

**Species Status Assessment Report for
Texas golden gladeceess (*Leavenworthia texana*)**



U.S. Fish and Wildlife Service

Texas Coastal Ecological Services Field Office

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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 golden gladeblossom (*Leavenworthia texana*) is an annual plant and member of the family Brassicaceae. The best available information suggests that four extant populations occur in Texas on private and state-owned lands within San Augustine, Sabine, and Nacogdoches counties, Texas. Three of these populations are natural, and one introduced (Nacogdoches County). They are distributed across the Weches geologic formation that loosely parallels State Highway 21 within these counties. Sites are relatively bare (treeless) and host a diverse set of associated species that vary throughout the annual cycle of the Texas golden gladeblossom. The species depends on cool, wet winter months to aid in its growth, promoting a short flowering season in February and March each year. When temperatures warm in summer, Texas golden gladeblossom withers away and drought-tolerant species emerge, growing and becoming visible on the glade. Glade exposures on the Weches geology are naturally small, giving rise to smaller population sizes. Due its annual nature, plant numbers fluctuate each year. Little is known about the species seed biology, reproductive strategies (i.e., need of pollinators), and/or genetic relatedness among and within populations. The Texas golden gladeblossom was listed as federally endangered in 2013 with 4 units of critical habitat. Known threats to the species include habitat loss, modification, degradation; climate change; small population size; and, ineffective management strategies.

To evaluate the current and future biological status of Texas golden gladeblossom, we considered the species' viability as characterized by its resiliency, redundancy, and representation (3R's). These 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 1,683 or more mature individuals in at least one out of every five years; exhibited climatic parameters that included wet winters with at least 13 inches (33.02 centimeters) or more of rain and February temperatures of an average of 51.8 °F (11 °C); tree-less glades (i.e., no overshading); and, connected populations that have one or more source features within proximity to each other. Using these factors, the current resiliency for the four extant populations was determined to be moderate.

Redundancy measures the risk to a species from natural or catastrophic events. For the Texas golden gladeblossom, we measured redundancy as the number of resilient populations that provided an exchange of genetic material, perhaps relying on pollinators. However, due to the low number of populations, their moderate resiliency rankings, our lack of understanding of the species ecology, and the overall restricted range of the species, the current redundancy of the species was determined to be low.

The measure of representation describes the ability of a species to adapt to changing environmental conditions over time. We lack genetic studies and/or how pollinators play a role in the exchange of genetic material for the Texas golden gladeblossom. Due to an absence of genetic information informing our measure of representation, we used ecological (habitat) diversity as a surrogate for genetic diversity. We assumed no ecological or niche diversity at any

of the four extant populations since Texas golden gladeceess is an extreme narrow endemic and therefore, it was determined the representation of the species is extremely low.

We forecasted two plausible future scenarios associated with resiliency, redundancy, and representation for Texas golden gladeceess. Each scenario examines climate change (a stressor), oil and gas development (a stressor), glauconite mining (a stressor), coupled with invasive species management (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. Given the provided analyses tools, we projected potential effects from climate change and oil and gas activity for 30 succeeding years. Glauconite mining is not regulated and therefore, difficult to predict the location, timing, and frequency of this stressor however, it is likely due to the occurrence of the Texas golden gladeceess on the Weches geologic formation, that at least one new mine will be developed within this timeframe. Future conservation benefits attributed to invasive species management were projected for 30 succeeding years. Since the Texas golden gladeceess is an annual plant and longevity studies are lacking, we do expect that the species seed bank is long-lived and therefore used climate change projection timeframes (i.e., 30 years) to evaluate this benefit as a proxy. The developed scenarios included:

- Scenario 1: This scenario assumed that effects from climate change would result in heightened changes to precipitation and temperatures changes. At least one linear oil and gas project is anticipated to occur, with at least one glauconite mine being constructed. Development of a glauconite mine would remove habitat and plants during construction and operation. We anticipate that landowner relations would continue as is or diminish , and therefore the likelihood of conducting habitat management to benefit the Texas golden gladeceess would not occur. Habitat features needed by the species would diminish and the overall viability would largely decline over time. Opportunities may still continue as-is to conduct some invasive species management.
- Scenario 2: We assumed the best possible conditions over the 30-year time period. Over time, almost all populations would remain stable in the presence of continued changes to our climate as well as ongoing oil and gas maintenance activities. In this scenario, we expect no additional glauconite mining to occur within suitable habitat. Landowner relations are expected to improve, providing more opportunities to manage for invasive species

The best way to improve the viability of the Texas golden gladeceess involves considerable coordination with partners, landowners, and land managers. Genetic studies as well as those focusing on the species basic biology (i.e., seed biology, pollination, response to management) are needed and would benefit our understanding of the species needs and viability. Despite increased management, coordination/outreach, and scientific studies, oil and gas activity within this habitat will remain a constant stressor to the Texas golden gladeceess.

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CHAPTER 1 – Introduction and Species Biology

1.1 Species Status Assessment – Background and Need

Texas golden gladeceess (*Leavenworthia texana*) is an annual plant and member of the mustard family (Brassicaceae family) and is endemic to the Weches geologic formation of eastern Texas in San Augustine and Sabine counties, Texas. The species was listed as endangered with critical habitat under the Endangered Species Act (Act) on September 11, 2013 (U.S. Fish and Wildlife Service (USFWS) 2013, entire).

The Service is required under Sections 4(c)(2)(A) and 4(c)(2)(B) of the Act to conduct a review of all its covered species at least once every five years. The Service initiated the 5-year review for the Texas golden gladeceess on July 26, 2019 (USFWS 2019a, pp. 36113 – 36116), and an estimated date of completion is planned for Fiscal Year 2022. This Species Status Assessment (SSA) is a comprehensive review of the Texas golden gladeceess and will provide the biological basis for the Service's recommendations in the 5-year review and its recovery plan.

Additionally, the SSA will be a basis to guide future actions, which may include Section 7 consultations, management plans, and any revisions or updates to recovery plans and/or 5-year reviews. 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 for the species to maintain long-term viability. For the purpose of this assessment, we define the viability of the Texas golden gladeceess 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).

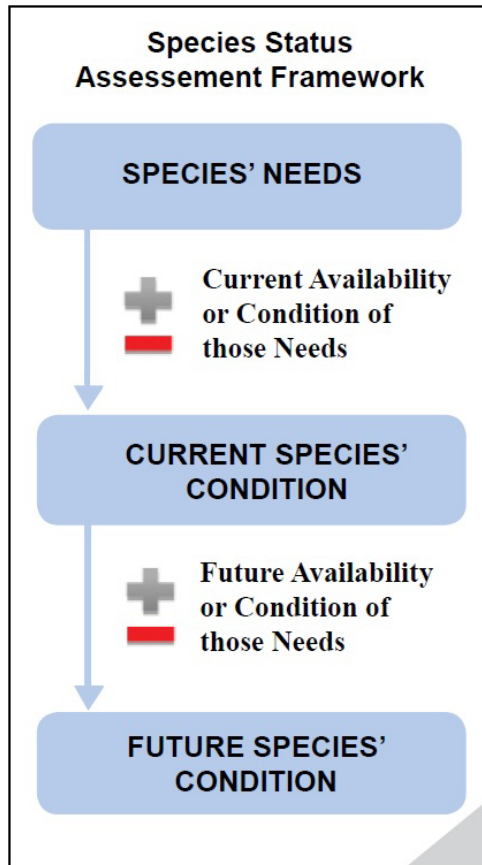


Figure 1.1.1. Species Status Assessment Framework.

In summary, this review is not a decision-making document, rather an inclusive scientific review of the available information related to Texas golden gladeceess, 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.

1.2 Species Morphology

The following description of Texas golden gladeceess is adapted from Mahler 1987 (pp. 239-242); Poole *et al.* 2007 (p. 286) who adapted it from others (Rollins *et al.* 1970, Mahler 1987, Rollins 1993; *In* Poole *et al.* 2007); and, Flora of North America (FNA) (Al-Shehbaz and Beck 2010c, pp. 486-487) (Figure 1.2.1):

Texas golden gladeceess is a weakly rooted, glabrous (smooth, glossy), winter annual. The species is small in stature, less than 3.9 inches (in) (10 centimeters (cm)) in height,

making it difficult to find except during flowering or when it bears fruit. The leaves are 0.8–3.1 in (2–8 cm) long and 0.4–0.6 in (1–1.5 millimeters (mm)) wide, forming rosettes at the base of the plant. Terminal leaf segments are wider-than- long, and usually distinctly lobed, with angular teeth. Flowers are bright yellow and borne on scapes that are 1.2–3.5 in (3–9 cm) long early in the flowering season. Later in the season, the flowers can occur in several-flowered short-stalked clusters. Later in the season, the flowers occur on unbranched flower clusters that come off a single central stem from which the individual flowers grow on small stalks, at intervals. The four petals are bright golden-yellow with a slightly darker base, narrowly obovate, 0.3–0.4 in (7–10 mm) long and 0.1–0.2 (3.5–5 mm) wide. The fruit is a siliqua, with a length (0.6–1.2 in (15–30 mm)) that is more than twice its width (0.08–0.22 in (2–5.5 mm)) and that contains 5 to 11 flattened, circular or spherically shaped seeds.

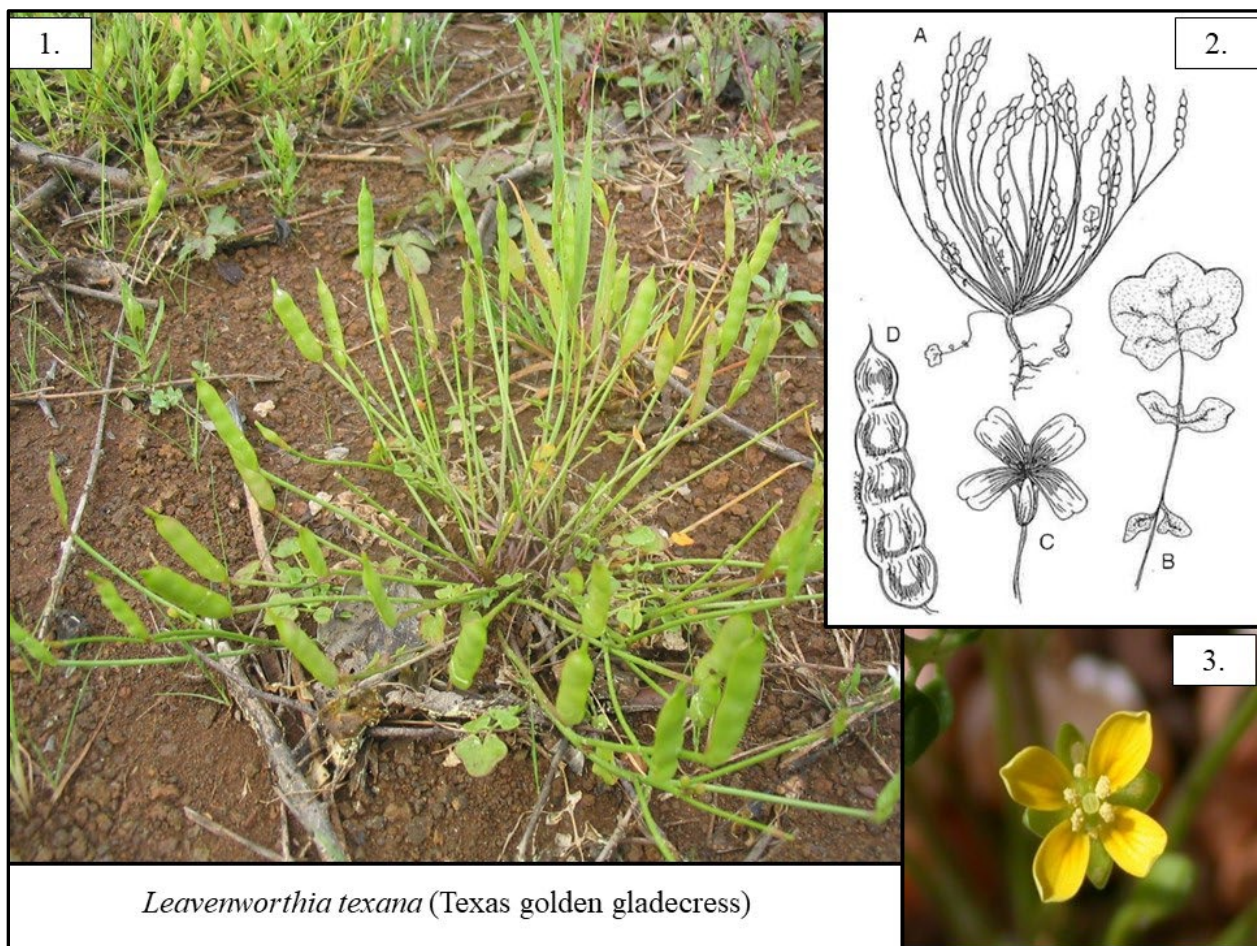


Figure 1.2.1. Diagram credits: 1. Whole plant in fruit (J. Singhurst); 2. Line drawing of habit (A), leaf (B), flower (C), and fruit (D) (Mahler 1981, *In Poole et al.* 2007, p. 287); and, 3. Flower (J. Singhurst, in Center for Plant Conservation (CPC)).

1.3 Taxonomy and Genetic Diversity

The Texas golden gladeceess is a small, annual, herbaceous plant belonging to the mustard family (Mahler 1987, p. 239). The Brassicaceae has a nearly worldwide distribution with about 3,780 species; 519 species are native to North America north of Mexico (Al-Shehbaz 2010, p. 224). The genus *Leavenworthia* is endemic to the United States and includes only eight species (Al-Shehbaz and Beck 2010a, p. 485). Distinguishing these species from one another can be difficult without mature fruit, as five of the eight species have minor differences that can make identification difficult (Al-Shehbaz and Beck 2010a, p. 485).

Leavenworthia texana is a distinct and valid species recognized by the FNA (Al-Shehbaz and Beck 2010c, pp. 486-487) and the Integrated Taxonomic Information Service (ITIS) (2020, p. 1). *L. texana* is listed as synonymous with *L. aurea* var. *texana* in the Plants Database (Natural Resource Conservation Service (NRCS) 2022a, p. 2); however, neither the Service nor the FNA consider this valid. Dr. M. C. Leavenworth, an Army physician, first collected *L. aurea* in Choctaw County, Oklahoma, in 1835. Torrey described these collected specimens as a new species in 1835 (Mahler 1981, pp. 76–77). From 1836 to 1837, Leavenworth collected similar specimens near the present-day town of San Augustine, San Augustine County, Texas, and these were also initially identified as *L. aurea*. E. J. Palmer (1915 and 1918), and D. S. and H. B. Correll (1961 to 1962) (as cited by W. H. Mahler (1981, pp. 83)) made later collections of the plant in the San Augustine area. George and Nixon (1990, pp. 117–127) studied and mapped populations in this area between 1979 and 1980. Mahler studied the collected specimens and their habitat, and described the Texas plants as a new species, *L. texana* (Mahler 1987, pp. 239–242), based on differences in leaf and flower morphology, chromosome number, and location (Mahler 1987, pp. 239–242; see Table 1.3.1 below). This is the species listed and protected under the Act in September 2013.

Table 1.3.1. Characteristic Differences between *Leavenworthia texana* and *L. aurea* (Al-Shehbaz and Beck 2010b and 2010c, pp. 486-488).

	Location	Flower Morphology	Leaf Morphology	Chromosome Number
<i>L. texana</i>	Texas, only known from San Augustine County	sepals widely spreading, oblong-linear; petals spreading, bright yellow, narrowly obovate	margins shallowly dentate with terminal lobe transversely broadly oblong, 0.24 – 0.28 in (0.6-0.7 cm) by 0.31-0.43 in (8-11 mm) (distinctly shorter than wide)	2n = 22
<i>L. aurea</i>	Oklahoma	sepals widely spreading, oblong-linear, petals spreading, pale yellow	margins shallowly dentate, terminal lobe suborbicular 0.24 – 0.47 in (6-12 mm) by 0.20 - 0.43 in (5-11 mm) (equal to or slightly longer than wide)	2n = 48

Genetic studies of Texas golden gladeceess are minimal and not comprehensive. However, Dr. Banta and Dr. Placyk (2015, pp. 5-6) sampled two of the known populations of Texas golden gladeceess and found that there was high gene flow between sampled populations. Additional genetic studies that include all of the extant sites should be completed to assess the inter-population and across-the-range genetics for the species. The Texas golden gladeceess is considered an outcrossing species. Extensive genetic studies have been conducted on other members of the genus *Leavenworthia* a summary of the studies in chronological order is below: *Lloyd 1965* – The species in genus *Leavenworthia* is discontinuously spread across 10 states, with species divided by states into an eastern and a western section. Western sections in Texas of *L. aurea* occur in the Coastal Plain province; all other western sections occur in Missouri, Arkansas, and Oklahoma. Dispersal within each species is very limited and so it is highly probable that members of the genus once occurred in the intervening habitats between the known extant and occupied areas (p.11). Lloyd also discusses the possible modes of dispersal.

Rollins 1963 – This is a very detailed treatment of the genus *Leavenworthia* including a discussion on hybridization; breeding systems (~~self-compatible~~ (SC) vs ~~self-incompatible~~ (SI) (see Section 1.4.2 Reproduction and Phenology for more detail)); and comparisons of anther position, flower size, flower odor, flower movements, pollen quality, style length, silique length, and silique width and thickness. The general growth cycle is discussed along with geographical information. Prior to the description of *L. texana* as a distinct species in 1987 by Mahler, Rollins, and other botanical reports and surveys described the species as *L. aurea*.

Solbrig 1972 – Eleven populations belonging to six species of *Leavenworthia* were analyzed using isozyme patterns to determine the breeding system. Research from Solbrig showed that species that are outcrossers tend to have offspring that are more polymorphic than SC species that are presumed to be self-fertile (p. 158).

Mahler 1987 – Provides the current taxonomically accepted description of the Texas golden gladeceess and describes differences between *L. texana* and *L. aurea* based on geography and chromosome number.

Baskin and Baskin 1988 – Interpopulation variability occurs in the breeding system, flower color and color pattern, flower and fruit morphology, and enzyme pattern (p. 833). Rollins (1963, p. 833) described four new varieties of *Leavenworthia* based on morphological variation in *L. alabamica*, *L. crassa*, and *L. exigua*. The amount of genetic variation in *Leavenworthia* is correlated with the breeding system, rather than the geographic range occupied, and the SI taxa are more viable than SC species (p. 833).

Beck pers. comm. 2004 – This study describes the differences between *L. texana* and *L. aurea* based on genetic sequencing results (*L. texana* has a unique insertion) (p. 287).

Busch 2005 – This work compared the inbreeding depression between SI and SC individuals in *L. alabamica*. Busch found that isolated and island environments have SC mating systems (p. 1503). In species with genetically controlled SI, reductions in plant density may limit reproductive success of individuals (p. 1503). Self-compatibility among the known *Leavenworthia* species has evolved independently four times in its history (p. 1504).

Beck, Al-Shehbaz, and Schaal 2006 - *Leavenworthia* became the focus of a wide range of evolutionary studies including evolutionary ecology, population genetics, and development (p. 151). Interest in these areas was largely due to multiple hypothesized origins of SC within the genus *Leavenworthia*, and the view that SC species were derived from SI ancestors (p. 151). *L. texana* is thought to be the diploid progenitor to the tetraploid *L. aurea* and the two species are morphologically very similar, sharing the SC phenotypic syndrome (p. 153). Among the remaining populations of *L. aurea*, the Texas populations are diploid (n=11), distinguishing them from the tetraploid (n=24) Oklahoma populations. Mahler named the diploid plants in Texas as *L. texana*. Given that the *L. aurea*/*L. texana* lineage apparently did not receive *L. torulosa* chloroplast genome as did the *L. exigua* lineage, the distinct nature of these lineages seems justified (p. 156).

Al-Shehbaz 2010 - the treatment description in the Flora of North America that includes 634 species of the Brassicaceae, with 616 found in the U.S. (418 of which are endemic). Since Rollin's account in 1993, an additional 50 species have been added to the family. Morphological data alone are sometimes unreliable in establishing phylogenetic relationships within this family.

Al-Shehbaz and Beck 2010c - the treatment of *L. texana* as described in the Flora of North America (pp. 486-487) that clearly identifies that the species is a distinct species based on differences between the *L. aurea* (Al-Shehbaz and Beck 2010b, pp. 486, 488) in petal color, shape and margin of the terminal lobe, and chromosome number.

Busch and Urban 2011 – The genetic and geographic basis for the two breeding systems of SI and SC in *Leavenworthia* are discussed.

Busch et al. 2011 – Genetic structure and the basis for SC (or selfing) were examined within certain species of *Leavenworthia*.

Koelling et al. 2011 – This study measured the genetic diversity and structure of two species, *L. alabamica* and *L. crassa*, that have both SI and SC populations but occur within similar glade habitats.

1.4 Life History – Growth, Phenology and Reproduction, Mortality

1.4.1 Growth

Texas golden glade cress is similar to other species of *Leavenworthia* in that their seeds germinate during fall rains and the plants overwinter as small, tap-rooted rosettes (USFWS 2012 p. 55971; USFWS 2013, p. 56028; see Figure 1.4.1).

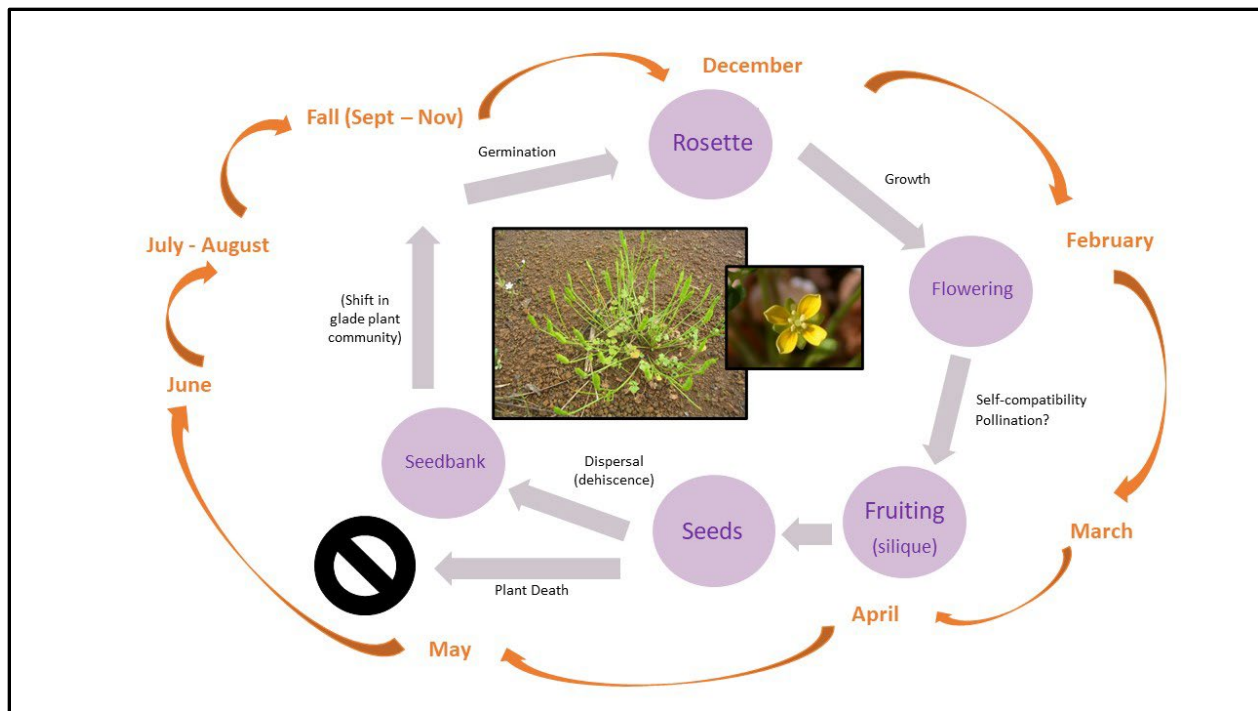


Figure 1.4.1. Life Cycle of Texas golden glade cress.

