FINAL PERFORMANCE REPORT

As Required by

THE ENDANGERED SPECIES PROGRAM

TEXAS

Grant No. TX E-146-R

(F12AP00864)

Endangered and Threatened Species Conservation

Data synthesis and species assessments to aid in determining future candidate or listed status for plants from the USFWS lawsuit settlements

Prepared by:

Anna Strong and Dr. Paula Williamson

TEXAS PARKS & WILDLIFE

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Executive Director

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Director, Wildlife

28 August 2015

FINAL PERFORMANCE REPORT

STATE: ____Texas_______________ GRANT NUMBER: ___TX E-146-R-1__

GRANT TITLE: Data synthesis and species assessments to aid in determining future candidate or listed status for plants from the USFWS lawsuit settlements

REPORTING PERIOD: ____1 September 2012 to 31 August 2015_

OBJECTIVE(S). A two year project to compile and prepare status assessments for 12 rare Texas plant species, which are under status review by USFWS, and prepare the data for entry into the TXNDD.

Segment Objectives:

Task 1. (Sep 2012 – June 2014)
Hard copy and electronic species information maintained by TXNDD, TPWD botanists, and other relevant sources (federal botanists, NGOs, private consultants, academicians and others) will be acquired.

Task 2. (Oct 2012 – July 2014)
Acquired information will be analyzed for pertinent data. Information will be sorted into two reference categories: general species data (e.g. genetics, habitat, threats) and population-specific data (e.g. sites, survey data). Population-specific data for new records as well as updated information for pre-existing records will be synthesized and given to TXNDD for extraction by TXNDD staff at a later date. All references will be scanned and electronically archived or shelved in the TXNDD reference library.

Task 3. (Nov 2012 – July 2014)
Efforts will be made to visit and update population data and location information for species with populations that have older records or are in areas of the state that are experiencing an increased level of threats. However, this may not be feasible for all such populations or species. Uncooperative landowners or poor climatic conditions may not allow surveys. Site visits would include collecting spatial representation, population (numbers, condition, etc.) and habitat data. Data collected from site visits will be referenced as outlined in Task 2.

Task 4. (Nov 2012-Aug 2014)
Prepare the status assessment for each species. Assessments will contain historic and current population information including land ownership, survey or monitoring data, trends, and current status; species description and taxonomy, habitat characterization; life history including any disease or predation; ongoing and potential threats; and past and current conservation efforts. The assessment and a bibliography of references (TXNDD generated report) will be sent to USFWS.

Significant Deviations:

None.

Summary Of Progress:

Please see Attachment A.

Location: Texas Parks and Wildlife Dept. headquarters located in Travis County at 4200 Smith School Rd, Austin, TX 78744, USA. Location of field work will depend upon final species selection.

Cost: ___Costs were not available at time of this report, they will be available upon completion of the Final Report and conclusion of the project.__

Prepared by: _Craig Farquhar_____________ Date: _28 August 2015

Approved by: ______________________________ Date:_____28 August 2015
C. Craig Farquhar

ATTACHMENT A

FINAL REPORT

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THE ENDANGERED SPECIES PROGRAM

TEXAS

Grant No. TX E-146

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Data synthesis and species assessments to aid in determining future candidate or listed status for plants from the USFWS lawsuit settlements

Prepared by:
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31 August 2015

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Abstract:
Assessments for twelve plant species currently undergoing status reviews by the United States Fish and Wildlife Service (USFWS) were completed after locating, reviewing, and synthesizing relevant historic and current species information. Fieldwork was conducted on nine species to update population information. Species assessments included population information, species description, habitat characterization, threats, and conservation efforts. The status assessments will provide USFWS with updated information to determine if these species should be listed.

Introduction:
The United States Fish and Wildlife Service (USFWS) lists species as endangered or threatened based on several factors including destruction of habitat, overuse for commercial purposes, etc. Findings on petitions to list species pertinent to this study appear in the Federal Register (December 2009, September 2011, October 2011). To evaluate the presence and degree of these listing factors, USFWS must have available to them sound scientific data [Endangered Species Act of 1973", 10 16 U.S.C. § 1533(b)(1)(A)]. Without the availability of sound data, the accuracy of species' status determinations is hindered, if not impossible.

Therefore, for the USFWS to accurately and efficiently review the status of rare plant species, information must be available to support these status reviews. One of the most reliable sources of information for Texas species is the Texas Natural Diversity Database (TXNDD), which is a part of the Texas Parks and Wildlife Department (TPWD). There are over 400 plant species actively tracked by the TXNDD. However, there is a backlog of information that has not all been processed, synthesized or entered into the TXNDD.

Therefore, we undertook this project to compile and synthesize information for Texas species currently undergoing status reviews by USFWS for possible listing and prepare the data for entry into the TXNDD. Twelve species were selected from a list derived from the settlement between USFWS, WildEarth Guardians, and the Center for Biological Diversity. In addition to these "multiple district litigation" (MDL) species, one candidate for listing, *Streptanthus bracteatus*, was included in this report.

Objective:
A two-year project to compile and prepare status assessments for 12 rare Texas plant species, which are under status review by USFWS, and prepare the data for entry into the TXNDD.

Methods:
Information was extracted from digital and paper files currently at TPWD and external to TPWD. Data were obtained from TXNDD, TPWD botanists, and other relevant sources (federal botanists, NGOs, private consultants, academicians and others). References were scanned and electronically archived or shelved in the TXNDD reference library. Field site visits were conducted to update population and threat information, as many populations have not been visited in 20 years or more. Information was compiled and prepared for entry into the TXNDD. Information was sorted into two reference categories: general species data (e.g. genetics, habitat,

threats) and population-specific data (e.g. sites, survey data). A status assessment of populations, habitat, and threats was prepared for each of the 12 species studied.

Results and Discussion:
Assessment and fieldwork were completed for *Agalinis navasotensis* (Navasota false foxglove), *Amsonia tharpii* (Tharp's blue-star), *Asclepias prostata* (prostrate milkweed), *Eriocaulon koernickianum* (small-headed pipewort), *Genistidium dumosum* (brush-pea), *Helianthus occidentalis* ssp. *plantagineus* (Shinner's sunflower), *Paronychia congesta* (bushy whitlow-wort), *Symphyotrichum puniceum* var. *scabricaule* (rough-stemmed aster), and *Trillium texanum* (Texas trillium). All but small-headed pipewort resulted in positive findings. Assessments were completed but fieldwork was not conducted on *Bartonia texana* (Texas screwstem), *Hexalectris revoluta* (Chisos coralroot), and *Streptanthus bracteatus* (bracted twistflower). Chisos coralroot and bracted twistflower were not visited due to more recent surveys. Texas screwstem will have surveys conducted after this report has been submitted. No assessment was written for *Physostegia correllii* (Correll's false dragonhead), but sites were visited to update population information. No assessment was written for *Salvia pentstemonoides* (big red sage), but recent fieldwork has been conducted on this species by the Botanical Research Institute of Texas as part of a TPWD Horned Lizard License Plant grant.

Each assessment contains historic and current population information including land ownership, survey or monitoring data, trends, and current status; species description and taxonomy; habitat characterization; life history including any disease or predation; ongoing and potential threats; and past and current conservation efforts.

The assessment for each species follows. Each assessment includes a figure showing distribution of extant populations of the taxon and a table detailing the population status with location and ownership. Each status assessment is organized into the following subsections:

- Species Information (history of knowledge of taxon)
- Present legal status (National and State)
- Description (local field characters)
- Geographical distribution (range and precise occurrences)
- General environment and habitat description (physical and biological characteristics)
- Population biology of taxon (demography, phenology, and reproductive biology)
- Population ecology of species (negative interactions)
- Land ownership
- Management practices
- Evidence of threats to survival
- Special management considerations (past, present, and future)
- Citations

These assessments will be valuable to the USFWS in updating the status of these rare plants. The status assessments provide USFWS with information needed to determine if these species should be listed. The information compiled will also likely prove useful to USFWS for planning, managing and restoring these species, if one or more are upgraded to threatened or endangered as a result of the status review process.

Navasota false foxglove

(*Agalinis navasotensis*)

Species information (history of knowledge of taxon)

Navasota false foxglove is only known from four counties in Texas: Grimes, Jasper, Newton, and Tyler (See Table 1 and Figure 1). The Grimes County site was discovered in 1983 and a specimen was collected (Ajilvsgi 8510, TAMU), but the specimen was identified as green false foxglove (*Agalinis viridis)* until 1993 when it was recognized as Navasota false foxglove or *Agalinis navasotensis* (Canne-Hilliker and Dubrule 1993). Subsequently, a 1967 herbarium specimen of Navasota false foxglove [originally identified as St. Mark's false foxglove (*Agalinis pulchella*)] was found (Correll 35187-A, LL), which led to the rediscovery of the Tyler County site in 2003 (Reed et al. 2005).

Present legal status (National and State)

In 2009, a 90-day finding was announced on 67 species from a petition to list 475 in the southwestern United States as threatened or endangered (U.S. Fish and Wildlife Service 2009). The petition presented scientific information to indicate that listing may be warranted for Navasota false foxglove. Scientific, commercial, and other information was requested and other available information was summarized by the U.S. Fish and Wildlife Service (USFWS). In their summary, the USFWS determined that of the five threat factors, which can be used to assess if a species may warrant listing as endangered or threatened, only threat factor A (the present or threatened destruction, modification, or curtailment of its habitat or range) was listed.

Navasota false foxglove is ranked as G1 or critically imperiled by NatureServe and is ranked as a Sensitive Species by the United States Forest Service. Although it is not listed as endangered or threatened by the State of Texas, the species is also listed on Texas Parks and Wildlife Department's 2010 List of the Rare Plants of Texas and as a Species of Greatest Conservation Need in the Texas Parks and Wildlife Department (TPWD) State Conservation Action Plan.

Description (local field characters)

The following description is adapted from Hilliker (in press). Navasota false foxglove is a 25-80 cm tall hemiparasitic annual with spreading- ascending, ridged branches. The leaves are opposite and spreading, but do not have axillary clusters of flowers. The filiform (long and slender) leaves [(11-) 17-30 (-40) mm long and 0.5-1.2 mm wide] are rough to the touch (with minute protrusions) on the upper side of the blade and on the midvein of the lower side of the leaf. Held in racemose-paniculate inflorescences, the pink to rose flowers are 15-24 mm long. The pedicels are ascending-spreading and (2-) 6-25 mm long. Straight-sided and inversely cone-shaped to funnelform, the calyces have 2.2-4.6mm long tubes and 0.5-1.5 mm long, triangular-subulate to subulate (narrowly- or truncate-triangular) lobes. The 15-24 mm long corolla has sparse, soft, long hairs on the indentation between its five spreading lobes, but is hairless within the corolla throat across the bases of the upper lobes. Numerous dark brown seeds (0.8-2.3 mm) are encapsulated within a (4-) 6-7 mm long ovoid to obovoid-oblong fruit.

Navasota false foxglove could easily be mistaken for Caddo false foxglove (*Agalinis caddoensis*) and, according to Agalinis specialists, could even be the same species (Hilliker 2013a). However, because Caddo false foxglove has not been collected since 1913 and reproductive structures are lacking from the one specimen, the two false foxgloves will remain distinct species until Caddo false foxglove is re-located. Navasota false foxglove has been found with other more common false foxgloves including ridgestem false foxglove (*Agalinis oligophylla*), beach false foxglove (*Agalinis fasciculata*), and St. Mark's false foxglove. Additionally, prairie false foxglove (*Agalinis heterophylla*), coastal plain false foxglove (*Agalinis harperi*), slenderleaf false foxglove (*Agalinis tenuifolia*), and green false foxglove occur in nearby moist soils. All of these false foxgloves have thin needle-like leaves and are similar in appearance to Navasota false foxglove. See Appendix 1 for key to distinguish Navasota false foxglove from the other similar co-occurring eastern Texas false foxgloves. The differences among the *Agalinis* species are subtle and each is defined by a suite of characters (Reed 2004). Navasota false foxglove key characters include filiform leaves [(11-) 17-30 (-40) mm long and 0.5-1.2 mm wide]; straight-sided calyx; short (0.5-1.5 mm long) calyx lobes; equally spreading (not arching over stamens) corolla lobes; and usually greenish-yellow stigmas (rather than lighter yellow) (Poole et al. 2007).

Geographical distribution (range and precise occurrences)

Navasota false foxglove has been recorded in two counties at two sites 100 miles away from one another. The Grimes County population consists of three sites, all within a mile of each other. The smallest site has been visited a few times but plants were only seen when the first specimen was collected in 1996 (Reed #1840, TAMU). The Tyler County population is made up of several patches of plants, at least one of which was estimated to be about 20 m^2 (Singhurst 2003). The patches cover about 1.5 acres.

When the Navasota false foxglove was named and located in 1993, it was suggested that searching for similar outcrops could reveal additional populations (Canne-Hilliker and Dubrule 1993). As a result, a project was initiated using soil maps and aerial photography to identify potential Navasota false foxglove sites in Grimes County (Linam 2002). Floristically-similar outcrops in adjacent Washington County and Burleson County were also searched (Reed 2000). These surveys did not result in any new populations; however, when the 1967 Correll specimen was found, the location description combined with aerial images of sparsely vegetated areas resulted in the rediscovery of the Tyler County population.

General environment and habitat description (physical and biological characteristics)

The Grimes and Tyler County populations of Navasota false foxglove differ in their habitat. The Grimes County sites occur over the Fleming Formation. Soils of the Grimes County sites consist of Renish-rock outcrop and Brenham clay loam. The soils are calcareous clay loam, loam, or gravelly loam over sandstone bedrock (Greenwade 1996). Some areas of bedrock are exposed (Greenwade 1996). Dominant species at this remnant prairie include Berlandier's sundrops (*Calylophus berlandieri* spp. *pinifolius*), plains nipple cactus (*Coryphantha missouriensis*), bluebonnets (*Lupinus* spp.), Texas skeleton-plant (*Lygodesmia texana*), witchgrass (*Panicum capillare*), paspalums (*Paspalum* spp.), dense-flowered bladderpod (*Physaria densiflora*), bladderpods (*Physari*a spp.), little bluestem (*Schizachyrium scoparium*), and prairie bluet (*Stenaria nigricans*).

The Tyler County site occurs in barrens of the Catahoula Formation. The soils are Browndell-Kitterll and Colita fine sandy loams, which consist of acidic loams and fine sandy loams over tuffaceous (compacted volcanic ash/dust) sandstone and siltstone (Steptoe 2008). These small, patchy areas of relatively sparse vegetation consist mostly of prairie-like herbaceous species, dominated by rayless goldenrod (*Bigelowia nuttallii*), pineweed St. John's-wort (*Hypericum gentianoides*), San Saba pinweed (*Lechea san-sabeana*), narrow-leaf pinweed (*Lechea tenuifolia*), sharp blazingstar (*Liatris acidota*), narrow-leaf gayfeather (*Liatris mucronata*), Kansas gayfeather (*Liatris pycnostachya*), slender gayfeather (*Liatris tenuis*), and hairy-awn muhly (*Muhlenbergia capillaris*), blue-joint panicgrass (*Panicum tenerum*), longleaf pine (*Pinus palustris*), little bluestem (*Schizachyrium scoparium*), slender bluestem (*Schizachyrium tenerum*), sand spikemoss (*Selaginella arenicola*), compass-plant (*Silphium laciniata*), pineywoods dropseed (*Sporobolus junceus*), and prairie bluet (*Stenaria nigricans*). The barren is surrounded by pine savanna. In both the calcareous outcrop and the sandstone barren, fire is an important factor in maintaining an herbaceous, prairie-like system.

Annual precipitation averages between 41 inches near the Navasota false foxglove sites in Grimes County and 53 inches near the sites in Tyler County. Monthly rainfall averages between 2.4 inches (July) and 4.8 inches (June) (in Grimes County) and 3.7 inches (April) and 6.3 inches (June) (in Tyler County) (National Oceanic and Atmospheric Association 2015).

Population biology of taxon (demography, phenology and reproductive biology)

The thin leaves and stems make it difficult to see Navasota false foxglove when it is not in bloom (Reed 2013b). Surveys of Navasota false foxglove have, therefore, usually included only reproductive individuals. The smallest site has only been seen once with plants present and consisted of only a few individuals (Reed 2013a). The largest of the three sites has periodically been visited since 1993, but more frequently since 2000. Counts of flowering plants taken at this site between 2000 and 2012 ranged between 24 (in 2006) and 500 plants (in 2001) (TXNDD 2015). The Tyler County population was surveyed only from 2003 to 2005 and ranged from 30 to approximately 200 plants. The site has not been visited since 2005.

False foxgloves' breeding systems vary from exclusively outcrossing [stiffleaf false foxglove or *Agalinis strictifolia* (Dieringer 1991)], to mostly selfing [Middleton false foxglove or *Agalinis neoscotica* (Stewart et al. 1996)] to selfing when pollinators are not present [Skinner's false foxglove or *Agalinis skinneriana* (Dieringer 1999), tenlobe false foxglove or *Agalinis obtusifolia* (Snider 1969), and earleaf false foxglove or *Agalinis auriculata* (Mulvaney et al. 2004)]. Due to their varied floral morphology, false foxgloves could be pollinated by multiple genera of bees (Canne-Hilliker 1987a). This has been shown to be the case with several false foxgloves. Neel (2002) observed common eastern bumblebees (*Bombus impatiens*) as the most frequent visitor coming in contact with anthers and stigma of sandplain false foxglove (*Agalinis acuta*). Mulvaney et al. (2004) observed a long-horned bee (*Melissodes bimaculata*) and common eastern bumblebee as the primary floral visitors to earleaf false foxglove. Dieringer (1992) reported American bumblebee (*Bombus pennsylvanicus*) and honeybee (*Apis mellifera*) as the most effective pollinators of stiffleaf false foxglove.

Population ecology of species (interactions and hybridization)

Like many members of the broomrape family (Orobanchaceae), Navasota false foxglove is a hemiparasite, a plant that obtains nutrients through the process of photosynthesis, but also by parasitizing neighboring plants through modified roots. Hemiparasites can influence their community structure disproportionately to their occurrence and, therefore, are considered keystone species (Press and Phoenix 2004). Not only could the disappearance of a hemiparasite negatively impact its neighboring plants, but without neighbors to parasitize, hemiparasitic plant growth could be stunted or prevented. Hemiparasites can have higher concentrations of nitrogen and phosphorous in their leaves (and subsequently litter) compared to host plants and can benefit surrounding plants by making these nutrients available when they decompose (Quested et al. 2003).

It has been shown in other hemiparasitic false foxgloves that host specificity can range from very narrow to very broad (Musselman and Mann 1979; Nickrent and Musselman 2004) and that without the preferred host(s), growth of the hemiparasite can be stunted (Cunningham and Parr 1990; Molano-Flores et al. 2003). Also, there could be multiple hosts: one or more to facilitate germination and others to serve as a nutrient source for the growing hemiparasite (Molano-Flores et al. 2003). Ear-leaf foxglove is a root parasite (Musselman 1972) and has been shown to parasitize at least four species of sunflowers (Asteraceae) (Cunningham and Parr 1990; Molano-Flores et al. 2003). Despite these abilities to tap into other plant's nutrients, hemiparasites still photosynthesize and compete with surrounding vegetation for light. Because of this competition, hemiparasites tend to grow in nutrient poor habitats (Matthies 1995) where competition is decreased and they can grow more easily. Many false foxgloves can thrive in fairly open, herb-dominated, disturbance-prone habitats (Pettengill and Neel 2008) like grasslands where grass roots are fine and easy to parasitize (Press and Phoenix 2004). The co-occurring King Ranch bluestem (*Bothriochloa ischaemum* var. *songarica*), a non-native invasive grass, which in 2014 was “quite abundant” at the FM 3090 site (Reed et al. 2014) could serve as a beneficial host for Navasota false foxglove, but could also out-compete it for sunlight.

Navasota false foxglove may also be negatively affected by encroachment from woody species. The Grimes County site is home to aggressive, non-native woody species like Japanese honeysuckle (*Lonicera japonica*) and various privets (*Ligustrum* spp.), as well as native woody species such as yaupons (*Ilex* spp.) and dogwood (*Cornus drummondii*). These woody plants could convert the savanna community into woodlands, which may not be able to support a sun-loving herbaceous understory. Competition from grasses and woody vegetation could account for the decline in number of individuals from 2001 to 2006 (~500 to 24). However, the year-to-year fluctuation of Navasota false foxglove (the population bounced back to 389 plants in 2012) is common in annual plants and cannot be ruled out as a possible influence.

There is no evidence that hybridization between false foxgloves exists (Canne-Hilliker 1987b).

Significance

Many false foxgloves are difficult to identify in the field. Despite this, genetic studies have shown that Navasota false foxglove is a good species (Pettengill and Neel 2008). Genetic studies have confirmed earlier anatomical and morphological studies, which were used to classify and name the group before genetic analyses were widely used (Pettengill and Neel 2008). Because of the challenges of naming and classifying false foxgloves, they are being used as model organisms to test the usefulness and accuracy of DNA barcoding, a method that uses one of an organism's parts (e.g., a leaf) to acquire a short genetic marker in its DNA to identify it to species level. False foxgloves have shown that barcoding has promise of differentiating among morphologically-confusing species and could be used in conservation of rare species to determine true identity and, therefore, distribution (Pettengill and Neel 2010). However, the utility of DNA barcoding will depend upon several factors, including barcoding's ability to differentiate between species within a genus and the uncertainty of the current taxonomy (Pettengill and Neel 2010). Although genetic studies have been conducted involving Navasota false foxglove, none of these studies looked at the variation between or among populations, just distinctness from other species.

Land ownership and management

All known Navasota false foxglove sites are either privately owned or on highway right-of-way. A portion of the privately-owned Grimes County site has never been cultivated and has not been grazed since 1958 (Keeney 1967). This may be because it is steep and has a thin layer of soil (Reed 2013b) over a calcareous outcrop. The Tyler County site was a pine plantation at one time, although apparently the soils were too thin to support pine and the plantation was unsuccessful (Keith 2013). The rock outcrops present at known Navasota false foxglove habitat may inadvertently be protecting this plant from destructive ranching and farming practices.

In the early 1990s the Texas Department of Transportation (TxDOT) was made aware of the only known population at the time (the Grimes County sites). Following due diligence for the National Environmental Policy Act, a 1993 TxDOT letter recommended that unmarked posts be installed to decrease the chance of crews inadvertently affecting this population (Bohuslav 1993). No posts are currently erected, but most known individuals of Navasota false foxglove are outside the rights-of-way maintained by TxDOT.

For at least a decade, the landowners of the largest site of Navasota false foxglove in Grimes County have cooperated with Texas A&M University and Texas Parks and Wildlife to manage the plants on their property. There is an educational component to this management. Classes and groups are allowed onto the outcrop to learn about the unique plant community and geology. There is even a website dedicated to the outcrop (Reed 2008), which lists species at the site, summarizes the 2006 burn, and requests that visitors take photographs, but otherwise not disturb the plants.

A low-intensity prescribed fire was conducted in December 2006 at the largest Grimes County site to decrease the invading brush and invasives (*Cornus drummondii*, *Ilex* spp., *Juniperus virginiana*, *Ligustrum* spp. and *Lonicera japonica*) (Reed 2008). It is likely that the burn was the first large-scale disturbance in the last fifty years (Keeney 1967). The fire consumed the smaller woody vegetation, but left the larger woody vegetation untouched. Some brush was manually removed and treated with herbicide (Reed 2008). The year after the burn there were "hundreds" of plants (Reed 2008), and although exact counts were not always made, every subsequent year the number of plants appeared to decrease until 2012. At this time the number of plants in flower bounced back to 389 plants (Reed 2013b). This upward trend continued in 2013 and 2014. It has been suggested that rainfall and occurrence of host plants are the reason behind this increase (Reed 2015). Baseline data were taken prior to the burn to establish vegetative cover and composition (Reed 2008). Unfortunately, these data cannot be located; however, data were taken in 2014 near the same transects (Reed et al. 2014). The two transects showed that dominant species were hairy grama (*Bouteloua hirsute*), prairie tea (*Croton monoanthogynous*), panic grass (*Dichanthelium* sp.), Reverchon's false pennyroyal (H*edeoma reverchonii*), prairie bluets (*Hedyotis nigricans*), eastern red cedar (*Juniperus virginiana*), little bluestem (*Schizachyrium scoparium*), late purple aster (*Symphyotrichum patens* var. *patentissimum*), and stiff greenthread (*Thelesperma filifolium*) (Reed et al. 2014).

Seeds have been collected from the Grimes County site and stored at Mercer Arboretum and Botanic Gardens in Humble, Texas. Because of difficulty in germinating seed (Tiller 2015), tissue culture techniques have been tested by the Cincinnati Zoo and Botanical Garden's Center for Conservation and Research of Endangered Wildlife (CREW). In 2000, seeds from the largest Grimes County site were germinated in vitro (Pence 2013). The best germination rate (11%) was obtained from seeds that were first stratified in 4°C for one month, then moved to a variable temperature incubator (30°C, 16 hrs day/ 15°C, 8 hrs night) for two weeks. Seedlings were then moved to nutrient media and rooting rates varied between 60% and 90%. Tissue cultures are still housed at CREW; however, transitioning these to soil has not been successful (Pence 2013). The lack of funding has curtailed further research at CREW. Like other false foxgloves, the difficulty in growing Navasota false foxglove to maturity could be due to lack of appropriate hosts (Molano-Flores et al. 2003), reduced fitness caused by the lack of gene flow between small isolated populations (Molano-Flores et al. 2007), or other factors.

Evidence of threats to survival

Throughout its range, Navasota false foxglove is threatened by habitat fragmentation and other factors. Although the largest site is managed (at least in part) for Navasota false foxglove and is regularly visited and surveyed, there is little information regarding the remaining sites. The largest number of plants ever seen in one year (2001) at two of the three known Grimes County sites was 570. Only a few plants have been observed at the remaining third site in Grimes County once when it was discovered in 1992. In Tyler County, the highest number of plants seen was 200 in 2005. The two populations are either privately owned or on highway ROW and occur in less than 2 acre patches. These factors highlight the vulnerability to development of these populations and the need for more surveys to locate additional sites.

Throughout the 1900s, Grimes and Tyler counties were converted to timberland, livestock and dairy ranches, cropland, and more recently, to oil and gas production. Navasota false foxglove can persist in shallow soils of rock outcrops, and may persist in the known sites because the soils are not usable for many industries. However, a past landowner attempted to plant pines at the Tyler County site, but was unsuccessful (Keith 2013).

As an annual plant, Navasota false foxglove may be able to respond quickly to disturbances like brush removal and application of fire. However, competition with other annual species (native or non-native) that also respond well to disturbances could eventually decrease Navasota false foxglove numbers. Another rare false foxglove, earleaf false foxglove, did respond well to brush removal and deer browsing (Vitt et al. 2009). It has been shown on a representative Hays County Blackland Prairie site that summer burns are more effective at curtailing King Ranch Bluestem growth compared to mowing (Simmons et al. 2007). Another study conducted in Blanco and Burnet counties looked at effectiveness of winter burns compared to unburned areas and found there was no difference in these two treatments (Gabbard and Fowler 2007). However, winter-prescribed burns are more common in Texas due to control and safety issues related to summer burns. Navasota false foxglove flowers in the early fall so seedlings could be affected by summer burns (Reed 2006). To determine how fire, brush removal, and how other neighboring plant species affect Navasota false foxglove, these interactions need to be studied.

Special management considerations

A combination of management strategies could be used to increase Navasota false foxglove numbers. Because Navasota false foxglove is an annual, it is unclear how much of the variation in numbers is due to internal factors like life cycle or external factors like competition, fire regime, precipitation, or other influences. With the efforts of the landowners and the volunteer community, including Texas A&M University and others, prescribed fires may continue at the Grimes County site as resources and schedules allow. Knowing how effective Navasota false foxglove is at competing with other annual herbs would increase effective management of healthy populations. Additionally, knowing preferred host plants would allow for management of host plants.

Additional surveys to identify more Navasota false foxglove sites should be conducted. Habitat modeling may not be effective since habitat varies between the two known sites. Finding additional sites may help to infer a better habitat model (Reed et al. 2005). If no additional populations can be located, genetic studies to determine the extent of gene flow within and between populations should be conducted in these small remaining populations of Navasota false foxglove. A monitoring plan could establish a protocol to regularly and systematically count the existing populations of this cryptic species and would help identify the extent to which internal factors (like annual habit) versus external factors (like competition and fire regime) affect the fluctuation in numbers within sites. Field surveys should occur in the morning or early afternoon before the blooms have dropped to increase detection of the plant (Reed et al. 2005). To determine if pollinators are essential to reproduction, the breeding system needs to be determined. If the plants are outcrossers, identifying pollinators will aid in determining pollinator habitat type (e.g., ground-nesting bees vs. wood-boring bees) and subsequent protection of pollinator habitat.

Citations

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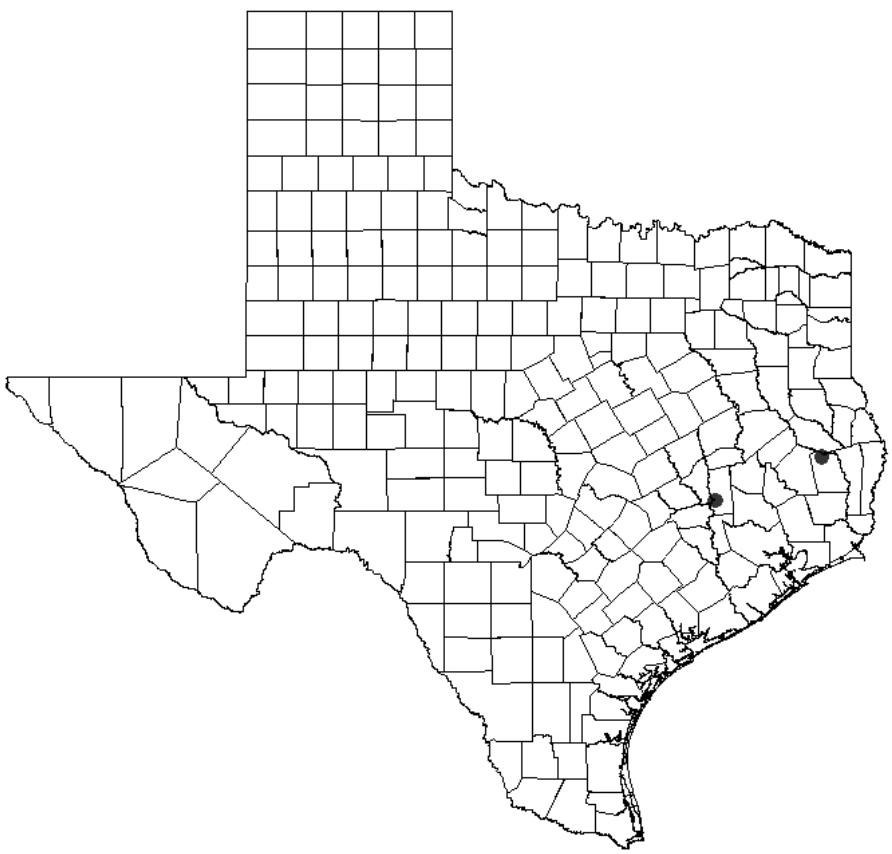
Table 1. Navasota false foxglove population status, including location and ownership (Texas Natural Diversity Database 2015).

County	Year discvrd	Year last seen	EO ID+	Site name	Landowner	Min. # per 1 subpop. *	Max. # per 1 subpop. *
Grimes	1983	2014	6674	Grimes	county ROW/ private	a few (1992)	500 (2001)
Tyler	1967	2005	9000	Tyler	county ROW/ private	15 (2003)	200 (2005)

+ EO ID is the unique number assigned to a new record (element occurrence) in the Texas Natural Diversity Database. An element occurrence is an area of land where a species resides/resided (i.e., a population). A population can consist of one or more subpopulations.
* represents number of individuals recorded in any year at a subpopulation; each count is based on surveyor effort and is only as good as the effort expended (e.g., zeros could be false negatives; larger numbers, like >1000, could be gross under- or overestimates)

Figure 1. Distribution of extant populations of Navasota false foxglove (*Agalinis navasotensis*) (TXNDD 2015).



Appendix 1. Key to species of *Agalinis* known to occur with or in the area of Navasota false foxglove (Hilliker 2013b).

1. Upper corolla lobes projected over anthers. . . . .*A. tenuifolia*

1. Upper corolla lobes erect to reflexed.

    2. Inflorescences of racemes with lateral flowers; bracts longer than pedicels; pedicels 0.5-9 mm long.

        3. Leaves narrowly lanceolate to elliptic-lanceolate, lowermost sometimes 3-cleft, 2-6 (-7) mm wide; lower corolla lobes glabrous externally; capsules ovoid-oblong, 5-9 mm long. . . .. *A. heterophylla*

        3. Leaves linear-filiform to broadly linear, entire, 0.5-3(-4) mm wide; lower corolla lobes pilose externally; capsules globose, 4-6 mm long

            4. Branches uniformly and moderately to often copiously and harshly scabrous; leaves 1-3(-4) mm wide; axillary fascicles well developed; calyx lobes ribbed but not strongly keeled. . . *A. fasciculata*

            4. Branches glabrous to scabridulous; leaves 0.5-1.4 mm wide; axillary fascicles absent or few and shorter than subtending leaves; calyx lobes so strongly keeled that calyx is fluted. . . . *A. harperi*

    2. Inflorescences racemiform-paniculate with some pseudoterminal flowers; bracts shorter to longer than pedicels; pedicels 2-50 mm long.

        5. Corollas (from sinus of calyx to apex of extended mid-lower corolla lobe) 8-12 mm long, pale pink to nearly translucent; calyx lobes lanceolate, 1.3-2.5 mm long; capsules obovoid. . . . .*A. viridis*

        5. Corollas 15-33 mm long, pink to rose; calyx lobes subulate to triangular subulate, 0.5-1.5 mm long; capsules globose or ovoid to obovoid-oblong

            6. Branches uniformly, densely, short scabrous; axillary fascicles well developed; pedicels scabrous; calyx glaucous; corollas 22-33 mm long. . . . . *A. pulchella*

            6. Branches glabrous to scabridulous; axillary fascicles absent; pedicels glabrous or scabridulous, especially proximally; calyx without white bloom; corollas 15-25 mm long.

                7. Leaves filiform, (11-) 17-30 (-40) mm long; branches obtusely quadrangular, ridged; pedicels (2-) 6-25 mm long; corolla throat glabrous within below upper corolla lobes but sparsely villous at sinus of lobes; capsules ovoid to obovoid-oblong; seeds dark brown. . *A. navasotensis*

                7. Leaves subulate, elliptic or filiform, (1-) 4-13 mm long; branches strongly quadrangular with prominent silicified ridges on angles and on midvein extensions below leaves; pedicels 2-16 mm long; corolla throat villous within below upper corolla lobes and sinus; capsules globose; seeds yellow to tan. . . . . *A. oligophylla*

Tharp's blue-star

(*Amsonia tharpii*)

Species information (history of knowledge of taxon)

Tharp's blue-star was first collected in Pecos County, Texas in 1943 by Benjamin C. Tharp (#43508, NY) and described by Robert Woodson in 1948. No additional populations have been found in Texas since these initial specimens were collected, but three (or four) sites of Tharp's blue-star were located in Eddy County, New Mexico in the 1990s.

Present legal status (National and State)

In 1983, Tharp's blue-star was added as a Category 2 taxa to the list of U. S. plants that were being reviewed for possible addition to the Endangered Species Act. Category 2 indicated taxa that proposal to list as endangered or threatened was possibly appropriate, but for which substantial data on biological vulnerability and threat(s) were not known or on file at the time to support a proposed ruling. To ascertain the status of the taxa in this category, biological research and field study were seen as possibly needed (U.S. Fish and Wildlife Service 1983). In 1985, the species was raised to a Category 1 listing, which indicated taxa with substantial biological vulnerability and threat(s) information on file to support the appropriateness of a proposed listing as endangered or threatened. Precise habitat data were being gathered, and development and publication of proposed rules were anticipated, but because of the large number of taxa in Category 1 a ruling was delayed (U.S. Fish and Wildlife Service 1985). In 1993, after the species was found in New Mexico, the species was moved to a Category 2 species (U.S. Fish and Wildlife Service 1993). In 1996, all Category 2 taxa were dropped from the Endangered Species Act, due to lack of information to justify proposed rules. The U.S. Fish and Wildlife Service (USFWS) felt that more biological research and field study were necessary to resolve the conservation status of Category 2 species, and that these species were the pool from which future candidate species could be drawn (U.S. Fish and Wildlife Service 1996). In 2009, a 90-day finding was announced on 67 species from a petition to list 475 in the southwestern United States as threatened or endangered. The petition presented scientific information to indicate that listing may be warranted for Tharp's blue-star (U.S. Fish and Wildlife Service 2009). Scientific, commercial, and other information was requested and other available information was summarized by the USFWS. In their summary, the USFWS determined that of the five threat factors, which can be used to assess if a species may warrant listing as endangered or threatened, only A (the present or threatened destruction, modification, or curtailment of its habitat or range) and E (other natural or manmade factors affecting its continued existence) were listed.

Tharp's blue-star is ranked as a G1, or critically imperiled across its entire range, by

NatureServe. Although it is not listed as endangered or threatened by the State of Texas, the species is listed as a 2010 List of the Rare Plants of Texas and as a Species of Greatest Conservation Need in the Texas Parks and Wildlife Department (TPWD) State Conservation Action Plan. In New Mexico, Tharp's blue-star is a state endangered species, classified as such because it is rare across its range (distribution and population sizes are limited) in New Mexico and unregulated taking could negatively impact the species and jeopardize its continued survival (19.21.2 New Mexico Administrative Code). The Bureau of Land Management (BLM) New Mexico Sensitive Species List includes Tharp's blue-star. This classification enables proactive management of the species through decreasing or eliminating threats to the species or improving habitat condition.

Description (local field characters)

Tharp's blue-star is a woody perennial, which grows up to 20 cm tall (McLaughlin 1982). Its leaves are dimorphic; the leaves on the upper part of the stem are linear (parallel leaf margins) to linear - lance-shaped (leaf margins broader at the base) and the lower leaves are elliptic (leaf margins broader in the middle of the leaf) - lance-shaped (McLaughlin 1982). The floral tubes are 13-15 mm in length and are slightly constricted at their orifice (McLaughlin 1982). The fruits of Tharp's blue-star are 2-12 cm long and bean-like (a follicle), but with only one side splitting to release the cylindrical seeds (7-9 mm x 2-3 mm) (McLaughlin 1982).

Only one other blue-star, tubular blue-star (*Amsonia longiflora* var. *salpignantha*), has been collected in Pecos County, but 17 air miles ESE of the Tharp's blue-star population (Turner #23-240). Tubular blue-star's upper leaves are more thread-like than those of Tharp's blue-star. When in bloom, the flowers are easily distinguishable because tubular blue-star's floral tubes are 35-45 mm long. Pritchett-Kozak observed that the Texas populations of Tharp's blue-star have petals which are wider, more ovate, and are not as recurved as the New Mexico population's petals (Pritchett-Kozak 1993). No recorded measurements are available to back up this observation. Several other blue-stars have been collected in nearby counties. Palmer's blue-star (*Amsonia palmeri*) has been collected in Brewster and Jeff Davis counties, woolly blue-star (*Amsonia tomentosa*) has been collected in Brewster County, and fringed blue-star (*Amsonia ciliata*) has been collected in Crockett County. Palmer's blue-star is generally taller than 30cm and the leaves are not noticeably dimorphic (both lower and upper leaves are linear to lance-shaped) (McLaughlin 1982). Woolly blue-stars are <15 cm tall and have 2-8 cm long fruit, which constrict between each of the elliptic seeds (8-21 mm x 3-6 mm) (McLaughlin 1982). No constriction of the fruit occurs in Tharp's blue-star. Fringed blue-star floral tubes are not constricted at their orifices, and the leaves, bracts, and calyx (leaf-like structures below the flowers) have long loose hairs on their margins (Tharp's blue-star lacks these hairs) (Correll and Johnston 1970).

Texas geographical distribution (range and precise occurrences)

The Pecos County population is about 160 air miles southeast of the Artesia, New Mexico population. In 1943, Tharp's blue-star was recorded as being frequent on limestone hills at the Pecos County site (Warnock #46183, TAES). The Texas population along Hwy 385/67 extends about a mile along the roadside (See Table 1 and Figure 1). There are two areas separated by about a 3/4 of a mile from one another along Hwy 385/67. In 2014, both areas were located along 385/67 ~¾ mile apart. Both areas have a few to many plants in the ROW. The northeastern area extends ~400 meters from the road (to the SE) and the southwestern area extends ~150 meters from the road (to the SE). In 1992, one plant was found on the northwest side of 385/67, but subsequently disappeared the following three years (Poole and Corlies 1992). No other plants have been recorded on the northwest side of the highway. It is unclear exactly how far away from the right-of-way (ROW) the areas to the east and southeast extend into adjacent University Lands – University of Texas System property (UT Lands). A 1981 specimen (Powell #3585, MO and SRSU) collected in the southwestern portion of the population indicates that an estimated several hundred plants were on 5/6ths of an acre, and the plants may have extended further than the observer could see (Powell 2014). In 1983, the Tharp's blue-star population was estimated to be about 1/2 to 3/4 of mile into the UT Lands property, covered less than a four square mile area (Rowell 1983), and consisted of about 400 plants (Sivinski and Lightfoot 1992). Most of Rowell's specimens indicate that he was approximately 20.4-20.5 miles northeast of Ft. Stockton, but one describes the location as approximately 18 miles northeast of Ft. Stockton (Rowell #16722, SAT). It is possible that the former describes road miles and the latter air miles. In 1991, Hughes reports that the UT Lands rangeland manager at the time indicated plants were located in two areas 1/3 mile and ~1 mile to the southeast of the highway (these areas were indicated on a map) (Hughes 1992). However, due to lack of necessary permissions, the plants were not re-located by Hughes at the time (Hughes 1992). In 2014, the area 1/3 mile southeast of the highway was surveyed, but no plants were located (Strong 2014a). A portion of the area ~1 mile to the southeast of the highway was surveyed, but a majority of this area is on property adjacent to UT Lands and was not surveyed (Strong 2014a). An additional seven areas on UT Lands were searched on foot without success (Strong 2014b, c, d, e). These sites were chosen by overlaying a soils layer (Lozier Rock and Upton) with a vegetation layer (Chihuahuan Desert grasslands) and then pinpointing areas on an aerial map with similar vegetation density as the known sites.

General environment and habitat description (physical and biological characteristics)

All known populations of Tharp's blue-star (in Texas and New Mexico) occur within the Pecos River Basin. In Texas, Tharp's blue-star occurs over the Fredericksburg and Washita Formations in Lozier-Rock Outcrop and Upton soil associations (Rives 1980). Lozier-Rock and Upton soils are shallow to very shallow, well-drained, gravelly and stony loamy soils (Rives 1980). Lozier soils are over limestone hills and Upton soils are over calcareous outwash sediments from these hills (Rives 1980). The Texas plants are in full-sun on flats, low ledges, and drainages between low hills. The Texas sites occur in desert thornscrub and short to midgrass grasslands in a transitional zone between the Edwards Plateau and Chihuahuan Desert (Rowell 1983). The average precipitation for Ft. Stockton, 18 miles to the west of the site, is 11.8 inches/year. Elevation at the site is around 2,800 to 2,900 feet.

The three New Mexico populations of Tharp's blue-star are on low and flat hills, ridges, slopes, and drainages in soils with variable concentrations of gypsum, and a short distance into the colluvial deposits at the base of slopes (Sivinski et al. 2013). They occur on Rustler and Castile Formations and older alluvial Quaternary deposits over Potter-Simona, Largo-Stony and Gypsum Land-Cotton soils (Sivinski et al. 2013). Potter-Simona soils are well-drained, shallow to very shallow, gravelly loam and gravelly fine sandy loam soils, which occur over indurated caliche along the tops and sloping edges of ridges and on steep fractures leading to drainage ways (Chugg et al. 1971). The loamier Largo soils occupy the flats between ridges where few, if any, Tharp's blue-star occur (Sivinski et al. 2013). The Stony lands are steep and dissected areas on ridges and hillsides with exposed sandstone, siltstone, mudstone, and gypsiferous rock (Chugg et al. 1971). The red hills are capped with what is believed to be dolomite (Sivinski et al. 2013). The Gypsum Land-Cottonwood soils are well-drained, very shallow, and contain gypsum crystals and gypsiferous rocks (Chugg et al. 1971). Elevation at the New Mexico sites is between 3,060 to 3,760 feet. Eddy County cities with weather stations record annual rainfall between 13.4 inches/year (Artesia, NM) and 14.1 inches/year (Carlsbad).

One observer who visited both the Texas site and the southeastern-most New Mexico population noted that topography and soil type were different between the sites (Center for Plant Conservation 2010). However, the southwestern-most New Mexico population may be more similar in that it occurs on un-vegetated hills visually like the Texas site (Kathy Rice pers. comm. in Howard 2006). All populations seem to be associated with eroded and exposed gypsum or limestone (calcium-containing) outcrops and in gravelly well-drained soils (Howard 2006). Soil samples from the Texas and southeastern New Mexico sites were taken in 1991 (Desert Botanical Garden 1991). Results showed high to very high concentrations of calcium, moderate concentrations of magnesium, and low concentrations of sulfur and other trace minerals (Desert Botanical Garden 1991).

Dominant vegetation at the Texas site includes creosote (*Larrea tridentata*), honey mesquite (*Prosopis glandulosa*), acacia (*Acacia* sp.), skeleton-leaf goldeneye (*Viguiera stenoloba*), red-berry juniper (*Juniperus pinchotii*), and four-wing saltbush (*Atriplex canescens*) (Rowell 1983). Other frequently associated species are dalea (*Dalea* sp.), yuccas (*Yucca* spp.), tarbush (*Flourensia cernua*), and ocotillo (*Fouquieria splendens*) (Rowell 1983).

Species at the three New Mexico sites, which have also been recorded at the Texas site in Pecos County, include angel trumpets (*Acleisanthes longiflora*), agarita (*Berberis trifoliolata*), javelina bush (*Condalia ericoides*), pointed sandmat (*Euphorbia acuta*), mariola (*Parthenium incanum*), desert sumac (*Rhus microphylla*), stemmed four-nerve daisy (*Tetraneuris scaposa*), oreja de perro (*Tiquilia canescens*), and white zinnia (*Zinnia acerosa*) (Carr 1992). Gyp grama (*Bouteloua breviseta*), desert sumac (*Rhus microphylla*), hairy tiquilia (*Tiquilia hispidissima*) occur at all three New Mexico sites of Tharp's blue-star. Species like oreja de perro (*Tiquilia hispidissima*) and gyp grama (*Bouteloua breviseta*) indicate that all three New Mexico sites are at least mildly gypsiferous (Sivinski and Lightfoot 1992).

Habitat characterization of the New Mexico populations has started by using a deductive method to determine habitat and guide future surveys (Sivinski et al. 2013). Satellite imagery, geology, and elevation data layers were combined with expert knowledge of Tharp's blue-star's current locations to determine high probability areas where new populations might be found (Sivinski et al. 2013). Another year of field work will hopefully show if and how well new unknown sites are found using this technique. The characterization did not include Texas habitat.

Many populations of blue-stars (*Amsonia* spp.) across the southwestern United States are either in or near washes, which may indicate that blue-stars are dispersed by water and could be disturbance-tolerant (Topinka 2006). In one instance in New Mexico after a road expansion through the edge of a Tharp's blue-star site, plants readily inhabited the newly disturbed area or grew through material moved on top of it (Howard 2010). During surveys of the Tharp's blue-star site in Texas in 2014, a new property fence was observed along the southeast ROW (Strong 2014f). A ~3 meter strip on either side of the fence had been cleared of vegetation to erect the new fence. In 1992, the old fence had at least two plants within a meter of it (Poole and Corlies 1992). The 2014 surveys located two plants within a foot of the new fence. These plants were near where the 1992 monitoring had recorded them. Although it is unknown if these plants were the same, it does suggest that the plant is somewhat tolerant to disturbance.

From 2011 to 2012 New Mexico had a record-breaking drought. The two years combined are the driest and warmest years on record (United States Drought Monitor 2013a). The spring of 2013 began a third year of drought with southeastern Eddy County experiencing abnormally dry conditions and northwestern Eddy County under exceptional drought conditions (the highest classification of drought) (United States Drought Monitor 2013a). The four New Mexico sites were estimated to have between 18,000 and 23,000 plants (Sivinski et al. 2013). However, when surveys at two of the New Mexico sites were conducted in April and May of 2013 only an estimated 10% of these plants were producing new stems or foliage and fewer than 10 individuals (of thousands) were in bloom (Sivinski et al. 2013). Plants were, in fact, a bright yellow-orange color instead of green. Rains in August of 2013 finally alleviated drought conditions to some extent across the state (United States Drought Monitor 2013b). When revisited in October of 2013, plants had grown new green leaves and stems, but no flowers or fruits were observed (Sivinski et al. 2013). The thick root and stems allow Tharp's blue-star to survive through drought (Sivinski et al. 2013) and may indicate that long-term persistence is possible even without reproduction (Howard 2006). Compared to neighboring associated species, Tharp's blue-star can resist the effects of drought to some extent. In 1999, plants at the Texas site were noted as green and healthy-looking, whereas nearby evergreen, drought-tolerant creosote bushes were brown and desiccated (Slauson 1999).

