SPECIES STATUS ASSESSMENT FOR
TEXAS SNOWBELLS
(*STYRAX PLATANIFOLIUS* ENGELM. EX TORR. SSP. *TEXANUS* (CORY) P.W. FRITSCH)

Southwest Region
U.S. Fish and Wildlife Service
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EXECUTIVE SUMMARY

Texas snowbells is a rare, endemic shrub of the Edwards Plateau of Texas. It was listed as an endangered species, *Styrax texanus*, on October 12, 1984 (49 FR 40036). We currently recognize this plant as *S. platanifolius* ssp. *texanus*, one of five closely related subspecies described in the most recent taxonomic treatment (Fritsch 1997).

When listed as endangered, only 25 individuals had been documented in 5 locations; however, a report of 4 individuals from Kimble County was later determined to be incorrect. The recovery plan (U.S. Fish and Wildlife Service 1987) listed 39 individuals in 6 sites. Since 1986, field surveyors have documented 400 mature and 452 immature Texas snowbells plants in 22 naturally occurring sites in Real, Edwards, and Val Verde counties. By comparing with other plant species that have similar, well-studied life histories, we estimate that the minimum viable size of metapopulations is from 900 to 1,200 individuals. The global population spans a range of 121 km (75 mi) east to west and 35 km (22 mi) north to south. The known populations occur along watercourses, on or near steep slopes, in exposed limestone and gravel of the upper reaches of the Nueces, West Nueces, and Devils River watersheds. We estimate that about 15,043 ha (37,172 ac) of potential habitat exist in these watersheds. An unconfirmed population has also been reported from the lower West Frio River.

Texas snowbells usually flowers in April, and if fertilized, flowers produce a typically single-seeded dry fruit that matures in August. However, investigations on the breeding system of Texas snowbells and another closely related species of *Styrax* indicate that it is an obligate out-crosser; fertilization requires transfer of pollen between individuals that are not too closely related. The known pollinators include native species of bumblebee and carpenter bee and the introduced honey bee. High rates of fertilization probably require that Texas snowbells plants are separated by no more than 0.5 to 1.0 km (0.3 to 0.6 mi). Almost all documented reproduction of Texas snowbells in the wild, as indicated by the presence of immature plants, occurs among populations that have at least 56 mature individuals dispersed over a distance of 1.6 km (1.0 mi) or less. Little or no reproduction occurs among isolated individuals and small populations.

Native white-tailed deer and introduced ungulate species are present at very high densities in many parts of the Edwards Plateau. Severe browsing by these ungulates causes very high mortality of seedlings and juvenile Texas snowbells plants. Consequently, mortality exceeds recruitment in all but the two largest populations of Texas snowbells. In addition to small population sizes and ungulate browsing, other factors that affect the subspecies' survival include low levels of genetic diversity within and among populations, isolation and fragmentation of populations, severe floods, and endemism to a small geographic and habitat range. Climate changes and pollinator deficiency may potentially affect future viability. A large portion of known individuals and populations occurs on privately owned lands, which makes effective conservation more challenging.

Our assessment of species viability, defined as the likelihood of persistence over the long term, is based on the concepts of representation, redundancy, and resilience. Texas snowbells is endemic to a small area and has a low level of genetic diversity, and therefore has low representation. There are few populations, hence redundancy is low. Resilience is low because all known populations are far below the estimated minimum viable population level. In synthesis, the viability of Texas snowbells is low.

Nevertheless, ongoing conservation efforts are continually improving the viability of Texas snowbells. The subspecies' conservation depends largely on the voluntary support of private landowners, underscoring the importance of landowner outreach. The core conservation strategy is to increase recruitment and

decrease mortality, thereby allowing populations to grow naturally. One of the most important objectives is to reduce the intensity of ungulate browsing throughout the subspecies' range, allowing populations to become self-sustaining without human intervention. Another high-priority objective is to enhance gene flow and fertilization rates between genetically diverse individuals and populations. This may be accomplished by augmenting small populations to increase their genetic diversity, the fertilization rate of flowers, and the production of viable seeds; and also by reintroducing populations to restore gene flow between isolated individuals and small populations through the transfer of pollen. If successful, augmentation and reintroduction can also increase population sizes, improving the subspecies' resilience. However, we predict that the strategic placement of reintroduced plants to restore population connectivity will be of greater benefit to the subspecies' viability than solely increasing population sizes without increasing connectivity. A group of cooperating landowners and volunteers, led by Mr. J.D. Bamberger, has made significant progress toward accomplishing many of these objectives. The time frame required to improve the viability of Texas snowbells is influenced largely by its life history. When all conservation actions have been accomplished, their effectiveness will be measured by the natural recruitment of new individuals, their growth to maturity, and the increase of populations to a viable level that is sustained without human intervention.

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

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I. Introduction.

Texas snowbells is a rare, endemic shrub of the Edwards Plateau of Texas. V.L. Cory discovered the plant in 1940 and described it as a species, *Styrax texana*, in 1943 (Cory 1943). It was listed as an endangered species on October 12, 1984 (49 FR 40036). We concur with the more recent taxonomic revision of Fritsch (1997) which recognizes this listed entity as subspecies *texanus* of *Styrax platanifolius*. The original recovery plan (U.S. Fish and Wildlife Service 1987) did not establish criteria for downlisting or de-listing. A draft revised recovery plan (U.S. Fish and Wildlife Service 1999) was prepared in 1999 by Jackie Poole, Texas Parks and Wildlife Department (TPWD), but never finalized. A subsequent draft revised recovery plan (U.S. Fish and Wildlife Service 2009) was also never finalized. This Species Status Assessment (SSA) compiles updated information on the subspecies' distribution, populations, ecology, and recovery efforts, and through an analysis of its requirements, factors affecting its survival, and current conditions, assesses the overall viability in terms of representation, redundancy, and resilience. The SSA documents relevant information that will be used for decisions and planning, including a revised recovery plan that will conform to updated standards established by the National Marine Fisheries Service and U.S. Fish and Wildlife Service (2010) and the Recovery Planning and Implementation Guidance established in 2016 (https://sites.google.com/a/fws.gov/recovery-planning-and-implementation/).

II. Subspecies Information.

II.1. Description, Taxonomy, and Genetics.

Description (adapted from Cory 1943, pp. 111-113; Gonsoulin 1972, pp. 212-214; Fritsch 1997, pp. 742, 744; Poole et al. 2007, pp. 476-477).

Texas snowbells is a multi-stemmed shrub or small tree up to 6 m (20 ft) tall (figure 1.1). The alternate leaves are broadly oval to elliptic, from 2.5 to 7.5 cm (1 to 3 in) long and wide, borne on petioles up to 18 mm (0.71 in) long. Bright green, smooth, upper leaf surfaces contrast visually with whitish lower surfaces (figure 1.3), which are festooned with dense microscopic hairs (figure 1.2). The leaf veins divide pinnately. The leaf margins are somewhat wavy, usually entire, and may have coarse teeth or three lobes (Fritsch 2009, p. 344). Clusters of (typically) 3 to 5 flowers (figure 1.6) arise from leaf axils; peduncles and pedicels are 10 to 12 mm (0.4 to 0.5 in) long and densely pubescent. Individual flowers have the following features: length 12 to 20 mm (0.5 to 0.8 in); subtended by minute bracts; whitish, bell-shaped, pubescent calyx, 4 to 6 mm (0.16 to 0.24 in) long, with up to 7 prominent teeth; white, bell-shaped corollas (hence the common name "snowbells") with five lobes 14 to 20 mm (0.6 to 0.8 in) long; 10 stamens as long as the corolla lobes, with yellow-orange anthers; a single style, pubescent at its base, often longer than the corolla lobes and stamens. The fruit is a globose drupe 7 to 8 mm (0.28 to 0.31 in) in diameter usually bearing a single smooth, globose seed. Flowering occurs in late March and April, and the drupes mature in August and September.

The leaves and general appearance of Texas snowbells resemble Texas redbud (*Cercis canadensis* var. *texensis*), which may occur in the same habitats. However, Texas snowbells is easily distinguished by the densely pubescent lower leaf surfaces, the infrequently toothed margins (Fritsch 2009, p. 344), and the pinnately veined leaves, unlike the palmately veined, glabrous, entire leaves of redbud.

Taxonomy

The genus *Styrax* currently includes about 120 recognized species; these are mostly tropical or subtropical woody plants of East and Southeast Asia, the Eastern Mediterranean, and the Americas (Gonsoulin 1974, p. 191; Fritsch 1997, p. 705). V.L. Cory described *Styrax texana* in 1943 based on several individuals he observed along two tributaries of Pulliam Creek in the Nueces River watershed of Texas (Cory 1943, pp. 112-113). He distinguished *S. texana*, *S. platanifolia*, and *S. youngae* based on the ornamentation of leaves, pedicels, calices, and styles.

Gonsoulin (1974) revised the genus *Styrax* in North America, Central America, and the Caribbean. He recognized 14 species in 2 series (Valvatae and Imbricatae) (pp. 220-258). In Texas and Northeast Mexico, this treatment included *S. platanifolia* with two varieties, *platanifolia* (pp. 211-213) and *stellata* (p. 213), *S. texana* (pp. 213-214), and *S. youngae* (pp. 214-215).

Fritsch's subsequent revision (Fritsch 1997) of *Styrax* of West Texas, Mexico, and Mesoamerica recognized 19 species and 24 taxa, including 7 geographically and morphologically distinct subspecies of two species. He determined that the characters used by Cory and Gonsoulin to distinguish the five taxa found in Texas and Northeast Mexico to be inconsequential or taxonomically unreliable; morphological, isozyme, and DNA sequence data indicated that these taxa are more closely related to each other than to other *Styrax* taxa and belong to a single species (p. 741) in section *Styrax* series *Imbricatae* (characterized by imbricate corolla lobes, dry fruits, and deciduous leaves; p. 712). However, distinct regional differences in the

morphology and abundance of trichomes within this group support the delimitation of five allopatric subspecies (p. 741); see table 1 and figure 2. Note that, following Nicolson and Steyskal (1976), Fritsch adopted the masculine gender for *Styrax* (p. 712).

Fritsch's taxonomic treatment of *Styrax platanifolius* and its subspecies, including *S. platanifolius* ssp. *texanus*, is currently recognized by the Flora of North America (Fritsch 2009, pp. 340, 341, 343-345), the Integrated Taxonomic Information Service (2014), Missouri Botanical Garden (Tropicos 2014), and the USDA Plants Database (Natural Resources Conservation Service 2014), among others. However, Turner and Nesom (2000) recognized the infra-taxa of *S. platanifolius* as varieties rather than subspecies. In the field of botany, the recommended nomenclature for infra-taxa continues to be debated. For practical reasons we have adopted Fritsch's treatment. Throughout this document, the common name "Texas snowbells," and "subspecies" by itself, refers to *Styrax platanifolius* ssp. *texanus*.

We offer a hypothesis to explain the geographic distribution of the subspecies of *S. platanifolius*. This riparian species may have been more abundant in mesic habitats along watercourses within its current geographic range during the Pleistocene, when the climate was cooler and wetter. As the climate warmed during the Holocene, populations may then have migrated along watercourses to higher elevations in the mountains of Mexico and West Texas and in protected, moist canyons of the Edwards Plateau, or may simply have persisted in those environments, while dying out elsewhere. Seeds probably do not disperse far from parent trees, limiting the rate of migration. Most Mesoamerican species of *Styrax*, including *S. platanifolius*, are narrow endemics that exist in small populations (Fritsch 1997, pp. 707-708). These relict *platanifolius* populations would have been reproductively isolated from each other for approximately 10,000 years, during which the lineages diverging from small founding populations would have been subject to genetic drift and adaptive radiation. It is also possible that genetic differences could have persisted following earlier periods of reproductive isolation.

Genetic Studies

Data from chloroplast and nuclear DNA sequences provide strong evidence of a monophyletic clade including the West Texas subspecies of *Styrax platanifolius* and *S. redivivus* from California; this group is sister to *S. officinalis* from the Western Mediterranean (Fritsch 2001, pp. 395, 396, 398-401, 405). Based on isozyme variation within this group, Fritsch (1996, pp. 349-350) estimated that these taxa had diverged between 5.0 and 13.8 million years ago. This investigation did not detect significant genetic differences between the subspecies *stellatus*, *mollis*, and *texanus*. The isozyme data also indicated that the Texas taxa had a relatively low genetic diversity and suggested that the group had undergone a genetic bottleneck (Fritsch 1996, p. 350; note that this analysis compared three populations of subspecies *texanus* and three individuals of subspecies *stellatus*). Adams and Poole (2011) used Random Amplified Polymorphic DNA (RAPDs) to analyze genetic differences among ten individuals collected from each of three populations of subspecies *texanus*. They found very little evidence of variation between individuals or among populations (pp. 200-202); thus, although conservation of multiple populations reduces the risk of extinction from catastrophic events, it may not conserve greater genetic variation (i.e., multiple populations would provide greater redundancy but not greater representation).

Figure 1. Images of Texas snowbells.

1.1 Mature shrub at San Antonio Botanical Garden. 1.2 Stellate hairs on underside of leaf. 1.3 Contrasting upper and lower leaf surfaces. 1.4 Seedlings propagated at San Antonio Botanical Garden. 1.5 Reintroduced shrub with protective cage. 1.6 Inflorescence.

Table 1. Distinguishing characters of *Styrax platanifolius* subspecies (adapted from Fritsch 1997, p. 742).

Characters	*platanifolius*	*mollis*	*stellatus*	*texanus*	*youngiae*
Upper leaf surface:	Glabrous	Scattered stellate or simple hairs	Scattered stellate hairs with 6-14 arms	Glabrous	Scattered stellate hairs with 6-14 arms
Lower leaf surface:	Glabrous	Surface visible through moderately-dense white stellate hairs; soft to the touch	Surface visible through hairs; rough to the touch; scattered stellate hairs on some leaves	Surface completely covered and obscured by thin, even layer of white stellate hairs	Surface completely covered and obscured by thick layer of white stellate hairs
Young twigs:	Scattered orange-brown to dark brown stalked stellate hairs at base	Dense white-stellate hairs and scattered orange-brown to dark brown stalked stellate hairs at base	Sparse white stellate hairs with scattered orange-brown to dark brown stalked stellate hairs at base	Faintly glaucous, glabrous with scattered orange-brown to dark brown stalked stellate hairs at base	Dense white stellate hairs with scattered orange-brown to dark brown stalked stellate hairs at base
Pedicels:	Glabrous	Pubescent	White stellate hairs	Thin, even layer of white stellate hairs	Thick, uneven layer of white stellate hairs
Lower leaf trichome morphology:	No data	Longest arm 0.8 mm (0.03 in) to over 1 mm (0.04 in)	Longest arms typically 0.4 mm (0.016 in), rarely to 1 mm (0.04 in)	No data	No data
Calyx features:	Glabrous; some teeth to 1 mm (0.04 in) long; teeth and margin densely glandular	Teeth up to 0.3 mm (0.01 in) long; margin sparsely glandular	White stellate hairs; teeth to 1 mm (0.04 in) long; teeth and margin densely glandular	Thin, even layer of white stellate hairs; teeth to 1 mm (0.04 in) long; teeth and calyx margin densely glandular	Thick layer of white stellate hairs of variable length; teeth to 0.6 mm (0.02 in) long; teeth and margin sparsely glandular
Style features:	Pubescent from base to 15-35% of length	Pubescent from base to 30-70% of length	Pubescent from base to 50-70% of length	Pubescent from base to 15-35% of length	Pubescent from base to 60-80% of length
Range:	Edwards Plateau in west-central Texas, 200-700 m (660-2,300 ft) elevation	Eastern slopes of mountains in Nuevo León, Tamaulipas, and Coahuila, 1,200-1,400 m (3,900-4,600 ft) elevation	Edwards Plateau in west-central Texas, 500-700 m (1,600-2,300 ft) elevation	Edwards Plateau in west-central Texas, 500-700 m (1,600-2,300 ft) elevation	Davis Mountains and eastern slopes of mountains of northern Coahuila, 900-2000 m (3,000-3,600 ft) elevation

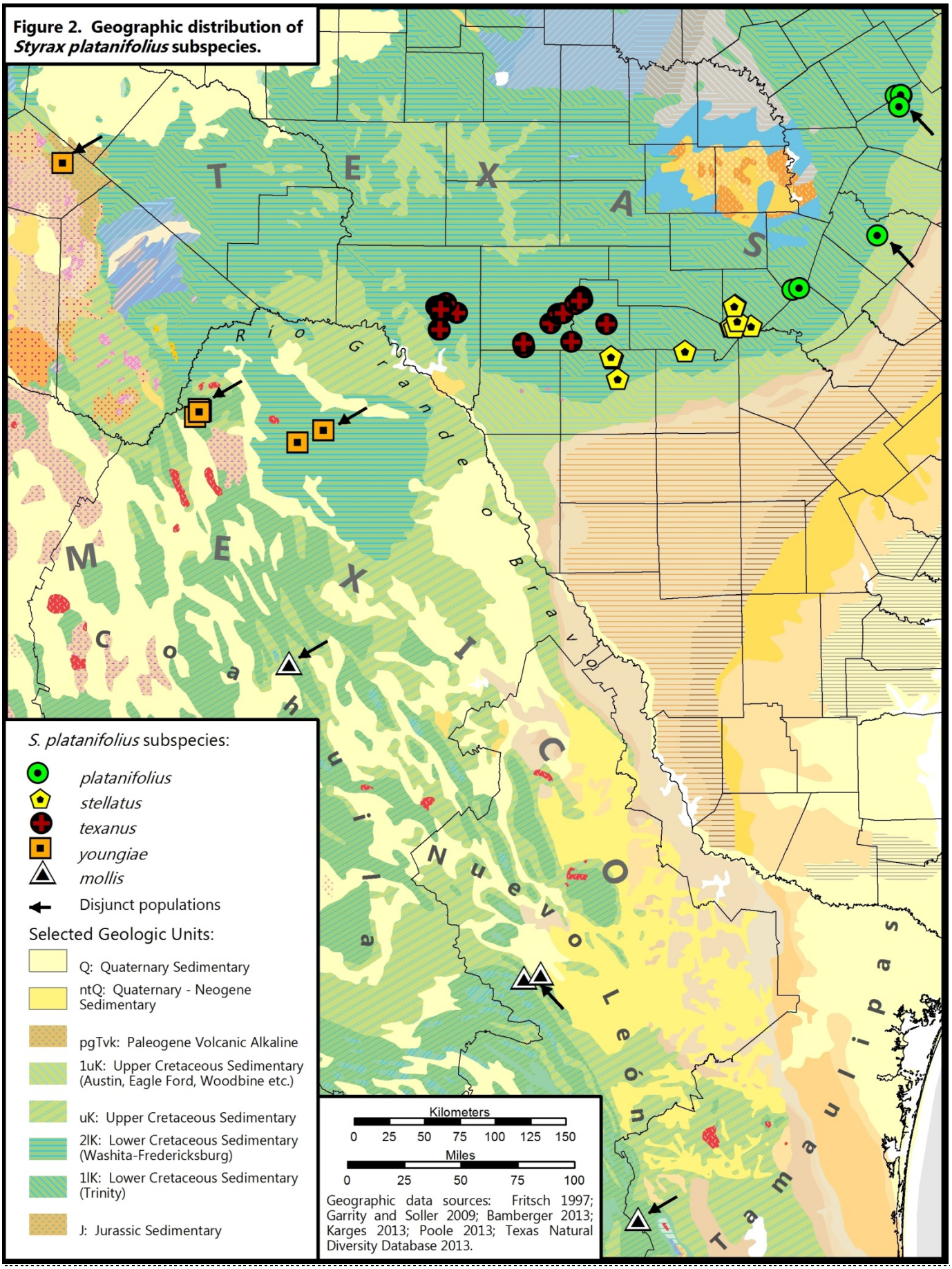


Figure 2. Geographic distribution of *Styrax platanifolius* subspecies.