1.4.2 Phenology and Reproduction

Flowering

Flowering begins in February and continues until March, but may extend into April in times of suitable weather conditions (USFWS 2012, p. 55971). Busch and Urban (2011, p. 18) state that all *Leavenworthia* species flower briefly in early March until the first days in May; however, field observations suggest that Texas golden glade cress has a narrower blooming period, peaking in mid to late-February and extending until mid-March (J. Singhurst pers. comm., In Bearb 2020, p. 1). Rollins (1963, p. 6) noted that varying species in *Leavenworthia* bloomed according to the temperature, moisture, and severity of winter freezes. In general, flowers of *Leavenworthia* are very sensitive to light and may close when sunny conditions change to cloudy conditions. Flowers close in late afternoon on normally sunny days, and they do not open at all on cloudy or rainy days. *Leavenworthia* may also open and close several times during the course of a day when there are periods of alternating sunny and cloudy periods (Rollins 1963, p. 28).

Reproduction

It is thought that Texas golden glade cress is SC (Rollins 1963, p. 19; Beck *et al.* 2006, p. 153). The species may have evolved to self-fertilize in response to conditions that are not favorable for insect-vectored pollination, lessening the species' dependence on pollinators for cross-pollination and survival. This adaption may potentially make the species more resilient under conditions of small, geographically separated populations (USFWS 2013, p. 56028). However, the relative frequency of outcrossing and self-fertilization is unknown.

Rollins (1963) and Lloyd (1965) report exhaustive examinations of the evolution and systematics of *Leavenworthia* and SC versus SI species. Rollins (1963, pp. 41-47, In USFWS 2013, p.

56028) speculated that species of *Leavenworthia* may have evolved from an original SI ancestor to become SC in order to persist in times of inadequate moisture and reference how these alterations effect opportunities to flower and ultimately, the availability of pollen transfer by insect pollinators. Lloyd (1965) investigated the differences between greenhouse grown individuals of both SC and SI species of *L. crassa* and *L. alabamica*. He found that the more ancestral individuals were closely related to SI species and had more floral characteristics that would facilitate pollination. Neither of the abovementioned studies focused on *L. texana*, although since the species was included with *L. aurea* at one point, looking at the SC characteristics could be helpful.

Seeds and Seed Biology

Fruits are siliques and are generally produced in early March (J. Singhurst, pers. comm., *In* Bearb 2020, p. 1; USFWS 2013, p. 56028), maturing in the first few weeks in April (J. Singhurst, pers. comm., *In* Bearb 2020, p. 1). Examination of herbarium records show that a Texas golden gladeceess plant may produce anywhere between two to 29 seed capsules (siliques) (see Figure 1.2.3, Mahler's 1981 specimen; A. Tiller, pers. comm. 2020). Each silique may contain between 5 to 11 seeds (Rollins *et al.* 1970, Mahler 1987, Rollins 1993, *In* Poole *et al.* 2007, p. 286). This information suggests that a Texas golden gladeceess plant may be able to produce upwards of 300+ seeds per plant. However, studies investigating the species seed biology, production, and seed viability have not been conducted. Siliques dehiscce explosively, dispersing seeds within an extremely limited range of the parent plant, about 6-8 in (15-20 cm) for the Texas golden gladeceess (J. Singhurst, pers. comm. 2011c, *In* USFWS 2013, p. 56028), a feature common in most other members of the *Leavenworthia* genus (Lloyd 1965, p. 11). When plants are in bloom and/or in fruit, glade communities are wet and ponded from rainwater. Both the Service and partners postulate that ponding and rain events may aid seed dispersal within a small glade community, but do not provide the connection between more distant population occurrences.

In nature, particularly in cedar glades, when environmental conditions become unfavorable for species within the genus *Leavenworthia* later in the flowering season, the silique growth is arrested. The length of a silique largely depends on the growth it can accomplish prior to glade becoming too dry (Lloyd 1965, p. 63). Baskin and Baskin (1978, p. 126) studied the seedbank of the *L. stylosa* (another annual and rare endemic) and found that even under optimal conditions, not all seeds in a seasons' seed crop germinated in the same year they were dispersed, sometimes spreading over multiple germination seasons. This phenomenon could be advantageous in re-establishment of individuals at a site after none survived and/or increasing the genetic variability and stability in the population (1978, p. 128). Baskin and Baskin (1978, p. 126) and Baskin (1981, p. 246) also suggest that seeds are dormant at maturity and some seeds in a seed population/bank will afterripen (lose dormancy) during the hot summer months. For the Texas golden gladeceess specifically, little is known about its seedbank although it is likely persistent. Texas golden gladeceess has reappeared at two sites where it was believed to have been lost due to habitat degradation (USFWS 2012, p. 55971). The population known to occur in Sabine County (Element of Occurrence (EO) ID 5290) was bulldozed in late March 1999 and was described as "lost" after being surveyed that flowering season; however, plants were found again in 2003 and continued to emerge in several subsequent years when surveyed (2005 – 2009). In most of the years since 2009 to the present, the private portion of EO ID 5290 has been surveyed and plants have been observed, including in 2017, 2018, 2019 (M. Buckingham, pers. comm. 2022) and two times most recently in March 2022 (B. Fogel, pers. comm. 2022; S. Walker, pers.

comm. 2022). At the second known Texas golden gladeceess population at EO ID 2930, San Augustine County, the species reappeared after brush clearing activities of a nonnative plant (*Rosa bracteata*, Macartney rose) were conducted. Prior to its appearance at this site in 1995, Texas golden gladeceess had not been seen for 10 years (USFWS 2013, p. 56028). Both accounts of reappearance suggest that Texas golden gladeceess may have a persistent seed bank, although this has not been studied.

1.5 Resource Needs (Habitat) of Individuals

1.5.1 General Habitat

All of the known Texas golden gladeceess populations occur within the Pineywoods ecoregion of East Texas. Referred to as the biological crossroads, the Pineywoods' mix of geology, climatic variation, and ecotonal transitional zones make it an area known for its extreme floral diversity and high species richness (Diggs *et al.* 2006, p. 31). The region is defined by pine-dominated forests and woodlands interspersed with bottomland, mesic slope, and bald cypress-tupelo swamp forests. Many of the rare plants and their communities are found in small-scale plant communities tied to “geologic and hydrologic conditions that are themselves rare on the landscape” (Poole *et al.* 2007, p. 6).

1.5.2 Geology and Soils

Common habitat characteristics among species of the *Leavenworthia* genus are found in glade habitats that share shallow soil depths embedded at or near the surface that contains a high moisture content (Rollins 1963, pp. 4-6). Some of these species' glades may contain dolomite; however, the Texas golden gladeceess is endemic to the soils and geology specifically associated with the Weches geologic formation (referred to as simply the Weches). During what was once known as the Tertiary period (now obsolete) an alternating complex of intergrading and interbedding marine sediment layers and calcareous clays deposited over the area form the Weches. These sediments ultimately becoming deposited along a band parallel to the Gulf of Mexico and running from Sabine to Frio counties, Texas (Figure 1.5.2.1). Glades found atop the Weches formation should not be confused with the cedar glades in Tennessee, although they may both share similar soil characteristics (Baskin and Baskin 2004, pp. 408-409; Baskin and Baskin 2007, pp. 314, 316).

All glades that support *Leavenworthia* species are extremely wet during the late winter and early spring and experience extreme drying out in summer (Rollins 1963, p. 5). Busch and Urban (2011) describe the distribution of *Leavenworthia* in the United States (U.S.) (Figure 1.5.2.2). The species spans across the southeastern U.S., into the central highlands of the Ozark Mountains, where the peak of species diversity can be found in the Central Basin of Tennessee in cedar glades (Busch and Urban 2011, p. 17).

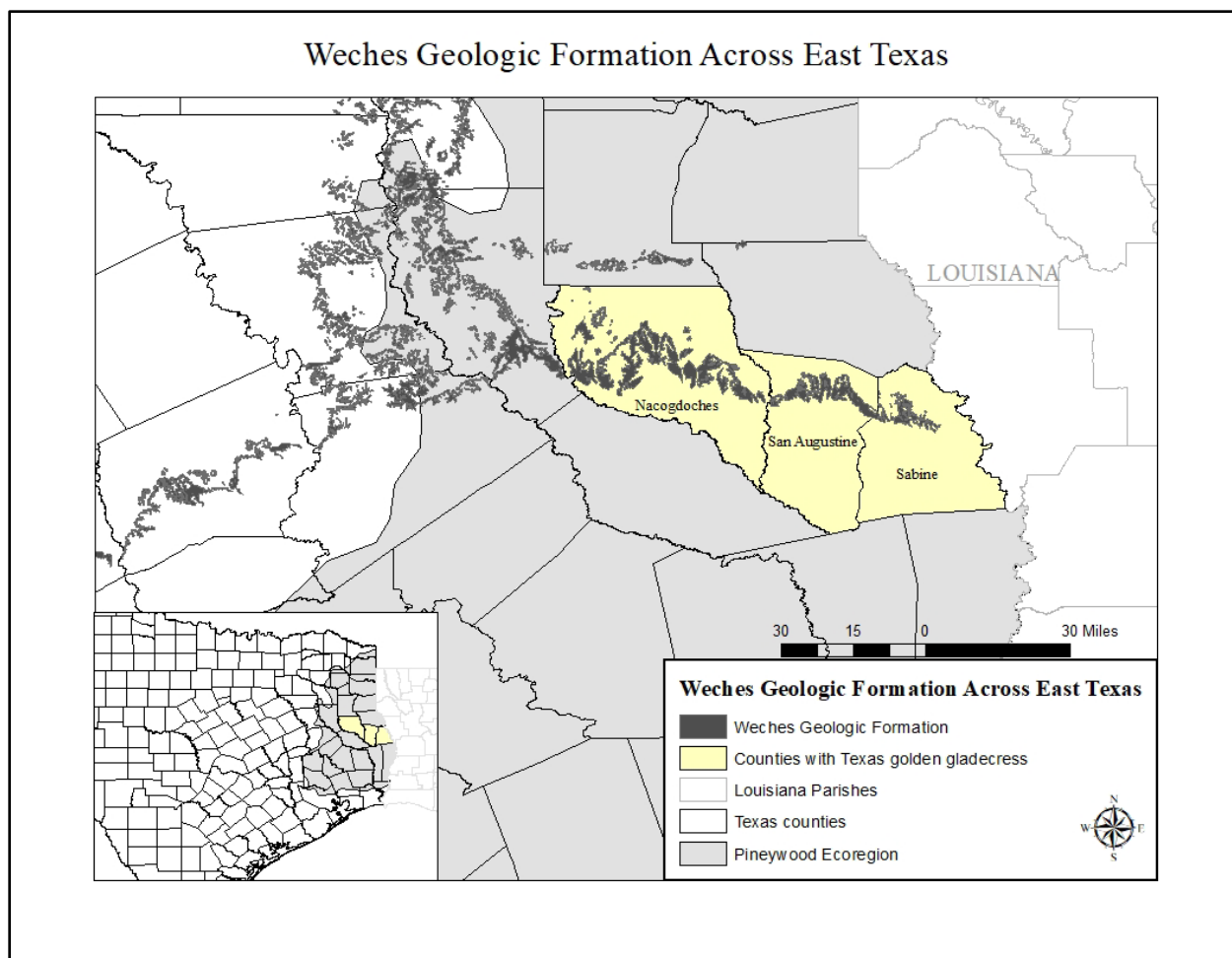


Figure 1.5.2.1. Band of Weches Geologic Formation across Texas.

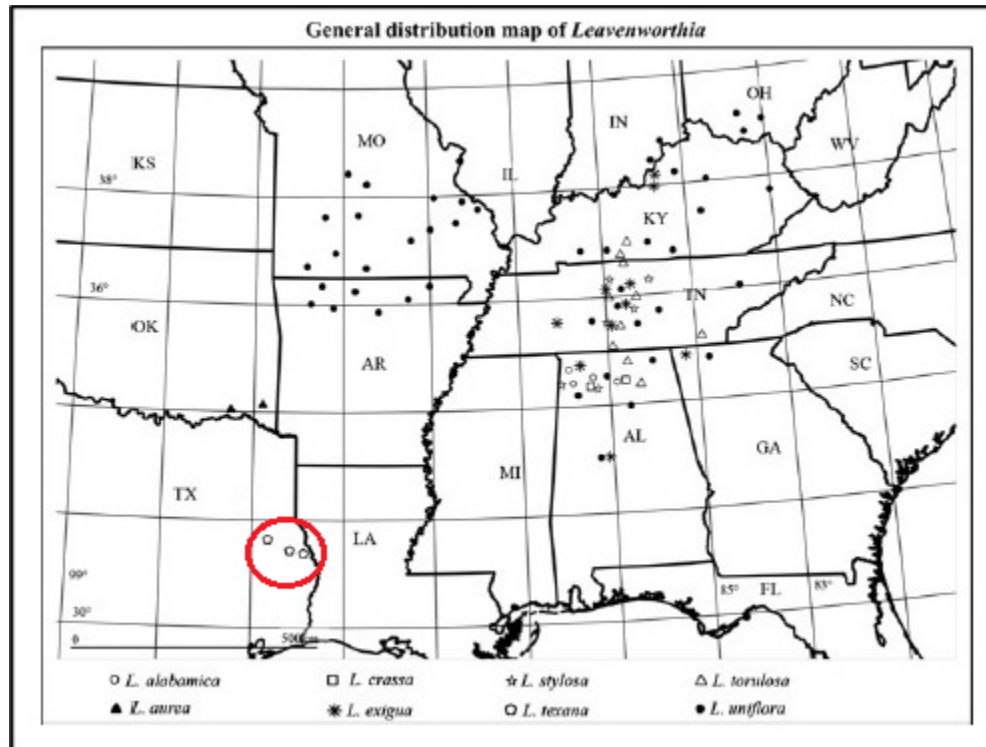


Figure 1.5.2.2. General distribution of all known species of *Leavenworthia* across the United States (In Busch and Urban 2011, p. 17). *L. texana* is circled in red in the above figure.

The Weches is characterized by the presence of the mineral glauconite along with clays, calcareous marls, rich marine fossil deposits, and mudstone (Sellards *et al.* 1932, In Diggs *et al.* 2006, p. 55; George 1987, pp. 8-9; George and Nixon 1990, pp. 117-118). The glauconite layer is normally exposed at the surface or is only covered by a thin layer of calcareous (calcium-containing) sediments measuring as deep as 20 in (50 cm). When exposed to the atmosphere, glauconite will change from its natural greenish state to red (Davis 1966, p. 17-18; George 1987, p. 9; Nemec 1996, p. 7), and may be referred to by locals as “redlands” (J. Ritter, pers. comm. 2011a). In some areas of the Weches, soluble ingredients of the Weches have leach out and iron becomes concentrated (Diggs *et al.* 2006, p. 55). Areas rich in iron are a focus for mining activities.

Soils of the Weches range from shallow and rocky which naturally limits growth of woody vegetation (George 1987, p. 3) on the steeper slopes to deeper on the flatter slopes; they have a basic pH; and, have a layer of glauconite clay (Diggs *et al.* 2006, p. 56). This soil is very crumbly with a low resistance to weathering and are classified within the Nacogdoches, Trawick, or Bub soil series (Griffith 2009, entire). Water will typically pond during the spring and summer months and slowly percolate off the glade because of the impermeable clays, ultimately exiting the hillsides and edges of outcrops (Diggs *et al.* 2006, p. 56; J. Singhurst, pers. comm. In Bearb 2020, p. 3). The down-slope seepage across the Weches glade terraces may also be important to maintain the hydrology required by the Texas golden gladecress (J. Singhurst, pers. comm. 2003). This suite of characteristics (soil, substrate, and slope) forms the Weches glade communities where the Texas golden gladecress is located. Banta and Placyk (2015, p. 4) investigated soil composition at sites with the species’ present and those without plants for

comparison. Their findings show a higher soil pH and soil phosphorus with lower soil potassium in glades occupied by Texas golden gladeceess as compared to unoccupied glades. Texas golden gladeceess may require a higher pH and potassium levels than previously documented, as compared with other habitat features of glades (2015, p. 4).

Another federally listed species, the white bladderpod (*Physaria pallida*) is found within similar glade habitats but to our knowledge is found only in San Augustine County, Texas. The Weches outcrop occurs in a band averaging 5 miles (mi) (8 kilometers (km)) in width that loosely parallels Texas' State Highway (SH) 21 (Sellards *et al.* 1932, *In* Diggs *et al.* 2006, p. 56). Individual glades can vary in size ranging from as small as a few meters to larger than 236 acres (ac) (95.6 hectares (ha)). Most extant and historic, Texas golden gladeceess glades are restricted to small areas that range from less than 0.0023 acres (ac) (0.0009 hectares (ha)) to 0.2 ac (0.1 ha).



Figure 1.5.2.3. Marine sediments visible at glade openings on the Weches Formation in East Texas (source: Singhurst 2012).

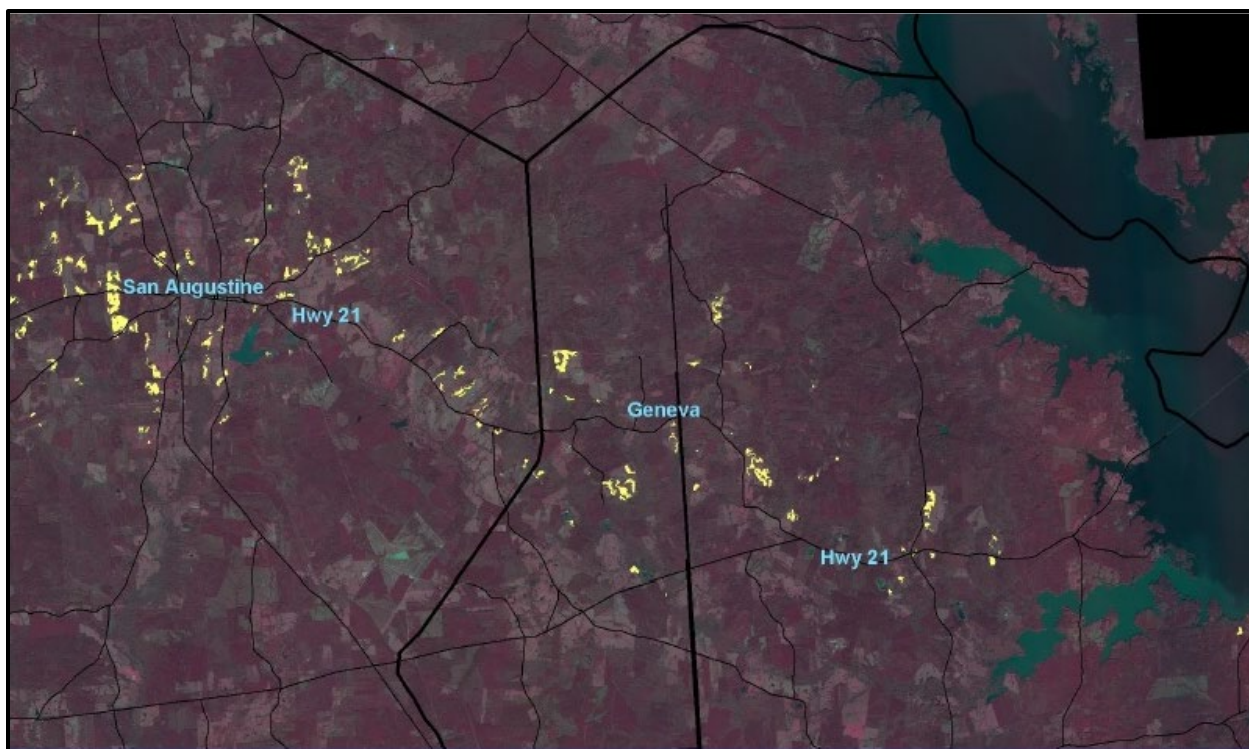


Figure 1.5.2.1. Mapped Potential Extent of Weches glades/prairies as it spans across San Augustine and Sabine counties, Texas, concentrating along SH 21 (J. Singhurst, pers. comm. 2012a).

1.5.3 Climate

Precipitation

A steep east-west precipitation gradient across East Texas exists with the wettest conditions occurring in the most southeastern corner of the region in Orange County with 58.93 in (150 cm) (Diggs *et al.* 2006, p. 70). The average annual rainfall in the Pineywood ecoregion is between 60 in (152 cm) along the southeastern border with Louisiana and 40 in (98 cm) to its most western edge (Diggs *et al.* 2006, p. 79). Precipitation is relatively evenly distributed throughout the year (Diggs *et al.* 2006, pp. 70, 79) although frequent thunderstorm activity and hurricanes may attribute to higher rainfall amounts in the summer months. Climographs of the Pineywoods (climate division/region #4 according to the National Climate Change Data) show that the summer months typically experience less frequent rain events with hotter temperatures (Figure 1.5.3.1).

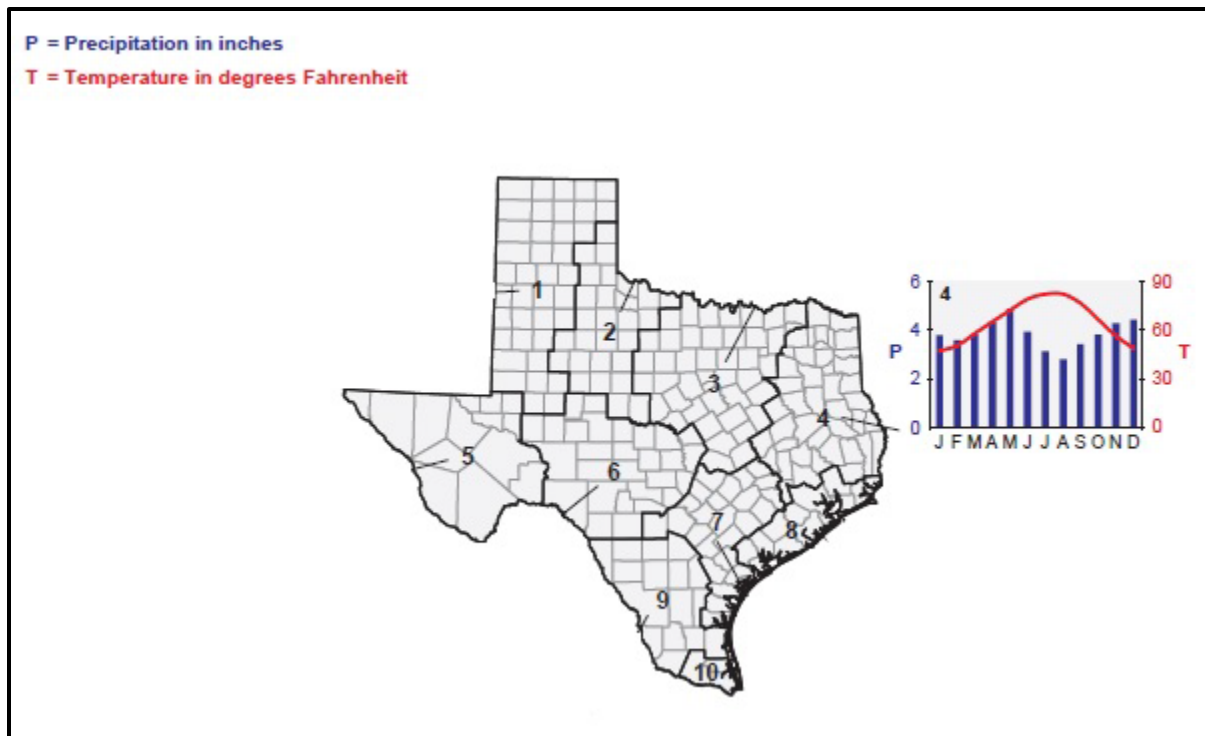


Figure 1.5.3.1. Climograph of Pineywoods Ecoregion (region #4) showing precipitation (in inches) and temperature (in degrees Fahrenheit) (source: NCDC, *In Texas Water Development Board* 2012, p. 4).

Within the known geographic range of the Texas golden glade cress, winter rainfall events in December, January, and February are important for spring ponding on the glade communities and the species' blooming. Average winter (Dec, Jan, Feb) precipitation amounts between 1999 and 2021 have ranged from a high of about 24.74 in (62.84 cm) in San Augustine County to a low of 7.27 in (18.47 cm) in Nacogdoches County during the winters of both 2013-2014 and 2018-2019, respectively (National Center for Environmental Information (NCEI 2021, 2022a) (Figures 1.5.3.2 and 1.5.3.3). Averages for the winters of 2014-2015, 2010-2011, and 2009-2010 at the San Augustine County station are displayed as zeros due to missing data for one or more months. Based on the available data at the San Augustine station, the average rainfall over this timeframe is 12.97 in (32.94 cm). Average winter precipitation for Nacogdoches County (station US1TXNC0005) from 2011-2021 is 13.38 in (33.99 cm) (NCEI 2022a) (Figure 1.5.3.3). There are several stations within/near the town of Nacogdoches, however these stations were not selected based on their perceived influence from heat island effects. Only one station is within proximity to the Sabine County population therefore, for this site we used the San Augustine station as our data reference point due to its proximity.