Population biology of taxon (demography, phenology and reproductive biology)

Other than short-term monitoring from 1992 to 1995, population trends at the Pecos County site are difficult to assess because site counts have involved different amounts of surveying effort, imprecise location information, and (possibly) varying interpretations of an individual plant. Although it is unclear *exactly* what area was surveyed, numbers of have been recorded multiple times. Plants in the southwest portion of the population were counted in 1986 (Poole 1986). Forty-four plants were recorded along the highway ROW (Poole 1986) and probably into the adjacent property to the east. In June of 1998, the northeast portion of the population was visited and 125 plants were located in the highway ROW and adjacent UT Lands property (Slauson 1999). Seventy-five of these plants were located inside a fence on UT Lands property and the survey was estimated to cover about an acre (Slauson 1999). In April of 2003, 18 plants were seen along the highway ROW and in adjacent UT Lands property (Turner #23-79, TEX). It is unclear where Turner's specimen was collected exactly or if he surveyed the entire stretch of highway when he made his estimate of how many plants were present. In 2014, several surveys were conducted on April 30, June 17, and July 13 after a bloom in late April (Strong 2014 f, g, h). Areas with differing amount of plants were located during each of the three surveys, but a total of 351 plants were counted along the highway ROW and on UT Lands property. Two main sites were mapped ~3/4 mile from one another, each encompassing ~23 and ~31 acres. The furthest any plant is from the road is a quarter of a mile. In April, of the 118 plants counted, 24%

were in flower and 52% had immature fruit (Strong 2014h). In June, of the 203 plants counted, 40% had immature fruits and 7% had mature (dehiscing) fruit (Strong 2014g). By July, the majority of plants in fruit were dehiscing and a seed collection was possible. A total of 154 fruits and 701 seeds were collected by the Lady Bird Johnson Wildflower Center from 61 plants following Center for Plant Conservation seed collection protocol (Marr 2014).

From 1992 to 1995, highway ROW plants were monitored in May along a 1 mile stretch of Hwy 385/67. Four areas of plants were located and tracked (Poole and Corlies 1992). Three of these areas were on the east side of the highway and one was on the west (Poole and Corlies 1992). The one plant on the west side of the highway is the only plant to ever be recorded on the west side of the highway. It was located in 1992, but went missing the next three years (Poole and Corlies 1992). The number of plants remained stable (48-52 plants) in the four years of monitoring (Poole and Janssen 1997). Only adults were recorded during this monitoring (Poole and Corlies 1992). Prior and unrelated to this monitoring, observers at the Texas site recorded that "almost no juvenile plants were observed" and suggested that seedlings were not surviving (Ecker and Hodgson 1990). In 2014, with the help of Poole and Corlies' 1992 data, 30 of the plants along the highway ROW were relocated (Strong 2014f). The fence where tags had been located in 1992 had been replaced in circa 2013 and tags were no longer present. However, with the 1992 data (angle and distance from fence), locating a few plants, and a new fence in approximately the same location, the directions could be back-tracked. These data show that plants can live up to at least 20+ years and probably longer.

Blue-stars originate from a woody, long-lived root (McLaughlin 1982) and although the lifespan of blue-stars is not established, it could be decades (Topinka 2006). This growth form makes exact counts difficult due to underground stems or roots producing more than one clump of above-ground branches (Sivinski et al. 2013). During more recent New Mexico surveys, an individual was defined as all adjacent stem clumps within <12 inches from one another (Sivinski et al. 2013). In the 1992-1995 monitoring an individual was any distinct woody clump. This same rule of thumb was followed in the 2014 surveys.

Flowering has been recorded from March through June; fruiting has been recorded from May to July. Tharp's blue-star may bloom after rain (Poole et al. 2007) and may delay flowering in the spring when rain is not adequate (Poole and Janssen 1997). In May of 1983 more than 50% of plants were observed to be in fruit (Rowell 1983). Another visitor to the Pecos County site (exactly when is unknown, but there is a seed collection made by this same group in 1989) recorded that about 95% of the 200-300 individuals were producing seed at the northwestern portion of the population (Ecker and Hodgson 1990). It has been suggested that the white tubular flowers are likely moth-pollinated (Sivinski et al. 2013), but no observations have been recorded to back up this claim.

Over 600 seeds were collected from the Texas site by Desert Botanical Garden staff in June of 1989 as part of their responsibility for Tharp's blue-star as a Center for Plant Conservation National Collection plant. The seeds were stored in a freezer (-20°C) and then in 1990 and 1991, multiple germinations were conducted to test best germination medium (Ecker 1991). Germination success varied between 48% and 61%, the best results were with a Metro Mix 200, with dolomitic limestone additive, and fungicide. This mix also seems to have been the best growth medium after germination. Seedlings grown from seed at the Desert Botanical Garden greenhouse had slow growth rates, which may indicate that Tharp's blue-star is slow in reaching maturity (Ecker and Hudgson 1990). However, in cultivation, Tharp's blue-star has started flowering at three to four years (Rice et al. 1994). Time to maturity in cultivation does not necessarily indicate a similar time to maturity in the wild.

Cross and self-pollinations were conducted on plants that survived from the 1990 and/or 1991 germinations at Desert Botanical Garden. Only open and hand-pollinated crosses resulted in fruit production (Rice et al. 1994; Rice 1996; Rice 2004), although only ten self-pollinations were conducted (Rice et al. 1994; Rice 1995). Thirteen of the plants, which were likely collected in 1989 and germinated in 1990 or 1991 (Ecker and Pritchett-Kozak1991), are still alive (Blackwell 2014). Seed collections from New Mexico from as recently as 2007 are stored at Desert Botanical Garden in a freezer (-30°F) (Blackwell 2014) and a back-up of this collection is at the USDA seed storage facility (National Center for Genetic Resources Preservation) in Ft. Collins, Colorado.

Population ecology of species (interactions and hybridization)

Some authors have suggested that because Tharp's blue-star is in the dogbane family (Apocynaceae) it may be toxic (Rowell 1983; Sivinski and Lightfoot 1992). Several dogbane genera have been found to have toxic alkaloids at certain amounts, for example, *Apocynum* (Turner and von Aderkas 2009), *Catharanthus*, and *Nerium* (Nellis 1997). Tharp's blue-star has not been tested for its toxicity. Several *Amsonia* species have alkaloids, which have been isolated and are of various classes (Glasby 1991). Alkaloids are known to frequently impart a bitter taste to the tissue they occupy (Rhoades 1979). Phytochemical tests of Arizona blue-star (*Amsonia grandiflora*) have shown the presence of triterpene acids, which may taste sour and make it non-palatable to herbivores (Wahyuono 1985). It is unclear if Tharp's blue-star is toxic or simply distasteful or neither. Most observers have seen no herbivory (Rowell 1983; Rowell 1990; Sivinski and Lightfoot 1992; Sivinski et al. 2013) despite cattle being present at some sites. However, herbivory has been documented once in New Mexico and was suggested to be mule deer (Howard 2010).

Arid areas across the southwest United States have been converted from grasslands into shrublands (Buffington and Herbel 1965). Fire suppression, drought, and overgrazing have caused and continue to cause much of the grassland decline in the southwest (Frederickson et al. 1998). Although cattle may not directly be impacting Tharp's blue-star populations, erosion could be exacerbated by grazing in Tharp's blue-star populations (Howard 2006). No empirical evidence has been collected to confirm if erosion or compaction caused by cattle could be impacting Tharp's blue-star populations. Plant community changes could also result in increased non-native plant competition (Center for Plant Conservation 2010). Although there is no direct evidence of this, two non-native species have been located on the disturbed soils of the highway shoulder at the Pecos County Tharp's blue-star site: white horehound (*Marrubium vulgare*) and Maltese star-thistle (*Centaurea melitensis*). Maltese star-thistle is considered a Class B noxious weed (limited to portions of the state) in New Mexico and is included in the Invasives Database on Texasinvasives.org.

Open pollinations of cultivated plants at Desert Botanical Garden have resulted in fruit production (Rice et al. 1994; Rice 2004). Other blue-stars [Arizona blue-star and Kearney's blue-star (*A. kearneyana*)] were present and resulting seeds could be hybrids (Rice et al. 1994), but more hand-crosses should be conducted to confirm this suggestion. Some horticultural forums claim that blue-stars hybridize readily (Darke 2005). In Texas, the other closest blue-star species, tubular blue-star (*Amsonia longiflora* var. *salpignantha*), was collected 17 miles from the Tharp's blue-star site (Turner #23-240, TEX). Cross pollination between two sites at this distance is unlikely. However, no surveys have been conducted to detect closer sites with other blue-star species.

Land ownership and management

The University Texas System and Texas Department of Transportation (TxDOT) own the Texas sites of Tharp's blue-star and BLM, and New Mexico State Land Office own the lands in New Mexico. Lessees of both the UT Lands System in Pecos County and the Bureau of Land Management in New Mexico graze cattle on lands with Tharp's blue-star. Lessees were grazing cattle on the UT Lands adjacent to the Texas ROW location in the 1980s at a "normal" stocking rate (Rowell 1983). From about to 2007 to 2014, the lessee grazed cattle at a light stocking rate (Petersen 2014a). In 1999 an exclosure surrounded some plants on the UT Lands, although plants were also located outside of the exclosure (Slauson 1999). It has been stated that this exclosure was to fence plants off from the rest of the pasture (Center for Plant Conservation 2010). When this exclosure was built is unknown, but was used to separate the Tharp's blue-star population from grazing (Center for Plant Conservation 2010). The exclosure fence was replaced in circa 2013 (Petersen 2014b) and is less than nine acres (Strong 2014h). Only two plants were found inside this exclosure during surveys in 2014 (Strong 2014g). Little to no evidence of cattle was observed during the 2014 surveys around Tharp's blue-star sites (Strong 2014g).

The mile-long narrow strip on Hwy 385/67 in Pecos County is owned and managed by TxDOT. Texas Parks and Wildlife Department and the Texas Department of Transportation have developed verbal agreements to protect the population on highway ROW from routine maintenance activities. In 1997 it was recommended that mowers along the Hwy 385/67 ROW be set at 12 inches at the Tharp's blue-star site (Poole and Janssen 1997). TxDOT strip-mows the area once a year and has been following this mowing regime for at least the last few years (Hudson 2014). It was recommended that strip mowing only occur after the flowering/fruiting ended in late summer (Poole and Janssen 1997). It is unknown when exactly the mowing occurs every year. In the early 1980s, it was observed that even when plants were mown in late May and early June (mower height unknown) plants flowered the following year (Rowell 1983). How this affected fruit set or overall health of the plants is unknown. However, regular observations throughout the 1980s showed that mowing was regularly occurring after flowering and fruit set (Rowell 1990). When plants were relocated in 2014 along the ROW, strip mowing was still occurring closest to the highway (~3 meter wide strip). No-mow signs are at either end of the Tharp's blue-star population along the highway. The property fence had been replaced along the southeast side of the highway and there was considerable disturbance within ~3 meters of the fence. The remaining ~5-6 meter area in the middle of the ROW was overgrown. Vegetation growing in the immediate vicinity of Tharp's blue-star included acacia, red-berry juniper, skeleton-leaf goldeneye, featherplume (*Dalea formosa*), threadleaf broomweed (*Gutierrezia microcephala*), and various grasses. Some utilities have a legal right to be placed on the TxDOT ROWs (Texas Department of Transportation 2013). Due to this, it is difficult to avoid habitat disturbance or population destruction during utility siting, construction, and maintenance.

Evidence of threats to survival

The northernmost New Mexico population of Tharp's blue-star is on BLM and adjacent State Trust Land, and is being directly impacted by pad sites, access road maintenance, and pipelines of oil and gas development (Sivinski et al. 2013). Four well pads have been built in either the center or edges of Tharp's blue-star sites. Most of these pad sites eliminated a few or less than 100 plants, but in one case a 4.3 acre well pad was built and removed an estimated few hundred plants. An access road and pipeline between these wells have also eliminated or displaced some plants (Sivinski et al. 2013). Two of the other New Mexico populations, although not directly impacted, are in close proximity to areas impacted by oil and gas. Roads and well pads have been built on mesas surrounding the drainage slopes occupied by Tharp's blue-star sites and, at least in one of these sites, development has been observed to be progressing rapidly (Sivinski et al. 2013).

Although no-mow signs are erected around the Tharp's blue-star population along the ROW in Pecos County, Texas, full width mowing does not seem to occur outside the no-mow signs either. Lack of full-width mowing in the ROW increases woody vegetation and grasses, which could be shading or out-competing Tharp's blue-star. Although most Tharp's blue-star plants in the ROW were robust and healthy-looking (likely due to run-off from the road), only one plant was observed in fruit (Strong 2014f). Vegetation cover was near 100% in the ROW (Strong 2014f), unlike any other known Tharp's blue-star site in Texas where bare ground can be 60-90% (Strong 2014g; Strong 2014h).

There are other potential threats to Tharp's blue-star, including collection from wild populations and herbicide use. Some of the New Mexico seed of Tharp's blue-star have entered the horticultural trade. In 2003, seeds were available in small amounts (~6 seeds / order) from ALPLAINS, a seed company (Rice 2004). This company still sells Tharp's blue-star on their website, now for $3.00/60 seeds (http://www.alplains.com). Tharp's blue-star has also been documented for sale at two other nurseries/seed companies, Arrowhead Alpines (Rice 2005) and www.rareplants.de (www.rareplants.de 2014).

On New Mexico BLM lands potential habitat of Tharp's blue-star may be treated with aerial herbicides to control shrubs as part of Restore New Mexico Program (Sivinski et al. 2013). This BLM program is attempting to convert overused areas with non-native and native trees and shrubs to healthier, more productive systems with native grasses and trees. TxDOT regularly uses mechanical and chemical means to control roadside vegetation. In 1997 they used herbicides on guardrails and pavement edges (Poole and Janssen 1997) along Hwy 385/67. It was recommended that herbicides only be applied by hand or at times of little to no wind (Poole and Janssen 1997) around the Tharp's blue-star site.

Although the Texas population of Tharp's blue-star has not experienced a direct threat from establishment of oil or gas development, it is occurring in Pecos and surrounding counties. According to the Railroad Commission of Texas, seven of the top ten gas production counties in Texas are just northeast of Pecos County (Upton County and six other adjacent counties) (Railroad Commission of Texas 2012). It is unknown if production will expand toward the Pecos County site. There are only a few dry holes and one plugged gas well within a mile of the Hwy 385/67 site, but five miles to the east there are many active gas and oil wells, plugged gas and oil wells, permitted locations wells, and cancelled/abandoned locations (Railroad Commission of Texas 2014).

Special management considerations

In 1995, Tharp's blue-star was included in a report on prioritizing conservation needs for Texas rare species (Linam 1995). Tharp's blue-star was considered a high priority given the single, small population known in Texas. Primarily, more surveys were recommended as an action Texas Parks and Wildlife Department should consider. Secondarily, gathering information on population trends, demographics, reproductive biology and habitat characterization was recommended (Linam 1995). In 1996, preliminary monitoring plans were written for many rare Texas species (Candee 1996). Significant or unacceptable declines were defined as a 20% decrease in total population in two consecutive years (Candee 1996). However, this percent was chosen for all 107 species with monitoring plans, likely because 20% was seen as a reasonable rate of change when information is lacking. To date, population trends, demographics, and reproductive information is still lacking and studies to resolve this lack of information should be conducted.

Surveys for Tharp's blue-star in Pecos County were conducted during the springs of 1981 to 1983. All surrounding roads within a 20-30 mile radius of the known site were driven or walked, but no additional sites were located (Rowell 1983). In the spring of 1991, four areas to the NNW and NW of the Pecos County site were surveyed by foot or car. Some of these areas include the north slope of Guayule Mountain, the north and east slopes of Saddle Butte and the northeast slope of East Mesa (Hughes 1992). Surveys were based off of elevation (ca. 2,800-3,000 ft) and aspect (north) known at the time (Hughes 1992). Additional surveys are recommended. Damude (1992) suggested searching areas along the Pecos River with gypseous substrates. After various unsuccessful searches in 2014, it is recommended that areas with similar topography and vegetation cover be surveyed around the existing Tharp's blue-star locations.

Recent droughts in 2011 and 2012 indicate Tharp's blue-star's ability to persist through a long-term drought (Sivinski et al. 2013). However, if climate change results in an increase chance of long-term droughts, it is unknown how well or how long the populations will be able to sustain through these conditions. Monitoring may clarify how tolerant the species is to drought and other natural and anthropogenic disturbances.

Kearney's blue-star (*Amsonia kearneyana*) has had microsatellite loci isolated and developed (Topinka et al. 2004). Five other blue-star species (including individuals of Tharp's blue-star from one of the NM populations) were assessed to find and utilize microsatellites in future analyses of other blue-star species and to examine their distribution of genetic diversity (Topinka et al. 2004). The extent of gene flow within and between populations would help clarify meta-population dynamics of Tharp's blue-star populations. Similar studies may also help determine if Tharp's blue-star is susceptible to hybridization with other nearby blue-star species.

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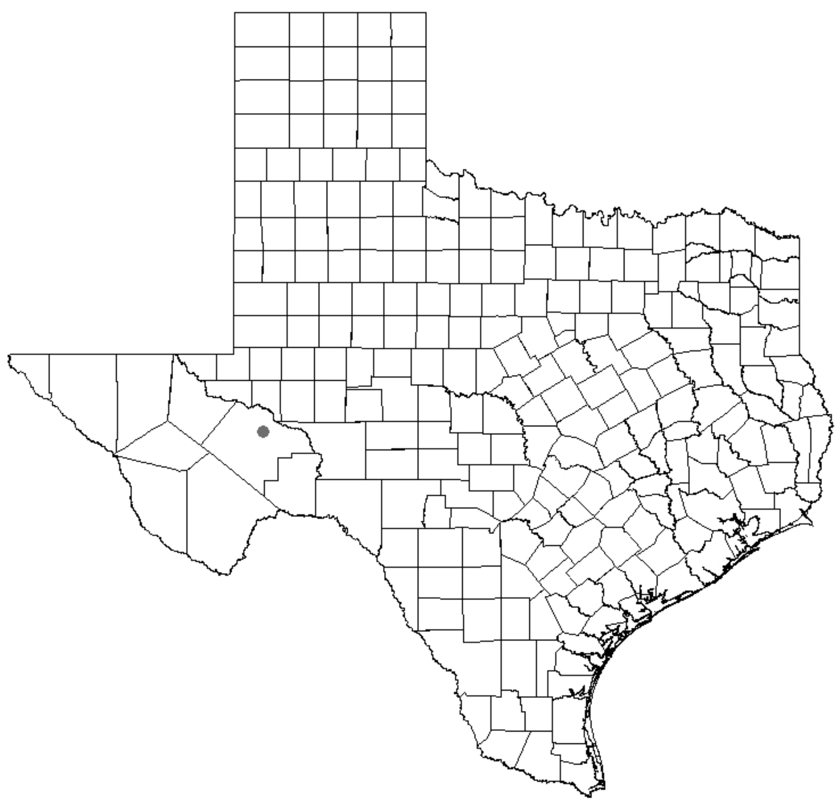
Table 1. Tharp's blue-star population status, including location and ownership (Texas Natural Diversity Database 2013).+

County	Year discvrd	Year last seen	EO ID*	Site name	Landowner	Min. # per 1 subpop.++	Max. # per 1 subpop. ++
Pecos	1943	2014	7742	Big Mesa	state/TxDOT	"locally frequent" (1983)	351 (2014)

* EO ID is the unique number assigned to a new record (element occurrence) in the Texas Natural Diversity Database. An element occurrence is an area of land where a species resides/resided.
+ a population can consist of one or more subpopulations
++ represents number of individuals recorded in any year at a subpopulation; each count is based on surveyor effort and is only as good as the effort expended

Figure 1. Distribution of populations of Tharp's blue-star (*Amsonia tharpii*).



Prostrate milkweed

(*Asclepias prostrata*)

Species information (history of knowledge of taxon)

Prostrate milkweed was first collected in 1932 by Marcus E. Jones from "below Laredo", Texas (#29138, TAES). In 1957, Donovan Correll and Ivan Johnston collected another specimen near Roma in Starr County, Texas (#18075, LL). In 1960, John Crutchfield and Marshall Johnston collected a specimen in Tamaulipas, Mexico (#5573, TEX), and, in 1966, Donovan Correll collected one near Roma in Starr County, Texas (#32275, LL). Based off of the Mexican specimen, prostrate milkweed was described by Will Blackwell in 1964 (Blackwell 1964). The species was not collected again until 1985, when Jackie Poole rediscovered the 1957 site (#2821, TEX) initially collected by Correll and Johnston.

Present legal status (National and State)

In 1985, prostrate milkweed was added as a Category 2 Candidate species to the list of U. S. plants that were being reviewed for possible addition to the Endangered Species list. Category 2 indicated taxa that a proposal to list as endangered or threatened was possibly appropriate, but for which substantial data on biological vulnerability and threat(s) were not known or on file at the time to support a proposed ruling (U.S. Fish and Wildlife Service 1985). Biological research and field study were suggested as needs to determine the status of species in this category (U.S. Fish and Wildlife Service 1985). In 1993, the species was given the status trend of U (unknown), which indicated additional survey work was needed (U.S. Fish and Wildlife Service 1993). In 1996, all Category 2 Candidate taxa were dropped from the Endangered Species list, due to lack of information to justify proposed rules. The U.S. Fish and Wildlife Service (USFWS) felt that more biological research and field study were necessary to determine the conservation status of Category 2 species, and that these species were the pool from which future candidate species could be drawn (U.S. Fish and Wildlife Service 1996). In 2009, a 90-day finding was announced on 67 species from a petition to list 475 in the southwestern United States as threatened or endangered. The petition presented scientific information to indicate that listing may be warranted for prostrate milkweed (U.S. Fish and Wildlife Service 2009). Scientific, commercial, and other information was requested and available information was summarized by the USFWS. Of the five threat factors, which can be used to assess if a species may warrant listing as endangered or threatened, the USFWS listed only E (other natural or manmade factors affecting its continued existence) for prostrate milkweed (U.S. Fish and Wildlife Service 2009). Threats listed were roadside mowing and competition from nonnative pasture grasses on right-of-way sites (U.S. Fish and Wildlife Service 2009).

Prostrate milkweed is ranked as a G1G2, or critically imperiled to imperiled across its entire range, by NatureServe. The species is also listed on Texas Parks and Wildlife Department's (TPWD) 2010 List of the Rare Plants of Texas and as a Species of Greatest Conservation Need in the Texas Parks and Wildlife Department (TPWD) State Conservation Action Plan. In 1995, prostrate milkweed was included in a report on prioritizing conservation needs for Texas rare species (Linam 1995). Prostrate milkweed was considered a high priority given the low number of populations known at the time mostly along highway ROWs.

Description (local field characters)

The following description is adapted from Blackwell (1964) and Correll and Johnston (1970). Prostrate milkweed is an herbaceous perennial with trailing stems up to 40 cm long. Characteristic of milkweeds, leaves and stems exude a milky sap when damaged. Leaves are 15-35 mm long and 5-20 mm wide, and triangular to deltoid-lanceolate. Stems twist, which give the opposite leaves an appearance of being in two rows on either side of the stem. Leaf bases are cordate to truncate and leaf apices are acute. Both sides of the leaves have scattered, minute, long, soft hairs. The few-flowered umbels arise from upper leaf axils and corollas are greenish-white to rose. Fruits are about 5.5 cm long and 2 cm wide, and split along one side to release many seeds crowned by tufts of silky hairs.

No other *Asclepias* species will likely be confused with prostrate milkweed; however, two other milkvines can be mistaken for prostrate milkweed when not in flower or fruit, Rio Grande Plains milkvine (*Matelea brevicoronota*) and mesquite plains milkvine (*Matelea parviflora*). Both of these milkvines smell like burnt rubber when crushed (Richardson and King 2011). Leaves of both milkvines are suborbicular-ovate to ovate lanceolate. And although named for its trailing nature, periods of severe drought can cause prostrate milkweed to curl and shrivel and exhibit a more upright habit (Damude 1992).

Geographical distribution (range and precise occurrences)

Prostrate milkweed occurs in two counties in South Texas (Starr and Zapata) and two states in northeastern Mexico (Nuevo Leon and Tamaulipas). In Texas, fifteen sites have been located (See Table 1 and Figure 1) across ~650 square miles. In this report, following the 2010 List of the rare Plants of Texas, historic populations are those which have not been seen for over 50 years. Extant populations have been observed in the last 50 years. Five sites have not been noted to have plants since 1999 or before, another seven sites have been recorded to have plants in more recent years (2003-2011), two sites were recorded to have plants in 2014, and the one remaining site is historical. The one historical site in Texas is known only from a specimen collected in 1932 from "below Laredo" (Jones #29138, TAES). Due to the vague description on the specimen label, this plant could have been collected in either Zapata or Webb County. If collected in Webb County, this would extend the historic range of the plant.

In addition to these populations, there are several sites based on erroneous identifications. The Southwest Environmental Information Network lists three Arizona State University specimens collected in Mexico as prostrate milkweed: Landye and Minckley #s.n.; McGill, Brown, and Pinkava #9788; and McGill, Reeves, Nash, and Pinkava #P13430 (Southwest Environmental Information Network 2014). These specimens occur well outside of prostrate milkweed's known habitat in Mexico and are likely milkvine (*Matelea*) species (Fishbein 2014). Additionally, in 1991, a specimen collected in Brooks County was misidentified as prostrate milkweed, but this was later corrected and identified as a *Matelea* species (Clayton #1040, TAMU-CC). In 1997, a consultant misidentified prostrate milkweed along US 83 near Alto Bonito, TX (Gonzalez 1997), but later the consultant corrected the identification. Both of these locations have been taken out of the Texas Natural Diversity Database (TXNDD).

Various attempts have been undertaken to locate more populations. Fourteen sites were unsuccessfully searched between 1985 and 1988 in Zapata County (along US 83), Starr County (along FM 650, Loma Blanca Rd, at Falcon State Park, and several USFWS Wildlife Refuges), and Hidalgo County (Bentsen-Rio Grande Valley State Park and Santa Ana National Wildlife Refuge) (Damude and Poole 1990). Additionally, 40 Lower Rio Grande Valley National Wildlife Refuge tracts were at least partially surveyed[1] in the mid-1990s for 71 rare plant species, including prostrate milkweed. Because of the number of tracts needing to be surveyed in a relatively short period of time, these surveys could not be fully comprehensive (Carr 1995). No prostrate milkweed was found during these surveys (Carr 1995). Neither Los Morteros or Arroyo Ramirez (extant locations of prostrate milkweed) was owned by USFWS at the time of these surveys.

One known site has undergone a status rank change. The Mission a Mier Visita site was ranked as extirpated in the early 1990s due to a drastic drop in plant numbers over a few years and the encroachment of the invasive non-native forage grass, buffelgrass (*Pennisetum ciliare*). However, this population has been re-ranked recently as failed-to-find to follow current ranking protocols (since the habitat was only altered and not destroyed, it is possible that plants and/or seeds might remain).

All known Texas populations of prostrate milkweed are within 8 miles of the Texas-Mexico border. However, on the southern side of the Rio Grande River, the species has been found over 100 miles south of the border, 220 miles southeast of the northernmost population in Zapata County, TX. There are at least five known sites in Mexico, in the states of Nuevo Leon and Tamaulipas.

General environment and habitat description (physical and biological characteristics)

Prostrate milkweed occurs in acacia shrublands in the uplands of South Texas Plains (Damude and Poole 1990). Plants have been found in grasslands, many of which have been cleared at some point to create pastureland and then seeded to buffelgrass (Damude and Poole 1990). Some of these areas are being re-invaded by shrubs (Damude and Poole 1990). Other sites are on highway right-of-ways (ROWs) and are regularly disturbed as part of safety measures with the Texas Department of Transportation (TxDOT). Prostrate milkweed seems to need full-sun exposure and can tolerate high temperatures. July and August have an average daily maximum temperature of 99°F, but from April to September the maximum temperature repeatedly reaches well over 100°F (National Oceanic and Atmospheric Administration 2014). It also can withstand

[1] Surveying occurs on new territory without the intent of returning regularly through time or obtaining population counts for comparison.

unpredictable and low water availability (annual average precipitation is ~21 inches). When rain does fall, it can be in downpours, causing flooding and erosion.

The species is mapped on the Jackson Group, Laredo and Yegua geologic formations and on the following soil associations: Brennan fine sandy loam, Copita fine sandy loam, Garceno clay loam, Hebbronville loamy fine soils, Jimenez-Quemado (gravelly, loamy alluvium) Maverick (calcareous, saline clayey rock debris), Zapata (calcareous loamy alluvium) (Molina and Guerra 2011; Thompson et al. 1972). However, ten of the sites are entirely or partly on Copita fine sandy loam (Molina and Guerra 2011; Thompson et al. 1972). The only known site to have had a soil core analyzed was at the Dolores site (where ashy dogweed, another endangered species, co-occurs) and it indicated that the soil was Hebbronville loamy fine sands (Damude and Poole 1990). The soils of the Tamaulipas, Mexico site have been described as sandy loam shallowly overlying caliche (Damude and Poole 1990).

Dominants for various sites have been recorded as blackbrush (*Acacia rigidula*), angel trumpets (*Acleisanthes longiflora*), grama grass (*Bouteloua* sp.), caesalpinia (*Caesalpinia* sp.), goat bush (*Castela texana*), coastal sandbur (*Cenchrus incertus*), hooded windmill grass (*Chloris cucullata*), javelina bush (*Condalia ericoides*), anacahuita (*Cordia boissieri*), three seed croton (*Croton lindheimerianus*), dwarf prairie clover (*Dalea nana*), common sunflower (*Helianthus annuus*), camphor weed (*Heterotheca latifolia*), Texas prickly pear (*Opuntia lindheimeri*), palafoxia (*Palafoxia* sp.), feverfew (*Parthenium* sp.), buffelgrass (*Pennisetum ciliare*), mesquite (*Prosopis glandulosa*), paperflower (*Psilostrophe* sp.), Mexican hat (*Ratibida columnaris*), ashy dogweed (*Thymophylla tephroleuca*), Buckley’s yucca (*Yucca constricta*), and lotebush (*Ziziphus obtusifolia*) (Poole and Janssen 1995a; Poole and Janssen 1995b; Damude and Poole 1990; Poole et al. 2007; Strong 2014a; Strong 2014b). Buckley’s yucca co-occurs with prostrate milkweed and is a local visual dominant that allows quick identification of potential habitat (Damude and Poole 1990). In several prostrate milkweed sites two other federally endangered species occur: ashy dogweed and Zapata bladderpod (*Physaria thamnophila*).

Prostrate milkweed seems to establish in open areas, which are surrounded by typical South Texas thornscrub. However, they have been recorded in the understory of shrubs. In 2004, at a private ranch near FM 3167, plants were recorded in open (either recently bladed or root-plowed) areas and under emerging ebony (*Pithecellobium ebano*) or mesquite (*Prosopis glandulosa*) sprouts (Carr 2004). More recently, several prostrate milkweed were found under the dappled shade of a full-grown huisache (*Acacia farnesiana*) (Strong 2014b).

Disturbance may be required for the species to establish. Historic disturbance types like flooding along the Rio Grande and its tributaries and fire, have largely been replaced by other disturbance types like overgrazing, blading, and root plowing. Prostrate milkweed may respond to increased light and/or decreased competition when native brush is removed (Damude and Poole 1990). Plants have regularly been found on highway ROWs and these areas may provide disturbance, which facilitates the dispersal and establishment of the species (Damude and Poole 1990). However, there is likely a limit to the disturbance prostrate milkweed can tolerate. This limit may be set by seedlings’ ability to establish in a constantly eroding site and/or the increased competition with earlier successional species. For example, prostrate milkweed was discovered at Los Morteros, a tract of the Lower Rio Grande Valley National Wildlife Refuge, where erodible soils, past rangeland management, and old roads had caused considerable erosion in some areas (Best 2005). Only one prostrate milkweed was found at this site along a more intact dirt road. Buffelgrass is a dominant species at this site where the soil has been disturbed (Best 2005).

Population biology of taxon (demography, phenology and reproductive biology)

Comparing population trends among years is difficult because site counts have involved different amounts of surveying effort (surveying is usually opportunistic and can cover different areas) and location information can be imprecise. Plant presence at known sites likely fluctuates dependent upon appropriate environmental conditions. However, with the available data some generalizations can be made. Zero to 137 plants were recorded at the same site in a span of five years (Poole 1986). Among all of the site visits ever conducted (includes all monitoring[2] or surveying, but not generally visits where just an herbarium specimen was collected), zero plants were noted ten times (21%). Another 32 (65%) of the site visits noted fewer than 40 plants. Only twice (4% of the time) has a survey found more than 100 plants. No survey has ever estimated more than ~200 plants. These counts may be driven by surveyor preference for manageable areas or numbers. Density within each population is fairly sparse and is generally described as scattered or scattered in clumps. During the monitoring of the Dolores site from 1991 to 1995, percent cover per square meter was measured. Prostrate milkweed covered less than 1% of each square meter (0.13% to 0.36%) (Poole and Janssen 1995b). Only five surveys conducted in the 1980s estimated density of plants. The estimates ranged from 1 plant/acre to 27 plants/acre (Poole 1985; Poole 1986).

Most of the fourteen populations have been surveyed more than once. On average, a site has been visited once every 6.5 years. Although only a portion of the site has been visited, the Dolores site has been more frequently visited (an average of once every 2 years), because it is on public land (highway ROW) and easily accessible. Also, this site is the largest site in terms of square acres mapped. And although the site as a whole is most frequently mapped, the private property adjacent to this site has only been partially surveyed once since the 1980s (Price et al. 2006).

From 1991 to 1995, three sites along the ROW of US 83 were monitored in April in Zapata and Starr counties (Arroyo del Tigre Chiquito, Dolores, and Arroyo Roma). Plant frequency and vigor was tracked at all sites over four years (except for the Tigre Chiquito site which was not located until 1992) and percent cover was tracked at the Dolores site for three years (Poole and Janssen 1997). A combination of line transects and 1 m^2 plots were used at these sites. The Dolores transects and 1 m^2 plots were on the west side of US 83 (Poole and Janssen 1995b), the Tigre Chiquito 1 m^2 plots were on the east side of US 83 (Janssen and Poole 1995), and the Arroyo Roma 1 m^2 plots were on both sides of US 83 ROW (Poole and Janssen 1995a). Over the four years of monitoring of prostrate milkweed, one site decreased in number of plants and all three sites decreased in number of branches per plant (Poole and Janssen 1997). The west side of the Dolores site ranged from 38 plants (1993) to 97 plants (1995); the Arroyo Roma site ranged from 7 plants (1995) to 15 plants (1992); and the Tigre Chiquito site ranged from 6 plants (1991,

[2] Monitoring is returning to the same exact area with some frequency with the ultimate aim of comparing population numbers through time.

1993) to 11 plants (1994) (Poole and Janssen 1997). No juveniles were noted during monitoring, but a few were noted at the Dolores site in 1987 (Poole 1985). Additionally, juveniles have been observed at (Falcon) (Carr 1994). Among all of the monitoring sites, average stem number varied from 2.3 +/- 1.3 to 6.2+/- 4.3 and stem length varied from 3.9 +/- 3.1 cm to 14 +/-8.0 cm (Poole and Janssen 1997). Entire taproots are not collected on herbarium specimens although the original description states that the plants arise from “thick woody crowns” (Blackwell 1964). It is unknown how long prostrate milkweed can persist.

Prostrate milkweed flowers and fruits from March through October. However, only one site visit outside of this time period (in February) has been recorded. It has been suggested that rainfall may influence flowering and fruiting (Damude and Poole 1990). Long assumed to be outcrossing as evident by its unique floral morphology (Woodson 1954), some milkweeds can self-pollinate (e.g., tropical milkweed, *Asclepias curassavica*; African milkweed, *A. fruticosa*; swamp milkweed, *A. incarnata*) (Wyatt and Boyles 1997) and others are clonal (e.g., common milkweed, *A. syriaca*; poke milkweed, *A. exaltata*; Mead’s milkweed, *A. meadii*) (Neyland et al. 1999; Wyatt et al. 1992; Schaal and Leverich 2004). No breeding system studies have been conducted on prostrate milkweed. Rhizomes, which can indicate asexual reproduction through cloning, have not been recorded on prostrate milkweed.

Instead of open pollen grains, pollen is in sacs, which attach mechanically and are transported as an entire unit by pollinators from one flower to another. Milkweeds rely heavily on hymenopteran and lepidopteran pollinators like bees, wasps, moths and butterflies (Fishbein and Venable 1996). Pollinators from the following families have been observed carrying milkweed pollinia: Anthophoridae (digger bees), Apidae (honey bees and bumblebees), Colletidae (plasterer bees), Hesperiidae (skippers), Ichneumonidae (ichneumonflies), Lycaenidae (hairstreak butterflies), Megachilidae (leaf-cutter bees), Nymphalidae (monarch and viceroy butterflies), Papilionidae (swallowtail butterflies), Pieridae (cabbage and sulfur butterflies), Sphecidae (thread-waisted wasp), Tiphiidae (tiphiid wasp), Vespidae (paper wasp) (Betz et al. 1994). In some species of milkweeds, dipterans have been found carrying pollinia (a thick-headed fly, *Zodion obliquefasciatum*) (Fishbein and Venable 1996). None of these potential pollinators have been recorded visiting prostrate milkweed flowers, but no formal studies have been conducted. Also, visitations by potential pollinators may not result in effective pollination. For example, queens (*Danaus gilippus*) have been recorded to visit butterfly milkweed (*Asclepias tuberosa*), which occurs throughout Texas except South Texas, but due to low visitation rates to flowers (compared to other pollinators) and low pollinia removal rates are considered poor pollinators of butterfly milkweed (Fishbein and Venable 1996).

Although not observed, dispersal of seeds of prostrate milkweed is likely by wind due to seed morphology. Seeds have 2 cm long silky white hairs, which act like a parachuting device when taken up by the wind. Studies have shown that longer hairs on common milkweed can increase the distance of dispersal (Sacchi 1987).

Population ecology of species (interactions and hybridization)

Some of the milkweeds have toxic secondary compounds, or cardenolides, which can deter vertebrate and invertebrate herbivory. However, some invertebrate herbivores have evolved special cells to sequester these toxins, which can persist throughout the invertebrate’s juvenile and adult stages. In 1988, a queen caterpillar (*Danaus gilippus*) was collected from a prostrate milkweed leaf, on which it was feeding (Poole 1988; Orr 1988). Queens are found all year round in South Texas (Scott 1992). Queens commonly associate with milkweeds and use them for their larval hosts. Queens and monarch butterflies (*Danaus plexippus*) visit Zizotes milkweed (*Asclepias oenotheroides*), which co-occurs at several sites with prostrate milkweed. The cardenolides are unpalatable to avian and other vertebrate predators and protect the queens from predation. Many milkweed species have been noted as host plants for queens, including several native and non-native South Texas milkweeds (tropical milkweed, *Asclepias curassavica*), white twinevine (*Funastrum clausum*), and Gulf Coast twinevine (*Funastrum angustifolium*) (Scott 1992). Milkweeds have been shown to have cardenolides in their leaf, root and flower tissues, although varying amounts (Malcolm and Brower 1989; Manson et al. 2012). It is unknown if prostrate milkweed has cardenolides in its leaf tissue or if queens negatively affect the plant. Milkweeds from lower latitudes are more likely to increase cardenolides after an herbivore attack, have more types of toxic compounds, and are more toxic than milkweeds at higher latitudes (Rasmann and Agrawal 2011). Observations from the Dolores site in the late 1980s indicates that prostrate milkweed could have some toxic secondary compounds as this private ranch had cattle but more plants than the adjacent ROW (Damude and Poole 1990). Alternatively, the disturbance caused by the cattle could be creating favorable habitat for the plant.

Buffelgrass (*Pennisetum ciliare*) was introduced to South Texas in the 1940s as cattle forage (Hanselka 1988) and is common on sandy loam soils (Hanselka 1988) and sandy soils (Gould 1978) in Texas. Buffelgrass has been shown to spread on soils with 61.1% sand, 17.5 % silt and 21.5% clay (Ibarra et al. 1995). Buffelgrass is the dominant grass on Copita fine sandy loams (Molina and Guerra 2011); one of the more common soil types prostrate milkweed tends to grow on. Buffelgrass has been associated with a decrease or loss of native plant species in three USFWS Wildlife Refuges in the Lower Rio Grande Valley (Esque et al. 2006). Because it is an early successional species, buffelgrass can out-compete native species and can quickly become the dominant species in old agricultural fields (Vora and Messerly 1990). Buffelgrass grows in thick stands up to 100 cm tall, much taller than the trailing prostrate milkweed, which tends to grow in open areas in the full-sun.

Buffelgrass has been recorded at most prostrate milkweed sites (Texas Natural Diversity Database 2013) and dominates many of them. At the Los Morteros site, prostrate milkweed only occurred in areas where the buffelgrass and woody vegetation was less dense (Best 2005). As early as 1985 (Dolores) and 1986 (Mission Mier a Visita), buffelgrass was noted as a common species in pastureland in and adjacent to prostrate milkweed sites (Poole 1985; Poole 1986) and was encroaching upon prostrate milkweed habitat. In 1999, Karen Clary photographed prostrate milkweed along US 83 at the Arroyo Roma site and states that she also saw plants growing "under the buffelgrass" (Clary 2014). No photograph was taken of the plant under the buffelgrass and no other surveyor has recorded a similar discovery. When buffelgrass dries out, it leaves behind a thick mat of last year's leaves, so dense that seeing below it is difficult. If areas dense with live buffelgrass can support prostrate milkweed, reproduction may be difficult in the deep shade of the grass.

Although not common, hybridization of milkweeds has been confirmed for several species [e.g., *Asclepias syriaca* x *A. exaltata*, *A. syriaca* x *A. purpurascens*, and *A. exaltata* x *A. quadrifolia*

(Wyatt and Hunt 1991)]. Only Zizotes milkweed (*Asclepias oenotheroides*) occurs at the same sites as prostrate milkweed, and Emory's milkweed (*A. emoryii*) has been reported from the same counties. But no hybridization has been observed.

Land ownership and management

TxDOT owns or partially owns eight of the fourteen extant sites of prostrate milkweed (one of these eight is on TxDOT, private and county property). USFWS owns two refuges near the Rio Grande River where prostrate milkweed occurs. Two of the four remaining sites are on private property, another site is on both private and county property, and one site is on county property.

All sites owned by TxDOT undergo management practices typical of maintaining ROWs. Also, some utilities have a legal right to be placed on the TxDOT ROWs (Texas Department of Transportation 2013). Due to this, it is difficult to avoid habitat disturbance or population destruction during utility siting, construction, and maintenance.

Texas Parks and Wildlife Department (TPWD) and the TxDOT developed verbal agreements to protect populations of rare plants on highway ROW from routine maintenance activities (Poole and Janssen 1997). It was confirmed by Poole and Janssen (1997) prior to 1997 that ROW sites along US 83 were full-width mowed once a year and strip mowed several times a year; herbicide was applied as needed on delineator posts, object markers, signs, and pavement edges; and some areas were bladed to control vegetation and disked to create fire lanes. However, it is unknown if this regime is still in place. In the Poole and Janssen (1997) report, ROW management was recommended specific to prostrate milkweed sites. To avoid plants, it was recommended that mowers be set at 6 inches and the area closest to the fence be mowed at least once a year in an effort to eliminate woody species (Poole and Janssen 1997). Herbicides were recommended only if necessary and sparingly at times of little to no wind (Poole and Janssen 1997). Stockpiling paving or construction materials and seeding or planting any species was discouraged (Poole and Janssen 1997). Because exactly how prostrate milkweed reacts to different types of disturbance is unknown, Poole and Janssen (1997) recommended disking on one side of the Dolores ROW site, but not the other. It was the hope of Poole and Janssen (1997) that through different management regimes, the question of disturbance type and extent could be answered. It is unknown if these management regimes were followed.

Prostrate milkweed occurs on two USFWS refuge tracts along the Rio Grande River. Both tracts had been grazed (if not overgrazed) prior to their purchase by USFWS (Best 2014). Most of the Lower Rio Grande Valley National Wildlife Refuge tracts serve as wildlife corridors and some are being restored to resaca habitat (U.S. Fish and Wildlife Service 2014). When visited in 2005, Best noted that the Los Morteros site was mostly buffelgrass in upland areas where disturbance had occurred and woody shrubs were replacing much of the native grass community. In areas where native grasses still persisted, forbs were dominant, but buffelgrass was encroaching into these areas as scattered clumps (Best 2005). Prostrate milkweed was found in areas where the plant community was still native grasses, but not where buffelgrass or woody vegetation was present in dense stands (Best 2005).

All privately owned sites (Salineno, FM 3167, part of Dolores, and part of San Julian) have likely been ranched in the past or are currently ranched. When visited in 2004, some roads on the

FM 3167 site had been bladed and some areas of the ranch had been root-plowed (Carr 2004). When visited in the 1980s, the privately owned portion of the Dolores site (adjacent and to the east of the ROW) had been bladed along roadsides (Poole 1985). The Dolores site has supported cattle and has been cleared of brush by various techniques (chaining, blading, dozing, disking) and then seeded to buffelgrass (Damude and Poole 1990). In 2003 or 2004, the owners of the San Julian, Dolores, and the FM 3167 sites were approached as part of a larger conservation agreement project in the Lower Rio Grande Valley (Price et al. 2006). Landowners allowed entry on to their property for surveys, but did not sign the voluntary conservation agreement, which committed owners to informally protecting rare plants on their property for a term of ten years (Price et al. 2006).

Evidence of threats to survival

Overgrazing, herbicide use, trampling, soil compaction, land clearing, and introduction of invasive non-native grass for forage are all common potential threats to rare plants and their habitats in South Texas. Drought is also a persistent hazard, particularly with the addition of climate change, which could increase current average temperatures and rainfall extremes. It is clear that prostrate milkweed can tolerate high temperatures and low water availability in areas where other plants fail to persist. This could in part be due to its ability to persist in soils other plants find uninhabitable or being an early successional species or other reasons. Many individuals have been found along ROWs or dirt roads, both of which can be inhospitable environments in South Texas. Disturbance may play a large role in prostrate milkweed's ability to persist in these locations. The plants may be more tolerant of trampling and soil compaction by cattle or land clearing practices used on ranches to open up areas for forage grasses. Similarly, highway ROWs are frequently undergoing disturbances related to brush removal and mowing in order to follow safety regulations. However, to what extent prostrate milkweed tolerates different types of disturbance is unknown. In addition, a frequent practice of both ranchers and the highway department is the seeding of grasses. Buffelgrass has been a popular and commonly used forage grass for decades and has the ability to out-compete other native species.

From narrowing the previous ROW (Arroyo Roma and Mission Mier a Visita) to scraping the ROW (Tigre Grande), and installing culverts and driveways (Arroyo de Los Mudos), the US 83 widening has undoubtedly impacted populations of prostrate milkweed. The entire stretch of US 83 from Roma to the Zapata/Webb County line is being widened to incorporate intermittent passing lanes, a four-foot buffer between the two lanes, and the widening of existing shoulders (Federal Highway Administration and Texas Department of Transportation 2012). Much of this construction has been completed or is near completion. Because prostrate milkweed is not a listed species, some sites have been disturbed, if not eliminated. However, because it co-occurs with two federally listed endangered plant species (ashy dogweed and Zapata bladderpod), some sites have been protected (Strong 2014c; Strong 2014d). All seven of the US 83 sites were visited in 2014, but only one ROW site had plants present (Strong 2014a). Because different stretches of the highway have been completed at different times and the only visit was made during construction (in 2014), it is unknown exactly what the disturbance was to some of these sites.

The two most southern sites (Arroyo Roma and Mission Mier a Visita) are in an area of US 83 that has doubled in width and now has curbs installed (Strong 2014e; Strong 2014f). Both of these stretches (or sites) of the highway now have four lanes, a middle turn lane, and an asphalt shoulder. No plants were found during surveys in 2014 at these two sites (Strong 2014e; Strong 2014f). It is likely that some plants were eliminated during the highway widening process. However, it is possible that plants growing closer to the property fences could have survived depending on the amount of disturbance during the recent construction. During the environmental review process, TxDOT surveyed for plants at the Mission Mier a Visita site, but found no plants (Texas Department of Transportation and Federal Highway Administration 2010). However, the vast majority of this prostrate milkweed site would have been part of another survey south of Loma Blanca Rd. To date, this author has not seen the environmental review for the stretch of highway between Loma Blanca Rd and FM 650. The dominant species at Arroyo Roma and Mission Mier a Visita is buffelgrass, which was mowed at the time of the 2014 visit (Strong 2014e; Strong 2014f). It appears the mower height was under six inches. Before the more recent construction, the Mission Mier a Visita ROW had been bladed and cleared of brush at various times in the past (Damude and Poole 1990). The pasture adjacent to the ROW at both sites has also been cleared in the past and seeded to buffelgrass (Damude and Poole 1990) to supplement cattle feed.

The northernmost Starr County site (Arroyo de los Mudos) is the single US 83 site where plants were found in 2014 (Strong 2014a). Two plants were located within about 75 meters from one another (Strong 2014a). One plant was within a meter of the roadway (Strong 2014a). It is unclear how much disturbance this site experienced during the US 83 improvements. Several one-meter tall acacias were present at this site (Strong 2014a), which indicates a lack of recent blading or scraping. However, it may be that the construction is not finished at this site. An uninstalled culvert was in between the two plants and depending on its ultimate placement, the plants may not survive (Strong 2014a). This prostrate milkweed site had not been entered into the Texas Natural Diversity Database before the US 83 improvement project.

The southernmost Zapata County site (Arroyo del Tigre Chiquito) is also a known Zapata bladderpod site and has been monitored or surveyed for both Zapata bladderpod and prostrate milkweed since 1991 (Janssen and Poole 1995). During the monitoring in the early 1990s, fiber optic cable was installed through the Tigre Chiquito site (Campos 1993). This site was protected during the recent US 83 widening as is obvious from the west side of the highway, which was scraped (Strong 2014c). The east side of the highway, although not recently mowed and dominated by buffelgrass, was intact, whereas the west side of the highway was mostly bare dirt (Strong 2014c). Both Tigre Chiquito and the site north of it (Arroyo del Tigre Grande) have a four-foot buffer along US 83 between the two lanes and a shoulder has been installed (Strong 2014c; Strong 2014g). On both sides of the highway ROW, the Tigre Grande site appeared scraped during the August 2014 visit (Strong 2014g). Presumably these two sites were more recently under construction since even buffelgrass had not bounced back.

