. comm. 2006a); no record of plants was observed. However, BTNP notes that they observed 15 plants again in 2006 (A. Bennett, pers. comm. 2018). Hurricane Rita caused damage to area known as "triangle area" in the BS Unit near FM 1276 and Hendricks Road; no phlox found (W. Ledbetter, pers.comm. 2006b). The Service noted that 1 ROW population was destroyed during Hurricane Rita clean-up (USFWS 2006). In the Spring 2006, the FM 1276 (the 'triangle') was thoroughly surveyed by L. Jameson. She found 17 total plants (J. Singhurst, pers. comm. 2006). On February 2, 2006, 13 plants were found (W. Ledbetter, pers. comm. 2006c). TxDOT is widening road in late Feb/March 2007. A construction barrier had been erected around the two populations found adjacent to BTNP and 1 population across the street. (Ledbetter 2006). R. Hammer samples five plants in November 2006, along FM1276 and BTNP boundary as part of genetics study. Reports only mention the number sampled, not the total number of plants at the population (Ledbetter 2006). BTNP staff found 15 plants in 2007 (A. Bennett, pers. comm. 2018). In 2008 or 2009, two plants in road ROW were impacted by road widening efforts by TxDOT (USFWS 2008, USFWS 2009). 15 plants observed in 2009 (A. Bennett, pers. comm. 2018). Between 2010 and 2013, there were 16, 13, 9, and 9 plants observed (A. Bennet, pers. comm. 2018). Historically, there were reports of plants on both sides of FM 1276. In 2015, TxDOT looked at population across street – did not find any plants (M. Buckingham, pers. comm. 2018b). On Feb 17, 2017, TxDOT observed 6 plants, all directly on or within 2 meters of the ROW line. All appear to be within the BTNP boundary: Three plants in flower or bud: five plants at existing stakes; one new location within 5m of staked plants. Plants appear to be in good health. Reintroduction site nearby had hundreds of plants, approximately 5-10% of which were in flower or bud. (M. Buckingham, pers. comm. 2018a). On March 10, 2017 – one plant in flower. All plants appeared to be in good condition. Approximately 10-20% of plants at reintroduction site in flower or bud (M. Buckingham, pers. comm. 2018a). On March 25, 2017, TxDOT did not find any plants in flower, though wilted flowers observed on two plants. Approximately 10% of plants at reintroduction site in flower (M. Buckingham, pers. comm. 2018a). The BTNP observed 21 plants in 2017 (A. Bennett, pers. comm. 2018). In 2017, TxDOT looked at population across street – did not find any plants (M. Buckingham, pers. comm. 2018b). On March 22, 2018, TxDOT, USFWS, and BTNP surveyed FM 1276 ROW (Miller 2018) and found six plants.		

	4			Polk	to county level only	Tharp (TEX 11714, 11715)	**Natural population**. In 1937, a specimen was collected, but exact location is unknown. The numbers of plants were not reported and the population has since been located due to the nondescript location information.	H	Unknown
	10	Ajilvsgi; 1980		Hardin	Big Thicket National Preserve, Turkey Creek Unit: North-Northeast of confluence of Village and Turkey Creeks, east of Turkey Creek		**Natural population**. Unpublished report by G. Ajilvsgi. This was reported to USFWS in 2002, but no other records found regarding occurrence.	H	Unknown
	11	Ajilvsgi; 1980		Hardin	Northeast of confluence of Village and Turkey Creeks, and east of Turkey Creek		**Natural population.** Unpublished report by G. Ajilvsgi. This was reported to USFWS in 2002, but no other records found regarding occurrence.	H	Unknown
	12	Ajilvsgi; 1980		Hardin	East of confluence of Village and Turkey Creeks, on east side of Village Creek		**Natural population**. Unpublished report by G. Ajilvsgi. This was reported to USFWS in 2002, but no other records found regarding occurrence.	H	Unknown
3	3	1931		Hardin	Roy E. Larsen Sandyland Sanctuary; west of junction on Hwy 327 and 96 in Silsbee	Whitehouse (TEX 1931); Cory (TAES 1947, SMU 1947)	**Natural population**. Personal Communication with W. Ledbetter states that this property likely comprises the phlox found on what is now Roy E. Larsen Sandyland Preserve land (TNC), Temple-Inland (timber), and other private property (W. Ledbetter, pers. comm. 2018b).	E-UV	Private

3	5 (and 13)	Amerson; 1972		Hardin	Hwy 418 between Kountze and Silsbee, across from TNC Sanctuary near dumpground; known as "dump"	Ajilvsgi (SMU 1980); Amerson (SMU 1972)	**Natural population**. These 2 EO records are combined, but the history ('observations') of each is maintained (J. Singhurst pers. comm. 2006). The first observation and collection were on March 9, 1972, where plants were in flower and in fruit (TXNDD 2018 – EO 5). 25 plants were recorded here (from EO 13). On April 1, 1980, another herbarium specimen was collected (TXNDD 2018). TPWD surveyed the site in 2004 – no records of plant abundance (J. Singhurst pers. comm. 2006). 85 plants were observed during March 14, 2006 survey; again, 41 plants were observed on March 15, 2006, in addition to the already 58 known for this area, making a total of 184 plants – highest concentration of natural phlox within the area. EO 13 "dump site combined with EO 5 (J. Singhurst pers. comm. 2006). In early July 2006, R. Hammer sampled seven plants from the "dump site" and along the road as part of his genetics work (W. Ledbetter, pers. comm. 2006d). In August 2006, R. Hammer also sampled 17 plants from the "dump site" as part of his genetics work (W. Ledbetter, pers. comm. 2006d)	E-UV	Private
	14	1985	1990?	Hardin	Roy E. Larsen Sandyland Sanctuary; north of pipeline-transmission line easement		No record or number of plants or observation data.	H	Private
	15	Ajilvsgi; 1980		Hardin	South of Hwy 327 and east of Village Creek		**Natural population**. There is no information on abundance or population status to date. Due to the vague locality information, this site has not been revisited.	H	
4	22	Singhurst; 1994?	Miller and Jackson; 2018	Hardin	Roy E. Larsen Sandyland Sanctuary - easement; east of Village Creek and Hwy 327, along a Forest Road		**Natural population**. J. Singhurst (1994) observed about 40 plants in flower and fruit (TXNDD 2018). About half of the plants were fully mature. At the time of its observation, TNC and Temple-Inland were involved with a Cooperative Agreement to implement a forest management plan on the site. The status of this plan is unknown. On October 27, 2015, Raven Environmental conducted a rare plant survey (by Eric Keith) on what was referred to as the Campbell Global Conservation Easements. The survey was completed in multiple units. They found 47 plants in Units #00376 (Keith 2015). The easement was leased by Temple-Inland and then Campbell Global, however as of May 2018 this unit is leased by TTT. This EO likely includes the land within this easement (Unit #00376), as well as plants found north of the Entergy Transmission line and south of the rail (W. Ledbetter, pers. comm. 2018b).	E	Private
4	23	Ledbetter; 1995	Miller and Jackson; 2018	Hardin	Roy E. Larsen Sandyland Sanctuary - easement; east of Village Creek and Hwy 327, and east of Mill Creek Road. On Tract 4		**Natural population.** The site first was documented by W. Ledbetter with 20 plants in May 1995 (TXNDD 2018; J. Singhurst pers. comm. 2006). On April 12, 2004, a total of 126 plants were documented (J. Singhurst pers. comm. 2006). On January 10, 2006, the Phlox Working Group spent the day looking at habitat and plant locations on Sandylands Preserve/Temple-Inland Conservation Easement (W. Ledbetter, pers. comm. 2006d). In October 2006, as part of ongoing genetics, R. Hammer sampled 3-4 plants from easement (W. Ledbetter, pers. comm. 2006d).	E	Private

					of Temple-Inland easement (now TTT).		On October 27, 2015, Raven Environmental conducted a rare plant survey (Eric Keith) on what was referred to as the Campbell Global Conservation Easement. The survey was completed in multiple units. 47 plants were found in Unit #00376 and 87 plants in Unit #00377 (Keith 2015). Miller (USFWS) and Jackson (Campbell) surveyed the site on March 21, 2018. Several sites of plants (likely one entire metapopulation) were visited. In Unit #00376, 5 sites were observed: site 1 had three flowers in bloom with vegetation covering plants; no plants were observed in site 2 (north side of road); at site 3, seven clumps of plants were observed; site 4 had a very robust and healthy population with an estimated 60-80 flowers in bloom (in full sun); and, site 5 had no plants and was overgrown with grasses. Most sites needed burning and management. Distance between some clumps was between 18-19 m. (60 -65 ft.). Longleaf pine in stand #00377 was planted in 2014. Between 5 and 7 clumps of plants were observed; no GPS points were taken. Two of the clumps had about 5 plants each, and additional plants added to one clump. Most of this unit is in partial shade and looks to be following the old road/depressional area (now overgrown with natives and pine). Yaupon on site needs to be managed. In some areas, grasses are invasive.		
	19	1991	Singhurst and Ledbetter; 1994	Hardin	North of SR 327, east of Mill Creek, and along road		**Natural population**. Plants recorded along Hwy ROW in 1991. Some plants were observed in 1994 in vegetative state, but plants previously observed in 1991 (Singhurst and Ledbetter) were not observed in 1992 or 1993 field seasons.	H?	
	7	Wherry; 1955?		Hardin	5 miles SE of Kountze		**Natural population.** Location information for the site is vague. Therefore, revisiting the site has not been possible.	H	
	16	Ajilvsgi; 1980		Hardin	Village Creek State Park; south of Hwy 327, north of Village Creek, and West of the Neches River		**Natural population.** Plants were not recorded in 2018, although there might be two marginal areas of habitat in the park that could potentially serve as future reintroduction sites (J. Rashall, pers. comm. 2018).	E-UV	State
	1	Whitehouse; 1931		Tyler	4 miles south of Woodville	Whitehouse (TEX 117118); Lundell and Lundell (TEX-LL 11282); Lundell and Lundell (TEX-LL 11126); Lundell and Lundell (SMU 11126);	**Natural population.** This site is the type locality for the species. Plants were both in flower and in fruit. Due to vague location information, site has not been revisited.	H	

						Lundell and Lundell (SMU 11282); Lundell and Lundell (TEX 11126); Lundell and Lundell (TEX-LL 11122, 11125, 111284); Lundell and Lundell (TEX 11125)			
	2	Lundell and Lundell; 1942		Tyler	about 5-6 miles north of Warren	Lundell and Lundell (TEX-LL 11280, 11278); Lundell and Lundell (SMU 11278)	**Natural population.** Site first observed in 1942. Plants were both in flower and fruit. Due to vague location information, site has not been revisited.	H	
	6	1987	2004	Tyler	Farm-to-Market 1013 east from Turkey Creek, located north of this site		**Natural population.** Site first observed in 1987. Land was cleared, plowed, and planted to a bahiagrass pasture. On March 29, 2004, surveys found two subpopulations with six plants (J. Singhurst pers. comm. 2006).	H?	
	20		1993	Tyler	Located at 1503 Pope Mill Road, Woodville, Texas.		**Natural population.** Site was not surveyed by TPWD in 1993.	H?	private
	26	Ajilvsgi; 1980	1980	Tyler	Old Hwy 69, south of new highway, west of Woodville, along roadside	Ajilvsgi (SMU 7339)	**Natural population.** When first observed in 1980, Ajilvsgi noted that plants were in flower, but there were 'few' plants.	H?	
	25	Ajilvsgi; 1980	1980	Tyler	West of Woodville, west on Hwy 190 to road with ball fields; south on Hwy 190		**Natural population.** In 1980, there were 'several' clumps of plants in flower.	H?	
	24	Parker		Tyler	from Hwy 69 and Hwy 190, go SW then south on improved road		**Natural population.** There is no information on abundance or population status to date. The site has not been revisited due to the vague locality information and lack of EO data.	H	

	8	Ajilvsgi; 1980	1980	Tyler	south side of East-West road, west of Woodville	Ajilvsgi (SMU 7340)	**Natural population.** In 1980, there were three plants in flower, all very small and two in bloom. Location information too vague to relocate again.	H	
	18	Davis; 1970		Tyler	town of Spurger	Davis (LAMU none)	**Natural population.** Location information for the site is vague. Therefore, revisiting the site has not been possible.	H	
5	9	Ledbetter; 1997	Smith, Buckingham, Miller; 2018	Tyler	Champion International Land (now RMS); east of Beech Magnolia Road; about 4.4 air miles west of junction of US Rt 287 and SR 256.		**Natural population.** On April 2, 1997, one clump of phlox discovered during a tour of "special areas" (Carr 1997). Plants were in flower, with about 426 blooms, with rare white corollas. One area was about 5 x 4 ft. in size (TXNDD 2018; J. Singhurst EO updates, in July 13, 2006 meeting notes). On March 22, 2018, the USFWS met on site with new RMS (was Champion) biologist, Jennifer Smith and colleague Mike Hamilton, and with USFWS. Site was burned in early March 2018 with anticipation that plant would re-sprout. Only had one single plant that appeared dead (no color) (Miller 2018). RMS has visited the site every 2 weeks after burn to monitor the phlox, but blooming and re-sprouting was not observed. RMS provided photos of plant post-burn (J. Smith, pers. comm. 2018).	E	Private
6		Multiple parties; 2007	USFWS, TxDOT, Hancock; 2018	Tyler	Hancock Forest Management property		**Introduced:** On December 19, 2007, 125 plants were planted onto private lands in five separate plots (USFWS 2009; L. Jameson, pers. comm. 2007). Data collected in 2008 and 2009 found three plants and 20 plants respectively. Overall, each plot exhibited a decline in survival rates, with lowest survival rate of 76 percent was in Plot 1 (WH-01). All five plots were burned in 2009, 2011, 2012, 2014, 2016, and 2018 (Miller 2018). J. Singhurst (TPWD) visited the site in 2017; he recommended clearing out the canopy to allow more light. Site most recently visited during March 2018 field surveys. Survey plot data for the five plots includes four flowers at plot 1; no plants at plot 2; about seven plants at plot 3; only two plants at plot 4; and, one plant observed at plot 5. Plants at plot 5 showed ant activity. On May 7, 2018, Hancock conducted a prescribed burn to clear out vegetation (R. Bounds, pers. comm. 2018a). Hancock surveyed the burned plots 2-weeks post-burn and found 98 of the 100 original stakes within the plots. However, there appeared to be fewer phlox plants than pre-burn conditions from March. With precipitation and time, phlox is likely to bloom after burns (W. Ledbetter, pers. comm. 2018a). Site surveyed in June 2018 post-burn (R. Bounds, pers. comm. 2018b-f).	E	Private
	27**	Singhurst and Ledbetter; 1994	2004?	Hardin	North of Hwy 327 along residential street adjacent to small patch of upland forest		**Natural population.** Site occurs in Hardin County, north of Hwy 327 along residential street adjacent to small patch of sandhill forest (J. Singhurst pers. comm. 2006). W. Ledbetter and J. Singhurst first observed the site on March 7, 1994, where they found two plants (J. Singhurst pers. comm. 2006). Singhurst revisited the site on April 2, 2004, but did not find plants (J. Singhurst pers. comm. 2006). To date, this site is not included in the EO records (TXNDD 2018).	U	