II.2. Distribution, Abundance, and Population Trends.

Population, site, location, and other terms are often used interchangeably or ambiguously to describe the geographic distributions of rare plants. NatureServe (2002, p. 10) defines Element Occurrences (EOs) as "area(s) of land and/or water in which a species or natural community is, or was, present." The Texas Natural Diversity Database (TXNDD) has adopted the EO standard for tracking records of plants, animals, and habitats of conservation concern. In this document, we use EOs if these are designated in the TXNDD, or otherwise, "site" to refer to a specific location where one or more Texas snowbells have been documented. Existing sites are probably remnants of formerly contiguous populations whose limits we can only guess.

V.L. Cory first observed Texas snowbells in 1940 along Pulliam and Polecat Creeks in Edwards County, Texas. In 1941 and 1942 he collected specimens from that site and from another site on the north side of Cedar Creek Canyon, a tributary of Pulliam Creek; these formed the basis of his species description (Cory 1943). The Texas Natural Diversity Database (2013, pp. 1 – 19) has labelled these sites as EOs 4 and 1, respectively. In 1941 and 1942, S.E. Wolff collected specimens, later determined to be ssp. *texanus*, along a dry arroyo at the Horace Faucett Ranch in Val Verde County (EO8). The specimens collected at EO1 and EO8 do not include precise location data and are therefore represented on our maps as relatively large circles rather than points. Element Occurrence 1 was last observed in 1983, but consisted of a single shrub subject to goat browsing, and EO8 was last observed in 1942. Hence, these EOs are considered historic (rather than extant).

Mahler (1981) documented the existence of 21 individual Texas snowbells plants at three sites. The final rule to list Texas snowbells as an endangered species (49 FR 40036-40038), published in 1984, states that only 25 individuals were known at that time: 7 along Polecat, Cedar, and Little Hackberry Creeks in Edwards County, 14 along the East Prong of the Nueces River in Real County, and 4 in Kimble County. However, the Kimble County records were later shown to be *S. platanifolius* ssp. *stellatus* (Poole et al. 2007, p. 477), and populations in Val Verde County had not yet been confirmed. Following the listing as an endangered species, additional surveys and increased public awareness have led to discoveries of new individuals and populations. Updated population surveys have been reported in the original recovery plan (U.S. Fish and Wildlife Service 1987), two unpublished draft revisions of the recovery plan (U.S. Fish and Wildlife Service 1999, 2009), and the five-year review (U.S. Fish and Wildlife Service 2008).

This SSA includes an analysis conducted in 2013 of the known populations and geographic locations, based on data obtained from Cox (2000), Fulton (2008, 2013), Adams and Poole (2011), Bamberger (2013a, b), Karges (2013), Poole (2013a-j), and the TXNDD (2013). Table 2 summarizes the 2013 population data, and Table 3 is a complete list of the currently known sites and EOs. Figures 3, 6, 7, and 8 are maps of the global distribution of Texas snowbells and its metapopulations in the Nueces, West Nueces, and Devils River watersheds, respectively. These maps and tables use the EO labels assigned in the TXNDD. However, we also use temporary labels to identify some of the more recently discovered sites that are not yet listed in the most recent update of the TXNDD (2013). A few of the populated sites reported here, such as B1 along the West Frio River in Real County, were reported by concerned citizens but have not yet been confirmed. These reports could be confirmed by a qualified botanist through examination of plants in the field or voucher specimens collected from the site and deposited in a herbarium (Poole 2013i).

In synthesis, these records collectively indicate that by 2013, 400 mature and 452 immature Texas snowbells plants had been documented in 22 naturally-occurring sites. The global population is endemic

to three watersheds, spanning a range of 121 km (75 mi) east to west and 35 km (22 mi) north to south. Fifteen of the documented sites had fewer than 10 individuals and 2 had at least 100. Fifteen naturally occurring populations are on private land, 5 are on private conservation land (Dolan Falls Preserve and conservation easements managed by The Nature Conservancy (TNC)), and 2 are on public conservation land (Devil's River State Natural Area). However, since access to privately-owned sites is subject to voluntary landowner approval, these totals include some sites that have not been monitored since 1986. Although Texas snowbells appears able to live for decades, if not longer, the mortality rate of seedlings and young trees is very high, largely due to severe browsing by ungulates and perhaps other animals. Hence, the future contribution of immature plants to the reproductive population is uncertain.

The subspecies has also been reintroduced in 22 sites on private land and 2 sites at Dolan Falls Preserve. Most of these plants have not yet reached reproductive maturity. However, figure 1.5 shows a propagated, reintroduced Texas snowbells plant that flowered for the first time in April 2013, about 10 years after planting.

A large proportion of the potential habitat of Texas snowbells is privately owned. Due to the access issues mentioned above, much of the potential habitat on private land has probably not been surveyed. Therefore, we believe that the actual size and numbers of populations and the degree of connectivity between them may be greater than the data from documented populations indicates. Sections II.4 and III discuss these issues in greater detail.

The number of mature, naturally occurring Texas snowbells plants documented in 2013 was 8 times greater than in 1984 when it was federally listed as an endangered species. However, this increase primarily reflects new discoveries of individuals and populations rather than actual population growth.

Table 2. Summary of known Texas snowbells populations.

Site Characteristics			Populations		
Population Origin	Status	Ownership	Number	Mature[1] Individuals	Immature[1] Individuals
Natural	Historic	Private	2	Unknown	Unknown
Natural	Extant	Private	15	286	143
Natural	Extant	Private Conservation Land	5	112	309
Natural	Extant	Public Conservation Land	2	2	0
Sub-total of extant natural populations and individuals:			22	400	452
Reintroduced[2]	Extant	Private	22	22	451
Reintroduced[2]	Extant	Private Conservation Land	2	0	2
Sub-total of extant reintroduced populations and individuals[2]:			24	22	453
Total of all extant populations and individuals:			46	422	905

1. Mature individuals have flowered at least once or are capable of flowering; immature individuals are not yet capable of flowering.
2. Ongoing reintroduction and the proportion of mature individuals continually adds to these totals. See also table 11 and discussion in Section III, Propagation and Reintroduction.

Table 3. Global populations of Texas snowbells.

Site Name	EO No. or other ID[1]	SF ID[1]	County	HU10 Watershed[2]	HU12 Watershed[2]	First Reported	Most Recent Report available to USFWS[6]			Ownership	Origin[3]	Current Status[4]
							Date	Mature	Immature			
Cedar Creek	EO1	7362	Edwards	Pulliam Creek	Cedar Creek	Jul 1941	1983	1	0	Unknown	N	H
Mare Creek (Reagan Wells)	EO2	1381	Uvalde	Dry Frio River	Mare Creek	Apr 1987	2000	9	0	Private	R	E
Greenwood Valley Monitoring Site	EO3	11427	Real	East Prong Nueces River	Lower East Prong Nueces River	Jul 1943	2005	33	118	Private	N	E
Polecat Spring	EO4	6057	Edwards	Pulliam Creek	Upper Pulliam Creek	Jul 1940	Apr 1986	9	0	Private	N	E
Minor North Tributary of Little Hackberry Creek	EO5	2126	Edwards	Pulliam Creek	Little Hackberry Creek	Aug 1943	Apr 1986	1	0	Private	N	E
0.8 mi S of Eagle Ranch	EO6	7287	Real	East Prong Nueces River	Lower East Prong Nueces River	Apr 1980	Apr 1986	2	0	Private	N	E
0.5 mi S of Nueces/East Prong Confluence	EO7	1686	Edwards	Headwaters Nueces River	Ruth Draw	Apr 1980	Apr 1986	2	0	Private	N	E
Horace Faucett Ranch	EO8	6533	Val Verde	Unknown	Unknown	Jun 1941	Jul 1942	Un-known	Unknown	Private	N	H
Northrup Ranch	EO9	5506	Bandera	Unknown	Unknown	Apr 1982	Apr 1982	Un-known	Unknown	Private	N	MI?
Sabinal Canyon 7.5 mi N of Vanderpool	EO10	5507	Bandera	Upper Sabinal River	Brushy Creek	1955	Apr 1956	Un-known	Unknown	Unknown	N	MI?

Site Name	EO No. or other ID[1]	SF ID[1]	County	HU10 Watershed[2]	HU12 Watershed[2]	First Reported	Most Recent Report available to USFWS[6]			Ownership	Origin[3]	Current Status[4]
							Date	Mature	Immature			
Dolan Springs	EO13	394	Val Verde	Dolan Creek	Lower Dolan Creek	1989	± 2000	1	0	TPWD - Devils River SNA	N	E
Eagle Nest/Joy Hollow Creek	EO14	11428 11429	Real	East Prong Nueces River	Lower East Prong Nueces River	Jun 1991	Jul 1991	23	25?	Private	N	E
Eagle Nest, East Prong of Nueces	EO15	2928	Real	East Prong Nueces River	Lower East Prong Nueces River	Jun 1991	Jul 1991	2	0	Private	N	E
Dolan Falls Ranch	EO16	1633	Val Verde	Devils River - Amistad Reservoir	Indian Creek	Sep 1992	2013	1	2	TNC[5]	N	E
Devil's River	EO17	9355	Val Verde	Deaton Draw	Blue Springs	May 1993	2015	±244	198	TNC	N	E
Dolan Creek	EO18	106	Val Verde	Deaton Draw	Blue Springs	Apr 1995	Apr 1998	1	0	TPWD - Devils River SNA	N	E
S Prong Cypress Creek	EO19	8178	Real	West Frio River	Lower East Frio River	Apr 1987	2000	13	0	Private	R	E
Pictograph Canyon	K1, K2, K3	n/a	Val Verde	Devils River - Amistad Reservoir	Indian Creek	18 May 1999	6 May 2004	≥3	Unknown	TNC - Dolan Falls Preserve	N	E
Dry Devils River	K4	n/a	Val Verde	Dry Devils River	Cedar Draw	1997	1997	2	0	TNC Conservation Easement on private land	N	E
Lower Grass Patch Canyon	K5	n/a	Val Verde	Devils River - Amistad Reservoir	Indian Creek	Apr 2013	Apr 2013	1	0	TNC - Dolan Falls Preserve	N	E
Dolan Falls Campground	K6	n/a	Val Verde	Devils River - Amistad Reservoir	Indian Creek	2013	2013	Un-known	Unknown	TNC - Dolan Falls Preserve	R	E
Grass Patch Canyon	K7	n/a	Val Verde	Devils River - Amistad Reservoir	Indian Creek	2 April 2013	2 April 2013	Un-known	Unknown	TNC - Dolan Falls Preserve	R	E

Site Name	EO No. or other ID[1]	SF ID[1]	County	HU10 Watershed[2]	HU12 Watershed[2]	First Reported	Most Recent Report available to USFWS[6]			Ownership	Origin[3]	Current Status[4]
							Date	Mature	Immature			
Cedar Canyon	P1, P2	n/a	Val Verde	Devils River-Amistad Reservoir	Dark Canyon		10 Nov 2003	≥ 100	Unknown	Private	N	E
Dobb's Run	P3, P4, P5, P6	n/a	Edwards	Upper West Nueces River	Cherry Creek	Apr 1998	Apr 2010	7	0	Private	N	E
Unknown	B1	n/a	Real	West Frio River	Lower West Frio River		Un-known	30	Unknown	Private	N	E
Unknown	B2	n/a	Edwards?	Headwaters Nueces River?	Camp Wood Creek/Lower Pulliam Creek/Dry Creek?		Un-known	3	Unknown	Private	N	E
Unknown	B3	n/a	Real	East Prong Nueces River	Lower East Prong Nueces River		Un-known	6	Unknown	Private	N	E
Unknown	B4	n/a	Edwards	Upper West Nueces River	Cherry Creek		Un-known	50	Unknown	Private	N	E
Unknown	B5	n/a	Edwards	Upper West Nueces River	Cherry Creek		Un-known	15	Unknown	Private	N	E
Unknown	B6	n/a	Val Verde	Deaton Draw	Blue Springs		Un-known	3	Unknown	Private	N	E
Lost Canyon	BR1	n/a	Real	Headwaters Nueces River	Dry Creek	2004	2008	0	23	Private	R	E
El Choya	BR2	n/a	Edwards	Pulliam Creek	Lower Pulliam Creek	2004	2008	0	58	Private	R	E
Buck Hollow	BR3	n/a	Uvalde	Dry Frio River	Mare Creek	2004	2008	0	34	Private	R	E
Shields	BR4	n/a	Real	Montell Creek	Ranch Creek	2004	2008	0	45	Private	R	E
Lewey	BR5	n/a	Uvalde	Montell Creek	Elm Slew	2004	2008	0	12	Private	R	E
Kickapoo	BR6	n/a	Edwards	Upper West Nueces River	Bluff Creek	2004	2008	0	57	Private	R	E

Site Name	EO No. or other ID[1]	SF ID[1]	County	HU10 Watershed[2]	HU12 Watershed[2]	First Reported	Most Recent Report available to USFWS[6]			Ownership	Origin[3]	Current Status[4]
							Date	Mature	Immature			
Dobbs Run	BR7, BR8, BR9, BR10	n/a	Edwards	Upper West Nueces River	Cherry Creek	2004	2008	0	47	Private	R	E
Monro	BR11	n/a	Val Verde	Devils River - Amistad Reservoir	Indian Creek	2004	2008	0	0	Private	R	E
Williams	BR12	n/a	Val Verde	Devils River - Amistad Reservoir	Indian Creek	2004	2008	0	0	Private	R	E
Jenkins	BR13	n/a	Real	East Prong Nueces River	Upper East Prong Nueces River		Un-known	Un-known	Unknown	Private	R	E
Total of 10 additional reintroduction sites	Un-known	n/a	Unknown	Unknown	Unknown		Un-known	0	175	Private	R	E
	Minimum population totals observed since 1986:							422	905			

1. EO = Element Occurrence in Texas Natural Diversity Database; SF ID = Source Feature Identification in Texas Natural Diversity Database; K = Information provided in Karges 2013; P = Information provided in Poole 2013c, f; B = Natural populations reported by Bamberger group; BR = Bamberger group reintroductions. B and BR information provided in Bamberger 2013c,d, Fulton 2008, Fulton 2013, Poole 2013b,d,g.
2. Natural Resource Conservation Service 1999-Present.
3. N = Natural; R = Reintroduced.
4. H = Historic; E = Extant; Unk = Unknown; MI = Misidentified.
5. TNC = The Nature Conservancy.
6. USFWS = U.S. Fish and Wildlife Service.

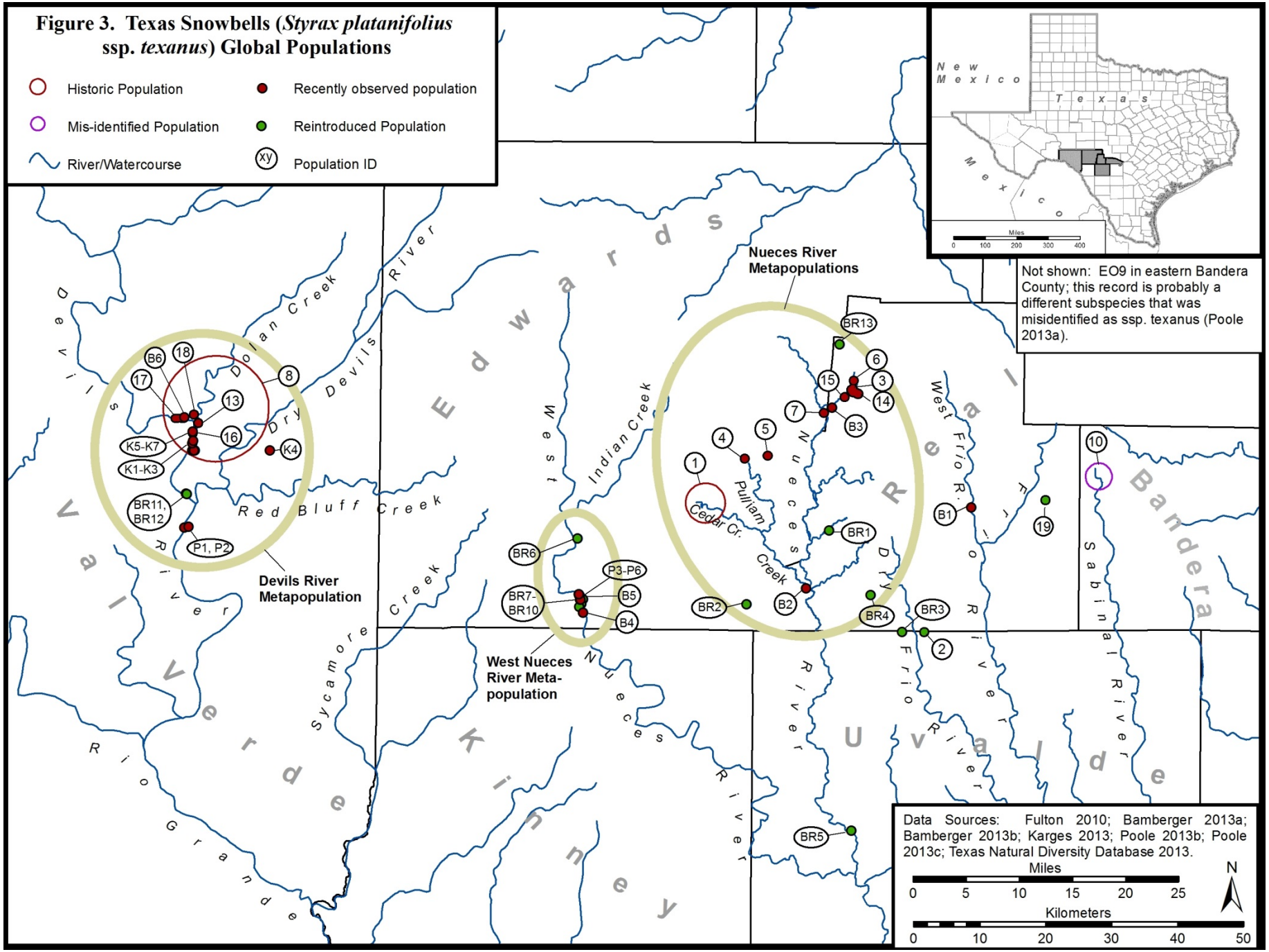


Figure 3. Texas Snowbells (*Styrax platanifolius* ssp. *texanus*) Global Populations
Historic Population
Recently observed population
Mis-identified Population
Reintroduced Population
River/Watercourse
Population ID
Nueces River Metapopulations
Devils River Metapopulation
West Nueces River Meta-population
Not shown: EO9 in eastern Bandera County; this record is probably a different subspecies that was misidentified as ssp. texanus (Poole 2013a).
Data Sources: Fulton 2010; Bamberger 2013a; Bamberger 2013b; Karges 2013; Poole 2013b; Poole 2013c; Texas Natural Diversity Database 2013.
Miles
0 5 10 15 20 25
Kilometers
0 10 20 30 40 50
N
New Mexico
Texas
Mexico
Miles
0 100 200 300 400
Edwards
Real
Bandera
Kinney
Uvalde
Val Verde
Dolan Creek
Devils River
Dry Devils
Red Bluff Creek
Indian Creek
West Nueces
Nueces
Pullium Creek
Cedar Cr.
Dry Nueces
West Frio R.
Frio River
Sabinal River
Sycamore Creek
Rio Grande
B6
18
17
8
13
16
K5-K7
K1-K3
K4
BR11, BR12
P1, P2
BR6
P3-P6
BR7-BR10
B5
B4
1
4
5
BR13
6
15
3
14
7
B3
BR1
B2
BR2
BR4
BR3
2
B1
19
10
BR5

II.3. Phenology, Reproduction, Demographics, and Minimum Viable Population.