Before the recent highway construction, the northernmost site of Dolores had experienced multiple disturbance events, including a gas pipeline ROW installation prior to 1985 (Poole 1985) and a fiber optic cable installation in 1995, which destroyed at least 100 prostrate milkweed plants (Grahl 1995). It is also likely that the ROW has been bladed in the past (Damude and Poole 1990). The site was actively undergoing highway construction during the 2014 surveys (Strong 2014d). Orange fences were erected on both sides of the highway to protect the federally endangered ashy dogweed (Strong 2014d). Unlike the east ROW, which had fences 4-5 meters from the property fence, orange fences on the west side of the highway were only one meter from the property fence (Strong 2014d). This may be due to a drag strip that had previously been created by the Border Patrol. The drag strip is maintained as a 4-5 meter wide strip where vegetation is kept clear (Texas Department of Transportation and Federal Highway Administration 2011) and the substrate is smoothed out to help track illegal immigrants. It was created between 2007 and 2011 as indicated by images in Google Maps. The drag strip follows the west side of the highway for the entire length of the Dolores US 83 site and is over 2.5 miles long. The drag strip has likely eliminated the entire population of prostrate milkweed on the west side of US 83, except possibly those plants closest to the fence. During monitoring in 1991 to 1995, this was the largest of the three monitored prostrate milkweed populations (from 38-97 plants, average of 68 plants) (Poole and Janssen 1997). The Dolores site ROW was surveyed prior to road construction in March of 2011 by TxDOT biologists and prostrate milkweed was found in association with ashy dogweed on the east side of the ROW (Texas Department of Transportation and Federal Highway Administration 2010). Road construction was expected to affect about a third of the ashy dogweed found along the Dolores ROW site within four meters of the pre-existing pavement (Texas Department of Transportation and Federal Highway Administration 2010). It is unknown if prostrate milkweed also co-occurred in this area and would be impacted. However, according to TxDOT, prostrate milkweed was located in an area with ashy dogweed and would be avoided as much as possible to minimize impacts to this species (Federal Highway Administration and Texas Department of Transportation 2012). Because construction was ongoing and surveys by Strong in 2014 were conducted while construction was active, only the southernmost portion (~1/4 mile on both sides of the ROW) of this site was surveyed (Strong 2014d).

Outside of the gas pipeline ROW, which crosses the Dolores site, no other gas or oil development has been observed at known prostrate milkweed sites. However, oil and gas development is occurring in Zapata and Starr counties. In 2007, Zapata was the state’s number one producer of natural gas (Whittaker 2007) and in 2012 Zapata was in the top ten of oil and gas producing counties in the state (Railroad Commission of Texas 2012). Many plugged, active, and permitted gas and oil wells occur throughout Zapata and Starr counties and several of these occur within 125 meters of known prostrate milkweed sites (Railroad Commission of Texas 2014).

Milkweeds are the required host plant for monarch larvae and a decrease in milkweeds across North America has been noted as playing a major role in significant decreases in monarch numbers at overwintering sites in Mexico and California (Xerces et al. 2011). Decline in milkweeds is possibly due to development and herbicide use (Xerces et al. 2011). Monarch populations have decreased by 87-99% since the mid 1990s at the US and Mexican overwintering sites (Xerces et al. 2011). Due to this incredible decline, there is a push by MonarchWatch to restore abundant, widely distributed milkweeds (MonarchWatch 2014). One group in South Texas is encouraging collection of the Texas native *Asclepias* species, including prostrate milkweed (Mild 2012). The group suggests only collecting a few seeds from rare milkweeds. This is particularly important for prostrate milkweed since other milkweeds, rare and more common, can have low recruitment rates. Mead’s milkweed (*Asclepias meadii*) and purple milkweed (*Asclepias purpurescens)* have low fruit production (Kettle et al. 2000; Wilbur 1976) and butterfly milkweed has low rates of seed survival (Klemow and Raynal 1986).

Special management considerations

Prostrate milkweed likely occurs on other private lands in Starr and Zapata counties. Gaining access and conducting additional surveys in these areas could result in identifying more populations. Because so much land in Texas is private, landowner contact is essential to accessing and encouraging protection of privately-owned populations.

To date, population trends, demographics, reproductive information, disturbance requirements, and management needs are still lacking and studies to resolve this lack of information should be conducted. Because very little research has been conducted on prostrate milkweed, very few conclusions can be made as to how to manage the populations. It is unclear how much of the variation in numbers is due to internal factors like low recruitment rate or external factors like competition, fire regime, disturbances, the introduction of non-native species, or other influences. Obviously, some disturbance, like widening roadways into prostrate milkweed habitat, will permanently alter required environmental conditions. But other disturbance, like blading, may be able to promote healthy populations of prostrate milkweed. Studies on the type and extent of disturbance prostrate milkweed tolerates would increase effective management.

A monitoring and management plan could establish a protocol to regularly and systematically count the existing populations of this species and might help clarify the extent to which internal factors (like reproductive biology) versus external factors (like succession and disturbance) affect the fluctuation in numbers within sites. Short-term monitoring was conducted at three sites from 1991 to 1995 (Poole and Janssen 1997). Monitoring methods were described and an unacceptable decline in population numbers and vigor (10%) was assigned (Poole and Janssen 1997). Similarly, preliminary monitoring plans were written for many rare Texas species in 1996 (Candee 1996). Significant or unacceptable declines were defined as a 20% decrease in total population in two consecutive years (Candee 1996). However, these percentages (10% and 20%) were chosen for all species within these two reports because they were seen as reasonable rates of change for species where information is lacking. The purpose of a management plan is to establish if these are in fact appropriate rates of change for prostrate milkweed.

To confirm that pollinators are essential to reproduction, the breeding system needs to be resolved. If the plants are outcrossers, identifying pollinators will aid in determining pollinator habitat type (e.g., ground-nesting bees vs. wood-boring bees) and guaranteeing protection of pollinator habitat. Monitoring could be conducted in conjunction with other federally listed plant species (ashy dogweed and Zapata bladderpod).

It was recommended that hand application of herbicides on buffelgrass and prescribed summer fires could be used to help sustain rare plants (Zapata bladderpod and prostrate milkweed) and their native grassland community at USFWS refuge tracts along the Rio Grande River (Best 2005). It has been shown that buffelgrass typically increases following winter fires in some communities of southern Texas (Hamilton and Scifres 1982). Studies should be conducted to show if fire is a viable management tool for prostrate milkweed and, if this species is dormant during a particular season. The creation of new roads on USFWS tracts along the border enables tracking and retrieval of illegal immigrants. Although prostrate milkweed has been found on dirt roads, the extent to which the plant can survive under continuous vehicular traffic is unknown and should be managed where possible.

Obviously, prostrate milkweed can persist through droughts; however, if climate change results in an increased chance of long-term droughts, it is unknown how well or how long the populations will be able to sustain through these conditions. Monitoring may clarify how tolerant the species is to drought and other natural disturbances.

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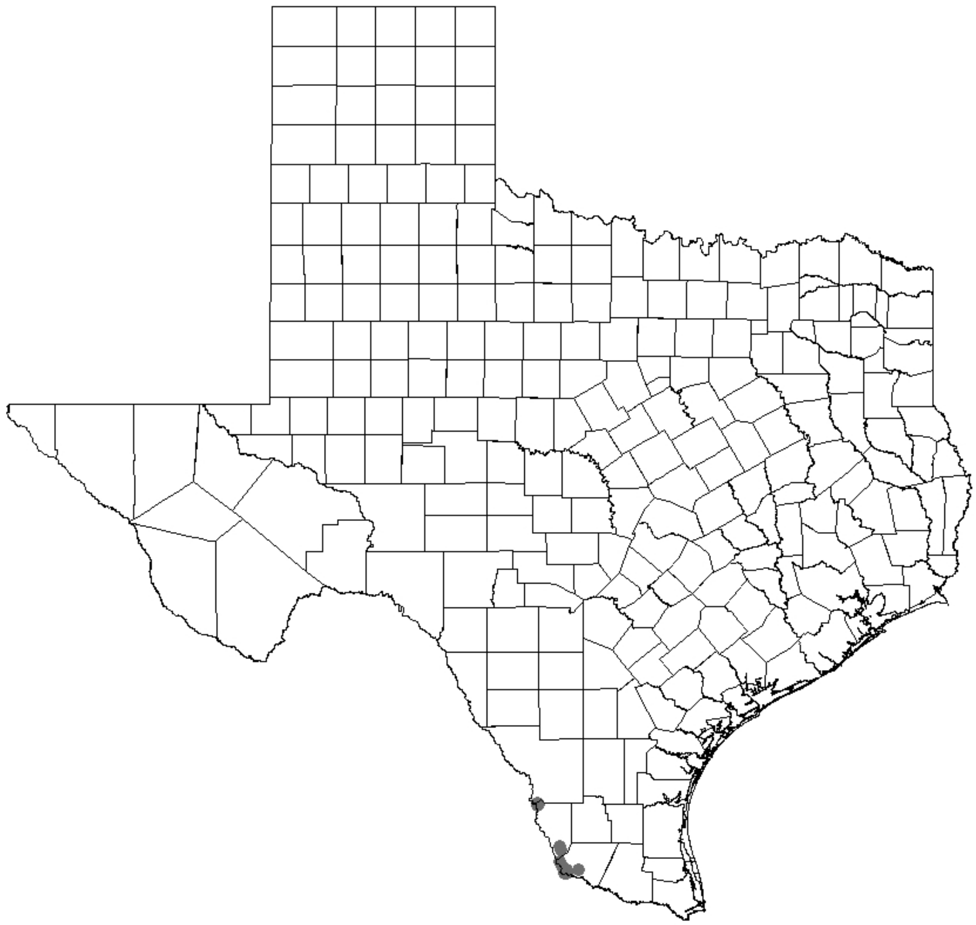
Table 1. Prostrate milkweed population status, including location and ownership (Texas Natural Diversity Database 2013). These sites have not undergone a comprehensive review and may be reorganized in the future. This is the author's best attempt at classifying sites.

County	Year discvrd	Year last seen	EO ID[+]	Site name	Landowner	Min. # per 1 subpop.[++]	Max. # per 1 subpop.[++]	Notes
Extant sites								
Starr	1957	1991	6223	Mission Mier a Visita	TxDOT	0 (2014)	~200 (1986)	disturbed by US83 construction
Starr	1966	1999	6491	Arroyo Roma	TxDOT	0 (2014)	137 (1988)	disturbed by US83 construction
Starr	1987	1995	1572	Falcon	TxDOT	0 (2014)	3 (1994)	Mowed
Starr	1990	*	not mapped	FM 2098	TxDOT	Present		Mowed
Starr	~1994	2007	8798	Salineno	Private	5 (2001)	20 (2000)	
Starr	1995	2014	not mapped	Arroyo de los Mudos	TxDOT	Present (1995)	2 (2014)	
Starr	2003	*	5533	Arroyo Ramirez	USFWS	1 (2003)		
Starr	2004	*	8325	FM 3167	Private	9 (2004)		
Starr	2004	2010	not mapped	Los Alvaros	County	0 (2014)	~30 (2005)	scraped?
Starr	2004	2005	not mapped	Arroyo Los Morteros	USFWS	6 (2005)	10 (2004)	
Starr	2007	*	not mapped	San Julian	County	0 (2014)	19 (2007)	
					Private	13 (2007)		
Zapata	1985	2014	3395	Dolores	TxDOT/ County/ Private**	0 (2009)	~100 (1993)	E side US83 fenced in recent construction-co-occurs with ashy dogweed; W side US83 Border Patrol drag strip
Zapata	1990	*	3803	Arroyo del Tigre Grande	TxDOT	0 (2014)	14 (1990)	disturbed by highway construction
Zapata	1992	2006	7771	Arroyo del Tigre Chiquito	TxDOT	0 (1992, 2014)	~30 (2005)	protected in recent US83 construction; co-occurs with Zapata bladderpod
Historic sites								
Webb or Zapata	1932	*	not mapable	Below Laredo	Unknown	Present (1932)		

+ EO ID is the unique number assigned to a new record (element occurrence) in the Texas Natural Diversity Database. An element occurrence is an area of land where a species resides/resided (i.e., a population). A population can consist of one or more subpopulations.
++ represents number of individuals recorded in any year at a subpopulation; each count is based on surveyor effort and is only as good as the effort expended (e.g., zeros could be false negatives; larger numbers, such as >#, #s, #+, could be gross overestimates or underestimates)
*only seen one year
**all surveys for different property owners at this site combined due to lack of location clarity among surveys

Figure 1. Distribution of extant populations of prostrate milkweed (*Asclepias prostrata*).



Texas screwstem

(*Bartonia paniculata* ssp. *texana*)

Species information (history of knowledge of taxon)

The first collection was made in 1965 by Donovan. S. Correll (#32006, LL) southeast of Colmesneil, TX (Tyler County). Correll subsequently described Texas screwstem as *Bartonia texana* in 1966 from his 1965 collection (Correll 1966). In 2009, Texas screwstem was reduced to *Bartonia paniculata* ssp. *texana* based on morphological characteristics and phylogenetic analyses (Mathews et al. 2009). Questions remain about Texas screwstem's taxonomy. It has been suggested that it may be a "slightly abnormal" population of twining screwstem (*Bartonia paniculata* ssp. *paniculata*) (Mathews et al. 2009), but, geographically, it seems to be clearly outlined and restricted (Mathews et al. 2009). However this was, in part, based on its presence on the Fleming Formation (MacRoberts and MacRoberts 1990), which it has been found outside of multiple times. Plants have also been located in three counties in Louisiana.

Present legal status (National and State)

Although not listed as endangered or threatened by the State of Texas, Texas screwstem is ranked as a G2 (an imperiled species) by NatureServe and is ranked as a Sensitive Species by the United States Forest Service (USFS). The species is also listed on Texas Parks and Wildlife Department's 2010 List of the Rare Plants of Texas and as a Species of Greatest Conservation Need in the Texas Parks and Wildlife Department (TPWD) State Conservation Action Plan.

In 1980, Texas screwstem was designated by the United States Fish and Wildlife Service (USFWS) as a Category 1 Candidate species (U. S. Fish and Wildlife Service 1980), a species which had sufficient biological status and threat information, but because of the large number of species in this category listing was delayed. In 1983, Texas screwstem was re-designated as a 3C Candidate (U. S. Fish and Wildlife Service 1983), a species which had been shown to be more abundant or widespread than was initially thought and was dropped from the list of species up for listing. In 2011, a 90-day finding was announced for 374 species from a petition to list 404 species in the southeastern United States as threatened or endangered (U.S. Fish and Wildlife Service 2011). The petition presented scientific information to indicate that listing may be warranted for Texas screwstem (U.S. Fish and Wildlife Service 2011). Scientific, commercial, and other information was requested and available information was summarized by the USFWS. In their summary, the USFWS determined that of the five threat factors, which can be used to assess if a species may warrant listing as endangered or threatened, A (present or threatened destruction, modification, or curtailment of its habitat or range) and D (inadequacy of existing regulatory mechanisms) were listed for Texas screwstem (U.S. Fish and Wildlife Service 2011).

Description (local field characters)

The following description is adapted from Correll (1966), Mathews et al. (2009), and Poole et al. (2007). Texas screwstem is a slender, erect annual 15.2 to 35.7 cm tall. The mostly alternate scale-like leaves (0.9-1.9 mm long) can grade into near opposite leaves at the top of the stem. Arranged in cymes, the flower calyces have four slender, awl-shaped lobes and are fused at the base. The corolla is whitish with usually ovate-acuminate (egg-shaped tapering gradually to a point) to ovate-apiculate (egg-shaped to ending in a small abrupt point) lobes (1.9-3.2 mm long). The style is short (0.4-0.8 mm long) and stout, and the two stigmas are spreading. The fruit is a capsule (1.7–2.7 mm long, 1.0–1.8 mm wide) and splits at its apex to release seeds. Seeds are minute and capsules contain ~2000 seeds (Nixon 1979a).

Recent studies show that the classic characters, which have differentiated Texas screwstem from the closely related twining screwstem (*Bartonia paniculata* ssp. *paniculata*) are unreliable due to overlapping measurements (calyx, corolla and style length) and other previously defining characters (capsule exceeding corolla or not, corolla lobe shape, sepal lobe shape, and capsule shape) (Mathews et al. 2009). The Mathews et al. (2009) key differentiates Texas screwstem from twining screwstem by the erect stem, ovate-acuminate corolla lobes, and the corolla lobe length (1.9-3.2 mm). Twining screwstem has occasionally twining stems, usually oblong-lanceolate lobes corolla, and usually a longer corolla lobe length (2.9–5.2 mm). An additional screwstem, white screwstem (*Bartonia verna*), also overlaps the Texas screwstem distribution. However, unlike Texas screwstem, white screwstem blooms in the spring, has mostly opposite leaves, a slender, longer style (1.6–2.1 mm long), converging stigmas, and a capsule which splits down the middle.

Geographical distribution (range and precise occurrences)

Texas screwstem has been recorded in nine East Texas counties at 21 sites across about 8,500 square miles (see Table 1 and Figure 1). Two sites in Tyler (and possibly Hardin) County were last observed in 1970 or earlier (Hyatt Estates and Turkey Creek Unit). Eleven sites in Hardin, Nacogdoches, Newton, Polk, San Augustine, San Jacinto, and Tyler counties have not been seen since the 1980s. Eight of these sites have only been visited once, the first time they were found. Four sites in Angelina, Hardin, and Jasper counties were discovered in the 1990s and have not been visited since. The four remaining sites in Newton, San Jacinto and Tyler counties were first located in the 2000s, but only one of these (Sand Ridge Cemetery) has been visited since and no plants were located. In fact, only four sites have been visited more than once (including the previously mentioned Sand Ridge Cemetery site). At least three sites have very vague directions (e.g.: “within Neches Bottom and Jack Gore Baygall Unit of the Big Thicket National Preserve” – this is a 13,300 acre area) making relocation difficult, if not impossible.

In 1979, Nixon visited and relocated plants at two previously known Texas screwstem sites [Clear Fork Creek and Stephen F. Austin (SFA) Experimental Forest] (Nixon 1979a). An additional sixteen sites in Rusk, Nacogdoches, Angelina, San Augustine, and Tyler counties were also searched, but no Texas screwstem was found (Nixon 1979a). It is unclear how these “negative” sites were selected. However, a year later Nixon found six new sites in Hardin, Newton, and San Jacinto counties (Nixon and Ward 1981). Five sites were reported to have been located in Newton County, but there is only evidence (herbarium specimens) from four sites

(Nixon and Ward #10543, #10801, #10823, SFA; Nixon #10588, SFA). It is unknown if there is one additional missing herbarium specimen or if there were in fact only four Newton County sites. It is likely that many other sites were searched, but how many sites and how sites were chosen is not known. In his 1981 report, Nixon only states that “many sites were searched”. However, during October and November of 1980, Nixon located at least six new sites, which justifies his statement that “this species [is]…more widely distributed than suspected…[and] it is very likely that other populations exist” (Nixon and Ward 1981). Nixon pointed out that because the species is “so small and inconspicuous” it tends to be missed (Nixon and Ward 1981).

Watson (1982) was unable to locate Texas screwstem on any Big Thicket National Preserve unit during her floristic surveys (in the late 1970s or early 1980s), but indicated that it was found “adjacent to” the Big Sandy unit. Watson predicted that due to this, the plant could possibly be found in the Big Sandy Unit though this has never been confirmed and mapped in the Texas Natural Diversity Database. Watson’s report is the only record of Texas screwstem being near the Big Sandy unit. The closest Texas screwstem site to the Big Sandy unit was found after Watson’s 1982 report and is five miles east of the unit (Buddy Lloyd Rd).

General environment and habitat description (physical and biological characteristics)

Texas screwstem is found in xeric sandylands of the West Gulf Coastal Plain (MacRoberts et al. 2002) in Texas and Louisiana. They seem to prefer baygalls (MacRoberts and MacRoberts 1998) with open forested areas (Nixon 1979a), but it has been suggested that the species only needs small openings in the shrubby under canopy (Singhurst pers. comm.). Plants grow in gently sloping to flat sites with perennial springs, seepages (Nixon 1979a), or creeks (Nixon and Ward 1981). Erosion in these wet areas creates elevated clumps (or hummocks) of tree bases, roots, and logs, which are associated with mosses and liverworts, and organic matter and soils with high organic matter (Nixon 1979a).

Texas screwstem is most commonly found on Catahoula, Fleming, Lissie, and Willis formations and on about eighteen different soil types. The most common soil types are Letney loamy sand, Tehran loamy sand, and Belrose loamy very fine sand. Together these soil types make up under a third of the soil types Texas screwstem has been found on. Both Letney and Tehran soils are deep strongly acidic loamy sands (Jasper-Newton soils). In 1979, soils from two sites (Clear Fork Creek and SFA Exp. Forest) were analyzed and had a 4.4-5.6 pH containing high levels of organic matter (Nixon 1979b). Presumably these soil samples were taken at the same time the plant collections were made in October of 1979. The levels of calcium and phosphorous were very low in comparison to agricultural needs (100 ppm calcium and 5 ppm phosphorous) (Nixon 1979b). Potassium and magnesium levels were low to medium, ranging from 40-125 ppm potassium and 35-90 ppm magnesium (Nixon 1979b). Precipitation from the southern to northern part of Texas screwstem range varies between 49.3 and 61.7 inches annually (National Oceanic and Atmospheric Administration 2014).

Of the about three dozen recorded sightings of Texas screwstem only about a third of these have associated species recorded. By far the most commonly reported associate species is sphagnum or the more general “mosses”. After visiting the two known locations in 1979 (Clear Fork Creek and SFA Experimental Forest), Nixon listed the following dominant associate species for Texas screwstem: red maple (*Acer rubrum*), smooth alder (*Alnus serrulata*), burmannia (*Burmannia* *biflora*), Virginia sweetspire (*Itea virginica*), sweetbay (*Magnolia virginiana)*, blackgum (*Nyssa sylvatica*), sensitive fern (*Onoclea sensibilis*), mosses and liverwort species (Nixon 1979a). Later in 1980, when Nixon had visited six other sites, he also listed swamp titi (*Cyrilla racemiflora*) and baygall holly (*Ilex coriacea*) as associates (Nixon and Ward 1981). In addition to these, Orzell recorded sweetgum (*Liquidambar styraciflua*), wax myrtle (*Morella heterophylla*), bald cypress (*Taxodium distichum*), primrose-leaved violet (*Viola primulifolia*), chain fern (*Woodwardia areolata*), and one species of liverwort, *Pallavicinia lyelli,* as "dominant" on labeled specimens collected at three sites [Orzell # 4863 (San Jacinto #45), #8462 (Jack's Creek), #8397 (Palo Gaucho), TEX]. Orzell relocated San Jacinto #45 in 1986, which had been previously visited by Nixon in 1980, but Jack's Creek and Palo Gaucho were discovered by Orzell in 1988. Finally, nodding nixie (*Apteria aphylla*) was recorded at two Texas screwstem sites in 1995 and 2004, Angelina 86 (MacRoberts and MacRoberts #2912, SFA) and Sand Ridge Cemetery (Singhurst #13194, TEX), respectively. Nodding nixie is ranked as apparently secure (G4) globally, but in the state of Texas it is ranked as imperiled (S2).

Texas screwstem is considered a typical plant in baygalls (MacRoberts and MacRoberts 2001). Seven sites have been recorded as occurring in or very close to a baygall (Angelina 76, Angelina 86, Buddy Lloyd Rd, Jack's Creek, Sam Houston National Forest, Sand Ridge Cemetery, and Turkey Creek Unit). These sites are shrub dominated and, like bogs, have a low pH and nutrient content with mucky soils (MacRoberts and MacRoberts 2001).

Watson (1982) suggests that Texas screwstem "tolerates fire well". If indeed Texas screwstem requires open understory areas of the forests to persist, a dense baygall is not the prime habitat. Baygalls do not require fire, but canopy cover can increase until the herbaceous species are shaded out and decrease until the area no longer can carry a fire (Drewa 1999). The exact light requirements of Texas screwstem are unknown and data to support Texas screwstem's ability to tolerate fire are lacking.

In the 1991 Big Thicket National Preserve Fire Management Plan, Texas screwstem is incorrectly listed as a rare plant within the wetland pine savannah vegetation type (Woods and McHugh 1991). However, this is a mistake possibly created from an abbreviation used in Watson's 1982 report, Vegetational Survey of Big Thicket National Preserve. Watson lists Texas screwstem as a rare plant within the acid-baygall or wetland baygall shrub thicket (WBS opposed to wetland pine savannah, or WPS). This mistake has been repeated in the more recent Fire Management Plan (McHugh 2004).

Population biology of taxon (demography, phenology, and reproductive biology)

Because most of the Texas screwstem population counts are based on herbarium specimens, at best, qualitative estimates ("locally rare" or "locally occasional") were taken and, at worst, no estimates were taken. Due to this lack of data, attempting to compare population trends among years is nearly impossible. Six populations were visited one to two times and only have qualitative estimates taken. Two populations were visited between 4 and 6 times (Clear Fork Creek and SFA Exp. Forest, respectively). The Clear Fork Creek site ranged from "widespread" and "numerous" (1965), "rare to occasional" (1979), "locally rare to occasional" (1980) to simply present (1985). In ca. 1979, plant density was estimated as 86 plants in a 7,500 square meter area (Nixon 1979a) (or 55 plants/acre). The SFA Experimental Forest site ranged from "rare" (1975) to "locally rare" (1980). However, plant density was estimated in ca. 1975 as 41 plants in a 3,000 square meter area (Nixon 1979a) (or 48 plants/acre). Ten of the populations have no count information and were simply recorded as present. One other population was estimated (Sam Houston) in 2006 and had "20 plants in three different locations". These "locations" are ~275 meters from one another based on GPS points.

After visiting the two sites known at the time (Clear Fork Creek and SFA Experimental Forest), Nixon observed that plants occurred in scattered groups with each group containing fewer than a couple dozen plants (1979a). However, Nixon (1979a) reported that botanists familiar with screwstem species believed that populations could vary greatly from year to year due possibly to reports that twining screwstem in East Texas could vary greatly. This is also not uncommon in other annual plant species. The closely-related twining screwstem typically occurs as individuals or as clumps and appears to only reproduce sexually (Hill 2003). Stem clusters could be many individuals or one to few plants with many stems (Hill 2003).

Plants in Texas have been observed flowering from mid-September to early November and fruiting has been seen from early October to mid-November (Nixon 1979a; Nixon and Ward #10823, SFA; Nixon and Ward #10537, SFA). In Louisiana, plants have been collected in flower starting in August (Reid #4638, LSU). Nixon reported nine flowers per plant and about 2,000 seeds per capsule (Nixon 1979a). Nixon's (1979a) observation of a low percent of plants germinating from seed remains unsubstantiated. One specimen in flower and fruit collected by Amerson (#17) in 1970 is reportedly from April; however, this specimen has not been located at BRIT and cannot be confirmed as Texas screwstem.

Population ecology of species (negative interactions)

Screwstems have long been suspected of being mycoheterotrophs, at least partially (Gillet 1959). Partial mycoheterotrophs can photosynthesize and parasitize fungi for nutrients. The combination of reduced leaf and stem area, highly branched mycorrhizal fungi on and inside the roots, and enriched tissues with the heavy elements Carbon-13 and Nitrogen-15 (13C and 15N) suggest that Virginia screwstem (*Bartonia virginica*) is partially mycoheterotrophic (Cameron and Bolin 2010).

A recent study analyzed a few Virginia screwstem and twining screwstem specimens and although a few plants had traits of both species, no plants had intermediate traits (Mathews et al. 2009), which indicates that hybridization may not be occurring among these screwstem species.

Only one invasive species has been observed at the Texas screwstem sites. Conner documented southern rockbell (*Wahlenbergia marginata*) at the Clear Fork Creek site prior to 1980 (Conner 1979). Southern rockbell occurs in southeast Texas and throughout the southeastern United States.

Land ownership and management

Twelve Texas screwstem sites occur on private property and one of these twelve populations is owned by The Nature Conservancy (TNC). The remainders of populations occur on federal lands: five populations occur on USFS lands and four sites occur on National Park Service (NPS) lands in the Big Thicket National Preserve. Although Texas screwstem is mentioned as occurring on the Big Thicket in its Fire Management Plan, no management of Texas screwstem or its habitat is described except that baygalls are typically not flammable (McHugh 2004).

The USFS conducts surveys for its proposed endangered, threatened, and sensitive species. After habitat is identified, these areas are protected and managed (U.S. Department of Agriculture – Forest Service 1996). Herbicide use is delineated by clearly marked buffers in areas within 60 feet (ground application) to 300 feet (aerial application) of threatened, endangered, proposed, or sensitive plant species (U.S. Department of Agriculture – Forest Service 1996). Clear cutting of trees is only used when it will "establish, enhance or maintain habitat for threatened, endangered or sensitive species" (U.S. Department of Agriculture – Forest Service 1996). Herbicides are not used within 30 feet (ground application) to 100 feet (aerial application) of wetlands or perennial or intermittent springs and stream (U.S. Department of Agriculture – Forest Service 1996). Undisturbed buffer zones are created around perennial and ephemeral streamside zones to maintain high water quality and protect riparian habitat and special plant communities (U.S. Department of Agriculture – Forest Service 1996). A few brief surveys for the Texas screwstem sites on the Angelina National Forest have been conducted, but they were not comprehensive and may have been at the wrong time of year (Philipps 2014). More surveys within the forest (and elsewhere in surrounding appropriate habitat) could turn up new populations.

Owned by the USFS, Stephen F. Austin Experimental (SFAE) Forest is a 2,600 acre research site for multiple-use studies (U.S. Department of Agriculture – Forest Service 1996). Silviculture, red-cockaded woodpecker, white-tailed deer, and pine regeneration studies have been undertaken at SFAE Forest (U.S. Department of Agriculture – Forest Service 1996). It is unknown where exactly the population of Texas screwstem is within the SFAE Forest and has not been seen since 1980. It is unknown when the last survey was conducted to locate Texas screwstem.

The Nature Conservancy's Roy E. Larsen Sandyland Sanctuary's management program attempts to protect and maintain the species at the preserve. General management of the preserve includes restoration efforts (prescribed burning, selective timber harvesting, and invasive species control) (The Nature Conservancy 2014). Within the general habitat of Texas screwstem, TNC tries to limit disturbance, such as that caused by feral hogs, invasive species, and soil damage (Ledbetter 2014).

Evidence of threats to survival

As a wetland species, twining screwstem, appears to be dependent on hydrology (constantly wet), a stable acidic substrate, and a lack of competition (Hill 2003). Given this, likely threats include hydrological changes by humans, livestock or surrounding forest trees, and/or habitat fragmentation (Hill 2003). Prior to 1979, the Clear Fork Creek site was clear-cut to the seep and spring margins and occasionally into the seeps and springs (Nixon 1979a). Poor streamside management practices like clear-cutting, planting pines across streams, and converting headwater baygalls to ponds or lakes can also alter/threaten Texas screwstem habitat to a point where plants can no longer grow (Poole 2011).

Decreased dispersal and genetic exchange of twining screwstem can result from clear-cuts, road/utility line corridors, and other developments (Hill 2003). Pipelines and possibly other utility corridors cross through the Big Thicket National Preserve units. These areas would have increased light where a shaded, closed canopy forest would normally exist (Watson 1982). Increased light would change baygall vegetation structure, including an increase in vegetation more typical of the longleaf pine wetlands or seepage slopes (Watson 1982). It is unknown how this change in vegetation might affect Texas screwstem. Because Texas screwstem also occurs in seepage slopes, this may not negatively affect the plant. However, transitioning a baygall into a longleaf pine wetland may or may not disrupt the natural habitat of Texas screwstem.

Watson (1982) observed that armadillo disturbance could be quite damaging on the forest floor, but was variable from year to year. Also, during her surveys for the National Park System, Watson observed that seepage slopes were almost bare presumably due to heavy grazing, which was allowed at the time on the Big Sandy Unit (Watson 1982). Although Texas screwstem was not found on the Big Sandy Unit of the Big Thicket National Preserve (it was noted as a potential species on this unit by Watson), it seems logical that heavy and/or frequent grazing along perennial or ephemeral mesic areas would greatly disturb all vegetation at these sites.

Special management considerations

To date, population trends, demographics, habitat requirements, and reproductive information are still lacking and studies to resolve this lack of information should be conducted. Known populations need to be relocated and regularly monitored to determine any trends. Nixon (1979a) suggested monitoring in combination with management practices. A monitoring plan could establish a protocol to regularly and systematically count Texas screwstem. Effective monitoring of Texas screwstem requires permanent, long-term transects to detect real demographic trends.

Integrating monitoring with different types of management in a formal plan is appropriate for all species because different management will likely effect plant population health differently. In order to track if the effect of management on population health is beneficial, an appropriate rate of change is also required. To effectively manage Texas screwstem, management decisions and changes should be recorded along with population health and status. Management conducted on public land should be assessed before and after activities are initiated.

At least two more extensive attempts have been made to locate new sites of Texas screwstem. Nixon's attempt in 1980 was successful and in two months six new sites were located. However, during Watson's more extensive floristic surveys of the Big Thicket National Preserve, no new or previously known sites were located. However, this may have been the difference between a survey specifically of Texas screwstem and a more expansive and complete floristic survey of a larger area. It is promising that six new sites could be found in the correct habitat and time of year. However, Texas screwstem's preference for widespread geologic formations and mesic sites results in a fairly large possible habitat area within East Texas. Additional surveys of known sites may help inform a more directed search. This is supported by the fact that almost half of the known locations are on public land or protected preserves and could more easily be accessed.

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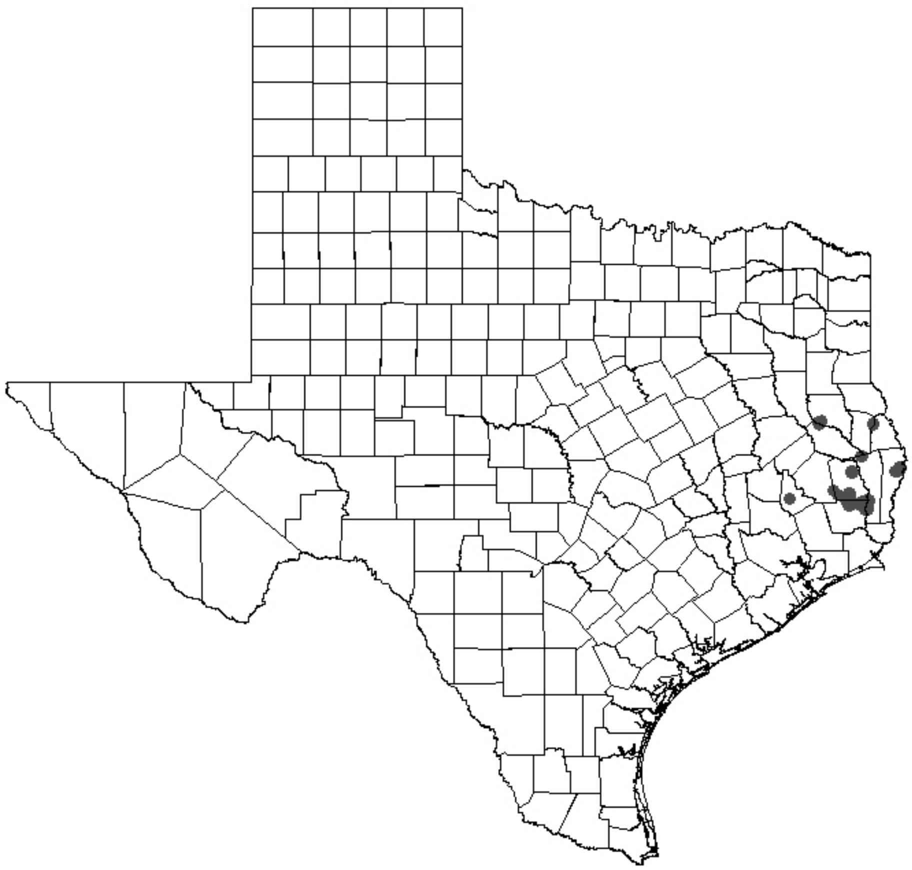
Table 1. Texas screwstem population status, including location and ownership (Texas Natural Diversity Database 2013). These sites have not undergone a comprehensive review and may be reorganized in the future. This is the author's best attempt at classifying sites.

County	Year discvrd	Year last seen	EO ID[+]	Site name	Landowner	Min. # per 1 subpop.[++]	Max. # per 1 subpop.[++]
Angelina	1996	*	not mapped	Angelina 76	USFS	present	
Hardin	1980	*	6395	Neches/Jack Gore	NPS	"locally rare"	
Hardin	1994	*	not mapped	Roy E. Larsen	TNC	present	
Jasper	1990	*	1875	Ward Branch	USFS	1	
Jasper	1995	*	not mapped	Angelina 86	USFS	present	
Nacogdoches	1975	1980	1030	SFA Experimental Forest	USFS	"rare" (1975)	41 (1979)
Newton	1980	*	2284	Moore's Branch	private	"locally occasional"	
Newton	1980	*	4701	Underwood Creek	private	"locally occasional"	
Newton	1980	*	1971	Stringtown	private	"locally rare to occasional"	
Newton	1980	*	7651	Little Quicksand	private	"locally rare"	
Newton	2004	*	not mapped	Sand Ridge Cemetery	private	0 (2011)	present (2004)
Polk	1988	*	913	Buddy Lloyd Rd/CR1450	private	present	
San Augustine	1988	*	8127	Palo Gaucho	private	present	
San Jacinto	1980	1986	6203	San Jacinto #45	private	"occasional" (1980)	"small population" (1986)
San Jacinto	2006	*	not mapped	Sam Houston NF	USFS	20	
Tyler	1965	1985	7943	Clear Fork Creek	private	86 (1979)	"numerous" (1965)
Tyler	1970	*	4783	Hyatt Estates	private	present	
Tyler	1988	*	4397	Jack's Creek	private	present	
Tyler	2007	*	not mapped	Beech Woods Trail	NPS	present	
Tyler	2007	*	not mapped	Beech Creek	NPS	present	
Tyler/Hardin	1967?	*	4782	Turkey Creek Unit	NPS	1	

+ EO ID is the unique number assigned to a new record (element occurrence) in the Texas Natural Diversity Database. An element occurrence is an area of land where a species resides/resided (i.e., a population). A population can consist of one or more subpopulations.
++ represents number of individuals recorded in any year at a subpopulation; each count is based on surveyor effort and is only as good as the effort expended (e.g., zeros could be false negatives)
*only seen one year

Figure 1. Distribution of extant populations of Texas screwstem (*Bartonia paniculata* ssp. *texana*).



Small-headed pipewort

(*Eriocaulon koernickianum*)

Species information (history of knowledge of taxon)

The first collection of small-headed pipewort was supposedly made by Charles Wright in "East Texas" while he was collecting there between 1837 and 1852 (Tucker 1983). The specimen is referenced in the original 1870 species description by van Heurck. However, after attempts to relocate this specimen, it remains missing (MacRoberts and MacRoberts 2005). After Wright's initial 1800s collection, the next Texas specimen of small-headed pipewort was not collected until 1946. Harris B. Parks (s.n., TAES) collected it in Texas in May around Wellborn in Brazos County, TX. Small-headed pipewort has also been collected in Arkansas, Georgia, Louisiana, and Oklahoma.

Present legal status (National and State)

Although not listed as endangered or threatened by the State of Texas, small-headed pipewort is ranked as a G2 (an imperiled species) by NatureServe and is ranked as a Sensitive Species by the United States Forest Service. The species is also listed on Texas Parks and Wildlife Department's 2010 List of the Rare Plants of Texas and as a Species of Greatest Conservation Need in the Texas Parks and Wildlife Department (TPWD) State Conservation Action Plan. In 1980, small-headed pipewort was designated by the United States Fish and Wildlife Service (USFWS) as a Category 2 Candidate species (U.S. Fish and Wildlife Service 1980), a species which warranted protection, but which lacked sufficient biological status and threat information. In 1993, general status trends were added to Candidate species, and for small-headed pipewort a status trend of declining was assigned (U.S. Fish and Wildlife Service 1993). However, in 1996, to allow USFWS to focus on protecting the many species for which sufficient information was available, all Category 2 Candidates were dropped from the list (U.S. Fish and Wildlife Service 1996). In 2011, a 90-day finding was announced for 374 species from a petition to list 404 in the southeastern United States as threatened or endangered (U.S. Fish and Wildlife Service 2011). The petition presented scientific information to indicate that listing may be warranted for small-headed pipewort (U.S. Fish and Wildlife Service 2011). Scientific, commercial, and other information was requested and available information was summarized by the USFWS. In their summary, the USFWS determined that of the five threat factors, which can be used to assess if a species may warrant listing as endangered or threatened, A (present or threatened destruction, modification, or curtailment of its habitat or range) and D (inadequacy of existing regulatory mechanisms) were listed for small-headed pipewort (U.S. Fish and Wildlife Service 2011).

Description (local field characters)

The following description is adapted from Moldenke (1942), Kral (2000), and Poole et al. (2007). Small-headed pipewort is a 5-8 cm tall annual (or possibly a short-lived perennial) herb. The linear leaves are 2-5 cm long and about 1 mm wide at the middle with large air spaces, which are more noticeable at the base. The monoecious flowers (male and female flowers are separate but on the same flower) are on 2-10 cm long peduncles and arranged in a 3-4 mm wide globose heads. Heads are dark-gray to gray-green with straw-colored outer bracts. The sepals and petals are rimmed with white hairs. Staminate flowers have two sepals (1-1.5 mm long, grayish) and two petals, both with white, club-shaped hairs on their apices. Pistillate flowers also have two sepals (1 mm long, gray) and two petals (1 mm, yellow-white), both with white or pale club-shaped hairs at their apices. Fruits are two-seeded, and seeds are deep reddish-brown, 0.5 mm, broadly egg-shaped or elliptic. More recent work shows that Texas small-headed pipewort plants are on average larger than eastern populations in Georgia (Watson et al. 2002). Although leaf length for Texas populations has been published, only the mean is given (5.66 cm, SD 3.03) (Watson et al. 2002). However, this indicates that the Correll and Johnston (1970), Moldenke (1942), Kral (2000), and Godfrey and Wooten (1979) treatments, which respectively state leaf length as <2.5 cm, 1.5-2.5 cm, 2-5 cm, 1-5 cm, is not accurate for all populations. Small-headed pipewort leaves can be up to at least 8.7 cm long.

At least two other pipewort species co-occur at small-headed pipewort populations: ten-angled pipewort (*Eriocaulon decangulare*) and Texas pipewort (*E. texense*). Both of these species have heads with white thread-like hairs, making the head appear mostly white. Pipeworts can be confused with other closely related plants, like bogbuttons (*Lachnocaulon* spp). However bogbuttons do not have the large visible air chambers on the leaf bases.

Geographical distribution (Range and precise occurrences).

Small-headed pipewort has been recorded in at least five East Texas counties at 11 sites spanning 225 miles from northeast to southwest (see Table 1 and Figure 1). One site was recorded (pre-1985) as being on the Jewett Mine, which spans across Leon, Freestone and Limestone counties. It is unknown from which county (or counties) the plant was recorded. Written communications in 1991 suggest that the Jewett Mine site could also have been a misidentification (Watson 1991). Several unsuccessful attempts have been made to relocate this population (MacRoberts and MacRoberts 2005; Mariah 1992; Watson 1991). If the site did exist, it may have been destroyed by the mining operation (Perino n.d.). The Brazos County location was collected in 1946 and 1947, but the location description is vague ("Wellborn") and has not been relocated [Parks, s.n. (four specimens), TAES]. Two sites have not been seen since the 1990s (Limestone and Baker Lake), although one attempt in 1999 to relocate the Limestone County site showed that the area was heavily disturbed and no plants were found (MacRoberts and MacRoberts 2005). The remaining seven sites have been seen in the 2000s, although only three of them since 2010 (the private Henderson County site, Arc Ridge Ranch and Enchanted Rock).

A Perino specimen (#4258, BRIT) is labeled Freestone County, but directions lead to a Limestone County site (MacRoberts and MacRoberts 2005). This site was relocated and verified to be in Limestone County in 1995, but was not relocated in 1999. A 1947 specimen collected by Cory (52778, LL) in Hardin County was misidentified as small-headed pipewort, but has been correctly identified as whitehead bogbutton (*Lachnocaulon anceps*). Moldenke (1942) reported that the type specimen of small-headed pipewort was collected by Wright in the 1800s from Tyler County. However, according to the van Heurck's species description from 1870, Wright's specimen only described the collection as being from "East Texas" (van Heurck 1870). It is unclear why Moldenke concluded that East Texas meant Tyler County. Moldenke states in his treatment that he had not in fact seen Wright's specimen or any Texas specimen (Moldenke 1942). Watson (1982) reported small-headed pipewort as being a "possible" species in three Big Thicket National Preserve units spanning Tyler and Hardin counties (Hickory Creek Savannah, Beech Creek, and Neches Bottom and Jack Gore Baygall) based on the species being found adjacent to this area. However, beyond Watson's report, there is no evidence that small-headed pipewort was located adjacent to these units. Nine of the ten extant populations (sites observed in the last 50 years) have been visited since 1995, although only two of the ten sites have been visited since 2010 and had plants present. Sites have rarely been visited more than a few times; 70% of sites have been visited only one or two times.

General environment and habitat description (physical and biological characteristics)

Known in Texas from the Edwards Plateau and the Post Oak Savanna regions, small-headed pipewort has been recorded in permanent seeps on granitic outcrops, bogs, marshes, and sandy seepage slopes (MacRoberts and MacRoberts 2005). One site is along the sandy edges of a marsh/bog in very shallow, but wet sands (MacRoberts and MacRoberts 2005). In Oklahoma and Arkansas, plants have been found along intermittent or perennial stream banks (Gentry et al. 1978; Kral 1966) and many populations are found in sandy soils (Kral 2000).

The most common associated species found at the Texas sites are ten-angle pipewort, dwarf St. Johnswort (*Hypericum mutilum*), sugarcane plumegrass (*Saccharum giganteum*), yellow pitcher plant (*Sarracenia alata*), horned bladderwort (*Utricularia cornuta*), and zigzig bladderwort (*Utricularia subulata*). Additionally, one or more unidentified species of spikerush (*Eleocharis*), rush (*Juncus*), beak-rush (*Rhynchospora*), sphagnum moss (*Sphagnum*), and yellow-eyed grass (*Xyris*) are also commonly noted.

Precipitation from the southern to northern part of small-headed pipewort's Texas range varies between 27.7-42.9 inches annually (National Oceanic and Atmospheric Administration 2014).

In Texas, small-headed pipewort has been mapped over Calvert Bluff, Carrizo Sand, Queen City Sand, Reklaw, Town Mountain Granite, and Wellborn formations, and terrace deposits. About half (56%) of the sites occur over Queen City Sands and another 12% occur over terrace deposits. Soils are described as granite outcrops, clay loam, fine sands, fine sandy loams, loamy fine sands, sandy loam, and loams. Approximately nine soil associations have been identified in relation to small-headed pipewort sites. The most common of these are Leagueville-Henco/Leagueville loamy fine sands.

MacRoberts and MacRoberts (2005) analyzed sandy soils at the edge of a bog in Anderson County. Although only from one site, the sample had a 4.6 pH, 3.4% organic matter, 41 ppm potassium, 200 ppm calcium, and 46 ppm magnesium (MacRoberts and MacRoberts 1998). These results show that soils are acidic and generally low to very low in their macronutrients (except for magnesium). Four soil samples from Anderson and Henderson counties were also taken and showed that soils are “acidic and generally nutrient poor” (MacRoberts and MacRoberts 2005). The samples showed organic matter was 1.8-2.0%, pH was 4.1-4.4, phosphorous was 6-12 ppm, potassium was 61-111 ppm, calcium was 257-447 ppm, and magnesium was 57-98 ppm (MacRoberts and MacRoberts 2005). Soil samples have also been analyzed at six Oklahoma sites in two counties (Watson et al. 1994). Soil pH ranged from 4.5 to 5.0, phosphorous from 6.7 to 25 kg/ha, potassium from 63.8 to 180.3 kg/ha, and nitrates from 6.7 to 8.9 kg/ha. For most sites, these results show that soil macronutrients were low and that soils were acidic. There were no significant differences between soils where small-headed pipewort was present and adjacent areas where it was absent, nor between sites, except one site where potassium and phosphorous were higher (Watson et al. 1994).

Small-headed pipewort may be an early successional species, needing sun and low competition (Tucker 1983). It can be a dominant species where it grows with 75% of coverage in the small areas it occurs (Tucker 1983). In Arkansas, most small-headed pipewort sites had few woody plants (Tucker 1983). At six sites in Oklahoma, bare ground averaged 61.8% among the quadrats sampled (Watson et al. 1994). Plots showed a statistically significant positive correlation between the presence of small-headed pipewort and bare ground (Watson et al. 1994). Another study showed that vegetation cover averaged 80% at an Anderson County, TX site (Andrew’s Bog), but that the plant was absent where there was high vegetation cover (MacRoberts and MacRoberts 2005). Small-headed pipewort was found in open, disturbed areas where animals had created trails and uprooted plants (MacRoberts and MacRoberts 2005). Additionally, when plots were burned or pruned of vegetation and seeded with small-headed pipewort, germination was significantly greater than plots left alone (Watson et al. 1994). This suggests that disturbance may contribute to the recruitment and maintenance of the plant (Watson et al. 1994). One site with “considerable disturbance” in Oklahoma was seen as unusual in 1983 compared to other known Arkansas sites at the time (Tucker 1983). However, it seems that small-headed pipewort can tolerate some amount of disturbance. A short-term monitoring project was attempted to create baseline plant population data to establish if feral hog disturbance was negatively effecting small-headed pipewort populations (MacRoberts and MacRoberts 2005). Andrew’s Bog was monitored annually from 2000 to 2002 to track six paired plots (inside and outside a hog exclosure) (MacRoberts and MacRoberts 2005). Although these results have not been statistically analyzed, there does seem to be a general downward trend of number of plants over the three years for both treatments and all plots. The range and mean number of plants declined from 2000 to 2002 [inside exclosure mean number of plants was 20.3 (2000), 14.2 (2001), and 2.2 (2002); outside exclosure mean number of plants was 20.7 (2000), 1.8 (2001), and 2 (2002)]. A statistical analysis of these data may give more insight into what, if anything, occurs when feral hog disturbance is removed from small-headed pipewort habitat.