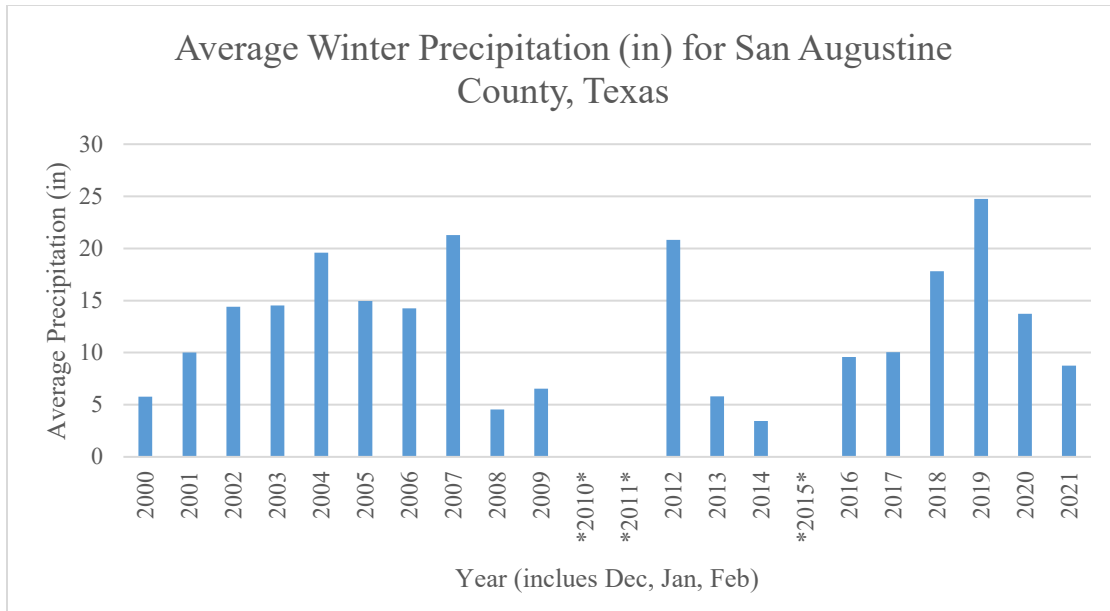


Figure 1.5.3.2. Average winter precipitation for NCEI weather station, San Augustine, Texas (Station USC00417951) from 1999-2021. Precipitation data was not available for years 2010, 2011, and 2015, and is therefore, denoted by an asterisk (*).

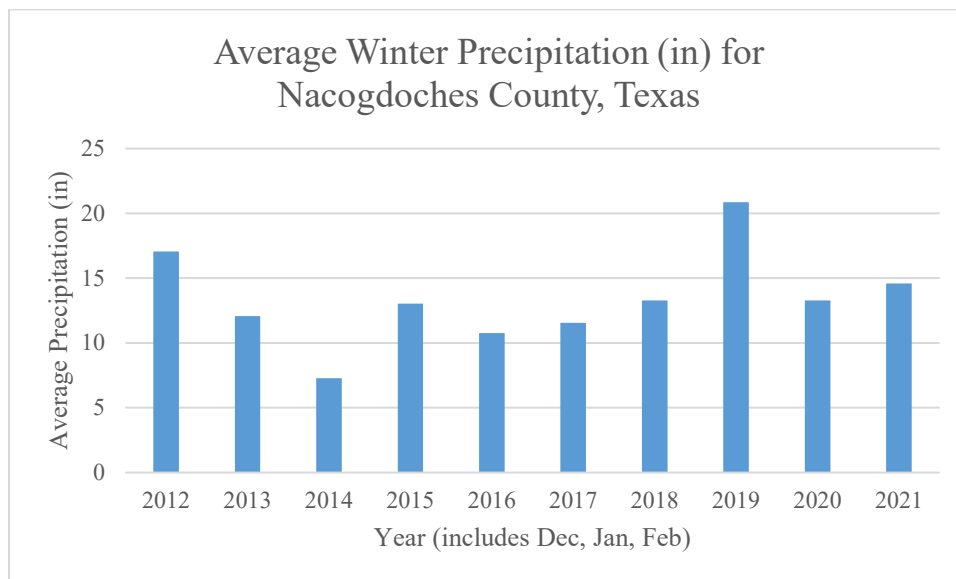


Figure 1.5.3.3. Average winter precipitation for NCEI weather station, Nacogdoches, Texas (Station US1TXNC0005) from 2011-2021.

Texas golden glade cress is dependent on late fall-winter precipitation in order to keep the glade sediments saturated and water pooled on the small outcrops. As stated in the species' final listing rule (USFWS 2013, entire), the species is highly restricted to wet microhabitats and even further restricted within suitable sites to seasonal seep runs and vernal pools (Singhurst 2011, p. 3).

Temperature

Temperatures within this 3-county region between 1980 and 2021, have historically ranged from an average low of 40.0 °F (4.44 °C) in December 1989 to an average annual high of 89.8 °F (32.1 °C) in August 2011 (NCEI 2022b-g, h-m, n-r, entire) (Figure 1.5.3.4). However, extreme temperatures have occurred within this region. For example, in February 2021, a historic weather event brought cold, snow, and ice along with freezing temperatures to the area, while in the summer of 2000 numerous days of 100+ °F were noted. When Texas golden glade cress is blooming in February, mild temperatures with a mean of 51.8 °F (11.0 °C) (between 1980 and 2021) (NCEI 2022b-g, h-m, n-r, entire) allow for water to remain ponded on-site on the glades. Once the summer temperatures are reached in July and August each year, standing water that once existed on each glade evaporates and soils become parched and dried out. The average temperature in August is 89.1 °F (27.6 °C) within the species known geographic range, from 1980-2021 (Figure 1.5.3.4)).

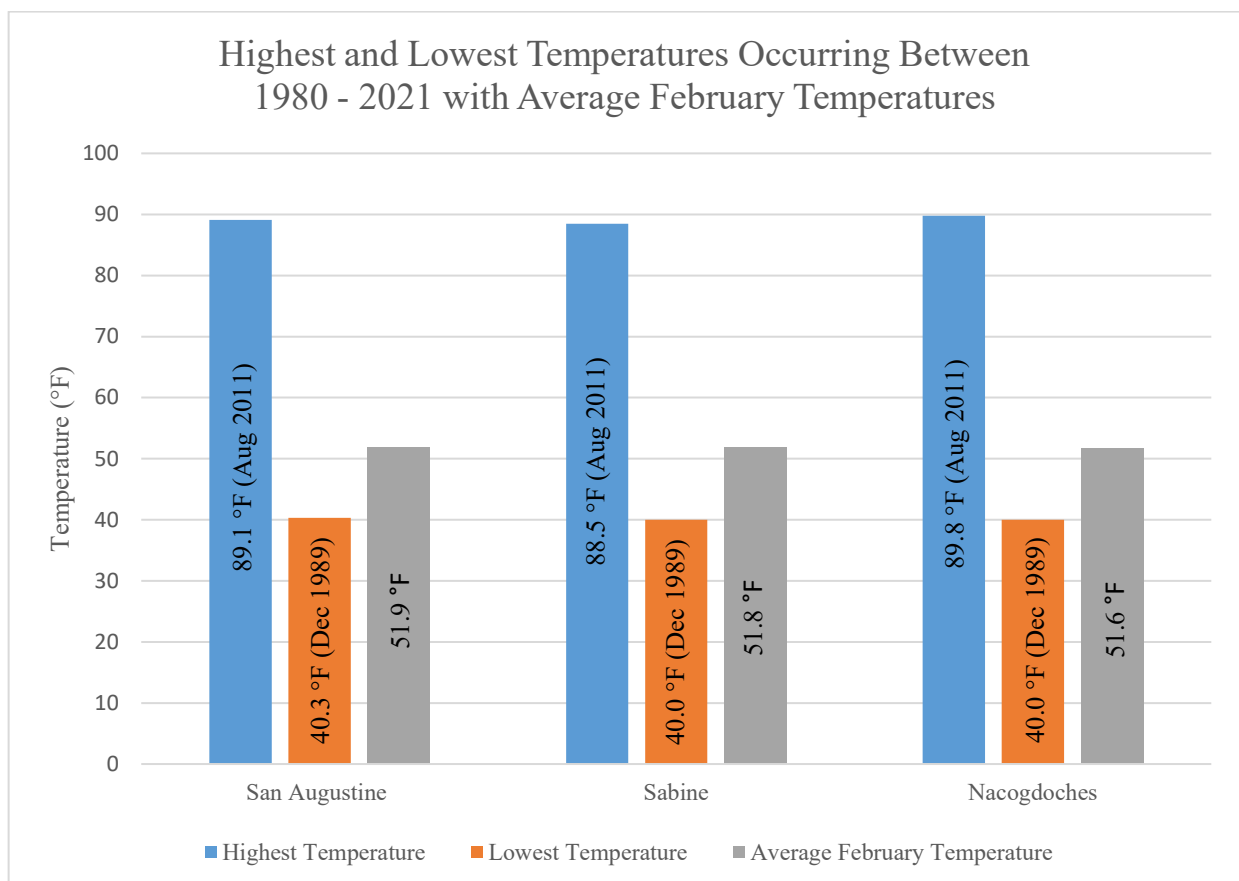


Figure 1.5.3.4. High and low temperatures exhibited for each county between 1980-2021 across the species known geographic range (NCEI 2022b-g, h-m, n-r, entire). Highest temperatures for each county were recorded in August 2011, with the lowest county temperatures all occurring in December 1989. Average February temperatures are noted across the species three-county range. The two outlying historic weather events in February 2021 (freeze) and summer 2000 (100+ °F) were not included in this figure.

1.5.4 Associated Glade Species

The Weches outcrops and surrounding glade sites show a large seasonal shift in species dominance as a result in the shift from wet winters/springs with saturated soils to hard, dry soils in the summer (George and Nixon 1990, pp. 120-124). Many of the glades have bare spots on top of the glade where seasonal water pools (similar to vernal pools). The Weches is dominated by species such as *Isoetes butleri* (Butler's quillwort), an obligate wetland species, and others that thrive and require spring seasonal ponding. The Weches within the range of the Texas golden glade is dominated by these and other herbaceous associated species (Tables 1.5.4.1, 1.5.4.2, 1.5.4.3, and 1.5.4.4), whereas in other areas of Texas with these glades the species composition is quite different. George and Nixon (1990, p. 120) examined the floral associates of three Weches outcrops and found that most glade associated plants began flowering during March, with spring blooming species comprising 53 percent of the yearly blooming species. Once the summer months arrive, these species are replaced by low-growing species such as *Sedum pulchellum* (stonecrop), *Portulaca oleracea* (common purslane), *Phemeranthus parviflorus* (sunbright), and *Eleocharis occulata* (limestone spikerush) (J. Singhurst, pers. comm. 2012b) that are upland and/or succulent species. The most prominent species associated observed in surveys of March 2022 appeared to be *S. pulchellum*, *Clinopodium arkansanum*, *Allium drummondii*, *Portulaca oleracea*, and *Opuntia* species (B. Fogel pers. comm. 2022). Glade species are well-adapted to the extreme change in seasonal temperatures and have evolved with, even adapted to, the extreme environmental conditions. However, even with this, native plants can be adversely affected by these extremes (Diggs *et al.* 2006, p. 67). The tables below depict the common associated species as discussed above as well as their National Wetland Indicator Status. Blanks within this column specifically indicate that the species is not associated with any type of wetland.

Table 1.5.4.1. Primary herbs associated with Weches outcrops (Lady Bird Johnson Wildflower Center and U.S. Department of Agriculture, NRCS wetland indicator status ranking for Atlantic and Gulf Coastal Plain region).

Scientific Name	Common Name	National Wetland Indicator Status
<i>Sedum pulchellum</i>	stonecrop, widows cross	<u>UPL</u> (upland – nonhydrophyte)
<i>Clinopodium arkansanum</i> (<i>Calamintha arkansana</i>)	Ozark savory, limestone calaminth, low calaminth	<u>FACW</u> (facultative wetland)
<i>Minuartia patula</i>	pitcher's sandwort	<u>FAC</u> (facultative)
<i>Minuartia drummondii</i>	Drummond sandwort	
<i>Valerianella radiata</i>	beaked cornsalad	<u>FACU</u> (facultative upland)
<i>Isoetes butleri</i>	Butler's quillwort	<u>OBL</u> (obligate wetland)
<i>Allium drummondii</i>	Drummond wild-garlic	
<i>Portulaca oleracea</i>	common purslane	FACU
<i>Phemeranthus parviflorus</i>	sunbright	
<i>Eleocharis occulata</i>	limestone spikerush	

Table 1.5.4.2. Other potential associated plants found on the Weches outcrops with Texas golden glade cress (Lady Bird Johnson Wildflower Center and U.S. Department of Agriculture, NRCS wetland indicator status ranking for Atlantic and Gulf Coastal Plain region).

Scientific Name	Common Name	National Wetland Indicator Status
<i>Erigeron strigosus</i>	daisy fleabane (possible invasive)	
<i>Physaria pallida</i>	white bladderpod	FACU
<i>Desmanthus illinoensis</i>	Illinois bundleflower	FACU
<i>Euphorbia dentata</i>	toothed spurge	
<i>Croton monanthogynus</i>	dove weed	
<i>Dalea purpurea</i>	purple prairie clover	
<i>Houstonia</i> spp.	bluets	
<i>Nassella leucotricha</i>	Texas wintergrass	
<i>Bouteloua curtipendula</i>	sidecoats grama	
<i>Eleocharis compressa</i>	flat-stem spike-rush	FACW
<i>Sporobolus vaginiflorus</i>	poverty dropseed	
<i>Thelesperma filifolium</i>	greenthread	
<i>Arnoglossum plantagineum</i>	groovestem Indian plantain	FACU
<i>Plantago virginica</i>	Virginia plantain	FACU
<i>Schizachyrium scoparium</i> var. <i>scoparium</i>	little bluestem	
<i>Polytaenia texana</i>	Texas prairie parsley	
<i>Onosmodium bejariense</i>	soft-hair marbleseed	
<i>Liatris punctata</i> var. <i>mucronata</i>	narrow-leaf gayfeather	
<i>Draba cuneifolia</i>	wedgeleaf draba	
<i>Paronychia virginica</i>	whitlow-wort	
<i>Camassia scilloides</i>	wild hyacinth	FACW
<i>Zigadenus nuttallii</i>	Nuttall's death camas	

Table 1.5.4.3. Algae associated with the Weches outcrops (Lady Bird Johnson Wildflower Center and U.S. Department of Agriculture, NRCS wetland indicator status ranking for Atlantic and Gulf Coastal Plain region).

Scientific Name	Common Name	National Wetland Indicator Status
<i>Nostoc</i> spp.	cyanobacteria	

Table 1.5.4.4. Frequent woody species associated with the Weches outcrops (Lady Bird Johnson Wildflower Center and U.S. Department of Agriculture, NRCS wetland indicator status ranking for Atlantic and Gulf Coastal Plain region).

Scientific Name	Common Name	National Wetland Indicator Status
<i>Juniperus virginiana</i>	eastern red cedar	FACU

<i>Pinus taeda</i>	loblolly pine	FAC
<i>Liquidambar styraciflua</i>	sweetgum	FAC
<i>Cornus drummondii</i>	roughleaf dogwood	FAC
<i>Sideroxylon lanuginosum</i>	gum bumelia	FACU
<i>Styphnolobium affine</i>	Texas sophora	
<i>Quercus muehlenbergii</i>	chinquapin oak	UPL
<i>Opuntia</i> spp.	prickly pear cactus	UPL
<i>Rhus glabra</i>	smooth sumac	
<i>Rhamnus lanceolata</i>	lanceleaf buckthorn	FAC

1.5.5 Open canopy

Glade communities across the country including those in Tennessee, Arkansas, Missouri, and Texas are typically surrounded by a savanna or woodland, with few tree species surrounding the glades themselves (NRCS 2017a, p. 1).

Texas golden gladeceess is found only on treeless glades in East Texas (Mahler 1987, p. 240) that are open in full sun (i.e., lacking any tree canopy/shading) (Quarterman 1950, p. 1; Rollins 1963, p. 5). Texas golden gladeceess occurs in an open, sunny, herbaceous-dominated community in the Weches glade (Bridges 1988, pp. 8-9). Like other glade endemic species, Texas golden gladeceess is shade intolerant as seen by its tight association to well-lit portions of the outcrop, without a closed canopy or without any leaf litter (Baskin and Baskin 1988, p. 834; CPC 2011, p. 3). The species is intolerant of competition with light resources and is most successful with sparse herbaceous ground cover. Carr (2005, p. 2) and Fogel (B. Fogel, pers. comm. 2022) found that most *L. texana* plants are found on or around a few spots of the glauconite where it is exposed rather than parts of the glade densely covered by herbaceous vegetation. Carr also observed that the total coverage or shading by trees (mainly *Pinus* spp (pine)) was less than 10 percent of the total polygon where plants were located (2005, p. 2).

1.5.6 Population connectivity

As stated in the species' proposed listing rule (USFWS 2012, p. 55995);

“The Weches glades form a small patch system of habitats...that primarily occur in Nacogdoches, San Augustine, and Sabine counties. The width of the Weches outcrop region varies from 2-5 mi (3.2 – 8 km) (Sellards *et al.* 1932, *In* Diggs *et al.* 2006, p. 56) and encompasses the route of SH 21. All known Texas golden gladeceess populations occur, or formerly occurred, within 1 mi (1.6 km) of SH 21. Populations in close proximity to each other were part of the EO ID 1786 that contained five of the eight known sites. This entire complex was located within an area that did not exceed 1 mi (1.6 km) from the most northern to most southern plant occurrences and extended less than 0.32 mi (0.53 km) from east to west. Multiple glades within close proximity to one another may have facilitated cross fertilization between populations, enhancing genetic diversity, and perhaps providing space for population expansion.”

There is the potential for additional glades to be present within the known geographic range of the Texas golden gladeceess. Singhurst mapped and ranked additional glade habitats that could support the species (J. Singhurst, pers. comm. 2012; see Figure 1.5.2.1). Most of these potential glades identified occur on privately-owned lands making access to verify the presence/absence challenging. With more populations likely spanning the landscape, it is possible there is more connectivity between populations. In March 2022, visits with all of the known Texas golden gladeceess landowners was attempted; however, permission to access was not granted for all populations. Therefore, connectivity between known populations of the Texas golden gladeceess is still a question.

Dispersal within the species is very limited and so it is highly probable that members of the *Leavenworthia* genus once occurred in the intervening habitats between the known extant and occupied areas (Lloyd 1965, p. 11). Texas golden gladeceess siliques dehisce (release) seeds only a few inches from the parent plant (J. Singhurst, pers. comm. 2011c, *In* USFWS 2012, p. 55971; Bearb 2020, p. 1), therefore the seed dispersal range is expected to be extremely limited, much like most other members of the *Leavenworthia* genus (Lloyd 1965, p. 11). Wet conditions and ponding on the glades may help to facilitate inter-glade movement of seeds, but more far-reaching dispersal is not likely feasible via this mechanism. Due to the limited number of known populations across the landscape and the species' limited dispersal abilities, connectivity between and among Texas golden gladeceess populations is essential for its genetic exchange and gene flow. It is unknown if animals act as potential dispersal vectors for seeds.

1.5.7 Pollinators

Much research has focused on the reproductive nature and the evolution of members of the *Leavenworthia* genus. Lloyd (1965) found that pollinators were less common in smaller glades, where selfing (SC species) appeared to evolve, inferring that small populations are more likely to have shifted to selfing as compared with larger populations (Busch and Urban 2011, p. 18). The amount of genetic variation within the *Leavenworthia* genus is correlated with its breeding system, rather than geographic range occupied, and the SI taxa are more viable than SC (Baskin and Baskin 1988, p. 833). Lloyd (1965, pp. 107, 114) found that species of *Leavenworthia* share the same floral structure of *Raphanus raphanistrum* (wild radish in Brassicaceae family) and have similar pollinators, primarily native solitary bees and honeybees. Lloyd's research was one of the first to suggest that the floral forms present today in *Leavenworthia* were a result of past pollinator-mediated selection (Anderson and Busch 2006, p. 866).

Texas golden gladeceess is considered a SC species meaning that it can reproduce via self-fertilization as well as through out-crossing with other individuals. Even when self-fertilized, fertilization may still require pollinators. Although pollinating insects have been associated with some *Leavenworthia* species, specific pollinators to the Texas golden gladeceess have not been identified. Potential pollinators of Texas golden gladeceess may include species from the orders Diptera (true flies) and Hymenoptera (ants, bees, wasps) (Turner 2001, *In* CPC 2011, p. 3; USFWS 2013, p. 56028) although we lack research evidence to support this.

CHAPTER 2 – Population-level Ecology

2.1 Geographic Range of the Genus

The species of *Leavenworthia* are spread over a considerable number of discontinuous areas in ten states (see Figure 1.5.2.2). *Leavenworthia* has extremely limited powers of dispersal (see below) and it is highly probable that members of the genus must once have occurred in the intervening areas between those presently occupied. Moreover, Lloyd (1965, p. 11) supported this theory by comparing the chromosome counts of *Leavenworthia*. He indicated that *Leavenworthia* most likely evolved from forms which are now extinct because the diploid chromosome number of $n=11$ and $n=15$, is vastly different than the isolated polyploid $n=24$ of *L. aurea*.

2.2 Population Distribution

The geographic location of plants has often been described by several interchangeable terms, including populations, sites, and locations. NatureServe (2020, p. 2) defines an 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 Texas Parks and Wildlife Department (TPWD), has adopted the use specifically of EO records to track and describe the location of plants, animals, and habitats of conservation concern.

TXNDD has noted 4 extant EO records for the Texas golden glade cress (Table 2.2.1) (Figure 2.2.2): EO IDs 1786, 5290, 2930, and 4779. As stated earlier, Mahler determined and identified these records as *L. texana* based on morphological differences between this species and *L. aurea*. Of the four known sites, three are natural and one in Nacogdoches County is introduced (EO ID 4779).

Table 2.2.1. Known EO records for *L. texana* from its known geographic range (TXNDD 2020, pp. 1-18). EO IDs 1786, 5290, and 2930 were visited in March 2022 and are denoted with an asterisk (*) (B. Fogel, pers. comm. 2022).