	28**	Singhurst; 2004		Hardin	east of TNC Roy E. Larsen Sandyland Sanctuary on Compartment 1191.		**Natural population.** Site occurs east of TNC Preserve on easement property in Compartment 1191. Singhurst first observed eight plants at this site on April 2, 2004 (J. Singhurst pers. comm. 2006). To date, this site is not included in the EO records (TXNDD 2018).	U	
	29** (was part of 13)	Singhurst; 2004		Hardin	Southeast of lower end of Turkey Creek Unit on BTNP; occurs on Temple-Inland Compartment 0192		**Natural population.** This EO used to be part of the EO 13, but is considered a separate, distinct record. J. Singhurst counted a total of five plants on April 2, 2004 (done in lead with consultant and seismic activity) (pers. comm. 2006). In Spring 2005, the site was surveyed by W. Ledbetter and B. Boensch where they found seven plants (there were previously 6 known) (J. Singhurst pers. comm. 2006).		
		Ledbetter; 2006		Polk	Alabama-Coushatta Indian Reservation		In mid-March 2006, potential habitat was surveyed over sandy uplands and highway frontage on Hwy 190 – no phlox were found (W. Ledbetter, pers. comm. 2006b). Through collaboration with Alabama-Coushatta tribe, USFWS, TPWD, Mercer (growing out plants), and other partners, it was determined in November 2006 that of 100 plants grown at SFA, 50 would go to Tribal lands. Brian Sewell (USFWS Tribal Liaison) would check with J. Singhurst about a location. K. Nemec would draft an Agreement with USFWS and Tribe (W. Ledbetter, pers. comm. 2006d).		Federal
7				Hardin	Big Thicket National Preserve, Turkey Creek (TC) Unit		**Introduced.** Test plantings were initiated in October and December 1995. Formal plantings occurred in Feb and Dec 2001. Re-planting occurred at some of these plots in April 2007. In this Unit, 5 plots (TC 1-5) were established within a single site located near a utility line ROW and the Sandhill Loop Trail (NPS 2015). Experimental irrigation treatments were attempted at the TC Unit plots in 2002 in response to visible drought stress. Plots were monitored by BTNP staff. For TC Units 1-5, these were monitored up to 3 times in the first summer of planting. TC Units experienced almost complete mortality within 2 years after planting (in 2004). Replanting was followed by lower mortality, though survival ranged 10-50% after three yrs. Between 1-2 plants survived between 2005 and 2015 (USPS 2015, p. 5). Mortality was higher in first few years after planting then declined over time. TC units had minimal impact from the 2011 drought. TC might not have been as successful as BS units because they occurred on well-drained, coarse sands that are prone to drought conditions and sparser canopy cover (2015, p. 6). BTNP staff provided plot by plot data including counts form all five plots from 2001 to present (A. Bennett, pers. comm. 2018). All units were burned in 2016.	E	Federal

** Denotes EO records that have been noted in the species files but have not yet been incorporated into the official TXNDD record by TPWD for this species.

Herbarium Key:
LAMU – Lamar University
SMU – Southern Methodist University
TAES – S. M. Tracy Herbarium, Texas A&M University, College Station, Texas
TEX – University of Texas Herbarium, Austin, Texas
TEX-LL – Lundell Herbarium, University of Texas, Austin, Texas

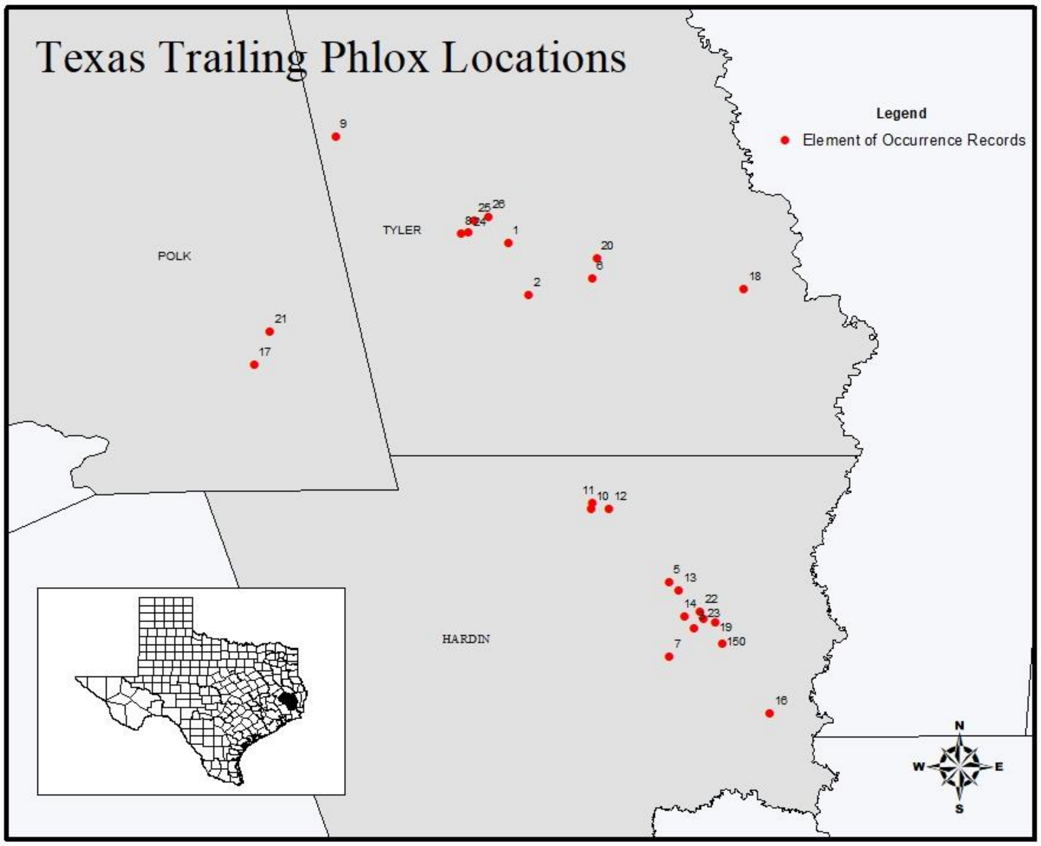


Figure 2.2.1. Geographic Distribution of Texas trailing phlox Element of Occurrence records within Hardin, Tyler, and Polk counties, Texas.

2.3 Population Genetics

Below is a summary of the genetics information we have for the Genus Phlox (2.3.1.) and the Texas trailing phlox (2.3.2.).

The Genetics of the Genus Phlox

The Genus *Phlox* is largely diploid (Anderson and Gage 1952, p. 399) with very few cases of polyploidy (Wherry 1955). Apomixis and chromosome interchange seem to be absent or rare (Wherry 1955). Basal studies of several members of *Phlox* by Flory and Meyer show that members of *Phlox* have a basal chromosome number of seven (Wherry 1955).

Texas trailing phlox is a member of the Eastern mat forming phlox species. Eastern members of *Phlox* have been the focus of many evolutionary studies, due to their variability of hybridization (Ferguson and Jansen 2002, p. 1324) and all are described as such based on their easterly location in North America. Some species undergo natural hybridization while others do not (Wherry 1955, Levin and Smith 1966, Levin 1967, Ferguson *et al.* 1999, Levin 1966; in

Ferguson and Jansen, 2002, p. 1324). It is very rare to encounter a herbarium specimen that appears to be a hybrid plant; active field work searching for a hybrid zone yields few such areas. However, various species of *Phlox* are reported to hybridize freely in gardens (Anderson and Gage 1952). The occasional hybridization that does occur suggests that there has been ample opportunity for gene exchange among some of these eastern *Phlox* species. It is noteworthy that hybridization can potentially have a variety of effects on phylogenetic relationships (Ferguson and Jansen 2002, p. 1333). Continuing to address the question of evolutionary processes in *Phlox*, developed microsatellite markers which were later used as the basis for the current markers (with slight modification) (Fehlberg *et al.* 2008). Ferguson and Jansen (2002) identified a chloroplast (cp) DNA restriction site phylogeny for eastern *Phlox* species. This internal transcribed spacer (ITS) study allowed direct comparison with the ITS phylogeny, identifying a need to investigate the evolutionary processes active in *Phlox*.

The Genetics of the Species and Subspecies

Chromosomes of *Phlox* are relatively large and few in number (Meyer 1943, p. 199). The chromosome number of *P. nivalis* and its varieties are 14 (the 2N number) (diploid), with some fragments (Meyer 1943, pp. 200, 209). The average length of chromosomes for *P. nivalis* is between 10-15.4 centimorgan, and the species has little variation in chromosome size (Meyer 1943, pp. 203, 205). Chromosomes of *P. nivalis* and *P. subulata* are very similar; other species have quite different length ratios (Meyer 1943, p. 216).

To date, the genetic variation among populations and within each population of Texas trailing phlox has not been investigated. Texas trailing phlox is one of two subspecies recognized in *P. nivalis* (ssp. *nivalis* and ssp. *texensis*). Currently, the nearest known population of ssp. *nivalis* in relationship to ssp. *texensis* more than 1,000 km (600 mi) east in northern Florida (USFWS 1995, p. 3). Based on this separation distance, it is unlikely that these two sites exchange gene flow and are, therefore, not likely to be genetically related.

Efforts began in 2006 to investigate the genetics of Texas trailing phlox, although they have not been completed. Researchers from academia collected tissue samples from naturally occurring populations in 2006 at the following sites: two collections of 24 plants at Sandylands (old dump ground and road); 3-4 plants on the Temple-Inland easement (now Campbell Easement); and, five plants along Farm-to-Market (FM) 1276 (BTNP land) (W. Ledbetter, pers. comm. 2006d). USFWS records indicate that research continued to identify key DNA markers to distinguish between natural and propagated plants, however efforts were eventually halted after a lack of funding. The use of microsatellite markers is a useful tool to identify whether the populations in Texas and Louisiana are the same or different, and could be used to improve the reintroduction of the species (W. Ledbetter, pers. comm. 2005).

For the purpose of this report, we define viability as the ability of the species to sustain populations in the wild over time. Species with greater numbers (redundancy) of healthy populations (resiliency), encompassing a broad array of ecological and genetic diversity in a spatial arrangement that maintains adequate gene flow (representation), are more likely to be viable. Using the SSA framework, we describe the species' viability by characterizing the status of the species in terms of its resiliency, redundancy, and representation.

CHAPTER 3 – Resource Needs of Population

3.1 Population Resiliency

For the Texas trailing phlox to maintain viability, its populations or some portion thereof must be resilient to stochastic factors such as drought, fires with extreme temperature or duration, and freeze events that have the potential to affect populations. We measure the population resiliency by examining the known demographic factors. Abundance (number of plants), the germination rate, mortality rate, percent of flowering/nonflowering individuals, and seed set are the mechanisms that could most affect the Texas trailing phlox viability at a population level. Abundance is considered the most reliable and prominent measure of Texas trailing phlox viability due to the available literature and data; therefore, this factor is carried through the population resiliency assessment. Resource needs directly influence the demographic factors. Extremes above or below the standard level of a resource need could affect the overall growth, reproduction, or habitat (resource function) of the Texas trailing phlox. Resource needs that the individual Texas trailing phlox requires to complete normal resource functions (i.e. reproduction, growth, and survival) were identified. The seven key resource needs of the species includes annual precipitation, undisturbed soils, optimal canopy structure, optimal climate, deep sandy soils, slope, and pollinators (Figure 3.1). Compounding factors that influence the resiliency of Texas trailing phlox populations include the ecological integrity of the plant community; population size and diversity; connectivity of populations; effects from stressors (i.e. development, oil/gas, silviculture, etc.), and the presence of healthy pollinators. We assumed that all populations of Texas trailing phlox interact similarly, that there are no differences in habitat or resource needs for any of the natural populations. Therefore, our Core Conceptual Model can be extrapolated to all extant populations.

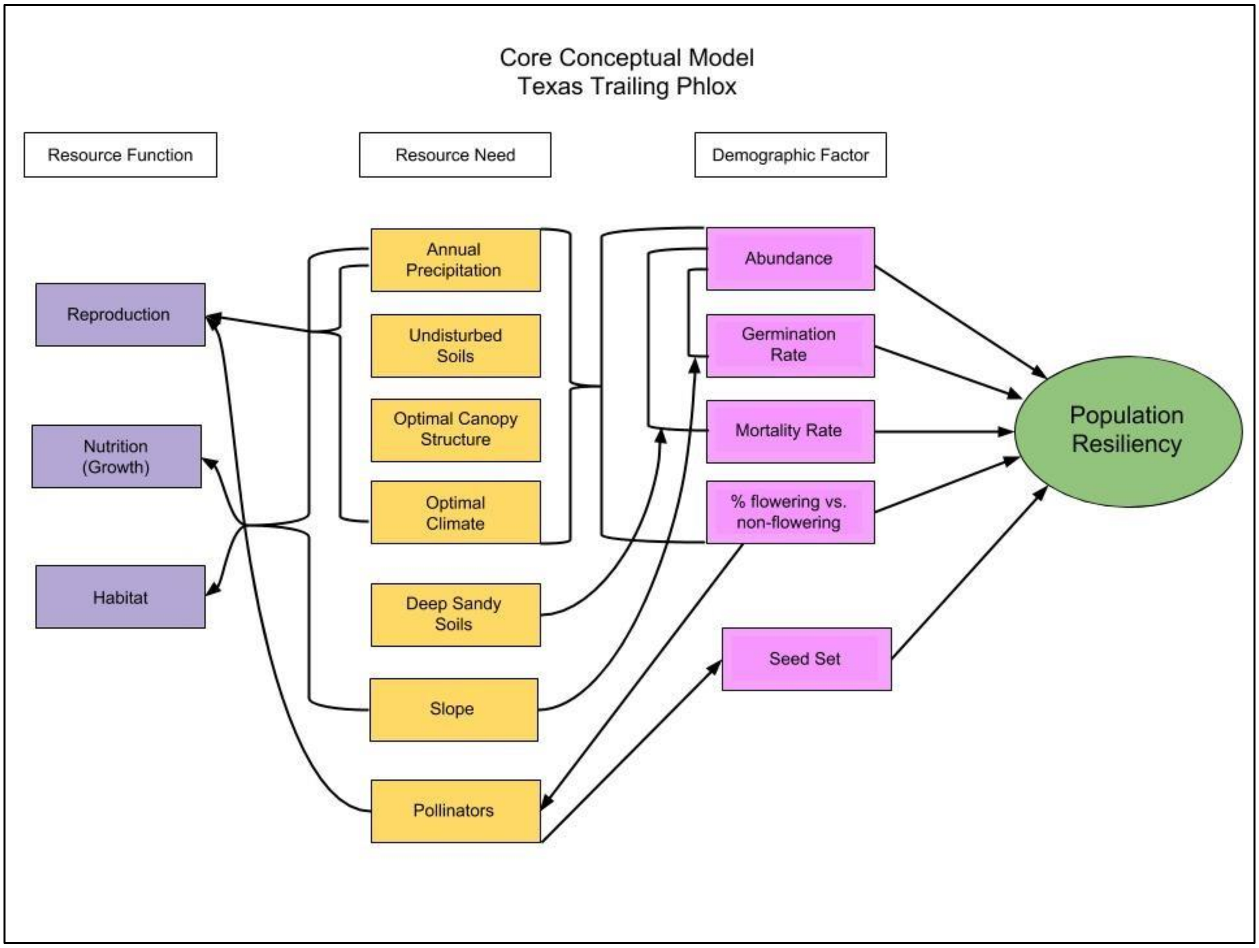


Figure 3.1. Population Level Resources that influence viability for Texas trailing phlox.