Population biology of taxon (demography, phenology, and reproductive biology)

Small-headed pipewort can grow scattered as individuals or small groups or as a dense stand (Tucker 1983) of thousands of plants. Estimating the number of small-headed pipewort is common since thousands of plants can occur in a small area. One 5m^2 Madison County, Arkansas site was recorded to have an estimated 6,000 plants in 1982 (=240 plants/m^2) (Tucker 1983). The Gillespie County, TX site had about 1,000 plants in the mid-1990s (MacRoberts and MacRoberts 2005). This was estimated from two 1 m^2 areas sampled, which totaled 50 and 60 plants/m^2, respectively (MacRoberts and MacRoberts 2005). In 2007, a 3m^2 area of this site was counted and totaled 527 plants (Singhurst 2007). The only site where permanent plots have been set up and counted over time was at the Andrew's Bog site. Three 1m^2 areas of the "several hectare" site were counted from 1999 to 2002 and counts ranged from 0 to 33 plants/m^2 (MacRoberts and MacRoberts 2005). Based on these counts, the site was estimated to total between 850 (2002) and 2,500 plants (1999) (MacRoberts and MacRoberts 2005).

Like other annuals, small-headed pipewort populations can vary widely from year to year, which could be driven by disturbance, annual climatic factors, like rain (Watson et al. 1994), or by its seed bank (MacRoberts and MacRoberts 2005). According to estimates taken in one area at the Andrew's Bog site in Anderson County, plants fluctuated from 1,000 plants in 1999 to 10 in 2000 (MacRoberts and MacRoberts 2005). Several factors were presented as possible reasons for this variable trend, including feral hog disturbance, lack of fire, and drought. Another species of pipewort, Parker's pipewort (*Eriocaulon parkeri*), can vary considerably in number and location over a small period of time (three years), which either supports its annual habit or could suggest a strong correlation with environmental factors (Haines 2000). A large seed bank might also explain plants emerging in areas thoroughly surveyed in previous years (MacRoberts and MacRoberts 2005).

Plants have been collected or observed in flower as early as May 4th in Texas and as late as July 17. Only one report of fruiting in Texas (mid-June) has been made (Singhurst 2007). The paucity of collecting specimens with fruit or recording fruiting dates may be an artifact of when sites are traditionally visited more than a biological trend.

Kral (1966) suggested that small-headed pipewort is wind-pollinated even though they have glands on the interior of their petals. However, these glands do not appear to produce nectar in other pipewort species [ten-angle and seven-angle pipewort (*Eriocaulon aquaticum*)] (Uphof 1927). Shore flies of the species *Allotrichoma abdominalis* have been recorded on ten-angle pipewort in Florida (Deyrup and Deyrup 2008). However, ten-angled pipewort is reported to have no nectaries (Uphof 1927), so if pollination is occurring, it is not due to a nectar reward. Watson et al. (1994) reported that no flying insects have been recorded visiting small-headed pipewort flowers, but ants were seen and could be the reason for the limited levels of self-pollination. The annual Parker's pipewort seems to rely on self-pollination, specifically geitonogamy (Sawyer et al. 2005), pollination of a flower from another flower on the same plant.

Several gossamer-winged butterflies (*Castalius rosimum*, *Chilades laius*, and *Talicada nyseus*), brush-footed butterflies (*Yphthima asterope* and *Y. huebneri*), bees (*Apis dorsata*, *Apis cerana indica*, and *Trigona* sp.), as well as a tiger moth (*Amata bicinota*) have been recorded at pipeworts in India (Balachandran et al. 2014). The stingless bee (*Trigona* sp.) had the highest visitation rates to pipeworts (*Eriocaulon* spp.) at 6.4 (+/- 4.3) bees/flower/every 5 minutes (Balachandran et al. 2014). Although visitors to pipeworts can help narrow down possible pollinators, many are not effective pollinators, but pollen thieves instead.

In a study involving Oklahoma populations of small-headed pipewort the mean number of flowers/inflorescence was 17.8 (SD = 6.1) with only about 40% of ovules developing into seeds (Watson et al. 1994). No vegetative reproduction was observed during these studies, but the number of small-headed pipewort plants was positively correlated with the number of small-headed pipewort seeds present in the topsoil (Watson et al. 1994). And although seeds were present, recruitment from seeds in situ may be low (Watson et al. 1994). After multiple attempts to germinate small-headed pipewort seeds ex situ, one treatment resulted in a 63% germination rate (Watson et al. 1994). The treatment involved storage for 10 months at room temperature, then a 48 hour wash in 37°C (98.6°F) water, followed by dark storage for 7 weeks at 3.5°C, and finally 3 weeks in a growth chamber with 14 hour light/day at 29°C (Watson et al. 1994).

As shown by isozyme tests, small-headed pipewort displays little genetic variation within or among populations (in AR, OK, GA and TX) and that a bottleneck may have occurred in the recent past (Watson et al. 2002). Watson et al.'s (2002) results suggest that the disjunct populations of this species colonized or recolonized coastal plain-like refugia after the Pleistocene glaciation. However, more studies are needed to clarify if the genus has naturally low levels of genetic variation (Watson et al. 2002).

Population ecology of species (negative interactions)

A smut fungus (or what was likely a smut fungus) has been observed in the closely related Texas pipewort (*Eriocaulon texense*) and flattened pipewort (*E. compressum*) (Kral 1966). A smut fungus is a type of pathogen that infects species of the grass and sedge families, like sugarcane and papyrus (Deacon 2005). Both the grass and sedge families are members of the Poales Order, as is *Eriocaulon*. Another kind of fungus, a type of sac fungus (*Curvularia eragrostidis*), has been found on spherical pipewort (*Eriocaulon sedgwickii*), an India species (Kore 2012). At least one other species of *Curvularia* has been documented in the United States, but on the grass zoysia (Roberts and Tredway 2008). No occurrence of either fungus has been documented on small-headed pipewort.

Small-headed pipewort showed no significant increase in seedling establishment from the seed bank after disturbance (Watson et al. 1994). However, with artificial seeding, the disturbance studies did show that clipping (simulated grazing) or burning significantly increased the number of seedlings established (Watson et al. 1994). This suggests that small-headed pipewort is a poor competitor and establishes more readily in open areas without other vegetation or litter (Watson et al. 1994). Another pipewort, the seven-angle pipewort, has been shown to persist on open, disturbed sandy soil habitat and is a poor competitor (Wilson and Keddy 1986).

Japanese honeysuckle (*Lonicera japonica*) has been recorded at one site of small-headed pipewort (Andrew's Bog at Engeling Wildlife Management Area (WMA). Japanese honeysuckle's evergreen/semi-evergreen nature, ability to girdle other plants, dense growth pattern, and competitive root growth enable the plant to out-compete other species (National Park Service 2009).

Land ownership and management

Three extant populations of small-headed pipewort occur on state land owned by Texas Parks and Wildlife. The remaining seven extant sites occur on private property. Plants seem to be tolerant of some amount of disturbance, but type and frequency is unknown (see Special Management Considerations section). Fire has been suggested as a potential management tool to maintain populations (MacRoberts and MacRoberts 2005).

At least one site on private property (Arc Ridge Ranch) had previously been a bog, but has reportedly been converted into a pond over time by beaver damming. In 2001 and 2002, 11 to 21 plants were located at this site. The site has not been burned in recent decades (MacRoberts and MacRoberts 2005).

Another privately owned site (Limestone) has undergone a considerable amount of disturbance including encroachment by hay crops and weedy forbs, grazing, bush hogging, and draining (MacRoberts and MacRoberts 2005). This site was visited in 1999 and 2005, but no plants have been found since 1995 (MacRoberts and MacRoberts 2005). The New York site is heavily grazed and the bog where small-headed pipewort occurs is highly disturbed (MacRoberts and MacRoberts 2005). Only three plants were found the one year this site was surveyed (MacRoberts and MacRoberts 2005).

Small-headed pipewort occurs at three bogs on the state-owned Engeling Wildlife Management Area. The WMA is currently grazed, but not near any of the bogs (Slack 2014). The bog has been burned since at least the 1970s to reduce woody vegetation (Lodwick n.d.a) and to increase plant and animal diversity (Slack 2014). Today, Engeling WMA conducts prescribed burns every 3-5 years, and attempts to light small, disjunct fires to decrease impact on non-fire tolerant species (Slack 2014). All bogs dry enough to burn are included in these burned areas.

Counts of two privately-owned sites resulted in low numbers of plants at both sites (3 plants), although one (Baker Lake) had been burned and the other (Black Hillside) had not (MacRoberts and MacRoberts 2005). Other reports of regularly prescribed burns at Engeling WMA indicate plants were “abundant after fire” although no pre-fire counts were made (MacRoberts and MacRoberts 2005).

Evidence of threats to survival

Because small-headed pipewort occurs in a mesic habitat, draining of sites is a potential threat (Kral 1983). Studies show that burning or artificial grazing in combination with seeding increases germination, which may indicate that the plant is a poor competitor (Watson et al. 1994). It has been suggested that the plant is sun-loving and prefers disturbance (Kral 1966). However, too much disturbance can be detrimental to small-headed pipewort sites. Heavily disturbed sites (by overgrazing), like the Limestone site, have shown a decline in the plant population (MacRoberts and MacRoberts 2005). The Limestone site was also recorded to have creeping eryngo (*Eryngium prostratum*), a species not usually found in bogs, but not blueflower eryngo (*Eryngium integrifolium*), a species commonly found in bogs (MacRoberts and MacRoberts 2005). These plants indicate an overall change in the habitat at this site. Disturbance by hogs at the Engeling WMA may also decrease population numbers (MacRoberts and MacRoberts 2005). Kral suggested that management practices involving heavy machinery or soil movement could destroy populations (Kral 1983). Invasion by non-native and/or weedy species into small-headed pipewort habitat could decrease numbers. Two sites (Engeling WMA, Limestone) were recorded to have non-native, invasive plants (Japanese honeysuckle at Engeling WMA and introduced forage grasses at Limestone) (MacRoberts and MacRoberts 2005). The decline of some Oklahoma and Texas populations may be because of fire suppression (Watson et al. 1994; MacRoberts and MacRoberts 2005). The Enchanted Rock site is within a few meters of one of the park’s main hiking trails and foot traffic, although not an observed problem, is a potential threat (Singhurst 2007). Biological factors which may be contributing to small-headed pipewort's rarity include low seed set and seed bank germination rates in situ, and lack of genetic diversity (Watson et al. 2002).

Special management considerations

In 1996, TPWD outlined management and monitoring ("action") plans for some of the tracked rare plants in the state (Candee 1996). Small-headed pipewort was included in these plans and was deemed a medium-high priority plant, due to its small populations, few occurrences (five were known at the time) and threat from development (Candee 1996). Recommendations for monitoring small-headed pipewort sites were delineated (Candee 1996). At each site, populations should be permanently mapped, marked, counted, and measurements of vigor, like height, should be recorded (Candee 1996). Monitoring could also include observations of herbivores, reproductive output, and/or recruitment (Candee 1996). Ideally, one site at Engeling and another outside of Anderson County should be selected for monitoring (Candee 1996). Also sites should be selected to show different habitat types and possible threats to the population (Candee 1996). An unacceptable decline in population numbers and vigor (20%) was assigned for two consecutive years (Candee 1996); however, this percentage was chosen for all species within the report because it was seen as a reasonable rate of change for species where information is lacking. The purpose of a management plan is to establish if these are in fact appropriate rates of change for small-headed pipewort.

A monitoring plan could establish a protocol to regularly and systematically count small-headed pipewort. A plan will help outline the successes and failures of past attempts and direct future efforts. Integrating monitoring with different types of management in a formal plan is appropriate for all species because different management will likely affect plant population health differently. In order to track if management is not negatively affecting population health, an appropriate rate of change is also required. To assess if this rate is appropriate, more monitoring under consecutive years of the same management is necessary. To effectively manage small-headed pipewort, management decisions and changes should be recorded along with population health and status.

Effective monitoring of small-headed pipewort requires permanent, long-term transects to detect real demographic trends. Although several sites at Engeling WMA were monitored from 1999 to 2002, no monitoring has been conducted since. Plant numbers decreased over the four years of monitoring a subset of the Engeling WMA site (MacRoberts and MacRoberts 2005). However, at the population level, more data than what are available is required to detect a real change, especially because small-headed pipewort is an annual. After the project was complete, it was recommended that hog and/or livestock removal or fencing in addition to prescribed fires be conducted (MacRoberts and MacRoberts 2005). Fencing has not been erected and fire frequency at the small-headed pipewort sites has not been recorded. If fencing and/or fires are appropriate management is unknown.

Because of the small size and inconspicuous nature of this plant, surveys must be conducted during the flowering season May through July. Additional surveys where habitat is present may identify more small-headed pipewort sites (MacRoberts and MacRoberts 2005). Surveying during drought years may result in decreased numbers of plants or populations (Chafin 2007). Although drought may have impacted the small-headed pipewort population numbers (no plants were found) during the 2014 and 2015 surveys at Enchanted Rock, it is not exactly clear why plants were not found (Strong and Singhurst 2014; Strong 2015).

The large number of populations on private land calls for more attention to be paid to appropriate management of these sites. Management conducted on public land should be assessed before and after activities are initiated.

To date, demographics, habitat requirements, reproductive system, and disturbance tolerance has been studied at least for Oklahoma populations. However, demographic information is sparse for Texas populations and disturbance tolerance needs to be fully fleshed out for the species as a whole.

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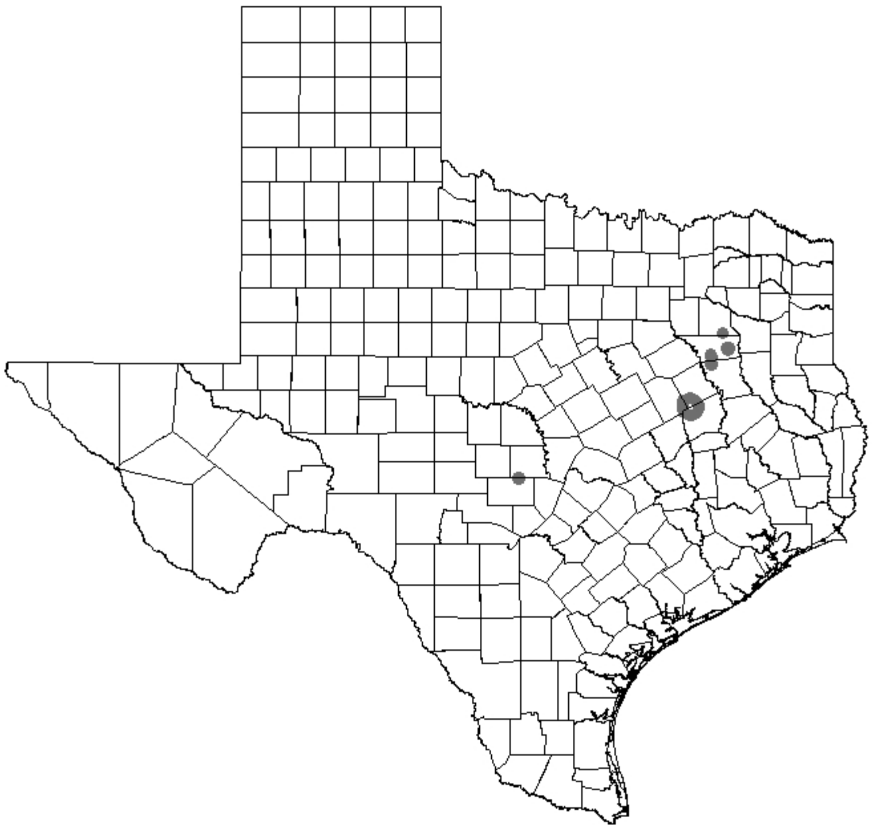
Table 1. Small-headed pipewort population status, including location and ownership (Texas Natural Diversity Database 2014).

<table>
<tr><th>County</th><th>Year discvrd</th><th>Last year seen</th><th>EO ID+</th><th>Site Name</th><th>Landowner</th><th>Min. # per 1 subpop.++</th><th>Max. # per 1 subpop.++</th><th>Notes</th></tr>
<tr><td colspan="9">Extant Sites</td></tr>
<tr><td>Limestone</td><td>1979</td><td>1995</td><td>7421</td><td>Limestone</td><td>private</td><td>0 (1999)</td><td>7-8 plants (1995)</td><td>1999: found no associated species, heavily disturbed</td></tr>
<tr><td>Anderson</td><td>1990</td><td>2002</td><td>2783</td><td>Engeling WMA - Andrew's Bog</td><td>TPWD</td><td>0 (1998)</td><td>~2,500 (1999)</td><td></td></tr>
<tr><td>Leon/Freestone/ Limestone</td><td>pre-1985</td><td>pre-1985</td><td>5169</td><td>Jewett Mine</td><td>private</td><td>present (pre-1985)</td><td>0 (1992)</td><td></td></tr>
<tr><td>Gillespie</td><td>1993</td><td>2007</td><td>8099</td><td>Enchanted Rock</td><td>TPWD</td><td>0 (2015)</td><td>~1,000 (1996)</td><td></td></tr>
<tr><td>Henderson</td><td>1999</td><td>*</td><td>2537</td><td>Baker Lake</td><td>private</td><td colspan="2">3 (1999)</td><td></td></tr>
<tr><td>Anderson</td><td>2001</td><td>2002</td><td>9382</td><td>Engeling WMA - Dale's Bog</td><td>TPWD</td><td>0 (2002)</td><td>5 (2001)</td><td></td></tr>
<tr><td>Henderson</td><td>2010</td><td>*</td><td>9418</td><td>private</td><td>private</td><td colspan="2">2,067 (2010)</td><td></td></tr>
<tr><td>Van Zandt</td><td>2001</td><td>2011</td><td>9419</td><td>Arc Ridge Ranch</td><td>private</td><td>11 (2011)</td><td>20 (2001)</td><td></td></tr>
<tr><td>Henderson</td><td>2000</td><td>*</td><td>9420</td><td>Black Hillside Bog</td><td>private</td><td colspan="2">3 (2000)</td><td></td></tr>
<tr><td>Henderson</td><td>2001</td><td>*</td><td>9421</td><td>New York</td><td>private</td><td colspan="2">3 (2001)</td><td></td></tr>
<tr><td colspan="9">Historic Sites</td></tr>
<tr><td>Brazos</td><td>1946</td><td>1947</td><td>3203</td><td>Wellborn</td><td>unknown</td><td>present (1946)</td><td>present (1947)</td><td></td></tr>
</table>

+EO ID is the unique number assigned to a new record (element occurrence) in the Texas Natural Diversity Database. An element occurrence is an area of land where a species resides/resided (i.e., a population). A population can consist of one or more subpopulations.
++ represents number of individuals recorded in any year at a subpopulation; each count is based on surveyor effort and is only as good as the effort expended (e.g., zeros could be false negatives; larger numbers, such as >#, #s, #+, could be gross under- and overestimates)
*only accessed one year

Figure 1. Distribution of extant populations of small-headed pipewort (*Eriocaulon koernickianum*).



Brush-pea

(*Genistidium dumosum*)

Species information (history of knowledge of taxon)

The first collection of brush-pea was made in 1940 by Johnston and Muller (#944, GH) in Coahuila, Mexico. Johnston subsequently described brush-pea as *Genistidium dumosum* in 1941 from his 1940 collection (Johnston 1941). The earliest specimen to be collected in Texas (Brewster County) still residing in herbaria is from September 14, 1947 Cyrus Lundell (#14765, LL). However, two separate sources (Turner 1977; Warnock 1977) state that specimens were being collected in Brewster County as early as 1940 or 1941.

Present legal status (National and State)

Although not listed as endangered or threatened by the State of Texas, brush-pea is ranked as a G1 (a critically imperiled species) by NatureServe. The species is also listed on Texas Parks and Wildlife Department's 2010 List of the Rare Plants of Texas and as a Species of Greatest Conservation Need in the Texas Parks and Wildlife Department (TPWD) State Conservation Action Plan.

In 1980, brush pea was designated by the United States Fish and Wildlife Service (USFWS) as a Category 1 Candidate species (U.S. Fish and Wildlife Service 1980), a species which had sufficient biological status and threat information, but because of the large number Category 1 Candidate species listing was delayed. In 1983, brush-pea was re-designated as a Category 2 Candidate, a species which was "possibly appropriate" to list, but more biological and threat information was needed to determine the status as endangered or threatened (U.S. Fish and Wildlife Service 1983). 1n 1993, a status trend designation was added, which classified brush-pea as "stable". A stable status trend was defined as "a species known to have stable population numbers in the recent past and/or for which threats have remained relatively constant" (U.S. Fish and Wildlife Service 1993). However, in 1996, to allow USFWS to focus on protecting the many species for which sufficient information was available, all Category 2 Candidates were dropped from the list (U.S. Fish and Wildlife Service 1996). Brush-pea mistakenly did not appear in this notice, but it was dropped from the Endangered Species list. In 2009, a 90-day finding was announced for 67 species from a petition to list 475 in the southwestern United States as threatened or endangered (U.S. Fish and Wildlife Service 2009). Scientific, commercial, and other information was requested and available information was summarized by the USFWS. The petition presented scientific information to indicate that listing may be warranted for brush-pea (U.S. Fish and Wildlife Service 2009). In their summary, the USFWS presented threat factors, which can be used to assess if a species may warrant listing as endangered or threatened, for brush-pea: A (present or threatened destruction, modification, or curtailment of its habitat or range), B (overutilization of species for commercial, recreational, scientific, or educational purposes), and E (other natural or manmade factors affecting species' continued existence) (U.S. Fish and Wildlife Service 2009). These threats were based on past and future road construction, erosion, and recreational activities occurring on private land nearby (A), collection pressure (B), and low population numbers and recruitment (E).

Description (local field characters)

The following description is based on treatments by Johnston (1941), Vines (1960), Powell (1988), Lavin and Sousa (1995), Henrickson (2004), and Poole et al. (2007). Brush-pea is an erect to ascending 1 meter tall bush with multiple, unarmed, stems arising from a swollen basal stem. Stems are slender and wiry with pubescent, young, green growth and hairless, old, olive-green growth. The alternate leaves have long, soft hairs and are mostly trifoliate, but can be solitary. Terminal leaflets of trifoliate leaves are slightly longer [5-20 (-25) mm long, 2-6 (-8) mm wide] with slightly longer petioles (1-4 mm long). Linear to oblanceolate leaflets are entire, hairy and have a midrib which extends beyond the blade into a short, abrupt point. Stipules (1-2 mm long) are slender and taper to a point. Flowers are axillary and either solitary or in pairs on the upper portion of the branches. The calyx is bell-shaped with a 2.5-3.5 mm long tube and narrowly triangular lobes (3-4 mm long). The flowers are papilionaceous with a larger upright banner petal, two lateral petals (wings), and a smaller keel, consisting of two fused petals. The flowers are mostly yellow with a greenish nectar guide on the banner and a yellowish to white keel. The banner petal is almost circular (6-8 mm long, 6-8 mm wide) and clawed, the wings are lunate-oblong (6-7 mm long) and clawed, and the keel is bluntly lunate (5.5-6.5 mm long). Nine of the ten filaments are fused at their base, the tenth is separate. The fruit has long, soft hairs and is linear (1.5-3 cm long, 4-6 mm wide) and splits on both sides to release 1-6 nearly round seeds (1.5-3 mm in diameter). The seeds are light brown with purplish mottling at maturity.

Although easy to distinguish when in bloom or with fruit, Trans-Pecos poreleaf (*Porophyllum scoparium*) can be confused with brush-pea when either is vegetative. However, Trans-Pecos poreleaf has linear, simple leaves, with odoriferous oil glands. In Coahuila, *Coursetia insomnifolia*, a similar-looking and closely-related legume, overlaps with brush-pea's range (Poole et al. 2007). *Coursetia insomnifolia* lacks hairs on its fruit and has four leaflets with a bristle where a terminal leaflet would occur in brush-pea (Lavin and Sousa 1995).

Geographical distribution (range and precise occurrences)

Brush-pea has been recorded in Brewster County in West Texas (see Table 1 and Figure 1), Tamaulipas, Mexico, and Nuevo Leon, Mexico (over 400 miles away from the Texas sites). Three sites in Brewster County are within a mile of one another and probably represent a single population (Reed Plateau/FM 170, NW and SE site). There is at least one other known but unmapped site on the Reed Plateau. This site(s) has not been mapped more precisely than the four square mile Plateau due to a vague label description (Powell #3339, TEX/SRSC). Outside of the much smaller area of the Reed Plateau/FM 170 site on the northwest portion of the Reed Plateau, no plants have been recently confirmed in the larger area.

Two of the three mapped Texas sites have only been seen once when they were discovered in 1990 (NW and SE sites). The Reed Plateau/FM 170 site has been visited about two dozen times since 1978. Most of these visits were conducted as part of surveys, monitoring, and seed/cutting collection trips. Other earlier visits were made, but due to vague herbarium label site descriptions, it is unknown where exactly specimens were collected.

At least three attempts have been made to locate new or relocate known sites. From 1988 to 1990 the west and southwest side of the Reed Plateau, the 38 Hill area, the limestone hills south of Terlingua Sinkhole, and limestone hills east and north of Amarilla Mountain were surveyed in preparation of compiling the status report (Poole 1992). Other areas on Big Bend Ranch State Park (limestone hills east of Contrabando Creek) and Big Bend National Park (south end of Cuesta Carlotta and limestone hills around Dagger Flat) were also surveyed (Poole 1992). The work done during Wendy Weckesser's thesis (Weckesser 2008) is the only organized attempt to document the flora of the Reed Plateau and adjacent areas. The focus of the study was not brush-pea, but two specimens were collected either within or nearby the Reed Plateau/FM 170 site (Weckesser #946, #1043, SRSC). One of these specimens is speculated to be outside the area on the highway right-of-way (ROW), but where exactly these plants are at this point is unknown. During field work conducted in 2015, limestone slopes east and west of Contrabando Creek (in Big Bend Ranch State Park) and around Villa de la Mina Rd (on private property) were unsuccessfully surveyed (Strong 2015a, b). The two known sites on private property to the northwest of FM 170 (the NW and SE sites) were also surveyed for the first time since 1990, but no plants were found (Strong 2015c). This survey is not noted in Table 1 because there was limited time and another survey should be conducted to verify this finding.

General environment and habitat description (physical and biological characteristics)

As part of the Chihuahuan Desert, the Texas brush-pea site is dominated by lechugilla (*Agave lechuguilla*) and creosote (*Larrea tridentata*). The greater area has rolling, rocky limestone hills separated by plains at lower elevations. In Texas, brush-pea grows on sparsely-vegetated, eroding, gravelly/stoney ridgetops and steep slopes between 3,000 and 3,200 feet (Poole 1992). The vegetative cover at the Texas sites is less than about 35% (Poole 1992). At the Mexican sites, elevation is <5,250 feet and soils have been described as volcanic tuff or rusty-reddish brown basaltic substrate (Poole 1992; Lavin and Sousa 1995).

Associate species include catclaw (*Acacia wrightii*), living rock (*Ariocarpus fissuratus*), three-awn grass (*Aristida* sp.), wavy cloakfern (*Astrolepis sinuata*), dense ayenia (*Ayenia microphylla)*, blue grama (*Bouteloua gracilis*), fairy duster (*Calliandra conferta*), strawberry cactus (*Echinocereus stramineus*), boundary ephedra (*Ephedra aspera*), candelilla (*Euphorbia antisyphilitica*), ocotillo (*Fouquieria splendens*), guayacan (*Guaiacum angustifolium*), false agave (*Hechtia texensis*), Torrey heliotrope (*Heliotropium torreyi*), leatherstem (*Jatropha dioica*), shorthorn jefea (*Jefea brevifolia*), range ratany (*Krameria parvifolia*), Emory mimosa (*Mimosa emoryana*), brown-spined prickly pear (*Opuntia phaeacantha*), blind prickly pear (*Opuntia rufida*), resurrection plant (*Selaginella lepidophylla*), narrowleaf moonpod (*Selinocarpus angustifolius*), plume tiquilia (*Tiquilia greggii*), tridens (*Tridens* sp.), Spanish dagger (*Yucca torryei*), and spinyleaf zinnia (*Zinnia acerosa*) (Poole 1992). Two other rare cacti co-occur at the brush-pea site: white column cactus (*Escobaria albicolumnaria*), a G2G3, and Boke's button cactus (*Epithelantha bokei*), a G3. Both of these plants are part of TPWD's list of

Species of Greatest Conservation Need.

The Brewster County brush-pea site is hot and dry much of the year. Precipitation in the area is highest from June to October, with an annual average of 12.1 inches (National Oceanic and Atmospheric Association 2015). Average maximum temperatures can reach 100°F and above for a month and a half May to July (National Oceanic and Atmospheric Association 2015). Average maximum temperatures of 97°F to 99.9°F are observed for another three months.

Brush-pea is found on Buda Limestone and Del Rio Clay-undivided and Santa Elena Limestone-Sue Peaks-Del Carmen Limestone-Telephone Canyon Formations-undivided. Soils of brush-pea include Geefour silty clays and Mariscal-Rock outcrop complexes. Geefour silty clays are formed from eroded, gravelly sediments over clayey soil weathered from mudstone (Natural Resources Conservation Service 2015). Mariscal-Rock outcrop complex is eroded from flaggy limestone. The Reed Plateau is composed mostly of Blackgap-Rock outcrop and Geefour silty clays complexes (Natural Resources Conservation Service 2015). Blackgap-Rock outcrop is from gravelly soil with some eroded sediment weathered from limestone (Natural Resources Conservation Service 2015).

Population biology of taxon (demography, phenology, and reproductive biology)

Comparing population trends among years is difficult because site counts have involved different amounts of surveying effort (surveying can cover different areas) and location information can be imprecise. Plant presence at known sites likely fluctuates depending upon how researchers have defined an individual plant. However, with the available data, some generalizations can be made.

A site near FM 170 has been known since the late 1940s. Some older specimens give indication of population numbers, although many have vague directions and where exactly these plants are is unknown. Barton Warnock collected two specimens in 1947 (#7585, LL) and 1949 (#1161, TEX) stating that plants were “infrequent” or “rare”. However, when Billie Turner first saw a population in 1948 “several hundred” plants were observed (Conner 1979). Even in more recent years, the site has never been fully mapped and its entire extent is not known. However, from 1979 to 2015, the Reed Plateau/FM 170 brush-pea site has been visited over twenty times. It is a small, localized population across an estimated five acres (Poole 1992) and as of 2015 was persisting (Poole 2015a, Strong 2015d). In addition to the plants closer to the highway, Powell collected a specimen in 1978 “at the head of a canyon” on the Reed Plateau, with an estimated 100 plants (#3339, TEX). This site has not been relocated. Two other sites on the north side of FM 170 were discovered in 1990 and have not been refound since. These two sites had 4 plants on <1 acre of land (SE site) and 21 plants on about 2 acres of land (NW site) (Poole 1992). In 2015, these sites were revisited and no plants were found; however, there was limited time for the survey and should be revisited before a concrete finding of no plants is stated (Strong 2015c). In 1992 all known Texas sites (Reed Plateau/FM 170, NW and SE) were estimated to have 48 plants (Poole 1992).

From 1991 to 1994, three years of monitoring data were collected from 16-23 plants at the Reed Plateau/FM 170 site. Data collection occurred in September or October and included plant height and width and presence/absence of reproductive structures (Poole and Janssen 1997). Over the three monitoring years, the plants did not vary much in size. Although there was some question as to what was a single individual, the largest plant seen was a meter tall (1.05 meters) and a meter and half wide (1.55 meters). Average height of an individual across all three years was 0.8 +/- 0.2 meters and average width ranged between 1.1+/-0.6 and 1.2+/-0.7 meters. The monitoring plot had only mature individuals (Poole 1992). In fact, no other stage class of plants has ever been observed.

In 1991, when the monitoring occurred in October, 56% of the plants were reproductive (flowering vs. fruiting was not differentiated) (Poole and Janssen 1997). In 1993 and 1994, when brush-pea was monitored in September, 0.05-33% of the plants were reproductive (Poole and Janssen 1997). According to the various specimens and surveys conducted, brush-pea blooms from April to October and fruits from August to October; however, Poole (1992) states that brush-pea has been observed in bloom in April and November and that flowering/fruiting is likely opportunistic. In Coahuila, specimens have been collected with flowers as early as March (Lavin and Sousa 1995). As with many desert plants, flowers may follow rains. At least once "several hundred fruits per plant" was observed in October (NW site) (Poole 1992). Fruits collected in 1996 contained a single mature seed and two or three aborted ovules (Rice 1996). Brush-pea is alone in its group (the Robinia-group, which includes *Coursetia, Genistidium, Olneya, Peteria, Robinia* and *Sphinctospermum*) in its low production of 4-6 ovules (Lavin and Sousa 1995).

Monitoring efforts show that the species could be clonal and therefore difficult to count (Poole 1992). Monitoring notes indicate that some individuals, even though they were treated as one plant, could have been more than one plant (Poole 1989). In a couple of cases, plants were considered one genetically distinct individual but the term "clump" was used (Poole 1989). Again this likely indicates that there is some question as to what is an individual brush-pea plant.

Seed dispersal has not been observed, but rainfall, ants and/or small mammals may disperse seeds (Poole 1992). However, one explanation for difficulty in collecting mature seed was rapid fruit dehiscence soon after maturing of seeds, creating a small window of time for collection (Ecker and Pritchett-Kozak 1991). Searching for dispersed seed has been unsuccessful in the past (Ecker and Pritchett-Kozak 1991). It was suggested that seeds could overwinter after collected seed was frozen and then germinated (Ecker and Pritchett-Kozak 1991). Pollinators have not been observed (Poole 1992).

Brush-pea belongs to a monotypic genus; that is, it is the only member of the genus *Genistidium*. Therefore, making comparisons between other species of *Genistidium* is not possible. However, recent studies show that *Peteria* is most closely related to *Genistidium* and both *Peteria* and *Genistidium* are closely related to *Olneya* and *Sphinctospermum* (Lavin 2015). *Genistidium* has solitary flowers in the axils of trifoliolate, basal leaves and has simple distal leaves, whereas *Peteria* has a terminal raceme (unbranched, short-stalked cluster of flowers along a main axis with older flowers toward the base) and extensive underground tuber-systems (Lavin and Sousa 1995). *Sphinctospermum* has simple linear leaves and seeds with a central constriction, and *Olneya* has overlapping calyx lobes and stout, recurved spinescent stipules (Lavin and Sousa 1995).

Rush peteria (*Peteria scoparia*), the only peteria in Texas, is rarely collected, but does occur in Brewster, El Paso, Jeff Davis, and Presidio counties. The closest populations of *Olneya* and *Sphinctospermum* are in southern Arizona. Desert ironwood (*Olneya tesota*), a member of the Sonoran Desert flora, flowers abundantly only about 2 years out of every 5 (Dimmitt 1999a) and in some years no flowers appear (Dimmit 1999b).

Population ecology of species (negative interactions)

Warnock reported that brush-pea "appeared to be browsed by deer" (Warnock 1970). Ecker and Pritchett-Kozak (1991) observed brush-pea fruits infested by bruchid beetle larvae. No other reports of herbivores have been recorded. However, herbarium specimens have been collected which had clipped stem tips (Lavin and Sousa 1995). Also, during Desert Botanical Garden's (DBG) propagation attempts of brush-pea, they reported observing fungal infections, fungus gnat larvae, red spidermites, black aphids, and other unknown greenhouse pests (possibly a lizard) in the greenhouse (Ecker and Pritchett-Kozak 1991; Pritchett-Kozak and Ecker 1992; Pritchett-Kozak 1993; Rice et al. 1994). Whiteflies and another unknown herbivore were observed on the plants outside the greenhouse (Pritchett-Kozak 1993). Although several of these pests are common to greenhouses, the Desert Botanical Garden propagators commented that these plants seemed "very tasty" to herbivores (Pritchett-Kozak 1993). It is unknown if plants in situ have herbivores or, and if they do, to what extent. Brush-pea's relatives are used as forage for domesticated and wild animals (Lavin and Sousa 1995). The closely related desert ironwood is one of the main forage species for mule deer in southeastern California (Marshal et al. 2004) and in Sonora, Mexico (Alcala-Galvan and Krausman 2012).

Land ownership and management

The area encompassing all known sites of brush-pea has been grazed, mined (active or inactive), and/or converted into rural residential property (Poole 1985). All sites are privately owned, except for a dozen or more plants on the highway right-of-way of FM 170. Except for the Reed Plateau/FM 170 site, land management is unknown. In 1997, management techniques at the Reed Plateau/FM 170 site consisted only of use of herbicides "on delineator posts, object markers, and signs" (Poole and Janssen 1997). There was no evidence that brush-pea was being affected by herbicide use (Poole and Janssen 1997).

As part of being the custodian for brush-pea, a Center for Plant Conservation National Collection plant, Desert Botanical Garden collected seed and cuttings of brush-pea from 1990 to 1996. Seed was collected in 1990, 1991, and 1996 and terminal and basal cuttings were collected in 1990, 1991, 1995, and 1996 (Ecker and Pritchett-Kozak 1991; Rice 1996). After being scarified with fine sand paper, mature seed had a germination rate of 66% (2 of 3 seeds) (Ecker and Pritchett-Kozak 1991). A 66% germination rate (2 of 3 seeds) was also seen with seeds that were first frozen from -18° to -20°C (Pritchett-Kozak and Ecker 1992). All of the plants that were germinated from seed had died by 1996 (Rice 1996). Attempts to keep plants alive from cuttings were ultimately unsuccessful. Cuttings collected in 1990 died by 1991 (Ecker and Pritchett-Kozak 1991), cuttings collected in 1991 had died by 1993 (Pritchett-Kozak 1993), and cuttings collected in 1995 and 1996 died by 1998 (Desert Botanical Garden 2015). However, a few plants rooted from cuttings and germinated from seed did flower (Pritchett-Kozak and Ecker 1992; Rice et al. 1994; Rice 1996). Due to the low success of rooting, collecting cuttings from the Reed

Plateau/FM 170 site was stopped (Rice 2004). Although flowering was limited, self-pollinations were attempted three times, and each time involved only a single plant (Pritchett-Kozak and Ecker 1992; Rice et al 1994). Only one plant set fruit, but ovaries were empty and the fruits eventually aborted (Rice et al. 1994). Hand cross-pollinations were conducted on <6 plants, but fruits failed to mature and eventually aborted (Rice 1996).

Propagation techniques with the most success were delineated in Pritchett-Kozak and Ecker's 1992 report. A seed germination mixture of 1:1 perlite:vermiculite had the most success although MetroMix 200 also obtained good results, but overwatering was a concern with this mix. Growing seedlings in both 2:1 Metro-Mix 300:pumice or 2:2:1 Metro-Mix 350:pumice:sand were successful (Pritchett-Kozak and Ecker 1992). Additional details about reducing damping off, rooting terminal cuttings, and protecting plants from greenhouse pests were briefly discussed (Pritchett-Kozak and Ecker 1992; Pritchett-Kozak 1993).

Two other institutions, Montana State University and Sul Ross State University, both attempted to grow brush-pea from seed, but were ultimately unsuccessful at keeping the material alive (Lavin 2015; Powell 2015). Although it is unknown why maintaining the plants was unsuccessful, seed germination was apparently 100% successful with a batch of 25-50 seeds (Lavin pers. comm. within Poole 1992).

Evidence of threats to survival

Although little is known about reproduction and recruitment of brush-pea, both are likely at least in part driven by rainfall. Given the current low levels of precipitation in the Terlingua area, additional decreases in rainfall (and possibly increases in temperatures) in association with predicted climate change may only exacerbate the low levels of recruitment.

Desert Botanical Garden made repeated attempts to collect seed of brush-pea. In each of 1991, 1998, 2000, and 2004, DBG visited the Reed Plateau/FM 170 site two to three times. Only during two of the nine visits were fruits observed (Ecker and Pritchett-Kozak 1991; Rice 2001; Slauson and Rice 1999; Rice 2005). A similar experience was had by Michael Powell, who regularly visited the Reed Plateau/FM 170 site for years in attempts to collect seed, but was only successful a couple times (Powell 2015). However, given the right conditions, a plant can produce hundreds of fruit and >50% of plants at a site can be reproductive (Poole 1992; Poole and Janssen 1997). It is unknown if these conditions are simply a rare occurrence or if lack of long-term demographic monitoring of larger populations has resulted in monitoring at the wrong times of the year. Or possibly, as suggested by desert ironwood, prolific flowering only occurs a few times a decade.

Low recruitment and aging populations could decrease genetic diversity and increase risk to the survival of this species. Warnock (1977) reported deer as a potential herbivore and Ecker and Pritchett-Kozak (1991) observed and collected fruit infested by bruchid beetle larvae on two separate occasions.

During the course of monitoring the Reed Plateau/FM 170 site from 1991 to 1994, five plants were located on or near the edge of the road cut (Poole and Janssen 1997). Early on, road expansion and erosion of the roadcut were noted as potential threats to this small population

(Poole 1985). Indeed, the road was proposed to be expanded 5 feet on both sides to smooth out curves in the highway (Clary 2003). Fortunately, Texas Department of Transportation (TxDOT) agreed to move most of the widening to the north side of FM 170 away from the brush-pea site (Rice 2005). Although assurances were given to limit disturbance, sacrifice of some plants was reported as possible (Rice 2005). During construction, a large cable was placed in the population (Rice 2005) and the road was moved much closer to the lowest plant in the population (Poole 2015b). One individual was reportedly being slowly buried due to its proximity to the road [and construction] (Alex 2004). Some time prior to October of 2007, the area was bladed, but the single plant closest to the pavement survived (Weckesser 2014).

The Terlingua area has long been known for mining and more recently for recreational use. Five active or inactive mercury mines are within half a mile of the SE, NW and Reed Plateau/FM 170 sites (US Mining 2015). One of these mines has at least doubled in size to >12 acres in surface disturbance since 1996. An additional three mines are located on the Reed Plateau within 2.5 miles of the Reed Plateau/FM 170 site (US Mining 2015).

Terlingua and the surrounding area is a tourist destination because of its proximity to Big Bend Ranch State Park and Big Bend National Park. Recreational activities, such as canoeing the Rio Grande River, are also very popular. In 1967 a local rancher started what has now become an annual chili cookoff attended by thousands of people. According to aerial imagery, the approximately 50 acre site occupied by the annual event has increased about 15 acres since 1996. The chili cookoff area is a quarter to a half mile from all three brush-pea sites.

Special management considerations

To date, population trends, demographics, habitat requirements, and reproductive information are still lacking. These studies would establish age structure, recruitment, seed biology, breeding system, effective pollinators, and pollinator habitat. Known populations need to be relocated and regularly monitored to determine phenology and status trends. A monitoring plan could establish a protocol to regularly and systematically count brush-pea. Effective monitoring of brush-pea requires permanent, long-term transects to detect real demographic trends. This is particularly true if fruit are developed sporadically or if fruits are maturing outside of the traditional time to survey (e.g., July is historically the wettest month, but few surveys have occurred during July). Because even less is known about the Mexican populations, these populations should be included in surveys and genetic studies, if possible (Poole 1992).

In 1996, TPWD outlined management and monitoring (“action”) plans for some of the tracked rare plants in the state (Candee 1996). Brush-pea was included in these plans and was deemed a medium-high priority plant, due to its small populations, few occurrences, and threat from highway expansion and maintenance activities at one site (Candee 1996). Recommendations for monitoring brush-pea sites were delineated (Candee 1996). At each site, populations should be permanently mapped, marked, counted, and measurements of vigor, like height and number of fruits or flowers, should be recorded (Candee 1996). Monitoring could also include observations of herbivores, pollinators, and/or recruitment (Candee 1996). Significant or unacceptable declines were defined as a 20% decrease in total population in two consecutive years (Candee 1996). However, this percent was chosen for all species within the report, likely because 20% was seen as a reasonable rate of change when information is lacking. To date, population trends, demographics, and reproductive information is still lacking and studies to alleviate this lack of information should be conducted.

Integrating monitoring with different types of management in a formal plan is appropriate for all species because individually developed management options will likely affect plant population health differently. In order to track if management is not negatively affecting population health, an appropriate rate of change is also required. To effectively manage brush-pea, management decisions and changes should be recorded along with population health and status. Management conducted on public land should be assessed before and after activities are initiated. The only known publically-owned site of brush-pea is on highway ROW and should be monitored for increased erosion (Poole 1992) and any detrimental TxDOT maintenance (e.g., herbicide use and other road work). Some utilities have a legal right to be placed on the TxDOT ROWs (Texas Department of Transportation 2013). Due to this, it is difficult to avoid habitat disturbance or population destruction during utility siting, construction, and maintenance.

Surveying for brush-pea sites is a priority. Only three attempts have been made to locate new sites or relocate known sites of brush-pea. In 1990, Jackie Poole discovered two sites by gaining access to private land. In 2006/2007, Wendy Weckesser gained access to several private properties on the Reed Plateau. This was the last comprehensive survey conducted. In 2015, access was gained to the two sites northwest of FM 170, but another more extensive survey is required to hopefully relocate these sites on private property. Locating and contacting landowners on and around the Reed Plateau may lead to additional brush-pea sites or the relocation of previously described sites by Weckesser (#1043, SRSC) and Powell (#3339, SRSC/TEX).

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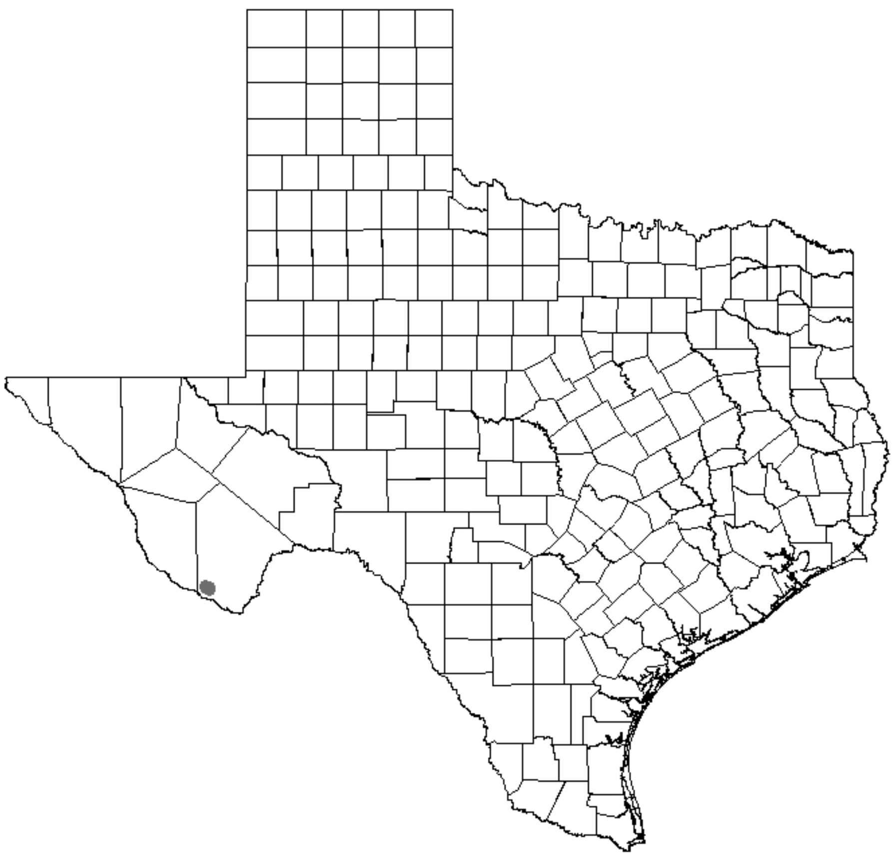
Table 1. Brush-pea population status, including location and ownership (Texas Natural Diversity Database 2015). A population can consist of one or more subpopulations; the below sites are considered one population.

County	Year discvrd	Year last seen	Site name	Landowner	Min. # per 1 subpop.+	Max. # per 1 subpop.+
Brewster	1990	*	NW	private	21	
Brewster	1990	*	SE	private	5	
Brewster	1948	2015	Reed Plateau/ FM 170	TxDOT/private	6-7 (1977)	"several hundred" (1948)

+ represents number of individuals recorded in any year at a subpopulation; each count is based on surveyor effort and is only as good as the effort expended
*only seen one year

Figure 1. Distribution of extant populations of brush-pea (*Genistidium dumosum*).



Shinner's sunflower

(*Helianthus occidentalis* ssp. *plantagineus*)

Species information (history of knowledge of taxon)

Shinner's sunflower was described in 1842 by John Torrey and Asa Gray from a Thomas Drummond specimen (#99, GH, 1833 or 1834, Austin County) collected in Texas (Torrey and Gray 1842). In August 1843, Ferdinand Lindheimer collected a specimen (#98, MO and GH) from "O[y]ster Creek bottom 40 miles" south of Houston, which indicates that the specimen was collected in Brazoria County. Charles Wright collected during expeditions throughout Texas between 1848 and 1852, and although the exact year and location were not recorded, a specimen of Shinner's sunflower was collected in Texas (s.n., GH). At least 70 years later, C. C. Albers collected a specimen in September of 1923 from Brenham, Texas, which is in Washington County (s.n., BRIT). No Shinner's sunflower has been re-located in either Brazoria or Washington counties since these initial collections, but several sites have been collected from Austin County since the first Drummond specimen.

