TARLETON STATE UNIVERSITY
Member of The Texas A&M University System

Stephenville | Fort Worth | Waco | Midlothian | RELLIS-Bryan | Online

Predictive Mapping of Rare Plants

Technical Report 0-6973-R1B

(Performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration)

Tarleton State University, Department of Wildlife and Natural Resources; Stephenville, Texas
Hemanta Kafley (PI)
Darrel Murray
Heather Mathewson
Mandira Sharma
Marissa Pensirikul
Jordan Craven
Lane Pressler

December 29, 2021

Published March 2022

Technical Report Documentation Page

1. Report No. FHWA/TX-22/0-6973-1B	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle Predictive Mapping of Rare Plants	5. Report Date November 2021 Published March 2022 6. Performing Organization Code
7. Author(s) Hemanta Kafley (PI) Darrel Murray, Heather Mathewson, Mandira Sharma, Marissa Pensirikul, Jordan Craven, Lane Pressler	8. Performing Organization Report No. 1-6973-1B
9. Performing Organization Name and Address Tarleton State University 1333 W. Washington Stephenville, Texas 76401	10. Work Unit No. (TRAIS) 11. Contract or Grant No. 0-6973
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Division 125 E. 11th Street Austin, TX 78701	13. Type of Report and Period Covered Technical Report June 2018–October 2021 14. Sponsoring Agency Code

15. Supplementary Notes

Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.

16. Abstract

Populations of rare plants are often endangered due to various natural and anthropogenic disturbances that interfere with their specialized niches. These isolated populations are difficult to detect without intensive field surveys. Predicting potential geographic distributions of these species is important for conservation by allowing the implementation of appropriate habitat management strategies in predicted habitats. In consultation with plant ecologists from the Texas Parks and Wildlife Department, Texas Department of Transportation (TXDoT), and Botanical Research Institute of Texas, this project identified 17 rare plant species in Texas and compiled the pertinent biological and ecological information of these species. This project carried out potential distribution modeling of the selected 17 rare plants using historical presence-only data and Maxent models. Models of four selected species were also validated using an independent dataset collected from field surveys conducted during this project. This project produced valid models that predict potential distribution of the plants. The results of the distribution models are appended in this report and all digital layers produced from this project will be submitted to TxDOT for future use. The results can be useful in conservation planning of the rare plant species in Texas.

17. Key Words Rare plants, Maxent, Species Distribution Model (SDM)	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Alexandria, Virginia 22312; www.ntis.gov.

19. Security Classif. (of report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified	508	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

TxDOT Report 0-6973-1B

Predictive Mapping of Rare Plants

(Final Report)

(Performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration)

Submitted to:

Texas Department of Transportation

125 E. 11th Street

Austin, TX 78701

Project Number: 0-6973

Prepared by:

Hemanta Kafley (PI)
Darrel Murray, Heather Mathewson, Mandira Sharma, Marissa Pensirikul, Jordan Craven, Lane Pressler
Department of Wildlife and Natural Resources
Tarleton State University

DECEMBER 29, 2021

Disclaimer

Acknowledgment

We greatly thank project committee members, Andrew Blair, Mark Fisher, Matt Buckingham, Becki Perkins, John Moravec, Chris Glancy, and Martin Dassi from the Texas Department of Transportation; Anna Strong, Jason Singhurst, Suzanne Walsh, and Laura Dugan from Texas Parks and Wildlife Department; and Chris Best from U.S. Fish and Wildlife Services, for serving in this committee. Your insights during the periodic project update meetings were very helpful for implementing the project.

An independent contractor, Marie Knipfer, collated historical data of species presence locations for us to develop the preliminary models. Kim Taylor and Sydney Jackson from the Botanical Research Institute of Texas provided input on the accuracy of the historical data and conducted fieldwork to collect independent field survey data to validate the models. We are thankful to them.

Finally, we thank Texas Department of Transportation for funding this project (Project Number 0-6973).

Table of Contents

List of Figures

List of Tables

List of Appendices

Chapter 1 Identifying Priority Rare Plants in Texas

Introduction

Significant loss of floral and faunal biodiversity has prompted increasing consideration of biodiversity conservation goals (IPBES 2018). The Convention on Biological Diversity (CBD) recommends that 30% of the world's land needs to be protected to halt species decline and extinction in the next decade (CBD 2020). Between 2001 and 2017, the U.S. lost 24 million acres of natural areas to development (Theobald et al. 2019). As a consequence, on 27 January 2021, the U.S. pledged to protect 30% of U.S. land by the year 2030. While losing natural areas is detrimental to overall biodiversity, the effect can be catastrophic for rare plants that have specialized niches. Identifying rare plant species and predicting their potential habitats allows targeted protection and management. This can be helpful for rare plants protection, ecological restoration, and overall conservation planning of TxDOT right-of-way (ROW) development and management. This project focusses on targeted protection of rare plants potentially found in TxDOT ROWs.

The role of rare plants in specific ecosystems is often unknown. In general, the loss of species often has cascading effects on ecosystem functions (Cardinale et al. 2006; Duffy 2009). Although rare plants often are low in abundance and restricted to specific habitat conditions, is it thought that these species have disproportionate impacts on ecosystems (Loreau et al. 2002). Rare plant species contribute to diversity because they tend to exhibit more functional variability related to specialized environmental requirements (Mouillot et al. 2013). Because rare species' contribution to the ecosystem is unknown or understudied and population numbers tend to be small, these species are considered a priority for protection by state and federal legislatures.

Although Texas adheres to the Endangered Species Act (1973), the state enacted its own legislature for plant conservation in 1988 (TPWD 2021a). Both the Texas Administrative Code and the Texas Parks and Wildlife Code detail requirements for "Threatened" and "Endangered" plants (TAC Section 69.01-69.9, Texas Parks and Wildlife Code Chapter 88). An "endangered plant" is one that is threatened with extinction throughout all or a significant portion of its endemic range; a "threatened plant" is one that is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range (TPW Code Section 88.001). However, plants are "candidate" species before being officially listed at the state or federal level. Candidate species are those that have reasonable documentation for listing, but do not have high priority compared to other species (TPWD 2021a).

Species listing requires adequate knowledge about optimal habitat, present population demographics, and potential risks to the species. This study identifies 17 rare species considered here as petitioned or candidate species, which undergo similar process by UFWS to determine if they warrant listing.

This project elevates the level of knowledge regarding the occurrences of rare plants, expected habitat, and how TxDOT can incorporate that knowledge into planning and development to deliver proposed projects. It is expected to assist planning & executing of roadside vegetation management, and helping to efficiently develop transportation projects. These models will allow TxDOT to identify potential impacts to these species early in project development stages by identify areas to evaluate for the potential presence of species, which allows rare plant surveys to be targeted and efficient, facilitating timely project deliverables.