Population No.	EO No.	EO ID	Source Features (SF)	County	Site Ownership	Estimated Maximum Population Size	Status
1	1	1786	21311, 11595, 4171, 8330, 420, 7825	San Augustine	Private/right-of-way (ROW)	1,000 plants in 1984.	Extant (natural) - last visited in March 2022 but no plants present.*
2	2	5290	5290, 21313	Sabine	Private/ROW	1,000 plants in 2007.	Extant (natural) – last visited in March 2022 and plants present.*
3	3	2930	11295, 21309	San Augustine	Private	200 plants in 2007.	Extant (natural) – last visited in March 2022 but no plants present.*
4	4	4779		Nacogdoches	Private	2,873 plants in 2005.	Unknown (introduced)
EXT (extirpated)		6465		San Augustine	Private		Extirpated (natural)

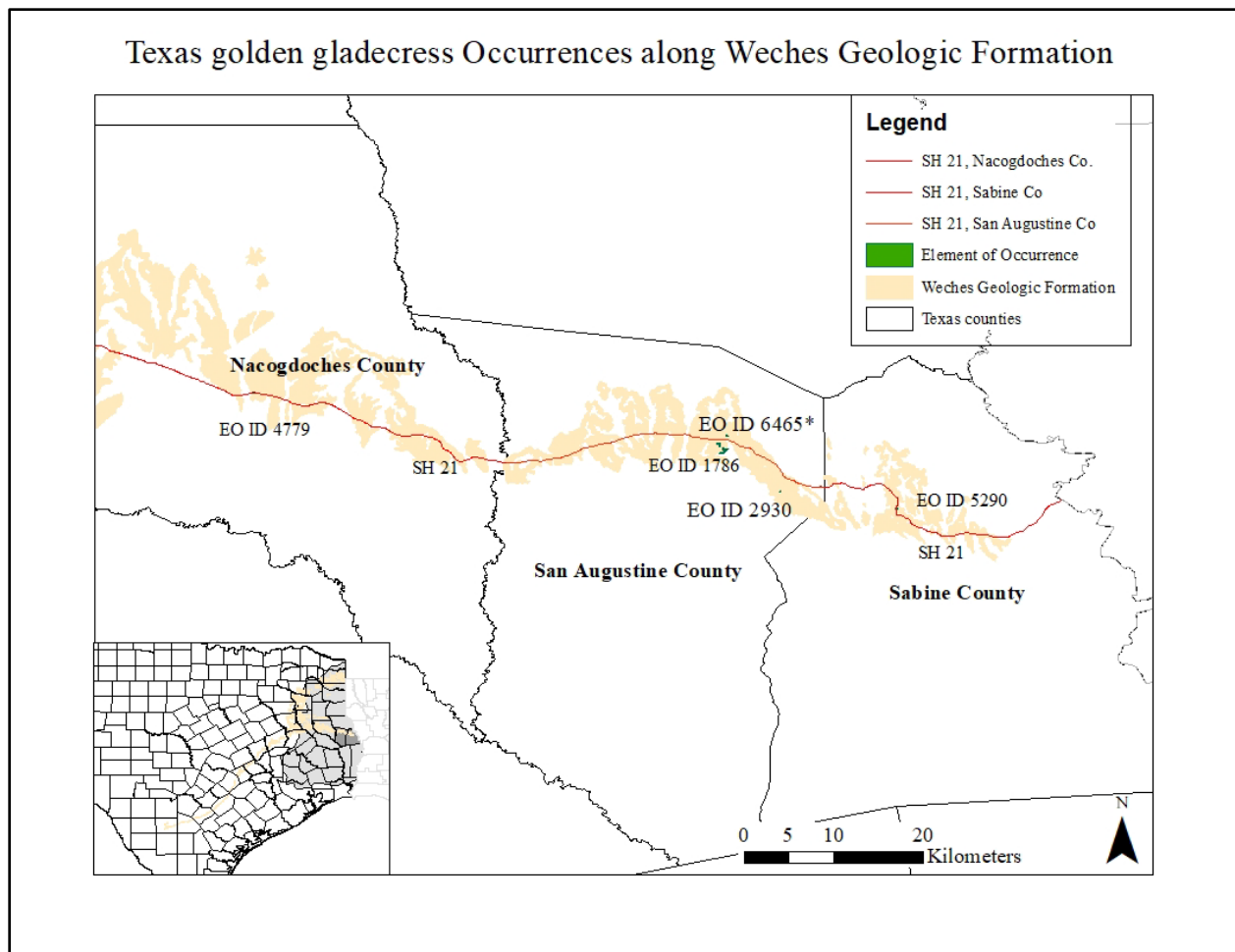


Figure 2.2.2. Geographic Distribution of natural Texas golden gladeceess EO records within San Augustine, Sabine, and Nacogdoches counties, Texas. EO ID 6465 is presumed extirpated and is denoted with an *.

The Service defines a Texas golden gladeecress population by using the standard separation distance between populations as outlined by NatureServe that states a separate population is ≥ 1.0 km (0.62 mi) apart (2020, p. 5). TPWD also uses this separation distance when data is lacking to suggest otherwise. Based on this separation distance, there are four recorded populations (three natural, one introduced). The EO ID 1786 has multiple source features (SFs) that are within this 1.0 km distance, atop the same geologic formation. Therefore, we refer to this site as a metapopulation. There are likely additional Texas golden gladeecress populations across the landscape and within intervening areas of suitable habitat. However, we are unsure of how populations are connected due limited access to properties. Also, the lack of management or use of effective management strategies (i.e., grazing of livestock during plants critical part of life cycle, prescribed burning, mowing to reduce invasive species, herbicide use, etc.) may be causing the sites to be inhospitable for the Texas golden gladeecress and its native plant associates. Intervening habitat between known sites has not been accessed and likely struggles from similar concerns.

The following information briefly describes the locations and status of the known populations of gladeecress. Additional information on these populations is listed above in Table 2.2.1.

EO ID 1786, San Augustine County, natural – extant

This glade complex includes four EO records: the original EO 1 (EO ID 1786), and EOs 6, 7, and 8 (EO IDs 420, 7825, and 4171, respectively). Part of EO ID 1786 extends into the ROW while the other EO IDs are found completely on private land (USFWS 2013, p. 56028). Multiple specimens have been collected from this complex, with the first dating back to 1915, and the site has been the focus of Robert George’s 1987 thesis work (site #2 in his work) (TXNDD 2020, p. 1). Additional occurrences within this complex have been recorded but the construction of a glauconite mine beginning in the late 1990s likely destroyed one of the larger populations. The records within the glauconite mine and on private land have not been accessible despite attempts by the Service and partners, and therefore we are uncertain the status of these habitats nor do we have estimates of this metapopulation. Two recent observations of the site, both in 2021, from the ROW noted that habitat was present, however no individual Texas golden gladeecress plants were present (S. Walker, pers. comm. 2022). In March 2022, part of this glade complex was accessed via an open and public oil/gas road. Many associative species were found, and outcrops were evident as well as where outcrops "used to be". Evidence of extensive gas field infrastructure was present though, along with associated roadways, tanks, constructed ponds, gates, in addition to past evidence of earthmoving activities (S. Walker, pers. comm. 2022).

EO ID 5290, Sabine County, natural – extant

This site is the only known extant population from Sabine County. First discovered in April 1987, this site is known from both private lands and within the SH 21 ROW. A specimen was again collected in 1988; however, the next visit was recorded in 1999, where 319 plants were observed (TXNDD 2020, p. 9). Unfortunately, a SF to this EO was destroyed in March 1999, one week after flowering plants were counted; the site was subsequently described as “lost or destroyed” (Turner pers. comm., 1999, *In* USFWS 2013, p. 56028). However, subsequent surveys showed that plants continued to emerge despite the prior deleterious activity in 1999 (TXNDD 2020, p. 9). Plants have been observed on site as recent as of spring 2021 (S. Walker,

pers. comm. 2021) and during two accounts in spring 2022. Observers noted 80+ flowering plants on March 9 (S. Walker, pers. comm. 2022) and 58 plants (5 in flower, 53 in fruit; although the actual number on-site is likely higher) on March 26, 2022 (B. Fogel, pers. comm. 2022). At that time, the landowner also communicated with the surveyors their intention of converting the site to pasture for cattle (S. Walker, pers. comm. 2022).

EO ID 2930, San Augustine County, natural – extant

This site was first observed in March 1987 in open areas along the roadside, extending into a nearby pasture (TXNDD 2020, p. 13). The site is less than 0.2 ac (0.1 ha) in size and lies between a pasture fence and a gravel road southwest of SH 21 in San Augustine County (USFWS 2013, p. 56030). The site is entirely on private land and does not extend into the road ROW (USFWS 2013, p. 56035). The white bladderpod co-occurs with Texas golden gladeceess at this site (USFWS 2013, p. 56039). This site is not currently under any form of federal protection although the landowner does mow and/or bush-hog the site at least once a year to try and halt encroachment of woody species into this small tract. These management actions specifically targeted the white bladderpod, although Texas golden gladeceess has responded positively and was again seen on-site after a 10-year absence (USFWS 2013, p. 56049). Neither Texas golden gladeceess nor white bladderpod were observed during the site visits in 2021 and 2022 (two visits) along with associated species but also encroaching vegetation (S. Walker, pers. comm. 2022).

EO ID 4779, Nacogdoches County, introduced – presumed extant

Introduced in 1984, this record is entirely on private lands. The seed source for this introduction is unknown. Abundance data from February 2009 show that there were 721 plants in bloom however, when visited in 2011, plants and habitat on-site were destroyed by the installation of a pipeline (USFWS 2013, p. 56029). The Service presumes that this site is extant as we have no indication that suitable habitat has been removed or destroyed.

EO ID 6465, San Augustine County, natural – extirpated (now a mine site)

Once used as another site of Robert George's 1987 thesis work (site #2) and the ~~type locality~~ for the Texas golden gladeceess, this population was extirpated by the construction of a glauconite mine in 2003 (K. Nemec, *In* TXNDD 2021, p.8).

2.3 Population Genetics

Despite the attention that the genus has received, to date, there has only been one study that examined the specific genetic health of Texas golden gladeceess populations. Banta and Placyk (2015, pp. 5-6) examined two populations, one in San Augustine and one in Sabine counties. Deoxyribonucleic acid (DNA) was extracted and amplified using the gene *LUMINIDEPENDENS* which has been used in other phylogenetic studies for *Leavenworthia* (see Urban and Bailey 2013). The total genetic variance in a subpopulation relative to the total variation (F_{ST} values) were used to examine how genetically similar populations were, or not, to each other. Banta and Placyk found that for the samples collected, there was relatively high gene flow among the two sampled populations and, therefore were both genetically healthy. The

results were surprising as these populations are nearly 14 mi (22.5 km) apart (Banta and Placyk 2015, p. 6). Banta and Placyk also state that since another population is only 7 mi (11.3 km) away from either of these sites and no plants were present to sample, that this site most likely took part in the genetic exchange between the two sampled populations (p. 6). The Service, the authors of this study as well as others, presume that there are additional plants/populations in between the sampled populations. Banta and Placyk (2015, p. 6) postulate that this connectivity is being facilitated potentially by pollinators. However, since a pollination study has not been completed to determine what, if anything, is assisting with the ultimate dispersal of the species genetics, this assumption cannot be validated (see Section 1.5.7).

CHAPTER 3 – Resource Needs of a Population

3.1 Population Resiliency

Resiliency gauges the probability that Texas golden gladeceess populations are able to withstand or rebound from environmental and/or demographic stochastic events. Such events could include droughts (low rain levels associated with certain key times of year for plant growth or reproduction); hurricanes or extreme weather events (heavy rains that could flood plants or habitat, move/disturb soils, knock down trees causing shading, etc.); or fires from lightning strikes (burning up plants during key reproductive times of the year). With only 3 known natural extant populations spread across two counties, we are concerned with the species resiliency. Abundance, germination rates, timing of plant mortality, and seed set are all demographic factors that affect the species' viability at a population level (see Core Conceptual Model, Figure 3.1). However, the only metric that has been consistently for any of the populations is abundance (number of plants) and is therefore carried through our assessment of the population resiliency. We assume that all Texas golden gladeceess populations interact similarly, therefore there are no differences in habitat or resource needs for any of the natural populations. Due to the lack of evidence from the introduced site (EO ID 4779, Nacogdoches County), we also assume that this population requires the same resource and/or habitat factors as the other natural populations.

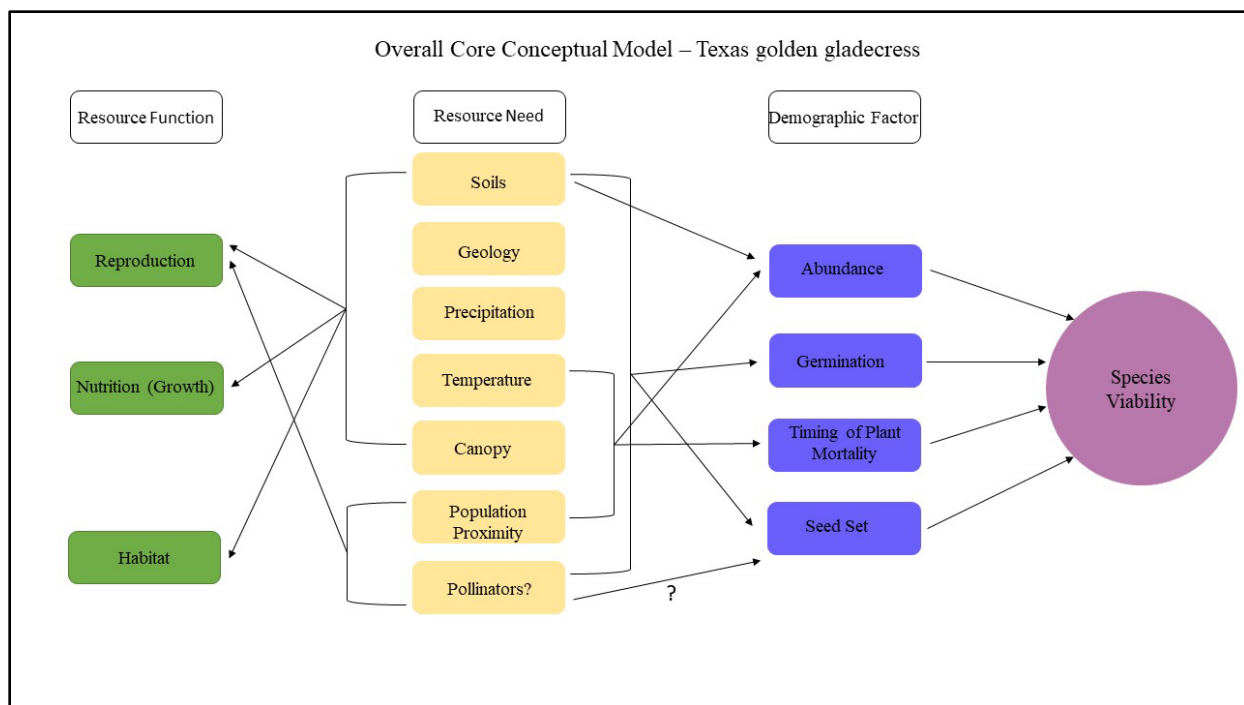


Figure 3.1. Population level resources that influence the viability of Texas golden gladeceess.

3.1.1 Population Factors

Abundance or Number of Individuals

Accurate population sizes between the Texas golden gladeceess sites are lacking largely due to inconsistent counting methods. The population size of annual plants, like the Texas golden gladeceess, are difficult as there is naturally a wide annual variation in the numbers of individuals present. Populations of many annual plants produce few individuals in most years, and large numbers in few years. Simply tracking the numbers of plants observed each year could lead to incorrect conclusions regarding the species status and demographic trends. Population sizes of annual plants with pulsed population numbers are more realistically determined by the size and extent of their soil seed reserves. Unfortunately, soil seed reserve sizes are very difficult to measure and have not been completed for the Texas golden gladeceess. One metric of a species' resilience is its minimum viable population (MVP). A conventional MVP, as outlined in Pavlik's guidelines (1996, p. 137), uses the biological and demographic 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 the Texas golden gladeceess as we do not possess the entirety of the baseline data needed to perform these calculations. However, Figure 3.1.1. was derived using adaptations of Pavlik's 1996 guidelines used to calculate MVPs for this species. This MVP will serve as the basis for population objectives 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 golden gladeceess is either more closely related to the life history characteristic in column A or column B or somewhere 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 Figure 3.1.1. indicate the life history

characteristic chosen for the species. Using the best scientific information available for each factor, we determined applicable characteristics and the estimated MVP value (listed in parentheses). The recommendations could change with the introduction of additional information on reproductive biology, gene flow, and/or population size, density, and distribution.

Table 3.1.1. Minimum viable population estimate for Texas golden gladeceess. Characteristics in bold specify those relevant to the species.

<i>Characteristic</i>	A. 50 individuals	(Mean 1,275)	B. 2,500 individuals	Rationale
<u>Longevity</u>	Perennial		Annual (2,500)	See Mahler's (1987) first description of the plant.
<u>Breeding system</u>	Selfing	Unknown – not included	Outcrossing	Literature points to the possibility of the Texas golden gladeceess being self-compatible. However, recent work by Banta and Placyk (2015, pp. 5-6) suggested that there was very high gene flow among the two populations they sampled, and that they were genetically healthy. Although we do have some data suggesting type of breeding system this still remains uncertain.
<u>Growth form</u>	Woody		Herbaceous (2,500)	See Mahler's (1987) first description of the plant.
<u>Fecundity</u>	High (50)		Low	Each silique may contain between 5 to 11 seeds (Rollins <i>et al.</i> 1970, Mahler 1987, Rollins 1993, <i>In</i> Poole <i>et al.</i> 2007, p. 286). This information suggests that a Texas golden gladeceess plant may be able to produce upwards of 300+ seeds per plant.
<u>Ramet production</u>	Common		Rare or none (2,500)	There are no records that indicate Texas golden gladeceess is clonal or produces ramets.
<u>Survivorship</u>	High	Unknown - not included	Low	Mercer Arboretum conducted seed germination tests from seed collected approximately 12 years ago; seeds showed low germination rates (A. Tiller, pers. comm. 2020). However, we have irregular abundance count data over the years, and have not collected data on the number of plants that have germinated and set seed.

<u>Seed duration</u>	Long	Unknown - not included	Short	Mercer Arboretum conducted seed germination tests from frozen seed and after 12 years, plants germinated at a low rate (A. Tiller, pers. comm. 2021). We have recorded data of disturbance occurring at EO ID 2930 and plants appearing 10 years later. This site was discovered in 1987. A specimen was again collected in 1988 but surveys with plant counts were only conducted in 1999, 2003, 2005, 2007, 2008, and 2009 (TXNDD 2020, USFWS data, and Carr 2005) and therefore, consistent annual counts to verify seed duration were not obtained. Much like the survivorship factor we are uncertain at this time about the species' seed duration and therefore did not include this factor.
<u>Environmental variation</u>	Low		High (2,500)	The glades environment drastically changes throughout the year. In winter, the habitat is wet and cool. Texas golden glade cress flowers in spring when sites still have standing water and the areas experience cooler temperatures. Plant species on the glades include those that are wetland associates. Summer months bring a dramatic shift in the temperatures and precipitation as the glades dry up, becoming parched. The plant associates at this time then change to more arid, succulent species.
<u>Successional status</u>	Climax (50)		Serial	Because of the seasonal shift from hydrophytes in the spring to almost succulent species in the summer atop these glade communities, there is high diversity at these sites.

In order to estimate the number of mature individual plants needed for a viable population, all of the known characteristics described by Pavlik specific to the Texas golden glade cress (6 in total) were combined and averaged (10,100 total/6 characteristics). The final average of 1,683 individual plants at each population is needed for the species.

Where possible, each population and the abundance over time has been graphed in the figures below (Figures 3.1.2, 3.1.3, 3.1.4, and 3.1.5).

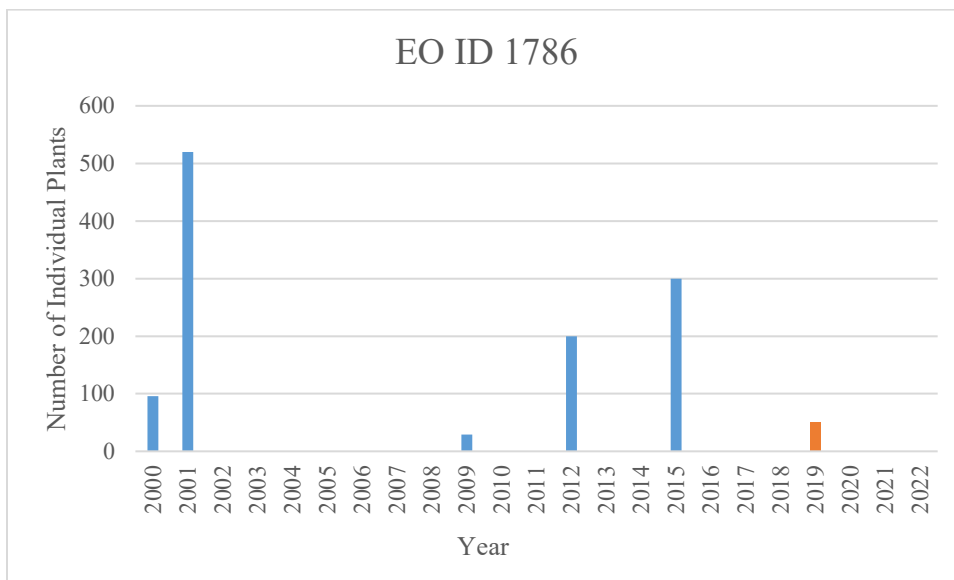


Figure 3.1.2. Plant abundance records at EO ID 1786 in San Augustine County, Texas. Year 2019 is highlighted as a count was conducted however, only the abundance was noted as a few. The site was visited in 2022 but no plants observed (B. Fogel, pers. comm. 2022).

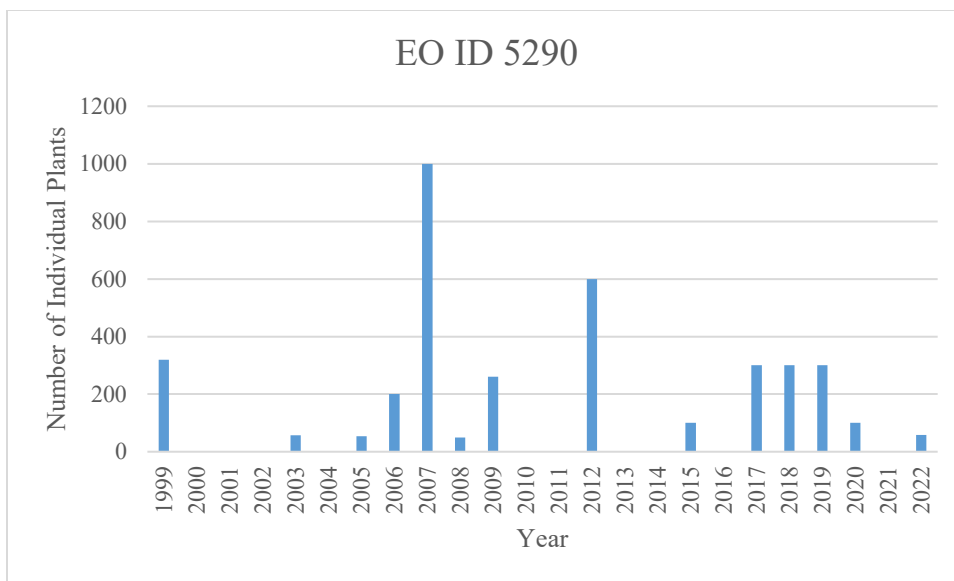


Figure 3.1.3. Plant abundance records at EO ID 5290 in Sabine County, Texas. These records include those from the population on private land as well as one extending into ROW. (TXNDD 2020; B. Fogel, pers. comm. 2022).

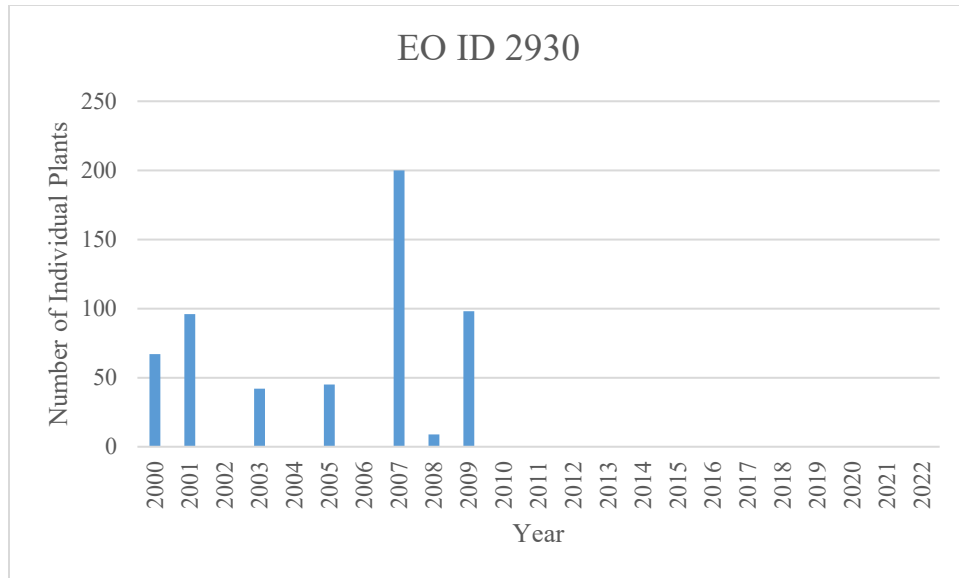


Figure 3.1.4. Plant abundance records at EO ID 2930 in San Augustine County, Texas (Carr 2005; TXNDD 2020). Site was visited in 2022 however, no plants were observed (B. Fogel, pers. comm. 2022).