After describing Shinner's sunflower as *Helianthus occidentalis* var. *plantagineus* in 1842, Elba Emanuel Watson elevated it to *Helianthus plantagineus* based on morphological differences of the leaves, leaf hairs, bracts, and achenes (Watson 1929). However, in 1969 Charles Heiser reduced the species to a subspecies (*Helianthus occidentalis* ssp. *plantagineus*) due to its geographical isolation from western sunflower (*Helianthus occidentalis* ssp. *occidentalis*) (Heiser 1969). He stated that morphologically the two subspecies differed only slightly (Heiser 1969). *Helianthus occidentalis* ssp. *plantagineus* is still the currently accepted name.

Present legal status (National and State)

Although Shinner's sunflower is not listed as threatened or endangered by the State of Texas, the species is ranked as imperiled (or S2) in the state and is on Texas Parks and Wildlife Department's (TPWD) 2010 List of the Rare Plants of Texas and as a Species of Greatest Conservation Need in the Texas Parks and Wildlife Department (TPWD) State Conservation Action Plan. It is also ranked as a Sensitive Species by the United States Forest Service. Shinner's sunflower has a NatureServe rank of G5T2T3, a rank that indicates that the exact status (T rank) of the subspecies (*plantagineus*) is uncertain, but that it is globally either imperiled or vulnerable across its entire range. Of the many factors analyzed to determine a taxon's status, G rank (global rank of the species) and T rank (global rank of the subspecies) are partially determined by how many extant populations exist. The categories for number of extant populations are 1-5 (G1/T1), 6-20 (G2/T2), 21-80 (G3/T3), 81-300 (G4/T4), and over 300 (G5/T5) (Master et al. 2012).

In 2011, a 90-day finding was announced by the U.S. Fish and Wildlife Service (USFWS) on 374 species from a petition to list 404 in the southeastern United States as threatened or endangered. The petition presented scientific information to indicate that listing may be warranted for Shinner's sunflower (U.S. Fish and Wildlife Service 2011). Available information was summarized by the USFWS, but additional scientific, commercial, and other information was requested. Of the five threat factors, which can be used to assess if a species may warrant listing as endangered or threatened, the USFWS listed A (the present or threatened destruction, modification, or curtailment of its habitat or range) and D (inadequacy of existing regulatory mechanism) for Shinner's sunflower (U.S. Fish and Wildlife Service 2011).

Description (local field characters)

The following description is adapted from Heiser (1969), Schilling (2006), and Marsh and Golden (1996). Shinner's sunflower is a 60-150 cm tall perennial often with reddish stems. Basal leaves are oval to egg-shaped or oblong-lance-shaped and 5-20 cm long and 1.5-7 cm wide. Basal leaves have 2.5-10 cm long "stems" (petioles). Leaves along the stem are smooth, are usually smaller than basal leaves, and occur in 1-4 opposite, well-developed pairs. There are typically 1-4 (-12) flower heads, which can be 2-3 cm in diameter. The 20-25 phyllaries (leaf-like structures under the flower heads) are lance-shaped, 1-5-2.5 mm wide, appressed, and have no glands on their undersurface. The 8-14 ray florets are yellow and 18-22 mm long. The 50+ disc florets have yellow lobes and are 4.5-5.5 mm long. The fruit is 3-4 (-5) mm long.

According to *Helianthus* experts, identification can be challenging from dried specimens and complications arise from hybridization among this group of plants (Schilling 2013). A dozen other *Helianthus* species overlap in range with Shinner's sunflower, but four more frequently overlap. All four species have many leaves on the stem, as opposed to Shinner's sunflower, which mostly has basal leaves and only a few pairs of opposite leaves on the stem. Swamp sunflower (*Helianthus angustifolius*) has narrower leaves [0.15–0.5(–1) cm]. Common sunflower (*H. annuus*) has larger [13–25 × (3–) 5–8 mm] ovate to lance-ovate phyllaries. Beach sunflower (*H. debilis*) has green stems and usually has reddish (but sometimes yellow) disc florets. Maximilian sunflower (*H. maximiliani*) has alternate leaves on the stem and 30-40 phyllaries with glands on the under surface of the phyllaries. Slender rosinweed (*Silphium radula* var. *gracile*) can also be confused with Shinner's sunflower. It has green stems and broad leaf-like phyllaries.

Significance

Shinner's sunflower is closely related to the cultivated sunflower (*Helianthus annuus*, the same species as the common sunflower) and can be hybridized with it to improve the cultivated sunflower's fitness. Shinner's sunflower has been crossed with cultivated sunflower to study the resulting hybrid's ability to resist *Sclerotinia*, a fungus which commonly infects cultivated sunflowers (Liu et al. 2012). The rubber (Stipanovic et al. 1980) and methanol content (Adams and Seiler 1984) of Shinner's sunflower have also been studied, but no recent articles on these topics seem to be available. The cultivated sunflower (*Helianthus annuus*) is grown for its seeds and vegetable oil content on over 22 million hectares worldwide (Sala et al. 2012). Although not complete yet, the entire genome of the cultivated sunflower is in the process of being sequenced. Over 80 flowering plant species have had their entire genome sequenced, and this will be one of the first Sunflower Family (Asteraceae) species to be sequenced (CoGePedia 2015). Sequencing the genome will help to improve research on the plant as a crop and as a biofuel (Genome British Columbia 2015). However, more recent reports suggest that biofuels overall are much less efficient at transforming sunlight into energy than solar power (Searchinger and Heimlich 2015). Also, according the National Sunflower Association, sunflower oil as biofuel may be cost prohibitive due to the food processing industry demands (National Sunflower Association 2015a).

Geographical distribution (range and precise occurrences)

Shinner's sunflower occurs in Arkansas, Louisiana, and Texas. Nineteen counties in south and southeast Texas have been recorded to have populations (see Table 1). In this report, following the 2010 List of the rare Plants of Texas, historic populations are those which have not been seen for over 50 years. Extant populations have been observed in the last 50 years. Extant populations occur in Austin, Bastrop, Caldwell, Colorado, Fayette, Harris, Kleberg, Lavaca, Lee, Newton, Victoria and Waller counties (see Figure 1). Historically (pre-1965), Shinner's sunflower occurred in Brazoria, De Witt, Dimmit, Goliad, Jackson, Matagorda, and Washington counties.

Specimens have been collected from over 40 sites, one as early as 1833 or 1834 (See Table 1). About a third of these sites could not (locality description vague) or have not been relocated in the last 50 years and are considered historic. These 18 historic sites have label descriptions that are largely too vague to ever relocate. However, three of these specimens have at least mileage and city noted (e.g., "ca. 8 miles north of Olivia"). But considering roads are not named and an exact starting point is not stated, these sites may never be relocated exactly (Shinners, #26583 & #26501, BRIT; Correll #14150, LL).

Although quite a few sites have been collected from and/or visited, only nine sites are known to have ever been revisited (Delhi, E of Flatonia, NE of Hope, Prairie View A&M, Rosanky, San Bernard, Siecke State Forest, W of Delhi, W of Waller). Seven sites found between 1973 and 1988 were relocated between 2000 and 2014 (Rosanky, Delhi, W of Delhi, San Bernard, NE of Hope, Siecke State Forest, and W of Waller). The remaining two revisited sites were observed (with plants present) prior to 1995 (E of Flatonia and Prairie View A&M). Thirty-one extant sites have been visited in the last 50 years: 1965-1979 (5 sites), 1980-1989 (9 sites), and 1990-1999 (2 sites). The remaining fifteen sites were seen from 2000 to 2014.

A couple locations of Shinner's sunflower are based on erroneous data. One specimen on the Plant Resources Center's Flora of Texas Database identified as Shinner's sunflower (Bruce s.n., TEX) has been annotated to *Helianthus annuus* (Wendt 2013). Turner et al. (2003) recorded Shinner's sunflower in Smith County, but this is incorrect (Turner 2013). This was repeated in the 2010 *List of the Rare Plants of Texas* (Poole et al. 2010). Additionally, the 2010 list does not include occurrences in Brazoria, Harris, and Kleberg counties. The specimens collected in these counties had probably not been located, because they had not been entered into easily-accessible online herbarium databases.

In 2013, several sites were visited to attempt to relocate Shinner's sunflower. All site locations were based on specimen descriptions. One site in Caldwell County (SH 304 - Chavez and Chavez, #PIC-BG1, TEX) "on" the highway was searched unsuccessfully in November (Carr

2013a), although other nearby sites had plants with dried flowering stalks. A site in Kleberg County (Kleberg - Churchill #90-1219, BRIT) and a site in Waller County (Prairie View A&M - Tveten #B-56D, SBSC) were also surveyed in 2013 with negative results (Strong 2015). Additional sites were searched in 2013 [E of Goliad, NNW of Waller, Prairie View A&M (Turner #2915, SMU)], but specimen label information was either too vague or the interpretation of the label was incorrect or surveys were not thorough enough.

General environment and habitat description (physical and biological characteristics)

The species has been documented in "cutover sandy longleaf pine savannah", "coastal prairie swales", "former coastal prairie", "barrens in partial shade of open post oak woodlands", and "ungrazed, unplowed right-of-ways" (Orzell & Bridges #11018 TEX; Singhurst #15714 BAYLU; Carr #22203, #32214, #19158 TEX). When the plant occurs within woodlands, it seems to occur on open edges with an open or absent shrub layer, although the lower graminoid layer can be thick to sparse (Carr 2013a). In Arkansas, the densest populations of Shinner's sunflower were in full sunlight (Marsh and Golden 1996). In Texas Shinner's sunflower populations map to various geologic formations including Queen City Sand, Reklaw, Manning, Wellborn, Catahoula, Oakville, Fleming, Lissie, Willis, Goliad and Beaumont. Soils in Texas vary due to the species widespread distribution and have been recorded as dry sandy loams to loamy sands to sandy clay loams. Although over two dozen soil associations are represented in the locations across east and southeast Texas, Flatonia loam, Hockley fine sandy loam, Patilo fine sand, Segno fine sandy loam, Straber loamy fine sand and loamy sand, Tremona loamy fine sand, Telferner fine sandy loam, and Wockley fine sandy loam are more frequently encountered under known populations of Shinner's sunflower (Soil Survey Staff et al. 2014). Rainfall in the 19 Texas counties where Shinner's sunflower occurs ranges from 20"-24" in Dimmit County to 56"-60" in Newton County (National Oceanic and Atmospheric Administration 2014). However, most collections are from areas with above 32" of rain annually.

Few associate species have been noted for any Shinner's sunflower sites in Texas except during seven of the more recent surveys (2003-2013). However, during these surveys little bluestem (*Schizachyrium scoparium*) was the most commonly encountered associate species (seen at five of the seven sites). Otherwise, only four species have been seen at more than one site. These associates include woolly croton (*Croton capitatus*), yaupon (*Ilex vomitoria*), brownseed paspalum (*Paspalum plicatulum*), and post oak (*Quercus stellata*). One rare species, branched gayfeather (*Liatris cymosa*), was seen co-occurring at a Lee County site (Singhurst and Creacy 2006).

Population biology of taxon (demography, phenology, and reproductive biology)

In the few cases it has been documented, the distribution of individual plants within populations of Shinner's sunflower can be patchy and either rare or frequent. Few estimates of population counts have been made and some are grossly qualitative (small, medium, or large). In the few instances where counts were taken, populations ranged from 22 rosettes to 300-400 rosettes (Carr 2013a). However, due to the underground runners, which give rise to new rosettes (Marsh and Golden 1996), it is nearly impossible to estimate how many genetically different individuals are present. One observer recorded that "flowering stems are usually connected by stolons to several small rosettes surrounding the parent plant" (Marsh and Golden 1996). One survey estimated approximately ten plants in a 7 m^2 area, although rosettes were seen throughout the whole area (Carr 2013b). This estimate was likely a guess on the author's part.

Due to a general lack of population information, it is difficult to ascertain the condition of the species. Because many observations are based on older herbarium specimens, observers did not take GPS coordinates, much less record the total area the population occupied. The species has generally not been the focus of surveys; therefore, total area of distribution and total number within a population were not taken. In many cases, time only allowed for noting the species' presence. These surveying practices are not unique to Shinner's sunflower.

At least in Arkansas, flowering stems have been observed dying back in the fall and producing new rosettes by the end of March (Marsh and Golden 1996). Flowering specimens have been collected as early as July 5 (Correll and Johnston #17467, TEX) and as late as November 4 (Ripple #51-573, TEX). Most often, specimens have been collected and surveys conducted in the second and third week of September, although this may be because of researcher bias (knowing that plants will likely be in bloom during this period). Marsh and Golden (1996) observed that many more rosettes are present in populations than flowering stems. This is true of a 2013 survey where 200-300 rosettes were observed while only 20 flowering stalks were counted (Carr 2013a). Fruits have not been recorded, although they likely develop in the fall.

Most sunflower species are self-incompatible, obligate outcrossers (Heiser 1969). One native United States sunflower, serpentine sunflower (*Helianthus bolanderi*), was recorded to have 94% of its visitors as bees (Wolf et al. 1999). Much more work has been done on the pollinators of cultivated hybrid sunflowers than wild sunflowers. In two studies conducted in Arkansas and Texas, apids (honey, long-horned, and bumblebees) and halictid bees (sweat bees) were the most frequent bee visitors (Posey et al. 1986; Chandler and Heilman 1982). Likely due to the presence of hives nearby (<2 miles away), honey bees (*Apis millifera*) were by far the most common visitor to sunflowers in the Texas study (Chandler and Heilman 1982). Not surprisingly, honey bees were also the most common visitor at a California study where hives were stocked at 1.5 hives per acre in the study area (Greenleaf and Kremen 2006). However, native bees were also recorded during this study and seed set was tracked. Four species of apids were the most efficient pollinators: long-horned bees (*Svastra oblique expurgata* and *Melissodes* spp.), an anthophorine bee (*Anthophora urbana*), and chimney bees (*Diadasia* spp.) (Greenleaf and Kremen 2006).

Like many sunflowers, Shinner's sunflower only has fertile disc flowers (the ray flowers are infertile). Although there can be 50+ disc florets (Schilling 2006), it is unknown how many of these flowers set seed. Typically there are 1-4 flower heads, but as many as 12 flower heads have been observed on one plant (Schilling 2006). No seedlings or juveniles have been recorded at any Shinner's sunflower site. Rosettes could be either mature individual or juveniles, but how to determine this is so far unknown.

Effective pollinators and the seed biology and dispersal of Shinner's sunflower are unknown. No seed dispersal or pollen vectors have been recorded at Shinner's sunflower sites. However, native bees have been shown to increase the pollination efficiency of cultivated sunflower by 100% (Greenleaf and Kremen 2006). Additionally, a positive relationship has been shown to exist between successive years of cultivated sunflowers planted near natural habitat (within 3 km) and the amount of native bee pollination occurring (Greenleaf and Kremen 2006).

Population ecology (positive and negative interactions)

Compared to other wild sunflowers, Shinner's sunflower has shown a strong resistance toward attack from sunflower moths (*Homoeosoma electellum*), carrot beetles (*Tomarus gibbosus*), sunflower beetles (*Zygogramma exclamationis*), and aphids (*Illinoia masoni*) (Herz et al. 1983; Rogers et al. 1980; Rogers et al. 1982). Terpenes, which may protect plants from herbivores, have been isolated from Shinner's sunflower (Stipanovic et al. 1979). Shinner's sunflower also has some ability to resist *Sclerotinia*, a fungus which commonly infects cultivated sunflowers (Liu et al. 2012).

In Arkansas, Shinner's sunflower was observed in dense, somewhat impenetrable colonies where even aggressive plant species (e.g., *Lespedeza cuneata*) made little headway (Marsh and Golden 1996). It has been suggested that in established sites, western sunflower's (*Helianthus occidentalis* ssp. *occidentalis)* rhizomatous growth can out-compete other species (Anderson and Liberta 1987). This may be made possible by western sunflower's early successional abilities. When plants can establish soon after a disturbance by means of rapid underground growth, they can prevent or slow other species' establishment (Anderson and Liberta 1987).

Hybridization has been recorded for many *Helianthus* species, including Shinner's sunflower, which is purported to naturally cross with ashy sunflower (*Helianthus mollis*) and results in a hybrid (*Helianthus* x *cinereus*) (Clevenger 1955). *Helianthus* x *cinereus* was collected in Bastrop County, Texas in the 1830s (Drummond #III.130, s.d., NY). Changes in habitat can interrupt the reproductive barriers between closely related species resulting in mixing of gene pools and creation of hybrids (Rhymer and Simberloff 1996). This may have happened in Indiana with ashy and western sunflower around the turn of the last century (Jackson and Guard 1957). At that time, woodlands were cut down and potential farmland was drained to utilize fertile soils (Jackson and Guard 1957). Both of these actions created new disturbed areas, which eliminated the natural barrier between the two species and allowed for hybridization to occur (Jackson and Guard 1957). Additionally, western sunflower has been shown to readily hybridize with ashy sunflower in at least four states where the two species grow in close proximity (Jackson and Guard 1956). Hand crosses of ashy sunflower and western sunflower have also resulted in viable seed (Jackson and Guard 1957). A few hybrids of western sunflower and sawtooth sunflower (*H. grosseserratus*) and western sunflower and woodland sunflower (*H. divaricatus*) have been found in Indiana (Jackson and Guard 1956).

Land ownership

Most of the extant site location descriptions do not identify property owner. However, both a Lee (Nails Creek) and Newton County (Siecke State Forest) site are at least partially on state land, state park and state forest, respectively. Ten populations (Beckendorff, Cat Spring, Delhi, E of Flatonia, E of Goliad, NE of Hope, Prairie View A&M, Rosanky, San Bernard, W of Delhi, and W of Waller) indicate that they are entirely or at least partially on highway right-of-way (ROW), either owned by Texas Department of Transportation (TxDOT) or the county. Except for one site where landowner is unknown (NNW of Waller), the remaining 18 sites are on or near highway ROWs, but it is unknown if plants were actually seen on the ROW or on adjacent private property or both (these are labeled as "Private?/TxDOT?" in Table 1). The location descriptions for these sites include language such as "along" or "off" or "near" a highway or state intersection.

Management practices

All of the sites on highway ROWs are maintained by either TxDOT or the county and undergo standard safety protocols of ROWs. These protocols include vegetation management, which may consist of herbicide application, brush removal, and/or mowing. Keeping other vegetation at bay may, in fact, be beneficial to Shinner's sunflower, because it may be an early successional species. Although little to nothing is known about the effect of mowing on Shinner's sunflower, it is likely that with mostly basal leaves the plant may tolerate mowing during the vegetative season before flowering stalks have been produced. However, it was observed at the Delhi site in 2013 that although plants were found closer to the pavement of the highway, plants with flowering stalks were concentrated along an unmown strip against the fence (Carr 2103a). To decrease effects of mowing on the reproductive output of the plants, mowing should occur between November and July. Some utilities have a legal right to be placed on the TxDOT ROWs (Texas Department of Transportation 2013). Due to this, it is difficult to avoid habitat disturbance or population destruction during utility siting, construction, and maintenance.

Shinner's sunflower seeds were at least collected in 1984 (in Texas) and in 2009 (in Arkansas) by United States Department of Agriculture – Agricultural Research Service employees (Germplasm Resources Information Network 2015). These seed accessions are still available online today to request for use. Of the accessions that have been tested for viability (germinated seedlings and living embryos), the 1984 collection showed 70% viability in 2002, and the 2009 collection showed 90% viability in 2010 (Marek 2015). A small germination trial has shown that scarification in combination with a treatment of the growth hormone, gibberellic acid, could increase germination in Shinner's sunflower seeds (Chandler and Jan 1985). Protocols for propagation of western sunflower are available through the Native Plant Network's Propagation Protocol Database (2015). According to these protocols, 75% germination of seeds can be expected within two to three weeks (Native Plant Network 2015).

Evidence of threats to survival

Shinner's sunflower is threatened by habitat modification and fragmentation and other factors. As habitats become more disturbed and fragmented and as more cultivated species are introduced by humans, previously geographically separated species are more likely to come in contact (Pysek et al. 1995). Suburban sprawl has been cited as a possible concern in Texas (NatureServe 2015). Hybridization risk increases with closely related species in disturbed habitats (Anderson 1948). If hybridization does produce viable offspring, the hybrids could be more competitive than their parents and could outcompete them (Wolf et al. 2001). Even if hybridization does not result in viable offspring, there is a wasted reproductive effort, which for small populations of rare plants can increase risks to the population (Ellstrand 1992).

Not only have cultivated sunflowers hybridized with neighboring wild sunflower populations, but these hybrids have reproduced and introduced genes of cultivated sunflowers into populations of wild sunflowers. Linder et al. (1998) tested three wild populations of common sunflower (*Helianthus annuus*) which had grown in contact with the cultivated sunflower between 20 and 40 years. Every plant tested from these populations had at least some genetic material present from cultivated sunflowers (Linder et al. 1998). First generation hybrids between the cultivated and wild sunflower were substituted by "advanced-generation hybrids" (Linder et al. 1998). Cultivated sunflower genes have been shown to persist in these hybrid populations for up to 5 years (Whitton et al. 1997). Genes flow in the opposite direction also. Studies to improve desirable traits (e.g., disease resistance) in cultivated sunflower (*Helianthus annuus*) have shown that when pollen from Shinner's sunflower has been crossed with cultivated sunflowers, gene flow is limited, but disease resistance can be transferred to cultivated sunflowers (Serieys et al. 2000). Although it is unknown if hybridization occurs between Shinner's sunflower and the approximately dozen overlapping native Texas sunflower species (*Helianthus* spp.), there is a high likelihood that they hybridize given the ease and rate of hybridization among other sunflower species. Climate change could alter the distribution of *Helianthus* species and increase the overlap between different sunflowers.

Genetic modification of crops is becoming a concern due to the increase in genetically-modified (GM) crop production, and fears that these genes will escape into natural populations of closely related plants. Although GM release permits have been approved to conduct field trials, no GM sunflowers have been released for commercial sale (Cantamutto and Poverene 2007). In fact, as early as 2007, the number of release permits in Argentina (the top producing sunflower seed country) and the US had already greatly decreased over the ten or more years prior to 2007 (Cantamutto and Poverene 2007). According to the National Sunflower Association (2015b), due to European and American regulations and risk to American native sunflowers, GM sunflowers are not being researched.

Because of its occurrence in highway ROW settings, it has been suggested that Shinner's sunflower is palatable and does not persist in cattle, goat, or horse pastures (Carr 2006). If so, the plant is restricted to highway ROW and has little chance of expanding (Carr 2006) beyond the narrow strip of managed land between roadway and property line. In 2013, plants were seen in the ROW but not beyond the fence, where the pasture was heavily grazed (Carr 2013b). Although its occurrence on highway ROWs may afford Shinner's sunflower some amount of protection from ranching, other risks are present. The application of herbicide along ROWs is a common management tool to keep vegetation out of the line-of-sight of drivers and off the pavement edges and markers. Also, if mowing occurs at the wrong time of year, the reproductive output of Shinner's sunflower will be decreased.

In Arkansas, Shinner's sunflower may abort fruit or produce non-viable fruit during drought (Marsh and Golden 1996). With climate change, current average temperatures could increase and rainfall extremes could be more common. It is unknown what, if any, effect drought in combination with climate change will have on Shinner's sunflower's overall reproductive output.

Special management considerations (past, present, and future)

According to Rogers et al. (1982), who ranked all (50+) United States *Helianthus* species in terms of "survival status" based on abiotic and biotic factors, Shinner's sunflower had an "excellent" survival status. This was based on its general habit ("variable"), annual precipitation (100-125 cm), branching habit ("reduced"), and flowering season (stated as "July-September") (Rogers et al. 1982). Survival status ranged from extinct, endangered, rare, good, to excellent. However, exactly how each of the variables was weighed is unclear and an "excellent" survival status may not be accurate. NatureServe, when assigning ranks to rare plants, includes many more variables than those listed above. Additionally, the Rogers et al.'s (1982) intent cannot be ignored. The authors worked for the U.S. Department of Agriculture and were trying to highlight the potential of *Helianthus* for use in plant breeding. However, more specimens than had been previously located were found during the writing of this status assessment. According to NatureServe (2015), at the time the status factors of Shinner's sunflower were completed or last updated, only 10-15 "collections"/"occurrences" were known from Texas.

Because very little research has been conducted on Shinner's sunflower, very few conclusions can be made as to how to manage the populations. It is unclear how much of the variation in population numbers is due to internal factors like extended juvenile stages or external factors like competition, herbivory, or other influences. Currently, species status is based on a few more recent opportunistic surveys, but mostly older herbarium specimens. Many specimens have been collected, but not with the purpose of assessing Shinner's sunflower's populations. Shinner's sunflower has a fairly large distribution in east Texas, but additional surveys of known and new populations are needed to update population information and landowner type. Precise habitat requirements would increase ability to manage and maintain suitable habitat. A long-term monitoring plan should be developed based on the nature of these plants to provide reliable information on growth, survival, mortality, and recruitment trends. Information regarding the reproductive biology is lacking. Identifying pollinators will aid in determining pollinator habitat type (e.g., ground-nesting bees vs. wood-boring bees) and guaranteeing protection of pollinator habitat. Recruitment via sexual and vegetative means should be determined. Although the plants are outcrossers, verifying if and determining to what extent Shinner's sunflower is clonal will ensure accurate monitoring protocols. It is likely that counts vary by observer in defining an individual plant. A rule of thumb needs to be decided, such as counting rosettes and flowering/fruiting plants.

A life-cycle simulation model has shown that competitive ability, initial number/frequency, and selfing rates of rare species were the most likely factors to make populations go extinct (Wolf et al. 2001). If hybrids are present, determining whether hybridization is a threat is ideal (Wolf et al. 2001). Estimating over multiple years the occurrence of the rare target species, its more common congener, and hybrids, could show if the rare species is decreasing (Wolf et al. 2001). Additionally, if the rare species has a protracted life-cycle, is clonal, self-fertilizes, has a high competitive ability, and has high fertility compared to the closely-related species and hybrids, it is likely at less risk (Wolf et al. 2001). Field surveys and genetic studies should be initiated to show if hybridization is occurring, at what rate, and if it is a threat. Because cultivated sunflowers are grown in Texas, choosing planting sites of cultivated sunflower based on location of Shinner's sunflower populations would be prudent.

While herbivory of Shinner's sunflower has not been observed, palatability to livestock has been suggested, and therefore occurrences in pasturelands may be more vulnerable to negative impacts from livestock grazing. Impacts from domestic and wild herbivores should be assessed. No populations have been observed to be sprayed by herbicide. However, like many ROW plants, it is recommended that herbicide application be conducted carefully by hand and sparingly at times of little to no wind (Poole and Janssen 1997). Populations are not only vulnerable to herbicide drift, but sites adjacent to cropland are vulnerable to insecticide drift. Collaborating with landowners and coordinating insecticide application with the nonreproductive season of Shinner's sunflower would minimize negative effects to pollinators during the flowering season.

Some disturbance may in fact be necessary to increase population health. As a prairie species, Shinner's sunflower could be fire-tolerant, but studies on the type and extent of disturbance tolerated would be necessary to increase effective management. Until much more is understood about the ecology and basic biology of Shinner's sunflower, the utility of recovery plans and the ability to analyze effects of climate change will be minimal.

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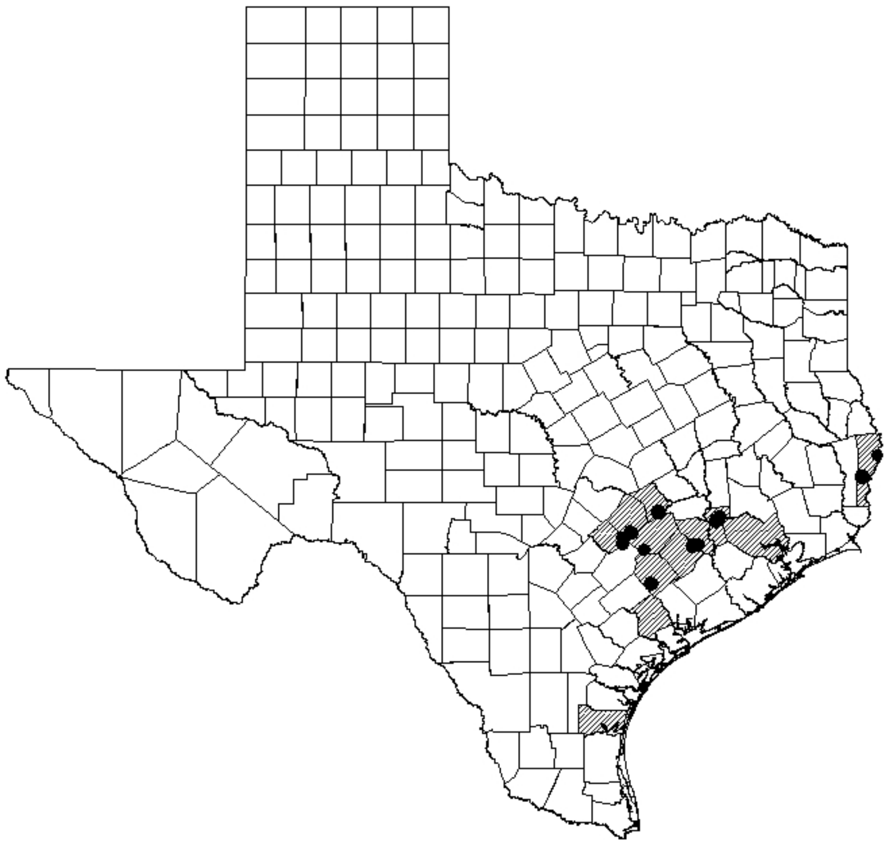
Table 1. Shinner's sunflower population status, including location and ownership (Texas Natural Diversity Database 2014). These sites have not undergone a comprehensive review and may be reorganized in the future. This is the author's best attempt at classifying sites.

County	Year discvrd	Last year seen	EO ID(s)+	Site name	Landowner	Notes
Extant sites						
Austin	2003	*	11266	Beckendorff	TxDOT	"locally common" (2003)
Austin	2005	*	not mapped	San Bernard	Private?/TxDOT?	"locally common" (2005)
Bastrop	1982	2013	8516/11275	Rosanky	County ROW (private?)	300-400 rosettes (2013)
Caldwell	1973	2013	8785	Delhi	TxDOT (private?)	an estimated 10 individuals but more rosettes (2013)
Caldwell	1973	*	8514	SH 304	Private?/TxDOT?	present
Caldwell	1986	2013	11130	W of Delhi	TxDOT (private?)	"one small population" (1986)/ ~22 rosettes (2013)
Colorado	1981	2014	11218	San Bernard	TxDOT (private?)	"locally common" (2005)
Colorado	1984	*	not mapped	W of Eagle Lake	Private?/TxDOT?	present
Colorado	1984	*	not mapped	W of Rock Island	Private?/TxDOT?	present
Colorado	2007	*	not mapped	SH 949	Private?/TxDOT?	present
Colorado	2012	*	not mapped	Pleasant Hill	Private?/TxDOT?	"rare" (2012)
Colorado	2014	*	not mapped	Cat Spring	TxDOT	present
Fayette	1957	1967	8513	E of Flatonia	TxDOT	"in colonies" (1967)
Fayette	1984	*	not mapped	S of West Point	Private?/TxDOT?	present
Fayette	1984	*	not mapped	N of Flatonia	Private?/TxDOT?	present
Fayette	2002	*	not mapped	NW of Waldeck	Private?/TxDOT?	present
Harris	2008	*	not mapped	Meadow Creek	Private?/TxDOT?	present
Kleberg	1990	*	not mapped	Kleberg	Private?/TxDOT?	present
Lavaca	1976	2005	8773	NE of Hope	TxDOT (private?)	"large population" (2002)/ "medium size population" (2005)
Lavaca	1984	*	not mapped	W of Sheridan	Private?/TxDOT?	present
Lavaca	1984	*	not mapped	E of Hallettsville	Private?/TxDOT?	present
Lee	1973	*	8742/11285	Giddings	Private?/TxDOT?	present
Lee	~2006	*	not mapped	Nails Creek	State Park	present
Newton	1988	2009	11232	Siecke State Forest	State Forest/ Private?/TxDOT?	present
Newton	1989	*	8437	E of Stringtown	Private?/TxDOT?	present

County	First year discvrd	Last year seen	Popln ID(s)[+]	Site name	Landowner	Notes
Victoria	1984	*	not mapped	S of Mission Valley	Private?/TxDOT?	present
Victoria	1984	*	not mapped	S of Nursery	Private?/TxDOT?	present
Waller	1951	1994	11126/11161	Prairie View A&M	TxDOT (private?)	"common" (1968)/ "frequent" (1984, 1986)
Waller	1936	2000	not mapped	W of Waller	TxDOT (private?)	"locally frequent" (2000)
Waller	1978	*	not mapped	Monaville	Private?/TxDOT?	"uncommon" (1978)
Waller/Harris	1978	*	8470	NNW of Waller	unknown	"rare" (1978)
Historic sites						
Austin	1904	*	not mapped	Industry	unknown	present
Austin	1940	*	11197	Sealy	unknown	present
Austin	1833/1834	*	not mapped	San Felipe de Austin	unknown	present
Brazoria	1843	*	not mappable	Brazoria County	unknown	present (directions illegible)
Colorado	1939	*	not mappable	Colorado County	unknown	present (only county)
De Witt	1941	*	11196 (not mappable)	De Witt County	unknown	present (only county)
Dimmitt	1931	*	not mapped	Carrizo Springs	unknown	present
Fayette	1935	*	not mapped	Schulenberg	unknown	present
Fayette	1949	*	not mapped	Muldoon	unknown	present
Goliad	1957	*	11125	E of Goliad	TxDOT	present
Harris	1877	*	not mapped	Houston	unknown	present
Jackson	1946	*	11164	Carancahua Creek	unknown	present
Matagorda	1934	*	not mapped	Gulf	unknown	present
Newton	1957	*	11203	S of Newton	unknown	present
Victoria	1913	*	not mapped	Aloe	unknown	present
Victoria	1941	*	11146 (not mappable)	Eastern Victoria	unknown	present (only county)
Washington	1923	*	not mapped	Brenham	unknown	present
Washington	1938	*	not mappable	Washington Co.	unknown	present (only county)

+EO ID is the unique number assigned to a new record (element occurrence) in the Texas Natural Diversity Database. An element occurrence (EO) is an area of land where a species resides/resided (i.e., a population). An EO can consist of one or more subpopulations.
*plants only seen one year

Figure 1. Distribution of extant populations of Shinner's sunflower (*Helianthus occidentalis* ssp. *plantagineus*). A comprehensive review has not been conducted on this species, and therefore several extant populations are not mapped. Cross-hatching indicates counties where extant populations of Shinner's sunflower occur.



Chisos coralroot (*Hexalectris revoluta*)

Species information (history of knowledge of taxon)

Although first collected in the Chisos Mountains in 1931 (Mueller #8957, TEX), Chisos coralroot (*Hexalectris revoluta*) was not described and named until 1941 by D. Correll from a collection made in Nuevo Leon, Mexico (Mueller and Mueller #767, GH). A report and photograph of Chisos coralroot from New Mexico was made at Guadalupe Mountains National Park (McDonald 2010). However, this documentation has not been located. Locations in Arizona were discovered and initially thought to be a subspecies of Chisos coralroot (Catling 2004), but was eventually determined to be a completely different species, Coleman's coralroot (*Hexalectris colemannii*) (Kennedy and Watson 2010).

Present legal status (National and State)

Chisos coralroot is ranked as a G1G2, a rank that indicates the exact status of the species is uncertain, but means Chisos coralroot is (globally) either critically imperiled or imperiled across its entire range and is ranked as a Sensitive Species by the United States Forest Service. Although it is not listed as endangered or threatened by the State of Texas, the species is also listed on Texas Parks and Wildlife Department's (TPWD) 2010 List of the Rare Plants of Texas and as a Species of Greatest Conservation Need in the Texas Parks and Wildlife Department (TPWD) State Conservation Action Plan.

In 1980, Chisos coralroot was designated by the United States Fish and Wildlife Service (USFWS) as a Category 2 Candidate species (U.S. Fish and Wildlife Service 1980), a species which listing may have been appropriate, but data to support listing was not known and further study was likely needed to determine species status. 1n 1993, a status trend designation was added, which classified Chisos coralroot as "unknown". An unknown status trend indicated that more surveys were needed to determine population trends (U.S. Fish and Wildlife Service 1993). However, in 1996, to allow USFWS to focus on protecting the many species for which sufficient information was available, all Category 2 Candidates were dropped from the list (U.S. Fish and Wildlife Service 1996). In 2009, a 90-day finding was announced on 67 species from a petition to list 475 in the southwestern United States as threatened or endangered (U.S. Fish and Wildlife Service 2009). The petition presented scientific information to indicate that listing may be warranted for Chisos coralroot. Scientific, commercial, and other information was requested and other available information was summarized by the USFWS. Of the five threat factors, which can be used to assess if a species may warrant listing as endangered or threatened, the USFWS listed only A (the present or threatened destruction, modification, or curtailment of its habitat or range) and B (overutilization of species for commercial, recreational, scientific, or educational purposes) for Chisos coralroot (U. S. Fish and Wildlife Service 2009).

Description (local field characters)

The following description is adapted from previous authors (Luer 1975; Correll 1978; Liggio and Liggio 1999; Goldman et al. 2002). Chisos coralroot is a non-photosynthetic perennial with erect 30-50 cm tall leafless stems. Flower stalks can be up to 20 cm long with 5-15(-20) flowers. About 1.5 cm long pedicels hold tan to pinkish brown or purplish flowers with six outward rolling petals and sepals. The sepals (petal-like structures arising behind the petals) are dimorphic. The dorsal sepal is oblong to oblong-elliptic or lanceolate (15-25 mm long, 3-8 mm wide) and the lateral sepals are obliquely elliptic to elliptic-lanceolate or obovate (15-22 mm long, 3-8 mm wide). The three petals are oblique, narrowly elliptic to obovate or oblanceolate (15-19 mm long, 4.5-7.5 mm wide). The lower petal (lip or labellum) is broadly elliptic and deeply 3-lobed (13-18 mm long and 9-13 mm wide) with a 3 mm or more space between the lobes. The side lobes of the lip are oblong and the unattached portion is 6 mm long and 3.3-4.5 mm wide. The middle lobe of the lip is obovate-cuneate, with a ridge or undulation on its upper margin (7-8.5 mm long, 5-6 mm wide). The column (a fused stamen and pistil) is purple in the front (or the area facing away from the stem). The fruit is an ellipsoid capsule 20 mm long by 5 mm wide.

Although the Glass Mountain coralroot (*Hexalectris nitida*), crested coralroot (*Hexalectris spicata*), and Warnock's coralroot (*Hexalectris warnockii*) occur in the Chisos and Glass Mountains, only Glass Mountain coralroot occurs with and closely resembles Chisos coralroot (See Table 2). In Chisos coralroot, when the lower petal (or lip) is spread out, it is broadly elliptic in outline, whereas Glass Mountain coralroot has an obovate lip. Also, the column of the Chisos coralroot is purple and white-purple, whereas the Glass Mountain coralroot is all white. The Chisos coralroot flowers are also generally larger compared to Glass Mountain coralroot flowers. The Glass Mountain coralroot dorsal sepal is 8-13 mm long and 3-4.5 mm wide; the lateral sepals are 8-11 mm long and 2-3.5 mm wide; and the petals are 8-11 mm long and 2-3.5 mm wide. Glass Mountain coralroot has 5-7 slightly raised veins near the base of the middle lobes whereas Chisos coralroot does not.

Geographical distribution (range and precise occurrences)

Chisos coralroot's range extends from the Sierra Madre Orientals in southeastern Mexico north to the Chihuahuan montane woodlands of far west Texas and southeastern New Mexico (See Figure 1 and Table 1). The Mexican locations of Chisos coralroot occur in four states (Coahuila, Nuevo Leon, San Luis Potosi, and Tamaulipas) along the Sierra Madre Oriental at 5,000 to 8,000 feet in pine-oak forests. Two of the Mexican occurrences have more recent (1973 and 1987) herbarium specimens (Johnston et al. #12147B, TEX; Hinton #19134, unknown herbarium, respectively). In 1986, Howell tried to relocate the Mueller collections from Nuevo Leon (#700, #733, #767, GH), but was unsuccessful. As the common name indicates, Chisos coralroot has most frequently been encountered in the Chisos Mountains of Brewster County, Texas. Only one report exists for each in the Glass Mountains, the Guadalupe Mountains in Culberson County, Texas, and the Guadalupe Mountains in Eddy County, New Mexico. However, only the documentation from Brewster County, Texas have been visited or verified in the last forty years. All other United States reports are based off of erroneous or ambiguous reports. None of these accounts have been verified since their initial observations. A 1986 observation from the Texas side of the Guadalupe Mountains is based on what is now believed to be a misidentification by the original and only observer (an orchid expert) (Jennings 1986; Jennings 2013). A photograph taken at this site does not show key characters from which to determine the difference between Chisos coralroot and the similar Glass Mountain coralroot (Kennedy 2013). Searches in 1987, 1988, and 2004 or 2005 at Guadalupe Mountains National Park turned up zero plants in the same area where Jennings reported Chisos coralroot (Higgins 1989; Kennedy 2013). In 1977, Warnock stated that Chisos coralroot's distribution was only the Chisos Mountains, but in the same reference he discusses a sighting made in the Glass Mountains. This inconsistency has not been resolved and plants have not been found in the Glass Mountains since this report. The New Mexico sighting of Chisos coralroot comes from a report and photograph submitted to the National Park Service (McDonald 2010). However, the report has not been located (Coles 2015; Roth 2015). Tom Todsen, an orchid expert, made the observation and took a photograph, but because no specimen was collected (McDonald 2010), the site cannot be verified. In general, misidentifications could be confounding Chisos coralroot's true distribution.

General environment and habitat description (physical and biological characteristics)

The documented Texas locations of Chisos coralroot are in the Madrean conifer-oak woodlands of the Chisos Mountains above 4,000 feet. On average, the Chisos Basin gets 19 inches of rain a year (National Oceanic and Atmospheric Administration 2015). Chisos coralroot has been recorded under oaks (*Quercus* spp.), pines (*Pinus* spp.), junipers (*Juniperus* spp.), and maples (*Acer* spp.). The species that have been specifically referenced in herbarium collections include bigtooth maple (*Acer grandidentatum*), Lacey oak *(Quercus laceyi),* Mexican pinyon pine (*Pinus cembroides*), Grave's oak (*Quercus gravesii*), and Chisos Mountain oak (*Quercus graciliformis*). Plants have been found over the South Rim Formation from Pine Canyon Caldera in Puerta-Madrone-Lazarus and Liv-Mainstay-Rock outcrop complexes (Cochran and Rives 1985). These complexes consist of loam and gravelly clay loam, silt loam and loam derived from igneous volcanic rock (Cochran and Rives 1985). On the mountain slopes, gravelly soils and fine-grained deposits have weathered from limestone and dolomite, and on the valley floors, gravelly sediment and rocks have settled at the base of hills (Cochran and Rives 1985). Many individuals have been found in nutrient-rich, higher water-holding capacity soils (humus) under an open canopy (Luer 1975). Recent observations within the Chisos Mountain range are between 4,100-7,160 feet in elevation (National Park Service 2007) and cover about ¾ of a square mile.

Population biology of taxon (demography, phenology, and reproductive biology)

Recent genetic studies have clarified relationships of all the *Hexalectris* species (Kennedy and Watson 2010). Still, it can be difficult, if not impossible, to identify Chisos coralroot from photographs. With that caveat, photographs, written and oral reports, and plant collections over the last 80+ years have documented Chisos coralroot, but unfortunately contain scant population information. If stated at all, the plant is usually described as being "rare" or "very rare" at any given site. In many instances, only a single individual was recorded. Specimens and surveys from the mid-2000s documented no more than about ten plants at a single site (Kennedy #262, MU; Kennedy pers. comm.). Most specimens and surveys have recorded one to six plants/stems at one site. One underground rhizome could produce multiple flower stalks, which may not be identifiable as a single individual above ground. Therefore, counts could in fact be over-estimating the actual number of individuals at one site. Because Chisos coralroot is generally seen as isolated individuals or small clumps across a large, difficult to traverse, isolated landscape, the population condition is difficult to establish. However, the closely related Arizona coralroot (*Hexalectris colemanii*) has been observed to fluctuate widely in its population numbers from year to year and may not emerge at all in a given year (Coleman 2001). Causes of this could be rainfall, as has been suggested for Arizona coralroot (Coleman 2005). Arizona coralroot has been shown to go dormant for several years after blooming (Coleman 2005). Due to the Chisos coralroot's cryptic coloration, sporadic bloom cycle, and brief above ground periods, plants are hard to detect. There are several documented and likely more undocumented cases of unsuccessful searches within the Chisos Mountains for Chisos coralroot, even in known locations (e.g., Poole 1993).

Plants are usually seen in flower or fruit (May-August). The orchid has a rostellum, the sterile structure between the fused, columnar sex organs in orchids, which deters self-pollination; however, Chisos coralroot can self-pollinate (Catling 2004) if pollinators are absent or are unable to transfer pollen from one orchid to the next.

Many myco-heterotrophs, like Chisos coralroot, are found in shady, leaf-littered areas with little understory (Leake 1994). A myco-heterotroph is an organism that obtains nutrients from a fungus and in return for nutrients the fungi are provided a home in the cells of the underground portion of the plant. Chisos coralroot is dependent on a specific subgroup of fungi in the Sebacinaceae family, jelly fungi that form symbiotic relationships with many terrestrial plants (Kennedy et al. 2011). Because the Chisos coralroot acquires its nutrients from fungi, the plant does not form leaves, which typically photosynthesize and produce the plant's nutrients (Leake 1994). For this same reason, myco-heterotrophs can live for years as tubers and not flower (Hill 2007). Other jelly fungi have been shown to associate with non-photosynthetic orchids, as well as surrounding trees (Selosse et al. 2002). In this case, nutrients created by the tree is transferred from the tree to the fungus and then to the orchid (Smith and Read 2008).

Population ecology of species (negative interactions)

In Mexico, Chisos coralroot is potentially threatened by predation; intense grazing by sheep and cattle in lower elevations was observed in sites similar to the Texas habitat of Chisos coralroot (Howell 1986). Like other orchids, coralroots are probably edible and, therefore, subject to foraging by deer, rabbits, cattle, and other animals (Hill 2007). The underground portions of coralroots may be vulnerable to consumption by feral pigs or rodents (Hill 2007).

It is unknown if Chisos coralroot hybridizes with other *Hexalectris* species. Terrestrial orchids have rarely been shown to hybridize naturally (Kennedy et al. 2011).

Land ownership and management

The populations on Big Bend National Park (South Rim, Panther Junction, Pinnacles) are managed by the National Park Service and for this reason, are relatively protected. The entire Chisos Mountain range is contained within Big Bend National Park and is managed by the National Park Service. Because these populations are managed by the Park system, Chisos coralroot is afforded a certain amount of federal oversight and populations are essentially protected from most disturbances. The Chisos Mountain trail system is inaccessible except by horseback or, more often, by foot. Recreational and facility maintenance could cause some disturbance to orchids near trails and campsites. Big Bend National Park classifies Chisos coralroot as a Sensitive Plant, a species that is very rare or subject to heavy poaching pressure and in danger of being extirpated or eliminated from the park. Big Bend Sensitive Plants are documented, photographed, and counted to better understand their habitat requirements. However, there have not been any funds designated towards Sensitive Plants since 2007. Guadalupe Mountains National Park is also owned by the National Park Service and is essentially protected from most disturbances. However, the Glass Mountains are privately owned and its stewardship is unknown.

Evidence of threats to survival

Throughout its range, Chisos coralroot is threatened by climate change, habitat modification, and possible overutilization for commercial purposes. As a high elevation species that occurs over 4,000 feet, Chisos coralroot could be negatively affected by climate change. Perennial, montane species are more vulnerable to increased temperatures because their ability to disperse will be limited by available habitat at appropriate elevations. If climate change in the Chisos Mountains is expressed as recurrent and extreme drought, Chisos coralroot's shady habitat would be at risk. Any disturbance or modification to the soil or jelly fungi providing the plants with nutrients will negatively impact coralroot populations (Hill 2007). The 2011 drought caused about 15% die off of trees in higher elevations of the park (~5,550 and ~6,300 feet) (Waring and Schwilk 2014). Cedar and oak tree species sampled included red-berry juniper (*Juniperus coahuilensis*), alligator juniper (*Juniperus deppeana*), weeping juniper (*Juniperus flaccida*), Emory oak (*Quercus emoryii*), and Grave's oak (*Quercus gravesii*). Fire is a continuous concern for all species in the park as drought continues and fuel loads increase (Sirotnak 2013a). Chisos coralroot habitat is to some extent protected by its more mesic condition and lack of understory. However, a typical fire in the Chisos Mountains combined with more recent drought-conditions and increasing fuel loads could lead to a large-scale canopy fire, which could permanently change the shady habitat Chisos coralroot requires (Sirotnak 2013a). Power plants in Mexico and the United Stated have given Big Bend National Park the dubious distinction of having the worst visibility of any of the western national parks (EPA 2001). This air pollution carries sulfates and nitrates, which acidify rainwater and consequently soil. Changes in the soil pH can change plant species distribution and arrangement (EPA 2001). It is unknown how the lowering of soil pH will affect Chisos coralroot and its associated fungus.

Recreational impact from hikers and campers, and park management practices like trail construction or maintenance and the use of horses or mules are other potential threats. All park improvements and maintenance should consider locations of Chisos coralroot.

In Mexico, Chisos coralroot is potentially threatened by trampling. Wood harvesting was observed in 1986 in Mexican sites, which resembled the Texas habitat of Chisos coralroot (Howell 1986).

Orchids are particularly prized by collectors and are valued by those willing to take the risk to collect unique, wild specimens. As is described in the Lacey Act, poaching of any plant on federal or state land (or, if private land, without permission by the landowner) can result in fines, jail time, and forfeiture of plants and even trafficking equipment. In addition to the legal issues, transplanting and propagating myco-heterotrophic orchids is particularly difficult (Hill 2007).

Orchid enthusiasts are typically aware of these biological realities (Hill 2007), whereas other uninformed poachers or park visitors may be uneducated. There are no documented occurrences of orchid poaching in Big Bend National Park (Sirotnak 2013b). However, succulent poaching in the park has been reported in the past (Sirotnak 2013b).