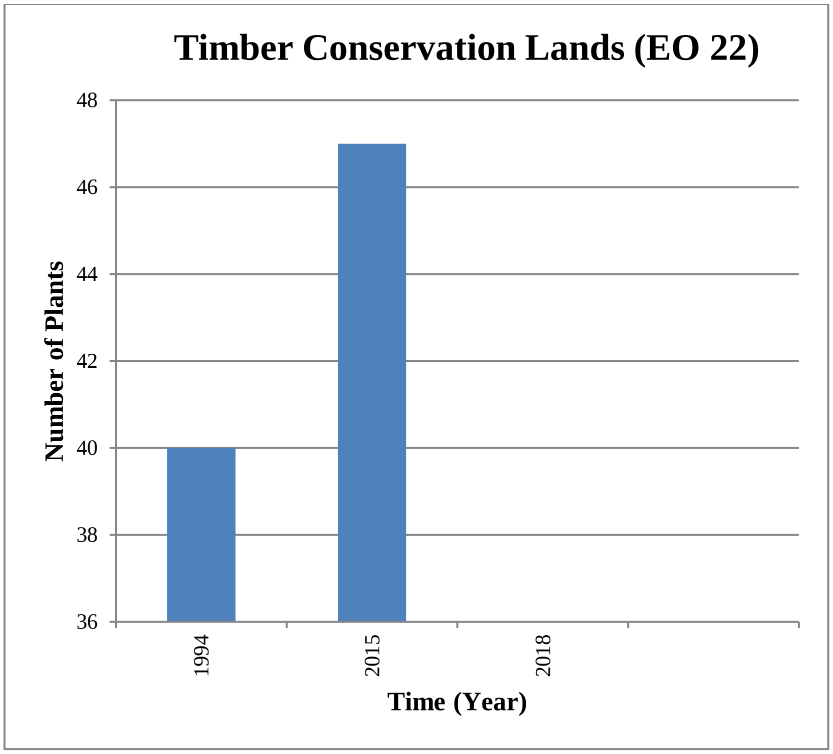
3.1.1 Population Factors

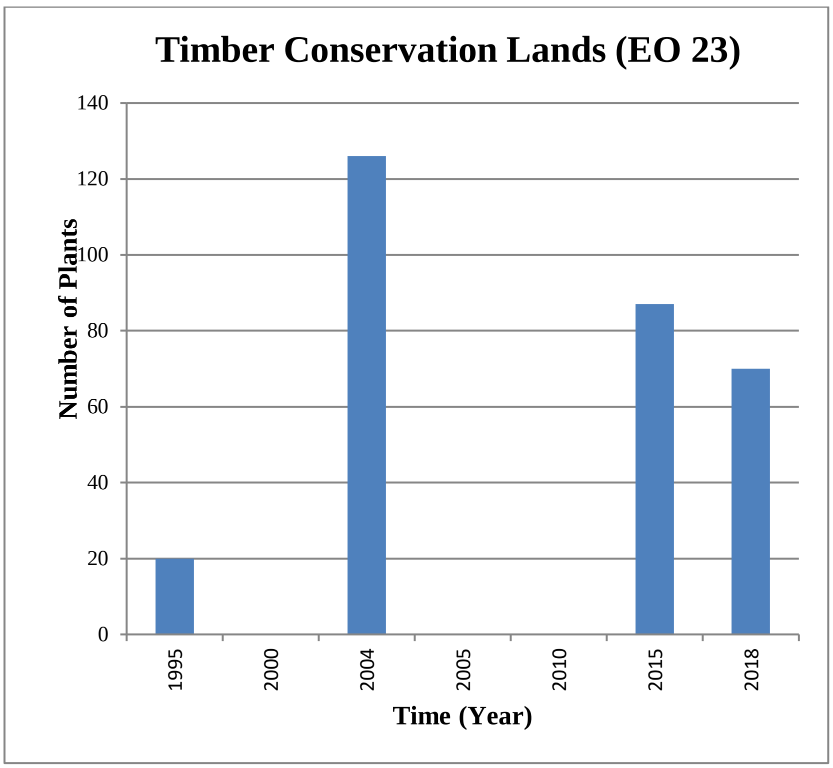
Abundance or Number of Individuals: Estimating a Minimum Viable Population (MVP) size is one approach for determining abundance (which can be used for recovery purposes). A conventional MVP, as outlined in Pavlik's guidelines (1996, p. 137), uses the biological and demographical information known about a species to estimate a MVP size (or individual and population numbers) in order to prevent extinction. A conventional MVP has not been calculated for Texas trailing phlox as we do not possess the entirety of the baseline data needed to perform these calculations. However, Table 3.1.1 was derived using adaptations of Pavlik's 1996 guidelines in order to calculate the MVP for this species. This MVP will serve as the basis for population abundance until there is sufficient data to conduct a population viability analysis (PVA) and estimate an actual MVP size. Each characteristic (i.e. longevity, breeding system, etc.) appears in the first column; Texas trailing phlox life history characteristics are closely related to information in column A or column B or somewhere in the midst of the continuum between A and B. A trait in column A would have MVPs near 50 individuals; species with traits in Column B would have MVPs upwards of 2,500 individuals. The **bold** letters in Tables 3.1.1 indicate the life history characteristic chosen for the species and where if falls in the table. For characteristics where we lack information on the species, the species received an intermediate value. Poole *et al*. (2000, pp. 63-66) determined applicable characteristics for this species and estimated MVP values (listed in parenthesis). The current MVP states that each population of Texas trailing phlox needs about 600 reproductive individuals (Poole *et al.* 2000, pp. 63-66). As new biological information becomes available, the MVP should be reviewed and updated.

Table 3.1.1. Minimum Viable Population estimate for Texas trailing phlox (Poole *et al.* 2000, pp. 63-66). Characteristics in bold are specific to the Texas trailing phlox.

	Minimum Viable Population (MVP)		
Characteristic	50 individuals	500 individuals	2,500 individuals
longevity	**Perennial (250)**		Annual
breeding system	Selfing	**X (500)**	Outcrossing
growth form	Woody		**Herbaceous (2,500)**
fecundity	High	**X (500)**	Low
ramet production	**Common (50)**		Rare or none
survivorship	High	**X (500)**	Low
seed duration	Long	**X (500)**	Short
environmental variation	Low	**X (500)**	High
successional status	**Climax (250)**		Seral or ruderal

Estimating population size for Texas trailing phlox is difficult. There is a lack consistent population counts across the species range given the difficulty in visibly distinguishing separate plants from one another (except through measuring separation distance); the lack of genetics work to understand the relatedness of plants within and between populations; and, the difficulty of identifying this small plant within its habitat. However, we have estimated the plant abundance over time for each of the following extant sites, where possible: Sandylands and surrounding areas (Figures 3.1.1, 3.1.2, 3.1.3); BTNP (Figures 3.1.4, 3.1.5, 3.1.6, 3.1.7); and, RMS (Figure 3.1.8).





Figures 3.1.1 and 3.1.2. Plant Abundance Records at timber conservation lands' sites (EO 22 and 23) in Hardin County, Texas.

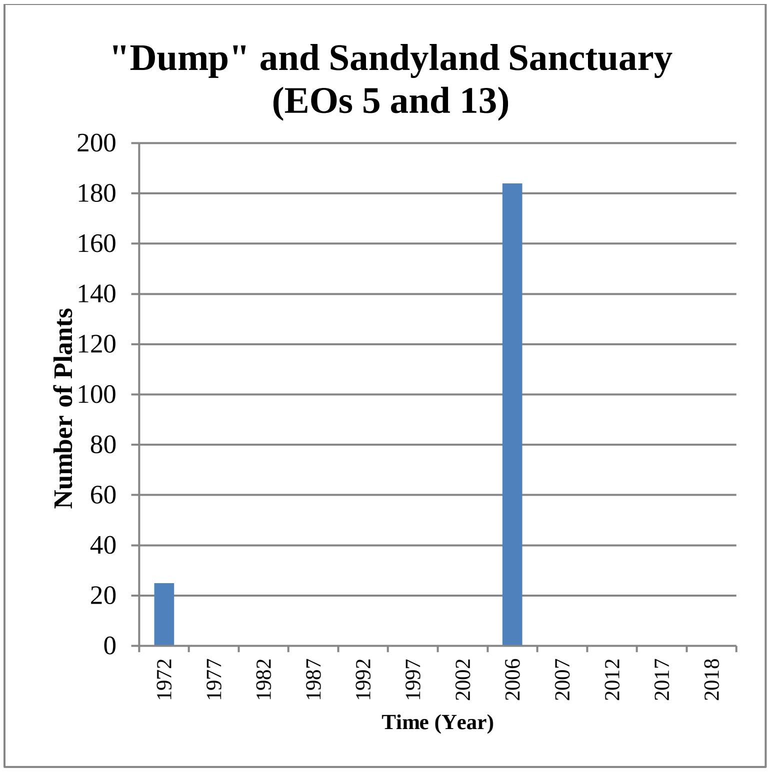


Figure 3.1.3. Plant Abundance Records for EO 5 (includes EO 13) on Sandylands, Hardin County, Texas

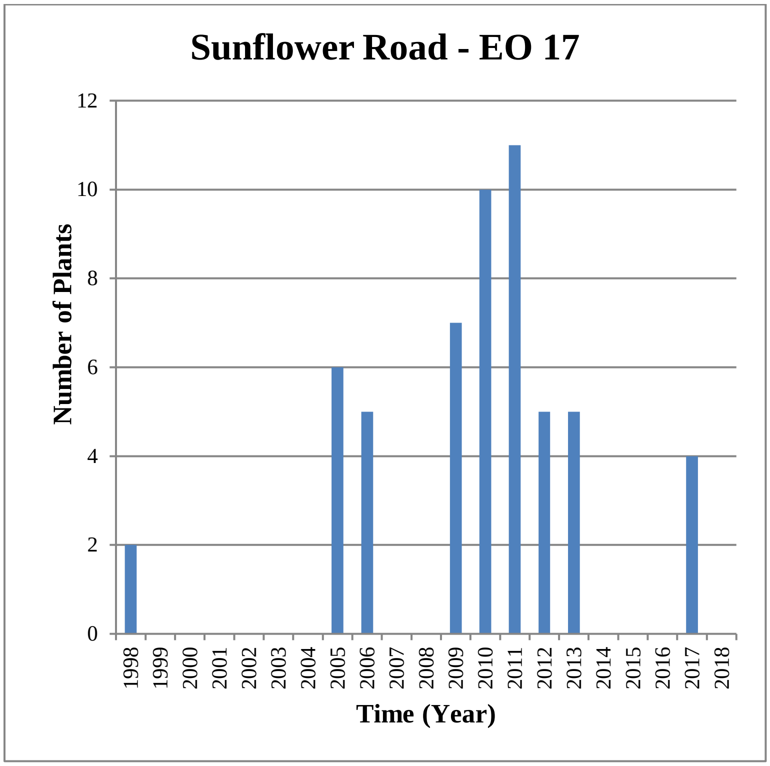


Figure 3.1.4. Plant Abundance Records for EO 17 along Sunflower Road, Hardin County, Texas.

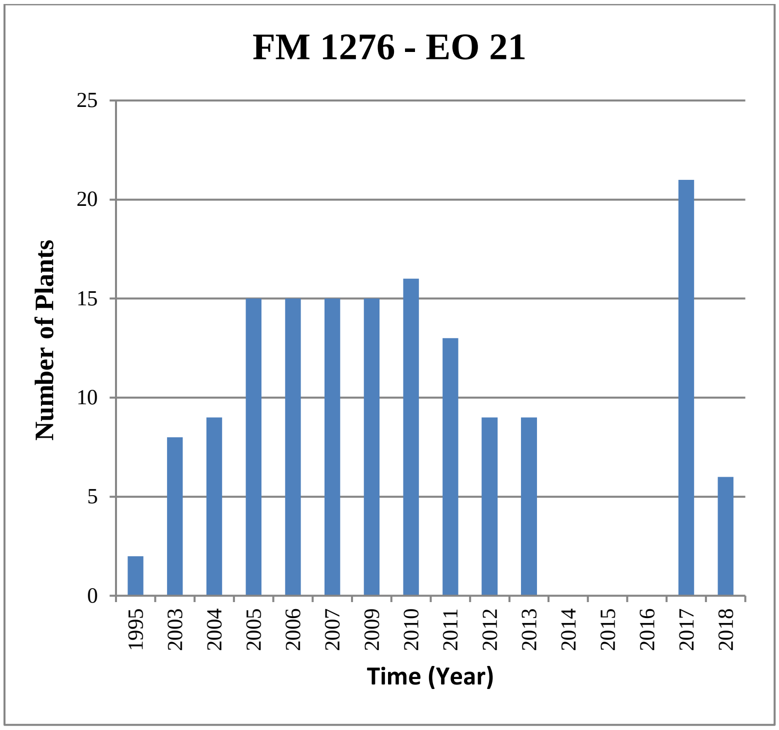


Figure 3.1.5. Plant Abundance Records for EO 21 along FM 1276, Hardin County, Texas.

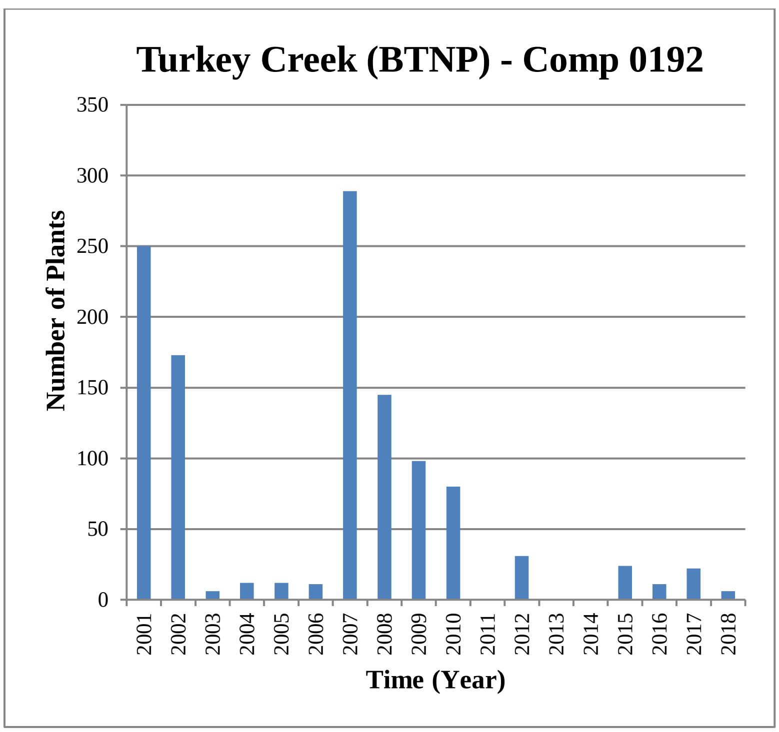


Figure 3.1.6. Plant Abundance Records for Turkey Creek (TC) Unit introduction, BTNP, Hardin County, Texas. An additional 98 plants supplemented the plots in 2007, causing the increase in overall abundance.