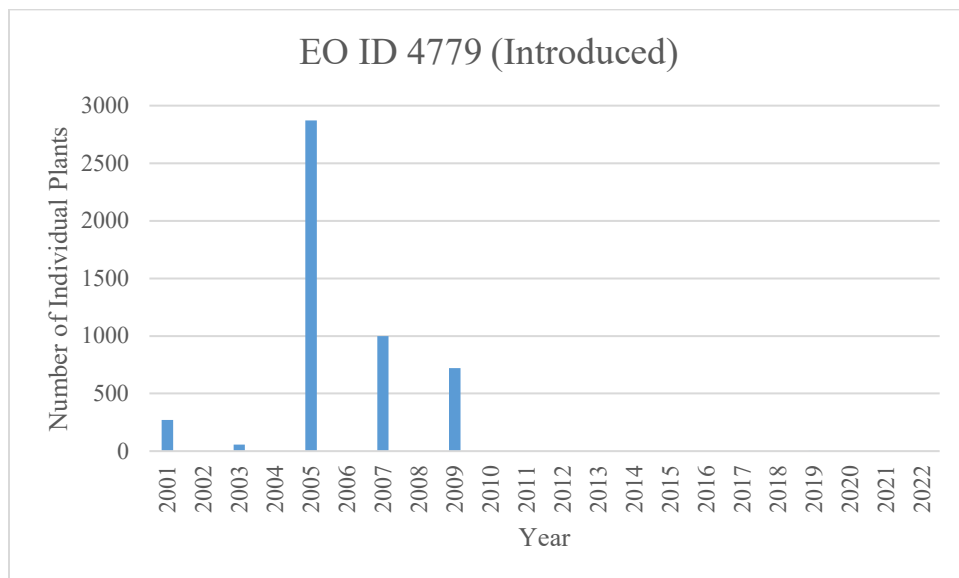


Figure 3.1.5. Plant abundance records at the EO ID 4779 in Nacogdoches County, Texas.

Habitat Occupancy of a Population Size:

Most Texas golden gladeceess populations, both historic and extant, are naturally restricted to small areas atop the glade habitat (USFWS 2012, p. 55973). Carr (2005, p. 1) stated that one glade site was approximately 0.14 ac (6,000 sq ft); the portion of habitat of which Texas golden gladeceess occupied atop those glades was even smaller. Of the three natural sites (EO IDs 1786, 5290, 2920), the total occupied area of these three populations was no greater than 0.007 ac (30 sq m) (Singhurst 2011, p. 3). Total area occupied by plants at these 3 sites covers less than 1.2 ac (121,405 sq m) (USFWS 2012 p. 55973). Individual records of population sizes at each site vary. See Table 3.1.6 for more detail.

Table 3.1.6. Estimated total area of occupied habitat by plants within each known Texas golden gladeceess population.

	Population			
	<i>EO ID 1786</i>	<i>EO ID 5290</i>	<i>EO ID 2930</i>	<i>EO ID 4779 (Introduced)</i>
<i>Total Area of Habitat Occupied by Plants</i>	0.002 ac (9 sq m) (no date of observation, <i>In</i> USFWS 2010, p. 3)	0.002 ac (9 sq m) (no date of observation, <i>In</i> USFWS 2010, p. 3)	0.5 ac (2,023 sq m) (Cobb 2011a, p. 4); 0.25 ac (1,011 sq m) (no date of observation, <i>In</i> USFWS 2010, p. 3); "occupying a small fraction of the glade site" (Carr 2005, p. 1)	0.004 ac (18 sq m) (no date of observation; <i>In</i> USFWS 2010, p. 3)

Populations with few individual plants could affect the genetic variation among individuals at a population or even exchange between populations. Genetic stochasticity (inbreeding and genetic drift in small populations) results in loss of genetic variation; and such, could cause decreased population viability (i.e., resiliency) (Newman and Pilson 1997, p. 354). Small populations are vulnerable to extinction by random demographic processes, as well as environmental stochasticity. A decrease in effective population size increases the rate of both inbreeding and genetic drift, which in turn can cause the random loss of alleles from small populations (Newman and Pilson 1997, p. 354).

For species that may require pollinators, population size could dictate how effectively pollinators could connect to each population and undergo pollination. Since we do not know for certain the role that pollinators play for Texas golden gladeceess, we cannot estimate the need for a certain population size as required for any such pollinating species. It appears that the area of suitable glade habitat occupied by plants may simply be a feature of the size of exposed glade, where all other habitat features (geology, climate factors, open canopy and population connectivity) exist. Therefore, the size of a population may not be as important as the number of populations spread across the species' geographic range (i.e., redundancy). Since we lack information on the importance of this demographic factor, this will not be carried through in the viability assessment.

3.1.2 Habitat Features

Texas golden gladeceess is found atop Weches glades and geology that spans across East Texas. These habitats are resilient when they have the proper timing and amount of precipitation; the proper temperature at the appropriate time; canopy; and, connectivity between populations needed by the gladeceess. Sections 1.5.3, 1.5.5, and 1.5.6 describe in more detail each of these habitat features and the specific metrics for each to the species.

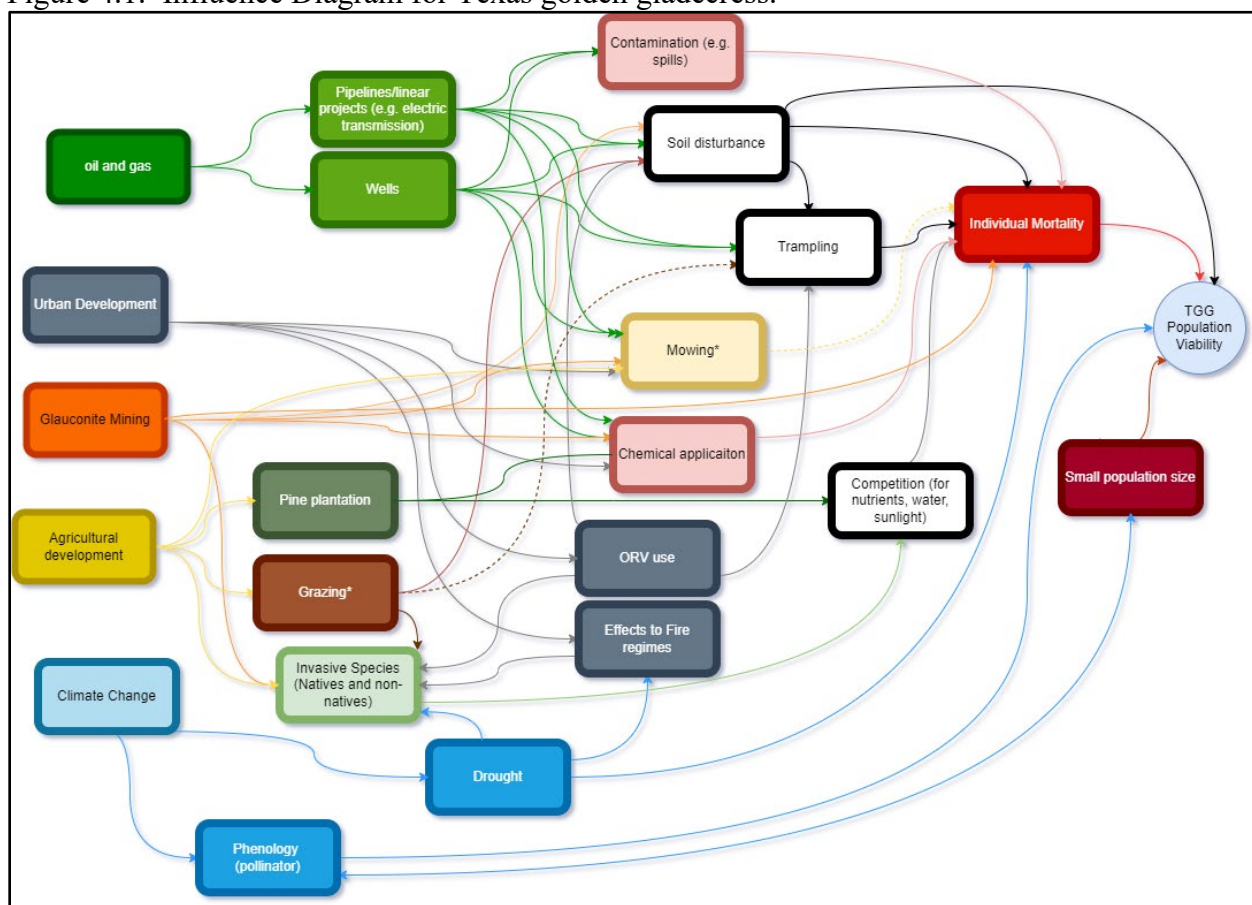
All known populations exist on private lands, where populations are less secure in terms of resiliency. The Service is currently collaborating with TPWD and researchers from Texas State University (TXST) to improve landowner relations and increase the protections for the Texas golden gladeecress at these sites.

CHAPTER 4 – Species Status and Influence on Viability

4.1 Stressors Influencing Viability

In order for Texas golden gladeecress to maintain viability, its populations must be resilient. Factors that have the potential to negatively influence the species' resiliency include habitat loss, modification, degradation; climate change; small population size; and management strategies. There is no evidence that disease is currently influencing the species viability and therefore, there is no discussion on this influence; see Figure 4.1 for a possible influence diagram.

Figure 4.1. Influence Diagram for Texas golden gladeecress.



The influence diagram (Figure 4.1) represents possible interactions between the sources and stressors to the Texas golden gladeecress with arrows indicating the direction of each interaction. With some sources, there is uncertainty with the level of effect and/or the level of effect may

vary depending on time or frequency. In those cases, connections are indicated by a dotted line (-----). For example, grazing has been noted to help reduce some level of invasives from surrounding glades and trampling from cattle has not necessarily been documented as a detriment to the Texas golden gladeceess. However, intense, and frequent grazing and/or inappropriate timing of grazing (i.e., during blooming or seeding periods for the species) could have a negative effect on the Texas golden gladeceess.

4.1.1 Habitat Loss, Modification, and/or Degradation

Glade Conditions Influencing Native and Nonnative Species

The glade communities of East Texas along with those of the Eastern U.S. occur in habitats with soils that naturally exclude the threat of competing native vegetation (Baskin and Baskin 1988, p. 836). The glades themselves are very small in size (see section 3.1.1) and is typically surrounded by a savanna or woodland consisting of a few tree species surrounding the glades. Glades are fire-maintained communities where grass species of the Weches outcrop tend to dominate in the fall (September through November) (George and Nixon 1990, p. 121). Shallow soils and the presence of mudstone naturally preclude the encroachment of trees and grasses into the glades themselves (George 1987, p. 8; George and Nixon 1990, p. 124). Many of the trees, shrubs, and woody vines only occur in pockets of deeper soils (George and Nixon 1990, p. 124) and many are stunted and express poor development because of the shallow soils and poor growing conditions (NRCS 2017a, p. 1). Harsh environmental conditions preclude tree establishment (Hartman 2005, p. 4); however, without disturbance, woody growth including that of the native eastern red cedar (*Juniperus virginiana*), shrubby plants, and commercial trees (blackjack oak (*Quercus marilandica*) and black hickory (*Carya texana*)) will invade a glade area (Hartman 2005, p. 4). When a glade starts to exceed 1/3 of its cover in eastern red cedar, herbaceous plant production declines (Rossiter 1995, p. 3). With increased canopy cover, habitat and growing conditions for the Texas golden gladeceess become less hospitable and therefore, likely that fewer plants can persist.

Nonnative Species

The prominent nonnative species documented as invaders on the Weches glades and surrounding savannas include: Macartney rose (*Rosa bracteata*), privet (*Ligustrum* species, likely *L. sinense*), Japanese honeysuckle (*Lonicera japonica*), Japanese clover (*Kummerowia striata*), bermudagrass (*Cynodon dactylon*), bahiagrass (*Paspalum notatum*), tall fescue grass (*Festuca arundinacea*), and English ryegrass (*Lolium perenne*) (Nemec 1999, p. 1; Carr 2005, p. 2; USFWS 2010, p. 4; Singhurst, 2011, pp. 3-4; USFWS 2012, pp. 55979-55980; S. Walker, pers. comm. 2022).

Native Species

Native species and common plant associates of the East Texas glade communities were discussed in Section 1.5.4 and Table 1.5.4.1. The presence of *Sedum pulchellum* (stonecrop) is a high indicator of the presence of Texas golden gladeceess at a site, whereas in its absence, habitat is likely unsuitable for the species (B. Fogel, pers. comm. 2022). Other native species found on the glade communities include broomsedge (*Andropogon virginicus*), spurge (*Euphorbia* sp.), black-haw viburnum (*Viburnum prunifolium*), and ivy treebine (*Cissus trifoliata*).

Although cedars can be associated with some glade communities, it is not a sign of a healthy habitat and for the Weches glades specifically, these species are not naturally occurring with the glade (Rossiter 1995, p. 2; Cobb 2012a, p. 2). Cedars do well on glades where little moisture may be available during much of the year and reproduce through seed spread by avian species (Rossiter 1995, p. 2). At EO ID 5290 in Sabine County in 2011, eastern red cedars had been noted around the glades, but in 2012 the site had recently been cleared and was devoid of any shading from trees or shrubs (Carr 2012, p. 5). In spring of 2022, eastern red cedar was noted as encroaching species during survey efforts, blocking out sun and increasing the canopy cover on the glade (B. Fogel, pers. comm. 2022). Lack of ineffective management of these species is discussed in the section below.

Extent of Native and Nonnative Species Encroachment and Effects

Deliberate plantings of nonnative grasses to the savanna habitats in East Texas continue in order to improve pastures for livestock, reduce/control effects of erosion, and aid in restoration projects with landowners (TPWD 2012, p. 22). These aggressive grasses have established in nearly every habitat type within the region (TPWD 2012, p. 22), including the savanna habitats containing Texas golden glade grass. Land conversion from both native and introduced species is documented heavily within the counties where the Texas golden glade grass is known to occur. Few, if any, areas of native range exist within San Augustine or Sabine counties with these areas converted to pasture fields of bermudagrass or bahiagrass (Cobb 2011c, p. 1). Macartney rose has been documented in some of these sites as early as the late 1980's (George 1987, p. 22) and continues to span across the geologic band of the Weches glades that runs along SH 21 (see figures 1.5.2.1 and 2.2.2), especially in San Augustine County (Cobb 2011c, p. 1; USFWS 2012, p. 55979).

Management along ROWs can cause ground disturbance and increase the chances that a ROW site, or one adjacent to a ROW, will become invaded. Plants like Chinese privet, Japanese honeysuckle, and Macartney rose will cover and invade any disturbed soils and gravel areas of a glade site, leaving only the small rocky outcrops devoid of woody plants (Singhurst 2011, p. 3). Other human activity will introduce species such as the eastern red cedar into the Weches glades and savannas. Not all soil disturbance may be detrimental to the Texas golden glade grass as it is likely that some types of management actions (i.e., mowing) could reduce the extent of natives and nonnatives encroaching into habitat. As noted during species surveys in March 2022, landowners at EO ID 5290 where Texas golden glade grass plants were observed, had mowed the property. Mowing was done in such a manner that plants were not affected (B. Fogel, pers. comm. 2022). However, optimal frequency, intensity, and timing of these activities, as well as other disturbance, are important to the species. Mowing during the flowering period of the Texas golden glade grass could crush flowers and plants, resulting in effects to its reproductive output (i.e., seed production and dispersal) and ultimately, lethal responses. See the section on Lack of Effective Management – Mowing, for more detail.

Prior to the species listing in 2013, it was noted that three of the four extant sites (Cobb 2011a, p. 5) were affected by some invasion of native and nonnative shrubs and trees into the formerly open, sunny-herbaceous glades (USFWS 2012, p. 55979). Fire was a natural and prevalent component of the savanna habitats within this region and helped reduce invasion from woody vegetation. It was noted in 2012 that fire suppression occurring over the last century has allowed

encroachment of species, resulting in a highly modified habitat (TPWD 2012, p. 22). Invading species compete with Texas golden gladeceess for nutrients and water (USFWS 2012, p. 55979).

Habitat Loss

Pipelines and Linear Projects

San Augustine, Sabine, and Nacogdoches counties are within what is known as the Carthage (Haynesville or Haynesville/Bossier) Shale Field. This geologic formation occurs in east Texas as well as northwestern Louisiana and is a hydrocarbon-producing formation capable of producing large amounts of natural gas (Railroad Commission of Texas (RRC) 2021, p. 1; Smye *et al.* 2019, p. 192). The RRCs online maps indicate that natural gas (and some crude oil) gathering, and transmission pipelines are found throughout Nacogdoches County. In Nacogdoches County a natural gas line has been constructed near EO ID 4779 along SH 21, In San Augustine County, the majority of existing pipelines are located in the area north of SH 21 and west of the town of San Augustine. To the east of San Augustine, there are fewer pipelines, but of those that are located in this area, several are large gas transmission lines; one of which lies directly adjacent to the extirpated site EO ID 6465 (specifically what was known as #7 in the TXNDD). Directly adjacent to extant EO ID 1786, an existing FERC-regulated pipeline was constructed in 2019. This line encompasses 22 mi (35.4 km) of natural gas line and is immediately adjacent to a population east of the line where Texas golden gladeceess plants were present (Perennial 2019, p. 5). EO ID 2930 does not have any mapped lines or wells near the site (RRC 2021a, p. 1). Sabine County has several major interstate pipelines, but fewer gathering and other transmission lines than the other two counties, and no pipelines near the EO ID 5920 site (RCC 2021b, p. 1). The RRC regulates the oil and natural gas industry in the state of Texas. The RRC has detailed information on all existing pipelines, but the agency has no way to predict future routes for new pipelines or wells; they are limited to location data found within permit applications (Nunley 2011, pers. comm.). New pipelines, as well as ones for which routes are being determined, do not display on the RRC website, so although we are aware of the impact that pipeline excavations can have on Texas golden gladeceess, we cannot tell where future pipelines may affect existing populations or suitable habitat. Since the species was listed in 2013, it appears that drilling permits issued by RRC declined (2013-2016) but started to increase again in 2017 (Figure 4.1.1). Permitted drilling has shown a steady decline from 2018 to a low in 2020, increases in 2021, and expected increases in 2022 although final numbers are pending (Figure 4.1.1).

The Haynesville Shale is the largest known reserve of natural gas in Texas (Murphy 2011, p. 1). A porous substrate tends to be more permeable and thus more productive (p. 2). It was noted in 2011, that the Haynesville Shale field (also known as a play) was projected to have an active drilling timespan until 2021 (Murphy 2011, p. 3) however this region still remains one of the top producers of natural gas in the United States (Paxton 2018, p. 4; Smye *et al.* 2019, p. 192) (Figure 4.1.2).

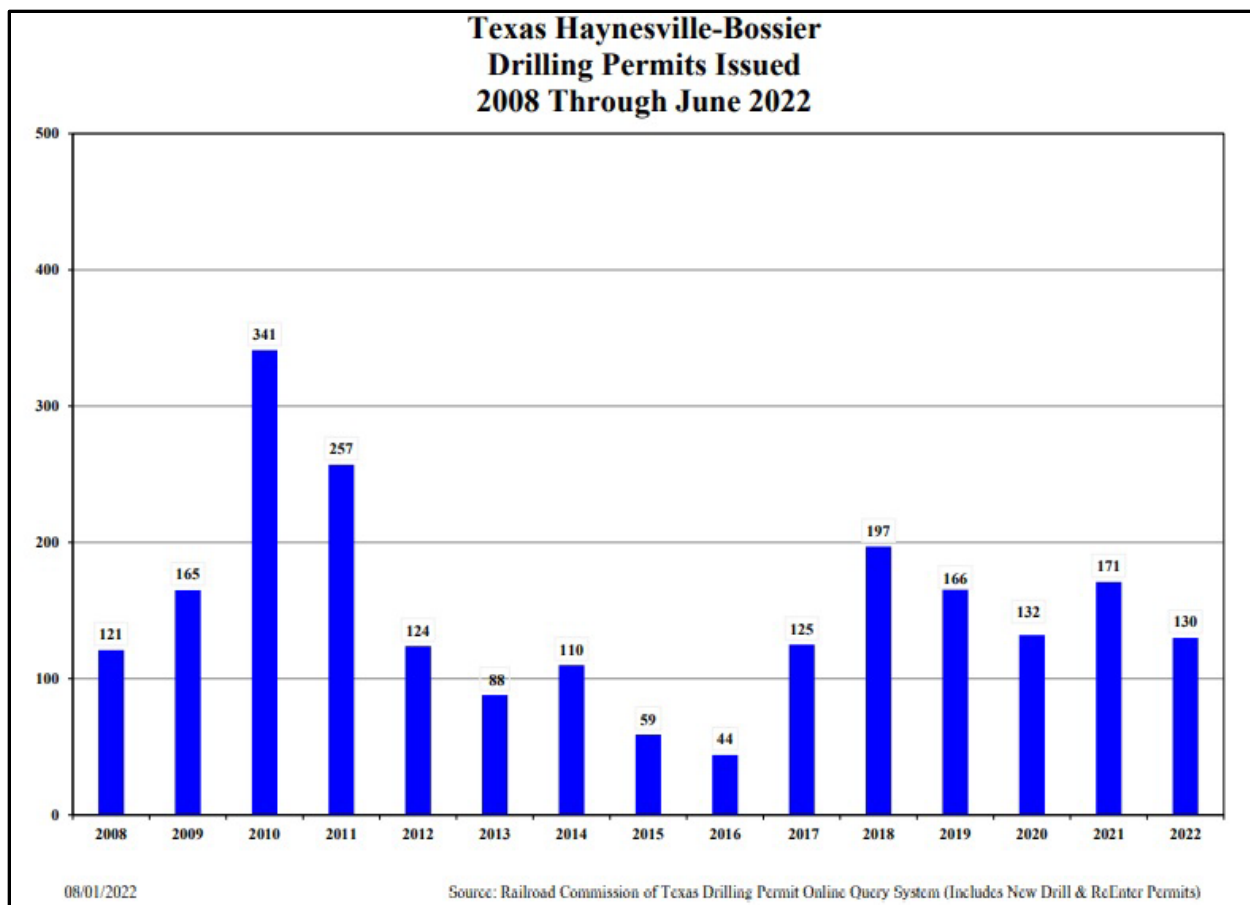


Figure 4.1.1. Presented drilling permits issued by RRC from 2008 – 2022 (RRC 2022).

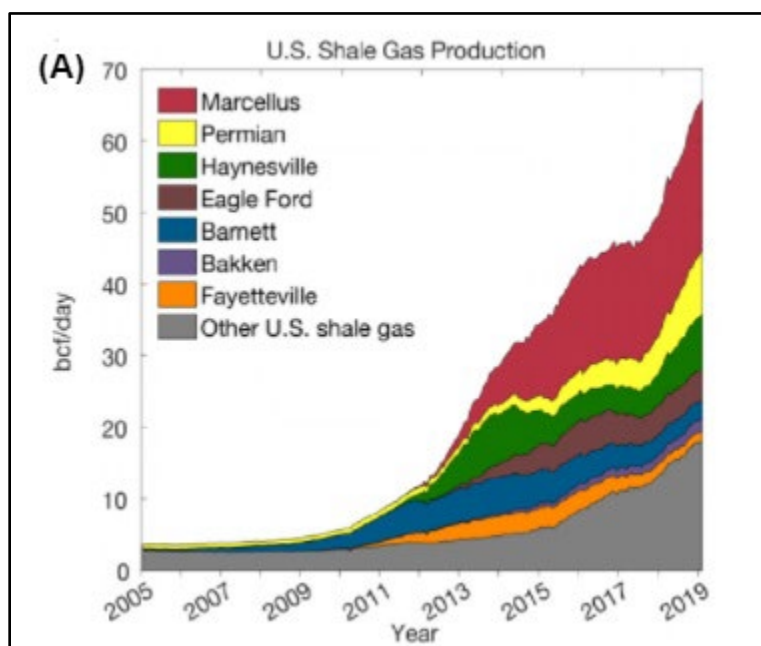


Figure 4.1.2. Adapted from Smye *et al.* 2019 comparing the U.S. shale gas production with Haynesville Shale in East Texas as the top third producer in 2019 (p. 192).

It was noted in 2011, that oil and gas development and associated activities were of concern to most of the Texas golden glade cress populations. Below is a snapshot of the activity known to occur at each of the populations along with any recorded outcomes (Figure 4.1.3).