Special management considerations

Orchids have a particularly complex life history compared to other plants. This fact, combined with the orchid's lengthy and sporadic dormant periods (as a seedling, juvenile, and adult), confounds biological studies of the plant. As a myco-heterotroph, Chisos coralroot requires a specific group of fungal symbionts to obtain its nutrients. Many of these fungi colonize several species and can exchange nutrients from one host plant to another. Chisos coralroot could be influenced not only by abiotic factors like soil chemistry and weather patterns, but also by associated organisms (fungus and possibly oaks, junipers, etc.), which are directly or indirectly providing nutrients to Chisos coralroot. Unfortunately, the ecology of fungal associates in general is poorly understood and a relatively new field of science. Until more is known about propagating this species, habitat protection and management is the only possibility for preserving Chisos coralroot. Tree die-off from the 2011 drought may be detrimental to Chisos coralroot. Monitoring areas where trees were affected may show if a correlation exists between canopy cover and orchid population health. Activities like trail maintenance should avoid Chisos coralroot habitat and should be timed to occur outside of the above-ground season. Camping and trail locations may need to be redirected to decrease the chance of inadvertent trampling (or collecting) by park visitors. Many orchids are edible to animals and could be fed upon by deer, rodents, or insects. Impacts from possible herbivores should be assessed. Possible impacts from soil acidification by air pollution and temperature changes should be investigated. Additional genetic studies should be undertaken to show if hybridization is probable or if subpopulations differ in terms of variability. Chisos coralroot can self-pollinate, but the degree to which self-pollination versus pollination by insects occurs should be determined. Although fruit is being produced, few insects have been observed on flowers (A. Kennedy pers. comm.). If the orchids are limited by pollinators, effective pollinators can be identified in order to protect those pollinators. Currently, Chisos coralroot's occurrence is based on somewhat opportunistic surveys and unreliable photographs. A long-term monitoring plan should be developed based on the elusive and unpredictable nature of these plants to provide reliable information on population sizes, trends, and health. Until much more is understood about the ecology and basic biology of Chisos coralroot, the utility of recovery plans and the ability to analyze effects of greater challenges like climate change will be minimal.

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Table 1. Chisos coralroot population status, including location and ownership (Texas Natural Diversity Database 2015). These sites have not undergone a comprehensive review and may be reorganized in the future. This is the author's best attempt at classifying sites.

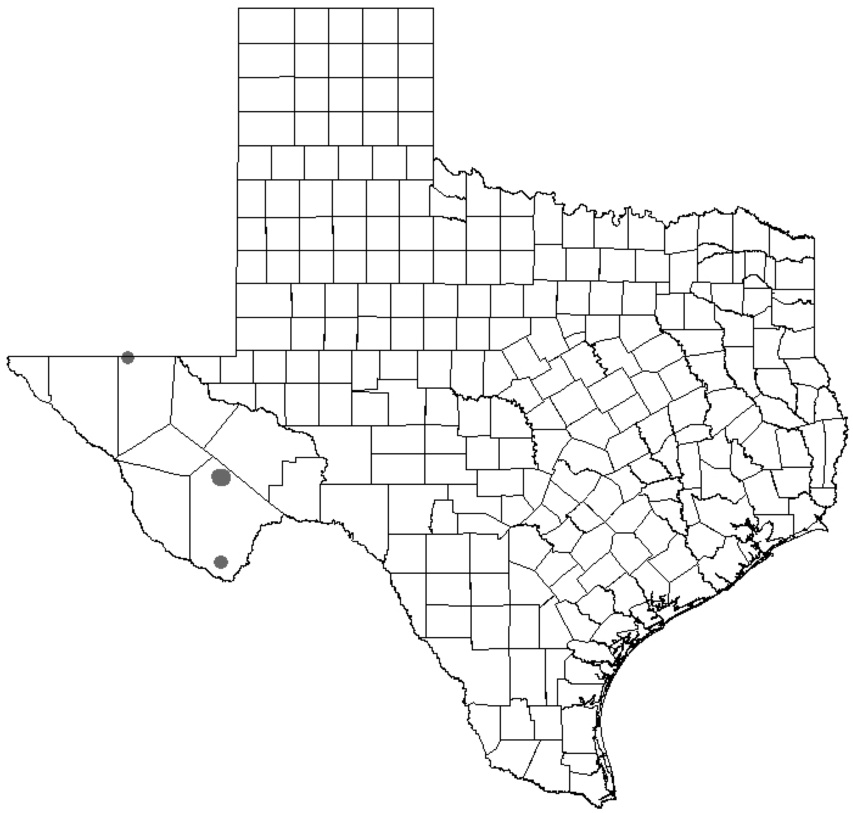
County	Year discvrd	Year last seen	EO ID+	Site name	Landowner	Min. # per 1 subpop.++	Max. # per 1 subpop.++	Notes
Brewster	1931	2007	7070/329	South Rim	National Park Service (NPS)	1 (multiple years)	6 (2004)	
Brewster	2006	*	not mapped	Panther Junction	NPS	~10		
Brewster	2004	2006	not mapped	Pinnacles	NPS	2 (2006)	5 (2004)	
Brewster	pre-1977	*	4628	Glass Mountains	private	present		Location discrepancy (Warnock 1977, pp. xi & 87)
Culberson	1986	*	4181	Guadalupe Mountains NP	NPS	2		Questionable ID

+ EO ID is the unique number assigned to a new record (element occurrence) in the Texas Natural Diversity Database. An element occurrence (EO) is an area of land where a species resides/resided (i.e., a population). An EO can consist of one or more subpopulations.
++ represents number of individuals recorded in any year at a subpopulation; each count is based on surveyor effort and is only as good as the effort expended
*site was only visited a single time

Table 2. Key characters to Chisos coralroot and Glass Mountain coralroot.

Species	Epidermis	Labellum shape	Mid-lobe shape	Mid-lobe ridge pattern	Sepal and petal sizes
Chisos coralroot (*H. revoluta*)	less waxy-looking	broadly elliptic	obovate-cuneate	ridge or undulation	**dorsal sepal** 15-25 mm long, 3-8 mm wide **lateral sepals** 15-22 mm long, 3-8 mm wide **petals** 15-19 mm long, 4.5-7.5 mm wide
Glass Mountain coralroot (*H. nitida*)	extra waxy-looking	obovate	suborbiculate	5-7 raised veins	**dorsal sepal** 8-13 mm long, 3-4.5 mm wide **lateral sepals** 8-11 mm long, 2-3.5 mm wide**petals** 8-11 mm long, 2-3.5 mm wide

Figure 1. Distribution of populations of Chisos coralroot (*Hexalectris revoluta*).



Section 6 Final Report: E-146 - *Data synthesis and species assessments to aid in determining future candidate or listed status for plants from the USFWS lawsuit settlements.*

Anna Strong and Paula Williamson, August 31, 2015

Bushy whitlow-wort

(*Paronychia congesta*)

Species information (history of knowledge of taxon)

Bushy whitlow-wort was originally collected by D. Correll and D. Wasshausen in 1963 (#27717, LL) and was subsequently described as *Paronychia congesta* in 1966 (Correll 1966). It was not until twenty years later this Jim Hogg County population was rediscovered by B. Turner in 1983 (#15132, TEX; Turner 1983).

Present legal status (National and State)

Bushy whitlow-wort is ranked as a G1 or critically imperiled across its entire range by NatureServe and is ranked as a Sensitive Species by the United States Forest Service. Although it is not listed as endangered or threatened by the State of Texas, the species is also listed on Texas Parks and Wildlife Department's (TPWD) 2010 List of the Rare Plants of Texas and as a Species of Greatest Conservation Need in the Texas Parks and Wildlife Department (TPWD) State Conservation Action Plan.

In 1985, bushy whitlow-wort was designated by the United States Fish and Wildlife Service (USFWS) as a Category 1 Candidate species (U.S. Fish and Wildlife Service 1983a), a species where listing was thought to be appropriate, but due to a large number of Category 1 species, listing was delayed. 1n 1993, a status trend designation was added, which classified bushy whitlow-wort as "unknown". An unknown status trend indicated that more surveys were needed to determine population trends (U.S. Fish and Wildlife Service 1993). In 1996, to allow USFWS to focus on protecting the many species for which sufficient information was available, all categories except for Category 1 species were dropped from the list and Category 1 species were reclassified as candidate species (U.S. Fish and Wildlife Service 1996). A listing priority of 11 was added to indicate that bushy whitlow-wort has a moderate degree of threat, but a low recovery potential (U. S. Fish and Wildlife Service 1983b). In 2006, bushy whitlow-wort was removed from the list of Candidate species due to a lack of information on biological vulnerability and threats (U. S. Fish and Wildlife Service 2006). In 2009, a 90-day finding was announced on 67 species from a petition to list 475 in the southwestern United States as threatened or endangered (U.S. Fish and Wildlife Service 2009). The petition presented scientific information to indicate that listing may be warranted for bushy whitlow-wort. Scientific, commercial, and other information was requested and other available information was summarized by the USFWS. Of the five threat factors, which can be used to assess if a species may warrant listing as endangered or threatened, the USFWS lists only A (the present or threatened destruction, modification, or curtailment of its habitat or range) and E (other natural or manmade factors affecting the continued existence of the species) for bushy whitlow-wort.

Description (local field characters)

The following description is adapted from Turner (1983), Poole and Damude (1990), and Hartman et al. (2005). Bushy whitlow-wort arises from a woody base and is an erect 6-10 cm tall perennial. The plant is covered in short hairs except for the stipules and bracts. The base of the stems and branches are covered with many overlapping leaves and bracts (a leaf-like structure under the flowers). The leaves are 4-7 mm long and about 0.5 mm wide, are linear or needlelike, and sharp-pointed. The stipules (a structure at the base of a leaf) are lance-shaped, silvery, and dry, which give the plant an overall dry, dusty appearance (Turner 1983). Flowers are held above the bracts and leaves and occur in clusters (7-28+ flowers) at the branch apices. Although lacking true petals, there are five lemon-yellow sepals (about 2.5 mm long) tipped with short spines (0.5-0.7 mm long). Fruits are small (0.8-0.9 mm long) and bladder-like and contain one dark-colored seed.

Although bushy whitlow-wort occurs near another rare whitlow-wort, McCart's whitlow-wort (*Paronychia maccartii*), this other species tends to occur on sandier soils (Turner 1983). McCart's whitlow-wort was collected across the county line in Webb County ten miles from the bushy whitlow-wort sites, but it is only known from a single 1962 collection (Alvarez, Guajardo, Salazar, McCart #7758, BRIT). McCart's whitlow wort differs from bushy whitlow-wort in that it is prostrate and laxly branched with distinct (not congested) leaves (Correll and Johnston 1970). The more common Jones' nailwort (*Paronychia jonesii*) is located in southern Jim Hogg County 30-40 miles away. Jones' nailwort is recognizable due to its horizontal, sprawling stems, white margined sepals, and oblanceolate, apically rounded leaves (as opposed to bushy whitlow-wort's erect habit, lemon-yellow sepals, and lanceolate, sharp-pointed leaves) (Correll and Johnston 1970). Other characteristics which make bushy whitlow-wort distinctive include the hairs present on all but the stipules and bracts, the overlapping leaves and bracts at the base of the stems, the flowers which are held above the bracts and leaves, and the short spines on the sepal tips (Correll 1966).

Geographical distribution (range and precise occurrences)

Bushy whitlow-wort occurs in the South Texas Brush Country in northwestern Jim Hogg County (Table 1 and Figure 1). Only two sites two miles apart are known. Bushy whitlow-wort was first collected in 1963 at one site, but this site has not been visited since 1987 (Texas Natural Diversity Database 2013). A second site was located in 1987 and last visited in 1994 (Texas Natural Diversity Database 2013). There are no available data to suggest contraction or expansion of these populations, but before sites became inaccessible the species had persisted in the area for almost 25 years.

General environment and habitat description (physical and biological characteristics)

Both sites of bushy whitlow-wort are located along the rocky, gentle slopes of the Bordas Escarpment, a fault line dividing the shrublands west of Hebbronville. The fault is composed of undulating hills or alternating ravines and ridges with little to no soil layer. The occasional areas with soil are classified as Zapata soils, which are sandy loam or sandy clay loam over caliche outcrops (Sanders et al. 1974). The entire area overlies the Catahoula Formation and Frio Clay (undivided) and Goliad Formation, notable for its large quantity of hardened calcareous material (Sanders et al. 1974). The combination of shallow soils with low water-holding capacity, high summer temperatures, and frequent droughty periods result in a fairly inhospitable and sparsely vegetated environment. Fully exposed to the sun, bushy whitlow-wort roots in crevices in the calcareous bedrock and shields itself with a dense covering of minute hairs. Average annual precipitation in the area is 23 inches with highest rainfalls in May and September (National Oceanic and Atmospheric Administration 2013).

Some vegetation concentrates in the immediate vicinity of bushy whitlow-wort in depressions where soil has accumulated. These species are mostly herbaceous or low shrubs and include fairy duster (*Calliandra conferta*), stinging cevallia (*Cevallia sinuata*), featherplume (*Dalea frutescens*), slimleaf heliotrope (*Heliotropium torreyi*), bluet (*Houstonia* sp.), ratany (*Krameria ramosissima*), and desert zinnia (*Zinnia acerosa*) (Poole et al. 2007). Outside of the immediate area of bushy whitlow-wort is deeper soil where larger shrubs reside including blackbrush (*Acacia rigidula*), desert olive (*Forestiera angustifolia*), cenizo (*Leucophyllum frutescens*), mesquite (*Prosopis glandulosa*), and Texas mountain laurel (*Sophora secundiflora*) (Poole et al. 2007).

Population biology of taxon (demography, phenology and reproductive biology)

The smaller, 5-acre southern population was relocated in 1983 and only four plants were located (Turner 1983). However, a more thorough search several years later turned up around 2,000 individuals (Poole 1987). The larger, 15-acre northern site was thoroughly surveyed in 1991 and 1994, and a total of 1,057 and 1,904 individuals were located, respectively (Poole and Janssen 1994). In addition to these surveys, monitoring plots were established at the northern site, and data were recorded in 1991, 1993, and 1994 (Poole and Janssen 1994). Data collection varied in plot location and characteristics measured, but included number of reproductive clusters and plant dimensions in a subset of the population (Poole and Janssen 1994). Because only three years of inconsistent data were collected, interpreting trends in the population is difficult, if not impossible. However, basic information like plant height and number of flowering branches was established. When monitoring was conducted in June of 1991, 15 1-m^2 plots were set up and within these plots 92 plants were counted and measured (Damude 1992). The average plant height was 5.65 +/- 2.5 cm, ranging from 1 to 10 cm tall and the number of flowering branches ranged from 0 (a non- flowering plant) to 40 (Poole and Janssen 1994). Out of the 92 plants monitored within these plots, 32% were flowering (Poole and Janssen 1994). There is no evidence that seedlings or juveniles have ever been recorded, though flowers and fruit have been observed repeatedly (Poole 1987; Poole and Janssen 1994). Fruits only produce one seed (Correll and Johnston 1970).

Other than what is listed above, little is known about bushy whitlow-wort’s reproductive biology. Another *Paronychia*, Rocky Mountain nailwort (*Paronychia pulvinata*), is known only to reproduce sexually (Forbis and Doak 2004). As a member of the Pink Family (Caryophyllaceae), whitlow-worts and nailworts are commonly self-compatible (East 1940). Rocky Mountain nailwort has two separate sexual types which co-occur in the same population; some plants have only female flowers and other plants have only hermaphroditic flowers (where both male and female structures occur on the same flower) (Puterbaugh 1998). Ants (*Formica neorufibarbis gelida*), as they forage for nectar, are 99% of the visitors to and are likely pollinators of Rocky Mountain nailwort (Puterbaugh 1998). However, studies have only shown that these ants regularly contact stigmas and anthers, pollen grains germinate, and pollen tubes grow down styles (Puterbaugh 1998).

Forbis and Doak (2004) demonstrated that Rocky Mountain nailwort's growth and survival of mature plants over the short-term would show little change (Forbis and Doak 2004). However, the life span of Rocky Mountain nailwort was predicted to be over 300 years (Forbis and Doak 2004). Seedling survival was predictably low in relation to its lifespan and potential reproductive output as an adult (Forbis and Doak 2004).

Population ecology of species (interactions and hybridization)

In 1990, both bushy whitlow-wort sites were active cattle ranches, but no information exists on the potential threat that herbivory by insects or mammals (domestic or wild) poses to bushy whitlow-wort. Many plants in semi-arid South Texas have physical or chemical defenses against herbivores in the form of spines, thorns, or poisonous, unpalatable, or foul smelling foliage. However, no physical defenses have been observed in bushy whitlow-wort and no chemical defenses have been studied. Seeds of another whitlow-wort, papery whitlow-wort (*Paronychia chartacea* ssp. *chartacea*), were eaten by invertebrates (type not identified) due at least in part to their small seed sizes (6 mm) in Florida (Stephens et al. 2012).

Land ownership and management

There is no information that indicates a major man-made or natural disturbance has recently occurred at the two known sites. Oil and gas wells and highway and transmission lines occur in the general area, but as far as could be determined from publically available aerial images construction and maintenance have not impacted the immediate area since the last site visits.

Although two of the three private landowners are known, these landowners declined to sign a Voluntary Conservation Agreement in 2006 (Price et al. 2006). The Agreement would have established the landowner's interest in avoiding and/or reducing alterations to areas with rare plants. These agreements were developed to help prevent the need to list candidate species as threatened or endangered (Price et al. 2006).

Evidence of threats to survival

Bushy whitlow-wort is threatened by habitat alteration or modification and other factors. The area has seen oil and gas exploration in the past, and several gas and oil wells have been drilled within a half mile of the southern population (Railroad Commission of Texas 2013). However, none of these wells are in the immediate vicinity of bushy whitlow-wort, nor do they currently pose any threat to the populations. Brush removal in relation to rangeland or pipeline right-of-way management may negatively affect plant populations. However, current brush removal practices are unknown. Widening of FM 649 could destroy portions of the populations, although no plants have ever been found on the highway right-of-way and this would be the most likely area to be effected by construction. Non-native grasses have been shown to invade South Texas rangelands. Buffelgrass (*Pennisetum ciliare*), Lehman's lovegrass (*Eragrostis lehmanniana*), and guinea grass (*Uruchloa maximum*) have all been recorded in Jim Hogg County and could out-compete native vegetation. Buffelgrass was observed along the highway right-of-way near the Thompsonville NE site in 2014 (Strong 2014). If spray herbicides are used to manage invasive grasses in the right-of-way or on the privately-owned site, drift could potentially damage individuals close to the target areas. Bushy whitlow-wort occurs on thin, calcareous soils along the Bordas Escarpment, a narrow fault line which starts along the Rio Grande River and runs northeast to Live Oak County. The species' limited distribution along the escarpment, small numbers within the two known populations, and possible low reproductive output increases bushy whitlow-wort's vulnerability to catastrophic natural or anthropogenic events. Fruits of bushy whitlow-wort contain a single seed (Correll and Johnston 1970), which may decrease the probability of juvenile recruitment. Extended droughty periods could exacerbate already low seed set by preventing or decreasing the chance of seed set, germination and/or establishment.

Special management considerations

The current status of bushy whitlow-wort is unknown. Landowner relations have been, at best, fragmented. Current landowners need to be determined and re-contacted, and their confidence gained. A limited amount of surveys were conducted in 1987; however, additional surveys should be reinitiated and conducted. Areas in Jim Hogg and Webb counties with willing landowners and similar habitat (soils, geology, and associated plant species) to known populations should be targeted. Long-term demographic monitoring should be set up to determine growth, survival, mortality, and recruitment trends. Information regarding the reproductive biology is lacking. While herbivory of bushy whitlow-wort has not been observed, frequent droughty conditions of South Texas may cause or increase negative impacts from livestock and wildlife grazing. The effects of herbivory should be determined. Competition studies should be initiated to determine if invasive exotic grasses negatively impact populations.

Monitoring methods were described and an unacceptable decline in population numbers and vigor (20%) was assigned (Candee 1996). Significant or unacceptable declines were defined as a 20% decrease in total population in two consecutive years (Candee 1996). However, this percentage was chosen for all species within the report because it was seen as a reasonable rate of change for a species where information is lacking. The purpose of a management plan is to establish if management in place is appropriate and if the default rate of change is appropriate for bushy whitlow-wort.

A monitoring and management plan could establish a protocol to regularly and systematically count the existing populations of this species and might help clarify the extent to which internal factors (like reproductive biology) versus external factors (like herbivory) affect the fluctuation in numbers within sites. In 1995, bushy whitlow-wort was assigned an overall high species priority by Texas Parks and Wildlife Dept. (TPWD), a qualitative designation which considered rarity, threat, ability of TPWD to recover, population trends, etc. (Linam 1995). Important needs for this species included more surveys on private lands, monitoring to determine demographic trends, maintaining appropriate stocking rates, and avoiding clearing the area (Linam 1995).

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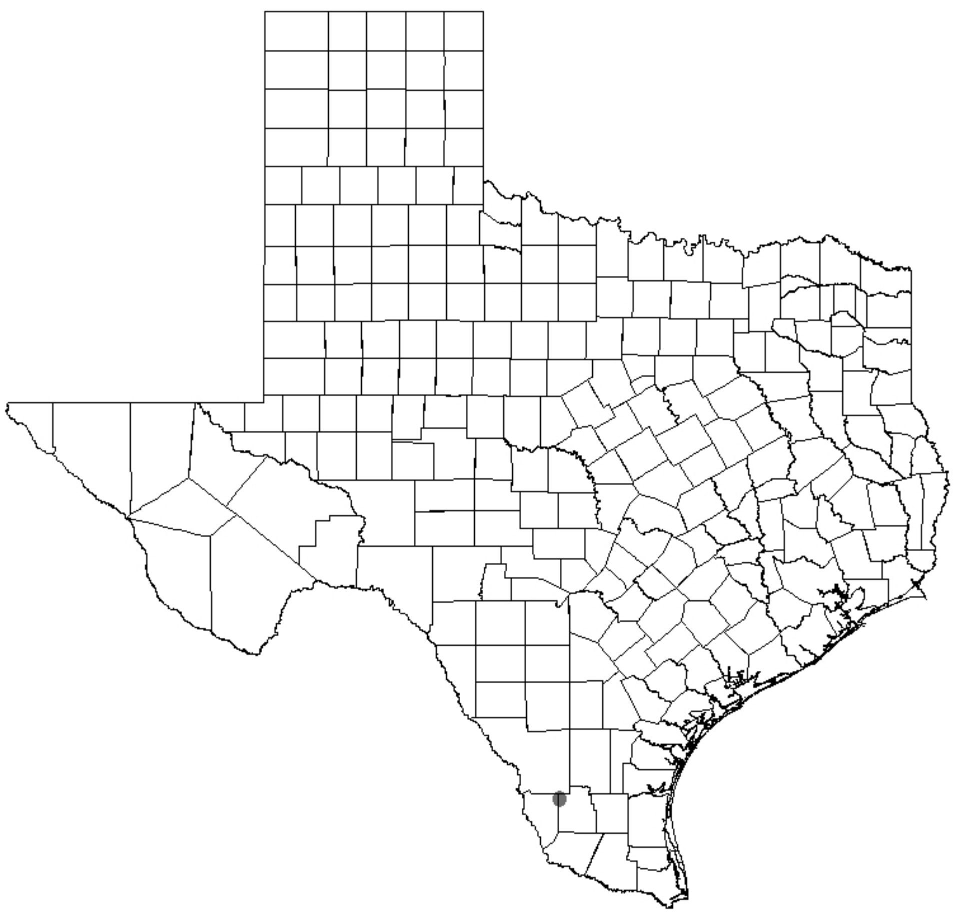
Table 1. Bushy whitlow-wort population status, including location and ownership (Texas Natural Diversity Database 2013).

County	Year discvrd	Last year seen	EO ID+	Site name	Landowner	Min. # per 1 subpop.++	Max. # per 1 subpop.++
Jim Hogg	1963	1987	1611	Thompsonville SW	Private	4 (1983)	~2,000 (1987)
Jim Hogg	1987	1994	7761	Thompsonville NE	Private	92 (1991)	1,904 (1994)

+ EO ID is the unique number assigned to a new record (element occurrence) in the Texas Natural Diversity Database. An element occurrence (EO) is an area of land where a species resides/resided (i.e., a population). An EO can consist of one or more subpopulations.
++ represents number of individuals recorded in any year at a subpopulation; each count is based on surveyor effort and is only as good as the effort expended (e.g., larger numbers, such as >1000, could be gross underestimates/overestimates)

Figure 1. Distribution of extant populations of bushy whitlow-wort (*Paronychia congesta*).



Addendum
After the writing of this assessment, access to a private property in Jim Hogg County was granted. Although allowed on the property, TPWD was not given permission to make public the location of the site. However, the data collected onsite can be shared. In July of 2014, a 1.8 acre site was surveyed for bushy whitlow-wort. A total of 633 plants were counted and 99% of these were in flower. Plants recorded in the immediate vicinity of bushy whitlow-wort included purple threeawn (*Aristida purpurea*), fairy duster (*Calliandra conferta*), stinging cevallia (*Cevallia sinuata*), sandmat (*Chamaesyce* sp.), featherplume (*Dalea frutescens*), bluet (*Houstonia* sp.), ratany (*Krameria ramosissima*), dotted blazing star (*Liatris punctata*), shrubby milkwort (*Polygala lindheimeri*), stiff greenthread (*Thelesperma filifolium*), and desert zinnia (*Zinnia acerosa*). Immediately outside of the bushy whitlow-wort population were larger South Texas shrubs and trees including blackbrush (*Acacia rigidula*), Mormon tea (*Ephedra* sp.), desert olive (*Forestiera angustifolia*), coyotillo (*Karwinskia humboldtiana*), cenizo (*Leucophyllum frutescens*), Texas mountain laurel (*Sophora secundiflora*), and Spanish dagger (*Yucca treculeana*).

Bracted twistflower
(*Streptanthus bracteatus*)

Species information (history of knowledge of taxon)

The first collection was made in 1846 by Ferdinand Lindheimer in New Braunfels, TX (Comal County) (#5180, BRIT). A year later, in 1847, this specimen was used to describe and illustrate the species. Other historic sites were collected from in 1884 (Bandera), Bexar (1849) and 1916 (Real) (Reverchon #1486, MO; Lindheimer #19 and #676, MO; Palmer #10155, MO). Historical herbarium specimens collected before 1950 have location information too vague to relocate.

Present legal status (National and State)

Although not listed as endangered or threatened by the State of Texas, bracted twistflower is ranked as a G1G2 (globally critically imperiled to imperiled) by NatureServe. The species is also listed on Texas Parks and Wildlife Department's 2010 List of the Rare Plants of Texas and as a Species of Greatest Conservation Need in the Texas Parks and Wildlife Department (TPWD) State Conservation Action Plan.

In 1980, bracted twistflower was designated by the United States Fish and Wildlife Service (USFWS) as a Category 2 Candidate species (U. S. Fish and Wildlife Service 1980), a species which warranted protection, but which lacked sufficient biological status and threat information. However, in 1996, to allow USFWS to focus on protecting the many species for which sufficient information was available, all Category 2 Candidate species were dropped from the Endangered Species Act (ESA) (U. S. Fish and Wildlife Service 1996). The discontinuation of Category 2 Candidates did not eliminate the ability for a species to be listed under the ESA, it only encouraged states to find better, more recent information on species of concern. Therefore, in 2011, after more biological and threat information was collected and provided to the USFWS, the bracted twistflower was designated as a candidate species (U. S. Fish and Wildlife Service 2011).

Although the 1996 Balcones Canyonlands Habitat Conservation Plan considered bracted twistflower a "primary species of concern", it did not specifically protect it. Seeing a need to coordinate activities by interested individuals, the Bracted Twistflower Working Group formed and has been meeting since the early 2000s to annually discuss progress, research, survey[3] counts

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[3] Surveying occurs on new territory without the intent of returning regularly through time or obtaining population counts for comparison.

[4] Censusing occurs in the same general area with the intent of returning regularly through time to obtain population counts.

and censusing[4], and current management concerns of the plant. The group includes current and former employees of the City of Austin (COA), Travis County, Texas Parks and Wildlife Department (TPWD), Lady Bird Johnson Wildflower Center (LBJWC), USFWS, the City of San Antonio (COSA), The Nature Conservancy, Bright Leaf Preserve, UT Austin, Texas A&M, and St. Edward's University professors and students, volunteers, and others. To officially coordinate protection efforts of bracted twistflower on all BCP lands, a voluntary Memorandum of Agreement was signed in 2004. The agreement addresses surveying and censusing, restoration and educational activities to be undertaken by the USFWS, TPWD, COA, Travis County, Lower Colorado River Authority, and LBJWC. As a result of the MOA, all known populations on COA land (the introduced Vireo population and the natural populations at Bee Creek, Mt. Bonnell, and Barton Creek) are annually censused and have been protected to some extent (some fencing and educational signage).

Description (local field characters)

Because bracted twistflower is a winter annual with a short flowering period and is a basal rosette for several months out of the year, special attention must be paid to locate and identify it. As a seedling, the plant is ½ cm to ~4 cm across and can have up to four secondary leaves clustered on a 1 cm long stem. Leaves are dark green with purplish overtones (Carr 1991). The smaller leaves have smooth leaf margins, whereas the larger leaves are slightly incised with the teeth pointing back toward the stem (Carr 1991). The larger leaves have ~1 cm long petioles and ~1 cm long blades (where the width is about 4/5ths of the length) (Carr 1991). Bracted twistflower can be confused with other closely-related mustards (Brassicaceae) and similar-looking rosette-forming sunflowers (Asteraceae). In flower or fruit, Brazos rockcress *(Streptanthus petiolaris*, formerly *Arabis petiolaris)* can be distinguished from bracted twistflower by the absence of bracts at the base of the flower's stem and shorter, flatter fruit. Bracted twistflower has bracts at the base of the flower's stem and longer, rounder fruit (Enquist 1987). When plants have only leaves, bracted twistflower can be identified by the clasping leaf bases on the stem, opposed to the non-clasping leaf bases of Brazos rockcress. Another rosette-forming plant, rock lettuce (*Pinaropappus roseus*), lacks the deep purple, which appears on the underside of bracted twistflower leaves (Zippin 1997).

Geographical distribution (range and precise occurrences)

Bracted twistflower has been recorded in eight Central Texas counties spanning 130 miles from east to west (see Table 1 and Figure 1). Three of these counties (Bandera, Comal, and Real) represent historical records known only from herbarium specimens. In 1982, bracted twistflower was discovered in Travis County off of Valburn Road in northwest Austin. From 1987 to 1995, populations were discovered in Uvalde County (in Garner State Park), Medina County, and Bexar County. By 2010, sixteen populations in five counties had been discovered. Half of these populations are in Travis County and five are (at least in part) on City of Austin (COA) land.

In the Flora of North America treatment, Austin and Blanco counties are listed as locations for bracted twistflower (Al-Shehbaz 2010). Al-Shebahz likely confused Austin, TX (Travis County) for Austin County. Blanco County is listed due to a specimen (Tharp #786, TEX) collected along or near the Blanco River. However, the Blanco River runs through Hays, Blanco, and Kendall counties. It is unclear where exactly Tharp collected this specimen. Finally, in Turner et al.

(2003) the bracted twistflower map includes a location in Burnet County. This was confirmed to be erroneous by Turner (Turner 2005).

General environment and habitat description (physical and biological characteristics)

A species endemic to the Texas Hill Country, bracted twistflower occurs over thin soils on Cretaceous limestone primarily of the Devils River, Edwards, Glen Rose, or Walnut formations (Natural Resources Conservation Service 2013). Plants have been located within 10km of the boundary between the Glen Rose Formation and the formation directly above it (Fowler 2014). Soils are described as Brackett, Bosque, Ector, Eckrant-Rock, mixed alluvial, Real, Speck, Tarrant-Rock, and Volente. As classified by the National Resources Conservation Service (NRCS), these soils are mostly clays and clay loams, which occur above low-porosity limestone or dolomite layers and follow the Balcones Fault Zone (Pepper 2010a). Zippin (1997) analyzed soils from five of the Travis County sites in 1996. The results of these samples indicated that soils were 36-49% sand, 18-32% clay, 4.2-5.2% organic matter, and 7.7-8.1 pH. These results show that the soils, at least in Travis County, are loamier than the soil series suggest. The limestone soils were slightly to moderately basic, which could cause phosphorous to immobilize in the soil and make it hard for plants to access this important micronutrient. A field experiment in an area not historically containing bracted twistflower showed that an area significantly higher in sand, sulfur, and calcium content and significantly lower in clay, nitrogen and phosphorous content, yielded decreased reproduction, growth and survival in planted seeds and seedlings compared to these same factors in areas where bracted twistflower naturally occurs (Zippin 1997). More recent soil analyses have been conducted for a few of the Travis County sites (Bright Leaf, Mt. Bonnell and Cat Mountain) (O'Donnell 2013).

Bracted twistflower is often found in low, dense shrubs, though this could result from herbivores preferentially selecting browse in more open areas. In 1989, it was reported that plants were mostly located on woodland edges and in the open, among grasses (Dieringer 1989). Canopy cover has been recorded between 25% and 100% (McNeal 1989); however, it has been shown that in certain circumstances, plants in 50% shade will not reproduce (Leonard and Van Auken 2013). One study indicates that canopy cover <50% is optimal (Fowler et al. 2012), but where or if there is a narrower range under 50% canopy has yet to be determined.

It has been suggested that seeps in the limestone "steps" or layers, along with humus deposition, provide suitable moisture requirements (Dieringer 1989). Plants occur on flat to steeply sloping (0-35%) hillsides on all aspects and from 580 to 1550 feet (Damude and Poole 1990). The habitat is usually dominated by Plateau live oak/Ashe juniper (*Quercus fusiformis*/*Juniperus ashei*), oak/ash/black cherry (*Quercus* spp./*Fraxinus* spp./*Prunus serotina*), Ashe juniper woodlands or Ashe juniper/little bluestem grassland (*Schizachyrium scoparium*) (McNeal 1989) and can be cut by seasonally wet drainages.

Associated species of bracted twistflower vary to some extent from site to site across the Hill Country, but drought-adapted species are common to all sites. Dominant tree species co-occurring with bracted twistflower include Ashe juniper (*Juniperus ashei*), Plateau live oak (*Quercus fusiformis*), Texas ash (*Fraxinus texensis*), black cherry (*Prunus serotina*), bastard oak (*Quercus sinuata*), Texas oak (*Quercus buckleyi*), Lacey oak (*Quercus laceyi*), Texas mountain laurel (*Sophora secundiflora*), and cedar elm (*Ulmus crassifolia*). Dominant shrubs include evergreen sumac (*Rhus virens*), Lindheimer's silktassel (*Garrya ovata* ssp. *lindheimeri*), oreja de raton (*Bernardia myricifolia*), skunkbush sumac (*Rhus trilobata*), Texas persimmon (*Diospyros *texana*), elbowbush (*Forestiera pubescens*), Mexican buckeye (*Ungnadia speciosa*), Texas redbud *(Cercis canadensis* var. *texensis*), and shrubby boneset (*Eupatorium havanense*). Dominant herbs and grasses include Plateau goldeneye (*Viguiera dentata*), seep muhly (*Muhlenbergia reverchonii*), little bluestem (*Schizachyrium scoparium*), sideoats grama (*Bouteloua curtipendula*), Pennsylvania pellitory (*Parietaria pensylvanica*), and cedar sedge (*Carex planostachys*). Other species often found in the same habitat are false day-flower (*Tintantia anomala*), white milkweed (*Asclepias texana*), rock lettuce (*Pinaropappus roseus*), snapdragon vine (*Maurandella antirrhiniflora*), red leather-flower (*Clematis texensis*), and pearl milkweed (*Matelea edwardsensis*).

Precipitation from the western to eastern part of bracted twistflower's range varies between 25-34 inches annually and falls mostly in May or June and September or October (National Oceanic and Atmospheric Administration 2013). Like other annuals, bracted twistflower population dynamics could be driven, at least in part, by annual winter precipitation (Damude and Poole 1990). This has not yet been shown to be definitively the case with bracted twistflower. One report informally compares subpopulation counts from multiple sites to rainfall totals for various time periods prior to data collection over several years (Linam 2002). Although one-to-one comparisons are difficult with existing data, it is clear that only one in every few years has higher plant counts.

As is the case for many annuals, some disturbance may play a role in the maintenance of bracted twistflower populations; however, the amount and type of disturbance is unknown. It has been suggested that like other eastern *Streptanthus* species, bracted twistflower may be an early successional species, more able to persist in open areas with some disturbance than areas with well-established canopies (Kral 1990). Arkansas twistflower (*S. maculatus* ssp. *obtusifolius*) has responded well to management with fire (Arkansas Native Plant Society 2006) and Goodman pineoak jewelflower (*S. squamiformis)* (Oklahoma Natural Heritage Inventory 2006) will persist in areas with light disturbance. Several California *Streptanthus* species have been noted to respond well to some disturbance [for example, pinewoods jewelflower (*S. longisiliquus*) (Clifton and Buck 2007), variable-leaf jewelflower (*S. diversifolius*) (Al-Shehbaz 2010), and Morrison's jewelflower (*S. morrisonii* ssp. *morrisonii*) (Yolo Natural Heritage Program 2009)].

Population biology of taxon (demography, phenology, and reproductive biology)

The great year-to-year variation in annuals can be attributed to long-lived seeds (seed banks), specific germination requirements, and/or environmental variation. As an annual, bracted twistflower can vary tenfold between years in the same area. Zero to 330 plants have been recorded at the same monitoring[5] plot in a span of four years (Zippin 1997). Plants appear to shift around their environment to occupy the most favorable sites. Populations are composed of multiple smaller subpopulations, which can be spread out across acres and move from year to year as seed set in different areas varies. Comparing population trends among years is difficult because surveying is usually opportunistic and generally covers different areas. Because it is easier, new areas are designated by surveyors each year (but see Zippin 1997) and this is guided somewhat by plant distributions, the landscape, etc. Therefore, if mapped, surveyed areas look erratic. Density within each subpopulation also varies, but is generally described as scattered or

[5] Monitoring is returning to the same exact area with some frequency with the ultimate aim of comparing population numbers through time.

in clumps. For example, one survey recorded 38 plants in 10 m^2 (108 ft^2) and another recorded 10 plants in 465 m^2 (0.1 acre). All subpopulations are rarely, if ever, counted in one year. One Travis County population (discovered in 1989) has over 60 overlapping subpopulations from 20+ years of surveys. Over half of the annual surveys of subpopulations contain 10 or fewer plants, while another third of the surveys have subpopulations of fewer than 100 plants (perhaps this is driven by surveyor preference for manageable areas or numbers). Annual surveys infrequently surpass 600 plants, although there are two recorded exceptions. Two of the Medina County subpopulations have been estimated to have >1000 and >2000 plants, in 2007 and 2001, respectively.

Although only a portion of each might be visited, most of the sixteen populations are regularly to semi-regularly surveyed (although site visits tend to decrease when ownership is private) and were visited in 2012 and/or 2013. The few exceptions to this include several privately owned populations: the Hays County site (plant last seen in 2010), Medina County-Bear Bluff site (last seen in 2001), Uvalde County-Annandale site (last seen in 1997), and the Travis County-Mesa site (plant last seen in 1995). Most of these populations have not been revisited since their initial discoveries, due to the logistics of visiting private lands.

Throughout the 25+ years of surveying, smaller sites are generally surveyed more thoroughly. Larger sites are opportunistically surveyed according to different factors, including the previous years' surveys and available time and surveyors. Survey location, size and shape vary from year to year, as does surveyor thoroughness. Some observers mark the boundary of what was surveyed, whereas others mark one point in the vicinity of the plants. In many cases the areas surveyed each year overlap, but only partially. These surveying practices are not unique to bracted twistflower. To decrease the natural variation of survey techniques between observers and streamline the process, a field form was created in 2012 specifically for individuals involved in bracted twistflower surveying. Observers are currently asked for single GPS coordinates and a distance to the furthest plant from the coordinates.

From 1993 to 1997 three sites in Travis County were formally monitored by David Zippin, a UT Austin graduate student. Permanent markers delineated each plot, each plant was tagged and monitored monthly (or bimonthly during the peak of the growing season), and numbers of new plants, flowers, fruit and seed were counted and recorded. Possibly dependent upon time constraints, areas surrounding the plots were surveyed and plants were either counted or estimated based on exact counts taken inside the plots. One monitoring site (Mt. Bonnell) had plots established on private land, and these were abandoned when the property was developed. However, different adjacent parkland areas continue to be censused. The remaining sites originally monitored by Zippin were owned by the city (Barton Creek and Bee Creek) and continued to be censused after 1997 by TPWD, then COA, and are still censused annually by COA. From 1999 to 2002, annual censuses were made of the plants inside the plots including number of buds, flowers, and fruit, but individual plants were not tracked (as they had been up to 1997). It was suggested that the original 1993 Travis County plots were too small (and possibly too fragmented) to capture the distribution and fluctuation of individuals each year (Linam 2002). Therefore, starting in 1999, plants in the general vicinity, but outside the plots, were counted in addition to plants inside the plots. Although the two COA areas have been censused the longest of any population, attempts to compare data trends over time are confounded by the methodology change from 1997 to 1999 and because fences were erected to decrease herbivory by white-tailed deer (Barton Creek - 1998; Bee Creek - 2004).

Bracted twistflower seeds germinate and produce inconspicuous basal rosettes in October and November (Zippin 1997). The rosettes overwinter and bolt in March growing 0.5 to 1.5 meters tall (Zippin 1997). The western populations appear to bolt, flower, and fruit about 2 weeks ahead of the eastern populations (Damude and Poole 1990). A 1989 study at one Travis County site (Valburn) showed that <33% of flowers produced fruit (Dieringer 1989). In 1989, 30 regularly monitored plants produced 3-38 flowers/plant, 0-13 fruits/plant, and 6-87 seeds/fruit (Dieringer 1989). Population dynamics models show that in dry years only 1-2% of a given plant population could be adults, whereas in wet years 2-15% of a population could be in adult stage (Zippin 1997). Flowering spans from March to June and peaks in May (McNeal 1989). Fruiting occurs from July to August (Zippin 1997).

Bracted twistflower reproduces primarily by out-crossing: outcrossed plants result in 60% fruit set opposed to a <10% fruit set in bagged, un-manipulated and self-pollinated plants (Dieringer 1989). Receptive pollen is presented on anthers, which extend before the stigma is visible. This separation in space most likely decreases the chance of self-pollination (Dieringer 1989). Although effective pollinators have not been identified, a 1989 study observed and recorded the following flower visitors: *Megachile comata* (Megachilid or leafcutter bee), a *Dialictus* bee (Halictid or sweat bee), a Bombiliid fly (bee fly), and a Syrphid fly (hoverfly) (Dieringer 1989). Only the leafcutter bee was thought to be a potential effective pollinator because of its size and frequency of contact with pollen and stigma (Dieringer 1991). Other visitors have been seen at bracted twistflower including a metallic wood-boring beetle (*Acmaeodera neglecta*) (Woolley 2010a, European honeybees (*Apis mellifera*) (Bracted Twistflower Working Group 2006), native bumblebees (*Bombus* spp.) (BTWG 2006), and sulphur butterflies (Pieridae) (Pepper 2010b).

Genetic analysis shows that there is enough differentiation within bracted twistflower populations that augmenting populations should be carefully planned (Pepper 2010a). Introduced plants should be from other populations close enough (in distance) and/or similar enough (in genotype) to the existing plants to retain, or not alter, local genetic adaptations. To maintain the bulk of genetic diversity of bracted twistflower, genotypes from some of the populations in Medina and Travis counties should be established in additional protected areas because these populations represent much of the diversity within the species (Pepper 2010a). Some smaller, isolated populations show low levels of genetic diversity [Eisenhower, Fall Trail (a portion of Mt. Bonnell), Bright Leaf, and Garner State Park] or high levels of inbreeding (Eisenhower – as distinguished from Camp Bullis in Pepper's article) for an outcrossing plant (Pepper 2010a). Some sites were sampled but had very few plants to collect from (Garner State Park, Bright Leaf Preserve) (Pepper 2010a) and several sites were not sampled (Bear Bluff, Annandale, Mesa, and Hays).To add robustness to the genetic results, plants from these sites should be sampled/resampled when populations have a healthy number of plants (Pepper 2010a).

Although neither mechanical nor facilitated dispersal has been observed, the combination of a hilly habitat and heavy bursts of rainfall would more than likely drive the seeds downslope. At Emma Long Park in 1997, a fairly flat site not known to have bracted twistflower, Zippin introduced an experimental population. He recorded that seed dispersal could happen quickly after a rain event; some seedlings emerged within 2 weeks after planting and up to 80 cm from plots (Zippin 1997). Bracted twistflower seeds can also go into dormancy and form a seed bank when environmental conditions are not suitable. At a Travis County site (Bee Creek), high recruitment was observed after a low seed production year (Zippin 1997). Only a portion of dormant seeds germinate when environmental conditions are favorable to safeguard seeds for following years (Pepper 2007). Dormant seed survival from one year to the next, at least in dry years, is crucial to a population's persistence (Zippin 1997). Population dynamics models show that seed bank persistence could vary depending upon successive wet or dry years. Assuming no additional seed production, consecutive wet years could deplete the seed bank in <15 years, whereas consecutive dry years could deplete the seed bank in 100 years (Zippin 1997).

Much research has been conducted on the light requirements of bracted twistflower. In 2008, an ex situ plot experiment conducted in Travis County (with Travis County seeds) showed that full-sun and shade wall plants produced more flowers and seed than shade cloth (all day in 58% shade) plants, but survival did not vary between treatments (Fowler et al. 2012). The full sun treatment was unshaded from sunrise to sunset (Fowler et al. 2012). The shade wall experiment represented what a plant would experience at the edge of a woodland where the plant would have some hours of full sun, some of full shade, and a few hours of part shade (Fowler et al. 2012). This study also showed that in situ Travis County populations of bracted twistflower prefer and thrive under 37-48% cover (and possibly lower), whereas canopy cover in the remaining natural habitat averaged 63-68% canopy cover, which may indicate that the plants are now persisting in suboptimal habitat (Fowler et al. 2012). Another shade cloth/pot experiment in Bexar County (using Medina County seeds, which had been crossed multiple times and chosen for non-dormancy, i.e., essentially cultivated), showed that basal diameter, shoot height, and mean dry mass were all significantly greater in the higher sun treatment(s) compared to lower sun treatment(s) (Leonard and Van Auken 2013). Both the Leondard and Van Auken (2013) and Fowler et al. (2012) studies agreed with Fowler's 2014 study, which indicated that higher light levels favor bracted twistflower when compared with light levels under closed canopy.

Population ecology of species (negative interactions)

Only white-tailed deer has been observed browsing on bracted twistflower (Zippin 1997), but other introduced, non-native ungulates could be feeding on the plant. In the 1930s, landowners in Texas began importing exotic axis deer (*Cervus axis*) and European wild hogs (*Sus scrofa*) for sport hunting. Although difficult to estimate, axis deer and feral hogs are estimated to be out-numbered only by white-tailed deer in Texas (Texas Tech University 1997; Taylor 1991). Populations of all three ungulates are kept healthy by the eradication of screwworm. Feral hogs have high reproduction rates and low hunting pressures. White-tailed deer are semi-protected in and around urban areas by hunting regulations and are well-fed with landscaping plants and food plots. The TPWD-owned Uvalde County site of bracted twistflower is said to be inhabited by white-tailed deer, axis deer, feral hogs, and goats.

Other vertebrate herbivores could also be browsing on bracted twistflower. In one study, three different methods (deer fencing alone, poultry wire around the base of deer fencing, and bird netting over the top of deer fencing) were attempted, but failed to reduce intense herbivory (Fowler 2010). Installing deer fencing and poultry wire around each individual plot finally decreased herbivory, suggesting a ground or tree squirrel (Fowler 2010). Because squirrel herbivory had not been observed prior to this study, it was suggested that the 2009 drought may have caused new (or increased) feeding patterns of herbivores. Although not mentioned by previous authors, rabbits, mice, or aoudads could also be feeding on bracted twistflower. Certainly, smaller herbivores could be influencing post-dispersal of seeds, and if so, a variety of predators could be at fault and could be affecting profound changes on demographic trends (Zippin 1997).

Invertebrate herbivores, although not as detrimental as deer, have been shown to decrease bracted twistflower's survival rate. These herbivores include falcate orange-tip butterfly and larvae (*Anthocharis midea*) and two flea beetles (*Psylliodes* sp. and *Phyllotreta* sp.) (Zippin 1997). These insects feed exclusively on and are common pests of members of the mustard family. The gray looper moth and larvae (*Rachiplusia ou)* and white lined sphinx larvae (*Hyles lineata*) (Price 2003) have also been recorded on plants, as has the checkered white butterfly (*Pontia protodice)* (Leonard 2010).

Non-native plants could pose a threat to bracted twistflower. Naturalized non-natives common at most sites include heavenly bamboo (*Nandina domestica),* glossy privet *(Ligustrum lucidum),* Chinese privet *(Ligustrum sinense),* chinaberry *(Melia azedarach),* Fraser photinia *(Photinia* x *fraseri*), and Taiwanese photinia (*Photinia serratifolia)*. Many of these woody species are found on Travis County sites and are removed as part of the management plan of the BCP to decrease competition with bracted twistflower.