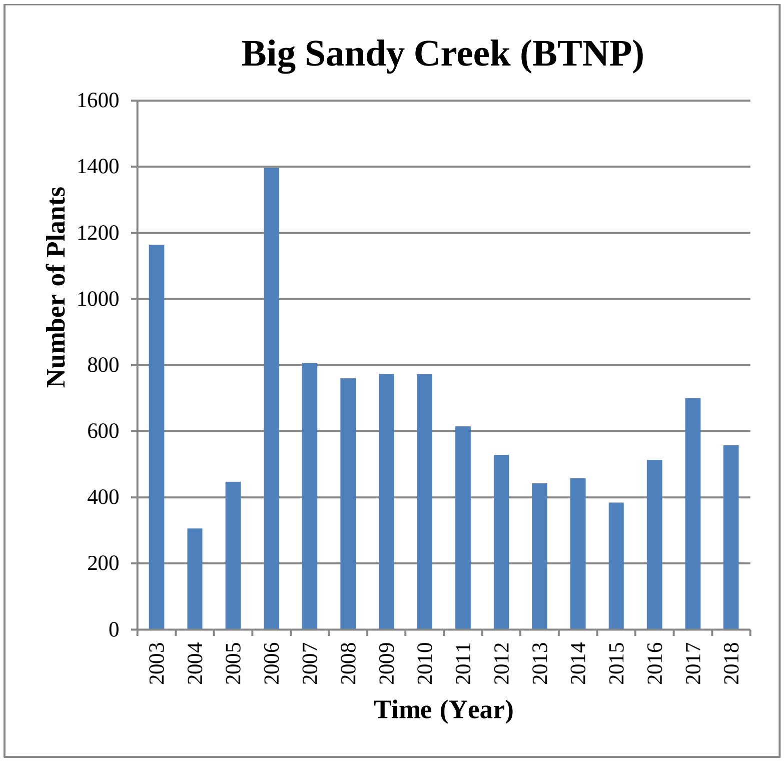


Figure 3.1.7. Plant Abundance Records for Big Sandy Creek (BS) Unit introduction, BTNP, Hardin County, Texas. The plots were supplemented with plants in 2003, 2005, and 2006 with 875, 100, and 597 plants, respectively. These supplementations can attributed to the overall increase in plant abundance.

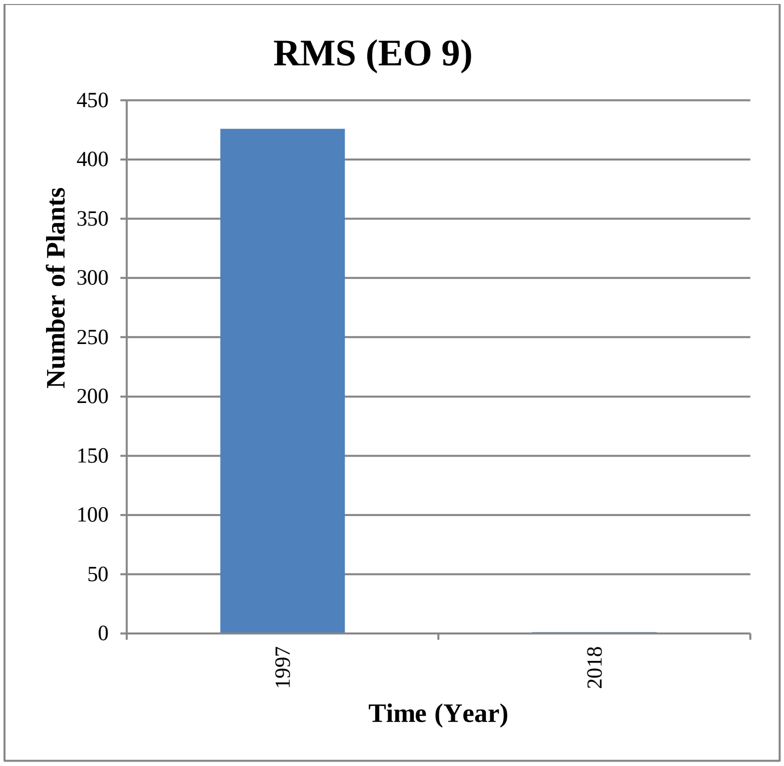


Figure 3.1.8. Plant abundance records for EO #9, RMS site, Tyler County, Texas.

Population Size: Effects to a species' reproductive biology can reduce its' overall population size. Effects from habitat fragmentation are the primary source of these impacts to the reproductive biology of any species (Yates and Ladd 2005), reducing species richness and genetic variability (Vargas *et al.* 2006). For plants, a reduction in the genetic variability affects pollen quality and seed production (Aspinwall and Christian 1992, Vargas *et al.* 2006), which in turn reduces the potential germination rate. As populations become more isolated their fitness lowers and germination rates continue to decline. Because of this effect, population sizes decreases (Frankham 2005, Young *et al.* 1996). There are also genetic concerns with small populations, including reduced availability of compatible mates, genetic drift, and inbreeding depression (Ellstrand and Elam 1993). Small populations of Texas trailing phlox have low resilience, leaving them particularly vulnerable to stochastic events. The influence of stochastic variation in demographic (reproductive and mortality) rates is much higher for small populations than large ones. Stochastic variation in demographic rates causes small populations to fluctuate randomly in size. In general, the smaller the population, the greater the probability that fluctuations will lead to extirpation. Information on the Texas trailing phlox germination and/or mortality rate is lacking. Therefore, since these two characteristics are so closely linked to the population size and this data has been collected, we use the numbers of individuals at each site for the effective population size (i.e. MVP). Population size has not been recorded at all sites, nor during all search efforts.

Population Connectivity: The population connectivity of any species is the degree to which the landscape facilitates or impedes movement among resource patches (Taylor *et al.* 1993). Habitat fragmentation is the primary impacting agent of connectivity, reducing the reproductive biology of a species (Yates and Ladd 2005), species richness, as well as its genetic variability (Vargas *et* *al.* 2006). Populations that are closer together geographically and within pollinator foraging distances are likely to attract more pollinators and have an increase in these pollination services (i.e. seed production, flowering plants). These populations also provide the necessary breeding and foraging resources for the pollinators. Exchange of genetic material is more feasible with connected populations. We anticipate that populations exchange gene flow either through stochastic events such as extreme flooding or rain occurrences, and/or through pollinators. Based on the seed dispersal habits of other perennial *Phlox* species and what we know of the short distance of seed dehiscence of Texas trailing phlox, stochastic events are the plausible mechanism for longer distance dispersal and exchange of genetic material. We speculate that historically more populations occurred on the landscape, connecting the existing extant populations, but with habitat alteration and modification, suitable habitat has been depleted or the plant has been directly affected. There are herbarium records of Texas trailing phlox that could indicate connectivity between extant sites in the past, however since most location information is vague, it has proven difficult to relocate these records. However, genetic studies have not been conducted, so we are unable to support this theory. We do not have any measures of flowering/non flowering plants, the seed set, or have an understanding of the known pollinators (and thus their foraging distances) at this time; therefore, the distance between populations is being used as a measure of population connectivity.

3.2 Habitat Elements

Texas trailing phlox is found in deep sandy, undisturbed soils, with minimal slope. Optimal habitat includes canopy structure and duff/litter layer that does not shade out trailing phlox (Figure 3.2.1). This habitat was historically maintained by natural fires often occurring from lightning strikes. Today the use of prescribed burning, chemical control (herbicides), and selective thinning are tools to maintain these habitat features.

Land ownership also influences the population resiliency. Federal and state owned lands provide security to plants through regulations that can include Section 7 and Section 10a(1)(A) of the Endangered Species Act (ESA), US Army Corps of Engineers 404 permitting, and state laws. Populations on private lands are typically less secure in terms of resiliency; however, in the case of Texas trailing phlox, several private land owners have chosen to collaborate with the Service to manage and monitor the species long-term.

Precipitation: One of the distinguishing features of the Pineywoods ecoregion is the average annual rainfall, which ranges between 48 – 60 in (121.9 – 152.4 cm) of rain per year (Diggs *et al.* 2006). The Pineywoods is one of the wettest ecoregions in Texas. The Gulf of Mexico is the predominant geographical feature affecting the state's climate, moderating seasonal temperatures along the Gulf Coast and, more importantly, providing the major source of precipitation for most of the state (Texas Water Development Board (TWDB,) 2012, Larkin and Bomar 1983). There are two pronounced rainy seasons in the spring and fall in East Texas. Both rainy seasons are impacted by polar fronts interacting with moist Gulf air, with the fall rainy season also impacted by hurricanes and tropical storms (TWDB 2017, p. 148). Hurricanes Rita (2005), Ike (2008), and Harvey (2017) have all impacted this area. Resident species must be able to withstand and/or rebound from the high winds, heavy rainfall, saturated soils, and flooding that accompany these storms.

Undisturbed Soils: In order to retain the seed bank and avoid direct mortality of Texas trailing phlox, the species needs undisturbed soils. Disturbance activities, such as digging, plowing, and disking up the soil could harm the individual plant and/or seed bank. Reports suggest that Texas trailing phlox is found in areas of previous disturbance (Dixie Environmental Services Company (DESCO) 2004), however their occurrence in these areas is likely a function of the increased light availability atop appropriate soils, rather than the species ability to withstand direct effects from disturbance.

Optimal Canopy Structure: In an effort to understand the effect of various management regimes on Texas trailing phlox, Maxey and Warnock (1996, p. 4) investigated how management practices could best be used to ensure survival. They determined that ideal vegetation characteristics for Texas trailing phlox are an open canopy (5-25 percent) of pines; less than 40 percent coverage of subcanopy trees (pines and hardwoods); and less than 40 percent coverage of shrubs (Maxey and Warnock 1996, p. 8; Schwelling *et al.* 2000). Suitable Texas trailing phlox habitat consists of herbaceous cover greater than 50 percent, with 30 percent composed of native grasses (Figure 3.2.1).

Depth of leaf litter (or duff) is very important factor in resiliency. In areas where the Texas trailing phlox grows the litter depth is generally 3-5 cm (1.2-2.0 in) deep, with coverage between 75-100 percent. Most litter is dominated by pine needles due to their association with pine canopy. The type of litter (pine, hardwood, grass) is not as critical as depth or degree of compaction. For the growth and function of the Texas trailing phlox, the litter must either be thin (sparse) or not compacted (USFWS 1995, p. 7). As little as 2.5 cm (1.0 in) of pure, densely compacted pine needle litter can severely limit the growth of Texas trailing phlox (USFWS 1995, p. 8).

Characteristic	Poor	Tolerated	Optimal
Overstory Coverage	>80 percent	25-80 percent	5-25 percent
Understory Coverage	not given	not given	25-70 percent
Shrub Layer Coverage	80-90 percent	25-40 percent	10-25 percent
Groundcover Coverage	not given	not given	25-70 percent
Slope	not given	not given	<5 percent
Soils	Deep sands	Deep sands	Deep sands
Elevation	not given	not given	9-75 m
Topography	not given	not given	Approximate level
Timing since last burn	>5 years	4-5 years	0-4 years

Figure 3.2.1. Optimal habitat conditions through management to ensure survival of Texas trailing phlox (Maxey and Warnock 1996).

Optimal Climate: Optimal climate conditions are wet and generally frost free. The frost and snow events are rare in the Pineywoods Ecoregion, with the number of frost free days averaging between 241 – 246 per year (Mahler 1980). Hardiness zones in the known range of Texas trailing phlox include Zone 9a (plants that can withstand freezing temperatures between 20-25 °F) for areas near Kountze and Silsbee and Zone 8b (plants that can withstand freezing temperatures between 15-20 °F) covering areas near Spurger, Dallardsville, and Woodville (U.S. Department of Agriculture (USDA) 2018a). Hardiness zones are the standard by which gardeners and growers can determine which plants are most likely to thrive at a location. These zones are based on the average annual extreme minimum temperature during a 30-year period in the past, not the lowest temperature that has ever occurred in the past or might occur in the future (USDA 2018b).

Deep, Sandy Soils: Texas trailing phlox is best supported by soils with a sandy surface, coupled with moisture bearing clays, or sandy clays at depths of 0.8-2.0 m (2.62 – 6.56 ft.) (Maxey and Warnock 1996, p. 8; Poole *et al.* 2007, pp. 374-375; and Bogler 1992). The USFWS described a similar soil depth range of 0.5-2.0 m (1.64 -6.56 ft.) in the Recovery Plan (USFWS 1995, p. 6). Such sites are often on the sandy (drier and usually upslope) side of transitions between sandy soils supporting pine species (dominated by *Pinus palustris* P. Mill.) savanna and clay or sandy clay soils supporting a mixed forest of hardwoods and pines (usually *P. taeda* L.). Texas trailing phlox occurs on surface sands, therefore the presence of subsurface clays or impermeable sandy layers are not always apparent. These sites that support Texas trailing phlox are often associated with the presence of hardwood species, including *Carya texana*, *Quercus falcata* (Maxey and Warnock 1996, p. 8), and *Q. incana*. Since Texas trailing phlox is linked only to these specific soil characteristics (i.e. soils that do not change), it will not naturally be present nor persist (in the case of ex-situ conservation) in habitats without these soils.

Slope: Texas trailing phlox requires slopes of less than 5 percent (Corlies and Warnock 1992; USFWS 1995, p. 7; Maxey and Warnock 1996, p. 8). Aspect of slope is not critical factor in the occurrence of Texas trailing phlox. Elevation within suitable habitat ranges from 9-75 m (30-240 ft.) and topography is level (USFWS 1995, p. 6; Maxey and Warnock 1996, p. 8). Slope influences the germination rate and overall presence/absence of Texas trailing phlox at a site.

Pollinators: Based on the floral structure of the Texas trailing phlox, long-tongued pollinators (Lepidopterans) are likely pollinators. The Nessus sphinx moth and Eastern Tiger swallowtail have been observed visiting these plants (G. Grant pers. comm. 2014, 2017; Neff pers. comm. 2008). Flies and bees (Parker and Warnock 1993), as well as some large terrestrial arthropods may also be trailing phlox pollinators (Poole *et al.* 2000). The percent of flowering versus non-flowering plants influences the function of pollination, while pollinators influence the overall seed set.

CHAPTER 4 – Current Conditions

4.1 Population Resiliency

Population resilience for the Texas trailing phlox was derived from two demographic factors (population size and population connectivity or distance) and three habitat factors (forest canopy openness and structure, undisturbed soils, and annual precipitation). To rank these five factors, we described conditions that were assumed to contribute to “low”, “moderate”, or “high” levels of population resilience and provided each with a quantified rank of “1”, “2”, or “3”, respectively (Table 4.1.1).

Some population level resources displayed in Figure 3.1 were not factored into the resiliency rankings. These habitat features (deep sandy soils, slope, and pollinators) were recorded as either present or absent, thus directly influencing whether the plant would occupy the habitat. Empirical data are not available to establish criteria for ranking these factors. The criteria discussed below represent assumptions that should be tested and refined over time through monitoring and research.

Population Size: True population sizes for Texas trailing phlox are currently unknown. However, they have been ranked using qualitative estimates based on counts of individual stems or clusters of stems. The latter was used to indicate numbers of genetically distinct individuals and the MVP estimate (Poole *et al.* 2000). Since Poole *et al.* (2000) determined that a healthy population would need 600 mature individual plants, this metric was used as the measure of a healthy (high) ranking criteria for population size.