Methods

Species Selection Process

Periodic project update meetings during the project period served as Focus Group Discussions (FGDs) for guidance of which plants to consider for the project. Expert opinion from plant ecologists associated with TxDOT, Texas Parks and Wildlife Department (TPWD), U.S. Fish and Wildlife Services (USFWS), Botanical Research Institute of Texas (BRIT), and Tarleton State University (TSU) were recorded and considered by the research team to identify the priority rare plants. Based on input from Andrew Blair and Matt Buckingham (TxDOT), Anna Strong and Jason Singhurst (TPWD), Kim Taylor (BRIT), Chris Best (USFWS), and Darrel Murray (TSU), we identified 17 rare plant species to proceed with data collection and predictive modelling for the project. These species included those identified by the USFWS as candidate species, petitioned or otherwise, or species under federal review for listing as threatened or endangered under the federal Endangered Species Act (ESA) and species not under federal consideration at this time, but considered rare globally (NatureServe rank G1-G2) and/or rare in Texas (NatureServe rank S1-S2), and/or considered a Species of Greatest Conservation Need in the state of Texas by TPWD.

These 17 species are indicated in Table 1- Project 0-6973 Final Species List. Also included in the table are listing status, whether the species is a federal or Texas priority species, relevant comments from TxDOT, TPWD, or TSU, and global and state range, including elements of occurrence (EO) to represent known populations of each species in Texas. This information was included in the table to document the process of species selection on the final list. Species are arranged in alphabetical order based on scientific name. Priority species for this project met the criteria of having limited populations with unique habitat requirements that can be mapped and modelled, are candidates for state or federal protection, and are potentially found in TxDOT ROWs.

We have also compiled a list of species that were considered for data collection and predictive modelling, but were not included within the project's final species list. These species are listed in Table 2 –Project 0-6973 Species Considered and Not Included on the Final Species List. As with Table 1, information on Table 2 includes listing status, whether the species is a federal or Texas priority species, relevant comments from TxDOT, TPWD, or TSU, and global and state range, including elements of occurrence (EO) to represent known populations of each species. This information was included in the table to document the process of species omission from the final list. Species are arranged in alphabetical order based on scientific name. Scientific names have been checked as to current status at the Integrated Taxonomic Information System (ITIS) and NatureServe. No species included on tables 1 or 2 are currently listed as endangered or threatened at either the federal or state level.

Table 1 Project 0-6973 Final Species List

	Scientific Name	Common Name	Federal or State priority	Listing Status	Agency Requesting Consideration / Agency Comments	Global Range / Location in Texas
1	*Agalinis calycina* Pennell	Leoncita false foxglove	State	State: SGCN, (G1,S1)	TxDOT: Prioritized as #6 on the project alternate species list. TPWD: 3 known sites	TX, NM, Mexico west Texas 3 EOs; 5 SFs
2	*Agalinis navasotensis* Dubrule & Canne-Hilliker	Navasota false foxglove	Federal	Federal: under considera tion State: SGCN, (G1,S1)	TxDOT: At least 3 sites, one on ROW. Tends to be associated with sandstone outcrops/barrens, may be easy to model based on seemingly specific habitat requirements. TPWD: Only 2 known current sites in Texas (2 elements of occurrence, 2015 species assessment, TXNDD, 5 SFs in Biotics), known to occur in ROWs. TSU: Problematic to model with only 2 known locations	TX east Texas 2 EOs, 5 SFs
3	*Asclepias prostrata* Blackwell	prostrate milkweed	Federal	Federal: under review State: SGCN, (G1,G2,S 1,S2)	TxDOT: Multiple ROW spots; good candidate for modeling TPWD: 14 elements of occurrence, 2015 species assessment, TXNDD, 13 elements of occurrence (40 SFs) in Biotics; Occurs on ROWs. TSU: Adequate data to model	TX, Mexico south Texas 14 EOs;40 SFs

	Scientific Name	Common Name	Federal or State priority	Listing Status	Agency Requesting Consideration / Agency Comments	Global Range / Location in Texas
4	*Bartonia texana* Correll synonym: *Bartonia paniculata* subsp. *texana* (Correll) K.G.Mathews, Dunne, E.York & Struwe)	Texas screwstem	Federal	Federal: under review State: SGCN, (G2,S2)	TxDOT, TPWD TxDOT: Generally occurs in mature forested seeps. Unlikely to occur in ROW habitat, however may occur close to ROW in some areas. Likely easy to model, however extremely difficult to locate. TPWD: 21 elements of occurrence, 2015 species assessment, TXNDD, 14 elements of occurrence (14 SFs) in Biotics; No known occurrences on ROWs. *TXNDD data collected TSU: Adequate data to model	LA,TX northeast Texas 21 EOs;14 SFs
5	*Cyperus onerosus* M.C.Johnston	Dune flatsedge (synonym: dune umbrella-sedge)	State	Federal: not listed State: SGCN, (G2,S2)	TxDOT, TPWD TxDOT: Prioritized as #4 on the project alternate species list. TPWD: occurs on ROWs	TX West Texas 9 EOs; 12 SFs
6	*Eriocaulon koernickianum* Van Heurck & Müll.Arg.	small-headed pipewort	Federal/State	Federal: under review State: SGCN, (G2,S1)	TxDOT, TPWD TxDOT: No comments. TPWD: 11 elements of occurrence, 2015 species assessment, TXNDD, & Biotics each (20 SFs); 7 sites in TX, 0 on ROW. TSU: Adequate data to model	AR, GA, OK, TX central & east Texas 11 EOs;20 SFs

	Scientific Name	Common Name	Federal or State priority	Listing Status	Agency Requesting Consideration / Agency Comments	Global Range / Location in Texas
7	*Isoetes lithophila* N. Pfeiff.	Rock Quillwort	State	Federal: not listed State: SGCN, (G2,S2)	TxDOT, TPWD TxDOT: Prioritized as #7 on the project alternate species list. TPWD: 0 on ROWs	TX central Texas 17 EOs; 21 SFs
8	*Lepidospartum burgessii* B.L.Turner	Burgress' Broomshrub (synontm: gypsum scalebroom)	State	Federal: not listed State: SGCN, (G2,S1)	TxDOT, TPWD TxDOT: Prioritized as #9 on the project alternate species list. TPWD: 6 known sites, 2 of which are more generally mapped	TX, NM west Texas 6 EOs; 11 SFs
9	*Liatris cymosa (H. Ness)* K.Schum.	Branched Gay-feather		Federal: not listed State: SGCN, (G2,S2)	TxDOT, TPWD TxDOT: Prioritized as #1 on the project alternate species list. Rare Texas endemic that occurs on ROW. TPWD: No comments	TX east Texas 43 EOs; 66 SFs
10	*Osmorhiza bipatriata* Constance & Shan synonym: *Osmorhiza mexicana* ssp. *bipatriata* (Constance & Shan) Lowry & A.G. Jones	Mexican sweet-cicely (synonym: Livermore sweet-cicely)	State	Federal: not listed State: SGCN, (G1,S1)	TxDOT, TPWD TxDOT: Prioritized as #10 on the project alternate species list. TPWD: 1 known site at high elevation in protected area	TX, Mexico west Texas 1 EOs; 1 SFs