Populations	County	Activity (date) and any Known Effects
EO ID 1786	San Augustine	Construction for a pipeline occurred in 1997, again in 2001. The Surveys in spring 2022 did not find any plants at this site although habitat is present (B. Fogel, pers. comm. 2022).
EO ID 5290	Sabine	No activity reported to date. Approximately 60 plants were observed in spring 2022, although numbers were more likely around 100 individuals (B. Fogel, pers. comm. 2022).
EO ID 2930	San Augustine	A pipeline crew was observed surveying along the county road, presumably preparing for construction or activity (Cobb 2011a, p. 4). In 2020, Section 7 consultation was concluded, and a 22-mi pipeline was constructed through critical habitat and west of occupied population with plants and glade. The company instituted required minimization measures to reduce potential effects to the glade and used horizontal directional drilling (HDD) to reduce soil disturbance effects (USFWS 2019b, entire).
EO ID 4779 (Introduced)	Nacogdoches	This was largest population counted in the last decade but as of October 20, 2011, it had been destroyed for a pipeline (USFWS 2012, p. 55972). Part of the habitat not destroyed by any pipeline activity is now covered by brush piles (Cobb 2011a, p. 6).

Figure 4.1.3. Oil and gas activity observed and/or recorded at each occupied Texas golden glade cress site in East Texas.

The vast improvements to the oil and gas industry and its processes (i.e., hydraulic fracturing, horizontal drilling) has caused the footprint of the industry's activity to increase exponentially across North America (Alfred *et al.* 2015, p. 401). Natural gas in Texas was only historically produced as a byproduct of oil and flared/vented off without capture, however with evolution of processes in the industry, the annual natural gas production steadily increased and peaked in 1972. Gas production has increased since 2005 in multiple plays, including the Haynesville Shale play, and has increased by more than 40 percent since 2018 (Smith *et al.* 2018, p. 2). Landscape effects are species-specific but could include alteration of habitat and its ecological variations or heterogeneity, food webs, landscape patterns, patch sizes, and hydrology (Pierre *et al.* 2018, p. 807, *In* Fahrig 2002; Sawyer *et al.* 2006; Fischer and Lindenmayer 2007; Hebblewhite 2011; and Pierre *et al.* 2015). Linear construction of roads and pipelines bisect contiguous habitat, help spread invasive species (Barlow *et al.* 2017, p. 209), and disrupt soil water and nutrient flow (Pierre *et al.* 2018, p. 2018, *In* Nasen *et al.* 2011). As noted in Naeth *et al.* 2020 (pp. 619-620), processes often included in pipeline construction such as topsoil and subsoil mixing, can alter soil properties including electrical conductivity, pH, salinity, soil water content, texture, and temperature (*In* de Jong and Button 1973; Naeth 1985; Ivey and McBride 1999; Olson and Doherty 2012; Shi *et al.* 2014; Xiao *et al.* 2014; Xiao *et al.* 2016). Construction activities could also affect a species seed bank, remove and/or alter associated vegetative communities, and cause lethal effects to plants (i.e., smothering or removal). Activities such as trenching, welding, and vehicular traffic can also result in elevated metal concentrations (Shi *et al.* 2014, *In* North *et al.* 2020, p. 620). During construction, native vegetation and topsoil are

usually removed, facilitating introduction and potential spread of nonnative and invasive plant species with the potential to form monocultures. These species can form monocultures, resulting in landscape fragmentation and altered wildlife habitat (Sousa 1984; Hobbs and Heunneke 1992; Smith and Knapp 1999; Craine *et al.* 2001; Parker 2005; Olson and Doherty 2012; Xiao *et al.* 2014 2016; Gasch *et al.* 2016, In Naeth *et al.* 2020, p. 620).

Natural gas and oil exploration effects to the Texas golden gladeceess and its habitat largely include the destruction, fragmentation, and loss of habitat, and/or the direct loss of plants. Activities associated with exploration that could occur within the occupied range of the Texas golden gladeceess includes construction of well pads, buildings, and roads to access drilling sites; installation and trenching of line; soil disturbance and encroachment of nonnative species; and exposure of oil and materials to plants and the habitat (USFWS 2012, p. 55977; USFWS 2019b, entire). There is the potential for effects to the species' seed bank and its overall resiliency however studies are lacking to demonstrate at what frequency and scale, and resulting effects occur. Well pad construction seems to be active closest to FM 711 and FM 321 (Cobb 2011c, p. 1). Observations of extensive oil and gas infrastructure were present near EO ID 1786 in March 2022. The area around this populations was accessed via an open oil/gas road, and the area was noted to have potential Texas golden gladeceess habitat included associated species and Weches outcrops (S. Walker, pers. comm. 2022). A recent natural gas pipeline was constructed in 2019 through a designated critical habitat area and west of a known population. Like most current activity across the country, acquisition of natural gas from the Haynesville Shale mostly uses horizontal wells and hydraulic fracturing ("fracking"). This particular company used hydraulic directional drilling (HDD) in sensitive areas of the critical habitat and adjacent to the population to reduce the surface disturbance. Despite these efforts, an inadvertent return of oil (IR) event occurred and unknown effects to the CH unit occurred.

Glaucanite Mining

Glaucanite mining includes the selection of site with known presence of glaucanite; removal of earth from a site whereby large mining pits, or quarries, are formed; and, the physical extraction of glaucanite from soil materials. Glaucanite is used for a variety of purposes including local road surface for oil and gas roads, well pads, and potentially some roadways (USFWS 2012, p. 55977). Glaucanite was used extensively in the iron and steel industry but have more recently been mined for us in cement/road work, as a weighing agent in well-drilling fluids, and in animal feed supplements (Kleiner 2022, p. 1). A study conducted by Button and Little (1997, p. 5) recommended that the Texas Department of Transportation (TxDOT) avoid the use of glaucanite on their roadways as it was found to be a variable aggregate, not passing strength and durability testing requirements, which could lead to construction problems. Today, TxDOT does not use glaucanite due to concerns with arsenic (Cobb 2011, p.1).

Outcrops where Texas golden gladeceess occurs can attract quarrying activity since glaucanite is a prime constituent and is found close to the surface, i.e., facilitating extraction (USFWS 2012, p. 55977). Excavation activities can alter the hydrology making Weches outcrops uninhabitable and can alter hydrology, interfering with pooling and seeping during the wet winter months (USFWS 2012, p. 55977). Construction of well pads can cover plants and habitat and alter habitat such that soil is usually cemented for pad stability. Vegetation may survive on the edges of such pad (B. Fogel, pers. comm. 2022). As of 2022, this industry is not regulated by any known federal, state, or local entity including those like the RCC, the Office of Surface Mining,

nor the Texas Commission of Environmental Quality. In some instances, TxDOT may assist counties with certain road construction and maintenance activities, and glaucanite is not used in these situations. County entities within the range of Texas golden gladeceess may still use glaucanite on county roads where a nexus with TxDOT is lacking. Glaucanite mining remains a present stressor to the species as glaucanite is readily available throughout the range of the Texas golden gladeceess. This fact in concert with the industry being unregulated, puts both the known populations and potential suitable habitat in danger of future mining activities.

Glaucanite mining effects have been observed on portions of both historic and current Texas golden gladeceess populations. Activities near the EO ID 1786 removed approximately 38 percent of habitat while effects of mining near the Marshburn site (an associated source feature of EO ID 6465, now extirpated) are unknown (Singhurst 2011, p. 3). One other landowner has been approached about allowing mining on their property, but as of 2012, they had not come to any agreement (Cobb 2012a, p. 1); as of July 2022, no further mines have been developed within Texas golden gladeceess suitable habitat. Glaucanite mining remains a present stressor to the species as glaucanite is readily available throughout the range of the Texas golden gladeceess. This fact in addition to the glaucanite mining industry being unregulated, puts both the known populations and potential suitable habitat in danger of future mining activities.

Habitat Conversion to Pine Plantation

Approximately 12 million ac across East Texas is currently in forest lands according to the U.S Department of Agriculture's Forest Service Forest Inventory and Analysis. Of these lands, 90 percent of those acres are privately owned properties (USDA Forest Service 2020, p. 1) and 2.9 million ac (24 percent) are in pine plantation (Coble and Pendergast 2014, p. 2). Commonly planted pine species in these plantations include loblolly (*P. taeda*), longleaf (*P. palustris*), shortleaf (*P. echinata*), and slash pine (*P. elliottii*) (In Hooker *et al.* 2021, p. 1). Loblolly is preferred due to the low-cost of seedlings, high rate of survival, and rapid growth in East Texas (Vogel 1981, Toups 1986, In Priest *et al.* 2006, p. 535).

It was noted in 2012, that the conversion of native vegetation to pasture or row crops in the region was much less common than previously occurring (USFWS 2012, p. 55980); however, one of the more prevalent land use changes across the known range of the Texas golden gladeceess is the conversion from pasture to pine plantation (J. Ritter, pers. comm. 2011b, p. 1). Generally, most Weches outcrops are avoided as soils are too rocky and do not naturally support the pine species desired for planting. However, many of the pines planted into plantations, are loblolly or longleaf, which have large tree centers (8-10 ft) (and thus large canopies) and when planted in proximity to an outcrop, can out shade the glade and plants (Cobb 2011c, p. 1). The small, natural openings within the glades are more attractive to timber companies and oil/gas operators as they are naturally "open" areas, good for staging areas. There were concerns about impacts from habitat clearing and planting overstory plants at EO ID 5290 (Cobb 2012a, p. 1). According to aerial imagery, it does not appear that any of the four known sites have directly been impacted by general silviculture practices; however, there are concerns with shading from canopy related to the invasion of woody and nonnative species. Therefore, the loss and/or conversion of habitat for silviculture is not a primary stressor to the Texas golden gladeceess but may have effects to the species' viability should adjacent plantings decrease the openness of a glade.

Grazing Effects and Associated Habitat Loss

Some grazing practices can degrade suitable grasslands, pine, and hardwood regeneration potential and can increase the encroachment of nonnative species. Effects from cattle stem from the destruction or modification of habitat rather than through direct consumption of any Texas golden gladeceess plants. Mahler noted during his monitoring efforts of the species in the 1980s that grazing of the Texas golden gladeceess habitat likely occurred over the past 150 years (Mahler 1981, p. 83). As of 2019, cattle have been noted on three of the four Texas golden gladeceess sites (George 1987, p. 22; Perennial 2019, p. 5). Clearing and conversion of savannas and pine forests to make way for improved pasturelands in East Texas is continuing to date, however how frequently these habitats are being converted is unknown. Clearing methods include shearing, piling, and burning followed by heavy disking and seeding of bahiagrass and Bermuda grasses or sprigging from another improved variety of grass (J. Ritter, pers. comm. 2011b, p. 1). Much of the land is now being converted to pine forests to pasture (J. Ritter, pers. comm. 2011b, p. 1). Many of the private lands across Texas, including the eastern portion of the state, are undergoing changes in their ownership size. Lands that remain in larger ranches versus smaller ranches (> 2,000 ac versus < 500 ac), are actively being converted into nonnative pastures (Wilkins *et al.* 2003, p. 5).

Texas golden gladeceess is not known to be a preferred food item of cattle (George 1987, p. 22; Cobb 2011, p. 3); studies to confirm this are lacking and need to be conducted. Macartney rose may provide protection from herbivory (J. Singhurst pers. comm., *In* Cobb 2011a, p. 4) yet this invasive species introduces its own set of concerns (see *Nonnative Species* section above). Macartney rose does well in pastures due to its thorny growth, prolific production of seed, and effective seed dispersal (McCully 1951, Taylor 1949, *In* Enloe and Lauer 2016, pp. 758-759). Effects from cattle most likely stem from habitat destruction rather than consumption (J. Ritter, pers. comm. 2011c, p. 1) however that is dependent on the availability of forage grasses existing on-site. Flowering Texas golden gladeceess plants have been photographed within existing cattle tracks (see Figure 4.1.4). During the winter and spring months when rainfall is prominent and blooming and seed dispersal are occurring, effects from trampling are a concern as habitat could be negatively impacted and plants could be destroyed. Direct effects of grazing were not considered a stressor to the species at its time of listing (USFWS 2012, p. 55980) however the extent, frequency, and timing of this stressor are not well understood, and it is unclear if effects to plants, its seedbank, and/or habitat are occurring. Grazing could be beneficial in maintaining an open canopy, should the timing and frequency coincide with the needs of the Texas golden gladeceess.

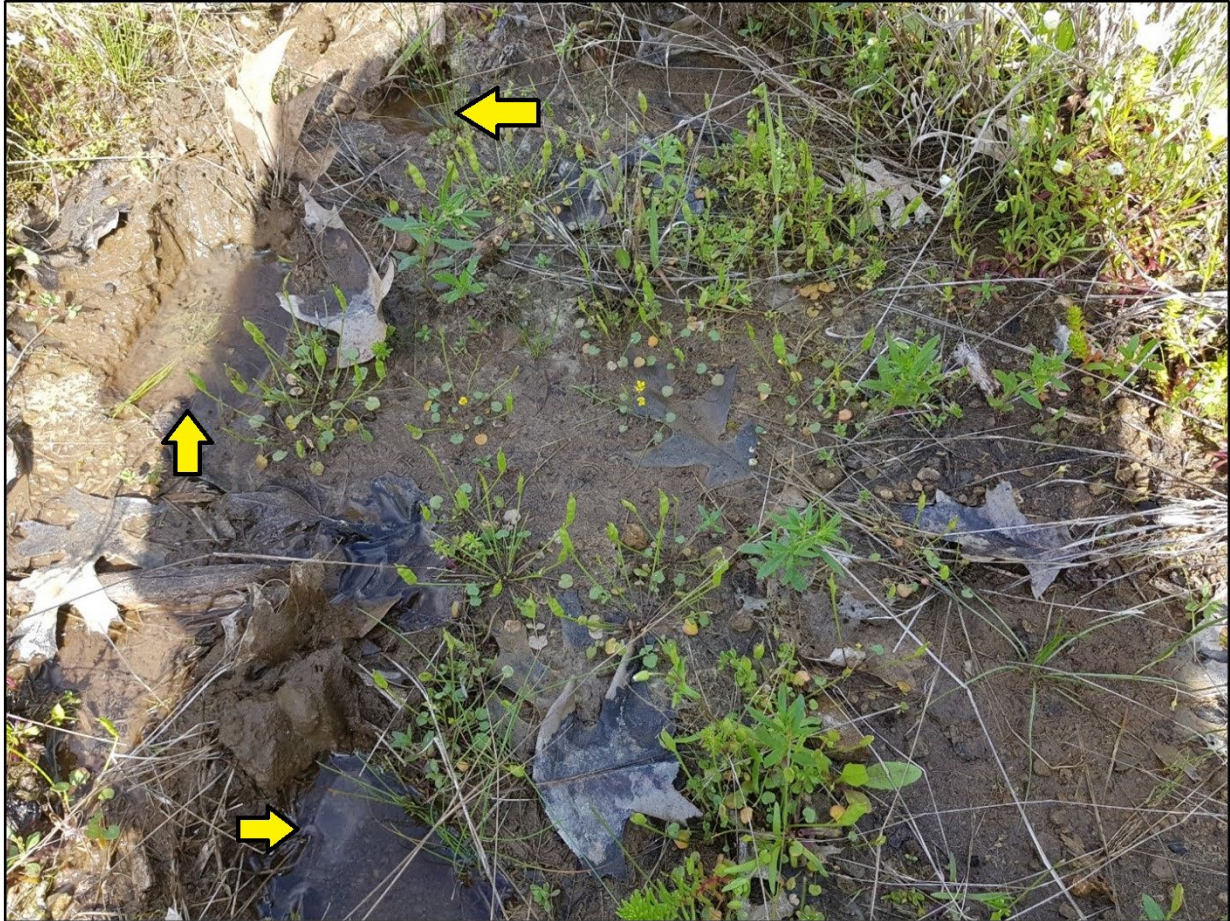


Figure 4.1.4. Pictures of flowering Texas golden gladeceess plants within cattle tracks observed during a pre-construction survey for pipeline, San Augustine County (Perennial 2019).

Off-Road Vehicle Use

EO ID 2930 is the only population that has noted off-road vehicle use; however, the extent of effect was not noted (J. Singhurst, pers. comm. 2006, p. 2). Due to a lack of additional observations of this type of activity, we do not anticipate that this is a concern for the species' viability.

Urban Development

Residential and commercial development have been listed as a possible stressor to the Texas golden gladeceess in the past (i.e., candidate assessment forms, USFWS 2013, p. 56047) however, the current rate of human population growth in the range of the species does not constitute a threat to the species. At the time of listing, neither San Augustine nor Sabine counties were experiencing increases in population growth. San Augustine County saw a 10.7 percent decline between 2010 and 2022 (U.S. Census Bureau 2022 p. 1), while Sabine County saw a modest increase of 3.5 percent (U.S. Census Bureau 2012a, b). Current and future county growth estimates have all counties declining in overall population size from 2010 to 2050 by 26.1 percent, 36.9 percent, and 10.5 percent for San Augustine, Sabine, and Nacogdoches counties, respectively (Texas Demographic Center (TCD) 2021a, b, c; Figure 4.1.5). Also, it was historically thought that developers may have specifically targeted developments atop the barren glade ecosystems to take advantage of an already-cleared area, however documentation is

lacking to support this (USFWS 2013, p. 56047). With the lack of evidence of urban sprawl occurring across the range for the species, we conclude that urban development is not likely to be a stressor to Texas golden gladeecress.

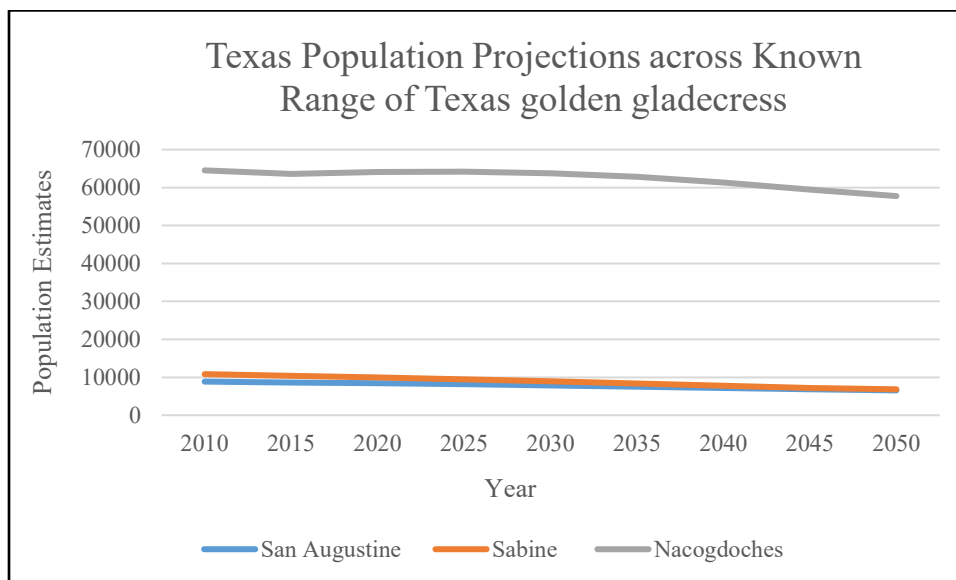


Figure 4.1.5. County growth from 2010 – 2050 for known range of Texas golden gladeecress (TDC 2021a, b, c).

Climate Change

The Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6) has concluded that warming of our atmosphere, ocean, and land are unequivocal (IPCC 2021a, p. 8). Long-term changes observed as a result include changes in precipitation amounts, global surface temperatures, changes in Arctic Sea ice, and more, most of which are human-induced. Texas is included in IPCC's Central North American (CNA) region and within the Southern Great Plains with the U.S. Global Change Research Program (USGCRP). Both resources suggest that temperatures have increased over time with average annual temperature over the contiguous U.S. having increased by 1.2 °F (0.7 °C) from 1986-2016 and 1.8 °F (1.0 °C) from 1895-2016 (Vose *et al.* 2017, p. 185). Specifically for the Southern Great Plains region, the expected change in annual average temperature is 0.76 °F (Vose *et al.* 2017, p. 187). Cold extremes have been less severe over the past century (Vose *et al.* 2017, p. 189) but heat waves have increased in frequency since the mid-1930's (p. 191). There will also be an increase in extreme precipitation (very likely confidence) events and an increase in the winter months (medium confidence) (IPCC 2021b, p. 2). Easterling *et al.* (2017, p. 211) also confirmed that the observed rate of change has increased most for the Southern Great Plains over the past 20 years in winter. Global average precipitation over land has likely increased since 1950, with a faster rate since the 1980s (medium confidence) (IPCC 2021a, p. 9). Both the frequency and intensity of these heavy rain events have increased (high confidence) yet increases in agricultural and ecological droughts have also been observed (IPCC 2021a, p. 12). Additionally, increases in heavy precipitation events are expected throughout all contiguous U.S. regions; extreme events under RCP 8.5 occurring two to three times more than historic averages, and under RCP 4.5, increases are

expected at 50-100 percent (Easterling *et al.* 2017, p. 218). Species dependent upon specialized habitats or climatic conditions, limited in distribution, or occurring at the periphery of their range may be more susceptible to the effects of climate change.

As Texas golden gladeceess is dependent on rainfall and winter rains to saturate sediment and produce the seeps and pooling during the spring months, changes in the frequency and timing of rainfall events can affect its reproductive capability. Reduced rainfall seen between January and March 1986 resulted in a reduction of the seepage flow over the Weches formations in early spring and a reduced number of plants appearing then in the subsequent spring (George and Nixon 1990, p. 118). George and Nixon (1990, p. 120) also noted a decline in the overall species richness and diversity on glades in summers following droughts, and a decline in the density of plants per square meter on the Weches. Droughts during 1999 and 2000 had pronounced effects on EO IDs 2930 and 1786 where plants reduced from 91 to 67 plants and 490 to 96 plants, respectively (USFWS 2010, p. 4).

The timing of rainfall events also could affect the Texas golden gladeceess. Rollins (1963, p. 42) suggests that based on the high-moisture content needs of the habitats by all members of the *Leavenworthia* genus, that species has evolved an earlier growth and flowering period due to habitats currently becoming dryer and warmer. Drying of glades from climatic shifts in response to climate warming could result in earlier flowering of *Leavenworthia* species and being “out of phase” with the emergence of needed natural pollinators (Busch and Urban 2011, p. 18). It is unclear if pollinators are needed for the Texas golden gladeceess and therefore, changes in the timing of the precipitation are not known to be a concern.

Small Occupancy Size of a Population

The total size of all occupied known populations is less than 1.2 ac (0.5 ha) (USFWS 2012, p. 55973), and even then, it has been stated that the occupied area may even be smaller, somewhere around 30 sq m (0.007 ac) (Singhurst 2011, p. 3). The Weches glades are naturally small in size where they have been observed in East Texas, with exposed glades within the geologic formation spanning an estimated 41 mi in length between known populations (see Figure 2.2.2). Naturally small areas of Weches habitat combined with the low abundance numbers historically recorded for the species throughout its range, make the Texas golden gladeceess extremely vulnerable to extinction by random and/or environmental stochastic events (see Section 3.1.1 for more detail). Likewise, given the small area of these glades, the lower abundance numbers recorded to date, and the few numbers of known populations, the species suffers from a heightened state of vulnerability to a random event. A single random event (such as the freeze that occurred in February 2021) could affect the species, depending on the timing and intensity of the event. Texas golden gladeceess relies on a stable and/or prolific seed bank during certain intervals of the species life cycle. Species with reduced seeds in their seedbank suffer from genetic instability due to their inability to buffer effects from a stochastic event (Baskin and Baskin 1978, pp. 128-129). Such effects could occur where soil disturbance takes place, and the seed bank is removed or destroyed. Wet winters (December, January, and February) allow for seeds to germinate and plants to perpetuate at a population site and therefore climatic events (i.e., drought, hurricane, freeze events) that alter the timing and frequency of environmental conditions could be especially impactful stressors to the species.

Minimal studies on the genetics of Texas golden gladeceess have been conducted (see Section 2.3 for more detail). It is unclear how the genetic structure of the species across its range could be impacted by a catastrophic event. Small populations are susceptible to an increased rate of both inbreeding and genetic drift (Newman and Pilson 2005, p. 354).