Since 1993, powdery mildew has been recorded at all bracted twistflower sites and counties. Powdery mildew is a pathogen caused by different species of fungi in the sac fungi order Erysiphales (Kendrick 2001). Although mostly studied on economically-important crop plants, sac fungi are species-specific to their host plant (Newman and Pottorff 2013). Texas crops with powdery mildew problems include crape myrtles, roses, zinnias, cucumbers and peppers (Texas Plant Disease Diagnostic Lab 2010). Powdery mildew has also been recorded on mustards (Brassicaceae), the family of which bracted twistflower is a member. The fungus is adapted to humidity and cooler temperatures (<90°) (Newman and Pottorff 2013). Powdery mildew appears as white patches and can infect most parts of the plant. Although powdery mildew fungi have been shown to decrease growth and yield in crop plants, the exact fungus infecting bracted twistflower is unknown. Management of plants infected with powdery mildew includes growing plants in full-sun (>6 hours/day) and pruning surrounding area to increase air flow to decrease humidity (Texas Agrilife Extension Service 2008). It may be prudent to avoid seed collection when powdery mildew is present on plants. Different observers disagree on the impact powdery mildew has on the growth and fecundity of bracted twistflower (Leonard 2010; Woolley 2010b; Fowler 2014). It may be site and microhabitat specific.

Although two *Streptanthus* species (*S. platycarpus* and *S. petiolaris*) overlap with the bracted twistflower range, they have not been observed at any of the known sites, nor have any hybrids been observed. According to Pepper, broadpod jewelflower (*S. platycarpus*) is most closely related to bracted twistflower, but the two are evolutionarily different from one another and have enough distinct characters to classify them as separate species (Pepper 2010a). Hybridization between other mustards has been observed in agricultural settings, but the chance for *Streptanthus* species to cross with members of the same genus or other members of the mustard family is unknown.

Land ownership and management

In 1982, bracted twistflower was discovered in Travis County off of Valburn Road in northwest Austin. From 1987 to 1995, populations were discovered in Uvalde County [in Garner State Park, owned by Texas Parks and Wildlife Department (TPWD)], Medina County [owned by Texas Department of Transportation (TxDOT), Medina County & private], and Bexar County

[owned by Department of Defense (DoD) and City of San Antonio (COSA)] (See Table 1). By 2010, sixteen populations in five counties had been discovered. Half of these populations are in Travis County and five are (at least in part) on City of Austin (COA) land.
The COA, along with Travis County, manages these sites as part of the Balcones Canyonlands Preserve (BCP) to protect rare plant and animal populations (City of Austin 2007). The Bexar County sites are managed by COSA as part of their preserve system. One of the Bexar County sites is also partially owned and managed by the DoD, but is a relatively small population. All populations are natural except for one Travis County population, which started as an experimental population in 2009 (the greenhouse/Vireo Preserve). This population has persisted for at least four years and is now considered to be an introduced extant population (extant populations are ones that have been observed in the last 50 years).

Contact has been made with various private landowners in the past. To some extent, private lands in Travis County are visited by volunteers of the Bracted Twistflower Working Group. Private land owners in Medina County have shown a particular interest in plant and animal conservation on their lands and in conservation easements (Pepper 2010a). There appear to be no regular attempts at establishing or continuing private landowner relations outside the occasional special project or survey or census.

Management practices

Where the species occurs on state land (Garner State Park), the plant is protected by state law, which specifies that unless in possession of a state-issued permit, it is illegal to “mutilate, injure, destroy, pick, cut, remove, or introduce any plant life” (TPWD Code, Section 59.134). However, Garner attracts over 300,000 visitors annually. One of the areas bracted twistflower occurs in the park is an area used extensively for hiking because of its close proximity to the main camping and swimming areas. Feral goats have been targeted and are being removed from the park (Riskind 2013). There are no specific restrictions at COA parks. Mt. Bonnell, a popular tourist park, has erected signage, which discusses the rare plant and the creation of the BCP, but does not dissuade visitors from collecting. Many smaller social trails have been cut into the area surrounding the main sight-seeing trail, which likely fragments, compacts, and increases erosion of bracted twistflower habitat at this small urban COA park.

At various times in the last two decades, seeds were collected and put into long-term storage or used for introductions or augmentations (see Table 2). All but one of the eight attempts to establish bracted twistflower failed to be self-perpetuating. At least another five attempts were made to grow plants from seeds in gardens and private residences. Several of these ex situ attempts produced seed but the seed were either grown out and did not reproduce or their fate is not known (Table 2). During the mid-1990s, several tracts of land with bracted twistflower were slated for development in Travis County. These populations were collected from multiple times between 1993 and 1995 (Zippin 1997). Some of this seed was used in experimental introductions (exact amount unknown). Seeds from the Valburn population were used in an experimental introduction at Emma Long Park (Zippin 1997). This study was conducted to show habitat preference of bracted twistflower. It demonstrated that plants survive better in a woodland habitat versus grassland habitat at an experimental site and that both propagule types (seeds and seedlings) survive equally well (Zippin 1997). However, even the introduced woodland plants did not fare as well as natural populations. Natural sites of this species are diverse mosaics of open shrublands to densely or moderately shaded woodlands (Zippin 1997). It was theorized that micronutrients (possibly phosphorous) might be lacking at Emma Long Park and specific soil requirements of bracted twistflower could limit its introduction into new areas (Zippin 1997). In 1993, seed was collected from the Bee Creek population by the COA and was sent to LBJWC or were used in various introductions at Zilker Preserve from 1995 to 1997 and Barton Creek in 1997 (Bracted Twistflower Working Group 2006). Seed was used in all of the introductions/augmentation, but of the few plants that emerged, none were recorded to have reproduced. Seed was also collected from Bee Creek and Mt. Bonnell and was either used to augment sites known to already harbor plants (e.g., Bee Creek seeds were moved to Barton Creek) or to introduce the species at other COA parkland (Mt. Bonnell seeds were broadcast at Mayfield Park). No plants were recorded to germinate from these broadcast attempts. There have been at least five organizations and individuals who have tried to propagate seeds in their greenhouses and/or gardens and the populations eventually died out or their fate is unknown. One of these germination attempts showed a 43-44% germination rate over an 11 day period, with 10% reaching their reproductive stage (Price 2001).

Evidence of threats to survival

Throughout its range, bracted twistflower is threatened by habitat fragmentation and destruction, predation, and other factors. Bracted twistflower's range overlaps with one of the nation's fastest growing areas: both Austin and San Antonio are in the top ten fastest growing metropolitan areas and have been for over a decade. The protected Travis and Bexar County sites are directly and indirectly affected by changes in the quality of the habitat caused by the encroaching urban populations. Construction, landscaping, and trash dumping from development could affect the surrounding vegetation through changes in water flow and quality, erosion, and soil removal and deposition (McNeal 1989). Road building and fire suppression fragments, destroys, or alters large tracts of plant habitat. Even protected sites allow recreational activities, like mountain biking and hiking, which can lead to the creation of informal trails and trampling of plants (Poole 2010). The three privately-owned Travis County sites (Valburn, Cat Mountain, and Mesa) are either threatened with destruction or have already been heavily impacted by development. Valburn and Cat Mountain, although still partly intact, have lost portions of habitat to development and the entire area is impacted by proximity to housing. The Valburn and Mesa sites were slated for destruction in the mid-1990s. As a result, all plants and seeds were collected at these two sites (Mesa: 1993, 1994, 1995; Valburn: 1995) as part of David Zippin's dissertation research (Zippin 1997). Despite the collections at Mesa, the seed bank produced a relatively large number of plants in 1995 after two years of harvesting 95% of the seed (Zippin 1997). Also, as recently as 2010, bracted twistflower has been observed at the Valburn and Cat Mountain sites. Plants have not been observed at the Mesa site since seed collection in 1995 presumably due to subsequent development in 1996. However, it is recorded that the site has only been visited and surveyed once after development in 2001. Aerial photos show that potential habitat could still exist (Zippin 2013).

Even though bracted twistflower seems to prefer a woodland habitat without ground and shrub cover, the overpopulation of white-tailed deer has likely pushed the plant to shadier, but more protected, sites (McNeal 1989). Following TPWD recommendations of deer densities, the BCP strives for one deer to every 15-30 acres in attempts to promote understory regeneration and a healthy habitat for wildlife (Travis County and City of Austin 2012). Annually, BCP culls deer from their lands, but still estimates of deer densities are high (1 deer: 7 acres) (Travis County and City of Austin 2012). Estimates are not made every year on all properties; therefore, deer densities at most bracted twistflower site are unknown. However, the deer population on the COA property adjacent to Vireo Preserve was estimated from 2008-2011 and ranged between 1 deer to 1.4 acres and 1 deer to every 3.3 acres. This preserve, like all BCP properties, is on COA land and hunting is not allowed except by special permit. Like other forbs that are not browse-resistant, bracted twistflower is negatively impacted by the high deer densities across Travis County. It has been shown that caged plants protected from white-tailed deer (*Odocoileus virginianus*) herbivory are not only more likely to survive, but also grow larger and are more likely to reproduce (Zippin 1997). Although other animals have been recorded to eat bracted twistflower, white-tailed deer eat more tissue, larger plants, and are more destructive (they will uproot more plants) than other herbivores (Zippin 1997). Deer herbivory can reduce plant survival by up to 40% and delay growth and reproduction (Zippin 1997). Population dynamics models show that deer herbivory impact population growth rate to such an extent that one Travis County site (Bee Creek) was predicted to go extinct in 50 to 100 years. In general, populations at risk of extinction were those in decline or those that had high variation in growth rates from year to year (Zippin 1997). However, in the absence of deer herbivory, all models indicated that bracted twistflower growth rate would increase (Zippin 1997).

The Medina County populations are potentially threatened by road maintenance and construction activities. It has been reported that the Hwy 1283 right-of-way site has been widened, impacting at least a portion of the population there (Pepper 2008). Also, if herbicide is used along the power lines near CR 270, these populations could be negatively affected by drift and/or direct spray. It has not been confirmed if herbicide is being used at this site.

Special management considerations (past, present, and future)

Although great effort has been expended attempting to determine the exact habitat requirements of bracted twistflower, they have yet to be resolved. Fowler (2014) found that occupied and unoccupied sites of bracted twistflower lack differences and concluded that currently unoccupied areas close (<50 meters) to currently occupied or historically occupied areas should be considered appropriate habitat. Not only is the plant elusive (it can be common at a site one year, absent the next, and common the third year), but surveying a site in only one year can give false negative results. For example, the Bright Leaf population was found only after four attempts, three in one year and another six years later (Carr 2001). A couple of organized attempts have been made to predict where new locations might occur. In 1987 an herbarium specimen location description was used to attempt to relocate a site along the Blanco River (Damude and Poole 1990). Again in 1990, in preparation for the Balcones Canyonlands Conservation Plan, surveys were conducted in Travis County based on habitat defined by McNeal in 1989 (Damude and Poole 1990). In total, 36 sites were visited but all gave negative results. In the mid-1990s, Zippin (1997) laid out eight habitat conditions from which field experiment sites should be chosen to most closely resemble healthy bracted twistflower habitat. In addition to ease of access, a protected woodland with the correct geology, aspect, and herbivore density was chosen; however, these carefully delineated conditions still failed to induce a sustainable population when plants were introduced to a methodically chosen new site (Zippin 1997).

There are different opinions as to the type and level of disturbance (if any) required by bracted twistflower to maintain healthy populations (Fowler et al. 2012; Reiner 2013). These differing views are based partly on the differing views of historic vegetation trends and fire frequency in the Texas Hill Country. Prescribed fires have been suggested as a management tool to decrease woody vegetation since the species has shown a preference for <50% canopy cover (Fowler et al. 2012). But at least in Travis County on public lands, this management is not considered suitable in an area where aerial photographs show a closed canopy since at least 1940 (Reiner 2013). Regardless of the historic trends and past fire frequency, bracted twistflower is surrounded by urban areas in most sites. Conducting prescribed burns will politically and logistically always be a challenge. Additionally, bracted twistflower overlaps with the federally endangered golden-cheeked warbler (*Dendroica chrysoparia*), which was one of the main drivers for the creation of the BCP lands and plan. The golden-cheeked warbler's preferred habitat is a closed canopy. Until definitive proof is shown that bracted twistflower relies on fire to sustain healthy populations, the legal and practical concerns will most likely out-weigh the possible needs of one unlisted species. Fire-suppression could be decreasing bracted twistflower numbers, but prescribed fires in urban areas are politically a hot topic. Field experiments in sites already undergoing prescribed fires (some BCP properties are managed with prescribed fires), but are not historically-known as bracted twistflower sites, may be appropriate sites to conduct such tests. Another option could be to conduct small scale ($10m^2$ plots) prescribed fires in known bracted twistflower sites.

Effective monitoring of bracted twistflower likely requires a large permanent transect to detect real demographic trends (i.e., multiple line transects with 30 $1m^2$ randomly chosen but regularly spaced quadrats). Censusing has replaced monitoring because it is less time consuming. Unfortunately, for this annual species, censusing is not necessarily informative about population trends. Finding the correct indicator of bracted twistflower population status is vital. Because the censusing of population numbers is opportunistic and therefore not necessarily indicative of population trends, another health indicator may more readily reveal status trends of the population. For example, a Travis County field experiment found that in 2009 and 2012 there was a significant and positive correlation between summed seedpod length (total length of all seedpods measured on an individual plant) and seed set (Fowler et al. 2012; Fowler 2014). To effectively manage for bracted twistflower, management decisions and changes should be recorded along with population health and status. A preliminary report outlining monitoring plans and management objectives for all candidate species suggested a 20% decrease in total population from one year to the next was considered a significant enough change in bracted twistflower populations to trigger management action (Candee 1996). However, at the subpopulation level, this decrease is not appropriate for an annual like bracted twistflower. At the population level, more data than what are available is required to detect a real change. More recently, the Balcones Canyonlands Preserve Land Management Plan outlined management objectives for bracted twistflower and two other rare plant species (City of Austin 2007). However, none of the objectives are specific enough, so measuring success of management is difficult. The objectives do not have a, "… standard, desired state, threshold value, amount of change, or trend…" that is measurable (Elzinga et al. 1998).

Much effort has gone into researching bracted twistflower to determine its habitat requirements and threats. This is partially due to the attraction and convenience of studying a rare plant within the major metropolitan areas of Austin and San Antonio. However, more research is needed to resolve basic biology and trends in the population. Annual plants are known for being difficult to monitor because of the large fluctuations they can experience from year to year within a single site. Due to this flux, they require longer-term monitoring than many perennial plants. Some annuals are best monitored via aspects of their habitat or their threats, which can be used as an indicator of the target species' success (Elzinga et al. 1998). A habitat indicator, for example, could be non-native or native plant density, percentage of site disturbance (by hikers, bicyclists or ROW maintenance), soil variables, herbivore densities or damage, etc. For bracted twistflower, it may be that monitoring one of these indicators is just as, if not more, revealing of population trends than monitoring the actual plants. However, these indicators are species-dependent (based on life history and morphology) and should be chosen carefully and be reassessed over time to verify the continued correlation between the indicator and the target species (Elzinga et al. 1998).

Deer removal can increase survival, reproduction, and growth of bracted twistflower (Zippin 1997). However, culling herds is not always effective or practical; therefore, fences have been erected around parts of two Travis County populations (Barton Creek and Bee Creek) and one Bexar County (Eisenhower Park) population. Another Bexar County population (Rancho Diana) is currently being fenced though completion date is unknown (Leonard 2013). Fencing may be an effective management activity for protecting populations from deer, but in lieu of or in addition to fencing on larger properties, other strategies should be explored. It has been proposed that bracted twistflower may be more palatable than other herbaceous vegetation (Poole and McNeal 1986); however, this has never been studied. Seed viability after passing through the gut of white-tailed deer could also be explored (Damude and Poole 1990). Palatability, frequency of herbivory by smaller herbivores, and seed viability after deer dispersal could give additional insight into how much herbivores impact bracted twistflower populations.

Introductions using seeds (vs. seedlings) were more successful and less time consuming (Zippin 1997). But there has been no success with repeated introductions using seeds in areas not previously occupied by bracted twistflower. It is possible that the areas chosen for introduction were not preferred habitat. But it could also be that a more involved protocol is required than broadcasting seed (for example, tracking individual seeds through time). Zippin has shown that seeds sown on the soil surface, opposed to just below the soil surface, can result in lower germination rates (Zippin 1997). This could be influenced by post-dispersal predators, which have not been observed as of yet. Seed bank size and viability needs to be determined. Zippin's studies show that a seed bank can form but under what conditions and how long it lasts is critical for understanding the entire life cycle of bracted twistflower.

Soil samples from Medina, Uvalde and Bexar counties may shed more light on habitat requirements across bracted twistflower's entire range. The species has a fairly large possible habitat area along the Balcones Fault so additional surveys in rural areas west of Travis County could result in more populations. In addition to new searches based on potential habitat, the DoD site should be thoroughly searched for additional bracted twistflower populations. It is actively managed for conservation and has distinct genetic diversity, which other sites do not (Pepper 2010a). Pollinators have not been sufficiently studied. Visitors are helpful in identifying effective pollinators, but effective pollinator studies across the species' entire range would elucidate if appropriate nearby pollinator habitat is also being protected. TxDOT ROW maintenance for Medina County along FM 1283 is full-width mowing twice a year, once in early summer and once in December (Hudson 2013). To ensure that mowing and herbicide use along roads and power lines are enacted at the right times, communication with maintenance crews is necessary. Because so many populations occur on private land in the urban setting of Travis County, landowner contact is essential to accessing and protecting privately-owned populations. Maintaining constant contact with these landowners will establish trust and continual access to these sites. Management conducted on public land should be assessed before and after activities are initiated. Without reassessment of management activities, bracted twistflower has less of a chance of being correctly managed. Although annual plants can create additional challenges more so than perennial plants, they also are short-lived and can respond quickly to management to show if a selected regime is appropriate (Elzinga et al. 1998).

A monitoring plan could establish a protocol to regularly and systematically count and/or help develop another health indicator of the existing populations of bracted twistflower. A reintroduction plan was started by members of the Bracted Twistflower Working Group, but languished with staff turnover. If reintroductions, introductions, or augmentations are to continue, and because many reintroductions have failed, a reintroduction plan should be completed before more attempts are made. A plan will help outline the successes and failures of past attempts and direct future efforts.

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Table 1. Bracted twistflower population status, including location and ownership (Texas Natural Diversity Database 2013).

County	Year discovered	Year species last seen	EO ID[+]	Site name	Landowner	Min. # per 1 subpop.[++]	Max. # per 1 subpop.[++]
Extant natural sites							
Bexar	1995	2013	7551	Eisenhower	COSA, DoD	0	129
Bexar	2010	2012	9013	Rancho Diana	COSA	0	119
Hays	2010	2010	9014	Hays	private	0	~40
Medina	1990	2012	625	Medina Lake N	TxDOT, county, private	0	424
Medina	1990	2012	4641	Medina Lake S	county, private	11	>1000
Medina	2001	*	3749	Bear Bluff	private	>2000	
Travis	1982	2012	2111	Valburn	private, COA	0	590
Travis	1983	2012	6457	Cat Mountain	private	0	248
Travis	1987	2013	8016	Mt. Bonnell	private, COA	0	346
Travis	1989	2013	6843	Barton Creek	COA	0	453
Travis	1989	2010	5603	Bee Creek	COA	1	174
Travis	1992	1995	6928	Mesa	private	0	167
Travis	2001	2013	4354	Bright Leaf	private	1	6-8
Uvalde	1987	2012	8017	Garner	state (TPWD)	0	232
Uvalde	1997	*	6292	Annandale	private	5	
Extant experimental/introduced sites							
Travis	2009**	2013	9015	Vireo	COA	0	~50
Historic sites							
Bandera	1884	*	23	Bandera Pass	Unknown	present	
Bexar	1849	*	3831	Comanche	Unknown	present	
Comal	1846	*	2210	New Braunfels	Unknown	present	
Real	1916	*	1989	Leakey	Unknown	present	

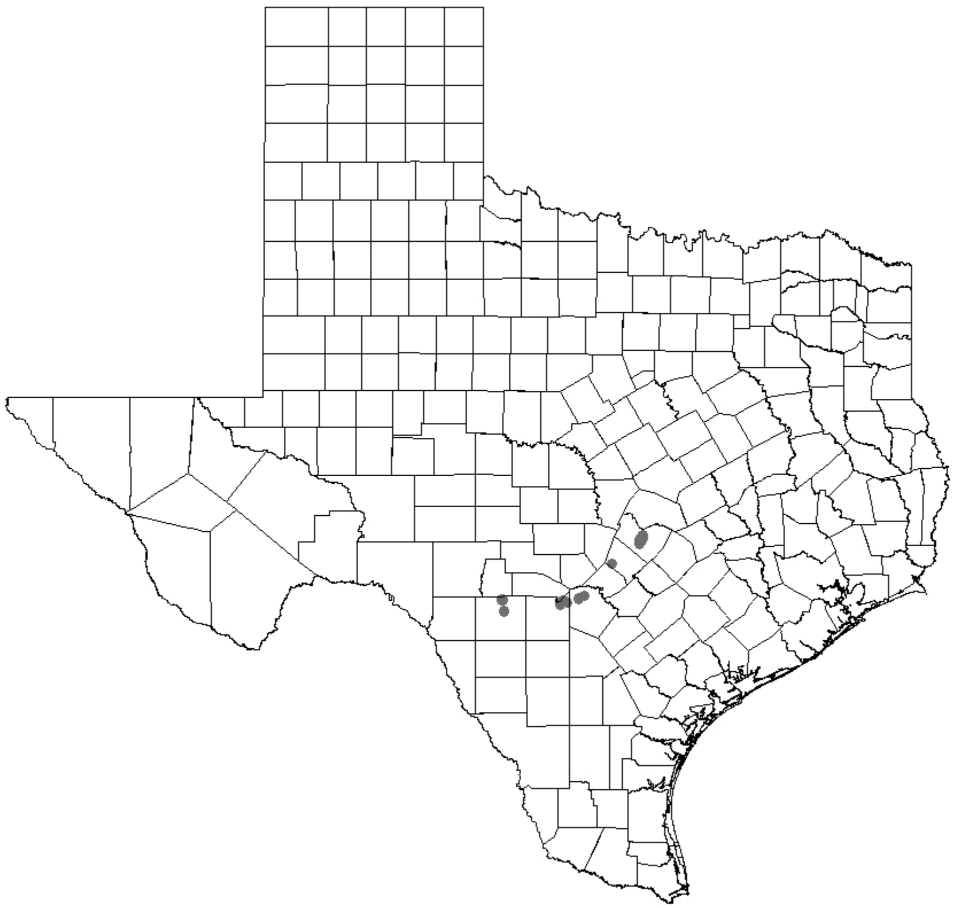
+ EO ID is the unique number assigned to a new record (element occurrence) in the Texas Natural Diversity Database. An element occurrence (EO) is an area of land where a species resides/resided (i.e., a population). An EO can consist of one or more subpopulations.
++ represents number of individuals recorded in any year at a subpopulation; each count is based on surveyor effort and is only as good as the effort expended (e.g., zeros could be false negatives; larger numbers, like >1000, could be gross under- or overestimates)
*indicates year planted, not discovered
**only seen one year

Table 2. In situ and ex situ introductions/augmentations/propagation with seed source, propagule number and type.

Type *	Date	Location	Seed Source	Methodology	Propagule	# propagule	Results
introduction	1997	Emma Long Park	Valburn	experimental	seeds/ seedlings	unknown	did not establish
introduction	1995	Zilker Preserve	Bee Creek	broadcast	seeds	1200	2 plants germinated but died in 1996
introduction	1996	Zilker Preserve	Bee Creek	broadcast	seeds	3055	4 plants germinated in 1997 but presumably died
introduction	1997	Zilker Preserve	Bee Creek	broadcast	seeds	~3500	no plants germinated
augmentation	1997	Barton Creek	Bee Creek	broadcast	seeds	~300	no plants germinated
augmentation	1997	Mt. Bonnell (away from foot traffic)	Mt. Bonnell (S popln)	broadcast	seeds	~250	unknown
introduction	1998	Mayfield Park	Mt. Bonnell (S popln)	broadcast	seeds	~100	unknown
ex situ	1998	Zilker greenhouse/ garden test plot	Bee Creek (but also possibly Barton Creek)	greenhouse/ garden	seeds	180	germ 43-44% over 11 days; 10% reached flowered, 90% died prior to flowering; produced 2769 seeds *(unknown what happened to these)*
ex situ	2002	LBJWC	unknown	greenhouse/ garden	seeds	unknown	seeds produced plants, transplanted to gardens and allowed to seed, unknown if germinated
ex situ	1998	San Antonio Botanic Garden	unknown	greenhouse/ garden	seeds	unknown	Unknown
experimental[+]	2009	greenhouse / Vireo Preserve	Valburn	greenhouse/ experimental	seedlings[++]		2013 count totaled ~50 plants

**introduction:* placement of biological material in a site that has never supported populations of the species;
augmentation: addition of individuals to an existing population, with the aim of increasing population size;
ex situ: refers to conservation of species in seed banks, greenhouses, and garden environments outside of the native habitats of the taxa;
experimental: a population created under strict experimental protocols to test techniques and theories; not intended to serve as founders for a reintroduction effort
[+]this population began as an in situ experiment but was left to go to seed and is now an extant new population
[++]seedlings were all from one individual

Figure 1. Distribution of extant populations of bracted twistflower (*Streptanthus bracteatus*).



Rough-stemmed aster

(*Symphyotrichum puniceum* var. *scabricaule*)

Species information (history of knowledge of taxon)

The first collection of rough-stemmed aster was made in 1947 by Lloyd H. Shinners northwest of Tyler, TX (Smith County) (#9504, SMU). Shinners subsequently described rough-stemmed aster as *Aster scabricaulis* in 1954 from his collection in 1947 and from another 1952 collection collected in Van Zandt County (Daly #157, SMU). Later, another specimen, which had been previously collected in 1943 from northwest of Tyler, TX, was located (Moore #564, US). In 1984, Almut Jones reduced rough-stemmed aster to a variety of *A. puniceus* ssp. *elliottii* based on morphology and chromosome numbers. In 1994, Guy Nesom transferred North American *Aster* to the genus *Symphyotrichum*, making the combination *Symphyotrichum puniceum* var. *scabricaule* (Nesom 1994). Other herbarium specimens indicate that rough-stemmed aster has also been collected in Alabama, Mississippi, and Louisiana (Nesom 1997; Poole et al. 2007).

Present legal status (National and State)

Although not listed as endangered or threatened by the State of Texas, rough-stemmed aster is ranked as a G5T2 (an imperiled variety of an otherwise widespread and common species) by NatureServe. The species is also listed on Texas Parks and Wildlife Department's (TPWD) 2010 List of the Rare Plants of Texas and as a Species of Greatest Conservation Need in the Texas Parks and Wildlife Department (TPWD) State Conservation Action Plan.

In 1980, rough-stemmed aster was designated by the U. S. Fish and Wildlife Service (USFWS) as a Category 2 Candidate species (U. S. Fish and Wildlife Service 1980), a species which warranted protection, but which lacked sufficient biological status and threat information. In 1985, the category assignment was changed to a 3C Candidate (U. S. Fish and Wildlife Service 1985), a species which had been shown to be more abundant. In 1990, the Category assignment was changed back to Category 1 Candidate (U. S. Fish and Wildlife Service 1990), a species which has sufficient biological status and threat information to support proposal to list. In 1993, general status trends were added to Category 1 Candidate species, and for rough-stemmed aster a status trend of declining was assigned (U. S. Fish and Wildlife Service 1993). However, in 1996, rough-stemmed aster was dropped from the list because it did not meet the Endangered Species Act's definition of species (U. S. Fish and Wildlife Service 1996a) and was undergoing a taxonomic review (U. S. Fish and Wildlife Service 1996b). In 2011, a 90-day finding was announced for 374 species from a petition to list 404 in the southeastern United States as threatened or endangered (U.S. Fish and Wildlife Service 2011). The petition presented scientific information to indicate that listing may be warranted for rough-stemmed aster (U.S. Fish and Wildlife Service 2011). Scientific, commercial, and other information was requested and available information was summarized by the USFWS. Of the five threat factors, which can be used to assess if a species may warrant listing as endangered or threatened, the USFWS listed A (present or threatened destruction, modification, or curtailment of its habitat or range) and D (inadequacy of existing regulatory mechanisms) for rough-stemmed aster (U.S. Fish and Wildlife Service 2011).

Description (local field characters)

The following is adapted from Shinners (1953) and Nesom (1997). Rough-stemmed aster is an herbaceous perennial with thick rhizomes, and has more or less erect stems with dense, uniform, coarse, stiff hairs (rough to the touch). The midstem leaves are lanceolate to lance-oblong or oblanceolate (usually 10–13 cm long). The midstem leaves have saw-toothed margins and auriculate-clasping leaf bases with minute coarse, stiff hairs. Hundreds of flower heads (6–10 mm wide) can form on larger plants and are in corymbiform clusters. Outer phyllaries are recurved and bracteal leaves (below the phyllaries) are similar in shape to the stem leaves but smaller (10–25 mm long). There are usually 20–50 ray florets, which are blue or purple and average 12–18 mm long. There are usually 30–50 yellow disc florets, which turn purplish at maturity and are typically 5–6.5 mm long. The fruits are 2.5–3.5 mm long and capped by 35–48 slender bristles.

There are half a dozen or more other East Texas asters with blue or purple ray florets. However, dense and uniform, coarse, stiff hairs on the midstem; clasping, auriculate midstem leaves; and recurved phyllaries distinguish rough-stemmed aster from other east-central Texas asters.

Geographical distribution (range and precise occurrences)

Rough-stemmed aster has been recorded in nine East Texas counties at 31 extant sites spanning 130 miles from north to south (see Table 1 and Figure 1). In this report, following the 2010 *List of the Rare Plants of Texas*, historic populations are those which have not been seen for over 50 years. Extant populations have been observed in the last 50 years. Four sites in Van Zandt and Smith counties were collected from or observed in the 1940s and 1950s. Three of these sites are now historic (Shinners #9504, SMU; Kral 1955; Moore #564, US) and have been searched for, but location information is too vague or inaccurate or the site has been destroyed (Poole 1997). However, the Van Zandt County site first collected in 1952 (Daly #157, SMU) was seen as recently as 2014, although only one plant was observed (Strong 2014a). From 1975 to 1984, populations were also discovered in three new counties: Cherokee, Anderson, and Wood. The Cherokee County population has not been visited since 1977 (Ajilvsgi #5114, SMU; Ajilvsgi #5195, TAMU) when it was first collected. In more recent years (1995 to 2006), populations have also been found in Franklin, Freestone, and Henderson counties.

One collection, supposedly made in Kaufman County (Singhurst #4381, TEX), is rough-stemmed aster. It is unknown where exactly this rough-stemmed aster collection was made. The site was revisited soon after the initial collection and no rough-stemmed aster habitat or plants were present (Poole 1997). For now, the Kaufman County site remains inaccurate and is considered to be a label mix-up (Poole 1997).

General environment and habitat description (physical and biological characteristics)

At least in part, rough-stemmed aster occurs in the Texas Post Oak Savanna Quaking Muck Bog ecological community, where it occupies poorly drained soils scattered with pools of stagnant water (NatureServe 2014). These areas are herb-dominated (sedges, grasses, and rushes) and open except on the margins where woody species can establish (NatureServe 2014). The Texas Post Oak Savanna Quaking Muck Bog community is deemed critically imperiled (G1) (NatureServe 2014). Many of the sites are in deep and highly decomposed muck stream valley bogs or in roadside ditches of forest openings at seepage-fed stream crossings (Bridges 2008). Rough-stemmed aster can tolerate full sun to partial shade and prefers saturated soils. Plants have been found along springheads, seeps, bogs, marshes, small impoundments, drainages (perennial or intermittent), or the degraded remnants of these wetlands (Poole 1997). Precipitation from the southern to northern part of rough-stemmed aster range varies between 46.6 and 47.4 inches annually (National Oceanic and Atmospheric Administration 2014).

Rough-stemmed aster has been mapped over alluvium, terrace deposits, Carrizo Sand, Queen City Sand, Reklaw, Sparta Sand, and Weches Formations. However, ~80% of sites occur over or near Queen City Sands. Soils are described as fine sandy loams, loamy fine sands, fine sands, loams and sands. Approximately twenty soil associations have been identified in relation to rough-stemmed aster sites. The most common of these are Cuthbert fine sandy loam, Darco fine sand, Manco loam, Pickton find sand, and Wolfpen loamy fine sand. MacRoberts and MacRoberts (1998) analyzed soil samples from sandy soils at the edge of a bog in Anderson County. Although only from one site, these samples had a 4.6 pH, 3.4% organic matter, 7 ppm phosphorous, 41 ppm potassium, 200 ppm calcium, and 46 ppm magnesium (MacRoberts and MacRoberts 1998). These results show that soils are acidic and generally low to very low in macronutrients except for possibly magnesium.

In 1984, the dominant species of the sites were listed as smooth beggarticks (*Bidens laevis*), sweetgum (*Liquidambar styraciflua*), seedbox (*Ludwigia* spp.), climbing hempweed (*Mikania scandens*), wax myrtle (*Morella cerifera*), sensitive fern (*Onoclea sensibilis*), water smartweed (*Persicaria punctata*), arrowleaf tearthumb (*Persicaria sagittata*), goldenrod (*Solidago* spp.), and plumegrass *(Saccharum* spp.) (Mahler 1984). After visiting 17 of the rough-stemmed aster sites in 1995, Poole reported, in addition to the 1984 dominants, red maple (*Acer rubrum*), bushy bluestem (*Andropogon glomeratus*), smallspike false nettle (*Boehmeria cylindrica*), blue mistflower (*Eupatorium coelestinum*), rush (*Juncus* sp.), black willow (*Salix nigra*), and calico aster (*Symphyotrichum lateriflorum*) (Poole 1997).

In 1995, a project was undertaken to identify potential, suitable and unsuitable habitat for rough-stemmed aster (Poole 1997). All sites known at the time were assessed for common traits, which included proximity to Tyler, TX (all sites at that time were known to be within 60 miles of Tyler), wetland habitat, and publicly accessible sites (e.g., highway right-of-way, state parks) (Poole 1997). The geology of all known sites was too widespread and was dropped from the site selection criteria (Poole 1997). Thousands of sites were identified on topographical maps that fit the description of wetlands on public land within 60 miles of Tyler, TX, but 467 sites were searched (Poole 1997). Of the sites searched, 70 were deemed potential habitat and nine new sites were found (Poole 1997).

Some disturbance may play a role in the maintenance of rough-stemmed aster populations. For example, fire maintains bogs from being shaded in by woody species on its margins (Bridges 2008); however, the amount and intensity of disturbance (by fire or otherwise) is unknown.

Population biology of taxon (demography, phenology, and reproductive biology)

Although rough-stemmed aster is a rhizomatous perennial, it is unknown to what extent it clones. Identifying population trends within sites is difficult with a rhizomatous plant. When counting plants, it is unknown what exactly is an individual. Although counts have been made where one stem is assumed to be one individual, multiple stems could be one individual (and therefore all counts are overestimates). To further complicate matters, because many older rough-stemmed aster sites are based on herbarium specimens, only qualitative estimates ("locally frequent" or "locally occasional") were taken. About 60% of the sites were counted or quantitatively estimated the one or two years they were visited. Of these sites, eight had less than 30 individuals, three had about 50 individuals, and seven had between ~100 and 508 plants. Because so little data are available, attempting to compare population trends among years is difficult. Additionally, surveying is usually opportunistic and generally covers different areas.

Only one short-term monitoring attempt was made in the early 1990s. From 1991 to 1993 one site (NE Palestine) was assigned a set boundary and was monitored (Poole and Janssen 1997). All plants were counted within the area and for each plant height, number of primary and secondary stems, and number of flowers were counted (Poole and Janssen 1995). Total plant number at the NE Palestine site increased from 16 (1991) to 268 (1995) (Poole and Janssen 1997). Two more sites were added (in 1993) and followed this same monitoring regime. Among all the sites and years monitored, the tallest plant was 2.21 meters, the highest number of primary branches recorded was 15, highest number of secondary branches was 116, and the highest number of flower heads on one plant was 766 (Poole and Janssen 1995). However, due to time constraints in 1994 and 1995, only number of plants was counted at the three sites (Poole and Janssen 1995). The Lake Lydia – Chinquapin site had the largest total number of plants and largest fluctuation between years ever recorded (Poole and Janssen 1997). In 1993, 185 plants were found and the next year >1,500 plants were recorded (Poole and Janssen 1997). This dramatic increase (and subsequent decrease in 1995 to 292) could not be explained (Poole and Janssen 1997).

Over half of the thirty-one populations have not been visited since 1996, although six sites were last visited between 2003 and 2009. Sites have rarely been visited more than a few times; 87% of sites have been visited one to three times. The remaining sites have been visited four to five times and one site (NE Palestine) has been visited nine times (from 1983 to 1995). Six sites with plants present were located in 2014 (Strong 2014a-f)

Flowering spans from July to November and fruiting starts in October. Fruiting is rarely recorded. This may be an artifact of when sites are traditionally visited more than a biological trend. It is also possible that due to identification problems, plants have not been visited when fruits are ripe (and leaves and phyllaries are likely dried out).

Although not studied for rough-stemmed aster, six other aster species [white heath aster (*Symphyotrichum ericoides*), heartleaf aster (*S. cordifolium*), skyblue aster (*S. oolentangiensis*), hairy white oldfield aster (*S. pilosum*), and New England aster (*S. novae-angliae*)] are known to be self-incompatible, including purple-stemmed aster (*S. puniceum* var. *puniceum*) (Woodcock et al. 2014).

In 1995, honeybees were recorded visiting rough-stemmed aster plants (Poole 1995). No other potential pollinators have been recorded on rough-stemmed aster. However, *Symphyotrichum* species are considered generalists and attract a broad assortment of pollinators (Woodcock et al. 2014). Additionally, other species of *Symphyotrichum* have had potential pollinators identified, including syrphid flies (Syrphidae), bumblebees and nomad bees (Apidae), melittid bees (Melittidae), leaf-cutter bees (Megachilidae), sweat bees (Halictidae), and lepidopterans (Castro et al. 2011).

Seeds were collected in 1995 from three different counties (Anderson, Van Zandt, Wood) and deposited for storage at Mercer Arboretum and Botanic Gardens (Mercer 2001). Seed germination trials conducted on the closely related purple-stemmed aster resulted in 100% germination of seeds for two different treatments in less than 10 weeks (Chmielewski and Ruit 2002). All seeds were collected in the fall and germinated the following spring after cold stratification (Chmielewski and Ruit 2002). Although germination rate may be high, seed set per inflorescence for purple-stemmed aster may be low. Another study conducted in Canada on wild seed, but in pots, showed that among five sites seed set ranged from an average of zero to about 12 seeds per inflorescence (Woodcock et al. 2013). Percent seed set was not given, but purple-stemmed aster is recorded to have between 50 and 150 florets per inflorescence (Nesom 2006).

Population ecology of species (negative interactions)

Fertile hybrids have been recorded between different species of *Symphyotrichum* even though parents might have different chromosome numbers, morphology, and/or have been placed in different subgroups (Nesom 1994). High levels of hybridization in *Symphyotrichum* likely have influenced the difficulties that have arisen in determining and defining species within the genus (Vaezi and Brouillet 2009). It has been proposed that this might be a result of a recent and rapid diversification of *Symphyotrichum* (Vaezi and Brouillet 2009). Systematic work to classify the genus is ongoing (Vaezi and Brouillet 2009; Morgan and Holland 2012).

Collections have been made of what appear to be hybrids of rough-stemmed aster and calico aster (*Symphyotrichum lateriflorum*) in Anderson and Henderson counties (Nesom #A95-2, #A95-5, SHSU; Poole #4285, SHSU) (Nesom 1997). Hybrids between purple-stemmed aster and calico aster and purple-stemmed aster and white arrowleaf aster (*S. urophyllum*) have also been reported (Semple et al. 1996).

One study involving western silvery aster (*Symphyotrichum sericeum*) showed that Anthonomous weevils were laying eggs in the receptacle under the florets and larvae were damaging many seeds and predating 37% of the flower heads (Robson 2010). Another purple-stemmed aster study recorded that white-tailed deer or groundhogs could have caused the loss of all plants at one experimental site and some losses at other sites (Woodcock et al. 2014).

Japanese honeysuckle (*Lonicera japonica*) has been recorded at a minimum of six sites of rough-stemmed aster (Poole 1997). Japanese honeysuckle’s evergreen/semi-evergreen nature, ability to girdle other plants, dense growth pattern and competitive root growth enable the plant to out-compete other species (National Park Service 2009).

Land ownership and management

Sixteen of the rough-stemmed aster sites are on highway right-of-way (ROW), six have vague directions and could be on either right-of-way or privately owned land (or both), eight sites are on private property, and one site is on state property. All of the sites on right-of-way are maintained by either Texas Department of Transportation (TxDOT) or the county and undergo standard safety protocols of right-of-ways. These protocols include vegetation management, which may consist of herbicide application and/or mowing. In the early- to mid-1990s, TxDOT was full-width mowing on ROWs once a year in early fall and strip mowing several times a years, as needed, at three rough-stemmed aster sites (NE Palestine, Lake Lydia - Chinquapin, and Ben Wheeler - Daly) (Poole and Janssen 1997). However, the Ben Wheeler site was rarely mowed because the site was commonly inundated (Poole and Janssen 1997). Where needed at the three rough-stemmed aster sites, herbicides were applied to delineator posts, around culverts, and at pavement edges (Poole and Janssen 1997). It was recommended that no-mow signs be erected, that herbicides be applied by hand, and that no additional plant species be seeded into the ROW (Poole and Janssen 1997). The Lake Lydia site is a steep ROW, and, at least in the mid-1990s, dirt and wood chips were dumped at this site to prevent erosion (Poole and Janssen 1997). It was recommended that erosion control be done carefully so as to not cover any rough-stemmed aster (Poole and Janssen 1997).

Visits to nine of these sites in 2014 resulted in positive surveys at six of the sites (Strong 2014 a, b, c, d, e, f). All but one of these sites were on ROW (the other is on state property). It does not appear that no-mow signs were erected at any sites, although deterring mowers may simply encourage woody growth or dense undergrowth, which could out-compete rough-stemmed aster. All sites owned by TxDOT undergo management practices typical of maintaining ROWs. Also, some utilities have a legal right to be placed on the TxDOT ROWs (Texas Department of Transportation 2013). Due to this, it is difficult to avoid habitat disturbance or population destruction during utility siting, construction, and maintenance.

Rough-stemmed aster occurs around three bogs on the TPWD-owned Gus Engeling Wildlife Management Area. Lake #2 was created in the 1950s (Lodwick n.d.a), but a bog south of the impoundment harbors plants. Andrew’s bog has been used for grazing in the past (prior to 1973), but was fenced off from grazing in the 1970s (Lodwick n.d.b), and still the WMA does not graze around the bogs (Slack 2014). The bog has been burned since the 1970s (and possibly prior) to reduce woody vegetation (Lodwick n.d.b). Today, Gus Engeling WMA attempts to conduct prescribed burns on a 3-5 year rotation (Slack 2014). An attempt is made to avoid burning large, contiguous areas (Slack 2014). These areas include all bogs dry enough to burn.

Evidence of threats to survival

Throughout its range, rough-stemmed aster is threatened by habitat destruction and alteration. Surveys in the 1990s of all known populations, showed that the major threat was conversion of the plant’s preferred habitat (Poole 1997). Like many mesic sites in Texas, rough-stemmed aster habitat is prone to being degraded or eliminated due to ditching, draining, and/or impoundment

(Bridges 2008). Marshes, ponds, and edges of lakes and streams have been converted into manicured, non-native Bermuda grass (*Cynodon dactylon*) lawns (Poole 1997). Ponds and marshes have been drained, beaver dams have been destroyed, and bogs have been dammed to create ponds and lakes (Poole 2011). Hydrological conditions at these sites have been permanently changed. Whether too xeric or too mesic, these sites are no longer preferred habitat. One previously known site (NE Palestine #2) was searched in 1991 and 1995, but could not be relocated (Poole 1997). This is likely due to the more recent site conditions, which include being highly manicured (Poole 1997). When the Quitman site was last seen with plants in 1984, the plants were "locally frequent" along the ROW in an open seepage area (Nixon #14022, SFA). When visited in 1991 and 1995, no plants, nor wetlands of any kind, were found (Poole 1997). The location description could be inaccurate or the site was destroyed (Poole 1997). Although they may not be preferred habitat, at least five sites (Lake Lydia – Chinquapin, East and Southeast; Red Branch; Ben Wheeler - Daly) were impounded and harbored rough-stemmed aster as of 1995 (Poole 1997). If impoundment edges are not mown or grazed in the fall, have appropriate inundation levels, and are relatively open, apparently rough-stemmed aster can persist. What the exact conditions are to maintain plants at impoundment edges has not been determined, however.

All rough-stemmed aster sites along ROWs are subject to maintenance schedules. In 1995, regular maintenance included mowing, which was conducted in the early fall when the plant is at its peak reproductive period (Poole 1997). Surveys conducted in 2014 demonstrated that mowing to stream, lake, drainage, pond and impoundment edges is a common practice, which may reduce rough-stemmed aster's ability to persist. Depending on season, mowing may not be detrimental to plants. Certainly, the more frequent a mowing regime, the more likely plants will not be able to grow to maturity. The Lake Brenda and Lake Park sites are manicured lawns of St. Augustine (*Stenotaphrum secundatum*) and Bermuda grass (*Cynodon dactylon*) and plants were not located in 2014. At least three sites (CR 3270, Stewart, and Fourmile) are likely somewhat protected from being mowed due to the boggy/inundated nature of the sites (Strong 2014b, c, d).

Utilities have a legal right to be placed in TxDOT ROWs (Texas Department of Transportation 2013). By 1995, digging for a pipeline along the Tyler North site had occurred and no plants were present (Poole 1997). Obviously, any herbicide use along the ROWs would negatively affect plants, either by drift or direct spray. The highly disturbed site at Tyler North showed signs of herbicide application along a power-line ROW (Poole 1997).

Fire keeps woody species, like hazel alder (*Alnus serrulata*), sweetgum (*Liquidambar styraciflua*), wax myrtle (*Morella cerifera*), and black tupelo (*Nyssa sylvatica* var. *biflora*), to the margins of bogs (Bridges 2008). Fire suppression may also be altering otherwise frequently disturbed, open sites. At Gus Engeling WMA, the rough-stemmed aster location where prescribed fire is used, woody species (hazel alder and wax myrtle) are abundant and growing over the plants at this site (Strong 2014e). It may be that fire intensity is not great enough to keep these species to the margins of the bogs and streams at this property.

Hog disturbance has been observed at two sites visited in 2014 (Gus Engeling WMA and NE Palestine/Anderson #1). Plants were not present at either site, but surveys were time-limited at the Engeling WMA, and mowing was likely more of a threat at the NE Palestine/Anderson #1 site than hog disturbance. However, if additional locations are found in the bogs at the Engeling

WMA where hog disturbance is extensive, fencing this area may effectively manage the hogs.

Special management considerations

To date, population trends, demographics, habitat requirements, and reproductive information is still lacking and studies to resolve this lack of information should be conducted. In 1995, TPWD outlined action plans for some of the tracked rare plants in the state (Linam 1995). Rough-stemmed aster was included in these plans and was deemed a high-medium priority plant, due to its conservation needs at the time (Linam 1995). High priority needs for rough-stemmed aster included more surveys and monitoring to suggest status and population trends (Linam 1995). Medium priority needs included conducting management to retain the natural habitat (Linam 1995). In 1996, recommendations for monitoring rough-stemmed aster sites were delineated (Candee 1996). These are still valid, although the following is only a portion of the recommendations. At each site, a subset of plants should be chosen for monitoring (e.g., ~30), and these plants should be tagged and mapped to track individuals through time. Measurements of vigor, such as number of primary and/or secondary stems, number of fruits and flowers, and/or height, could be recorded. Monitoring could also include observations of herbivores, potential pollinators, reproductive output, and/or recruitment. Ideally, one site should be selected for each county of occurrence and sites should be on both private and public lands.

A monitoring plan could establish a protocol to regularly and systematically count rough-stemmed aster. A plan will help outline the successes and failures of past attempts and direct future efforts. A monitoring project was attempted to create baseline plant population data to establish if current ROW management was compatible for the highway department and the species of concern (Poole and Janssen 1997). Integrating monitoring with different types of management in a formal plan is appropriate for all species because different management will likely effect plant population health differently. In order to track if management is not negatively affecting population health, an appropriate rate of change is also required. In the 1997 monitoring and management report, a significant or unacceptable rate of decline was defined as a 10% decrease in total number of individuals or a 10% decrease in vigor (e.g., total number of flowers) over a sequential three-year period (Poole and Janssen 1997). If a decline occurred and the cause was related to management, recommendations could be altered. However, because species information was (and is still) lacking, a default rate of change of 10% was assigned. A 10% rate of change is reasonable when working on a species for which information is lacking. To assess if this rate is appropriate, more monitoring under consecutive years of the same management is necessary. To effectively manage rough-stemmed aster, management decisions and changes should be recorded along with population health and status.

Effective monitoring of rough-stemmed aster requires permanent, long-term transects to detect real demographic trends. Although three sites were monitored from 1991 to 1995, no monitoring has been conducted since. After four years of monitoring total number of individuals at three sites, one population had increased in total population size and this was attributed to a delayed mowing schedule (Poole and Janssen 1997). However, at the population level, more data than what are available is required to detect a real change. After the project was complete, it was recommended that delineator posts be used to dissuade mowers from mowing indicated areas, that herbicides be applied by hand, and that no other species be planted or seeded (Poole and Janssen 1997). If this was done or if this was the appropriate management is unknown.

One organized attempt has been made to predict where new locations might occur. However, rough-stemmed aster's preference for mesic sites and a widespread geologic formation results in a fairly large possible habitat area within central-east Texas (Poole 1997). Newer predictive techniques and completed soils maps may be able to refine habitat preference to identify new populations of rough-stemmed aster. The large number of populations on public right-of-way calls for more attention to be paid to appropriate management of these sites. Management conducted on public land should be assessed before and after activities are initiated. To ensure that mowing along roads are enacted at the right times, communication with maintenance crews is necessary.