	Scientific Name	Common Name	Federal or State priority	Listing Status	Agency Requesting Consideration / Agency Comments	Global Range / Location in Texas
11	*Physostegia correllii* (Lundell) Shinners	Correll's false dragon-head	Federal	Federal: under review State: SGCN, (G2,S2)	TxDOT, TPWD TxDOT: Historic ROW sites. There is potential for it to occur in ROW. Believed to occur in ROW in LA. I'm unaware of any specific habitat requirements contributing to its rarity. TPWD: 4 elements of occurrence, 2015 species assessment, TXNDD, & Biotics each (32 SFs); 4 sites in TX; 1 ROW site that may or may not still be persisting. TSU: Adequate data to model.	LA, TX south-central Texas 4 EOs;32 SFs
12	*Physostegia longisepala* P.D.Cantino	long-sepal false dragon-head		Federal: not listed State: SGCN, (G2,G3,S2)	TxDOT, TPWD TxDOT: Prioritized as #2 on the project alternate species list. Rare WGCP endemic - population seems to be mostly restricted to ROW. TPWD: No comments.	LA, TX east Texas 18 EOs; 26 SFs
13	*Rayjacksonia aurea* (A.Gray) R.L.Hartm. & M.A.Lane Synonym: *Machaeranthera aurea* - (Gray) Shinners)	Houston Machaeranthera (synonym: Houston camphor daisy, Houston tansyaster)	State	Federal: not listed State: SGCN, (G2,S2)	TxDOT, TPWD TxDOT: Prioritized as #3 on the project alternate species list. TPWD: a preliminary model has been created for this species by Tarleton; 2 or 3 sites may still be persisting on ROWs.	TX east Texas 27 EOs; 30 SFs

	Scientific Name	Common Name	Federal or State priority	Listing Status	Agency Requesting Consideration / Agency Comments	Global Range / Location in Texas
14	*Salvia pentstemonoides* Kunth & C.D.Bouché	big red sage	Federal	Federal: under review State: SGCN, (G1,S1)	TxDOT, TPWD TxDOT: No comments TPWD: 20 elements of occurrence, 2015 species assessment, TXNDD, & Biotics each (38 SFs); A preliminary model has been created for this species by Tarleton. TSU: Adequate observation data to model. Recommend re-model. TXNDD data pre-existing.	TX central Texas 20 EOs;38 SFs
15	*Streptanthus bracteatus* A. Gray	bracted twistflower	Federal	Federal: Candidate (listing priority 8) State: SGCN, (G1,G2,S1,S2)	TxDOT, TPWD TxDOT: No comment TPWD: 19 elements of occurrence, 2015 species assessment, TXNDD, &22 in Biotics each (212 SFs); a preliminary model has already been created for this species; of a couple dozen sites, only 1 is on ROW. It has been suggested by a species specialist that this species is not a good species to model. TSU: Adequate observation data to model. Recommend re-model. TXNDD data pre-existing.	TX Central Texas 19 EOs;212 SFs

	Scientific Name	Common Name	Federal or State priority	Listing Status	Agency Requesting Consideration / Agency Comments	Global Range / Location in Texas
16	*Symphyotrichum puniceum* var. *scabricaule* (Shinners) G.L.Nesom Synonym: *Aster puniceus* var. *scabricaulis* (Shinners) A.G. Jones	rough-stem aster	Federal	Federal: under review State: SGCN, (G5,T2,S2)	TxDOT, TPWD TxDOT: Multiple ROW spots TPWD: 31 elements of occurrence, 2015 species assessment, TXNDD, & 25 in Biotics each (30 SFs); occurs on ROWs. TSU: Adequate observation data to model.	LA, MS, TX (Tx only on ECOS) Northeast Texas 31 EOs;30 SFs
17	*Trillium pusillum* var. *texanum* (Buckley) C.F. Reed Synonyms: *Trillium texanum* Buckley, *Trillium pusillum* Michx.,	Texas trillium	Federal	Under Federal Review State: SGCN, (G2,S2)	TxDOT, TPWD TxDOT: A few sites in or very close to ROW. This species could occur in ROW under the right conditions. I also think it would be a fairly easy species to model. TPWD: 20 elements of occurrence, 2015 species assessment, TXNDD, & 19 in Biotics each (39 SFs); has been found on 1 ROW but most sites are not on ROW. *TXNDD data collected. TSU: Adequate observation data to model.	LA, TX east Texas 20 EOs;39 SFs

Table 2 Project 0-6973 Species Considered and Not Included on the Final Species List

Scientific Name	Common Name	Federal or State priority	Listing Status	Agency Requesting Consideration / Agency Comments	Global Range / Location in Texas
Amsonia tharpii Woodson	Tharp's bluestar (synonym: Tharp blue-star)	Federal	Federal: under review State: SGCN, (G1,S1)	TxDOT, TPWD TxDOT: No comments TPWD: 1 site in TX (and on ROW) (1 element of occurrence, 2015 species assessment, TXNDD, 12 SFs in Biotics); modeled in NM only - has been shown to be difficult to model. TSU: Problematic to model with only 1 known location. TPWD indicated NM model – not able to validate with field observations	NM, TX west Texas 1 EOs; 12 SFs
Calopogon oklahomensis D.H.Goldman	Oklahoma Grass-pink		Federal: not listed State: SGCN, (G3,S1,S2)	TxDOT: Prioritized as #5 on the project alternate species list. Formerly petitioned for listing. Generally rare to uncommon throughout its range, certainly very rare in Texas. Have seen it in state ROW TPWD: No comments	AL, AR, GA, IA, IL, IN, KS, LA, MN, MO, MS, OK, SC, TN, TX, WI