Population sizes are currently unknown. However, preliminary criteria for ranking population sizes are as follows:

- **Low:** ≤ 100 individuals (i.e., clusters)
- **Moderate:** 101-600 individuals
- **High:** ≥ 600 individuals

Given the difficulty in estimating true population size in the absence of genetic data, future consideration should be given to revising this criterion, possibly basing it on area occupied by Texas trailing phlox within each population. Future monitoring efforts should attempt to incorporate this measure for future assessments of the species' condition.

Population Connectivity: Texas trailing phlox populations have been delineated based on a combination of political boundaries (i.e. county boundaries) and distance between sites where the species is present on the landscape. Population connectivity is defined by the distance between two distinct populations, with each being separated by at least 2.0 km (1.24 m) (USFWS 1995).

Since population connectivity is closely related to the ability of pollinator visitation, we analyzed if pollinator foraging distances should be considered in this criteria. Although we have anecdotal evidence that suggests what species are potential pollinators for Texas trailing phlox, we do not know if these species are effective. Further, we cannot draw definitive conclusions about the needed foraging distances for these pollinators. However, the Texas trailing phlox is an outcrossing and having healthy populations of pollinators is essential to its reproduction.

We assume that healthy (high) ranking populations allow for genetic and pollinator connectivity within and between populations, and therefore populations that are within this 2.0 km range are ranked as healthy (high).

Preliminary criteria for ranking population connectivity are as follows:

• **Low:** population is separated from nearest population by a distance of > 5 km (3.11 mi); type and quality of habitat between these populations is reduced and lacks the native pine savanna habitat to facilitate pollinator usage and/or dispersal.
• **Moderate:** population is separated from nearest population by a distance of >2-5 km (1.24 - 3.11 mi) increasing population connectivity; intervening remnant pine savanna habitat present in landscape to facilitate pollinator usage and/or dispersal.
• **High:** population is separated by a distance of 2 km (1.24 mi); intervening remnant pine savanna habitat is present between populations and facilitates pollinator usage and/or dispersal.

Canopy Openness and Structure: Canopy structure and percent cover is adequate in sites where Texas trailing phlox populations are able to experience population growth. Sites should be associated with native plant community and common associates to a pine savanna habitat. The optimal canopy cover, litter, and slope are defined by Maxey and Warnock (1996) and therefore, we used this information to determine this ranking criteria.

Preliminary criteria for ranking canopy openness are as follows:

• **Low:** canopy overstory is >80 percent, shrub layer is 80-90 percent, litter depth is >8 cm; and/or prescribed burning activities occur every 5 years or more.
• **Moderate:** canopy overstory is between 26-80 percent, shrub layer is between 26-40 percent, litter depth is between 6-8 cm; and/or prescribed burning activities occur every 3 years.
• **High:** canopy overstory is between 5-25 percent, shrub layer is between 10-25 percent, litter depth is 3-5 cm, and/or prescribed burning activities occur every 1-2 years.

Undisturbed Soils: Texas trailing phlox relies directly on undisturbed soils for resiliency of species within the seedbank and as growing, mature plants. We assume that with soil disturbance, those seeds within that population's seedbank are not provided an opportunity to mature into reproductive plants. In turn, we also recognize that collection of seeds from mature plants reduces the seedbank. Using this basis, we defined soil disturbance by using the Center for Plant Conservation (CPC) seed collection guidelines to help define how much soil disturbance could occur without harming seed and plant viability. The CPC recommends that no more than 10 percent of a rare species' seed should be collected (Guerrant *et al.* 2004). Since we lack information regarding the species seedbank, we use the CPC guidelines to define the most extreme level of disturbance (low ranking).

Preliminary criteria for ranking undisturbed soils are as follows:

• **Low:** >10 percent of the occupied population with plants and seedbank is disturbed
• **Moderate:** some disturbance up to 10 percent of the occupied population with plants and seedbank is disturbed
• **High:** 0 percent of the occupied population with plants and seedbank is disturbed

Annual Precipitation: Texas trailing phlox tends to decline in years where the precipitation is lower than the average annual amounts. Lower precipitation values affect all life stages of the

Texas trailing phlox. Diggs *et al.* (2006) defines the average annual rainfall in the Big Thicket region as 48-60 in per year. Therefore, we use this metric to define the most optimal (high ranking) habitat conditions.

Preliminary criteria for ranking annual precipitation amounts are as follows:
- **Low:** ≤ the amount of rainfall during the 2011 drought (average annual rainfall of 3.058 in (National Oceanic and Atmospheric Administration 2018, p. 1 – precipitation data for Silsbee, Texas)
- **Moderate:** >3.058– 48 in of rain per year
- **High:** 48-60 in of rain per year

Table 4.1.1. Current population resilience for Texas trailing phlox based on two population factors and three habitat factors. Each factor was provided equal weight in our resiliency assessment.

Population Name (and EO #)	Population Size	Population Connectivity	Canopy Openness and Structure	Undisturbed Soils	Annual Precipitation	OVERALL AVERAGE
Sunflower Road (EO 17); BTNP, BS Creek (reintroduction)	Low - 1	Moderate - 2	Low - 1	Moderate - 2	High - 3	**Low** – 1.8
FM 1276 (EO 21)	Low - 1	High – 3	Low - 1	High - 3	High - 3	**Moderate** – 2.2
Timber Conservation Lands (EOs 22, 23)	Moderate - 2	High – 3	Moderate - 2	Moderate - 2	High - 3	**Moderate** – 2.4
Sandylands (EOs 3, 5, 13)	Moderate - 2	High – 3	Moderate - 2	Low - 1	High - 3	**Moderate** – 2.2
RMS (EO 9)	Low - 1	Moderate - 2	Moderate - 2	Low - 1	High - 3	**Low** – 1.8
Hancock (introduced)	Low - 1	Low – 1	Moderate - 2	High - 3	High - 3	**Moderate** - 2
BTNP, TC (reintroduced)	Low - 1	Moderate - 2	Low - 1	Moderate - 2	High - 3	**Low** – 1.8

4.2 Species Representation

Identifying and evaluating representative units or habitat that contribute to a species' adaptive potential are important components of assessing its' overall viability. This is because populations distributed throughout multiple representative units may buffer a species' response to environmental changes over time. Capturing and conserving the genetic variability among and between populations is important to preserve the evolutionary potential and ecological variation of a species (Taberlet *et al.* 2016, p. 1440). Species with a high level of heterozygosity have been repeatedly shown to confer resistance to environmental change (Hanski *et al.* 2006, Willi *et al.* 2006, Bonin *et al.* 2007). Model simulations suggest that species with low heterozygosity, but large ranges, will suffer a spatial redistribution of heterozygosity, depending on the level and length of the disturbance. Taxa with limited distributions with severe and frequent disturbance will suffer dramatic declines in heterozygosity, regardless of initial levels of heterozygosity (Davies *et al.* 2016). Genetic variability within most *Phlox* populations is high (C. Ferguson, pers. comm. 2018), however, genetic studies specific to the Texas trailing phlox have not been completed to verify the variability within and among its' populations. Further genetic analysis of Texas trailing phlox would be needed to determine to what extent, if any, the impact of range contraction contributes to the loss of the genetic variability. In the absence of definitive genetic information, it is often useful to use ecological diversity as a surrogate for genetic diversity. However, we assume that there is no ecological or niche diversity at any of the specific sites therefore, the representation of Texas trailing phlox is extremely low.

4.3 Species Redundancy

Redundancy refers to the risk that a large portion of the species' range will be negatively affected by a natural or anthropogenic, and potentially catastrophic, event at a given point in time. Species that have resilient populations spread throughout their historical range are less susceptible to extinction. The Texas trailing phlox is distributed throughout a 3-county geographic range in Texas. High redundancy for Texas trailing phlox is defined by an adequate number of resilient populations distributed across the 3-county range that provide the exchange of genetic material and foraging opportunities for pollinators. Due to the low or moderate resilience rankings of most populations, low number of extant populations, and restricted known geographic range of the species, we rank the overall redundancy of Texas trailing phlox as low.

CHAPTER 5 – Species Status and Influences on Viability

5.1 Stressors Influencing Viability

When the species was listed in 1995 as endangered, the known threats to Texas trailing phlox included low population numbers and a limited geographic distribution; lack of regulatory protections; loss of habitat; and, habitat disturbance. Habitat loss was attributed to housing development; land clearing and site preparation for silviculture; encroachment of a closed canopy due to fire suppression; herbicide exposure; and, industry construction (i.e. pipeline, powerline, railroad, and highway). Additional threats, including: off-road vehicle use, illegal dumping, burning of debris, and commercial take of plants, combined with existing stressors were listed as potential effects to continued loss of habitat (USFWS 1995, p. 10). The following list describes the factors affecting Texas trailing phlox. They are not listed in order of severity and are based on the best available scientific information. These sources and stressors should be routinely reviewed and monitored to ensure that their geographic scope, impact, and magnitude remain the same. Any changes should trigger review and updating the current SSA analysis.

Low Population Numbers: Texas trailing phlox has been documented in seven distinct populations. Of these sites, most do not include more than 100 mature individual plants. Although the introductions at BS and TC on the BTNP have had abundance numbers above the MVP estimate, these sites were supplemented with additional plants and they do not currently contain more than 100 mature individuals. Currently, the rangewide population is less than the estimated MVP estimate of about 600 adult, reproductive individuals (Poole *et al.* 2000, pp. 63-66). The low population size makes the species susceptible to stochastic events, affects pollinator relationships (see section below), and decreases the genetic fitness of the species (see section below).

Pollinator Deficiency: Pollinator visitors to the Texas trailing phlox have included the eastern swallowtail butterfly (G. Grant 2014, p. 1), flies, and bees (USFWS 1995). Based on photographic evidence and the floral structure of the species, the Texas trailing phlox is likely pollinated by long-tongue Lepidopterans. Currently, we have not investigated the effectiveness of these insects on pollination services (i.e. reproduction), nor monitored populations to identify additional pollinating species. Small population sizes can impact the interactions between a plant and its pollinators (Ratchke and Jules 1993, Aizen and Feinsinger 1994, Agren 1996; in Hendrix and Kyhl 2000). Small isolated remnants of habitat could be less attractive to pollinators, therefore reducing the reproductive rate of the plant (Hendrix and Kyhl 2000, p. 305).

Lack of Genetic Diversity: Genetic studies have not been completed to demonstrate the relatedness of Texas trailing phlox plants, either within a population or between-species interactions. However, it is likely that natural hybridization occurs (C. Ferguson, pers. comm. 2018). Small, isolated populations can suffer from decreased gene flow, loss of rare alleles, and increased expression of harmful alleles which lower fitness (Barrett and Kohn 1991, in Hendrix and Kyhl 2000, p 305). A lack of genetic diversity could reduce adaptability of species to new threats (i.e. forest pests, extreme weather, and climate change).

Habitat loss, Fragmentation, and/or Degradation: Texas trailing phlox is a rare endemic, occurring in longleaf pine savanna habitats. These habitats are characterized by a sparse tree canopy and a ground layer usually dominated by herbs (Bridges and Orzel l989, Peet and Allard 1993; in Glitzenstein *et al.* 2001, p. 89). Longleaf pine savannas once covered a vast amount of habitat in the southeastern United States (Frost 1993, Harcombe *et al.* 1993, in Glitzenstein *et al.* 2001), ranging from Texas to the Carolinas. With land conversion and development increasing, only about 3 percent of the 37 million acres of this region remain (Glitzenstein *et al.* 2001, p. 89). Contributing factors to habitat loss of longleaf pine savannas include logging, clearing, forest conversion, herbicide use, and fire suppression or exclusion (Glitzenstein *et al.* 2001, p. 89). Many endemic species of this habitat, including *Pinus* species (pine) and other herbs, require frequent (i.e. mean fire return intervals less than 5 years), low-intensity fires. Specific habitat loss and fragmentation factors relevant to the Texas trailing phlox are discussed below.

> *Silviculture*: There are about 32 million acres of pine plantation in the southern United States (Wear and Greis 2002, in Fox *et al.* 2007, p. 337). In general, the site preparation activities across this region prior to the planting of pines may include anchor chaining, chopping, burning, root raking, shearing, spraying, and/or disking (Balmar and Little 1978, p. 60); anchor chaining is not used in Southeast Texas. Silviculture practices directly remove habitat; change the canopy structure and species composition of the understory and other forest layers; can introduce nonnative species or allow native vegetation to become aggressive; and can disturb and/or remove plants and their seedbank.
>
> There are three populations that are on lands under active pine harvest that include lands owned/managed by Timber Conservation lands, Hancock Timber, and RMS. Other sites (Sandylands and BTNP reintroductions) manage their sites for pine species, but lands are not in active timber sales. All three sites under active silviculture collaborate with the USFWS on monitoring and enhancing the Texas trailing phlox habitat. Herbicide use is also common with silviculture to remove unwanted vegetation growth without causing soil erosion, however their use can increase incidents of aerial drift to nontarget sites and species (Balmar and Little 1978, p. 63). However, in areas where pine is currently being harvested, the canopy is too dense so Texas trailing phlox does not occur. Therefore, no

further analysis of effects will be discussed in this SSA in Chapter 6 as we do not anticipate that silviculture is a stressor to the species.

Housing Development: The species is a rare endemic, with populations only known from Hardin, Tyler, and Polk counties. Both Hardin and Polk counties have seen 4.6 and 8.3 percent increases in the human population respectively, while Tyler County has seen a 1 percent decrease between 2010 to 2017 (U.S. Census Bureau 2018a, 2018b, 2018c). An increase in land clearing activities for residential development could meet the needs of the increasing population trends. However, we do not have any data to support that lands have been sold for residential developments and the increases in population are limited. Therefore, no further analysis of this stressor is included.

Oil and Natural Gas Pipeline Activity: Salt domes serve as important underground storage sites for oil and natural gas. The primary development in the Big Thicket area began between 1902 and 1908, after the discovery of a salt dome in Sour Lake (Cozine 1979, p. 24). Oil development increased in the area surrounding the Hardin County towns of Sour Lake, Saratoga, and Batson after this discovery and, by August 1903, 220 wells were producing over 100,000 barrels a day (Cozine 1979, p. 26). The first salt dome in Saratoga, a town within close proximity to existing Texas trailing phlox populations, was discovered in 1901 and created an additional rush of exploration activity.

The current use of hydraulic fracturing in the area allows the extraction of even further natural gas product. Habitat and soils, and seedbank are disturbed in order to construct buildings, well pads, or roads to access drilling sites. Natural gas pipeline installation requires trenching and clearing that can destroy Texas trailing phlox plants, habitat, and seedbank within the pipeline ROW. In addition, excavation of sites could alter the natural slope of sites, making them unsuitable for the Texas trailing phlox that prefers slopes at less than 5 percent. Southeast Texas remains as the main distribution system across the state for natural gas operations (Dick 2019, p. 2).

Extensive oil and gas activity occurs in all three counties, that includes linear natural gas pipelines and constructed well pads (primarily on Sandylands site). Therefore, since this stressor affects all life stages of the Texas trailing phlox, with a large geographic scope, we will further analyze this stressor in Chapter 6.

Exposure to Herbicide: Herbicide activities within the known range of the Texas trailing phlox is predominantly associated with management activities along road, pipeline, and powerline ROWs, as well as site preparation and maintenance for silviculture. The final listing rule notes that aerial drift from herbicide spray could also be detrimental to plants (56 FR 49638). There are two populations of Texas trailing phlox that occur along road ROWs where plants, seedbank, and habitat could be impacted by herbicide. TxDOT uses herbicides on ROWs only after mechanical clearing techniques have been attempted (M. Buckingham, pers. comm. 2018). To date, we do not have any records indicating incidents from direct herbicide spraying or aerial drift to the Texas trailing phlox along these ROWs.