Phenology and Reproduction.

Texas snowbells flowers as early as late March (Poole 2017, p. 14), in April (Cory 1943, p. 113; Gonsoulin 1974, p. 214; Mahler 1981, p. 4; Poole 1993, p. 2) or from April to May (Fritsch 1997, p. 744). Poole (1993, pp. 1-4) observed the population of EO3 from 1989 through 1992. Fruit development was evident in May 1989, one month after flowering, and continued through August when fruits began to dehisce. Reproductive plants in the study area ranged from 2 to 26 stems (average 13) and stems ranged from 3 to 48 mm (0.12 to 1.89 in) in basal diameter. In 1991, 3,300 flowers formed 1,200 fruits (36 percent fruit set). In 1995, Poole and Cook (1996, pp. 1-3) tracked 25 flowering plants at EO3 that produced 1,986 flowers and 1,482 fruits (75 percent fruit set). During the same year, 58 plants at EO17 had 7,638 flowers that yielded 3,537 fruits (46 percent fruit set). The minimum size of flowering plants at both sites was 61 cm (2 ft) in height and 6 mm (0.24 in) in basal cross-section. The average size of flowering adults was 2.1 m (7 ft) in height and 24 mm (0.94 in) in diameter. These two studies did not determine the number or viability of seeds produced. Fruits usually have one seed, but may have up to four under the most favorable conditions (Poole et al. 2007, p. 476). While seed set per flower was lower at EO17, the assumed average number of seeds per flowering individual was nearly the same (59 at EO3 and 61 at EO17). Seeds disperse by gravity or may be carried by stream flows; however, rodent dispersal may also be important (see discussion under demographics, below). Reemts *et al*. (2016, all) summarized the conclusions of continued annual monitoring at EO17 from 1995 to 2015: Average annual mortality was 6 percent (excluding trees killed during the exceptional drought of 2011); from 71 to 97 percent (average 87 percent) of flowering trees produced seeds; fruits can remain on trees as late as September.

Relatively few studies have been conducted on reproductive biology within the genus *Styrax* (Fritsch 1997, pp. 708-711). Sugden (1986) investigated pollination and reproduction in California populations of *S. officinale* ssp. *redivivum* (Torr.) Thorne (syn. *Styrax redivivus* (Torr.) L.C. Wheeler). Due to conservative floral evolution in the genus *Styrax* (Fritsch 1997, p. 711), the pollination system in Texas snowbells may be similar to *S. redivivus*. Sugden found that anthesis, stigma receptivity, and nectar production occurred on the same day (pp. 921-922) and that the highest fertilization rate occurred when stigmas were pollinated during anthesis (p. 923). However, fertilization resulted only when recipient flowers received pollen from a different individual (pp. 923-924), confirming that this subspecies is an obligate out-crosser. Flowers produced large amounts of high-sucrose nectar and might be expected to attract hummingbirds; nevertheless, although hummingbirds were present they very rarely visited the flowers (pp. 922, 928). The determination of pollinator efficacy, defined as "...the relative potential of a flower visitor species as a successful pollen vector for a given population of plants," considered both the efficacy of individuals as well as populations of potential pollinator species (pp. 921, 924-927). The most efficacious pollinator, on both the individual and population basis, was the pipevine swallowtail (*Battus philenor*), a large Papilionid butterfly. Queens of the large bumblebee *Bombus vosnesenskii* were individually efficacious but present at low densities. A smaller bumblebee, *Bombus edwardsii*, was individually less efficacious but present in higher densities. A carpenter bee, *Xylocarpa tabaniformis*, and a halictid bee, *Halictus ligatus*, were not important pollinators. Pollen-foraging honeybees (*Apis mellifera*) were more efficacious than nectar-foraging honeybees, and due to their high densities were moderately efficacious at the population level. However, Sugden speculated that high densities of honeybees may reduce the reproductive output of this *Styrax* subspecies due to competition for pollen and nectar with other more efficacious native pollinators (p. 928).

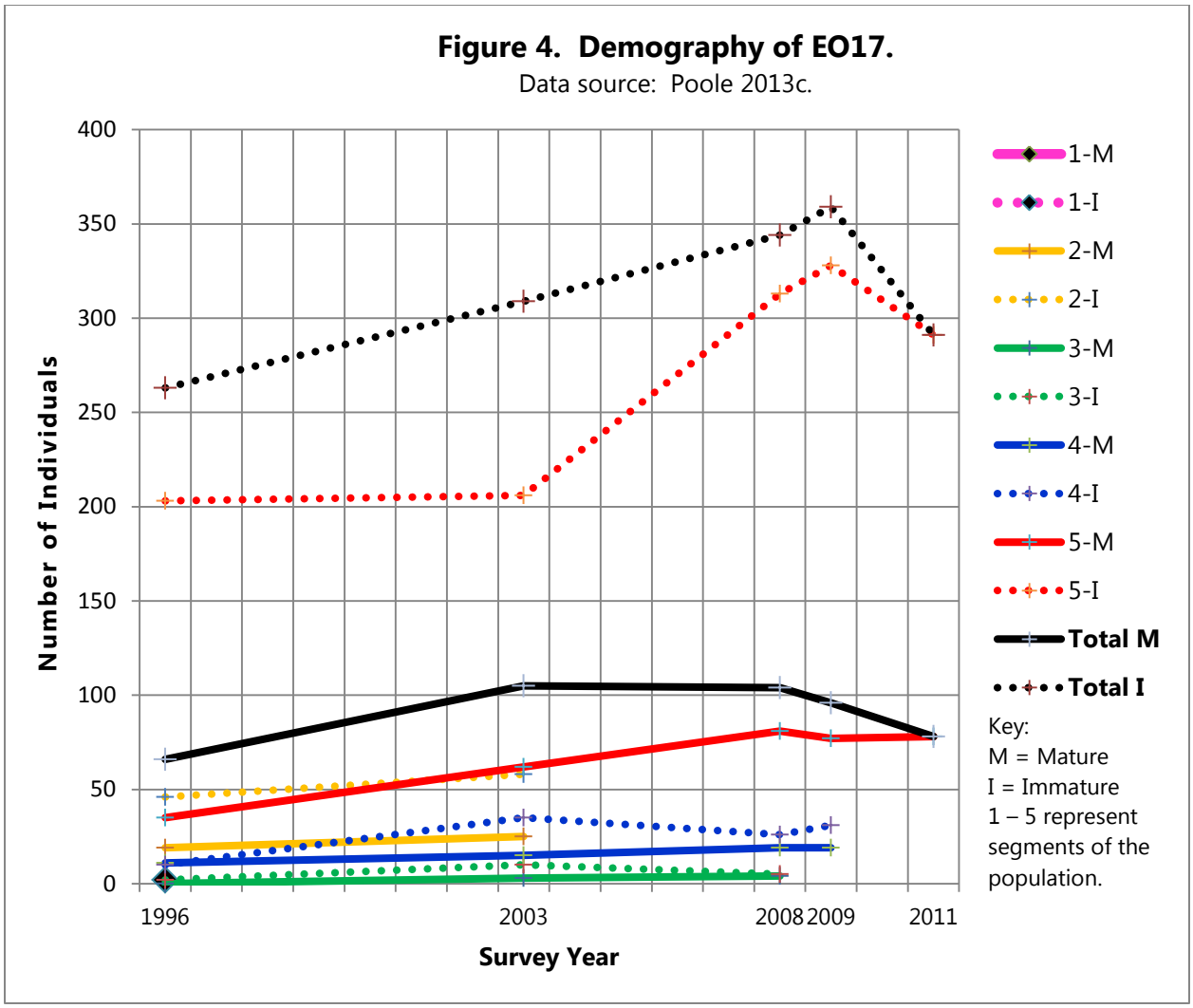
Fulton (2010, pp. 4-9) investigated pollination and reproduction of Texas snowbells in the Nueces, West Nueces, and Devils River watersheds from 2008 to 2010. Floral visitors included the American bumblebee (*Bombus pensylvanicus*), honey bee, a sweat bee (*Lasioglossum morrilli*), California carpenter bee (*Xylocopa californica*), northern cloudy wing butterfly (*Thorybes pylades*), tiger swallowtail (*Papilio glaucus*), pipevine swallowtail, and black-chinned hummingbird (*Archilochus alexandri*). By controlling access to open flowers, he determined that the honey bee, American bumblebee, and California carpenter bee are all effective pollinators of Texas snowbells (results summarized below). No fruits developed from 57 flowers that were hand-pollinated with pollen from the same individual and 33 fruits developed on 95 flowers hand-pollinated with pollen from other Texas snowbells plants. Although the sample size was small (two trees at one site), this evidence supports the hypothesis that Texas snowbells is self-incompatible (obligately xenogamous).

Table 4. Summary of Texas snowbells pollination documented in Fulton 2010, pp. 4-9.

Pollinator species	Flowers visited per minute	Fertilization rate (number of fruits per visited flower). Rates from different sites or years are separated by semi-colon.	
		Single Visit	Multiple Visits
American bumblebee	13.5	0.086; 0.304	0.385
California carpenter bee	15.5	0.217	0.142
Honeybee	5.0	0.057; 0.152; 0.631	0.014; 0.102; 0.429

Demographics.

Most of the known populations have not been monitored long enough or at a sufficient frequency to permit the determination of demographic trends. An important exception is EO17, where Poole (2013c) conducted five surveys (1996, 2003, 2008, 2009, and 2011; figure 4). Although not all segments of this EO were surveyed each time, the data suggests that this EO has been increasing or stable during this 15-year period. In 1996, 66 mature and 263 immature individuals were counted. By 2003 the population had grown to 105 mature and 309 immature plants. In 2011, surveyors found 78 mature and 291 immature snowbells, but they did not observe portions of the EO where 48 mature and 96 immature plants had previously been reported; hence, the total population may have comprised 126 or more mature plants. The large numbers of immature plants at this EO and the survival of some immature plants to a mature, reproductive stage are important indicators of healthy demographic trends. Several features appear to contribute to the viability of this population. The site, which is located along the Devils River at TNC's Dolan Falls Preserve, has been managed for conservation purposes at least since 1991 (The Nature Conservancy 2014). Populations of white-tailed deer (*Odocoileus virginianus*) and introduced ungulates and the consequent browsing intensity are relatively lower there, compared to elsewhere in the Edwards Plateau (Kevin Connally, U.S. Fish and Wildlife Service, pers. comm. 2014). Most of the Texas snowbells plants grow in sites that are inaccessible to ungulates, such as very steep slopes or cliff faces and within clusters of less palatable species (Reemts 2017, p. 15). The population possessed at least 66 individuals of reproductive age distributed in relatively close proximity along about 1.5 km (0.9 mi) of the Devils River; evidence of ongoing reproductive success (numerous immature plants) indicates that the population has sufficient genetic diversity for successful fertilization.



The only other natural populations where large numbers of immature individuals have been documented are EO3 and EO14; these and four other EOs are located along the lower East Prong of the Nueces River in Real and Edwards counties. EO3 and EO14 are in close proximity along about 1.6 km (1.0 mi) of stream, and perhaps should be combined into a single EO. Collectively, they had 56 mature and 143 immature plants (when last reported). In contrast, among 11 natural extant EOs that had fewer than 10 mature individuals, only one (EO16) had immature plants; EO16 is within about 1.6 km (1.0 miles) of two other EOs and might have been cross-pollinated by one of those plants. Therefore, almost all documented reproduction of Texas snowbells, as indicated by the presence of immature plants, occurs among populations that have at least 56 mature individuals dispersed over a distance of 1.6 km (1.0 mi) or less.

The sites identified as P1 and P2 on our maps are the approximate endpoints of a single population estimated to have about 100 individuals. However, we do not currently know what the ratio of mature to immature plants is for this population; based on evidence from EOs 3, 14, and 17, we predict that reproduction and recruitment is occurring at P1-P2. The site is privately owned and protected by TNC through a conservation easement.

Reproductive success depends on the size and distribution of populations for two reasons. First, Texas snowbells is very likely to be obligately xenogamous (Sugden 1986, pp. 923-924; Fulton 2010, pp. 4-9). Consequently, closely related individuals, such as the progeny of a single pair of plants, may not be able to fertilize each other's flowers, and small populations may not have sufficient genetic diversity for sexual reproduction to occur. Second, pollen must be transferred between genetically compatible individuals that are within the foraging range of suitable bee or butterfly pollinators. Although foraging ranges have not been published for the Texas snowbells pollinators documented by Fulton (2010), the published foraging ranges of closely-related species may serve as surrogates. Rao and Strange (2012, pp. 908-911) found average foraging ranges of *Bombus vosnesenskii* (yellow-faced bumble bee) colonies in the Willamette Valley, Oregon, of 1.31 to 7.28 km (0.8 to 4.5 mi); maximum foraging ranges were at least 11.6 km (7.2 mi). Reported estimates of average foraging ranges of European bumble bees (*Bombus terrestris*) are 275 m (902 ft; Osborne et al. 1999, pp. 524-526), 1.5 km (0.9 mi; Osborne et al. 2008, p. 412), and 2.5 km (1.6 mi; Hagen et al. 2011, pp. 4-6). The median and maximum foraging ranges of *Xylocopa flavorufa*, a carpenter bee in Kenya, were 720 m and 6,040 m (2,362 ft and 3.75 mi; Pasquet et al. 2008, p. 2). Beekman and Ratnieks (2000, pp. 492-494) determined median foraging ranges of European honey bees of 6.1 km (3.8 mi) in August 1996 and 1.0 km (0.6 mi) in May 1997; they attributed this difference in foraging ranges to the distances to high-value forage sources in different seasons. In the studies cited, long-distance bee foraging occurred where large amounts of high-value forage justified the energy consumed to reach them; examples include patches of heather (*Calluna vulgaris*) greater than 1 km (0.6 mi) in width (Beekman and Ratnieks 2000, p. 495), 6- to 25-ha (15- to 62-ac) crop fields of red clover (*Trifolium pratense*) and arrowleaf clover (*T. vesiculosum*) (Rao and Strange 2012, p. 912), and a 2-ha (5-ac) field of borage (*Borago oficinalis*) (Osborne et al. 2008, pp. 412-413). We presume that pollinators would receive insufficient reward to travel such distances to forage on isolated individuals of Texas snowbells. Therefore, although it is possible that cross-pollination could occur between Texas snowbells plants as far as 5 to 10 km (3.1 to 6.2 mi) apart, we assume that the probability of effective pollination between isolated Texas snowbells individuals must be very low at greater distances. Since mortality of Texas snowbells progeny is high (discussed below), populations must have high reproductive rates to be sustainable. Based on foraging data from species that are similar to the known pollinators of Texas snowbells, high reproductive rates probably require that individuals of genetically diverse populations are located not more than about 0.5 to 1 km (0.3 to 0.6 mi) apart.

The absence of immature plants among small and isolated populations may be due to reproductive failure as well as to high mortality from browsing or other possible factors. In many parts of the Edwards Plateau, palatable vegetation has been severely depleted by high population densities of ungulate browsers, including native white-tailed deer and introduced species such as goats (*Capra aegagrus*), sheep (*Ovis aries*), axis deer (*Axis axis*), and aoudads (*Ammotragus lervia*). The original recovery plan (U.S. Fish and Wildlife Service 1987, p. 12) identified ungulate browsing as a significant cause of mortality to Texas snowbells. Poole (1993, pp. 1-4 and Appendix) documented the fates of 86 Texas snowbells seeds that had germinated at EO3 between mid-February and May 1990; 44 were protected from mid- to large-size mammalian herbivores within fenced exclosures, and 42 were unprotected. By 1992, 25 of the protected seedlings (57 percent) and 5 unprotected plants (12 percent; includes one plant that germinated in 1991) had survived to juvenile stage. This study and Poole and Cook (1996), discussed below, classified plants that are less than 1 year old as seedlings, juveniles as more than 1 year old but not yet able to reproduce, and mature plants are those able to flower and set seed (Poole 2017, p. 17). This study confirmed that mortality of seedlings and juvenile plants is high and largely due to browsing by larger mammals. Other causes of mortality included drought during the summer and uprooting by armadillos (*Dasypus novemcinctus*) (p. 2) and insect herbivory (p. 4). Seed predation also occurred within the protective cages, and rock squirrels (*Otospermophilus variegatus*) were observed near the plants (p.

2). Seed caches were observed in crevices of an adjacent limestone cliff, which may explain why Texas snowbells are often found on cliff faces (p. 4).

In April 1995, Poole and Cook (1996, pp. 1-3) discovered 12 new seedlings and 14 new juvenile and mature Texas snowbells at EO3. By August of that year, 8 of these seedlings (67 percent) and 12 of the juvenile and mature plants (86 percent) had survived, and 6 plants observed in previous years were missing. The authors state that the total population in August was 95 plants, hence it appears that the initial population that year was 81 plants. At EO17, 92 new seedlings found in April 1995 added to about 290 juvenile and mature individuals. By August, 33 seedlings and 13 juvenile and mature plants had died; the total population grew during this period to 336. Herbivory affected 62 percent of plants at EO3 and 66 percent at EO17.

The average age at sexual maturity of Texas snowbells is unknown; however, individual plants have begun flowering at 5 (Poole 2017, p. 33), 10 (Bamberger 2013 a, p. 1, 2013 c, p.1, 2014, p.1), and 13 years of age (Cox 2000, p. 4). Those plants that survive to maturity, if not subjected to severe browsing, may have very long lives. Flowering Texas snowbells plants observed by V.L. Cory in the early 1940s may be among those still living at EO4 and EO5 (TXNDD 2013, pp. 4-5). Like many multi-stemmed broadleaf shrubs of the Edwards Plateau, mature Texas snowbells plants are able to re-sprout from root stocks if the main stems have been cut or burned (Poole 2017, p. 18). For this reason, it may be possible to judge the age of individual stems, based on their size or on annual rings, but not the age of the root stocks from which they arise.

Minimum Viable Population.

Minimum viable population (MVP) refers to the smallest population size that has a high probability of surviving a prescribed period of time. For example, Mace and Lande (1991, p. 151) propose that species or populations be classified as vulnerable when the probability of persisting 100 years is less than 90 percent. Determinations of MVP usually take into account the effective population size, rather than total number of individuals; 10 genetically identical individuals (for example, clones) would have an effective population size of 1. Since Texas snowbells has perfect flowers and is probably self-incompatible, we assume that the effective population is essentially the same as the total population. However, genetic analyses might prove otherwise.

Unfortunately, the calculations of MVP require data that we do not currently possess for Texas snowbells, and that we are unlikely to obtain soon enough to benefit its recovery (see discussion in Pavlik 1996, p. 135). As a practical alternative, we estimate the likely range of MVP of Texas snowbells by comparison to species with similar life histories for which MVPs have been calculated, using the following guideline adapted from Pavlik (1996).

Table 5. Minimum viable population guidelines applied to Texas snowbells (adapted from Pavlik 1996). Factors applicable to Texas snowbells are in bold text.