Scientific Name	Common Name	Federal or State priority	Listing Status	Agency Requesting Consideration / Agency Comments	Global Range / Location in Texas
Donrichardsia macroneuron (Grout) H.A. Crum & L.E. Anderson	Don Richard's spring moss	Federal	Federal: under Review State: SGCN, (G1,S1)	TxDOT: no comments TPWD: 1 element of occurrence, 2015 species assessment, TXNDD, & Biotics each (1 SFs); only 2 known sites. TSU: Problematic to model with only 1 known location.	TX central Texas 1 EO;1 SF
Fissidens hallii Austin	Hall's Pocket Moss	Federal	Federal: under review State: not assessed (G2, SRN)	TxDOT: No comment TPWD: Recommended not to include this species. Species may come off federal list; not a good species (according to FNA, now F. amoenus and occurs into S. America) TSU: TPWD indicated species off petition list. Recommend not to model.	
Genistidium dumosum I.M.Johnst.	brush-pea (synonym: unnamed bush-pea)	Federal / State	Federal: under Review State: SGCN, (G2,S1)	TxDOT: No comments TPWD: 3 elements of occurrence, 2015 species assessment, TXNDD, & 2 in Biotics (12 SFs); 2 sites in TX; 1 on ROW. TSU: Problematic to model with only 2 known location.	TX, Mexico west Texas 2 EOs; 12 SFs

Scientific Name	**Common Name**	**Federal or State priority**	**Listing Status**	**Agency Requesting Consideration / Agency Comments**	**Global Range / Location in Texas**
Helianthus occidentalis subsp. *plantagineus* (Torr. & A.Gray) Shinners	Shinner's Sunflower	Federal	Federal: under review State: SGCN, (G5,T2,T3,S2,S3)	TxDOT: No comments TPWD: Recommended not to include this species. May be removed from Federal list due to being more common than originally thought. TSU: Adequate observation data to model.	AR, LA, TX south, central, east Texas 22 EOs; 52 SFs
Hexalectris revoluta Correll	Chisos Mountain crested coralroot (synonym: Chiso coral-root)	Federal	Federal: under review State: SGCN, (G1,G2,S1)	TxDOT: Occurs in protected sites away from ROW. Also would be a very difficult species to model based on life history/detectability TPWD: 5 elements of occurrence, 2015 species assessment, TXNDD, & Biotics each (3 SFs); all known sites at high elevations in either protected areas or inaccessible areas. Agreed – may be a difficult species to model.	TX, Mexico west Texas 5 EOs, 3 SFs

				TSU: Adequate observation data to model. Difficult to model based on TxDOT & TPWD comments.	
Scientific Name	**Common Name**	**Federal or State priority**	**Listing Status**	**Agency Requesting Consideration / Agency Comments**	**Global Range / Location in Texas**
Paronychia congesta Correll	bushy whitlow-wort	Federal	Federal: under review State: SGCN, (G1,S1)	TxDOT: No comments TPWD: 2 elements of occurrence, 2015 species assessment, TXNDD, & Biotics each (2 SFs); Only 2 known sites, 1 on ROW TSU: Problematic to model with only 2 known location.	TX south Texas 2 EOs; 2 SFs

Pediomelum pentaphyllum (L.) Rydb. Synonym: *Pediomelum pentaphyllum* (L.) J.W.Grimes	Chihuahua scurfpea	Federal	Federal: under review State: SGCN, (G1,SH)	TxDOT: No comments TPWD: 1 element of occurrence, 2015 species assessment, TXNDD, & Biotics each (1 SFs); 1 historic location in TX, if ever occurred in TX. Location may be suspect. TSU: Problematic to model with only 1 known location.	AZ, NM, TX, Mexico west Texas 1 historical EO
Scientific Name	**Common Name**	**Federal or State priority**	**Listing Status**	**Agency Requesting Consideration / Agency Comments**	**Global Range / Location in Texas**
Schoenoplectus hallii (A.Gray) S.G.Sm. Synonym: *Schoenoplectiella hallii* (A.Gray) Lye	Hall's bulrush	Federal	Federal: under review State: SGCN, (G2,G3,S1)	TxDOT: No comments TPWD: 1 element of occurrence, 2015 species assessment, TXNDD, & Biotics each (1 SFs); 1 known protected site (not on ROW). TSU: Problematic to model with only 1 known location in Texas.	GA, IA, IL, IN, KS, KY, MA, MI, MO, NE, OK, SC, TX, WI N.central Texas 1 EO; 1 SF

Spiranthes longilabris Lindl.	Giant-spiral Ladies'-tresses		Federal: N/A State: SGCN, (G3,S1)	TxDOT: Prioritized as #8 on the project alternate species list. Generally rare throughout its range (perhaps with the exception of Florida). Occurs in ROW TPWD: No comments	AL, FL, GA, LA, MS, NC, SC, TX east Texas 5 EOs;5SFs

Literature Review

We collated necessary information on all candidate species under consideration. We conducted an in-depth literature review and reported available accounts of the 17 selected species. This included a search for relevant information for developing predictive models, including environmental requirements, known plant community associations, and known locations of each plant species.

Results

The following 17 species were identified as the priority rare plants to include in the project. Information includes scientific names, common name, state and global conservation ranking, life history and physical characteristics, location information, and habitat (environmental requirements).

Agalinis calycina

Agalinis calycina Pennell, also known as Leoncita False Foxglove is in the family Scrophulariaceae. It is S1 critically imperiled in Texas and New Mexico and G1 critically imperiled globally (Morse et al. 1996). *Agalinis calycina* is an annual, surviving a single growing season. It relies on pollination and seed dispersal for reproduction. However, pollinators of the species are not well known. *A. calycina*, like other members of the genus, is hemiparasitic. *A. calycina* is commonly found with *Distichlis stricta var. spicata* as a host but is considered a facultative parasite which means it does not need a host to complete its life cycle. Although it does not need a host it has been documented that the plant grows more robust when associated with a host (Sivinski, R.C. 2011).

Agalinis calycina is described as "Annual, hemiparasitic, somewhat succulent, glabrous (except floral parts), to about 50 cm tall, with numerous divergent, ascending branches, green or purplish, drying blackish; leaves mostly opposite (especially below), linear, entire, stem leaves 2-4 cm long, 1-1.5 mm wide; inflorescences racemose, bracteate, 4 to 12-flowered, pedicels ascending, glabrous; calyx tube 5-6 mm long, campanulate, calyx lobes narrowly triangular to nearly linear, 5-15 mm long, finely puberulent within; corolla pink, 20-25 mm long, tube 17-21 mm long, lobes 3-5 mm long, rounded-truncate, ciliate, pubescent outside; stamens 4, in two pairs of unequal length, anthers and usually filaments lanate; style about 15 mm long, pubescent; fruit a capsule about as long or slightly longer than the calyx lobes, apex rounded and mucronate; seeds numerous (New Mexico Rare Plant Technical Council)."

A. calycina is found in Texas, New Mexico, and Mexico. Populations in Texas historically have been found in the Chihuahuan Desert, specifically Pecos County, Dimond Y and Leon Springs (Sivinski, R.C. 2011). It lives in wetland marshes found in arid regions known as ciénega, which are fed by springs.