Both lands in active timber production/sales and those managed solely to conserve the habitat, have the potential to use herbicides for site preparation or management. However, we do not have resources to point to the specific effects or incidents of herbicide on these lands. In addition, the aerial drift threat from low flying aircraft spraying herbicides onto Sandylands was noted in 1991 in timber areas (Mahler 1990, in 56 FR 49638). However, we do not have actual records of aerial drift incidents.

Despite literature references (Brown 1987, Ahn *et al.* 2001, Russell and Schultz 2010; in LaBar and Schultz 2012, p 177) that point to the potential impacts of herbicides on habitat, plants and its processes, and pollinators and their services, we do not have any information directly related to impacts on Texas trailing phlox. Therefore, we will not be carrying this stressor through in our SSA analysis.

Illegal Dumping: Rajpal (2002, p. 42) states that most illegal dumping is done primarily to avoid disposal fees or the time and effort required for proper disposal. Typical dumping materials includes construction and demolition wastes (roofing, lumber, bricks, concrete; abandoned automobiles, autoauto parts and scrap tires), household trash, bulky waste (furniture, appliances), garden refuse (tree cuttings, grass cuttings, plants), and, medical waste (pharmacies, surgeries, hospitals and clinics) (Eilrich *et al.*, 1997, in Rajpal 2002). There are numerous illegal dumping sites on or near the BTNP, ROW populations, and the Sandylands. Dumping can smother plants and other native vegetation, and introduce wastes that could kill or harm plants, seedbank, and native vegetation. Despite the wide ranging threat of this stressor, we do not have any data that states the direct impacts of illegal dumping on the Texas trailing phlox therefore we are not assessing this stressor further in our SSA.

Disease and Predation: We do not have any record of pests that impact the Texas trailing phlox. Therefore, we are not considering the species vulnerabilities to disease and/or predation further in our SSA.

Climate Change: The International Panel on Climate Change (IPCC) is an international group that reviews and assess the most recent scientific, technical, and socio-economic information produced worldwide relevant to understanding climate change. The IPCC has tracked changes in our climate since 1988. Current trends show the warming of our climate system is unequivocal.

Droughts are not uncommon in Texas, but can have significant impacts to the viability of the Texas trailing phlox. Texas has experienced numerous droughts since 1955. Over the past 20 years, there has been widespread drought in the following years: 1999-2002, 2005-2006, 2007-2009, and 2010-2011 (Texas Water Resources Institute 2011, pp. 25-28). Extreme drought conditions in east Texas was somewhat mitigated by the rainfalls brought in by Hurricanes Dolly and Ike and tropical storm Edourad (Nielsen-Gammon 2011, p. 10).

The Standardized Precipitation Index (SPI) is a drought index used to evaluate rainfall shortages. SPI was used to evaluate the drought of record conditions observed between October 2010 and September 2011, the worst drought on record since 1956 (Nielsen-Gammon 2011, pp. 3, 9). We examined the 12-month SPI, as this is most useful in characterizing precipitation on time scales relevant to the recharge of reservoirs and some aquifers, as well as deep soil moisture available to trees (i.e. pine) (p. 12). Nielsen-Gammon (2011) provides records for the drought of record using the SPI indices (Table 5.1.1).

Table 5.1.1. Standard Precipitation Indices (SPI) for East Texas during record 2010-2011 drought.

Date	Standard Precipitation Index (SPI) Conditions
October 2010	Dry conditions, becoming increasingly clear, as some rainfall events prior to the summer no long contribute to the SPI values.
November 2010	SPI indices show Tyler and Polk counties with -1.5 to -1.0 amount of rainfall.
December 2010	East Texas considered in drought conditions. The year 2010 was the 8th driest, with the highest drought conditions occurring along the Louisiana border (and wettest on Texas border with Oklahoma).
January 2011	SPI indices show Hardin, Tyler, and Polk counties with -1.5 to -1.0 amount of rainfall.
February 2011	True drought conditions present throughout east Texas.
March – May 2011	Area exhibiting serious drought conditions; over 43 percent of the Texas was classified with 'extreme drought' conditions according to the U.S. Drought Monitor data (2011). May 2011 was the ninth-driest May on record, and the three month period from March through May was the driest March-May on record.
June 2011	Polk County reached the -2.5 to -2.0 inches below normal rainfall.
July 2011	Prolonged dry and hot weather begun to impact the root systems of trees. The deep soil moisture became seriously depleted in east Texas and trees (like pine) started to dry out.
August 2011	Drought conditions reached near record highs with SPI values below the -3.0 value.
September 2011	Record lows for precipitation with SPI values below -3.0.

The IPCC (2013, p. 11) does not provide regional precipitation in their climate projections, however, several downscaling tools are publicly available. The National Climate Change Viewer (NCCV; https://www2.usgs.gov/climate_landuse/clu_rd/nccv/viewer.asp) uses 33 models under multiple scenarios to generate projections for temperature and precipitation variables. These models show little change in annual precipitation in Tyler, Hardin, and Polk counties when historical data (1950-2005) are compared to future projections (2006 – 2100). Given that rainfall amounts and patterns appear to be relatively stable in these future projections, we do not use this information to project future scenarios for the Texas trailing phlox in this SSA. The NCCV shows significant increases in annual temperatures in Tyler, Hardin, and Polk counties when historical data (1950-2005) are compared to future projections (2006 – 2100). However, we do not know how Texas trailing phlox would respond to such changes in temperatures. These changes in climate conditions could be detrimental to the Texas trailing phlox and its continued survival. However, due to the lack of specific temperature tolerance information, we do not use this information to project the future scenarios for the Texas trailing phlox in this SSA.

Land Ownership: A large portion of Texas trailing phlox populations occur on privately owned lands. Since approximately 97 percent of Texas is privately owned, we estimate that additional areas of habitat suitable for in-situ conservation may also occur on private lands, but have not yet been surveyed for Texas trailing phlox. Land ownership itself does not constitute a threat to species conservation or management of its habitat; many private landowners collaborate with the USFWS. However, species conservation on private lands can be more challenging due to the limited access. Texas trailing phlox found on federal lands are held to Section 7(a)(2) of the Endangered Species Act, as amended, that states that Federal agencies are required to ensure that activities they authorize, fund, or carry out are not likely to jeopardize the continued existence of a listed species or to destroy or adversely modify its critical habitat.

5.2 Conservation Efforts
Current and/or ongoing conservation efforts for the Texas trailing phlox include seed banking; outreach; monitoring; and, propagations and reintroductions.

Seed Banking: Mercer Arboretum and Botanic Gardens (Mercer) has four accessions of Texas trailing phlox seed (A. Tiller, pers. comm. 2018). These seeds were collected with the intent for long-term seed storage for use at ex-situ populations. The accession information is as follows:

Accession 1 (Mercer 93090111-00) includes 31 seeds collected from the wild by Dr. Warnock (collection number 11973) in Tyler county and received by Mercer on Sept. 23, 1993. The specific location of this collection by Warnock and corresponding EO record are unknown.

Accession 2 (Mercer 950110-00) includes 120 seeds collected in Hardin County at the Sandylands and Temple-Inland (now Champion) tracts during pollination. These seeds generated by Mercer in 1995 through open pollination match wild cuttings of three plants collected in Hardin County by Dr. Warnock. The specific location of this collection by Warnock and corresponding EO record are unknown.

Accession 3 includes 433 seeds (Mercer 950911-00) generated by open pollination efforts in 1995 from about 40 cuttings of individual wild plants collected in Hardin County by Dr. Warnock. There are no details on coordinates for collection sites of cuttings used to generate these seeds, however, named cuttings were from TNC Sandylands Sanctuary (Hardin) and "Temple Tract 5 along road" (Hardin) were used. Seeds were pooled and combined for this accession.

Accession 4 includes 1,847 seeds (Mercer 960263-00) generated by Mercer staff and collected in April-May 1996. Seeds were generated by open pollination of wild plants collected by Dr. Warnock from Hardin County. Coordinates for where the plants were collected are unknown.

Outreach:

Demonstration gardens: There are two demonstration gardens that include Texas trailing phlox: one at Mercer and the other at the SFA – Plant Material Center (PMC). Texas trailing phlox plants at Mercer are located in the Endangered Species Garden, a garden for rare native plants. The Endangered Species Garden was founded in 1994 through a donation and is home to threatened or endangered annual and perennial native plant species. It serves as an important teaching tool to the more than 100,000 visitors to Mercer annually. The three plants on display at the Mercer were replacements for plants impacted from Hurricane Harvey and were received from SFA-PMC in 2018 (A. Tiller, pers. comm. 2018). Additionally, Mercer has three plants, serving as back up education stock material, in their conservation nursery. These plants originated from SFA-PMC from a patch of plants maintained at SFA Native Plant Center. These plants are currently being used as the source for propagation work initiated by SFA. The demonstration garden at SFA-PMC houses Texas trailing phlox plants. SFA received their plant material from Mercer in 1994. These plants were collected by Dr. Warnock at the Sandylands properties (A. Tiller, pers. comm. 2018).

Landowner and Land manager outreach: A Phlox Working Group was previously organized to collaborate and coordinate recovery and conservation efforts specific to the species. The group included members of the conservation community: TNC, BTNP, landowners, land managers, Mercer, SFA, TPWD, and USFWS (both Ecological Services and Partners for Fish and Wildlife programs). The group recently convened in 2006, but since then the group has only met infrequently. Recent efforts by the USFWS to reconvene the group have occurred.

Monitoring: Monitoring efforts have occurred on most, if not all, of the sites with extant populations. However, most of these efforts have been sporadic for several populations so we lack information on the annual changes occurring with each population size and structure. Monitoring efforts have been routinely conducted on Sandylands by TNC staff, volunteers, USFWS, TPWD, and other partners. TNC has provided survey data via shapefiles to the USFWS for use in this SSA (S. Benedict, pers. comm. 2018). Annual monitoring has also occurred on BTNP and Hancock for their introductions and reintroductions from the time of planting until currently. These efforts have also included partners as well.

Propagation and Reintroductions: All plant material produced for Texas trailing phlox reintroduction in Texas (BTNP, Turkey Creek and Big Sandy Creek; Hancock) were grown at SFA from plant material produced by cuttings from Dr. Warnock from the Sandyland collections. Production of reintroduction stock was managed by Greg Grant at SFA (A. Tiller, pers. comm. 2018). Reintroductions are discussed in Chapter 2.

CHAPTER 6 – Future Conditions

This SSA Report assesses the representation, redundancy, and resiliency of Texas trailing phlox within its known range. In Chapter 3, we considered the current resource conditions affecting the viability of Texas trailing phlox. Additionally, in Chapters 4 and 5, we reviewed the risk factors and conservation benefits that are driving the historic, current, and future conditions of the species. In this chapter, we consider the conditions that will likely affect the species in the future.

Individual populations of Texas trailing phlox face an array of stressors, as well as a varying level of future risk, stemming from natural and anthropogenic stressors. A decrease in individual plant populations, from a high of 17 populations in 1995 to only seven extant populations in 2018 is evidence of these stressors. Additionally, these populations have become fragmented (discussed in Chapter 5). As of 2000, the rangewide population is less than the estimated MVP estimate of about 600 adult, reproductive individuals (Poole *et al.* 2000, pp. 63-66). At present, the most prominent threat to these populations is from oil and natural gas pipeline activity. Based on the best scientific information available, we apply our future forecasts to the concepts of resiliency, redundancy, and representation to assess the future viability of Texas trailing phlox.

6.1 Scenario Assessments

Three plausible future scenarios were forecasted and we assessed the resiliency, redundancy, and representation for Texas trailing phlox under each scenario. Each scenario examines oil and gas development (stressor) coupled with prescribed burning (conservation benefit) because these are the most significant to the species as a whole (seedbank, plant, habitat), and are likely to be continued into the future. We developed three scenarios incorporating the ongoing stressor and conservation benefit at current levels as well as increasing and decreasing levels. We then evaluated the subsequent expected responses of Texas trailing phlox. Table 6.1 below summarizes the three scenarios.

Risk	**Stressor: Oil and gas Activities**	**Conservation Benefit: Prescribed burning to restore longleaf pine habitat**
Risk Described	Construction, maintenance of pipeline, ROW, well pads; could include use of herbicide as maintenance; site disturbance attributed to maintenance and regular activities	Prescribed burning; shade prevention; maintain canopy structure, reduce litter layer
Scenario 1	A leveling off or only a small increase in the amount of oil and gas produced in the State	Frequency of prescribed burning increases and is consecutively conducted across a 7-year interval, thereby improving the quality of habitat, reducing fuel loads, and reaching a restorative phase of prescribed burning (i.e. maintenance burning to occur approximately every 5-8 years)
Scenario 2	A moderate increase in the amount of oil and gas produced in the State	Frequency of prescribed burning increases but is sporadic. Burning regimes do not meet the recommended 7-year fire return interval therefore, a restorative burning phase is not achieved
Scenario 3	A large increase in the amount of oil and gas produced in the State	Frequency of prescribed burning is sporadic or does not occur.

Table 6.1.1. Future Scenario Descriptions for Texas trailing phlox.

We have data on how the stressor and the conservation benefit will affect the Texas trailing phlox, but all scenarios incorporate some degree of uncertainty. There is uncertainty when the stressor will occur in the future and exactly which population of Texas trailing phlox will be impacted. Each scenario only presents a plausible range of future conditions.

Oil and Gas Development
We assessed the effects that oil and gas development activity (including related activities, e.g. maintenance) would have on the Texas trailing phlox at all populations. We examined multiple oil and gas activity data sets during our analysis with the goal of identifying historic trends that we could project into the future (10 years). These data sets included:

1. All Section 7 consultations specific to oil and gas activity received by the TCESFO between 2001 to 2018;
2. Cumulative miles of oil and gas pipeline within the species' geographic range received by the TCESFO via Section 7 from 2008 to present; and,
3. New construction data for pipelines from 2008 to present from The Railroad Commission of Texas (RRC).

Each of these data sets had high levels of uncertainty and many assumptions would be required for further analysis. For instance, the number of Section 7 consultations received by the TCESFO is variable and does not likely reflect the amount of on-the-ground activity. Not all companies provide information for their projects to TCESFO. Additionally, activities tracked by the TCESFO do not necessarily account for routine maintenance. Although these data sets helped inform our understanding of the current conditions, none of these data sets were used for projections into the future, due to the aforementioned uncertainty and built in assumptions.

We also have data spanning from 1935 to 2017 showing the amount of oil production in Texas (Figure 6.1). However, the uncertainty within the industry is very high for a number of reasons,including: potential regulatory changes to Organization of Petroleum Exporting Countries (OPEC); potential regulatory changes to local, state, and federal regulations; the volatility of the industry in general; advancements of new research and drilling techniques; fluctuations in industry economics (i.e. future oil prices); and, synergistic impacts with other industries, both nationally and internationally. Given the high levels of uncertainty in the industry, future trends were projected over the next 10 years for oil and gas development, which is the longest timeframe we felt confident in projecting.