	Minimum number of individuals in a viable population		
Factor	50	1,000	2,500
Longevity	**Perennial**		Annual
Breeding System	Selfing		**Outcrossing**
Growth Form	**Woody**		Herbaceous
Fecundity	High	**Moderate**	Low
Ramet Production	Common		**Rare or None**
Survivorship	High	**Low seedling survival; mature plants may have long lifespans**	Low
Seed Duration	Long	**Unknown**	Short
Environmental Variation	Low	**Low or High**	High
Successional Status	**Climax**		Seral or Ruderal

The bold letters in the table indicate values, if known, for Texas snowbells. Two factors (outcrossing and rare ramet production) require more individuals, four factors (moderate fecundity, mixed survivorship, environmental variation, and unknown seed duration) are intermediate or unknown, and three factors (perennial lifespan, woody growth form, and climax successional status) require fewer individuals, suggesting an estimated MVP for Texas snowbells of at least 900 to 1,200 mature individuals. This provisional MVP range may be revised in the future if accumulated data permits actual calculation. For this purpose, a mature individual is one that has flowered at least once or is judged capable of flowering. This estimate of MVP is based only on mature individuals because most seedlings die before they are able to reproduce and therefore do not contribute to the effective population size. Furthermore, population surveys that do not distinguish mature plants from seedlings would appear to fluctuate wildly, depending on how recently seeds had matured and germinated and the proportion of surviving seedlings.

Fritsch (1997, p. 707) observed that many *Styrax* species of Texas, Mexico, and Mesoamerica "are narrow endemics and are likely to be rare, vulnerable, endangered, or extinct..." Populations of *Styrax* species are often small (less than 30 individuals; p. 708). Two species (*S. tuxtlensis* and *S. panamensis*) are known only from single locations (p. 707); all 5 subspecies of *S. platanifolius* (including subspecies *texanus*) are rare (p. 707). Some plant species are naturally rare and are able to persist in low densities (Barrett and Kohn 1991, pp. 6-7); examples include many tree species in Neotropical forests. Since botanists had been collecting and describing plant species in the Edwards Plateau for a century before Texas snowbells was first noticed, it was probably never abundant. Furthermore, the potential habitat is restricted to narrow riparian corridors in the upper reaches of three watersheds, and we estimate that the total amount of potential habitat is very limited (discussed below). The few EOs known today may be fragments of larger, contiguous populations that were formerly dispersed along these corridors. For example, six sites along or near the East Prong of the Nueces River (EO3, EO6, EO7, EO14, EO15, and B3; see figure 6) are currently considered separate EOs in the TXNDD, but may be relicts of a single historic population; this cluster of small, fragmented populations should be considered a metapopulation. Therefore, this provisional MVP of 900 to 1,200 individuals is more realistically applied to metapopulations, of which there is one or perhaps several in each of the three major watersheds.

A draft, revised recovery plan (U.S. Fish and Wildlife Service 1999, p. 21) proposed a recovery criterion that specified an age-class ratio of 1 seedling : 7 juveniles : 2 reproductive plants; this ratio was modeled on the largest, healthiest known population of Texas snowbells. However, recovery criteria based on age-

class ratios would be difficult to apply to perennial plants of semi-arid regions, such as Texas snowbells, because most recruitment occurs during those few years when rainfall patterns coincide with requirements for flowering, seed development, germination, and establishment. Recruitment, even in large, healthy populations of woody plants, tends to be pulsed; in most years few seeds germinate, and these are mostly killed by browsers, but in boom years browsers are overwhelmed by an abundance of food sources, allowing some seedlings to survive to juvenile and mature stages. In well-managed habitats, recruitment might occur in Texas snowbells only once or twice per decade, and a plant that survives to maturity might contribute offspring to future populations 10 or 20 times during its lifespan. Therefore, even among stable and increasing populations, the ratio of seedlings, juveniles, and reproductive plants fluctuates widely from year to year. Consequently, a more appropriate criterion would track the frequency of successful recruitment. Population viability should also address fertilization rates, gene flow within and between populations, and other attributes of population health, in addition to numbers of individuals.

Table 6. Population sizes of Texas snowbells metapopulations.

	Natural		Reintroduced		Total Mature
Watershed	Mature	Immature	Mature	Immature	Population Size
Nueces River[1]	81	143	0	93	81
West Nueces River	72	0	0	104	72
Frio/West Frio Rivers[2]	30	0	13	0	43
Dry Frio River[2]	0	0	9	79	9
Devils River	217	311	0	2	217
Totals	400	454	22	278	422

1. May constitute two or more metapopulations.
2. Natural populations have not been independently confirmed in these watersheds.

II.4. Habitat and Ecology.

Fritsch (1997, p. 708) noted that many *Styrax* species occur in relatively mesic micro-habitats, such as canyons, draws, and riparian sites. He described the habitat of S. *platanifolius* ssp. *texanus* as steep limestone cliffs of the Edwards Plateau, ranging from 500 to 700 m (1,640 to 2,300 ft) elevation (p. 744). Mahler (1981, pp. 3-4) observed Texas snowbells growing from crevices in vertical limestone cliffs. However, the original recovery plan (USFWS 1987, p. 12) observed: "It is quite possible that cliffsides are not preferred habitat for *Styrax texana*, but simply represent refuges free from browsing pressure." The discoveries of additional plants and populations have broadened our understanding of the subspecies' habitat, as stated in Poole et al. (2007, p. 477):

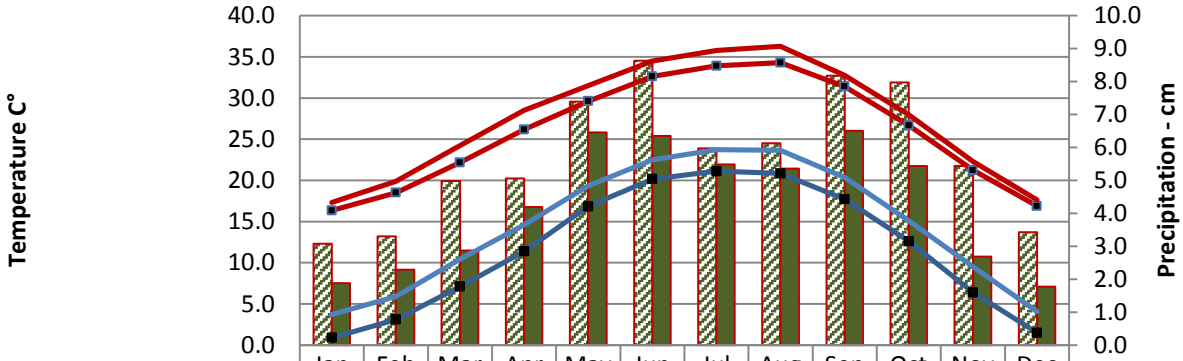
> "Limestone bluffs, boulder slopes, cliff faces, and gravelly stream-beds, usually along perennial streams or intermittent drainages in canyon bottoms, in full sun or in partial shade of cliffs and/or sycamore-little walnut woodlands, oak-juniper woodlands, or mixed oak-shrublands."

The known Texas snowbells populations, based on the Geologic Map of North America GIS database (Garrity and Soller 2009), occur within the Edwards, Glen Rose, and Devils River Limestone formations; one

site (P1 and P2) may also be associated with Salmon Peak Limestone. The subspecies does not appear to be associated with highly specific geologic or soil features. However, it is possible that individuals may be sustained by the seepage of groundwater from fissures between limestone strata.

Weather stations at Camp Wood and Del Rio, Texas, are closest to the Nueces/West Nueces River and Devils River populations, respectively. Thirty-year climate data from these stations indicate the range of temperature and rainfall tolerated by Texas snowbells (see figure 5). Average annual precipitation is greater at Camp Wood (69.5 cm; 27.4 in) than Del Rio (51.3 cm; 20.2 in). The greatest amounts of rainfall occur in May, June, September, and October at both stations. Del Rio is consistently warmer throughout the year than Camp Wood (see table 7), due primarily to the difference in elevation between these weather stations (304 m (999 ft) at Del Rio versus 723 m (2,372 ft) at Camp Wood). The known populations of Texas snowbells all lie within the elevation range of these two stations (see table 8).

Figure 5. Camp Wood and Del Rio Temperature and Precipitation: 1981 - 2010 Averages (National Climate Data Center 2014a, 2014b).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Camp Wood Prec.	3.1	3.3	5.0	5.1	7.4	8.6	6.0	6.1	8.2	8.0	5.4	3.4
Del Rio Precip.	1.9	2.3	2.9	4.2	6.5	6.4	5.5	5.4	6.5	5.4	2.7	1.8
Camp Wood Max T°	16.3	18.5	22.2	26.2	29.6	32.6	33.9	34.3	31.4	26.7	21.2	16.9
Camp Wood Min T°	0.9	3.1	7.1	11.4	16.8	20.2	21.1	20.8	17.7	12.6	6.4	1.5
Del Rio Max T°	17.3	19.9	24.2	28.5	31.5	34.5	35.8	36.3	32.7	27.9	22.3	17.6
Del Rio Min T°	3.7	5.9	10.4	14.6	19.3	22.5	23.7	23.7	20.3	15.1	9.5	4.1

Table 7. Average monthly temperature differences between Del Rio and Camp Wood, Texas.

Maximum T°	1.6° ± STD 0.5° C	2.9° ± STD 0.9° F
Minimum T°	2.8° ± STD 0.3° C	5.0° ± STD 0.5° F

Table 8. Elevation ranges of known Texas snowbells populations.

Elevation Range:	Lower (m)	Lower (ft)	Upper (m)	Upper (ft)
Nueces River:	457	1500	579	1900
West Nueces River	488	1601	524	1719
Devils River:	372	1220	488	1600

Therefore, the known populations of Texas snowbells are circumscribed by these parameters: They occur in the upper portions of the Nueces, West Nueces, and Devils River watersheds in areas of limestone geological formations; annual precipitation ranges from 51.3 cm (20.2 in) to 69.5 cm (27.4 in); average temperatures range from a minimum of 0.9° C (33.6° F) in January to a maximum of 36.3° C (97.3° F) in July; and elevations range from 372 to 579 m (1,220 to 1,900 ft). Plant species associated with Texas snowbells (table 10) provide further indications of its habitat requirements.

Texas snowbells potential habitat model.

Within the broad range of parameters described above, Texas snowbells populations occupy a very small portion of the landscape. Two additional features that are common to all known populations are close proximity to watercourses and to slopes. We developed a simple model (described in Appendix C), based on distances of the naturally occurring populations to watercourse and slope, to estimate the amount of potential habitat within each occupied watershed (Table 9), and to map potential habitat distribution (Figures 6, 7, and 8).

Table 9. Estimate of potential habitat of Texas snowbells in the Nueces, West Nueces, and Devils River watersheds.

	Hectares			Acres				
Stream Order	Nueces	West Nueces	Devils River	Nueces	West Nueces	Devils River	Totals (Hectares)	Totals (Acres)
1st	1,292.5	198.2	1,431.4	3,193.8	489.8	3,537.0	2,922.1	7,220.5
2nd	2,532.9	2,659.2	1,869.2	6,258.8	6,570.9	4,618.8	7,061.3	17,448.5
3rd	1,658.9	808.8	2,592.2	4,099.1	1,998.5	6,405.3	5,059.9	12,503.0
Totals:	5,484.3	3,666.2	5,892.8	13,551.7	9,059.2	14,561.1	15,043.3	37,172.0

Discussion. The potential habitat model presented here identifies the relatively small portion of the landscape that is suitable for Texas snowbells, based on where it currently exists. We discuss potential sources of error in Appendix C. Although there appears to be a clear association of Texas snowbells with slope, we don't know why. Understanding the underlying cause of this association could improve habitat modeling. We offer three possible explanations that are not mutually exclusive: a) Steep slopes serve as refuges from severe ungulate browsing; b) slopes provide shade and protection from wind, and concentrate water flows into specific areas, thus lowering drought stress; c) Texas snowbells plants are sustained by groundwater seeping from fractures between limestone strata exposed along slopes.

Other factors, currently unknown, could further refine the model. For example, given the out-crossing requirement and limitations of pollinator foraging, larger habitat patch sizes and clusters of habitat patches could prove to have greater potential than smaller, more isolated habitat patches. Discoveries of new populations could improve our understanding of the subspecies' requirements, leading to refinements of the model that change the estimated amounts and distribution of potential habitat.

Despite these limitations, the model clearly demonstrates that a finite amount of potential Texas snowbells habitat is unevenly distributed within a small geographic area. The model suggests where additional surveys could be focused (access permitting), and will aid in the design of recovery efforts. In the upper Nueces River watershed, potential habitat appears to be most abundant in the following tributary watersheds: Cedar Creek, Upper Pulliam Creek, Little Hackberry Creek, Lower Hackberry Creek,

Ruth Draw, Lower East Prong, and Lower Bull Head Creek. In the tributary watersheds of the West Nueces River, Cherry Creek, Bluff Creek, Two Mile Draw, Cutting Pen Draw of Indian Creek, and Five Mile Draw, and portions of Griffin Creek and Upper Sycamore Creek have significant clusters of potential habitat. The Devils River tributary watersheds with relatively large amounts of potential habitat include Dark Canyon, Indian Creek, Blue Springs, Cedar Mott Draw, Brushy Draw, Wallace Canyon, Trail Canyon, West Dolan Creek, Middle Dolan Creek, Lower Dolan Creek, Cedar Draw, and Open Hollow.

The total population size of Texas snowbells could be estimated if we knew the extent of its potential habitat and how much potential habitat had been adequately surveyed, in addition to the numbers of plants detected in surveys. Unfortunately, surveyors who reported the plants and populations listed in table 3 usually did not record the amount of area surveyed, including where surveys were conducted without finding Texas snowbells. David Bamberger, Steve Fulton, and other personnel of Bamberger Ranch Preserve (see Section III) have conducted Texas snowbells surveys on 24 private properties totaling over 52,610 ha (130,000 ac) within the subspecies' potential range (Best 2011, pp. 36-37). Mr. Bamberger indicated that they had found 107 Texas snowbells plants at six locations, listed in table 3. However, since many of the participating private landowners requested confidentiality, we don't know where surveys were conducted, how much potential habitat was surveyed, or if they discovered other wild populations that they are not at liberty to report. John Karges (TNC) and Jackie Poole (TPWD) have surveyed conservation land owned or managed by TNC and TPWD in the Devils River watershed (see figure 8); however, considering that new individuals were discovered there as recently as 2013, we assume that more may remain undiscovered among the potential habitats on those conservation lands as well as surrounding private lands. Fulton (2010, p. 3) found no new Texas snowbells in surveys conducted from 2008 to 2010 on 12 private ranches, totaling about 20,200 ha (50,000 ac), in the Upper Frio River, Nueces River, West Nueces River, Sycamore Creek, and Dolan Creek watersheds. Although not included in the present model, it is apparent that suitable habitat could exist in the upper Sycamore Creek tributary of the Rio Grande (not to be confused with the Sycamore Creek tributary of the West Nueces River) and upper Frio River watersheds. Sycamore Creek of the Rio Grande is the intervening watershed between the West Nueces and Devils Rivers, and the Frio River is immediately east of the Nueces River. Fulton provided a polygon shapefile named Areas_Searched totaling 259.5 ha (641.2 ac). Thus, it appears that about 1.3 percent of the properties surveyed consisted of areas Fulton had identified as high-potential habitat; the intensively surveyed areas during this three-year study are equivalent to 1.7 percent of the amount of potential habitat identified by this model.

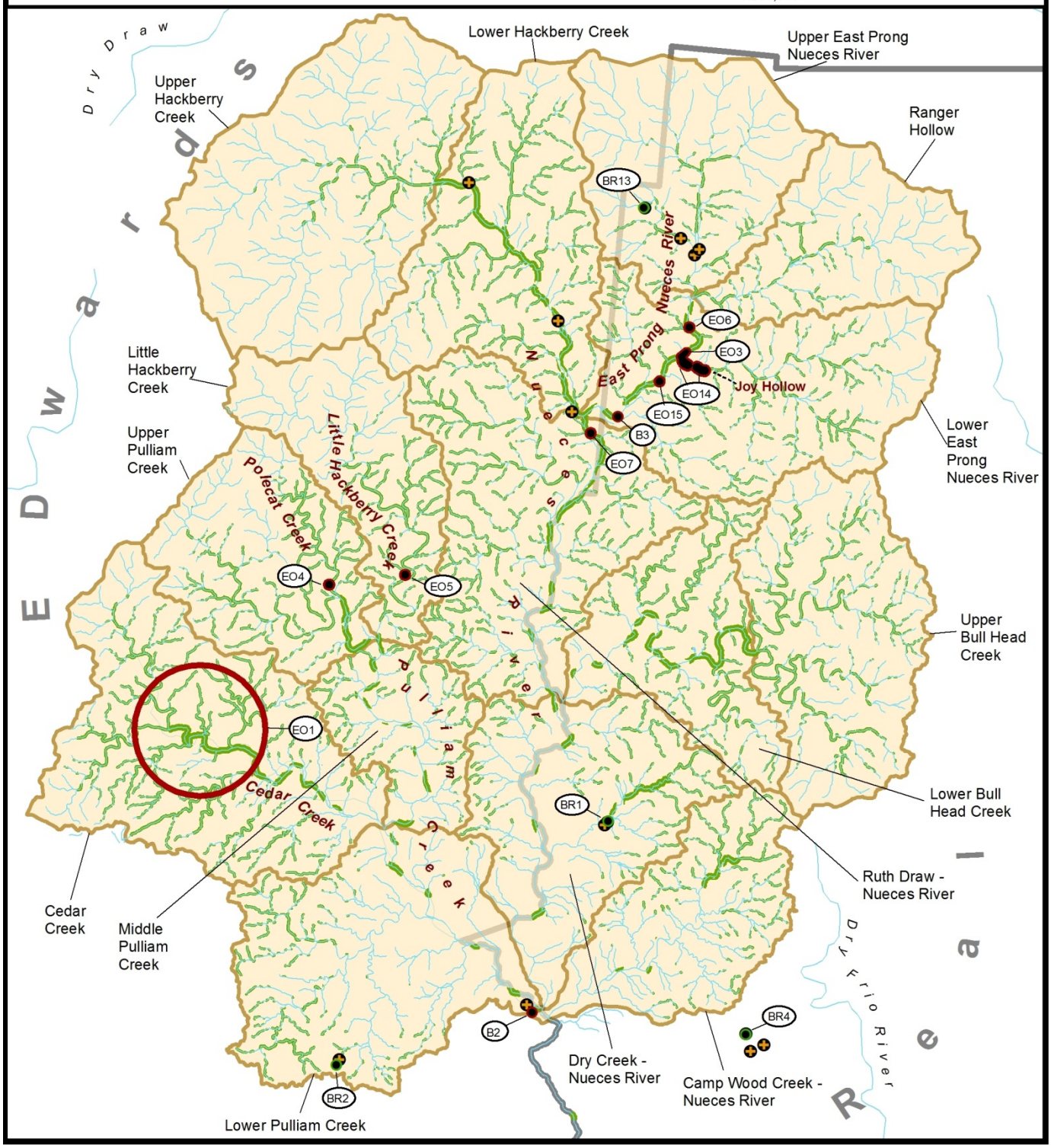
For these reasons, it is apparent that only a small fraction of the potential habitat has been adequately surveyed, and that the total wild population of Texas snowbells may be several times larger than the totals reported in table 3. A realistic estimate of the total wild populations of Texas snowbells could be derived through a systematic sampling of the identified potential habitats, provided that surveyors have access to enough sites and are allowed to share the data they have collected.

Figure 6. Texas snowbells potential habitats in upper Nueces River watersheds.

Data Sources: Bamberger 2013a, 2013b; Fulton 2010; Poole 2013b, 2013c; Texas Natural Diversity Database 2013; USDA/NRCS 1999-Present; USGS DEM files ned_2011_30m_2900.dem, ned_2011_30m_2999.dem, ned_2011_30m_3000.dem, ned_2011_30m_3099.dem.

* Populations labeled B and BR have unknown geographic precision.