Its roots are almost always saturated in alkaline water that has a relatively high salinity level. There is typically no woody vegetation in these areas (Sivinski, R.C. 2011). One of the main threats to this species is the loss of water. Heavy aquifer use has reduced the water levels in ciénegas. Human modification to the wetlands has also impacted the population of *A. calycina* (Sivinski, R.C. 2011).

Agalinis navasotensis

Agalinis navasotensis Dubrule & Canne-Hilliker, commonly known as Navasota False Foxglove is in the family Scrophulariaceae. It is endemic to Texas with known populations only occurring in Tyler and Grimes counties. It is ranked as S1 critically impaired in Texas by Nature Serve.

A. navasotensis is described as "Stems branched, 25–80 cm; branches spreading-ascending, nearly terete proximally, obtusely quadrangular-ridged distally, glabrous or scabridulous distally. Leaves proximal to mid reflexed or recurved, distal spreading; blade filiform, (11–)17–30(–40) x 0.5–1.2 mm, not fleshy, margins entire, siliceous, abaxial midvein scabridulous, adaxial surface scabridulous; axillary fascicles absent. Inflorescences racemiform-paniculate, flowers 1 or 2 per node; bracts both longer and shorter than, or shorter than, pedicels. Pedicels ascending-spreading, (2–)6–25 mm, scabridulous proximally or glabrous. Flowers: calyx funnelform-obconic, tube 2.2–4.6 mm, glabrous, lobes triangular-subulate to subulate, 0.5–1.5 mm; corolla pink to rose, with 2 yellow lines and red spots in abaxial throat, 15–24 mm, throat pilose externally and glabrous within across bases of adaxial lobes, sparsely villous at sinus, lobes spreading, 5–7 mm, equal, glabrous externally; proximal anthers parallel to filaments, distal perpendicular to filaments, pollen sacs 2–3.2 mm; style exserted, 11–15 mm. Capsules ovoid to obovoid-oblong, (4–)6–7 mm. Seeds dark brown, 0.8–2.3 mm. 2n = 26 (Canne-Hilliker, J., & Hays, J. 1993)."

The two known populations of Agalinis navasotensis grow in open areas with sandy soil. The population in Grimes County grows in full sun. A study done by T. Keeney in 1967 found the outcropping to be sandstone with large amounts of shells. The soil is sandy and shallow with a ph. range of 7.4-7.6. The population in Tyler County grows in sandy soil with little competition. Annual rainfall for the two sites ranges from 41 inches in Grimes County and 53 in Tyler County (Strong, A., and P. S. Williamson. 2015). A. navasotensis like many of the genus is an annual plant serving for only one growing season. Flowering is most likely spread by seed dispersal. One of the main threats to A. navasotensis is habitat loss and fragmentation (Strong, A., and P. S. Williamson. 2015). Navasota False Foxglove does not exhibit resilient characteristics and is likely a poor competitor.

Asclepias prostrata

Asclepias prostrata Blackwell, commonly known as Prostrate Milkweed is a member of the Apocynaceae family. It is distributed across southern Texas Starr and Zapata Counties as well as

Tamaulipas Mexico. It is considered S1 critically imperiled in Texas (Nature Serve). There are less than 10 known occurrences of Prostrate milkweed in Texas (Poole et al).

A. Prostrata is described as a "Herbaceous perennials from thick woody crowns. Stems prostrate, ca. 1-2 mm. thick, simple, 1-4 dm. long, conspicuously pilosulose distally, eventually glabrate. Leaves opposite, pseudodistichous by twisting of stems; blades triangular to deltoid-lanceolate, 15-35 mm. long, 5-20 mm. broad, basally very shallowly cordate (proximal leaves) or truncate, apically acute (or the most proximal leaves ob- tuse), marginally entire and on drying crispate, texturally mem- branous, firm, minutely pilose on both surfaces, grayish-green, dull; petioles 1-3 mm. long; stipules reduced to interpetiolar lines. Umbels axillary, ca. 5-flowered; peduncles 5-12 mm. long, pilosulose; pedicels 10-20 mm. long, ca. 0.5 mm. thick, pilosulose. Calyx-lobes lanceolate, ca. 4-5 mm. long, dorsally minutely pilosulose; corolla reflexed-rotate, greenish-white or at the tips of the lobes faintly rosy, the lobes 12-15 mm. long, narrowly obovate or broadly oblanceolate; gynostegium long-stipitate, cream-colored suffused with rose-color, the column conic, ca. 3.5 mm. long and 2 mm. broad, the hoods obovate and slightly flabellate, 7-8 mm. long, narrowed below (above the mid- point) to a spongy-solid and somewhat laminate stipe, basally with laminate auricles, the horn compressed-clavate, with an acicular mucro inflexed over the anther head, slightly shorter than the hood and wholly adnate to it, the anther head cylindrical, 4 mm. long and 4.5 mm. broad. Follicles not available in the isotypic specimen; seeds also unknown (Blackwell, W. H. 1964)".

A. prostrata prefers sand and fine sandy loams in areas void of competition. The specimen collected in Starr County was found in gravel like soil along the roadside (Correll, D. S. 1966). Prostrate milkweed is a perennial herb surviving multiple growing seasons. Blooms between the months of June and August. Blooms are often creamy white with tenges ranging from yellow to pink (Lady Bird Johnson Wildflower Center 2014). Being a weak competitor, it is highly vulnerable to invasive nonnatives such as buffelgrass (Poole et al).

Bartonia texana

Bartonia texana, commonly known as Texas Screwstem is a member of the family Gentianaceae. It can be found in Texas and Louisiana in the West Gulf Coastal Plain within Baygall communities. Texas counties consist of Angelina, Hardin, Jasper, Nacogdoches, Newton, Polk, San Augustine, San Jacinto, and Tyler (Poole et al. 2007). It is considered S2 imperiled in Texas and S1 critically imperiled in Louisiana by NatureServe. *B. texana* grows in forested areas with shade and high precipitation often in association with springs and seeps. The soil in areas found ranges from loamy sand to loamy, very fine sand with high concentrations of organic matter (Arlington, Texas Ecological Services Field Office 2017). It commonly grows elevated on liverwort and mosses that have been created through erosion.

Often times these areas are at the bases of trees and shrubs such as "*Magnolia virginiana*, *Nyssa sylvatica*, *Acer rubrum*, *ltea virginica*, *Alnus serrulata*, *Cyrilla racemiflora*, and *Ilex coriacea* (NIXON, E. S., & WARD, J. R. 1981)". Possible threats to B. texana are loss of habitat through logging, changes in water flow, and habitat damages associated with grazing (Hill 2003).