Lack of Effective Management

Mowing

Most Texas golden gladeceess sites are not being managed. Some of the sites, including the property within the SH 21 ROW and private lands (EO ID 5290, Sabine County) have been shredded, and potentially sprayed with herbicide in 2011 (Cobb 2011a, p. 4). During site visits in spring 2022, most sites had evidence of suitable habitat or associated species with the Texas golden gladeceess, but management was lacking; only one site had been mowed (B. Fogel, pers. comm. 2022). Since an open canopy is an essential habitat feature for the Texas golden gladeceess, mowing is a valuable management tool. The timing and frequency of mowing, however, are crucial when considering implementation. Mowing has been shown to cause soil disturbance and to increase the likelihood of invasion from nonnative species (Singhurst 2011, p. 3) when conducted during times and/or seasons of predicted heavier rainfalls. Avoiding mowing when soils are wet could help alleviate rutting; it was noted that soils were rutted from brush hogging/shredding well into the spring when soils remained wet (Carr 2005, p. 2). The prime reproductive period (including flowering and setting seed) of late February to early March of the Texas golden gladeceess should be avoided. Mowing plants during this time could directly impact reproduction that year. Mowing outside of this time period is encouraged to combat nonnatives like the Macartney rose, an extremely pervasive species that needs management (Scrifes 1975, *In* Enloe and Lauer 2016, pp. 758-759). Periodic mowing has kept the canopy of the known Texas golden gladeceess sites open (such as along the ROW site at EO ID 2930), however nonnative invasive species rebounded quickly in between mowing events (Singhurst 2011, p. 4).

Herbicide Application

Within the known county-range for Texas golden gladeceess, the use of herbicides is frequent on both private and state-owned lands to combat encroaching vegetation. In 2011, the site within the SH 21 ROW and private lands (EO ID 5290, Sabine County) was potentially sprayed with herbicide (Cobb 2011a, p. 4); none of the other populations have recorded herbicide spraying. One of the primary concerns for the species is the threat from Macartney rose. The NRCS currently recommends the use of herbicide and/or prescribed burning to control Macartney rose (NRCS 2017b, p. 8). The NRCS Environmental Quality Incentive Program (EQIP) program used by many private landowners, provides technical and financial assistance to address resource concerns. Currently, the program has roughly 500 ac (202 ha) with 3-4 landowners enrolled in the EQIP program within the Nacogdoches District (J. Parks, pers. comm. 2021). Macartney rose control is often addressed through this assistance program but through secondary means (i.e., the species control is not the primary intent of the requested assistance). The use of Grazon P+D to remove Macartney rose can be 76 – 100 percent effective in its root kill when applied appropriately. However, when rose hedges have become too large to get an effective herbicide application, NRCS recommends railing (dragging rail lines behind a tractor or piece of equipment, although not widely used) first prior to such application. Application of Grazon P+D

is a restricted use pesticide and therefore requires a Texas Department of Agriculture Pesticide Applicators License (Hanselka 2021, p. 3). Grazon P+D has active ingredients of picloram and 2,4-D (dichlor) and can persist in some soils for months and act as a pre-emergent, killing germinating Texas golden gladeceess seedlings (USFWS 2012, p. 55981). Therefore, to reduce potential effects to the species, the application of Grazon P+D should be at least 200 yards (yd) (183 m) outside of areas described as habitat within the East Texas region, and use should also be limited to July 1 – August 30 (The Nature Conservancy 2003, pp. 30-31).

Along ROWs, TxDOT includes both mowing and herbicide applications as management tools. In areas where mowing occurs, prior application of chemicals such as Roundup may be used to rid the area of any undesirable non-woody plants. This is not a typical practice though as most chemicals are usually applied only as needed (J. Ritter, pers. comm. 2011b, p. 1). On a District-wide scale, mowing is most likely to occur once a year unless the area is designated as a “no mow” zone. There is one Texas golden gladeceess site on ROW land, but it has not been designated as a “no mow” zone meaning that mowing activities are restricted from occurring at any point during the year on that stretch of marked habitat. These areas have now been converted to a “Restricted ROW Activity” designation to encompass more management activities instead of just solely mowing (Cobb 2011b, p. 1) (i.e., restricted herbicide use). These signs are present within designated Texas golden gladeceess critical habitat areas only and found within areas of SH 21, FM 3483, and FM 353. TxDOT normally conducts mowing operations in early summer in most years, allowing fruits plenty of time to dehisce. However, landowners will occasionally mow these areas without TxDOT knowledge or approval (M. Buckingham, pers. comm. 2022).

Fire Suppression

Glades in most parts of the United States are declining due to grazing, fire suppression, and the subsequent invasion by woody vegetation. In pre-settlement times, glades were maintained by periodic fires and browsing of woody vegetation by white-tailed deer (*Odocoileus virginianus*) and elk (*Cervus canadensis*). This natural disturbance regime changed over the last century due to active fire suppression and hunting that diminished the natural presence of browsing species (Rossiter 1995, p. 2). Without these natural disturbance events occurring across the landscape, woody plants will invade (Hartman 2005, p. 4). It is unknown how frequently prescribed fires have been conducted on any of the known Texas golden gladeceess populations. Warnock (1992, p. 9) investigated the effects of different management procedures on white bladderpod, another annual species endemic to glade habitats of East Texas and found that prescribed burning was shown to be a positive associate to increase that species density; it is likely that Texas golden gladeceess would respond similarly. Therefore, we recommend considering the implementation of this tool along with others, to effectively treat encroaching vegetation and maintain the species open-canopy glade habitat.

Disease/Hybridization

There is no evidence to suggest that Texas golden gladeceess is vulnerable to disease and/or hybridization (Rollins 1963, p. 4). Therefore, no further discussion is provided. Should new information about disease occurrence or effects become available, the Service will reassess those in the future.

4.2 Conservation Efforts

Seed Collections, Banking, and Germination Studies

Seed banking is the ex-situ storage of seeds for future plant conservation efforts (Smith *et al.* 2003, In Martyn *et al.* 2009, p. 75), including obtaining representative samples of extant genetic diversity of wild populations. The longevity of a seed collection depends on the biology of the collected species and is influenced by the quality of the collected material, and storage and handling protocols (Martyn *et al.* 2009, p. 75). Seed collections and banking efforts help preserve traditional species over an extended period of time; despite this, all collections are vulnerable to catastrophic loss associated with the facility itself (event of a power failure, natural disaster) and inadequate maintenance and management of collections. Therefore, it is important to supplement collections over time.

Seed collections would adhere to the Center for Plant Conservation (CPC) guidelines stating that collections would not include more than 10 percent of an individual or population seed production in one season and no more than 10 out of 90 years (Menges *et al.* 2004, In CPC 2019, p. 42). The CPC outlines details on the frequency and intensity of seed collection; storage and maintenance of collections; genetic and ecological considerations; and, future uses/reintroduction of seed. The Service adheres to these guidelines and recommends any future collections do as well. Texas golden gladeceess seed has been collected but efforts within the past two or three years to connect with landowners to collect new batches of wild seed have been attempted, but land access denied.

The CPC has a Memorandum of Understanding with the U.S. Department of Agriculture, Agricultural Resource Service National Laboratory for Genetic Resources Preservation (NLGRP), however there are no accessions for the Texas golden gladeceess being housed there at this time (C. Walters, pers. comm. 2022, p. 1). However, Mercer and the Lady Bird Johnson Wildflower Center (LBJWC) have Texas golden gladeceess seed accessions banked for the CPC National Collection (A. Tiller, pers. comm, 2022). Mercer and LBJWC are participating institutions of the CPC which serves as an emergency backup for species that may become extinct or are no longer reproducing in the wild (CPC 2022, p. 2). There are three accessions housed at Mercer, all taken from 2002, two from sites in San Augustine County and the last from EO ID 4779, Nacogdoches County (A. Tiller, pers. comm. 2020).

Germination studies for several species in the *Leavenworthia* genus have been investigated by Baskin and Baskin (1971, entire). Their germination studies of *L. stylosa*, *L. uniflora*, and *L. torulosa*, all winter annuals, included both field studies and those in the and laboratory testing age, temperatures, and light and darkness. Results from the laboratory studies found that freshly-harvested seeds had very little or no germination success at any of the temperatures tested, but as the seeds aged, germination generally increased (1971, pp. 29-30). The total rate and percentage of germination increased with afterripening and with cooling of temperatures (1971, p. 30). Specific research on the germination of the Texas golden gladeceess has been undertaken by Mercer, the East Texas Plant Materials Center (PMC), and by Dr. P.C. Rajangam from the University of Wisconsin. Mercer found that from the few plants that flowered in their nursery from seeds germinated in 2002, none produced viable seed (A. Tiller, pers. comm. 2020). The PMC tried to germinate seeds as well from 2002 stock but were unsuccessful (A. Tiller, pers.

comm. 2020). Dr. Rajangam received two batches of seeds from Mercer in 2012 and 2013 to study both the genetic characterization of the genus *Leavenworthia* as well as test the germination protocol for *Leavenworthia* species. The best available protocols to germinate the Texas golden glade cress specifically are outlined by Rajangam (A. Tiller, pers. comm, 2020), and are detailed in Appendix A.

Invasive Species Management

Current management was discussed above in Section 5, Lack of Effective Management.

Research

As of 2022, several research efforts were underway looking at the genus *Leavenworthia* as a whole. Texas A&M University student, Kyle Simpson and Professor Dr. Daniel Spalink, are examining the morphometric characteristics of flowers of the genus. As of summer 2022, they collected between 800-900 samples of all *Leavenworthia* species except the *L. texana* due to access. Each floral sample was measured for petal and sepal lengths and widths, as well as the lengths of the stamen and stigma. The data will be used to help describe the morphometrics between populations of the same species and among color morphs for the *Leavenworthia* spp. with multiple, distinct flowers. Floral data can help understand how traits evolved throughout the evolutionary history for the *Leavenworthia* (K. Simpson, pers. comm., 2022). Additionally, Dr. Spalink's lab hopes to grow *L. texana* plants from seed in order to perform a chromosome study and determine if the species is actually SC (K. Simpson, pers. comm. 2022).

Additionally, Dr. Paula Williamson, Dr. Jason Martina, and students, from TXST, were funded through Traditional Section 6 in Fiscal Year 2021 to work on a project titled "Habitat assessment, monitoring and landowner outreach for *Leavenworthia texana* and *Physaria pallida*". Objectives of this three-year study include mapping areas of potential habitat for both species; identifying and contacting landowners to gain access and survey populations; establish permanent demographic monitoring sites/plots; and, develop a landowner outreach program with the goal of establishing voluntary landowner conservation agreements to protect both species. Year 1 of the project started in fiscal year 2022 so the studies' objectives and goals are pending. The mapping component of the project will include mapping of areas of suitable habitat in ArcGIS using parcel data, Weches geologic formation, TXNDD population data, and the Service's critical habitat layers. Resulting polygons will be ground truthed where possible. Additionally, ecological niche modeling (ENM) will be used to predict areas of occurrence for the Texas golden glade cress.

Outreach efforts

Please see the section above on *Research* for more details on landowner outreach as funded through Traditional Section 6.

CHAPTER 5 – Current Conditions

5.1 Population Resiliency

Population resilience for Texas golden gladeceess was derived from one demographic factor (abundance) and 4 habitat factors (temperature, precipitation, canopy, and population connectivity). To rank four of the 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 5.1.1). For the remaining factor (population connectivity), the ranking was either a “yes” or “no” with a quantified ranking of either “3” or “0”, respectively. Each factor was assigned the same weight as we lack any data that would suggest one factor is more important for the viability of Texas golden gladeceess than any other. Refer to Table 5.1.1 for details.

Table 5.1.1. Summary ranking table for Texas golden glade current conditions.

	Population Size	Timing and Amount of Precipitation	Timing and Degree of Temperature	Canopy	Population Connectivity
High (3) – Yes (3)	≥ 1,683 mature individual plants per population that will appear in at least once out of every five years	Wet winters (Dec, Jan, Feb) with averages of precipitation ≥ 13 in (330.2 mm) of rain	Temperatures in February are an average of 51.8 °F (11.0 °C); only after February and March do temperatures increase	Habitat on glade is in full-sun (no overshadowing from cedar, pine, or other tree and/or shrub species; no encroachment from invasive species extending onto glade)	A population with ≥ 1 source feature in proximity (≤ 1.0 km) (i.e., is a metapopulation)
Moderate (2)	A high of between 1,000 – 1,682 mature individual plants per population that will appear in at least once out of every five years	Wet winters (Dec, Jan, Feb) with average rainfall between 10 in (254 mm) - 13 in (330.2 mm) of rain	Temperatures in February exceed the average temperatures observed between 1980 and 2021 of 51.8 °F (11.0 °C)	Shading in glades is ≤ 10 percent where plants occur (from Carr 2005)	N/A
Low (1)	< 1,000 mature individual plants per population that will appear in at least once out of every five years	Winters (Dec, Jan, Feb) with precipitation levels that fall < 10 in (254 mm) of rain	Temperatures during the months preceding the blooming season (November, December, January) exceed temperatures of 51.8 °F (11.0 °C)	Shading in glades is > 10 percent (Carr 2005)	N/A
No (0)	N/A	N/A	N/A	N/A	Does not have any nearby source features (i.e. ≤ 1.0 km and is not part of a metapopulation.)

Some population level resources displayed in Figure 3.1 were not factored into the resiliency rankings. These habitat features (soils and geology) 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. Pollinators were not included as a resiliency factor as we lack an understanding of the connection and relationship between these and the Texas golden glade. The criteria discussed below represent assumptions that should be tested and refined over time through monitoring and research.

Population Occupancy of Habitat/Abundance:

Exact population sizes for Texas golden glade are unknown. What is considered ‘current’ estimates are from the most recent recorded data (see Figures 3.1.3, 3.1.4, 3.1.5, and 3.1.6). Each known population has been ranked using quantitative estimates based on counts of individual plants derived from the MVP estimate (Table 3.1.1). We determined that a healthy population needs at least 1,683 mature individual plants and therefore, this metric is considered our healthy (high) ranking criteria for the population size.

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

High: $\geq 1,683$ mature individual plants per population that will appear in at least once out of every five years (ranking value = 3)

Moderate: a high of between 1,000 – 1,682 mature individual plants per population that will appear in at least once out of every five years (ranking value = 2)

Low: $< 1,000$ mature individual plants per population that will appear in at least once out of every five years (ranking value = 1)

Timing and Amount of Precipitation:

Texas golden glade flowers in February when habitat conditions are wet and cool. Winters (December, January, February) leading up to and during blooming average 12.97 in (32.94 cm) of rainfall in San Augustine County and 13.38 in (33.99 cm) in Nacogdoches County. Data observed at the San Augustine station was also used for the Sabine County site due to their proximity. Precipitation data is based on NCDC records from 1999 to 2021 and 2011 to 2021 for those months for San Augustine and Nacogdoches counties, respectively. Literature indicates that Texas golden glade blooming is completed over a few weeks in February whereby precipitation amounts start to decline. By summer, precipitation has declined precipitously causing soils and glades to dry out and shift from a wet vegetative species composition to one with succulents and other drought-tolerant species. Therefore, we use the metric of recorded rainfall in winters to define healthy habitat conditions.

Preliminary criteria for ranking annual precipitation amounts are as follows:

High: wet winters (Dec, Jan, Feb) with averages of precipitation around 13 in (330.2 mm) of rain (ranking value = 3)

Moderate: wet winters (Dec, Jan, Feb) with average rainfall between 10 in (254 mm) - 13 in (330.2 mm) of rain (ranking value = 2)

Low: winters (Dec, Jan, Feb) with precipitation levels that fall < 10 in (254 mm) of rain (ranking value = 1)

Timing and Degree of Temperature:

Based on climate data from occupied Texas golden glade sites, cooler temperatures are exhibited during the species flowering period. Recorded average temperatures across the 3-county known range of the species during the months of February averages 51.8 °F (11.0 °C) between 1980 and 2021 (NCEI 2022b-g, h-m, n-r, entire). Glade sites with plants typically have standing water. Cooler temperatures during the winter months (December, January, and February) allow for standing water at the site to remain until increasing heat of the summer months causes water to evaporate, thus resulting in dry, parched soils. In addition to a shift in the amount of standing water available, the species composition changes drastically to include these species that thrive and/or need water (hydrophytes) to succulent, drought tolerant species. Texas golden glade plants are not likely to withstand hotter temperatures during its blooming period as the plant/root system could dry out and die. Therefore, we use the metric of both the timing and degree of temperature to measure the viability of the species.

Preliminary criteria for ranking annual temperature amounts are as follows:

High: temperatures in February are an average of 51.8 °F (11.0 °C); only after February and March do temperatures increase (ranking value = 3)

Moderate: temperatures in February exceed the average temperatures observed between 1980 and 2021 of 51.8 °F (11.0 °C) (ranking value = 2)

Low: temperatures during the months preceding the blooming season (November, December, January) exceed temperatures of 51.8 °F (11.0 °C) (ranking value = 1)

Canopy:

Glade communities are naturally devoid of trees, shrubs, and woody vegetation due to the presence of mudstone in its soils (George and Nixon 1990, p. 118). Baskin and Baskin (1988, p. 834) found that endemic species of rock outcrops generally are restricted to well-lit portions of an outcrop suggesting their intolerance to shading. Numerous accounts from the field suggest that the Weches glade sites for Texas golden glade are found in areas where glauconite soils in the geology are exposed, rather than where dense cover that included herbaceous vegetation (and/or trees) (Mahler 1987, p. 240; Carr 2005, p. 2; Cobb 2011, p. 4). Shading can occur from adjacent tall pines, cedar, and other tree and shrub species.

To assess the percent canopy cover at each of the four known populations, we used TXNDD shapefiles of the known boundaries overlain on Google Earth imagery (most recent is from August 2015), along with personal observations or known records of canopy cover.

Preliminary criteria for ranking canopy needs are as follows:

High: habitat on glade is in full-sun (no overshadowing from cedar, pine, or other tree and/or shrub species; no encroachment from invasive species extending onto glade) (ranking value = 3)

Moderate: shading in glades is ≤ 10 percent where plants occur (Carr 2005) (ranking value = 2)

Low: shading in glades is > 10 percent (Carr 2005) (ranking value = 1)

Population Connectivity:

Texas golden glade seeds dehisce only a few inches from the parent plant (J. Singhurst, pers. comm. 2011c, *In* USFWS 2012, p. 55971), therefore the seed dispersal range is expected to be extremely limited, much like most other members of the *Leavenworthia* genus (Lloyd 1965,

p. 11). Large rain events, other extreme weather events, and perhaps animal dispersers (although this is not known) may help to distribute seeds and ultimately increase the overall genetic exchange within a population. Connectivity between multiple sites within a population could increase the genetic exchange therefore, we assume that a healthy (high) ranking population would include multiple source features within a 1.0 km distance.

Preliminary criteria for ranking connectivity needs are as follows:

Yes: A population with ≥ 1 source feature in proximity (≤ 1.0 km) (i.e., is a metapopulation) (ranking value = 3)

No: Does not have any nearby source features (i.e., ≤ 1.0 km) (ranking value = 0)

The overall viability rankings of each known population are below in Table 5.1.

Table 5.1. Current population resiliency for the Texas golden gladeceess based on one population metric and four habitat metrics. Each factor was assigned equal weight in our assessment. Introduced population is denoted by an “I” within the table.

<i>EO ID</i>	Population Size	Timing and Amount of Precipitation	Timing and Degree of Temperature	Canopy	Population Connectivity	RESILIENCY (average)
1786	Low (1)	High (3)	High (3)	Low (1)	Yes (3)	Moderate (2.2)
5920	Low (1)	High (3)	High (3)	Moderate (2)	No (0)	Moderate (1.8)
2930	Low (1)	High (3)	High (3)	Moderate (2)	No (0)	Moderate (1.8)
4779	Low (1)	High (3)	High (3)	Moderate (2)	No (0)	Moderate (1.8)

5.2 Species Redundancy and Representation

The viability of the Texas golden gladeceess depends on the presence of redundant and resilient populations that are represented across its known range. Texas golden gladeceess is a narrow endemic, only found on soils associated with the Weches geologic formation. With only four known populations within a three-county range, and with suitable habitat being naturally small in size and needing specific habitat parameters, the species has a low redundancy and is unable to withstand effects from a catastrophic event. Representation can be measured by the genetic health of a species however, genetic studies to show the relatedness between populations and/or among individuals of a population are lacking. Environmental diversity can be used as another measure of representation, but with the Texas golden gladeceess being a narrow endemic, the species has a lowered potential to adapt to any environmental changes.

CHAPTER 6 – Future

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

Individual populations of Texas golden gladeceess face an array of stressors, as well as a varying level of future risk, stemming from natural and anthropogenic stressors. The number of populations that may have been lost since the species was first studied and discovered is unclear because only intermittent monitoring efforts have been completed. Weches glade sites are extremely small and most with extant populations of Texas golden gladeceess are on private lands. We do not have a range wide estimate for the number of individuals on the landscape due to these factors, however we estimated that each population needs 1,683 adult, reproductive individuals at each population. At present, the most prominent threat to these populations is from oil and natural gas pipeline activity, glauconite mining, and effects from climate change and invasive species. 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 the species.

6.1 Scenario Assessments

Two plausible future scenarios were forecasted, and we assessed the resiliency, redundancy, and representation for Texas golden gladeceess under each scenario. Each scenario examines oil and gas development (stressor); effects from climate change, specifically changes in timing and amount of precipitation and temperature (stressor); glauconite mining (stressor); coupled with habitat management (conservation benefit) because these are the most significant to the overall viability of the species (i.e., they impact the seedbank, individual plants, and their habitat), and are likely to be continued into the future. We developed two scenarios incorporating the ongoing stressors and conservation benefit at current levels as well as increasing and decreasing levels. We then evaluated the subsequent expected responses of gladeceess. Table 6.1.1 below summarizes the two scenarios.

Table 6.1.1. Future Scenario Descriptions for Texas golden gladeceess.

Risk	<i>Stressor: Climate Change</i>	<i>Stressor: Oil and Gas Activities</i>	<i>Stressor: Glauconite Mining</i>	<i>Conservation Benefit: Invasive Species Management</i>
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Risk Described	Expected climate conditions important to the Texas golden gladeceess (temperature and precipitation) forecasted to occur across the species' range between 2040 and 2069.	Construction and maintenance of pipeline, ROW, well pads; could include removal of habitat, seedbank, and cause disturbance; possible oil/fuel spills associated with activities.	Mine construction and resulting removal of glauconite that results in direct loss of habitat, plants, and/or seedbank.	Activities that both target specific habitat management needs of Texas golden gladeceess and/or existing voluntary measures not specific to the plant but that positively affect the species (i.e., mowing, grazing with restrictions, canopy control, burning).
Scenario 1	Climate conditions reach levels of RCP 8.5 causing a heightened increase in precipitation and temperature across the range of the species.	One new linear oil and gas project that bisects habitat, disturbs soil, with possible oil/fuel spill.	One mine is constructed within suitable habitat.	On the ground management continues as-is (status quo).
Scenario 2	Climate conditions reach levels of RCP 4.5 causing an increase in precipitation and temperature across the range of the species.	Ongoing maintenance and/or decommissioning of existing lines, well pads.	No additional glauconite mining occurs within suitable habitat.	In areas with suitable Texas golden gladeceess habitat, an increase in the implementation of on-the-ground management actions.

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

Climate Change

Climate change, specifically effects from changes in the amount and timing of precipitation and temperature, are important habitat factors required by the species. As discussed in detail in Section 1.5.3, Texas golden gladeceess needs winter rainfall events in December, January, and February for spring ponding and species blooming. Average winter precipitation is 12.97 in (32.94 cm) and 13.38 in (33.99 cm) for San Augustine and Nacogdoches counties, respectively (NCEI 2021, 2022a, entire); precipitation estimates for San Augustine were used for Sabine County as only one station was within proximity to the Sabine County population but was further away than the San Augustine County station.

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, and 2070-2099). We used scenario RCP 4.5 to forecast changes in climate under a more conservative approach but considered RCP 8.5 as 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). Based on the species biology and longevity of seed in the seedbank, we examined each RCP scenario under the 2040-2069 time period (i.e., 30 years).

Temperatures across the species range under RCP 8.5 from 2040-2069 are expected to increase (Table 6.1.2). Precipitation in San Augustine County will increase but Nacogdoches County station forecasts a decrease by 0.41 in (1.05 cm) under RCP 8.5 (Table 6.1.2).

Table 6.1.2. Climate change scenario and forecasted changes across the Texas golden gladeceess range from 2040-2069 based on average winter precipitation and temperature during this time period. The double asterisk (**) signifies that precipitation estimates were captured, and San Augustine County station was used as a proxy due to a closer proximity to an extant population.