** Thickness of potential habitats is slightly increased in this map to aid visibility. Actual habitat dimensions are slightly smaller.



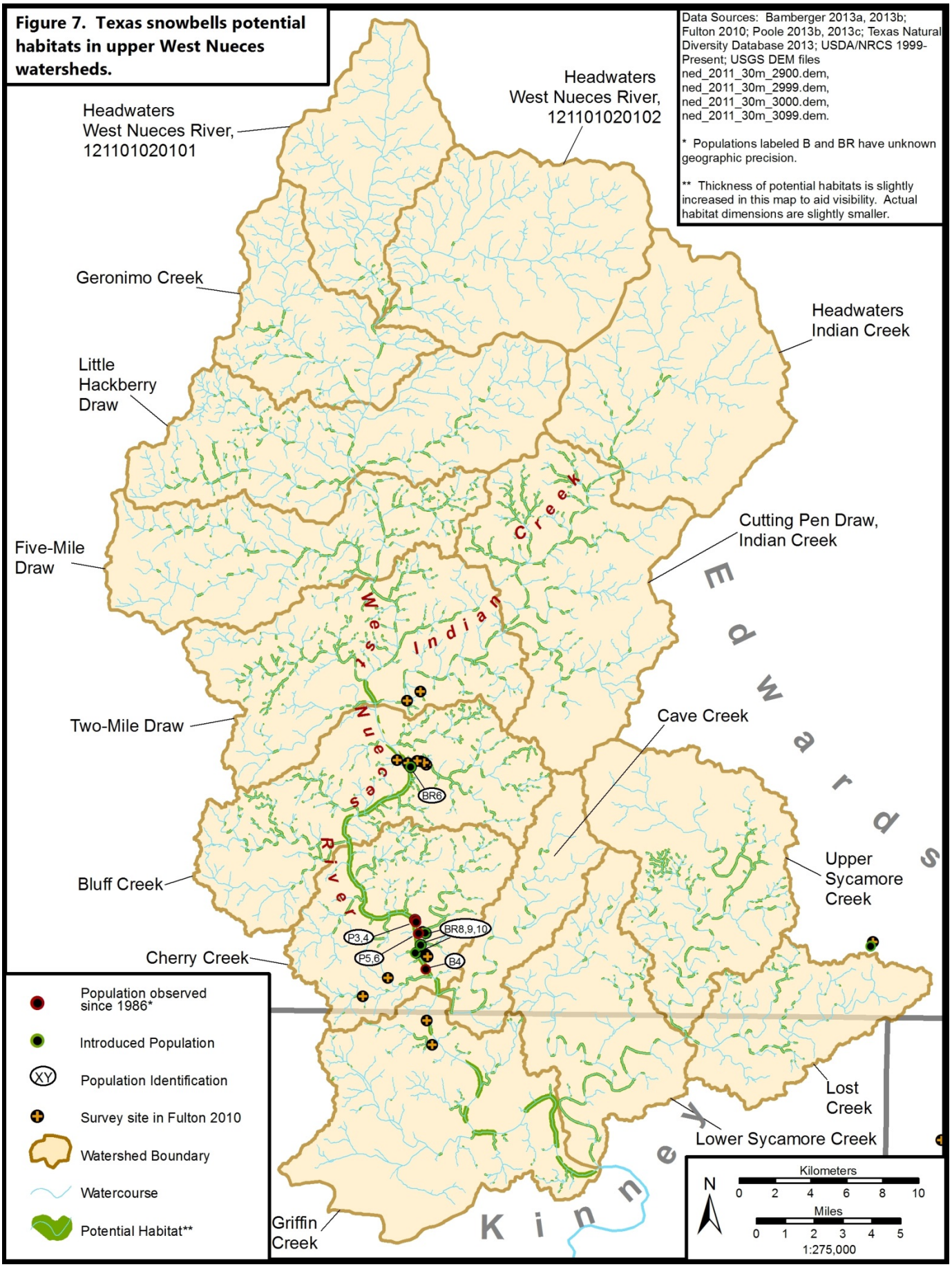


Figure 7. Texas snowbells potential habitats in upper West Nueces watersheds.

Figure 8. Texas snowbells potential habitats in the Devils River, Dolan Creek, and Dry Devils River watersheds.

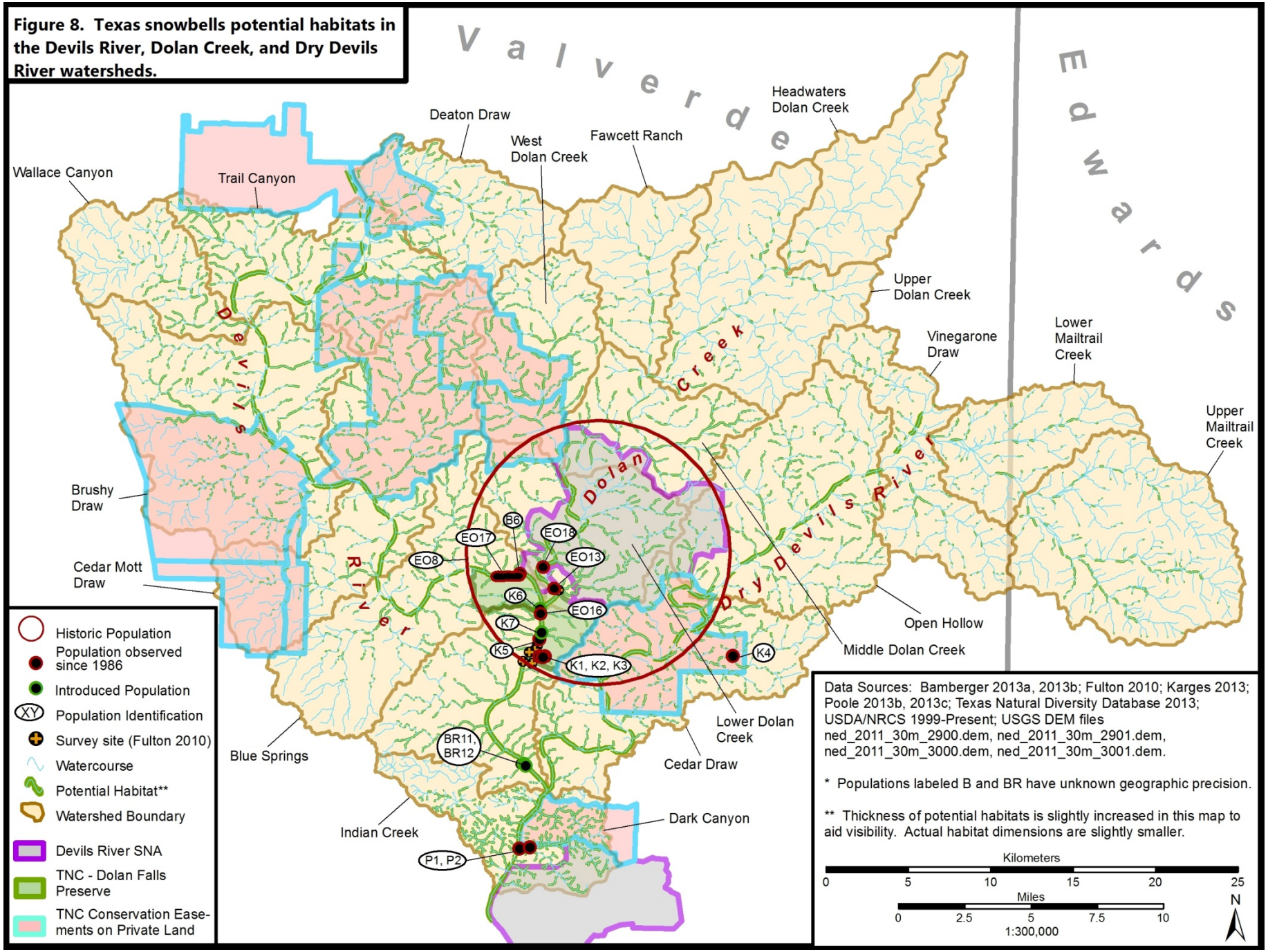


Table 10. Plant species associated with Texas snowbells.

Family	Genus[1]	Species	Synonym[2]	Common Name	Habit	Source[3]
Agavaceae	*Yucca*	*rupicola*		Twist-leaf yucca	Rosette	RP
Anacardiaceae	*Rhus*	*aromatica*		Fragrant sumac	Shrub	RP
Anacardiaceae	*Rhus*	*Virens*		Evergreen sumac	Shrub	RP, P
Anacardiaceae	*Toxicodendron*	*radicans*	*Rhus toxicodendron*	Poison ivy	Vine	RP
Anemiaceae	*Anemia*	*mexicana*		Mexican fern	Fern	RP
Asclepiadaceae	*Asclepias*	*viridis*		Green milkweed	Forb	RP
Asclepiadaceae	*Matelea*	*edwardsensis*		Plateau milkvine	Forb	RP
Asteraceae	*Baccharis*	*texana*		Texas baccharis	Shrub	RP
Asteraceae	*Brickellia*	*dentata*		Leafy brickellbush	Shrub	RP
Asteraceae	*Chaetopappa*	*bellidifolia*		Whiteray leastdaisy	Forb	RP
Asteraceae	*Chaetopappa*	*effusa*		Spreading leastdaisy	Forb	RP
Asteraceae	*Chrysactinia*	*mexicana*		Damianita	Forb	RP
Asteraceae	*Gaillardia*	*pulchella*		Indian blanket	Forb	RP
Asteraceae	*Gaillardia*	*suavis*		Pincushion daisy	Forb	RP
Asteraceae	*Liatris*	*mucronata*		Cusp blazing star	Forb	RP
Asteraceae	*Melampodium*	*leucanthum*		Plains blackfoot	Forb	RP
Asteraceae	*Tetraneuris*	*scaposa*	*Hymenoxys scaposa*	Four-nerve daisy	Forb	RP
Asteraceae	*Thelesperma*	*curvicarpum*		Edwards Plateau greenthread	Forb	RP
Asteraceae	*Verbesina*	*microptera*		Texas crownbeard	Forb	RP
Asteraceae	*Vernonia*	*lindheimeri*		Wooly ironweed	Forb	RP
Asteraceae	*Wedelia*	*texana*	*Zexmenia hispida*	Orange zexmenia	Forb	RP
Berberidaceae	*Mahonia*	*trifoliolata*	*Berberis trifoliata*	Agarita	Shrub	M, RP, P
Boraginaceae	*Lithospermum*	*incisum*		Narrowleaf stoneseed	Forb	RP
Capparaceae	*Polanisia*	*dodecandra*		Clammy weed	Forb	RP
Caryophyllaceae	*Paronychia*	*jamesii*		James's nailwort	Forb	RP
Cupressaceae	*Juniperus*	*ashei*		Ashe juniper	Tree	M, RP, P
Cyperaceae	*Rhynchospora*	*nivea*	*Dichromena nivea*	Showy whitetop	Grass-like	RP
Dryopteridaceae	*Dryopteris*	*filix-mas*		Male fern	Fern	RP
Ebenaceae	*Diospyros*	*texana*		Texas persimmon	Tree	RP, P
Euphorbiaceae	*Acalypha*	*phleoides*	*A. lindheimeri*	Shrubby copperleaf	Forb	RP
Euphorbiaceae	*Chamaesyce*	*angusta*	*Euphorbia angusta*	Blackfoot sandmat	Forb	RP
Euphorbiaceae	*Euphorbia*	*cyathophora*		Fire on the mountain	Forb	RP
Euphorbiaceae	*Euphorbia*	*marginata*		Snow on the mountain	Forb	RP
Euphorbiaceae	*Phyllanthus*	*polygonoides*		Smartweed leaf-flower	Forb	RP
Euphorbiaceae	*Stillingia*	*texana*		Texas toothleaf	Forb	RP
Euphorbiaceae	*Tragia*	*nigricans*		Dark noseburn	Forb	RP

Family	Genus[1]	Species	Synonym[2]	Common Name	Habit	Source[3]
Fabaceae	*Acacia*	*berlandieri*		Guajillo	Shrub	P
Fabaceae	*Desmanthus*	*velutinus*		Velvet bundleflower	Forb	RP
Fabaceae	*Eysenhardtia*	*texana*		Texas kidneywood	Shrub	RP, P
Fabaceae	*Lespedeza*	*texana*		Texas lespedeza	Forb	RP
Fabaceae	*Mimosa*	*roemeriana*		Roemer's mimosa	Forb	RP
Fabaceae	*Sophora*	*secundiflora*		Texas mountain laurel	Tree	RP, P
Fagaceae	*Quercus*	*buckleyi*	*Q. texana*	Texas red oak	Tree	M, RP
Fagaceae	*Quercus*	*fusiformis*		Escarpment live oak	Tree	RP, P
Fagaceae	*Quercus*	*laceyi*	*Q. glaucoides*	Lacey oak	Tree	RP, P
Fagaceae	*Quercus*	*sinuata* v. *breviloba*		Bastard oak	Tree	P
Fagaceae	*Quercus*	*vaseyana*		Sandpaper oak	Tree	P
Garryaceae	*Garrya*	*ovata* ssp. *lindheimeri*		Lindheimer's silktassel	Shrub	M, RP
Gentianaceae	*Centaurium*	*calycosum*		Arizona centaury	Forb	RP
Juglandaceae	*Juglans*	*microcarpa*		Little walnut	Tree	RP, P
Lamiaceae	*Hedeoma*	*drummondii*		Drummond's false pennyroyal	Forb	RP
Lamiaceae	*Salvia*	*farinacea*		Mealy blue sage	Forb	RP
Lamiaceae	*Salvia*	*roemeriana*		Roemer sage	Forb	RP
Lamiaceae	*Scutellaria*	*wrightii*		Wright's skullcap	Forb	RP
Lamiaceae	*Teucrium*	*canadense*		Canada germander	Forb	RP
Liliaceae	*Nolina*	*lindheimeriana*		Devil's shoestring	Rosette	RP
Loasaceae	*Mentzelia*	*oligosperma*		Stickleaf	Forb	RP
Malpighiaceae	*Galphimia*	*angustifolia*	*Thryallis angustifolia*	Narrowleaf goldshower	Forb	RP
Oleaceae	*Forestiera*	*reticulata*		Netleaf swampprivet	Shrub	RP, P
Oleaceae	*Fraxinus*	*albicans*	*F. texensis*	Texas ash	Tree	M, RP
Onagraceae	*Calylophus*	*berlandieri* ssp. *pinifolius*	*C. drummond-ianus*	Berlandier's sundrops	Forb	RP
Plantaginaceae	*Plantago*	*helleri*		Heller's plantain	Forb	RP
Platanaceae	*Platanus*	*occidentalis*		Sycamore	Tree	RP, P
Poaceae	*Bouteloua*	*curtipendula*		Side-oats grama	Grass	RP
Poaceae	*Chasmanthium*	*latifolium*		Indian woodoats	Grass	RP
Poaceae	*Elymus*	*canadensis*		Canada wild-rye	Grass	RP
Poaceae	*Hilaria*	*belangeri*		Curly-mesquite	Grass	RP
Poaceae	*Leptochloa*	*dubia*		Green sprangletop	Grass	RP
Poaceae	*Muhlenbergia*	*schreberi*		Nimblewill	Grass	RP
Poaceae	*Schizachyrium*	*scoparium*		Little bluestem	Grass	RP
Poaceae	*Sporobolus*	*vaginiflorus*		Poverty dropseed	Grass	RP
Poaceae	*Tridens*	*muticus*		Slim tridens	Grass	RP
Poaceae	*Tripsacum*	*dactyloides*		Eastern gama-grass	Grass	RP
Polemoniaceae	*Giliastrum*	*incisum*	*Gilia incisa*	Splitleaf gilia	Forb	RP
Polemoniaceae	*Giliastrum*	*rigidulum*	*Gilia rigidula*	Bluebowls	Forb	RP

Family	Genus[1]	Species	Synonym[2]	Common Name	Habit	Source[3]
Polygalaceae	*Polygala*	*lindheimeri* v. *parvifolia*	*P. tweedyi*	Shrubby milkwort	Forb	RP
Pteridaceae	*Adiantum*	*capillus-veneris*		Maidenhair fern	Fern	RP
Rubiaceae	*Cephalanthus*	*occidentalis*		Common buttonbush	Shrub	RP
Rubiaceae	*Stenaria*	*nigricans*	*Hedyotis nigricans*	Diamondflowers	Forb	RP
Sapindaceae	*Ungnadia*	*speciosa*		Mexican buckeye	Shrub	RP, P
Sapotaceae	*Sideroxylon*	*lanuginosum*	*Bumelia lanuginosa*	Gum bumelia	Tree	M,P
Smilacaceae	*Smilax*	*bona-nox*		Greenbriar	Vine	P

1. Taxonomic classifications published in PLANTS database (Natural Resource Conservation Service 2014).
2. Names used in original reports, if these differ from classifications currently used in PLANTS database.
3. M = Mahler 1981, p. 4; RP = Recovery Plan (U.S. Fish and Wildlife Service 1987, pp. 8-10); P = Poole et al. 2007, p. 477).

III. Conservation Efforts.

Populations on Protected Conservation Land.

The known Texas snowbells populations and potential habitats in the Nueces and West Nueces River watersheds all occur on privately-owned land. The Endangered Species Act (ESA) protects listed plant species on federal lands or where there is a federal nexus; examples of "nexus" include federally funded highway construction and federal regulation of pipeline installation under the Environmental Protection Agency or Army Corps of Engineers wetlands permitting. Where there is no federal nexus, conservation of listed plants on private lands depends entirely on the landowner's voluntary cooperation or benign neglect.

The Nature Conservancy owns or manages through conservation easements a total of 41,086.8 ha (101,525.5 ac) in the Devils River watershed (Gilbert 2013). Approximately 330 Texas snowbells plants have been documented in this watershed, of which about 227 individuals (68.8 percent) occur on TNC-owned or managed land (including 2 individuals at Devils River State Natural Area). The remaining 103 plants are on privately-owned land. Consequently, a large portion of the known Devils River population is protected and managed for conservation purposes by TNC. Populations of native and introduced ungulates are relatively small. Periodic monitoring of Texas snowbells plants confirms their successful reproduction, and although the subspecies remains very rare, its populations are stable or increasing. For these reasons, the Devils River population of Texas snowbells appears relatively secure.

Private Landowner Outreach.

In 1969, J. David Bamberger, a retired businessman, acquired a 1,767-ha (5,500-ac) ranch in Blanco County, Texas. Like much of the Edwards Plateau at that time, the vegetation, wildlife, and hydrology of the property had been severely damaged through decades of poor rangeland management. Mr. Bamberger has worked since then to restore the ecological resources of the property, and in 2002 he established a non-profit foundation, Bamberger Ranch Preserve, to promote natural resource conservation in the Edwards Plateau (Greene 2007; Bamberger Ranch Preserve 2014a). Since 1994, Bamberger and his employees and volunteers have promoted the conservation of Texas snowbells among private landowners (Greene 2007, pp. 168-179; Best 2011, pp. 36-37; Bamberger Ranch Preserve 2014b-g). A number of private landowners have granted permission for the Bamberger group to search for Texas snowbells on lands that state and federal agencies are not able to access; this work has led to the discovery and conservation of new populations (discussed in section II.4) and to a large-scale reintroduction program (discussed below).

Propagation and Reintroduction.