Bartonia texana is an annual plant surviving a single growing season. It flowers between mid-September to mid-November (Arlington, Texas Ecological Services Field office 2007). It is described as "a slender, erect annual plant that measures 6 to 14 inches tall. Leaves are reduced to scales and alternate, but can be positioned opposite of each other at the top of the stem. Flowers are four-lobed and arranged in clusters. The sepals are slender, awl-shaped lobes that are fused at the base. The petals are whitish, egg-shaped tapering gradually to a point or ending in a small abrupt point. The fruit is a capsule that splits at its apex to release seeds. (Arlington, Texas Ecological Services Field Office)."

Cyprus onerosus

Cyprus onerosus M.C. Johnston, commonly known as Dune Flatsedge is a member of the Cyperaceae family. It is *Cyprus onerosus* is found only in sand dunes specifically the Monahans Sandhills. They grow around permanent freshwaters ponds on the edges of the dunes (El-Hage, A., & Moulton, D. W. 1998) They can also be found in patches of wet sand in depressions in the dunes (Locklear, J.H. 2017.) *C. onerosus* is endemic to Texas found in Andrews, Winkler, and Ward counties in Western Texas sand dunes. It is considered S2 imperiled in Texas by NatureServe. Habitat loss is a major threat to *C. onerosus*. Sand-mining and off-road vehicles throughout Monahans Sandhills are causing habitat destruction. Water exploitation is also becoming a threat as the water sources for the plant to grow in dunes begin to deplete. (Poole, J. M., & Maybury. 1984)

Dune Flatsedge is a perennial plant persisting for multiple growing seasons. Fruiting occurs from May to June. It is described as "Glabrous, yellowish-green, rhizomatous perennials; roots fibrous, reddish-brown; rhizomes 1-2 mm. thick, 5-80 mm. long, with a brown fibrous covering or usually with brown, lanceolate scales 6-13 mm. long; aerial culms solitary or in few-culmed tufts along the rhizome, 30-49 cm. long below the inflorescence, erect, 1.5-4 mm. broad across each of the flat sides, sharply triquetrous (the angles smooth, minutely cartilagi- nous); leaves mostly crowded at the base, 15-40 cm. long, sheaths not sharply differentiated, 6-14 mm. broad and often brownish basally, tapering gradually upward and becoming pallid-stramineous, firm-membranous (marginally very thin and erose-hyaline), striate-veined (transverse venation absent); blades 6-8 mm. broad basally, yellowish green, long-tapered to a narrow point, membranous, minutely striate-veined; bracts ca. 4, blade-like, the lowest one 11-22 cm. long, exceeding the inflorescence, the others much reduced, the midrib of the lowest bract minutely antrorsely scabrellate; inflorescence compound, of 7 to 15 primary, obscurely trique- trous branches 2-11 cm. long, the shorter of these bearing 3 to 5 head-like glomerules of spikelets or the longer bearing 3 to 12 branchlets 2-25 mm. long and these bear- ing 3 to 5 head-like glom-rules of spikelets; glomerules with 8 to 16 spikelets; spikelets linear with 10 to 42 (usually 16 to 26 when mature) flowers; rachilla wingless, its internodes ca. 0.3-0.4 mm. long; spikelets occasionally proliferous (Rowell 60-072); scales conspicuously distichous, much overlapping, ovate-elliptic, slightly acuminate (the acumen straight or usually slightly bowed outward), 2.3- 2.9 mm. long, 1.2-1.4 mm. broad (when unfolded), medially strongly green-ribbed, laterally thin, colorless and translucent, eventually in a narrow zone near the midrib becoming brown or reddish brown, on each side with 2 (rarely 3) nerves which dissipate before reaching the distal margin (or one occasionally stronger and fully acrodrome), the scales eventually turning brownish and mostly opaque and falling individually from the rachilla; florets strongly protandrous; stamens 3, filaments flattened, whitish, ca. 2 mm. long; anthers ca. 1.2-1.5 mm. long, versatile; ovary narrowly elliptic-trigonous; style 0.8-1 mm. long with 3 filiform branches ca. 2 mm. long; achene elliptic to narrowly elliptic, acuminate at both ends, 0.7- 0.8 mm. long, 0.25-0.3 mm. thick, trigonous, whitish or eventually turning pallid brownish, shiny (Johnston, M. C. 1964)."

Eriocaulon koernickianum

Eriocaulon koernickianum Van Heurck & Mueller-Argau, commonly known as Dwarf pipewort is a member of the Ericaulaceae family. *E. koernickianum* is distributed across multiple states in the lower 48 including Arkansas, Oklahoma, Georgia and Texas (MacRoberts & MacRoberts, 2005). In Texas E. koernickianum is found in East Texas with one disjunct population in central Texas. MacRoberts' study found the presence of E. koernickianum in five counties including Anderson, Gillespie, Henderson, Limestone, and Van Zandt (2005). Its preferred Habitat consists of areas with high moisture content such as bogs, wetland pine savannas, and sites with seepage from uphill. Preferred soil type consists of sandy, acidic soils with a PH between 4-5. These soils were also found to be low in nutrient values (MacRoberts & MacRoberts, 2005). Studies have shown that *E. koernickianum* is a poor competitor, preferring sites with no shade or encroachment from woody or herbaceous plants (Watson et. al). Natural disturbances such as fire and animal activity are key components in the production of suitable habitat. Fire has served as a competition reducer; and fire suppression in recent years have been one of the contributing factors for the decline of the species *E. koernickianum* (MacRoberts & MacRoberts, 2005). Disturbance from animals such as light rooting from feral hogs was beneficial. However, areas of heavy rooting had a negative impact on the populations (MacRoberts & MacRoberts, 2005). E. koernickianum is imperiled in Texas, Arkansas, Oklahoma, and Georgia (Ogle et al., 1996).

Eriocaulon koernickianum is considered an annual or weak perennial and does not expand through vegetative means such as runners or rhizomes. This means seed growth and dispersal is vital for maintaining and growing populations. However, Watson et al. studied the reproductive biology of *E. koernickianum* on sites in Oklahoma and found that the seeds set within the species are relatively low between 40-60% (Watson et al. 1994). The issue of seed setting was not caused by enviable pollen because testing found that 90% of pollen grains to be viable. The issue of low seed set may reside with pollination. The pollination methods are relatively unknown, during their study no pollinating animals were noted and they concluded that self-pollination is highly unlikely (Watson et al. 1994). The positive correlation between disturbances and improved abundance of *E. koernickianum* may have something to do with pollination as well as reduced competition. However, further research would have to be done in order to conclude this hypothesis. The presence of *E. koernickianum* in the seed bank was conflicting between two studies. In Watson et al. their study found that there were few seeds in the seed bank and attempted germination of the seeds was relatively unsuccessful (1994). In contrast MacRoberts study indicated a viable seed bank on a site in Gus Engeling Wildlife Management Area (2005). Can be flowering from spring till early fall (eFloras).