<i>Scenario 1 (RCP 8.5)</i>	Current Temp	Future Temp	Change in °F [°C]	Current Precipitation	Future Precipitation	Change in inches [cm]
San Augustine County	51.9 °F (11.1 °C)	53.2 °F (11.8 °C)	(+) 1.3 °F [0.7 °C]	12.97 in (32.94 cm)	14.8 in (37.59 cm)	(+)1.83 in [4.65 cm]
Nacogdoches County	51.6 °F (10.9 °C)	53.6 °F (12.0 °C)	(+) 2.0 °F [1.1 °C]	13.38 in (33.99 cm)	12.97 in (32.94 cm)	(-) 0.41 in [-1.05 cm]
Sabine County	51.8 °F (11.0 °C)	53.5 °F (11.9 °C)	(+) 1.7 °F [0.9 °C]	**	**	

Temperatures across the species range under the conservative climate change scenario of RCP 4.5 from 2040-2069 are expected to increase, but not as much under scenario RCP 8.5 (Table 6.1.3). Precipitation in San Augustine County will increase but Nacogdoches County station forecasts a decrease by 0.48 in (1.22 cm) under RCP 4.5 (Table 6.1.3).

Table 6.1.3. Climate change scenario and forecasted changes across the Texas golden gladeceess range from 2040-2069 based on average winter precipitation and temperature during this time period. The (**) signifies that precipitation estimates were captured, and San Augustine County station was used as a proxy due to a closer proximity to an extant population.

<i>Scenario 2 (RCP 4.5)</i>	Current Temp	Future Temp	Change in °F [°C]	Current Precipitation	Future Precipitation	Change in inches [cm]
San Augustine County	51.9 °F (11.1 °C)	52.2 °F (11.2 °C)	(+) 0.3 °F [0.1 °C]	12.97 in (32.94 cm)	14.8 in (37.59 cm)	(+)1.83 in [4.65 cm]
Nacogdoches County	51.6 °F (10.9 °C)	52.4 °F (11.3 °C)	(+) 0.8 °F [0.4 °C]	13.38 in (33.99 cm)	12.9 in (32.77 cm)	(-) 0.48 in [-1.22 cm]
Sabine County	51.8 °F (11.0 °C)	52.4 °F (11.3 °C)	(+) 0.6 °F [0.3 °C]	**	**	

Oil and Gas Activities

We assessed the effects that oil and gas development activity (including maintenance) would have on all of the Texas golden gladeceess populations. This type of activity could include construction and maintenance of pipeline, ROW, well pads; could include removal of habitat, seedbank, and cause disturbance; and, possible oil/fuel spills associated with activities. 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 (30 years).

These data sets included:

1. All Section 7 consultations specific to onshore, above- and/or below-ground oil and gas activity received by the Service's Texas Coastal Ecological Services Field Office (TCESFO) between 2014 (following Texas golden glade/cedar listing under Act in 2013) to 2021 for Nacogdoches, San Augustine, and Sabine counties; and,
2. New construction data for pipelines from 2013 to present from the 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 as not all projects may require consultation under the Act. Only one project has been identified as an oil and gas activity that underwent Section 7 review within the known range of the Texas golden glade/cedar. In 2019, GulfSouth, the non-federal representative for the Federal Energy Regulatory Commission (FERC), consulted with TCESFO on a 22.0 mi natural gas pipeline expected to run through both San Augustine and Sabine counties. Adjacent to a section of the pipeline was EO ID 1786 (see Figure 2.2.3). Although the site was not directly impacted by the project's disturbance because it was not within the action area, there was an IR of material causing concerns for both plants and its habitat. The RRC website shows numerous other linear projects that have gone unregulated which include two other pipelines at two other known EO IDs (see Figure 5.1.4) exposing three of the four known populations to some sort of oil/gas stressor.

Routine oil and gas and well pad maintenance activities are expected to continue within these counties. However, depending on the project details some companies may not be required to provide maintenance-specific project information to the Service/TCESFO unless it is part of a reporting requirement from a Section 7 consultation. Well pads require some annual, or even quarterly, inspections by the State and the RRC tracks this data. The RRC online database shows the existing and plugged wells, but they are not efficiently tracked through time. Given the number of oil and gas wells in the East Texas play/field, we anticipate some routine maintenance occurring into the future.

Future projections for oil/gas activities are based on a 30-year timeframe of expected human population projections. Data from the TCD from 2010 to 2050 shows that within each of these counties, all human population projections will decline (Figure 6.1.4) and therefore, we assume that most oil and gas activity will be shifted towards larger urban centers. However, based on the increases in natural gas production in the Haynesville Shale play (Smith *et al.* 2018, p. 2), an increase in oil and gas and that these counties will likely see at least a small increase in oil and gas activity.

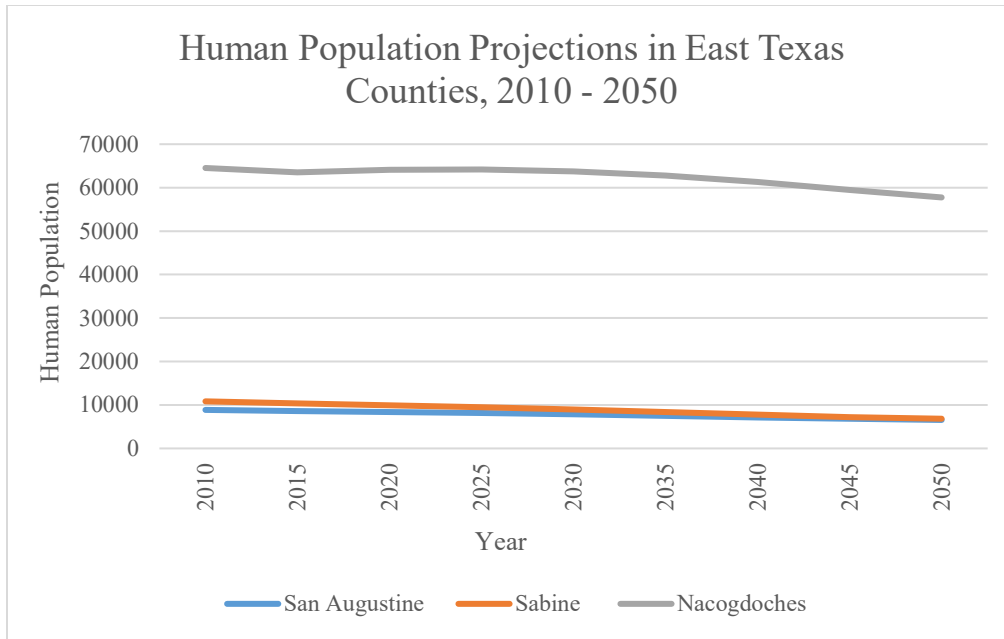


Figure 6.1.4. Human Population Projections for San Augustine, Sabine, and Nacogdoches counties, Texas, between 2010 and 2050 (TDC 2021a, b, c).

We assume the populations of the Texas golden gladeceess are 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. Therefore, we forecast that oil and gas activities will increase and will likely include at least one new linear oil or liquid natural gas pipeline within the species habitat over the next 30 years under Scenario 1. Under Scenario 2, we project that oil and gas activities will not include any new linear oil or liquid natural gas pipelines but will remain at current levels and will include ongoing maintenance and/or decommissioning of an existing line.

Glaucanite Mining

The glauconite mining industry is not regulated by any known federal, state, or local entity and therefore forecasting the future quantity and placement of these mines is challenging. Mining activities would be focused on selecting sites where glauconite is present, a key habitat feature needed by the Texas golden gladeceess. Glaucanite mining impacted EO ID 1786 by removing 38 percent of the mapped Weches habitat at the site. The use of glauconite was in practice for local road surface for oil and gas roads, well pads, and potentially some roadways at the time the species was listed under the Act (USFWS 2012, p. 55977). Due to the lack of regulation of the industry and the co-occurrence with Texas golden gladeceess on glauconite, we expect that there will be future effects to the species. Therefore, we forecast the likelihood of having an additional mine developed under Scenario 1 and no additional mines developed under Scenario 2.

Invasive Species Management

The potential conservation benefit of invasive species management was assessed using data from the Service's Partners for Fish and Wildlife Program (PFW) and the NRCS. Conservation

measures that have been planned or implemented relative to the management of habitat for the Texas golden gladeceess have included the following:

- Brush-clearing of a known white bladderpod site (EO ID 5290, Sabine County) that also historically contained the Texas golden gladeceess, was cleared in 1995. Brush-clearing resulted in the return of the white bladderpod to the site after a 10-year absence (Nemec 1996, p. 5). Warnock conducted a study in 1992 on the management activities of white bladderpod and found that brush hogging (clearing) alone was beneficial to the species but in combination with “pasture improvements” (i.e., broadleaf herbicide use, cultivation, and seeding of nonnative grasses) were deleterious (p. 9).
- Mulching of 6.0 ac (2.4 ha) of habitat on, and adjacent to, the Weches Outcrop in San Augustine County in November 2008. The goal of the PFW was to remove encroaching brushy species and to re-establish suitable glade habitat. Monitoring of the project post-mulching was part of the project in an effort to track the possible reappearance of the Texas golden gladeceess and assess reseeding needs should a sufficient seed base at the site can be established (USFWS 2010, p. 6). The landowner conducted the monitoring and as a result of this project, planted some white bladderpod but never observed the Texas golden gladeceess before or after the restoration activities.
- The landowner of EO ID 2930 used mechanical methods to remove brush during the winter of 2008-2009 (Singhurst 2009, *In* USFWS 2010, p. 6), presumably to improve grazing conditions for his cattle. It is not known what effect this action may have had upon the species. Additional brush removal at this site could be effective in removing overgrowing vegetation and opening canopy for the Texas golden gladeceess (B. Fogel, pers. comm. 2022).
- Burning, grazing, and prescribed burning were conducted on known white bladderpod habitat in 1995 (Warnock 1995, p. 3). Prescribed burning had a beneficial impact on reproduction. Most mechanical means of brush removal were positive for reproduction as well. Light to moderate grazing had little effect except to delay reproduction but heavy grazing would be expected to delay reproduction. Since the white bladderpod is another annual plant that co-occurs with the Texas golden gladeceess and requires similar habitat factors (i.e., geology, soils, canopy), it is likely that Texas golden gladeceess may respond in a similar manner as did the white bladderpod. Texas golden gladeceess needs routine maintenance of nonnative invasive species that may encroach and invade the glades and surrounding areas. Since most of the extant sites are on private lands except for a small portion of EO ID 5290 in Sabine County, and relationships with landowners have been tenuous in the past, achieving on-the-ground habitat management may depend on outside programs from NRCS or others. However, the Service started working to improve landowner relationships through a Traditional Section 6 project in 2021 and anticipates this work will build better working relationships. Therefore, under Scenario 1, future scenarios would likely exhibit conservation management actions continuing as-is. Under Scenario 2, we project that there will be additional opportunities to manage for nonnative species as landowner relations will likely have improved or become stronger.

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 four 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 6.1.5).

Table 6.1.5. Qualitative and quantitative ranking metrics used for each Texas golden gladeceess population.

	Demographic Factors	Habitat Factors				Viability Ranking
Numeric Value Assigned	# Mature Individuals Plants at a Site	Timing and Amount of Precipitation	Timing and Degree of Temperature	Canopy and Invasive Species Management	Population Connectivity	Overall Status (overall numeric range)
0	Extirpated; 0	Not Applicable	Not Applicable	Population is in full canopy - no more glade opening; and/or habitat management activities do not occur.	Not Applicable	Extirpated (0 – 0.75)
1	Low; < 1,000 mature individual plants per population that will appear in at least once out of every five years	Winters (Dec, Jan, Feb) with precipitation levels that fall < 10 in (254 mm) of rain	Temperatures during the months preceding the blooming season (November, December, January) exceed temperatures of 51.8 °F (11.0 °C)	Shading in glades is > 10 percent (Carr 2005); and/or habitat management has not occurred more than once in 5-10 years at a site.	none	Declining (0.76 – 1.5)
2	Moderate; a high of between 1,000 – 1,682 mature individual plants per population that will appear in at least once out of every five years	Wet winters (Dec, Jan, Feb) with average rainfall between 10 in (254 mm) - 13 in (330.2 mm) of rain	Temperatures in February exceed the average temperatures observed between 1980 and 2021 of 51.8 °F (11.0 °C)	Shading in glades is ≤ 10 percent where plants occur (Carr 2005); and/or habitat management occurs between every 2-5 years at a site.	none	Stable (1.6 – 2.25)

3	High; $\geq 1,683$ mature individual plants per population that will appear in at least once out of every five years	Wet winters (Dec, Jan, Feb) with averages of precipitation around 13 in (330.2 mm) of rain	Temperatures in February are an average of 51.8 °F (11.0 °C); only after February and March do temperatures increase	Habitat on glade is in full-sun (no overshadowing from cedar, pine, or other tree and/or shrub species; no encroachment from invasive species extending onto glade); and/or habitat management occurs annually at a site, as needed.	A population with ≥ 1 source feature in proximity (≤ 1.0 km) (i.e., is a metapopulation)	Healthy (2.26 – 3.0)
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6.2 Future Scenario Rankings

Scenario 1

Scenario 1 (Table 6.2.1) assumes that effects from climate change under RCP 8.5 will result in increased precipitation for San Augustine and Sabine counties with a decrease in winter precipitation in Nacogdoches County; temperature is forecasted to increase range-wide between 1.3 and 2.0 °F. Table 6.1.2 outlines the forecasted changes for these habitat factors. We assume under this Scenario that landowner relations have not improved and ability to access populations is not feasible. Beneficial actions specifically targeting the removal of invasive nonnative and native species (i.e., opening up canopy on the glade) would likely continue as-is or decrease. Based on this, populations will continue to become encroached, and the canopy cover is expected to increase, choking out suitable habitat on the glades for the Texas golden gladeceess. Population counts are expected to decline as a result. Connectivity between populations is also expected to be nonexistent and/or decline and encroachment of canopy and/or invasives into suitable habitat onto possible connecting glades. Scenario 1 also forecasts the development of at least one linear pipeline in/near Texas golden gladeceess habitat along with the continued maintenance expected across the range. In this worst case, an additional glauconite mine would be constructed, removing habitat and plants during construction and operation.

Table 6.2.1. Status of each population under Scenario 1 over the next 30 years.

Demographic Factors	Habitat Factors	Viability Ranking
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<i>EO ID</i>	# Mature Individuals Plants at a Site	Timing and Amount of Precipitation	Timing and Degree of Temperature	Canopy and Invasive Species Management	Population Connectivity	Overall Average - Quantitative	Overall Average - Qualitative
1786	1	3	1	0	3	8/5 = 1.6	Stable
5290	1	3	1	1	0	6/5 = 1.2	Declining
2930	1	3	1	1	0	6/5 = 1.2	Declining
4779	1	2	1	1	0	5/5 = 1.0	Declining

Scenario 2

Scenario 2 assumes that effects from climate change under RCP 4.5 will result in an increased amount of precipitation only in San Augustine and Sabine counties with a decrease in winter precipitation in Nacogdoches County; temperature is forecasted to increase range-wide between 1.3 and 2.0 °F. Table 6.1.3 outlines the forecasted changes for these habitat factors. We assume under this Scenario that landowner relations have greatly improved through outreach efforts and the ability to access populations is more plausible. Therefore, the likelihood of conducting habitat management for invasive species control is more likely to occur on a more routine basis. We projected that each current management status would improve within the 30-year timeframe. With this, canopy cover on/near suitable habitat within the glades should become more optimal through routine management, which may lead to new populations, and plants. Connectivity will likely increase with additional searches and existing glades and populations will become more viable. This scenario requires coordination with partners, nonprofit groups, and private landowners to think creatively to ensure access and improve landowner relations.

Table 6.2.2. Status of each population under Scenario 2 over the next 30 years.

Demographic Factors	Habitat Factors	Viability Ranking
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<i>EO ID</i>	# Mature Individuals Plants at a Site	Timing and Amount of Precipitation	Timing and Degree of Temperature	Canopy and Invasive Species Management	Population Connectivity	Overall Average - Quantitative	Overall Average - Qualitative
1786	2	3	1	1	3	10/5 = 2.0	Stable
5290	2	3	1	2	3	11/5 = 2.2	Stable
2930	2	3	1	2	3	11/5 = 2.2	Stable
4779	2	2	1	2	3	11/5 = 2.2	Stable

6.3 Status Assessment Summary

We used the best available information to forecast the probable future conditions of Texas golden gladeceess over the next 30 years under two different scenarios. The needs of the species both in terms of demography and habitat were assessed in order to describe its' viability and is presented in terms of the representation, redundancy, and resiliency. Under Scenario 1, the future viability of the species would decrease at three of the four sites due to various changes in the amount of winter precipitation but an expected increase in summer temperatures; an increase in canopy cover; and, the construction and operation of at least one linear pipeline and glauconite mine. Since all known populations and likely any suitable habitat and glades connecting these extant populations occur on private lands, access to monitor demographic and habitat factors would not be possible. Therefore, both scenarios require engagement with landowners and land managers in order to control habitat encroachment and/or continue managing habitat and assess site-specific demographics. Conditions under Scenario 1 are the most detrimental to the Texas golden gladeceess and would result in the loss of the species viability range wide. Scenario 2 would result in an expected stable viability of all known Texas golden gladeceess populations. Intense coordination with private landowners, land managers, and partners including TPWD, TxDOT, and other state, local, non-governmental partners to gain trust and access to monitor plants on a more routine basis and implement management actions is needed, where necessary. Scenario 2 would require considerable coordination to seek out new opportunities for ex-situ recovery and conservation. We foresee that even with some increased level of management, the impacts from oil and gas will remain a constant based on the location of the Texas golden gladeceess in East Texas in relation to oil and gas plays.

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GLOSSARY OF TERMS

Annual: a plant that germinates from seed, grows, flowers, produces seeds, and then dies within a period of less than a year

Breeding system: the degree by which a plant reproduces sexually by means of outcrossing (cross-fertilization), autogamy (self-fertilization), apomixis (asexual reproduction without fertilization), or by mixed breeding systems, in which two or even all three breeding systems are used (Adapted from Wikipedia 2022).

Diploid: containing two sets of similar chromosomes

Dolomite: rock-forming mineral with a chemical composition of $\text{CaMg}(\text{CO}_3)_2$, or calcium magnesium carbonate; can be found in limestone and in those cases would be referred to as dolomitic limestone

Environmental variation: amount of variation of a plant on a yearly basis

Extrorse: when anthers release their pollen to the outside of the flower so promoting cross-pollination

Facultative species (FAC): hydrophyte occurring in wetlands and non-wetland habitats (USDA, NRCS Plants Database 2022b, p. 23)

Facultative upland species (FACU): nonhydrophyte usually occurring in non-wetlands but may occur in wetland habitats (USDA, NRCS Plants Database 2022b, p. 23)

Facultative wetland species (FACW): hydrophyte usually occurring in wetlands but may occur in non-wetland habitats (USDA, NRCS Plants Database 2022b, p. 23)

Fecundity: a measure of the number of viable offspring produced

Glauconite: a green-colored iron potassium silicate related to micas and clays (Diggs *et al.* 2006, p. 55)

Growth form: the morphology of a plant, especially in relation to its physiological adaptations to its environment

Introrse: anthers that release their pollen to the inside of the flower promoting self-pollination

Longevity: lifespan of individuals, including the longevity of dormant seed viability

Marls: a carbonate-rich mud or mudstone containing variable amounts of clays and silt; chiefly contains mixture of clay and calcium carbonate that were formed under freshwater conditions (Adapted from Wikipedia 2022)

Mudstone: a type of mudrock that is primarily composed of clays and muds; also used to describe carbonate rocks such as limestone and dolomite, or siliciclastic mudstone (containing silica)

Obligate species (OBL): hydrophyte almost always occurring in wetland habitats (USDA, NRCS Plants Database 2022b, p. 23)

Obovate: egg-shaped with the petiole attachment at the narrower/top end of the “egg”

Outcrossing: (outbreeding) the production of offspring by the fusion of gametes from individuals that are not closely related; majority of plants have developed mechanisms to promote this process

Ramet production: the amount of clonality, or clones produced

Rosettes: arrangement of leaves or other structures resembling leaves, at or near the soil.

Scapes: the leafless stem of a solitary flower or inflorescence

Seed duration: length of time seeds can remain healthy and viable in the seed bank

Self-compatibility phenotypic syndrome: described by Durand *et al.* 2020 (p. 1280) as, “Self-incompatibility (SI) is a widespread mechanism to avoid selfing in flowering plants, whereby fertile plants are capable of self-pollen recognition and rejection and require compatible outcross pollen to produce seeds. At the phenotypic level, SI is typically determined by the segregation of a finite (often large) number of mating types, corresponding to as many distinct pollen–stigma recognition specificities.”

Self-incompatible: a reproductive mechanism that prevents self-fertilization, encouraging outcrossing. In plants with SI, fertilization is inhibited, and therefore no seeds are produced (unless by other means)

Silique: type of fruit or seed capsule with two fused carpels (flower pistils)

Silviculture: controlling the establishment, growth, composition, health, and quality of forests and woodlands to meet the diverse needs and values of landowners and society such as wildlife

habitat, timber, water resources, restoration, and recreation on a sustainable basis. Treatments used in silviculture can include thinning, harvesting, planting, pruning, prescribed burning and site preparation

Successional status: series of changes in the composition of the plant and animal life of an area over time. May begin as *primary succession* and may gradually change towards *climax community*.

Survivorship: the number of plants that germinate and then flower and set seed

Tetraploid: plant with four sets of chromosomes

Traditional species: also known as orthodox seed banking practices, these species are capable of being dried to internal seed moisture of less than 12 percent water, stored at freezing temperatures, and surviving

Type locality: is the geographical place of collection where a holotype or type specimen of a nominal species or subspecies was first found and described

Upland nonhydrophyte (UPL): nonhydrophyte almost never occurring in wetland habitats (USDA, NRCS Plants Database 2022b, p. 23)

Appendix:

Germination Protocols

Dr. P.C. Rajangam from the University of Wisconsin received two batches of seeds from Mercer in 2012 and 2013 to study both the genetic characterization of the genus *Leavenworthia* as well as test the germination protocol for *Leavenworthia* species. Protocols (A. Tiller, pers. comm, 2020) are provided below:

1. Take up to 10 seeds each in two 50 mL falcon tubes. Fill one with tap water and another with distilled water. Water should be at room temperature.
2. The top one centimeter of the tube should be left empty. Leaving a bit of empty space in the tube ensures free flow of water to ensure constant motion of seeds. Having maximum water in the tube ensures that the seeds are always in water and do not get stuck to the sides of the tube.
3. Leave the tubes standing in a test tube stand for an hour.
4. After one hour, place the tubes on a three-dimensional shaker/tilter to keep the seeds in constant motion. The speed of the shaker has to be very slow (the speed has to be such that the seeds get to move from one end of the tube to another along with the shaker). The Tubes should be exposed to sunlight and may be placed near a window.
5. Change water in the tubes after one hour, without removing the seeds from the tube. Do not remove the seeds from water at any point in time.
6. After changing water, leave the tubes on the shaker after fastening the tubes to the platform.
7. Change water the next day, without removing the seeds from the falcon tube. Do not remove the seeds from water at any point.
8. Germination can be observed between 7-10 days.
9. Keep changing the water on a daily basis, till the first two leaves are observed, which will be between 10th and 12th day.
10. Prepare two falcon tubes, one with distilled water and the other with tap water and add a pinch of Fafard Superfine Germination mix in each.
11. Isolate the germinated seeds which have two leaves, (using tweezers and taking the support of newly formed leaves) and transfer them to the new tubes mentioned in step 10 and put all the tubes back on the shaker. This introduces the seedlings to the germination mix. Add a second pinch of the germination mix to the tubes mentioned in 10. After 24 hours no pressure should be applied to the germinated seedlings. No water change is required in tubes with the germination mix.
11. Changes to the leaf coloration can be distinctly observed after adding the germination mix. Depending on the intensity of the leaf coloration, the seedlings may be transplanted to germination mix taken in plastic pots. The germination mix in the posts should be saturated with water and should be a thick slurry. This will ensure less post-transplantation shock.
12. The transplanted pots may be placed in the growth chamber with long day conditions.
13. The water content in the germination-mix slurry may be gradually reduced till the soil has minimum moisture content.