We assessed the historic and potential future trends in oil production for the entire state of Texas. Oil and gas data production trends specific to the East Texas region for Hardin, Polk, and Tyler counties are not currently available; oil play (i.e. oil fields) data is readily available for the more prominent petroleum plays or oil fields (i.e. Permian Basin, Haynesville Shale, etc.). The stressor of oil and gas development and potential impacts to the Texas trialing phlox are discussed in-depth in Chapter 5.1. Based on our understanding of this stressor and given the limitations of available data for these three East Texas counties, we assumed that oil and gas development occurring within Texas trailing phlox habitat would mirror those of other well-studied parts of the state.

We used data produced by the RRC as a basis for our analysis. Both the Bureau of Economic Geology (BEG) and RRC have tracked the amount of billion barrels of oil (BBO) produced per year, however, the RRC data spans from 1935 to 2017 (Figure 6.1) and the BEG data from 1950 to 2016 (Figure 6.2). Both data sets demonstrate the same trend in oil and gas production over time; however, we chose to use the RRC data due to the larger breadth of data and the availability of raw quantitative data. According to the RRC, oil production peaked in 1973 from conventional reservoirs at approximately 1.25 BBO. Over time, production decreased significantly until the year 2000. By 2011, the production from hydraulic fracturing ("fracking") in South Texas and the Permian Basin allowed for the dramatic increase in production. The U.S. Energy Information Administration (EIA) estimated that U.S. crude oil production averaged 11.4 million barrels per day (b/d) in October 2018, down slightly from September 2018 levels because of hurricane-related outages in the Gulf of Mexico (p. 1). The EIA expects that U.S. crude oil production will average 12.1 million b/d in 2019 (EIA 2018, p. 1). Natural gas usage in Texas has been tracked since 1967, with withdrawals peaking in 1972 at 9,550,469 million cubic feet (Figure 6.3) but over time gas withdrawals have not been consistent (EIA 2018, p. 1). With the combination of horizontal drilling and fracking techniques, the footprint of oil and gas activity has increased exponentially since 2008 (Pierre *et al*. 2018, p. 87). We assume that increased oil and gas production infers increased soil disturbance, habitat loss, and/or fragmentation from new construction and maintenance activities.

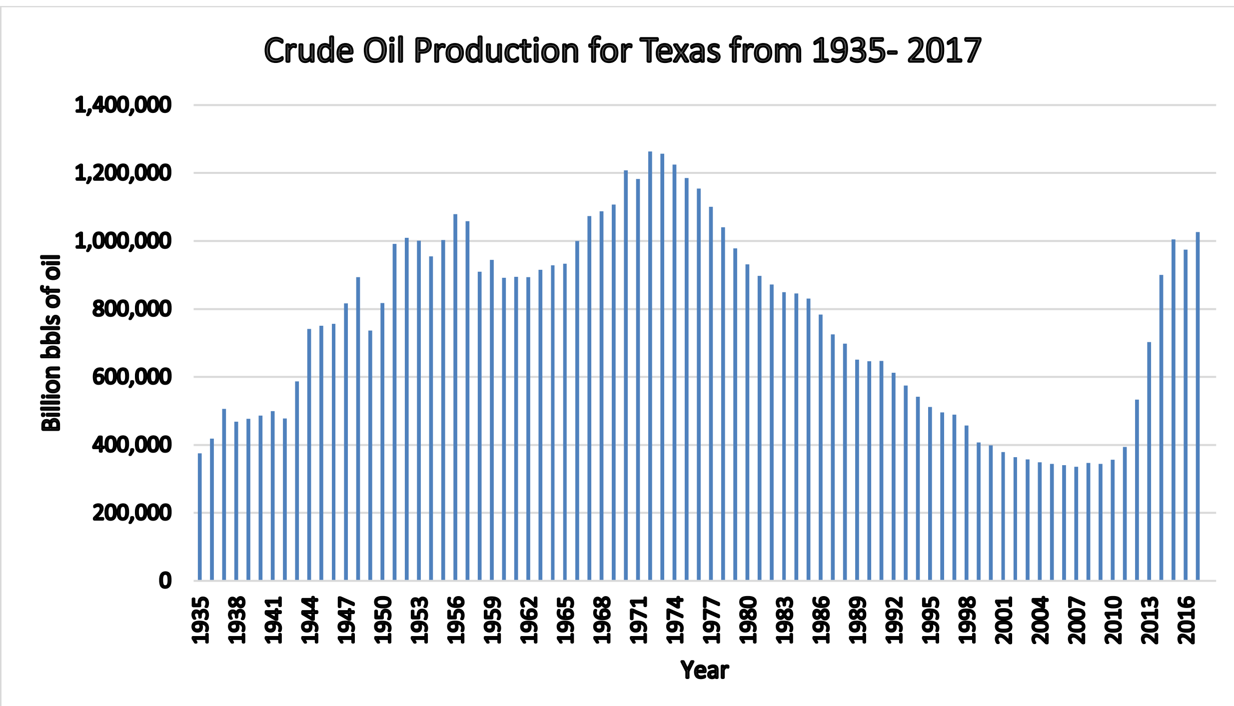


Figure 6.1. Crude Oil and Well Production in Texas from 1935 to 2017 (RRC 2018).

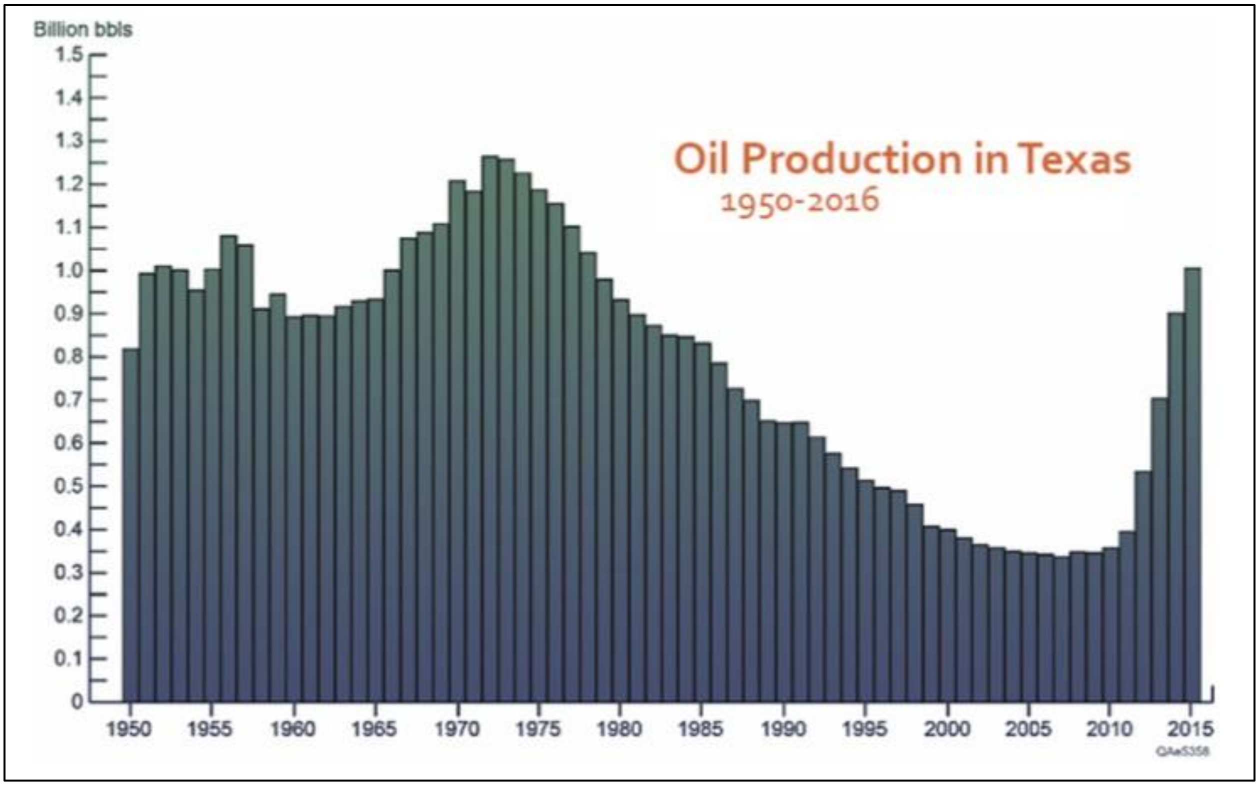


Figure 6.2. Oil Production in billion barrels (bbls) from 1950-2016 for Texas (BEG 2018 online).

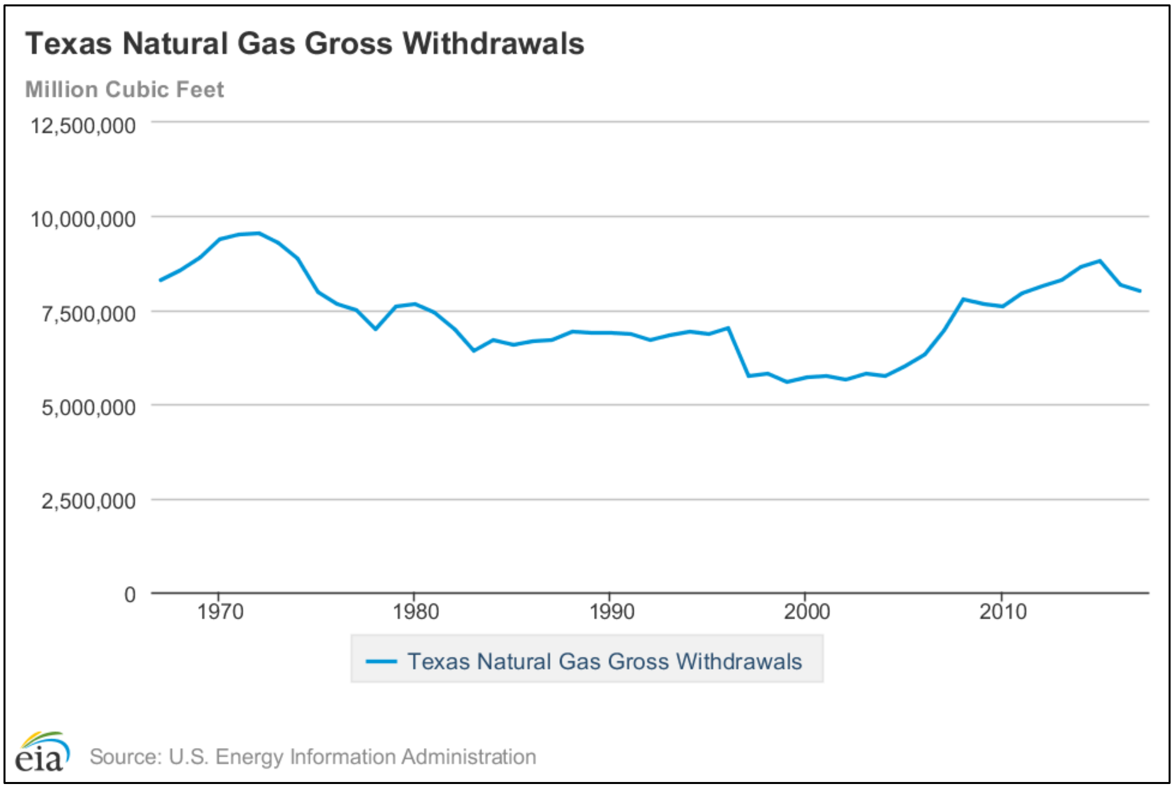


Figure 6.3. Gross Withdrawals for Natural Gas in Texas (EIA 2019).

We assume that each population of Texas trailing phlox is susceptible to the same degree of oil and gas development into the future. We further assume that populations subjected to oil and gas exploration and maintenance activities (i.e. at a well pad) will be impacted by the same level of potential soil disturbance and/or habitat fragmentation. Oil and gas activities are projected to increase steadily over the next 10 years under Scenario 2. Oil and gas activities are projected to have a large increase under Scenario 3 and under Scenario 1, oil and gas activities are expected to increase slightly over the next ten years.

Prescribed Burning

The potential conservation benefit of increased fire frequency (prescribed burning) within longleaf pine communities in East Texas was assessed using data from Maxey and Warnock (1996). They described optimal overstory, understory, and litter depth conditions under varying fire regimes and how that affects Texas trailing phlox. Since most extant populations do not meet these optimal forest conditions because fire has been suppressed for so long, we assume that the conservation benefit of prescribed burning in each scenario will be to reach a restorative state within the ecosystem rather than to mimic historic fire return intervals. Once restoration is accomplished, a maintenance phase of prescribed burning can begin (Rideout *et al.* 2003, p. 267). Rideout *et al.* (2003, p. 267), DellaSala and Frost (2001), and Manley *et al.* (2001) provide insight into the frequency of prescribed burning. They state that dormant burns should be conducted every two years to reduce fuel loads, followed by at least two more cool season burns; these can be followed by spring burns every three years to establish a restorative phase. After optimal forestry conditions are met, a maintenance phase of burning every five to eight years might be appropriate. In our assessment, it was assumed areas not routinely burned will likely have hot, intense burns as the amount of fuel loads are high (from the leaf litter). Hotter burns are more likely to kill plants, therefore reducing post-burn blooming opportunities that could occur if habitat burned under more optimal fire conditions. It was also assumed for all scenarios that prescribed burning events are optimized to meet the biological needs of both the Texas trailing phlox and longleaf pine species in the community (i.e. burns do not occur during candling of longleaf pine). Fire is a necessary tool in these communities, needed by many species for their survival. Texas trailing phlox relies on prescribed burning to maintain its habitat. We assume that the timing and placement of prescribed burns across the landscape would be thoughtfully planned. Prescribed burns that are too frequent or that occur when the plant is in bloom or in seed, can severely reduce the reproductive fitness and success. The frequency of prescribed burning during the maintenance phase should be assessed on a site-by-site basis.

For each scenario, we projected the conservation benefit of prescribed burning over the next 30 years. We selected 30 years to evaluate what is likely to occur over three generations of the plant based on the life history of the Texas trailing phlox. Refer to Chapter 1.3 for more information. Since few landowners/land managers currently burn populations consistently, all scenarios assess a prescribed burn frequency that will reach a restorative phase in order to maintain quality habitat conditions. For Scenario 2, we assume prescribed burning would increase but would remain sporadic. In this scenario, burning regimes would not meet the consecutive 7-year fire return interval as detailed in Rideout *et al.* (2003, p. 267), DellaSala and Frost (2001), and Manley *et al.* (2001). Scenario 1 would entail an increase in the prescribed burning frequency with fires conducted consecutively across a 7-year interval. We assume in this scenario an improvement in the quality of habitat and a reduction in fuel loads, such that a restorative burning regime (i.e. maintenance burning to occur approximately every 5-8 years) is achieved. Under Scenario 3, prescribed burning remains sporadic or continues to be nonexistent.

Climate Change

Climate change is important to consider, as the Texas trailing phlox habitat factors require specific climate and weather conditions (i.e. precipitation). This SSA does evaluate climate change, but future trends do not indicate changes to the habitat factors that would be outside of the precipitation range needed by the Texas trailing phlox to survive and reproduce, therefore climate change was not included in the development of future scenarios or in this assessment of future conditions. The average rainfall in East Texas is 48-60 in., with precipitation levels evenly distributed throughout the year in both Hardin (Wiedenfeld 2006, p. 3) and Polk counties (McEwen *et al*. 1988, p. 2). Using the Northwest Climate Toolbox, climate variables can be forecasted under different future climate scenarios (Representative Concentration Pathways (RCPs 4.5 and 8.5)) and under different time periods (2010-2039, 2040-2069, 2070-2099). We used scenario RCP 8.5 because it considers the current trajectory of increased greenhouse gas emissions and population growth through the end of the century with nominal policies to reduce emissions (IPCC 2018 online) (Figure 6.3). The annual predicted precipitation projections are not expected to be outside of the range of what is needed by the Texas trailing phlox to survive and reproduce. Therefore we did not analyze changes to climate further.