It is described as "Herbs, perennial, 5--8 cm. Leaves linear-attenuate, 2--5 cm, apex subulate to blunt. Inflorescences: scape sheaths as long as leaves, inflated; scapes filiform, 0.5 mm wide, 3--4-ribbed; heads dark gray or gray-green with rims of bracts and perianth pale, nearly globose or short-oblong, 3--4 mm wide, soft; receptacle glabrous; outer involucral bracts usually not reflexed, not obscured by bracteoles and perianth, straw-colored, very lustrous, broadly oblong to suborbiculate, 1--1.25 mm, margins nearly entire, apex rounded, glabrous; inner bracts, receptacular bracteoles dark gray, gray-green, or gray-brown, very lustrous, oblong to cuneate, obliquely keeled, 1.5 mm, margins slightly erose, apex acute to obtuse, apiculate, with a few white, club-shaped hairs. Staminate flowers: sepals 2, grayish, linear-curvate, 1--1.5 mm, apex with a few white, club-shaped hairs abaxially, marginally; androphore broadly club-shaped; petals 2, low, toothlike, nearly equal, apex with club-shaped hairs; stamens 4; anthers black. Pistillate flowers: sepals 2, gray, linear-curvate, 1 mm, apex with scattered hairs abaxially, hairs pale, club-shaped, otherwise glabrous; petals 2, yellow-white, stipitate, broadly suborbiculate-rhombic, 1 mm, apex with white, club-shaped hairs abaxially; pistil 2-carpellate. Seeds deep reddish brown, broadly ovoid or ellipsoid, 0.5 mm, often indistinctly reticulate or rugulose, papillate (eFlora)."

Isoetes lithophila

Isoetes lithophila N.E. Pfeiffer, commonly known as Rock quillwort is a member of the Isoetaceae family. *I. lithophila* is an endemic species to the Edwards Plateau. With only a few populations known spread out across four counties (Strong A. 2017). It has a very specific habitat, growing in pools of water formed in granite outcroppings called vernal pools (Strong A. 2017). Rock quillwort is a perennial species persisting for multiple generations. It reproduces through spores produced during the late winter to spring. When the pools dry up rock quillwort will die back (Strong A. 2017). It is described as "Leaves deciduous, bright green, pale toward base, spirally arranged, to 12(--20) cm, pliant, gradually tapering to tip. Velum covering entire sporangium. Sporangium wall unpigmented. Megaspores light gray to gray-brown, 290--360 µm diam., obscurely rugulate with low ridges; girdle obscure. Microspores brown in mass, 30--33 µm, tuberculate to spinulose (Flora of North America)". It is considered S1 critically imperiled in Texas according to NatureServe. *I. lithophila* is considered a weak competitor and is likely threatened by habitat loss.

Lepidospartum burgessii

Lepidospartum burgessii B.L. Turner, commonly known as Burgess' broomsage is a member of the Asteraceae family. "Gypsum scalebroom is a woody shrub with numerous stems growing up to 1.2 m tall. The stems have multiple branches and are covered with silvery, matted, felt-like hairs out of which protrude numerous small oil blisters. The leaves are needlelike, alternate, and 5 to 12 mm long. There are three or four terminal flower heads on stems with three, rarely four, bright yellow flowers per head. The achenes are covered by dense white hairs and topped by a pappus of many slender bristles (Ladyman and Gegick 2001)".

Populations of *L. burgessii* have been in the northern edge of the Chihuahuan desert. This includes far west Texas and Otero County NM. Burgess' broomsage grows on both stable and mobile gypsum soil. Precipitation is often sparse in arid regions. Temperatures also fluctuate greatly between winter and summer. One note of concern for the species with regards to habitat made by Ladyman and Gegick is the drop in ground water levels. The lowering of groundwater levels from crop irrigation and other agricultural practices could be a cause of the population decline (Ladyman and Gegick 2001). *L. burgessii* is a perennial plant surviving multiple growing seasons. Flowers are pink, blooming occurs most commonly between July and September. Reproduction occurs through clonal propagation. Ladyman and Gegick attempted propagation of seeds but were unsuccessful and seeds did not appear to produce new individual in the wild.

L. burgessii is considered S1 critically imperiled in both Texas and New Mexico according to NatureServe. Ladyman and Gegick identified three possible threats to the species, loss of groundwater, Tingidae wasps, and the fungus Alternaria. Tingidae wasps were noted to infest L. burgessii and cause dieback of the stems. Alternia was noted to affect the flowers and seeds (Ladyman and Gegick 2001). The degree to which the wasps and fungus affect the population is unknown. However, coupled with the lowering of the groundwater levels are possible factors in the decline of the species.

Liatris cymose

Liatris cymose (H. Ness) K. Schum, commonly known as Aggie-land Gayfeather, Branched Gayfeather, and Branched Blazingstar is a member of the Asteraceae family. Branched Gayfeather was described by H. Ness in 1899 in the bulletin of the Torrey Botanical Club. H. Ness's description is as followed "Perennial from globular or oblong tuberous root 1-2 cm. in. diameter: stem slender, erect, rigid, 35-45 cm. high, corymbose branched above, leafy puberulent throughout : leaves smoothish and minutely punctate; the radical and lower cauline 15-20 cm. long and 1-1.5 cm. wide, lanceolate and tapering at the base to a clasping petiole ; the upper sessile, linear, and gradually smaller :inflorescence a simple or, on stronger specimens, a compound cyme; heads about 25 mm. high, with about 20 purplish-red or pale-purplish flowers ; involucre about 2 cm. long, oblong-cylindrical ; scales numerous, closely imbricated in about six series, puberulent and ciliate-margined, with rounded or almost truncate, appressed, and often slightly mucronate apices ; the outer orbicular to oblong; the inner oblong to linear with dark-purplish tips : pappus purplish, plumose, shorter than corolla-tube, but about equal to the achenes ; the corolla about 1 5 mm. long, smooth inside, with lanceolate, obtusish spreading teeth; stamens included, with the usual notched terminal appendages ; style exserted, the branches flat, dilated upwards, and several times longer than the short purple-colored stigmatic lines ; achenes oblong, about 8 mm. long, 10-ribbed, hispid on the ribs (Ness, H. 1899)." Blooms from July through October.

L. cymose is a Texas endemic and found in several counties around Bryan in east Texas. Known counties of occurrence are Brazos, Walkere, and Washington (Brown et al. 1985). It is found within post oak savannas in barren grassy openings. Soil associated clay loam, chalky, or gravel like soils (Brown et al. 1985). It is considered S2 imperiled by NatureServe. Possible threats include sevelopment of farmlands, fields, and urban growth (Brown et al. 1985).