The first documented reintroductions of Texas snowbells were initiated at two sites in Uvalde and Real counties (EO2 and EO19, respectively) (Cox 1987, pp. 1, 8; Keeney 1988a,b, p. 1; McDonald 1996, pp. 411-416; Cox 2000, p.4). In September 1986, Paul Cox, of San Antonio Botanical Garden (SABG), Toney Keeney, a professor at Southwest Texas Junior College (Uvalde) and preparer of the original recovery plan, and Paulen Clayton collected seeds from two Real County wild populations (EO3 and "Porta Grande Ranch"). The seeds were germinated at SABG following a 6- to 8-week period of cold, moist stratification, and the germinated seeds were planted in potting soil in pots at SABG. The seedlings were 12 to 20 cm (5 to 8 in) tall after 1.5 years. On May 21, 1987, 25 seedlings from the EO3 collection were planted along Mare Creek (EO2). Most or all of these seedlings were destroyed by flooding from heavy rain during the

following month. On July 7, 1987, 24 seedlings were replanted in a more secure location at that site. One week later, 24 seedlings from the Porta Grande collection were planted along Cypress Creek (EO19). All seedlings were protected from browsing with wire cages, and Keeney monitored and watered the plants for about 5 years. In June, 2000, Jackie Poole (TPWD) and Cox monitored these sites. Nine of the original 24 plants at Mare Creek had survived, and three, in shaded sites, were about 1.5 m (5 ft) tall and had about 20 maturing capsules. At Cypress Creek, 13 of the original 24 plants survived but were severely browsed by feral goats.

The San Antonio Botanical Garden continues to propagate Texas snowbells, and mature specimens are on display at the garden (see figures 1.1-1.4 and 1.6).

David Bamberger, Steve Fulton, and others have conducted a large-scale reintroduction of Texas snowbells since 2003 (Bamberger Ranch Preserve 2014b-g). This ongoing effort has received support from the USFWS Partners for Fish and Wildlife Program (channeled through the TPWD Landowner Incentive Program), the National Fish and Wildlife Foundation, and Bamberger Ranch Preserve, and much of the project labor has been donated by volunteers (Best 2011, p. 36). Fulton (2008, pp. 1-12) provided survival and growth data for Texas snowbells seedlings planted from 2004 through 2008 at 19 sites. Our analysis of the data is summarized in table 11 (below). During this period, a total of 691 seedlings were planted, of which 451 (73 percent) were observed alive in 2008. Growth rates averaged 9.6 cm (3.76 in) per year. Initially, all seedlings were protected from ungulate browsers with wire cages; more recently, locally abundant juniper trees have been cut and placed to protect seedlings. Bamberger (2013a, p. 1) stated that 230 previously-established seedlings had died during the exceptional drought of 2011; nevertheless, by January 2013, the program had successfully established 694 Texas snowbells seedlings (560 in the Nueces and West Nueces watersheds and 134 in the Devils River watershed). Figure 1.5 shows a mature flowering individual from this reintroduction project that was photographed on April 20, 2013. In September 2013 the Bamberger group collected 346 seeds from a grove of reintroduced trees (Bamberger 2014). They stratified the seeds for 60 days and in January 2014 planted these seeds in the soil in marked locations along a dry creek. Initially, 29 plants emerged from these seeds, although 12 were subsequently washed away in a flash flood.

Currently, only informal guidelines for reintroduction of Texas snowbells have been discussed. This includes a recommendation that reintroductions should only use source material that originated within the same major watershed (Devils River and Nueces/West Nueces Rivers), in order to prevent potential harm from outbreeding depression (Edmands 2007, pp. 464-469). Additionally, Texas snowbells should not be introduced within the ranges of closely-related subspecies, such as *Styrax platanafolius* ssp. *stellata*. In the event that this has already occurred, seeds that may have resulted from outcrossing with other subspecies should not be used for reintroduction within the natural range of Texas snowbells. The recommendations should be formalized in a controlled propagation and reintroduction plan (USFWS and NMFS 2000 (FR 65: 56919)).

Table 11. Summary of Texas snowbells reintroduction efforts from 2004 – 2008 (data source: Fulton 2008).

Site	No. Planted	Alive[1]	Dead	Unknown[1]	Survival Rate	Average Annual Growth Rate (in/yr)
Choya	76	58	18	0	0.76	4.59
Dobbs Run	68	47	21	0	0.69	3.37
Clark R	15	0	4	11	0.00	n/a
Silver R	56	46	10	0	0.82	4.27
Lost Canyon	46	23	0	23	1.00	4.33
Buckhollow	46	34	12	0	0.74	3.32
Shields	52	45	6	1	0.88	5.45
Bluff Creek	51	43	8	0	0.84	2.80
Kickapoo	73	57	16	0	0.78	3.11
Munro	14	0	1	13	0.00	n/a
Coolwater	28	24	3	1	0.89	4.02
Lewey R	27	12	1	14	0.92	3.57
Williams R	6	0	0	6	Unknown	n/a
Piñon R	17	17	0	0	1.00	1.65
Dolan Falls	47	16	31	0	0.34	4.31
Hackberry Creek	15	0	15	0	0.00	n/a
Russel R	20	2	18	0	0.10	2.00
Four Canyon	16	12	4	0	0.75	1.64
Estrella	18	15	3	0	0.83	5.28
TOTALS:	691	451	171	69	0.73	3.76

1. Status observed in 2008.

The work of SABG, David Bamberger, and others demonstrates that it is feasible to collect, store, and germinate seeds of Texas snowbells, propagate seedlings, and successfully reintroduce the plants into appropriate sites. Reintroduced plants can attain a mature size, flower, and produce seeds within 10 years of planting, and seeds from genetically robust reintroduced populations can be used to expand reintroduction efforts without continuing to harvest seeds from limited wild populations.

IV. Summary of Individual, Population, and Subspecies Requirements.

Individuals.

Suitable habitat for Texas snowbells occurs in narrow riparian corridors where first-, second-, and third-order streams have cut steep ravines into limestone formations of the Edwards Plateau. Populations have only been documented in the upper watersheds of the Nueces, West Nueces, and Devils Rivers (a report from the West Frio River has not been independently confirmed). The subspecies has not been reported in the upper watersheds of Sycamore Creek of the Rio Grande, located between the West Nueces and Devils Rivers, but may occur there. Populations occur where elevations range from 372-579 m (1,220 to 1,900 ft) and where average annual precipitation ranges from 51.3 to 69.5 cm (20.2 to 27.4 in). Temperatures range from an average low of 0.9° C (33.6° F) in January, at Camp Wood, to an average high of 36.3° C (97.3° F) in August, in Del Rio.

The breeding system of Texas snowbells is very likely to be obligately xenogamous; fertilization requires the transfer of pollen between separate individuals that are not closely related. Documented pollinators include the American bumblebee, California carpenter bee, and honey bee. Tiger swallowtail and pipevine swallowtail butterflies also visit the flowers; the latter species is an effective pollinator of *Styrax redivivus* in California.

Although the average age at sexual maturity of naturally-occurring Texas snowbells plants has not been documented, flowering may begin in as little as 5 years after germination (Poole 2017, p. 33). Propagated, 1-year old plants reintroduced into the wild have begun flowering and setting seed at 10 and 13 years post-transplant. The potential lifespan of Texas snowbells plants is apparently long. Mature plants observed by V.L. Cory in the early 1940s at EO4 and EO5 may still be alive, indicating that some individual plants may live more than 80 years.

Ungulate browsers, including native white-tailed deer and introduced goats, sheep, axis deer, and aoudads, are a significant cause of mortality, particularly to seedlings and juvenile plants. Successful reproduction and recruitment require low population densities of ungulate browsers and/or protection from browsers.

Populations.

Population recruitment is possible when seed production and seedling establishment rates are greater than mortality rates from browsing and other causes. Only two populations have had sufficient recruitment to be considered stable or increasing. These populations have at least 56 mature individuals distributed within 1.6 km (1.0 mi). Based on forage range data from bee species that are similar to the known pollinators of Texas snowbells, high fertilization rates probably require that genetically unrelated individuals are not more than 0.5 to 1 km (0.3 to 0.6 mi) apart. Little if any seed production and recruitment occurs among isolated individuals and small groups of individuals. Populations are most likely to persist where larger amounts of potential habitat are geographically clustered.

Long-term population viability depends on healthy populations of native bumblebees, carpenter bees, honeybees, butterflies, and other potential pollinators. These pollinators in turn must be sustained by abundant, diverse, and reliable sources of nectar and pollen plants.

Comparison to plant species with similar life histories suggests an estimated MVP size of at least 900 to 1,200 mature individuals. However, Texas snowbells probably never existed in high densities, and remaining "populations" – often one or a few plants – are probably relicts of once larger, widely-spread populations. Therefore, this MVP should apply to what are now considered metapopulations.

Subspecies.

The viability of a taxonomic entity (species or subspecies) can be assessed in terms of its representation, redundancy, and resilience (Shaffer and Stein 2000, pp. 307-310).

Representation refers to the breadth of genetic diversity necessary to conserve long-term adaptive capability. Texas snowbells has been found in the Nueces, West Nueces, and Devils River watersheds. A population was recently reported near the West Frio River, but has not yet been independently confirmed. None of the known populations have been lost, but we assume that population sizes were larger in the past, that undiscovered populations may have been lost, and that some portion of the subspecies' genetic diversity may have been lost. Although investigators have detected very little genetic diversity within the subspecies, it is conceivable that existing populations possess undetected genetic differences that will be important for long-term adaptability and survival. Therefore, conservation and recovery of the subspecies requires conservation of all of its known populations and metapopulations.

Redundant populations increase the subspecies' chances of surviving catastrophic events. The currently known status suggests that a single metapopulation exists in each of the three watersheds, although scattered outlying individuals in the Nueces River and Devils River watersheds may represent remnants of additional metapopulations. Redundancy is therefore low, but could be improved through augmentation of existing metapopulations and establishment of additional metapopulations within each watershed. The discovery of new individuals and populations, such as any confirmed natural populations in the Frio, West Frio, Dry Frio, and Sycamore Creek watersheds, would contribute to this objective. Currently, Texas snowbells occupies only a vanishingly small amount of its estimated potential habitat. Therefore, redundancy could be greatly increased. Nevertheless, the subspecies is naturally endemic, and the extent of its range may have never been greater than it is today.

Resilience refers to population sizes; larger populations are more likely to endure than small ones. None of the known metapopulations of Texas snowbells has more than a fraction of the estimated MVP of 900 to 1,200 individuals (see table 6). Thus, all known metapopulations and the subspecies itself have very low resilience.

V. Factors Affecting the Survival of Texas Snowbells: Threats, Vulnerabilities, and Conservation Challenges.

When listed as endangered, the known threats to Texas snowbells included erosion of stream bank habitats, browsing by cattle and deer, lack of reproduction, and small population sizes; over-collection for scientific or horticultural purposes was included as a potential threat (49 FR 40037). The recovery plan (U.S. Fish and Wildlife Service 1987, pp. 11-14) also included diseases of fungal or bacterial origin and alteration of groundwater as threats and elaborated that browsing may include deer, goats, cattle, sheep, and exotic ungulates. The following list describes factors that affect the continued survival of Texas snowbells, based on our current understanding. These largely interrelated factors are not listed in order of severity.

Low population sizes. Texas snowbells has been documented in 22 sites; 15 of these sites had less than 10 individuals. The entire global population of about 400 mature, reproductive individuals is less than an estimated MVP of 900 to 1,200 individuals. In addition to the lack of reproduction (discussed below), small populations are more vulnerable to extirpation from stochastic (random) events. For example, it is more likely that a single landslide or flood could wipe out every individual of a small colony of Texas snowbells than a larger population with colonies spread out over a wider area.

Lack of genetic diversity. Fritsch (1996, p. 350) found low levels of genetic diversity among the Texas subspecies of *Styrax platanifolius*, suggesting that the group had undergone a genetic bottleneck. Adams and Poole (2011, pp. 200-202) also found very little evidence of variation between individuals or among populations of Texas snowbells. This lack of genetic diversity may reduce the potential to adapt to new or existing diseases and parasites, extreme weather, and climate changes. Low genetic diversity may also reduce fertilization and seed production if remaining individuals are too closely related for out-crossing.

Population fragmentation and isolation. Successful fertilization probably requires the transfer of pollen between individuals that are not closely related. In addition to low population size, the fragmentation and isolation of individuals and small colonies decreases the likelihood of successful reproduction. The progeny of small colonies may be too closely related to fertilize each other, so small colonies are more likely to die out than larger ones. An important factor for long-term management of the subspecies is the effective pollination range of its insect pollinators. We estimate that genetically diverse individuals should be not more than about 0.5 to 1.0 km (0.3 to 0.6 mi) apart for high fertilization rates to occur.

Pollinator deficiency. We currently do not have information on the population statuses of the known pollinators of Texas snowbells. However, many pollinator species, including bumblebees (Williams and Osborne 2009, pp. 368-374), have declined in many parts of the world. Since fertilization of Texas snowbells probably requires outcrossing, and depends on bumblebees and other insect pollinators, declines in populations of these pollinators within the subspecies' habitats represents a potential threat to its viability.

Browsing by white-tailed deer, goats, and introduced ungulates. White-tailed deer population density is very high in much of the Edwards Plateau. In addition, ranchers introduced large numbers of goats in Real County (and elsewhere) beginning in the early 20th century; by 1930 there were 137,000 goats in the county (Minton 2010, pp. 3-4). More recently, the introduction of exotic ungulates has been promoted as an economic opportunity for Texas landowners (Mungall and Sheffield 1994, pp. 188-194). Some introduced ungulates, including aoudads, blackbuck antelope (*Antilope cervicapra*), axis deer, and fallow deer (*Dama dama*), have escaped and established large breeding populations in the wild. All of these

ungulates browse to some degree on woody plants (Huerta-P. et al. 2005, pp. 239-242). In many parts of the Edwards Plateau an abrupt browse line in trees and shrubs provides stark evidence of the intensity of ungulate browsing. Poole (1993) demonstrated that browsing is a major cause of mortality to Texas snowbells seedlings. Fulton (2010, attachment) provided photographic documentation of feral aoudads eating Texas snowbells plants. Successful recruitment and reintroduction of Texas snowbells occurs where plants are protected from browsers with fencing or other barriers, or where population densities of ungulate browsers are lower. Barriers are useful, short-term solutions to the browsing problem; full recovery of Texas snowbells will require better management of deer and feral ungulate populations.

Climate Change. The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (IPCC 2013, p. 23) projects the following changes by the end of the 21st century, relative to the 1986 to 2005 averages: It is virtually certain that most land areas will experience warmer and/or fewer cold days and nights; it is virtually certain that most land areas will experience warmer and/or more frequent hot days and nights; it is very likely that the frequency and/or duration of warm spells and heat waves will increase in most land areas; it is very likely that the frequency, intensity, and/or amount of heavy precipitation will increase in mid-latitude land masses; it is likely that the intensity and/or duration of droughts will increase on a regional to global scale. The magnitude of projected changes varies widely, depending on which scenario of future greenhouse gas emissions is used. These scenarios are called Representative Concentration Pathways (RCPs). Under the best-case scenario of RCP2.6, the combined emissions of carbon dioxide, methane, and nitrous oxide, expressed as the carbon dioxide equivalent, will stabilize at 475 parts per million (ppm) by the year 2100. This figure rises to 630, 800, and 1,313 ppm under the RCP4.5, RCP6.0, and RCP8.5 scenarios, respectively (IPCC 2013, p.22).The report also states, "In many mid-latitude and subtropical dry regions, mean precipitation will likely decrease..." (p. 16). However, the Fifth Assessment does not simulate regional precipitation patterns well (p. 11). Furthermore, we do not know how Texas snowbells would respond to changes in temperatures and rainfall amounts and patterns. Since these changes could be detrimental to the subspecies, climate change represents a potential threat to its continued survival.

Endemism. Texas snowbells is endemic to a very limited area. We estimate that only about 15,043 ha (37,172 ac) of potential habitat exist in the upper portions of three watersheds; the subspecies' global range spans 121 km (75 mi) east to west and 35 km (22 mi) north to south. While endemism is not a threat, per se, it increases the subspecies' vulnerability to other threats. For example, climate change could further reduce the amount of potential habitat, or a single prolonged drought or catastrophic rainfall and flooding could increase mortality throughout the subspecies' range.

Severe floods. The steep, rocky terrain of the Edwards Plateau and frequent occurrence of heavy rainfall contribute to the severity of the region's flash floods (Eckhardt 2015, pp. 1-2). Texas snowbells seeds often fall on dry stream beds and may germinate and establish there, only to be swept away during flash floods. The vulnerability of young Texas snowbells plants was demonstrated when a flood washed away the seedlings that were initially planted at EO2. The incidence of flash flooding is a natural and unavoidable feature of the narrow riparian habitats of Texas snowbells. However, flash flooding could become more frequent or more severe as a result of climate change.

Drought. Tree ring data indicate that severe, extended droughts have occurred repeatedly in the Edwards Plateau since the year 1500 (Cleaveland *et al.* 2011, all). At EO17, average annual mortality of Texas snowbells was 6%, but increased to about 22% during the exceptional drought of 2011 (Reemts *et al.* 2016, p. 1). Therefore, the intensity and duration of drought are factors that affect the survival of Texas snowbells. Since it is likely that the intensity and/or duration of droughts will increase on a regional to

global scale due to climate changes (IPCC 2013, p. 23), the viability of Texas snowbells may decline as a result.

Land ownership. A large portion of the known individuals and populations of Texas snowbells occurs on privately owned land. This does not constitute a threat to the subspecies, and in fact many landowners have demonstrated interest and enthusiasm for conservation of Texas snowbells. However, private ownership makes conservation more challenging for several reasons. Access to populations and habitats is subject to the interests of hundreds of individual landowners. Consequently, our knowledge of the subspecies' actual status is far from complete. Establishing and maintaining cooperative relationships with large numbers of private landowners is time-consuming, and these important relationships may lapse when personnel of conservation organizations retire or pursue other career choices. The ownership of private lands changes hands over time, and future owners may choose not to continue conservation efforts that were supported by previous owners. Hence, it is difficult to assure permanent conservation on private lands. These challenges underscore the importance of effective landowner outreach in the conservation of Texas snowbells.

VI. Current Status.

When listed as endangered in 1984, only 25 Texas snowbells plants had been discovered (49 FR 40036). Since 1986, 400 mature and 452 immature Texas snowbells plants have been documented in 22 naturally occurring populations. The two largest metapopulations (as described in Section II.3, Minimum Viable Population), EO3/EO14 and EO17, appear to be stable or increasing.

Texas snowbells has been successfully propagated and reintroduced. By 2008, at least 475 plants that were grown from wild-collected seed had been successfully reintroduced into the wild. By September 2013 this figure increased to 694 surviving individuals, including mature individuals from which 346 seeds were collected.

Two-thirds of the Devils River populations occur on 41,087 ha (101,526 ac) of protected conservation land. In contrast, there is no publicly owned conservation land in upper Nueces River or West Nueces River watersheds. A private landowner group organized by David Bamberger has promoted voluntary conservation and reintroduction of the subspecies on at least 24 privately owned properties, totaling 52,610 ha (130,000 ac), within the range of Texas snowbells. However, we do not know the amount and distribution of potential habitats on these private properties.

Management of wild populations and the design of reintroduction efforts has benefited from the knowledge gained on reproductive biology and pollination.

The total global population of 400 mature wild plants is less than our estimated MVP of 900 to 1,200 for a single metapopulation. Recruitment rates at many sites are low, due to intense browsing from dense populations of white-tailed deer and introduced ungulates. Many of the known plants are isolated; since the subspecies probably requires out-crossing, and considering the limited range of its pollinators, we expect little or no reproduction among isolated plants and very small, closely-related groups. As reintroduced plants mature, they may contribute to wild populations, allowing metapopulations to approach the estimated size needed for long-term viability. Reintroduced plants may also alleviate the isolation of remaining wild plants and increase fertilization and gene flow between individuals. However, since we do not know where many reintroduction sites were conducted on private property, we are not able to evaluate their potential contributions to the subspecies' viability.