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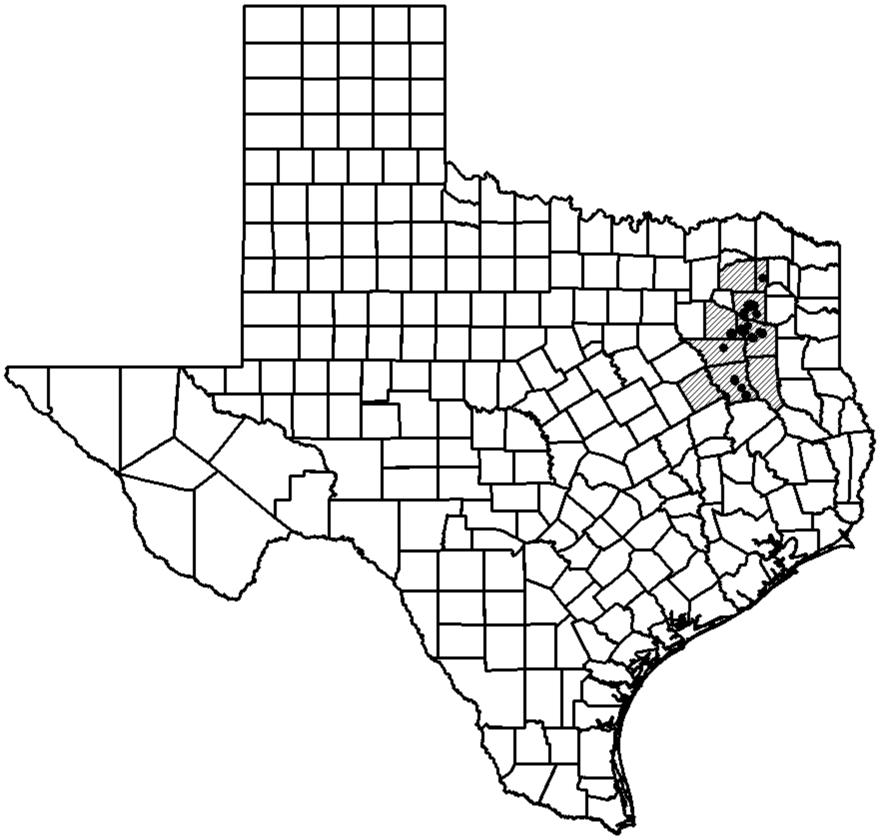
Table 1. Rough-stemmed aster population status, including location and ownership (Texas Natural Diversity Database 2014). These sites have not undergone a comprehensive review and may be reorganized in the future. This is the author's best attempt at classifying sites.

County	Year discvrd	Year last seen	EO ID+	Site name	Landowner	Min. # per 1 subpop.++	Max. # per 1 subpop. ++	Notes (Poole 1997)
Extant Sites								
Anderson	1975	2006	2154	Texas State Railroad Historical Park	private	present (2006)	25 (1993)	
Anderson	1983	1995	3789	NE Palestine/Anderson #1	ROW	0 (2014)	268 (1995)	
Anderson	1983	*	6786	Slocum	ROW?/private?	0 (1995)	rare (1983)	vague locality
Anderson	1983	1986	349	NE Palestine/Anderson #2	ROW?/private?	0 (1995)	rare (1983)	
Anderson	1993	2014	not mapped	Engeling WMA	state	present (1993)	~10 (2014)	
Cherokee	1977	*	not mapped	Cherokee	ROW?/private?	Present		
Franklin	1995	1996	8334	Blundell	ROW?/private?	present (1995)	22 (1996)	
Freestone	2006	*	not mapped	Brinkley	private	Present		
Henderson	1995	*	7612	Athens	ROW	~300		hybrids present
Henderson	2003	*	not mapped	Gator Lake	private	Present		
Henderson	2003	*	not mapped	CR 4330	private	Present		
Hopkins	1996	*	not mapped	Wilcox	ROW	17		
Smith	1983	*	1903	Tyler North	ROW	0 (1995)	"locally occassional" (1983)	
Smith	1995	*	3893	Wiggins	ROW	13		
Smith	1995	*	3894	Lake Park	ROW	0 (2014)	~100 (1995)	
Smith	1995	2014	1612	Stewart	ROW	172 (2014)	508 (1995)	
Smith	1996	*	not mapped	~Lindsey Park	ROW	14 (Oct1996)	20-30 (Nov1996)	
Smith	2004	*	not mapped	Indian Creek	private	Present		
Van Zandt	1952	2014	5846	Ben Wheeler - Daly	ROW	1(2014)	445 (1994)	
Wood	1984	2014	7018	Lake Lydia - Chinquapin	ROW	<30 (2014)	>1,500 (1994)	
Wood	1984	1995	7019	Red Branch	county ROW	1 (1991)	27 (1995)	

County	Year discvrd	Year last seen	EO ID+	Site name	Landowner	Min. # per 1 subpop.++	Max. # per 1 subpop. ++	Notes (Poole 1997)
Wood	1984	*	5509	Quitman	ROW?/private?	0 (1995)	"locally frequent" (1984)	vague locality or site destroyed
Wood	1984	2004	2322	E Lydia Lake	private	0 (1991)	"locally frequent" (1984)	
Wood	1984	1988	6231	SE Lydia Lake	private	0 (1995)	"locally occassional" (1984)	
Wood	1984	*	1146	Shiloh	ROW?/private?	0 (1995)	"locally frequent" (1984)	vague locality or site destroyed
Wood	1984	2014	not mapped	CR3270	ROW	"locally occassional" (1984)	~50 (2014)	
Wood	1993	1996	7744	Lake Brenda	private	0 (2014)	50 (1995 or 1996)	
Wood	1995	*	1266	Buck North	ROW	125		
Wood	1995	*	2963	Mineola Club Lake	ROW	10		
Wood	1995	*	4307	Mineola South	ROW	present		hybrids present
Wood	1995	2014	3540	Fourmile	ROW	1 (2014)	~50 (1995)	
Historic Sites								
Smith	1943	*	2982	Owentown		Present		vague locality
Smith	1947	*	7405	Tyler NW		Present		vague locality
Van Zandt	1955	*	906	Ben Wheeler - Kral		Present		vague locality or site destroyed

+ EO ID is the unique number assigned to a new record (element occurrence) in the Texas Natural Diversity Database. An element occurrence (EO) is an area of land where a species resides/resided (i.e., a population). An EO can consist of one or more subpopulations.
++ represents number of individuals recorded in any year at a subpopulation; each count is based on surveyor effort and is only as good as the effort expended (e.g., zeros could be false negatives; larger numbers, such as >1000, could be gross underestimates/overestimates)
*only seen one year

Figure 1. Distribution of extant populations of rough-stemmed aster (*Symphyotrichum puniceum* var. *scabricaule*).



Texas trillium

(*Trillium texanum*)

Species information (history of knowledge of taxon)

Although Texas trillium was described in 1860 by Samuel Buckley from a specimen he collected in Panola County, Texas (Buckley 1860), the actual specimen has never been located, even after a thorough search of herbaria during the 1960s (Freeman 1994). Almost 60 years later, Ernest J. Palmer collected a specimen in 1918 “near Grapeland, Texas” in Houston County (#13179, MO). Due to the vague location descriptions of these historic specimens, no Texas trillium has been re-located in either Panola or Houston counties (but see Timmerman-Erskine et al. 2002a). However, in the late 1960s and 1970s, locations of Texas trillium were discovered in Cass, Harrison, Nacogdoches, Smith, and Wood counties.

Because of their similarities, dwarf trillium (*Trillium pusillum*) and Texas trillium have been considered synonymous multiple times since Texas trillium was named in 1860 (Watson 1879; Peattie 1927; Samejima and Samejima 1987; and others). Many of the conclusions from these studies are said to arise from lack of and from difficulty in obtaining material to examine (Freeman 1994). A considerable amount of research in the last 40 years has been conducted to resolve the relationship between Texas trillium and the dwarf trillium complex (*Trillium pusillum* varieties), of which Texas trillium has been considered a variety of by Reveal and Broome (1981). Additionally, family classification has changed from Liliaceae (Lily Family) to Trilliaceae (Trillium Family) to the most recent family, Melanthiaceae (Bunch-flower Family). However, after enzyme, morphological, and genetic studies, Texas trillium is considered a distinct species apart from dwarf trillium (*Trillium pusillum*) (Timmerman-Erskine et al. 2002a; Timmerman-Erskine et al. 2002b; Timmerman-Erskine et al. 2003; Farmer 2006). Smaller stomatal size (Timmerman-Erskine et al. 2002b), upper and lower leaf surface stomata (Freeman 1970), and greater morphological differences in Texas trillium compared to dwarf trillium populations in other states (Timmerman-Erskine et al. 2002a) support these findings. Texas trillium also flowers later than other dwarf trilliums (Freeman 1996). However, Texas trillium is said to have a similar blooming period compared to other trilliums occurring in Texas (Singhurst et al. 2002).

Present legal status (National and State)

In 1980, Texas Trillium was added as a Category 2 Candidate taxon to the U.S. Fish and Wildlife Service’s (USFWS) list of plants that were being reviewed for possible addition to the Endangered Species Act (ESA). Category 2 indicated taxa that listing as endangered or threatened might be appropriate, but substantial data on biological vulnerability and threat(s) were not known at the time to support a ruling. Biological research and field study were seen as a possible need to ascertain the status of taxa in this category (U.S. Fish and Wildlife Service 1980). In 1983, Texas trillium was removed from the candidate species list due to findings that indicated the species was more abundant and/or widespread than previously believed (U.S. Fish and Wildlife Service 1983). In 1990, Texas trillium was added back as a Category 2 Candidate species (U.S. Fish and Wildlife Service 1990). It is unclear why it was added back to the candidate species list. In 1996, all Category 2 taxa were dropped from the ESA due to lack of information to justify a ruling. The USFWS felt that more biological research and field study were necessary to resolve the status of Category 2 species, and that these species could be the pool from which future candidate species were drawn (U.S. Fish and Wildlife Service 1996). In 2011, a 90-day finding was announced on 374 species from a petition to list 404 in the southeastern United States as threatened or endangered. Scientific, commercial, and other information was requested. For the target species, USFWS only had what was provided by the initial petition and through NatureServe. With the information available, the USFWS determined that factors A (the present or threatened destruction, modification, or curtailment of its habitat or range), D (inadequacy of existing regulatory mechanism), and E (other natural or manmade factors affecting its continued existence) might be threats to Texas trillium and justified listing (U.S. Fish and Wildlife Service 2011).

Although not listed as endangered or threatened by the State of Texas, Texas trillium is ranked as a G2 (imperiled) by NatureServe and is ranked as a Sensitive Species by the United States Forest Service. The species is also listed on Texas Parks and Wildlife Department's 2010 List of the Rare Plants of Texas and as a Species of Greatest Conservation Need in the Texas Parks and Wildlife Department (TPWD) State Conservation Action Plan.

Description (local field characters)

Four other trilliums [(slender trillium (*Trillium gracile*), Louisiana trillium (*Trillium ludovicianum*), prairie trillium (*Trillium recurvatum*), and Ozark green trillium (*Trillium viridescens*)] overlap with the range of Texas trillium and, if plants have flowers, they are fairly easy to identify. Texas trillium is the only trillium with a pedicel (2-4 cm long) (Singhurst et al. 2002). In their vegetative state, most trilliums (slender trillium, Louisiana trillium, and Ozark green trillium) in east Texas have sessile bracts ("leaves"). However, Texas trillium and prairie trillium have leaf-like bracts (bracts with a short "stem" or petiole). Texas trillium bracts are almost sessile or shortly petiolate (Case 2003) and generally smaller (6-8 cm x 1.3-1.9 cm) (Singhurst et al. 2002), whereas prairie trillium bracts are strongly petiolate (Case 2003) and generally larger (5-18 cm x 2-12 cm) (Singhurst et al. 2002). Also, Texas trillium bracts have blunted or rounded apices, whereas prairie trillium bracts have apices which are somewhere between gradually pointed (acute) and slightly acuminate (long tapering) (Singhurst et al. 2002).

Texas trillium is the only trillium in Texas with numerous stomata (specialized cells which open and close to regulate gas and water movement into/out of the plant) on upper and lower surfaces of its bracts (Freeman 1970). The stomata impart a mealy appearance to the upper leaf surface (John Freeman pers. comm. in Roe 1978). This is said to impart a grayish color to the bract even from a distance (Kral 1982).

Little club spur orchid (*Platanthera clavellata*) and yellow fringed orchid (*Platanthera ciliaris*) can be found in several Texas trillium sites. When the orchids only have one basal leaf, they can appear similar to vegetative Texas trilliums with one bract. Texas trilliums have generally smaller leaf-like bracts (6-8 x 1.3-1.9 cm bracts) (Singhurst et al. 2002), whereas the orchids have typically larger leaves (3-19 x 0.8-3.5 cm - *P. clavellata*; 5-40 x 0.6-6 cm – *P. ciliaris*) (Sheviak 2003).

Geographical distribution (range and precise occurrences)

Texas trillium occurs across thirteen counties in East Texas and into northwestern Louisiana (Caddo Parish) (Thomas and Allen 1993). In Texas, twenty sites have been located (See Table 1 and Figure 1) across at least 6,000 square miles. Two populations in Texas are only known from historic specimens collected in 1860 from Panola County (Buckley #s.n., unknown herbarium cited in Freeman 1994) and in 1918 from Houston County (Palmer #13179, MO). However, two tissue collections from Houston County are cited in Timmerman-Erskine et al. (2002a), which were either taken from existing herbarium specimens or from fresh field collections during the morphometric study of Texas trillium (Timmerman-Erskine et al. 2002a). One of the two collections is likely the Palmer specimen from 1918, but it is unclear where the other Houston County collection came from. The author is now deceased and attempts to find herbarium specimens at her alma-mater have failed. If Texas trillium was indeed collected from Houston County during Timmerman-Erskine's studies in the 1990s, it may be that it was "near Grapeland, TX", the directions given in the Houston County collection (Palmer #13179, MO). At least one attempt to re-locate Texas trillium in Houston County has been made about 1 mile south of Grapeland to the west of Hwy 19 near where the railroad splits west from the highway, but no plants were found (Singhurst pers. comm.).

Of Texas trillium's associate species recorded at several sites in Angelina County, 70% of them also occur in baygalls in central Louisiana (MacRoberts and MacRoberts 2004). This may indicate that Texas trillium could occur outside its known range as part of the widespread baygall community over the Coastal Plains. However, attempts to find Texas trillium in central Louisiana baygalls has returned no results (MacRoberts and MacRoberts 2005). Other attempts to locate the species in southern portions of Sabine National Forest in Sabine County resulted in no new locations (MacRoberts and MacRoberts 1998).

The three Texas trillium specimens from Wood (Ajilvsgi #7264, BRIT), Angelina (or Jasper) (Schultz #434, TEX), and Harrison (Ajilvsgi #4097, BRIT) counties have problematic location descriptions and may never be re-located definitively. Road intersections are described that no longer or never existed for these three sites. Because the descriptions are problematic, they limit the mapping of these populations to county level (Wood County is 696 square miles), to a national forest (Angelina National Forest is 239 square miles), and a reservoir (Brandy Branch in Harrison County is ~2 square miles), respectively. Although the Harrison County occurrence is the most likely of the three specimens with problematic descriptions to be re-located, the specimen was collected along the creek before it was flooded and converted into a reservoir in 1983 and could as likely be flooded by the lake as not.

In addition to the possible destruction of the Harrison County site, three other sites were either slated for destruction or may have been destroyed by large-scale disturbances. The Cherokee County site was first visited in 1995 (Singhurst #3632, BAYL), but prior to 2008 was revisited and found to be clear cut across the spring feeding into Texas trillium habitat. This resulted in the silting in of the baygall, the drying up of the habitat, and the population collapsing due to exposure and change in hydrology (Singhurst 2014a). The Rusk County site was visited in 2001 (Singhurst 2004). The area just north of the Texas trillium population is a strip mine. The general area had been altered enough (since the previous visit in 1994: Singhurst #3627, BAYL) that it was nearly unrecognizable, and it was difficult to ascertain if the population was affected directly or indirectly by the strip mining adjacent to the site (Singhurst pers. comm.), or if it had been affected at all. This site needs to be revisited to verify its status (Singhurst 2014b). One of the Nacogdoches County sites (Naconiche Creek) was slated for destruction by the landowner in 2001 to create a reservoir (Tiller 2014). In 2001, Mercer Arboretum and Botanical Gardens collected an estimated 18% of the plants (mostly vegetative) and transferred them to the garden premises (Tiller 2001). The population has not been visited since 2001 but aerials indicate no reservoir was created.

In addition to the historic sites (2), possibly destroyed sites (2), and sites with problematic descriptions (3), there are an additional thirteen sites (See Table 1). Eight of these remaining sites have been seen in more recent years (2001-2014), four were seen in the mid-1990s (1994-1996), and one has not been seen since 1985.

There are several other locations cited in the literature for which there is no basis or not enough information to confirm presence. Texas trillium is said to occur in Arkansas (Candee 1996; U.S. Fish and Wildlife Service 2014), but this information is from specimens of dwarf trillium (*Trillium pusillum* or *T. pusillium* var. *ozarkanum*) (Poole et al. 2007). Texas trillium has not been found outside of Texas or Louisiana. The Rare Plant Study Center cited Hardin County as an area of distribution for Texas trillium (Rare Plant Study Center 1974). There is no justification for this reference nor has Texas trillium been located in Hardin County. Therefore, Hardin County is considered an erroneous report (Singhurst 2014c). The Texas Organization for Endangered Species (TOES) Endangered, Threatened and Watch Lists of Plants of Texas listed Texas trillium as occurring in Tyler County (Texas Organization for Endangered Species 1981), although no justification for this location exists. By 1992, Tyler County was struck from the Texas Natural Heritage Program's Special Plant List (the list to succeed the TOES list) and Smith County was added (which suggests that the city of Tyler in Smith County is what was initially meant, not the county of Tyler, but this cannot been verified) (Texas Natural Heritage Program 1992). Candee (1996) mentions that Texas trillium was found in Wood County, but that it was a questionable identification (no specimen/reference is cited). If this arose from a specimen or a survey is unknown. The only known Texas trillium specimen from Wood County has been confirmed as such (Ajilvsgi #7264, BRIT). This may or may not be the Wood County site referenced by Candee.

General environment and habitat description (physical and biological characteristics)

Populations of Texas trillium have been found over the Queen City Sand, Carrizo, Sparta Sand, and Weches formations, and a variety of other geologic formations. Although many soil associations are represented across these formations, Tenaha loamy fine sand, Darco loamy fine sand, Mantachie loam, and Cuthbert fine sandy loam are the most frequently encountered under known populations of Texas trillium (Natural Resources Conservation Service 2014).

Texas trillium is found in the ecotone between riparian baygall and sandy pine/oak uplands in the shaded edge (MacRoberts and MacRoberts 1996) and at the heads of deep sand springs and seepages (Singhurst et al. 2002). The most commonly recorded associated species among all Texas trillium locations include red maple (*Acer rubrum*), jack-in-the-pulpit (*Ariseama triphyllum*), America holly (*Ilex opaca*), tassel-white (*Itea virginica*), sweetgum (*Liquidambar styraciflua*), sweetbay (*Magnolia virginiana*), black gum (*Nyssa sylvatica*), cinnamon fern (*Osmunda cinnamomea*), royal fern (*Osmunda regalis*), loblolly pine (*Pinus taeda*), sphagnum moss (*Sphagnum* sp.), possomhaw (*Vibunum nudum*), and primrose-leaf violet (*Viola* x *primulifolia*). Also, bog coneflower (*Rudbeckia scabrifolia*), another rare plant, has been located in the Angelina National Forest in Texas trillium habitat (MacRoberts and MacRoberts 1996; Singhurst 2013).

Soil samples taken at two Angelina National Forest sites show pH to be acidic (5.0 – 5.2) and soil nutrients as poor (phosphorus: 7-15 ppm, potassium: 21-22 ppm, calcium: 90-110 ppm, magnesium: 20-25 ppm) (MacRoberts and MacRoberts 2005). Texas trillium grows in locations that support plant associations that suggest high soil acidity (Freeman 1994). Plants tolerant of acidic soils, and commonly found at Texas trillium sites, include jack-in-the-pulpit, river birch (*Betula nigra*), flowering dogwood (*Cornus florida*), beechnut tree (*Fagus grandifolia*), black gum, cinnamon fern, royal fern, loblolly pine, willow oak (*Quercus phellos*), hoary azalea (*Rhododendron canescens*), and highbush blueberry (*Vaccinium corymbosum*).

Soils are not inundated, but are wet most, if not all, of the year (MacRoberts and MacRoberts 2005). Average rainfalls in East Texas rainfall are the highest in the state. Within Texas trillium's distribution, average annual rainfall is between 45-47 inches in the west (Cherokee, Houston, Smith, and Wood counties) and 49-57 inches in the east (Angelina, Marion, Nacogdoches, and Rusk counties) (National Oceanic and Atmospheric Administration 2014). High rainfalls, like those experienced in East Texas, carry away water-soluble soil nutrients (Ca, Mg, K, etc.) and result in acidic soils (Appleton et al. 2009). Although not attempted in a controlled test, several trillium species transplanted to gardens in Alabama suggest that soil pH is not a major factor restricting the species to specific soil types (Freeman 1994). It is unknown what the soil pH was at this Alabama site or how many Texas trillium transplants were involved.

No field studies have been conducted on the level of disturbance needed or tolerated by Texas trillium. However, Freeman (1994) suggested that populations of Texas trillium and dwarf trillium could respond favorably to disturbance by increasing flowering and fruiting compared to more stable sites (Freeman 1994). Disturbance was defined as tree falls, logging, road building, ditch digging, and transplanting (Freeman 1994). Without disturbance, it has been suggested that trilliums may persist indefinitely, but may flower less and less until another disturbance occurs (Freeman 1994). There is obviously a limit to disturbance tolerated in all plants, and large-scale disturbances like clear-cutting is likely very detrimental to Texas trillium populations. Jules (1998) reported that clear-cutting or logging and replanting of plantations results in high rates of mortality and little recruitment of western trillium (*Trillium ovatum*), and restricts populations to uncut forest fragments. Kral (1982) suggested practices like bull-dozing, cutting the over-story, establishing plantations, draining the habitat, and grazing would destroy populations of Texas trillium.

Population biology of taxon (demography, phenology, and reproductive biology)

In many cases, the distribution of individual plants within populations of Texas trillium is scattered in clumps. At one Angelina National Forest population, three small areas, each a few square meters, were found across approximately 2 hectares (4.9 acres) (MacRoberts and MacRoberts 1996). Some of these small isolated patches can consist of only a few plants (MacRoberts and MacRoberts 1996). The largest populations to date have had an estimated 10,000 plants along an 800 meter stretch of a creek (Dogwood Creek) (Singhurst 1994a) and about 2,000 plants in an approximately $100m^2$ area (Naconiche Creek Preserve) (Singhurst 1994b). Distribution of plant patches within these sites was not recorded.

Comparing population trends among years is difficult because surveying is rare and taking population estimates is normal (instead of the more time-consuming exact counts). Although infrequent, when areas are resurveyed, new areas are designated by surveyors each year because they likely do not know what area was surveyed by previous groups and relocating these exact areas is difficult and unnecessary Because many observations are based on herbarium specimens, observers mark one point in the vicinity of the plants, not the total area the population occupies (or was surveyed). At times, the species is not the focus of a survey, and things like the total area of distribution and total number within a population is not taken. In many cases, time only allows for noting the species' presence. These surveying practices are not unique to Texas trillium. Additionally, surveying for Texas trillium is slow going, considering its rarity, scattered nature, and inconspicuous appearance (MacRoberts and MacRoberts 2005). Counts are likely all based off of the convention of one "leafless stem" (or scape) is equivalent to one plant. This is obviously not always the case as specimens from Stephen F. Austin herbarium show [Cox and Young #87; Nixon #1806 (2 of 3 sheets)]. These plants have two scapes arising from one rhizome. This means that counts could overestimate the number of plants actually present.

In the only known monitoring of Texas trillium, seven $1m^2$ plots were tracked at three sites in the Angelina National Forest from 1995 to 1997 (MacRoberts and MacRoberts 2005). Plots were placed within varying populations of plants. Some sites were more isolated and had small groups of plants within a very small area ($<1m^2$) and other sites were larger, but with thousands of plants scattered in an area of over a hectare (MacRoberts and MacRoberts 2005). Counts within the seven plots ($7m^2$) totaled 177 plants (1995), 351 plants (1996), and 325 plants (1997) (MacRoberts and MacRoberts 2005). In this study one stem (or scape) was considered to be one individual (MacRoberts 2014). Monitoring at this same site during the flowering season showed that Texas trillium has an earlier bud burst compared to the surrounding herbaceous cover (ground cover was below 30%) and the deciduous canopy (which had not leafed out yet) (MacRoberts and MacRoberts 2005). Before flowering, plants produce one to three bracts. During the 1995-1997 monitoring, 95-98% of plants had a single bract (MacRoberts and MacRoberts 2005). The remaining plants had three bracts (1-3%) or were in flower (1-3%).

Between late winter and early spring Texas trillium sends up scapes (Tiller 2002) and from March to May it flowers. Freeman (1996) gives mid-April as peak flowering time. Flowering specimens have been collected as early as March 17 (Orzell # 5946, TEX) and as late as May 29 (MacRoberts and MacRoberts #3342, TEX). Most surveys that note flowering were conducted in the last week of March, and most specimens were collected in the last week of March; however, this may be because of researcher bias (knowing that plants will likely be in bloom the last week of March). Specimens have also been collected from the third week of March through the third week of April. Few specimens have been collected with mature fruit, although there is one from mid-May (Correll and Correll #35746, LL). Surveys in March of 1994 noted the presence of fruit at populations in Cass and Nacogdoches counties (Singhurst 1994b; Singhurst 1995).

Texas trillium spends most of the year as underground stems (rhizomes) and only spends a couple of months as reproductive (Tiller 2002). Kral concluded that Texas trillium was strongly clonal, with often several hundred scapes (clones) arising from rhizomes growing up to 10 cm long (Kral 1982). Based on estimates calculated from number of constrictions on rhizomes, one study showed that white trillium (*Trillium grandiflorum*) lives at least 30 years (Hanzawa and Kalisz 1993). This technique of counting the constrictions has been known since the early 1900s, but may only be useful when plants are younger (Brandt 1916). The oldest portion of the root can rot away and the age of the plant may be underestimated by counting the annual constrictions (Brandt 1916).

Although the reproductive biology is largely unknown in Texas trillium, other trilliums reproduce sexually and can occasionally or frequently reproduce vegetatively (Ohara 1989). Several trilliums, including red trillium (*Trillium erectum*), white trillium (*T. grandiflorum*), toadshade (*T. sessile*), and painted trillium (*T. undulatum*), have been reported to reproduce asexually (Timmerman-Erskine 1999) by parthenogenesis. Trilliums have also been reported to self-pollinate and outcross (Timmerman-Erskine 1999). Outcrossing rates have been estimated for four sites in Texas and only one of the sites sampled showed high levels of outcrossing (Timmerman-Erskine et al. 2003). Using allozyme data to compare genotypic frequencies, Timmerman-Erskine et al. (2003) found that the Texas trillium populations sampled were still generally genetically diverse.

Trillium berries contain between 1 and 200+ seeds depending on the species (Solt 2002). Red trillium (*Trillium erectum*) produces one fruit per plant, averaging about 30 seeds per fruit (Lapointe 1998). At least seven other American trillium species produce similar seed amounts ranging between averages of 9.7 (+/-6.4) (lance-leaf trillium or *Trillium lancifolium*) and 25.3 (+/-9.8) seeds per plant (Louisiana trillium or *Trillium ludovicianum*) (Ohara and Utech 1986; Sawyer 2010). However, in at least six southeast American trilliums, the estimated number of seeds produced and the number of juveniles located per population indicates that seed establishment is low and that vegetative reproduction is the primary mode of recruitment (Ohara and Utech 1986). It has been suggested that all trilliums have adapted to exact habitat conditions and even the most common species is restricted to certain soil types, temperatures, and acidity, or amounts of competition (Case 1975). Trillium seedlings demand very particular environmental conditions, which may make recruitment and seedling establishment difficult (Case 1975).

Effective pollinators and the seed biology and dispersal of Texas trillium are unknown. No seed dispersal or pollen vectors have been recorded at Texas trillium sites. However, trillium seeds have elaisomes, external food structures consisting of fatty oils and sugars, which can attract ants and other invertebrates and aid in at least short distance seed dispersal (Timmerman-Erskine 1999). Occasional dispersal by water has been suggested (Cullina 2002), a logical conclusion in habitats with high rainfall near streams and seeps. Large-flower trillium (*Trillium grandiflorum*) has been noted to have no seed bank (Hanzawa and Kalisz 1993); however, some trilliums exhibit double dormancy, a phenomenon where seeds must experience two winters before they will emerge from the soil (Diboll 2008). Seed germination can occur in the first year, but all development is underground (Diboll 2008). Seedlings emerge with their first leaves (cotyledons) in the spring after the second winter (Diboll 2008). In cultivation, trilliums can take up to eight years to become reproductive and wild plants may take longer (Cullina 2002).

Population ecology of species (negative interactions)

Texas trillium may flower early enough in the season that it is not until fruits are near maturity that the deciduous canopy starts shading the under-story (Freeman 1994). But plants can be overgrown by typically later developing herbaceous species, like ferns (*Osmunda* and *Woodwardia*) (MacRoberts and MacRoberts 2005). Over-story competition from these native species may decrease trillium population sizes or otherwise negatively affect Texas trillium (Freeman 1994).

Land ownership

All Texas trillium sites are privately owned except for three sites within Angelina National Forest and two sites wholly or partially on highway right-of-way. Angelina National Forest is maintained by the U. S. Forest Service (USFS) and is managed according to Forest Service regulations. Highway right-of-way is managed by Texas Department of Transportation.

The 2010 Rare Plant List of Texas defines historical as "not observed or collected within 50 years". Anything observed or collected within 50 years would then be extant. Of the extant sites where location description is not problematic, seven have known private landowners and another six sites have landowners who are unknown, but could be determined. In these cases, the landowner is likely private. There are an additional two sites where location description is problematic (erroneous or vague).

The few known private landowners generally manage populations passively. Two of the sites with known private landowners are owned by non-profits. The Nature Conservancy owns Sheff's Woods in Smith County. No past management is known to have occurred at Sheff's Woods, although management plans for this site have been initiated (Ledbetter 2014). The Texas Land Conservancy owns Naconiche Creek Preserve in Nacogdoches County. The Texas Land Conservancy manages properties for overall preserve health (Stuemke 2014).

Management practices

Texas Trillium populations on the Angelina National Forest are within the Longleaf Ridge Area, which was established to enhance the (westernmost) longleaf pine forests and savannas and other significant plant communities, like pitcher plant bogs and evergreen acid seep forests (U.S. Forest Service 1996). Most management in this portion of the National Forest centers around enhancing habitat of the endangered red-cockaded woodpecker, also found in the forest (Strong 2014). The area allows recreation, such as off-road-vehicle (ORV) use, hiking, camping, biking, horse-back riding, and fishing. Hikers and motorized traffic have designated trails and roads to keep impact from these activities down to a minimum (U.S. Forest Service 1996). Prescribed fires are used in rotation about every two to three years (Strong 2014) to control the mid-story canopy, promote upland forest communities, and to reduce fire hazard (U.S. Forest Service 1996). Within the Angelina National Forest, the Buck Branch Creek subpopulation was burned in the winter of 1995/1996. The burn took out or reduced the shrub layer in much of the drainage, often to the stream edges (MacRoberts and MacRoberts 1996). Texas trillium seemed to respond well to the burn as several hundred plants were seen in the spring of 1996 with "many" plants in flower (MacRoberts and MacRoberts 1996). This site was surveyed in March of 2014 and only a couple dozen vegetative plants within a $1m^2$ area were found (Phillips and Loos 2014).

Many trilliums have seed that do not tolerate drying [for example, whip-poor-will flower (*Trillium cuneatum*), red trillium (*T. erectum*), white trillium (*T. grandiflorum*), prairie trillium (*T. recurvatum*), and painted trillium (*T. undulatum*) (Cullina 2000)]. If these species are stored in a refrigerator at 30-90% internal (seed) moisture content, seed viability may be maintained for 5 years (Cullina 2000). However, western species, which inhabit drier environments, can be more desiccation-tolerant, for example, Idaho trillium (*Trillium petiolatum*) (Cullina 2000).

Mercer Arboretum and Botanical Gardens (Mercer) collected plants at the Naconiche Creek site in 2001. Some plants from this collection were potted, some were planted on the grounds at Mercer, some were refrigerated at Mercer in an attempt to maintain the rhizome's dormancy, and some plants were sent to Cincinnati Zoo & Botanic Garden's Center for Research of Endangered Wildlife (CREW). Most plants at Mercer (potted and planted in the gardens) have died, except for a few with unknown viability still in refrigeration (Tiller 2014). Mercer partnered with CREW to attempt to develop tissue culture methods from sections of the underground stems and embryos of fresh seed because trillium seeds do not typically tolerate drying (Tiller 2002). Additionally, trilliums can be difficult to propagate and have a lengthy juvenile stage (Patrick 1973; Samejima and Samejima 1987); therefore, tissue cultures could relieve wild populations from collection pressure (Pence and Soukup 1993). The CREW still has some Texas trillium in culture, although even in culture, trilliums are slow-growing (Pence 2014).

Evidence of threats to survival

Bottomland areas of Texas trillium and surrounding upland habitats are being drained, clear-cut, and converted to pine plantations, woodland pastures (Kral 1982), and reservoirs. Direct disturbance to the soil, hydrology, and canopy-cover are destructive to trillium habitat (Kral 1982). Indirect disturbance from converting sand hills to pine plantations, increases erosion and can bury trillium habitat (bottomland trees and herbaceous cover) in sandy washes (Kral 1982). Timber harvesting can open a typically shady woodland and increase competition with more aggressive species, including some non-native plants like Chinese privet (*Ligustrum sinense*) and Japanese honeysuckle (*Lonicera japonica*) (Louisiana Natural Heritage Program 2012).

Many East Texas counties including Cass, Marion, Nacogdoches, Panola, Rusk, Smith, and Wood counties are experiencing extensive natural gas and oil exploration, which could negatively impact Texas trillium habitat, if sites are subjected to disturbances (Poole 2011). Lignite mining occurs throughout Cherokee, Panola, Rusk, and Smith counties and would eliminate any populations in its path (Poole 2011). Another potential threat is livestock grazing/trampling (Louisiana Natural Heritage Program 2012). One Smith County population of Texas trillium (Hill 2014), which has been known for 30+ years, has been damaged by wild hogs, and in more recent years seems to have fewer individuals than earlier observations (Loper 2013). It is unknown if the hogs are the cause of the decline.

Trillium is popular within the horticultural trade in America and Europe (Timmerman-Erskine 1999). Trillium's popularity, difficulty in propagation, and extended period of maturation increases the likelihood of collection, especially in regions further east (Appalachia) (Cullina 2002), where more trilliums occur. In these areas thousands of plants are collected to stock commercial suppliers of America and Europe (Cullina 2002). Collection of Texas trillium by enthusiasts or for commercial purposes has not been recorded, but is a distinct possibility. At least in the past, it has been called a "worthy garden subject", although outside its range its hardiness was in question (Case 1981). Indeed, Texas trillium was listed at (presumably transplanted?) John Lambert's Mountain Fork River Arboretum in Mena, Arkansas (Case 1981). Texas trillium's status at the Arboretum is unknown. A short search on the internet for the Arboretum returned no results.

Several trilliums are known to have phytoplasmas that spread a pathogen, and can be identified by various symptoms including deformed petals, bracts, and stamens (Case and Case 1997). The disease may be spread by leafhoppers and can infect whole populations, causing populations to decline or disappear (Case and Case 1997). White trillium (*Trillium grandiflorum*), red trillium (*Trillium erectum*), and painted trillium (*Trillium undulatum*) have been observed to have the pathogen (Case 1981), although the closest populations of these are in Alabama and Tennessee. Phytoplasmas have never been recorded in Texas trillium populations.

Special management considerations (past, present, and future)

Texas trillium has a fairly large distribution in northeast Texas and adjacent Louisiana. Additional surveys in these areas could result in more populations. Because so many populations occur on private land, landowner contact is essential to accessing and encouraging protection of privately-owned populations.

Because very little research has been conducted on Texas trillium, very few conclusions can be made as to how to manage the populations. It is unclear how much of the variation in numbers is due to internal factors like extended juvenile stages or external factors like competition, fire regime, hydrological disturbances, or other influences. Obviously, damming streams to create reservoirs (like Brandy Branch) and even poor streamside management practices, like building plantations across stream heads, can change the required hydrological regime. But other practices, like leaving an undisturbed strip of timber to protect streams from upslope sand washing into bottomlands (Louisiana Natural Heritage Program 2012), may be sufficient to sustain healthy populations of Texas trillium. Some disturbance may in fact be necessary to increase population health. Burning has shown positive results in at least one Texas trillium site on Angelina National Forest lands (MacRoberts and MacRoberts 1996). However, if, like other North American trillium species, Texas trillium is dispersed short distances by ants, populations can easily be fragmented by development (Cullina 2002). It has been suggested that trilliums, in general, have trouble recolonizing sites when they are eliminated from them (Cullina 2002). Studies on the type and extent of disturbance that Texas trillium tolerates would increase effective management.

To determine if pollinators are essential to reproduction, the breeding system needs to be resolved. If the plants are outcrossers, identifying pollinators will aid in determining pollinator habitat type (e.g., ground-nesting bees vs. wood-boring bees) and guaranteeing protection of pollinator habitat. At least one Nacogdoches Texas trillium site showed high levels of outcrossing and all populations exhibited high levels of variability within and among populations (Timmerman-Erskine et al. 2003). When these plants were sampled, tissue was taken from individuals one meter apart from other individuals to decrease chance of selecting clonal offshoots (Timmerman-Erskine et al. 2003). Verifying if and determining to what extent Texas trillium is clonal will ensure accurate monitoring protocols.

In 1996, a monitoring plan was suggested for Texas trillium sites along with 107 other rare Texas plants (Candee 1996). Number of plants, flowers and fruit, as well as vigor measures were suggested annually for at least a subset of each population during the flowering and fruiting season (March to May) (Candee 1996). A significant or unacceptable 20% decline in total population numbers in consecutive years was chosen as a preliminary threshold to indicate that more comprehensive research and/or management was needed. However, this percent was chosen for all 107 species with monitoring plans, likely because 20% was seen as a reasonable rate of change when biological information is lacking. To date, population trends and demographics are still lacking and studies to resolve these unknowns should be conducted. A monitoring plan could establish a protocol to regularly and systematically count the existing populations of this somewhat cryptic species and would help identify the extent to which internal factors (like annual habit) versus external factors (like competition and fire regime) affect the fluctuation in numbers within sites.

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Table 1. Texas trillium population status, including location and ownership (Texas Natural Diversity Database 2013).

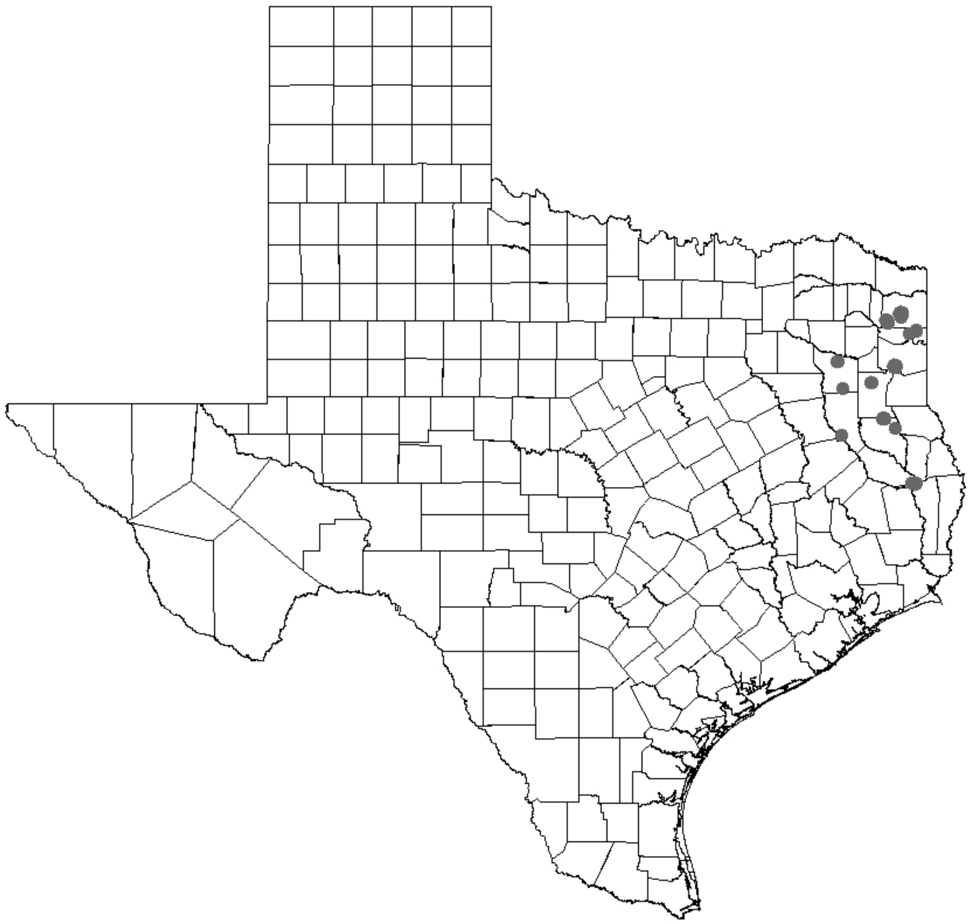
County	Yr discvrd	Last yr seen	EO ID[+]	Site Name	Landowner	Min. # per 1 subpop.++	Max. # per 1 subpop.++	Notes
Extant Sites								
Angelina	1993	*	not mapped	Angelina NF - Schultz	USFS	Present (1993)		location description problematic
Angelina/Jasper	1995	2007	11362	Angelina/Jasper	USFS	0 (2014)	100+ (1995)	
Cass	1968	1994	5649	Hughes Springs	private	0 (1991, 1992)	>2000 (1994)	
Cass	1969	1985	3763	Linden	private	Present (1969, 1970)	100s (1985)	
Cass	1987	1994	5566	Jim's Bayou	private	“common” (1987)	>2000 (1994)	
Cherokee	1995	2007	11366	Box Creek	private	0 (~2007)	>2000 (1995)	extirpated between ‘95 & ‘07; hydrology altered
Harrison	1978	*	6777	Brandy Branch	description problematic	Present (1978)		location description problematic; possibly flooded
Jasper	1996	*	11367	Trout Creek	USFS	0 (2014)	100s (1996)	
Marion	2002	2014	11363	Mill Creek	private	Present (2013)	715-775 (2014)	
					TxDOT	Present (2002)	Present (2007)	
Marion	2013	2014	11364	Site 34	private	Present (2013)	174 (2014)	
Marion	2013	*	11365	Site 90	private	0 (2014)	Present (2013)	
Nacogdoches	1973	1994	2125	Camp Tonkawa	private	0 (2014)	<1000 (1994)	
Nacogdoches	1970	2001	1154	Naconiche Creek	private	100s (1988)	>2000 (1994)	reservoir construction announced; ~20% plants collected Mercer(2001)
					TxDOT	0 (1992)	data not clear	
Nacogdoches	1994	2007	11369	Naconiche Creek Preserve	private (TX Land Cons.)	50 (2007)	>2000 (1994)	
Rusk	1985	2007	3309	Dogwood Creek	private	0 (1992, 2007)	>10,000 (1994)	possibly extirpated; needs confirmation
Smith	1971	2007	788	Sheff's Woods	private (TNC)	Present (1971)	Present (2007)	
Smith	1993	2014	11368	Troup W.	private	75-100 (2014)	>2000 (1994)	
Wood	1979	*	5867	Wood County	description problematic	Present (1979)		location description problematic
Historic sites								
Houston	1918	*	2047	Grapeland	unknown	Present		
Panola	1860	*	6778	Panola County	unknown	Present		herbarium specimen has never been located

+EO ID is the unique number assigned to a new record (element occurrence) in the Texas Natural Diversity Database. An element occurrence is an area of land where a species resides/resided (i.e., a population). A population can consist of one or more subpopulations.

++ represents number of individuals recorded in any year at a subpopulation; each count is based on surveyor effort and is only as good as the effort expended (e.g., zeros could be false negatives; larger numbers, such as >#, #s, #+, could be gross over- or underestimates)

*plants only seen one year

Figure 1. Distribution of extant populations of Texas trillium (*Trillium texanum*).



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Literature Cited:

This section contains general literate cited. Literature specific to each species is included in the species assessments.

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"Endangered and Threatened Wildlife and Plants; Review of Native Species That Are Candidates for Listing as Endangered or Threatened; Annual Native of Findings on Resubmitted Petitions; Annual Description of Progress on Listing Actions, Proposed Rule." Federal Register 76: 207 (26 October 2011) p. 66370.

Appendix:
List of botanical sources contacted.

Contact/Organization	*Agalinis navasotensis*	*Amsonia tharpii*	*Asclepias prostrata*	*Bartonia texanum*	*Eriocaulon koernickianum*	*Genistidium dumosum*	*Helianthus occidentalis plantagineus*	*Hexalectris revoluta*	*Paronychia congesta*	*Streptanthus bracteatus*	*Symphyotrichum puniceum scabricaule*	*Trillium texanum*
Angelo State Natural History Collections Herbarium		x										
Baylor University Herbarium	x	x	x	x	x	x	x	x	x	x	x	x
Botanical Research Institute of Texas	x	x	x	x	x	x	x	x	x	x	x	x
Harvard University Herbaria						x	x					
Indiana University Herbarium							x					
John D. Freeman Herbarium (Auburn University)												x
LBJ Wildflower Center	x	x	x	x	x	x	x	x	x	x	x	x
Missouri Botanical Garden	x	x	x	x	x	x	x	x	x	x	x	x
National Museum of Natural History (online)	x	x	x	x	x	x	x	x	x	x	x	x
New Mexico State University Herbarium							x					
New York Botanical Garden (online)	x	x	x	x	x	x	x	x	x	x	x	x
Spring Branch Science Center	x	x	x	x	x	x	x	x	x	x	x	x
Stephen F. Austin State University Herbarium	x	x	x	x	x	x	x	x	x	x	x	x
Texas A&M University Herbarium	x	x	x	x	x	x	x	x	x	x	x	x
University of Texas at Austin Plant Resources Center (online)	x	x	x	x	x	x	x	x	x	x	x	x
Abbott, Kendra /St. Edwards University										x		
Ajilvski, Geyata /Independent Contractor				x								x
Blackwell, Steve /Desert Botanical Garden		x										
Auburn University												X

Contact/Organization	Agalinis navasotensis	Amsonia tharpii	Asclepias prostrata	Bartonia texanum	Eriocaulon koernickianum	Genistidium dumosum	Helianthus occidentalis plantagineus	Hexalectris revoluta	Paronychia congesta	Streptanthus bracteatus	Symphyotrichum puniceum scabricaule	Trillium texanum
Carr, Bill /Independent Contractor							x					
Clary, Karen /LBJ Wildflower Center			x									
Coles, Janet /National Park Service								x				
DeJong, Gabriel /UT Austin										x		
Fishbein, Mark /Oklahoma State University			x									
Fowler, Norma /UT Austin										x		
Hilsenbeck, Richard /The Nature Conservancy		x										
Holmes, Walter /Baylor University											x	X
Howard, Michael /Retired BLM botanist		x										
Hudson, Buddy /Texas Department of Transportation		x								x		
Jennings, Bil /Retired botanist								x				
Jyotsna, Sharma /Texas Tech University								x				
Kennedy, Aaron /US Department of Agriculture								x				
Lavin, Matt /Montana State University						x						
Ledbetter, Wendy /The Nature Conservancy												X
Leonard, Wendy /San Antonio Parks and Recreation Natural Areas										x		
Linam, Leeann /Texas Parks and Wildlife										x		

Contact/Organization	*Agalinis navasotensis*	*Amsonia tharpii*	*Asclepias prostrata*	*Bartonia texanum*	*Eriocaulon koernickianum*	*Genistidium dumosum*	*Helianthus occidentalis plantagineus*	*Hexalectris revoluta*	*Paronychia congesta*	*Streptanthus bracteatus*	*Symphyotrichum puniceum scabricaule*	*Trillium texanum*
MacRoberts, Michael /Louisiana State University					x							
Marek, Laura /National Plant Germplasm System, ISU and USDA-ARS							x					
McCullough, Rayo /Natural Heritage New Mexico								x				
Neal, Jayne /San Antonio Parks and Recreation Natural Areas										x		
Nesom, Guy /Botanical Research Institute of Texas											x	
Patterson, Tom /University of Texas at Austin Plant Resources Center			x									
Pepper, Alan /A&M University										x		
Peterson, Joe /UT Lands												
Philipps, Tom /US Forest Service	x			x								x
Powell, Michael /Sul Ross University		x				x						
Reed, Monique /Texas A&M University	x										x	
Reiner, Bill /City of Austin										x		
Reyes, Ernesto /U. S. Fish and Wildlife Service			x									
Rice, Kathy /Scottsdale Community College		x										
Richardson, Alfred /University of Texas Brownsville			x									
Riskind, David /TPWD										x		
Roth, Daniela /New Mexico State - Forestry Division								x				

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Singleton, Pauline /Watson Preserve				x								
Sirotnak, Joe /National Park Service								x				
Sivinski, Bob /Biological Consultant		x						x				
Slack, Tucker /TPWD					x						x	
Slauson, Liz /Scottsdale Community College		x										
Tiller, Anita /Mercer Arboretum and Botanic Gardens	x										x	
Watson, Linda /Oklahoma State University					x							
Weckesser, Wendy /National Park Service						x						
Whitsell, Theo /Arkansas Natural Heritage Commission					x		x					
Yatskievych, George /Missouri Botanical Garden					x							
Zippin, David /ICF International										x		