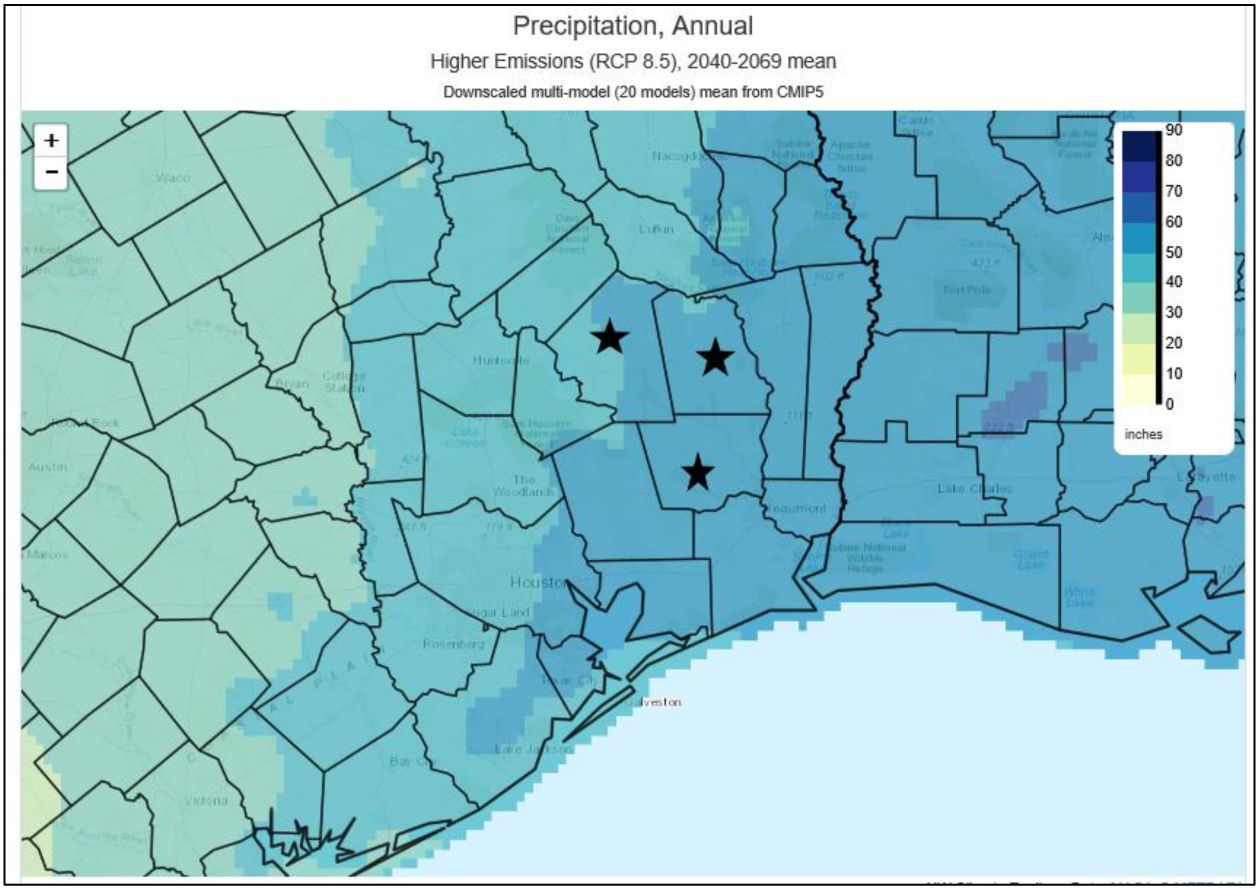


Figure 6.3. Annual precipitation amount forecasted for the RCP 8.5 scenario for 2040-2069 within counties of known range of Texas trailing phlox (Source: Northwest Climate Toolbox 2018).

We assessed each scenario using the best scientific information and literature available on future trends. The demographic factors (numbers of plants per population and distance between populations, i.e. connectivity) and habitat factors (undisturbed soils, canopy structure and prescribed burning) were used to determine the trend for each of the seven extant populations. These factors are in Chapters 3 and 4. Each population was individually assessed and determined to be declining, stable, or improving based on the demographic or habitat factors, stressors, and conservation benefits. Each population in each scenario has qualitative and quantitative rankings, defined by both a value between 0 and 3, and an overall descriptive status ranking (Table 6.4):

Table 6.4. Qualitative and quantitative ranking metrics used for each Texas trailing phlox population.

	Demographic Factors		Habitat Factors		**Viability Ranking**
Numeric Value Assigned	# of plants at site	Distance between populations	Undisturbed soils	Canopy Structure and prescribed burning	Overall Status (overall numeric range)
0	Extirpated; 0	No genetic exchange	100 percent of the occupied population with plants and seedbank is disturbed	Canopy overstory is >80 percent, shrub layer is 80-90 percent, litter depth is >8 cm; and/or prescribed burning activities do not occur.	Extirpated (0-0.75)
1	Low; ≤ 100 individuals (i.e., clusters)	Population is separated from nearest population by a distance of > 5 km (3.11 mi)	>10 percent of the occupied population with plants and seedbank is disturbed	Canopy overstory is >80 percent, shrub layer is 80-90 percent, litter depth is >8 cm; and/or prescribed burning occurs consecutively for 2 years in the dormant season	Declining (0.76-1.5)
2	Moderate: 101-600 individuals	Population is separated from nearest population by a distance of >2-5 km (1.24 -3.11 mi) with remnant pine savanna habitat present in landscape to facilitate pollinator dispersal	Some disturbance up to 10 percent of the occupied population with plants and seedbank is disturbed	Canopy overstory is between 26-80 percent, shrub layer is between 26-40 percent, litter depth is between 6-8 cm; and/or prescribed burning occurs consecutively for 2 years in the dormant season, followed by another 2 years of consecutive cool season burns	Stable (1.6-2.25)
3	High: ≥ 600 individuals	Population is separated by a distance of 2 km (1.24 mi) and intervening remnant pine savanna habitat is present.	0 percent of the occupied population with plants and seedbank is disturbed	Canopy overstory is between 5-25 percent, shrub layer is between 10-25 percent, litter depth is 3-5 cm, and/or prescribed burning occurs consecutively for 2 years in the dormant season, followed by another 2 years of consecutive cool season burns, and another 3 years of consecutive spring burns. Prescribed burning is in a restorative phase (i.e. maintenance)	Healthy (2.26-3.0)

6.2 Scenario 1

Scenario 1 assumes the best possible conditions over the next 30 years (Table 6.5). Under this scenario, the risks from oil and gas activity will likely become static or only increase slightly. For this scenario, we assume that prescribed burning is more effective to manage for an open canopy structure and optimal litter layer as defined by Maxey and Warnock (1996) (Figure 3.2.1). The Texas trailing phlox is not a shade tolerant species and dense canopy cover and structure resulting from a lack of fire would be detrimental to the plants' survivability. However, under Scenario 1, consecutive years of prescribed burning does occur at some populations, reducing fuel loads and maintaining habitat conditions. The USFWS will work with landowners and land managers to develop plans on a site-specific basis to continue this conservation effort. In terms of the 3R's (representation, redundancy, resiliency), almost all populations would remain stable with the Sandylands and Timber Conservation lands' units remaining healthy. Refer to Table 6.4 for the qualitative and quantitative rankings and overall status metrics.

Table 6.5. Status of each population under Scenario 1 over the next 30 years.

Scenario 1	Demographic Factors		Habitat Factors		**Viability Rankings**	
Population Name	# of plants at site	Distance between populations	Undisturbed soils	Canopy Structure and prescribed burning	**OVERALL AVERAGE - Quantitative**	**OVEARLL AVERAGE - Qualitative**
BS, BTNP (reintroduction) and EO 17	2	2	2	2	2.00	stable
BTNP (EO 21)	2	2	2	2	2.00	stable
Timber Conservation Lands (EOs 22, 23)	2	3	2	3	2.50	healthy
Sandylands (EOs 3,5,13)	2	3	2	3	2.50	healthy
Hancock	2	1	2	3	2.00	stable
RMS (EO 9)	1	1	2	3	1.75	stable
TC, BTNP (reintroduction)	2	2	2	2	2.00	stable

6.2 Scenario 2

Scenario 2 assumes the current conditions will continue over the next 10 years for oil and gas development and 30 years for prescribed burning (Table 6.6). Under this scenario, the risks from oil and gas activity would increase in this region, resulting in increased land being cleared/maintained for well construction and maintenance activities. This would affect the Texas trailing phlox by reducing the numbers of plants likely per population, reducing the connectivity between populations, and increasing soil disturbance. Pollinator foraging and fitness would be impacted, thereby reducing the genetic exchange among Texas trailing phlox populations – meaning a reduced genetic representation across the landscape and a reduced resiliency. Given future trends in oil and gas, we assume its associated development will increase. In time, habitat at the extant sites would become more fragmented and connectivity between populations would reduce. Oil and gas development limits the opportunities to conduct prescribed burning and therefore, less optimal habitat conditions would increase. Because Texas trailing phlox is not a shade tolerant species, dense canopy cover and structure resulting from lack of fire would be detrimental to plant survivability. Several populations would continue with the sporadic occurrence of prescribed burning causing a reduction in the habitat quality and quantity effecting the Texas trailing phlox resiliency. In terms of the 3R's (representation, redundancy, resiliency), most populations are expected either to remain stable or decline over time. Refer to Table 6.4 for the qualitative and quantitative rankings and overall status metrics.

Table 6.6. Status of each population under Scenario 2 over the next 30 years.

Scenario 2	Demographic Factors		Habitat Factors		**Viability Rankings**	
Population Name	# of plants at site	Distance between populations	Undisturbed soils	Canopy Structure and prescribed burning	**OVERALL AVERAGE - Quantitative**	**OVEARLL AVERAGE - Qualitative**
BS, BTNP (reintroduction) and EO 17	1	2	2	1	1.50	declining
BTNP (EO 21)	1	2	2	1	1.50	declining
Campbell units #00376, #00377 (EOs 22, 23)	2	3	2	2	2.25	stable
Sandylands (EOs 3,5,13)	2	3	2	3	2.50	healthy
Hancock	1	1	2	3	1.75	stable
RMS (EO 9)	1	1	2	3	1.75	stable
TC, BTNP (reintroduction)	1	2	2	1	1.50	declining

6.3 Scenario 3

Scenario 3 assumes the risks from oil and gas activity will increase considerably in this region (Table 6.7). Habitat would be severely fragmented; soils highly disturbed to make way for new well pads, associated roads, and maintenance; and, the likelihood of herbicide use to maintain safe conditions within oil and gas ROWs would increase. All populations would be susceptible to these impacts, with both the population size and connectivity greatly impacted. It is likely that the genetic integrity of the Texas trailing phlox populations would be greatly reduced. Oil and gas development would severely limit the opportunity to conduct prescribed burning and therefore, suboptimal habitat conditions would increase. Prescribed burning would occur only sporadically or not at a Texas trailing phlox population. Under this scenario, canopy openness and structure would also be the least optimal and could shade out the Texas trailing phlox, reducing its survivability. In terms of the 3R's (representation, redundancy, resiliency), most populations would decline over time. Since there is only one known plant at the RMS, this population is expected to become extirpated under Scenario 3. Refer to Table 6.4 for the qualitative and quantitative rankings and overall status metrics.

Table 6.7. Status of each population under Scenario 3 over the next 30 years.

Scenario 3	Demographic Factors		Habitat Factors		**Viability Ranking**	
Population Name	# of plants at site	Distance between populations	Undisturbed soils	Canopy Structure and prescribed burning	**OVERALL AVERAGE - Quantitative**	**OVEARLL AVERAGE - Qualitative**
BS, BTNP (reintroduction) and EO 17	1	1	1	1	1.00	declining
BTNP (EO 21)	1	1	1	1	1.00	declining
Timber Conservation Lands (EOs 22, 23)	1	2	2	1	1.50	declining
Sandylands (EOs 3,5,13)	1	2	2	2	1.75	stable
Hancock	1	1	2	2	1.50	declining
RMS (EO 9)	0	0	1	2	0.75	extirpated
TC, BTNP (reintroduction)	1	1	1	2	1.25	declining

6.4 Status Assessment Summary

We used the best available information to forecast the probable future conditions of Texas trailing phlox over the next 30 years for prescribed burning and the next 10 years for oil and gas development. The needs of the species both in terms of demography and habitat were assessed, in order to describe its' viability. The viability is presented in terms of the representation, redundancy, and resiliency. Under Scenario 1, the future viability of the species would require considerable coordination and collaboration with private landowners and oil and gas industry to reduce potential negative effects to the species and its habitat. Without these efforts and seeking new opportunities for ex-situ recovery and conservation, conditions would likely slip into Scenario 3. Under this Scenario, the Texas trailing phlox individual plants and populations would experience a huge increase in negative impacts. We foresee that even with some increased level of management (i.e. prescribed burning), the impacts from oil and gas could remain insurmountable despite conservation efforts. We do not anticipate that Scenario 1 is probable and foresee that conditions will likely remain at levels described in Scenario 2 or slip into Scenario 3 if conservation activities decrease and oil and gas activity accelerates.

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APPENDIX – Glossary of Terms

Accession - a group of related plant material from a single species which is collected at one time from a specific location. Each accession is an attempt to capture the diversity present in a given population of plants. Accessions are given a unique identifier, an accession number, which is used to maintain associated information in the GRIN database. This is similar to call numbers that libraries use, except instead of books we are able to manage plants (The Ohio State University 2018, online)

Anthesis – period from flower opening to fruit set

Apomixis – asexual reproduction in plants

Appressed - pressed closely to another organ but not united)

Bract – a leaflike organ subtending an inflorescence

Dehiscence – the splitting open along predetermined lines of certain plant organs, such as anthers, spore capsules, and fruits, to release their contents

Fire scars - injuries caused by fire that involve the disruption and death of some of the vascular cambium (Smith and Sutherland 2001, in Henderson 2006, p. 316).

Florivory – flower predation

Granivory – seed predation

Mean fire-return interval – an expression of the fire frequency as the average number of years between fires (Frost 1998, p. 72)

Open pollination – conditions where plants are pollinated naturally by birds, insects, wind, or human hands

Outcrosser – also known as outbreeding, the production of offspring by the fusion of distantly related gametes

Polyploidy – the condition in which an organism has three or more complex sets of chromosomes in its nuclei; originate when more than one chromosome set fuse; common in flowering plants

Sepal – an individual unit of the calyx; it is usually green and often hairy but in some species, can appear brightly colored and assume the function of the flower petals

Stomata – (singular stoma) a pore in the epidermis of aerial parts of a vascular plant, providing a means for gaseous exchange between the internal tissues and the atmosphere; surrounded by guard cells

Xeric - Dry soils include extremely well-drained sand, gravel and rock. These soils never have standing water and rainfall drains rapidly through them.