VII. Viability Assessment.

Table 12 (below) summarizes the requirements, factors affecting survival, and current conditions of Texas snowbells individuals, populations, and the subspecies. The viability of the subspecies overall is expressed in terms of its representation, redundancy, and resiliency. All three of these viability characteristics are low, and therefore, the subspecies' viability is low. If not for the dedicated conservation efforts of the last 30 years, it would likely have continued to decline toward extinction.

However, both our knowledge of Texas snowbells and its actual status have improved significantly since it was listed as endangered in 1984. The threat of imminent extinction is lower, but the subspecies is still vulnerable to extinction. Population recruitment is evident only at the two largest populations (EO3-EO14 and EO 17), and may also occur in a third large population (P1-P2). Most of the remaining 161 mature plants that have been reported to us – 38 percent of the reported global population - occur in small, isolated groups where mortality probably exceeds recruitment. If no actions are taken to alleviate this isolation, we expect that isolated individuals and small groups will eventually die out without contributing to the future genetic diversity of the surviving populations. The two or three larger populations might endure, but the loss of representation and redundancy would reduce the subspecies' viability.

The viability of Texas snowbells, however, may be improved by accomplishing the conservation recommendations listed in Appendix 1. All conservation actions involve voluntary support of private landowners, underscoring the importance of landowner outreach. The core conservation strategy is to increase recruitment and decrease mortality, allowing populations to grow naturally. One of the most important objectives is to reduce the intensity of ungulate browsing throughout the subspecies' range. Exclosures and cages are useful emergency measures to protect individuals or small groups, and may help to build populations to a more secure size, but the long-term goal is populations that are self-sustaining without human intervention. Another high-priority objective is to enhance gene flow and fertilization rates between and among genetically diverse individuals and populations. This may be accomplished by augmenting small populations to increase the fertilization of flowers and production of viable seeds, and by restoring connectivity between isolated individuals and small populations to allow pollen transfer between and among them. If successful, augmentation and reintroduction can also increase population sizes, improving the subspecies' resilience. However, we predict that the strategic placement of reintroduced plants to restore population connectivity will be of greater benefit to the subspecies' viability than solely increasing population sizes without increasing connectivity. The Bamberger group has made significant progress toward accomplishing these goals, and has gained valuable experience that will aid continued reintroduction and augmentation efforts. Guidelines for augmentation and reintroduction are discussed briefly in Appendix B.3. The importance and scale of these efforts emphasizes the need to prepare a detailed controlled propagation and reintroduction plan in accordance with the U.S. Fish and Wildlife Service and National Marine Fisheries Service Policy on Controlled Propagation, which was published on September 20, 2000 (FR 65: 56919).

The time frame required to improve the viability of Texas snowbells is influenced largely by its life history. When all conservation actions have been accomplished, their effectiveness will be measured by the natural recruitment of new individuals, their growth to maturity, and the increase of populations to a viable level that is sustained without human intervention. We estimate that the minimum time to judge the effectiveness of recovery efforts and resulting population trends would be 2 to 3 generations, or about 30 years.

Table 12. Summary of requirements, factors affecting survival, and current conditions of Texas snowbells individuals, populations, and subspecies.

INDIVIDUALS	POPULATIONS	SUBSPECIES
I. Requirements of Texas snowbells.		

• Narrow riparian corridors in ravines of Edwards Plateau limestone.
• Elevation range of 372-579 m (1,220 –1,900 ft).
• Precipitation average of 51.3-69.5 cm/year (20.2-27.4 in/year).
• Annual temperature range of 0.9°-36.3° C (33.6°-97.3° F).
• Relatively low browse pressure.
• Must survive about 10 years or more to become reproductive.
	• Fertilization requires unrelated individuals within estimated pollinator range 0.5-1.0 km (0.3-0.6 mi).
	• Groups of 56 or more genetically diverse individuals clustered within 1.6 km (1.0 mi).
	• Healthy populations of American bumblebees, California carpenter bees, and/or other effective pollinators; consequently, healthy populations of pollen and nectar plants.
	  • Estimated MVP of 900 to 1,200 individuals.
		• Representation: Extant genetic diversity conserved throughout the range.
		• Redundancy: One or more viable metapopulations in each known watershed (Nueces, West Nueces, and Devils Rivers); Frio, West Frio, Dry Frio, and Sycamore Creek of the Rio Grande watersheds may be added to this objective if natural populations are confirmed there.
		  • Resiliency: 900 to 1,200 individuals in each metapopulation.

II. Factors affecting the survival of Texas snowbells.		
• Severe browsing pressure by native and introduced ungulates reduces individual survival.	• Low population size impedes reproduction. • Low genetic diversity impedes reproduction. • Population fragmentation and isolation impedes reproduction. • Severe browsing pressure by native and introduced ungulates impedes recruitment. • Endemism limits the amount of potential habitat able to support populations. • Pollinator deficiency potentially impedes reproduction. • Climate change potentially reduces the amount and distribution of suitable habitat. • Private land ownership creates additional challenges to monitor and manage populations.	• Low genetic diversity limits representation. • Population fragmentation and isolation reduces gene flow within and among populations, contributing to low representation. • Endemism limits the geographic range and redundancy of the subspecies. • Climate change potentially reduces range and redundancy. • Low population sizes reduce resilience. • Severe browsing pressure impedes survival and growth of populations, thereby reducing resilience. • The large proportion of populations on private land creates challenges to monitoring and recovering the subspecies.

III. Current Conditions of Texas snowbells.		
• Individuals that are protected from browsing are able to grow and reach reproductive size in about 10 years. • Individuals that can be accessed by ungulate browsers have low survival and growth rates.	• 22 natural populations, totaling 400 mature and 452 immature individuals, are known from 3 (and possibly a 4th) watersheds. • About 2/3 of Devils River population is on public or private conservation land. • 24 private landowners are cooperating with surveys, monitoring, and conservation efforts. • Recruitment has been documented at the two largest populations. • Smaller populations and isolated individuals have little or no recruitment, due to low genetic diversity, small population size, and low fertilization rates. • Mortality from ungulate browsing is high in the Nueces and West Nueces River watersheds and moderate in the Devils River watershed. • 694 individuals have been successfully reintroduced in 24 sites; 346 viable seeds have been harvested from reintroduced plants. • All known metapopulations are far smaller than the estimated MVP.	• Representation: Genetic analyses have so far detected very little genetic variation within or among populations. • Redundancy: Natural metapopulations have been confirmed in 3 watersheds. A fourth natural population may occur on the West Frio River. • Resilience: The natural metapopulations are all smaller than the estimated MVP. However, two of the larger natural populations have naturally increased in size. Successful reintroductions have augmented some natural populations.

VIII. Literature Cited.

Adams, R.P. and J. Poole. 2001. Low variability of DNA fingerprints of Texas snowbells: Conservation implications. Phytologia 93: 198-202.

Bamberger, J.D. 2013a. Fwd: Snowbell Plans. Email and attached digital photographs sent to Chris Best, U.S. Fish and Wildlife Service. May 30, 2013.

Bamberger, J.D. 2013b. Excel spreadsheet summarizing results of reintroductions of Texas snowbells by Bamberger Ranch Preserve and partners. Created June 6, 2013.

Bamberger, J.D. 2013c,d. Letters to Chris Best, U.S. Fish and Wildlife Service, dated June 13 and June 27, 2013, respectively.

Bamberger, J.D. 2014. Re: Snowbell Plans. Email to Chris Best, U.S. Fish and Wildlife Service. December 12, 2014.

Bamberger Ranch Preserve. 2014a. About us. http://bambergerranch.org/about-us/. Accessed: December 12, 2014.

Bamberger Ranch Preserve. 2014b-g. Blogs dated: March 3, 2008 (b), April 20, 2008 (c), December 14, 2008 (d), May 24, 2009 (e), June 28, 2009 (f), and March 1, 2010 (g). http://bambergerranch.org/about-us/. Accessed: December 12, 2014.

Barrett, S.C.H. and J.R. Kohn. 1991. Genetic and evolutionary consequences of small population size in plants: implications for conservation. Pp. 3-30 *in* D.A. Falk and K.E. Holsinger (eds.), Genetics and Conservation of Rare Plants. Oxford University Press, New York, New York. 283 pp.

Beekman, M. and F.L.W. Ratnieks. 2000. Long-range foraging by the honey-bee, *Apis mellifera* L. Functional Ecology 14: 490-496.

Best, C. 2011. Taking pride in conservation: Landowners restore rare species in Texas. Endangered Species Bulletin 36: 36-37. U.S. Fish and Wildlife Service, Arlington, VA.

Cleaveland, M.K., T.H. Votteler, D.K. Stahle, R.C. Casteel, and J.L. Banner. 2011. Extended chronology of drought in South Central, Southeastern and West Texas. Texas Water Journal 2:54-96.

Cory, V.L. 1943. The genus *Styrax* in central and western Texas. Madroño 7: 110-115.

Cox, P. 1987. Chasing the wild Texas snowbells. The Center for Plant Conservation 2: 1, 8.

Cox, P. 2000. In hot pursuit of the Texas snowbell. News from the Botanical Garden, San Antonio Botanical Society. Fall 2000. P.4.

Eckhardt, G. 2015. Regional climate and water availability. 6 pp. http://www.edwardsaquifer.net/climate.html. Accessed: January 26, 2015.

Edmands, S. 2007. Between a rock and a hard place: evaluating the relative risks of inbreeding and outbreeding for conservation and management. Molecular Ecology 16: 463-475.

Fritsch, P.W. 1996. Isozyme analysis of intercontinental disjuncts within Styrax (Styracaceae): Implications for the Madrean-Tethyan hypothesis. American Journal of Botany 83: 342-355.

Fritsch, P.W. 1997. A revision of *Styrax* (Styracaceae) for western Texas, Mexico, and Mesoamerica. Annals of the Missouri Botanical Garden 84: 705-761.

Fritsch, P.W. 2001. Phylogeny and biogeography of the flowering plant genus *Styrax* (Styracaceae) based on chloroplast DNA restriction sites and DNA sequences of the internal transcribed spacer region. Molecular Phylogenetics and Evolution 19: 387-408.

Fritsch, P.W. 2009. Styracaceae de Candolle & Sprengel; *Styrax* Linnaeus; *Styrax platanifolius* Engelmann *ex* Torrey subsp. *texanus* (Cory) P.W. Fritsch. Flora of North America 8, pp. 339-341, 344-345.

Fulton, S. 2008. Re: Recovery data call for Texas snowbells. Email and attached Excel file summarizing growth and location of reintroduced snowbells, sent to Christina Williams, U.S. Fish and Wildlife Service, August 22, 2008.

Fulton, S. 2010. Section 6 Grant E-92-R. Status assessment and ecological study of *Styrax platanifolius* ssp*. texanus*. Final Report, December 3, 2010. 21 pp. + 11 Attachments.

Fulton, S. 2013. Re: Texas snowbells populations and maps (no. 1 of 4). Email to Chris Best, U.S. Fish and Wildlife Service, September 18, 2013.

Garrity, C.P. and D.R. Soller. 2009. Database of the Geologic Map of North America; adapted from the map by J.C. Reed, Jr. and others (2005). U.S. Geological Survey Data Series 424. http://pubs.usgs.gov/ds/424//. Accessed: June 16, 2014.

Gilbert, S. 2013. Snowbell related TNC Lands. Email and attached shapefile sent to Chris Best, U.S. Fish and Wildlife Service, September 9, 2013.

Gonsoulin, G.J. 1974. A revision of *Styrax* (Styracaceae) in North America, Central America, and the Caribbean. Sida 5: 191-258.

Greene, J. 2007. Water from Stone: The story of Selah, Bamberger Ranch Preserve. Texas A&M Press, College Station, TX. 218 pp.

Hagen, M., M. Wikelski, and W.D. Kissling. 2011. Space use of bumblebees (*Bombus* spp.) revealed by radio-tracking. PLoS ONE 6:e19997. Doi:10.1371/journal.pone.0019997.

Huerta-Patricio, E., K.D. Cameron, G.N. Cameron, and R.A. Medellín. 2005. Conservation implications of exotic game ranching in the Texas Hill Country. Pp. 237-252 *in* V. Sánchez-Cordero and R.A. Medellín (eds.), Contribuciones Mastozoológicos en Homenaje a Bernardo Villa. Universidad Nacional Autónoma de México y CONABIO. México D.F. 706 pp.

Integrated Taxonomic Information Service. 2014. *Styrax platanifolius* ssp. *texanus* (Cory) P.W. Fritsch. http://www.itis.gov. Accessed June 18, 2014.

Intergovernmental Panel on Climate Change. 2013. Summary for Policymakers. *In* T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 29 pp.

Karges, J. 2013. Re: Texas snowbells populations. Email and attached Excel file sent to Chris Best, U.S. Fish and Wildlife Service, July 30, 2013.

Keeney, T. 1988a. *Styrax texana* reintroduction – Mare Creek. (Internal report to U.S. Fish and Wildlife Service) 1 p. + 15-page table.

Keeney, T. 1988b. *Styrax texana* reintroduction – Cypress Creek. (Internal report to U.S. Fish and Wildlife Service) 1 p. + 17-page table.

Mace, G.M. and R. Lande. 1991. Assessing extinction threats: Toward re-evaluation of IUCN threatened species categories. Conservation Biology 5: 148-157.

Mahler, W.F. 1981. Status report on *Styrax texana* Cory. Contract 14-16-0002-79-169. Submitted to Office of Endangered Species, U.S. Fish and Wildlife Service, Albuquerque, NM. 8 pp.

McDonald, C.B. 1996. Case Study 3: Texas snowbells (*Styrax texana*) reintroduction. Pp. 411-416 *in* D.A. Falk, C.I. Millar, and M. Olwell (eds.), Restoring Diversity: Strategies for reintroduction of endangered plants. Island Press, Washington, D.C. and Covelo, California. 505 pp.

Minton, J. 2010. Real County. Handbook of Texas Online. Texas State Historical Association. http.www.tshaonline.org/handbook/online/articles/hcr04. Accessed December 15, 2014.

Mungall, E.C. and W. J. Sheffield. 1994. Exotics on the Range: The Texas example. Texas A&M University Press, College Station, Texas. 265 pp.

National Climatic Data Center. 2014a. 1981-2010 Normals. Camp Wood, TX, US. http://www.ncdc.noaa.gov/cdo-web/datatools/normals. Accessed: July 10, 2014.

National Climatic Data Center. 2014b. 1981-2010 Normals. Del Rio, TX, US. http://www.ncdc.noaa.gov/cdo-web/datatools/normals. Accessed: July 10, 2014.

National Marine Fisheries Service and U.S. Fish and Wildlife Service. 2010. Interim endangered and threatened species recovery planning guidance. Version 1.3. http://www.nmfs.noaa.gov/pr/recovery/. Accessed: January 10, 2011.

Natural Resources Conservation Service. 1999-Present. 12-Digit watershed boundary data 1:24,000. National Cartography and Geospatial Center. Ft. Worth, Texas.

Natural Resources Conservation Service. 2014. The PLANTS Database. *Styrax platanifolius* Engelm. ssp. *texanus* (Cory) P.W. Fritsch. Texas snowbell. http://plants.usda.gov/core/profile?symbol=STPLT. Accessed: June 18, 2014. National Plant Data Center, Baton Rouge, LA 70874-4490 USA.

NatureServe. 2002. NatureServe Element Occurrence Standard. http://www.natureserve.org/prodServices/eodata.jsp. Accessed: June 26, 2009.

Nicolson, D.H. and G.C. Steyskal. 1976. The masculine gender of the generic name *Styrax* Linnaeus (Styracaceae). Taxon 25: 581-587.

Osborne, J.L., S.J. Clark, R.J. Morris, I.H. Williams, J.R. Riley, A.D. Smith, D.R. Reynolds, and A.S. Edwards. 1999. A landscape-scale study of bumble bee foraging range and constancy, using harmonic radar. Journal of Applied Ecology 36:519-533.

Osborne, J.L., A.P. Martin, N.L. Carreck, J.L. Swain, M.E. Knight, D. Goulson, R.J. Hale, and R.A. Sanderson. 2008. Bumblebee flight distances in relation to the forage landscape. Journal of Animal Ecology 77:406-415.

Pasquet, R.S., A. Peltier, M.B. Hufford, E. Oudin, J. Saulnier, L. Paul, J.T. Knudsen, H.R. Herren, and P. Gepts. 2008. Long-distance pollen flow assessment through evaluation of pollinator foraging range suggests transgene escape distances. Proceedings of the National Academy of Sciences 105: 13,456-13,461.

Pavlik, B.M. 1996. Defining and Measuring Success. Pp. 127-155 *in* D.A. Falk, C.I. Millar, and M. Olwell (eds.), Restoring Diversity: Strategies for reintroduction of endangered plants. Island Press, Washington, D.C. 505 pp.

Poole, J.M. 1993. Section 6 Project E-1-4 (Job 3-1): Reproductive biology of Texas snowbells (*Styrax texana*). Final Report, January 31, 1993. 4 pp. + 3 Appendices.

Poole, J.M. 2013a-j. Emails to Chris Best, U.S. Fish and Wildlife Service, dated: April 28, 2013 (a), June 17, 2013 (b), June 18, 2013 (c), July 16, 2013 (d and e), August 20, 2013 (f), August 29, 2013 (g), September 24, 2013 (h), September 27, 2013 (i), and December 10, 2013 (j).

Poole, J.M. 2017. Peer Reviewer Comments on the Texas Snowbells Species Status Assessment, Recovery Plan, and Recovery Implementation Strategy. September 30, 2017.

Poole, J., W. Carr, D. Price, and J. Singhurst. 2007. The Rare Plants of Texas. Texas A&M University Press. College Station, Texas. 640 pp.

Poole, J. and T. Cook. 1996. Progress report on a monitoring and comparison study of two populations of Texas snowbells (*Styrax texanus*). 3 pp.

Rao, S. and J.P. Strange. 2012. Bumble bee (Hymenoptera: Apidae) foraging distance and colony density associated with a late-season mass flowering crop. Environmental Entomology 41: 905-915.

Reemts, C., J. Poole, and J. Ferrato. 2016. Twenty years of monitoring the endangered Texas snowbell (*Styrax platanifolius* ssp. *texanus*). Poster presented at the Texas Plant Conservation Conference, Ft. Worth, Texas, November 3-4, 2016.

Reemts, C. 2017. Peer Reviewer Comments on the Texas Snowbells Species Status Assessment, Recovery Plan, and Recovery Implementation Strategy. August 31, 2017.

Shaffer, M.L. and B.A. Stein. 2000. Safeguarding our Precious Heritage. Pages 301-321 *in* B.A. Stein, L.S. Kutner, and J.S. Adams (eds.), Precious Heritage: The status of biodiversity in the United States. Oxford University Press. 399 pp.

Sugden, E.A. 1986. Anthecology and pollinator efficacy of *Styrax officinale* subsp. *redivivum* (Styracaceae). American Journal of Botany 73: 919-930.

Texas Natural Diversity Database. 2013. Element occurrence printouts for *Styrax platanifolius* ssp. *texanus*. Wildlife Diversity Program of Texas Parks and Wildlife Department. April 26, 2013.

The Nature Conservancy. 2014. Dolan Falls Preserve. http://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/texas/placesweprotect/dolan-falls-preserve.xml. Accessed: July 3, 2014.

Tropicos. 2013a. *Styrax platanifolius* subsp. *texanus* (Cory) P.W. Fritsch. http://www.tropicos.org/Name/50125775. Accessed: June 18, 2014.

Turner, B.L. and G.L. Nesom. 2000. Use of variety and subspecies and new varietal combinations for *Styrax platanifolius* (Styracaceae). Sida 19:257-262.

U.S. Fish and Wildlife Service. 1987. Texas snowbells (*Styrax texana*) recovery plan. U.S. Fish and Wildlife Service, Albuquerque, New Mexico. 53 pp.

U.S. Fish and Wildlife Service. 1999. Texas snowbells (*Styrax platanifolius* ssp. *texanus*) recovery plan (draft revision). U.S. Fish and Wildlife Service, Albuquerque, New Mexico. 52 pp.

U.S. Fish and Wildlife Service. 2008. Five-year review of Texas Snowbells (*Styrax platanifolius* ssp. *texanus*). U.S. Fish and Wildlife Service, Albuquerque, New Mexico. 17 pp.

U.S. Fish and Wildlife Service. 2009. Texas snowbells (*Styrax platanifolius* ssp. *texanus*) recovery plan (draft revision). U.S. Fish and Wildlife Service, Albuquerque, New Mexico. 67 pp.

U.S. Fish and Wildlife Service and National Marine Fisheries Service. 2000. Policy Regarding Controlled Propagation of Species Listed Under the Endangered Species Act. Federal Register 65:56912-56922. September 20, 2000.

U.S. Geological Survey. 2011. Digital Elevation Models: ned_2011_30m_2900, ned_2011_30m_2901, ned_2011_30m_2999, ned_2011_30m_3000, ned_2011_30m_3001, and ned_2011_30m_3099. http://ned.usgs.gov. Accessed: August 21, August 29, and September 11, 2014.

Williams, P.H. and J.L. Osborne. 2009. Bumblebee vulnerability and conservation world-wide. Apidologie 40: 367-387.

Appendix A. Photo credits, acronyms used, and scientific units.

Photographic Credits.

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Acronyms Used.

ESA	Endangered Species Act	TNC	The Nature Conservancy
FR	Federal Register	TPWD	Texas Parks and Wildlife Department
GPS	Global Positioning System	TXNDD	Texas Natural Diversity Database
MVP	Minimum Viable Population	USFWS	U.S. Fish and Wildlife Service

Scientific Units.

ac	acre	in	inch
C°	Degrees Celsius	km	kilometer
cm	centimeter	m	meter
F°	Degrees Fahrenheit	mi	mile
ft	feet	mm	millimeter
ha	hectare		

Appendix B. Conservation Recommendations.

1. Private landowner outreach. Promote awareness of Texas snowbells through written and on-line sources. Promote the continued efforts of private landowners to conserve Texas snowbells. Provide technical and/or financial assistance, as needed, to support monitoring, surveys, and management actions. Promote conservation easements for long-term protection of habitats and populations among willing landowners.
2. Reduce ungulate browse pressure. An immediate but short-term objective is to protect vulnerable individuals and small populations, where possible, with deer-fencing or other methods of exclusion. A more permanent objective is management of white-tailed deer and introduced ungulates at densities that do not deplete Texas snowbells and other native vegetation.
3. Population augmentation and reintroduction. Use nursery-propagated seedlings and/or direct-seeding to augment small populations to: a) increase numbers of individuals and genetic diversity within pollinator ranges to ensure high fertilization rates; and b) increase metapopulation size to MVP levels (increase resiliency). Reintroduce populations into currently unoccupied potential habitats to: a) reduce isolation and fragmentation and establish gene flow among populations; and b) establish additional metapopulations (increase redundancy). Prepare a controlled propagation and reintroduction plan, as required by Service policy (FR 65: 56916). Limit augmentation and reintroduction to the upper watersheds of the Nueces, West Nueces, and Devils Rivers; augmentation and reintroduction may also be appropriate in the Frio, West Frio, Dry Frio, and Sycamore Creek watersheds if natural populations are confirmed there.
4. Pollinator conservation. Promote conservation and management of native bees, butterflies, and other pollinators. This may include management and restoration of diverse native grasslands, shrublands, and savannas.
5. Search for new populations. Conduct surveys, with landowner permission, in potential habitats throughout the subspecies' range. In particular, the discovery or confirmation of populations in the Frio, West Frio, Dry Frio, or Sycamore Creek watersheds would increase our knowledge of the subspecies' geographic range and adaptability, and might confer greater genetic diversity (representation) to the subspecies as a whole.
6. Develop an improved potential habitat model, using actual slope, distance-to-slope, and distance-to-watercourse data (and possibly other factors) collected from plant locations in the field.

Appendix C. Development of Texas Snowbells Potential Habitat Model.

We used ArcGIS 10.1 software to calculate distances of reported Texas snowbells plants and populations to slope and watercourse features, using only the sites for which we have fairly precise geographic locations; consequently, EO1, EO8, B1, and B2 were excluded. The geographic data from some sites was recorded with Global Positioning Systems (GPS) and have a precision of a few meters. EOs reported in the TXNDD are represented with 200 m-wide buffers, so measurements were made from the geographic centers of the EOs. For watercourse measurements, we digitized polyline shapefiles through the centers of watercourses observed in Digital Ortho Quarter-Quad (DOQQ) natural color aerial images, and measured the distances from Texas snowbells plants to the nearest watercourse line. For slope measurements, we used the ArcGIS Slope tool to calculate slopes of 30-m Digital Elevation Models (DEMs) obtained from U.S. Geological Survey (USGS). This tool compares the elevation of each 30 x 30 m (98 x 98 ft) pixel to its neighboring pixels and calculates the change in elevation divided by 30 m horizontal distance; note that areas of differing slope smaller than the pixel size would not be detected. We classified the resulting raster files into five slope categories: 0 to 25 percent, >25 to 50 percent, >50 to 75 percent, >75 to 100 percent, and >100 percent. We then converted the raster files into polygon shapefiles, and measured distances from Texas snowbells plants to the nearest polygon in each slope category (excluding 0 to 25 percent).

Texas snowbells plants typically occur along the banks or slopes adjacent to watercourses rather than the stream beds themselves; hence, plants are further from the center lines of larger streams, but may be very close to the center lines of minor drainages. Larger streams are also further from steep slopes than smaller streams. Therefore, we classified the distance data according to the size of the nearest streams, based on the Strahler Stream Order (Wikipedia 2014), to create a more consistent habitat model. The known Texas snowbells populations are located along first-, second-, and third-order streams. Table C1 summarizes the characteristics of these stream orders.

Table C1. Definitions of stream order as used in this document.

Strahler Stream Order	Criteria	Typical Appearance in Aerial Images of the Upper Nueces, West Nueces, and Devils River Watersheds
1st	Headwater stream with no tributaries	Gravel beds < 10 m width
2nd	Formed by joining of two or more first-order streams	Gravel beds > 10 m in width
3rd	Formed by joining of two or more second-order streams	Running water or scattered intermittent pools, gravel beds mostly > 50 m in width

The distances of Texas snowbells plants to watercourse center lines and slope polygons are shown in table C2. Table C3 summarizes the average distances from these features and calculates a linear buffer for each feature equal to the average distance plus an estimated 95 percent confidence interval (=1.96 standard deviations). We then created distance-to-watercourse and distance-to-slope polygon shapefiles from the source features (watercourse center lines or slope polygons) plus their respective buffers. Finally, we intersected the buffered distance-to-watercourse and distance-to-slope polygons to create polygons of areas that are near both streams and slopes. These intersection polygons estimate potential habitat within the three watersheds of concern. The results are shown in Section II.4, above. Table 9 summarizes the amounts of potential habitat in the three watersheds, and the maps in figures 6, 7, and 8 display the geographic distribution of potential habitats.

Results. The only slope category that showed a consistent relationship to Texas snowbells locations was the distance to 25 percent slope or greater, so only this category was included in subsequent calculations.

Table C2. Distances of Texas snowbells plants and populations to streams and slopes.

EO/ID No.	Stream Order	Distance to Nearest Stream	Distance to Slope > 25%	Distance to Slope > 50%	Distance to Slope > 75%	Distance to Slope > 100%
B3	3rd	14	42	107	197	4842
B4	3rd	49	8	18	2333	2398
B5	1st	17	6	35	83	406
B6	3rd	68	78	107	137	820
EO3 (min)	3rd	4	0	407	515	539
EO3 (max)	3rd	12	15	585	886	906
EO4	3rd	18	13	150	469	1054
EO5	2nd	28	0	3	419	3011
EO6	3rd	36	22	37	120	888
EO7	3rd	30	105	139	1147	6319
EO13	3rd	84	192	193	219	245
EO14 (min)	2nd	21	0	18	920	920
EO14 (max)	2nd	49	91	291	1144	1155
EO15	3rd	103	0	21	112	2357
EO16	3rd	17	21	51	388	1490
EO17 (min)	3rd	29	0	39	67	67
EO17 (max)	3rd	75	68	318	393	1094
EO18	3rd	46	195	230	300	420
K1	1st	13	0	26	436	1087
K2	1st	8	0	78	706	1090
K3	1st	5	10	10	502	1118
K4	1st	19	0	656	2501	2515
K5	3rd	24	35	75	114	173
K6	3rd	42	105	168	641	1219
K7	3rd	82	140	181	282	340
P1	2nd	8	36	159	1414	2338
P2	2nd	8	12	156	780	2078
P3	3rd	81	0	8	194	247
P4	3rd	116	0	0	179	236
P5	3rd	102	0	141	316	375
P6	3rd	133	0	134	307	369

Table C3. Derivation of polygon buffers based on distances to stream and slope features.

	Distances (m) Classified by Stream Order					
	First Order		Second Order		Third Order	
	Stream	Slope > 25%	Stream	Slope > 25%	Stream	Slope > 25%
n	5	5	5	5	21	21
Minimum	5	0	8	0	4	0
Maximum	19	10	49	91	133	195
Average	12	3	23	28	55	49
Standard Deviation	5	4	15	34	37	62
1.96SD:	10	8	30	67	73	121
Buffer	**22**	**11**	**53**	**95**	**128**	**170**

Discussion. Possible sources of error in this model's current form include the lack of precise geographic data for some Texas snowbells locations, and the large pixel size of DEMs used, which would not detect small areas of differing slope. This model based on proximity to stream and slope could be improved by obtaining source data directly from plant locations in the field: more precise GPS data of plant locations, and measurement of the actual slope and proximity to slope of plant locations. Mapping of potential habitat could also be more precise if slope was determined from files with smaller pixel sizes, such as the USGS 10-m DEMs; however, the very large file sizes result in slower processing speeds.

Appendix D. Glossary.

Term	Definition
Adaptive Radiation	Multiple taxa that evolve from a single progenitor through adaptation to different environments.
Allopatry	Members of a clade that occupy the different habitats or geographic areas.
Alternate	An arrangement of plant tissues, such as leaves, branches, or floral parts, having a single part at each node.
Anther	The pollen-bearing part of the stamen. (Correll and Johnston 1979).
Anthesis	The period when a flower is receptive to fertilization.
Axil	Upper angle formed by a leaf or branch with the stem (Correll and Johnston 1979).
Bract	A reduced leaf subtending a flower, usually associated with an inflorescence (Correll and Johnston 1979, p. 1747).
Calyx	The external whorl of a flower (Correll and Johnston 1979, p. 1747); the sepals, collectively.
Chloroplast	A double-membrane organelle found in higher plants in which photosynthesis takes place.
Clade	The scientific classification of living and fossil organisms to describe a monophyletic group, defined as a group consisting of a single common ancestor and all its descendants (Wikipedia 2017).
Coppice	Regeneration of woody stems from a caudex or root crown.
Corolla	The inner perianth of a flower (Correll and Johnston 1979, p. 1749); the petals, collectively.
Dehiscent	Structure that naturally splits open along lines of mechanical weakness.
Demography	Scientific study of populations.
Drupe	A fleshy one-seeded indehiscent fruit containing a stone with a kernel; a stone-fruit such as a plum (Correll and Johnston 1979, p. 1750).
Effective population size	The size of an idealized population in which individuals contribute equally to the gamete pool and have the same variation in allele frequencies and levels of inbreeding as the observed population (Barrett and Kohn 1991).
Element Occurrence	An area of land and/or water in which a species or natural community is, or was, present (NatureServe 2002).
Endemic	An organism restricted to a specific habitat or geographic range.
Genetic drift	A change in allele frequencies within a population over time.
Glabrous	Lacking surface ornamentation, such as trichomes.
Halictid	A cosmopolitan family of the order Hymenoptera consisting of small (> 4 mm) to midsize (> 8 mm) bees which are usually dark-colored and often metallic in appearance; commonly referred to as sweat bees (Wikipedia 2017).
Holocene	Geological epoch which began approximately 12,000 years ago (Wikipedia 2017).
Imbricate	Arrangement in two or more overlapping series.
Infra-taxa	A subdivision of a taxon (e.g., infra-species).

Term	Definition
Isozyme	Enzymes that differ in amino acid sequence but catalyze the same chemical reaction; also known as isoenzymes or more generally as multiple forms of enzymes (Wikipedia 2017).
Mesic	Habitat or ecological region with intermediate moisture availability (between wet and xeric).
Mesoamerica	Geographic region ranging from Central Mexico to Central America.
Metapopulation	A group of spatially separated populations of the same species that interact at some level (Wikipedia 2017).
Micro-habitat	Very specific or fine-scale portion of a habitat that is occupied by a species.
Minimum viable population	The fewest individuals required for a specified probability of survival over a specified length of time (Pavlik 1996; Mace and Lande 1991).
Monophyly	A group of organisms which consists of all the descendants of a single common ancestor.
Nuclear DNA	DNA contained within the nucleus of a Eukaryotic organism.
Ornamentation	Trichomes or other structures formed on the epidermis of a plant.
Outbreeding depression	The reduction in reproductive fitness in the first or later generations following attempted crossing of populations (Frankham et al. 2011, p. 466).
Palmate	Arrangement of veins, lobes, leaflets, etc., dividing and radiating from a single point.
Papilionidae	A family of butterflies commonly known as swallowtails.
Pedicel	The stalk of a single flower in a flower cluster or of a spikelet in grasses (Correll and Johnston 1979).
Peduncle	The stem of an inflorescence.
Petiole	A leaf stalk (Correl and Johnston 1979, p. 1758).
Phenology	Seasonal pattern of plant growth, development and reproduction.
Pinnate	A compound leaf, having the leaflets arranged on each side of a common petiole; featherlike (Correll and Johnston 1979, p.1758).
Pixel	In digital imaging…a physical point in a raster image, or…the smallest controllable element of a picture represented on the screen (Wikipedia 2017).
Pleistocene	Geological epoch beginning about 2,588,000 years ago and ending about 11,700 years ago (Wikipedia 2017).
Polyline	A type of shapefile containing linear features.
Ramet	An individual, genetically-identical plant reproduced as a clone of the parent plant.
Raster	In computer graphics…a dot matrix data structure representing a generally rectangular grid of pixels, or points of color, viewable via a monitor, paper, or other display medium (Wikipedia 2017).
Recruitment	Addition of new individuals to a population.
Redundancy	The number of populations or sites necessary to endure catastrophic losses (Shaffer and Stein 2000, pp. 308-310).
Reintroduction	Restoration of populations of a species where it is currently absent but within its former range and habitat.
Representation	The genetic diversity necessary to conserve long-term adaptive capability (Shaffer and Stein 2000, pp. 307-308).

Term	Definition
Resilience	The size of populations necesssary to endure random environmental variation (Shaffer and Stein 2000, pp. 308-310).
Ruderal	Early stage of succession (colonization).
Section	In botany, a section is a taxonomic rank below the genus and subgenus, but above series and species (Wikipedia 2017).
Self-incompatible	Incapable of self-fertilization.
Seral	An intermediate developmental stage in ecological succession (Wikipedia 2017).
Series	In botany and plant taxonomy...a subdivision of a genus, a taxonomic rank below that of section (and subsection) but above that of species (Wikipedia 2017).
Shapefile	A digital geospatial vector data storage format developed by Esri. (Wikipedia 2017).
Sister taxon	A sister group or sister taxon is a systematic term from cladistics denoting the closest relatives of a group in a phylogenetic tree (Wikipedia 2017).
Species viability	A species' ability to sustain populations in the wild beyond the end of a specified time period, assessed in terms of its resilience, redundancy, and representation (USFWS 2015).
Stamen	Male reproductive structure of the flower, consisting of a filament and anther: the androecium (Anderson 2001).
Stellate	Star-shaped.
Style	A narrowed, often elongate portion of a pistil between the stigma and ovary (Correll and Johnston 1979).
Subspecies	A taxonomic group that is a division of a species; usually arises as a consequence of geographical isolation within a species (Biology-online.org 2011).
Subtend	Positioned directly below a specified structure.
Subtropical	Climatic region intermediate between tropical and temperate, where freezing temperatures occur infrequently and are of limited duration and intensity.
Taxon	(Plural, taxa). A natural group of organisms at any rank in the taxonomic hierarchy (Anderson 2001).
Taxonomy	Scientific classification of living organisms.
Trichome	Any hair-like growth of the epidermis, as a hair or bristle (Correll and Johnston 1979, p. 1763).
Ungulate	In the broad sense, hooved mammals.
Voucher specimen	A plant or animal specimen deposited in a collection to confirm the species identification and location.
Watershed	A physiographic area bound by a drainage divide and within which precipitation drains to a point of interest (NRCS 1999-Present).
Xenogamy	Sexual fertilization between different, unrelated individuals.

Literature cited in glossary.

Anderson, E.F. 2001. The Cactus Family. Timber Press, Portland, OR. 776 pp.

Barrett, S.C.H. and J.R. Kohn. 1991. Genetic and evolutionary consequences of small population size in plants: Implications for conservation. Pages 3-30 *in* Falk, D.A. and K.E. Holsinger (eds.), Genetics and Conservation of Rare Plants. Oxford University Press, New York, New York.

Biology-online.org. 2011. http://www.biology-online.org/dictionary/. Accessed June 30, 2011.

Correll, D.S. and M.C. Johnston. 1979. Manual of the vascular plants of Texas. University of Texas at Dallas, Richardson, Texas. 1881 pp.

Frankham, R., J.D. Ballou, M.D.B. Eldridge, R.C. Lacy, K. Ralls, M.R. Dudash, and C.B. Fenster. 2011. Predicting the probability of outbreeding depression. Conservation Biology 25: 465-475.

Mace, G.M. and R. Lande. 1991. Assessing extinction threats: Toward re-evaluation of IUCN Threatened Species Categories. Conservation Biology 5:148-157.

Natural Resources Conservation Service. 1999-Present. 12-Digit watershed boundary data 1:24,000. National Cartography and Geospatial Center. Ft. Worth, Texas.

NatureServe. 2002. NatureServe Element Occurrence Standard. http://www.natureserve.org/prodServices/eodata.jsp. Accessed June 26, 2009.

Pavlik, B.M. 1996. Defining and measuring success. Pages 127-155 *in* Falk, D.A., C.I. Millar, and M. Olwell, (eds.), Restoring Diversity: Strategies for reintroduction of endangered plants. Island Press, Washington, D.C. 505 pp.

Shaffer, M.L. and B.A. Stein. 2000. Safeguarding our Precious Heritage. Pages 301-321 *in* B.A. Stein, L.S. Kutner, and J.S. Adams (eds.), Precious Heritage: The status of biodiversity in the United States. Oxford University Press. 399 pp.

U.S. Fish and Wildlife Service. 2015. USFWS species status assessment framework: an integrated analytical framework for conservation. Version 3.3. August 2015.

Wikipedia.org. 2017. Articles on clade, Holocene, isozyme, metapopulation, pixel, Pleistocene, raster graphics, Section (botany), Series (botany), and shapefile. http://en.wikipedia.org/ Accessed August 11, 2017.