Osmorhiza mexicana ssp. bipatriata

Osmorhiza mexicana ssp. *Bipatriata*, commonly known as Livermore Sweet-cicely is a member of the family Apiaceae. *O. bipatriata* is a perennial species lasting for multiple growing seasons. Recruitment occurs most likely through seed dispersal but not much is known. Flowering occurs between June and July (Lowry, P. P., & Jones, A. G. 1984).The only location *O. bipatriata* is found in Texas is in the Davis Mountains. Other populations have been noted in the Mexico states of Nuevo Leon and Coahuila, as well as Mt. Livermore. The species, *mexicana*, has a much broader range from Texas all the way down to Argentina (Poole, J., & Texas Parks and Wildlife. 1997). With that in mind there is a possibility of other populations of *bipatriata* that have not been found. Specimens from the Davis Mountains were found at elevations between 2,100 and 2750 meters in shaded ravines (Lowry, P. P., & Jones, A. G. 1984). *O. bipatriata* is considered S1 critically imperiled in Texas by NatureServe.

Sweet-cicely is described as “Plants slender, 2-7 dm high; stems sparingly hirsutulous to glabrescent. Root system some- what shallow, with a weak anise-like scent. Leaves 2-3-ternate, ovate to broadly ovate, 4-10(-14) cm long, villous or pilose, especially on the veins below; leaflets ovate to ovate-oblong, (0.7-)1.2- 4 cm long, 0.5-3 cm wide, acute to acuminate, coarsely serrate-laciniate to lobed or divided at the base; petioles 4-10(-12) cm long. Umbels loose and rather open; peduncles 1-3, terminal and often lateral, 3-15(-18) cm long; involucre wanting, or often composed of 1(-2) linear, foliaceous, ciliate bracts, each 4-10 mm long, 0.5- 0.8 mm wide; rays spreading-ascending, (1.4-) 1.6-6.5 (-7.5) cm long; umbellets (2-)3-9 per umbel, (0-) 1-4(-6) of them producing only staminate flowers; involucel of 1-4 linear, acuminate, ciliate bractlets, each (2-)3-4.5 mm long, 0.3-1 mm wide, spreading; pedicels (3-)4-20 (-22) per hermaphrodite umbellet, (3-)4-17 per staminate umbellet, spreading, those of the her-maphrodite flowers (3-)4-7.5(-8) mm long, those of the staminate flowers (1.5-)2-3.5(-4) mm long. Hermaphrodite flowers 1-3 per umbellet, (2-)5- 10 per umbel, staminate flowers (4-)6-21 per hermaphrodite umbellet, (33-)40-70(-125) per umbel; corolla white, or sometimes tinged with purple, pink, or green, rather inconspicuous; styles (including stylopodium) 0.5-0.75 mm long, stylopodium 0.25-0.3 mm long, low-conic, often with a conspicuous disc. Fruit linear-fusiform, tapering into a short beak at the apex, concave furrowed, 9-11 (-12) mm long, the ribs glabrous, or with a few retrorse bristles at the base, the caudate appendages lacking, or sometimes to 1.8 mm long (Lowry, P. P., & Jones, A. G. 1984).”

Physostegia correllii

Physostegia correllii (Lundell) Shinners commonly known as Correll’s false dragonhead. It is distributed in Texas, Louisiana, and northern Mexico. *P. correllii* has been documented to grow in 6 to 10 counties in Texas. Most recent documentations have been in Travis County at Lady Bird Lake (Arlington). Correll’s false dragonhead is considered imperiled in Texas and critically imperiled in Louisiana by NatureServe.

P. correllii is a perennial plant that can live for several years. Spreading occurs through Rhizomes and seeds. The obedient plant family relies on bees for pollination (Arlington). Studies have shown that P. correllii prefers newly deposited sediment on streams with little to no overhead shading or ground competition for establishment (Williams et al.). *P. correllii* can grow up to a meter or more in height. Leaves are dark green, elliptical in shape, often serrated and sessile. The inflorescence ranges in color from purple to pink in a pike arrangement (Almost Eden Plants). Found in riparian zones as well as along irrigation ditches and roads. Mainly occurring on the edges of streams and rivers. Soil preference of P. correllii is “silty sediment, gravel, bedrock, sand, concrete, or decomposed organic compounds (Arlington)”. Early establishment of False dragon heads are associated with fresh sediment deposits along streams and rivers with little to no shade or competition. Older colonies can be found in more compact soil with surrounding vegetation. However, surveys have found that heavy canopy cover and dense surrounding vegetation causes a decline in health and colony size. (Williams et al.) This makes P. correllii an early stabilizer of banks after a flood or disturbance. Flowering occurs between the months of June and September. (TWC staff).

Physostegia longisepala

Physostegia longisepala Cantino, commonly known as Long-sepal Dragonhead, is a member of the Lamiaceae family. It is found in Eastern Texas including Hardin, Jasper, Jefferson, Newton, Orange and Tyler County. As well as southwestern Louisiana along the gulf coast (Singhurst, J. R. 1996). *P. longisepala* is perennial persisting for multiple growing seasons. Recruitment occurs through seeds and rhizomes. Blooms are lavender to red with purple dots on the inside. Flowering occurs during June and July (Singhurst, J. R. 1996).

P. longisepala has been found growing in poorly drained soils but does not prefer standing water. Areas such as between coastal prairies and pine forests seem to be the current area of preference. It is speculated this species grew in the interior of the forest but lacked the ability to compete. *P. longisepala* has also been found in areas with disturbance that mimics the edge habitat such as road ditches, canals, and powerlines (Singhurst, J. R. 1996). Long-sepal Dragonhead is described as "Erect perennial herbs to 1 m high, with 9-15 nodes below the inflorescence. Primary rhizome branching to produce 1-many elongate, horizontal secondary rhizomes up to at least 15 cm long. Lowest 4-8 pairs of stem leaves petiolate and frequently still present at anthesis; petiole up to 3.5 cm long; blade of petiolate leaves 5-8 cm long, 1-1.5 cm wide, elliptical, oblong, or oblanceolate, base cuneate to attenuate, apex obtuse to acute, margin repand or with a few widely spaced blunt teeth. Sessile leaves of central part of stem 5-12 cm long, 0.5-1.7 cm wide, elliptical to oblanceolate downwards on stem and elliptical to lanceolate upwards, base attenuate to cuneate downwards on stem and rounded to auriculate upwards, most leaves clasping the stem, apex usually acute to attenuate, margin repand, bluntly toothed, or serrate, Upper stem leaves moderately to greatly reduced in size over central leaves (those of second pair below the terminal raceme 2.7-6 cm long and three-tenths as long as to about half as long as the internode directly above), lanceolate to elliptical, often widest near the clasping base of the blade. Flowers borne in 1-7 racemes, raceme axis densely pubescent, some (usually many) of the trichomes 0.15-0.25 mm long; floral bract, lanceolate, attenuate, (3-)4-6(-7) mm long, 1-2 mm wide; flowers 23-32 mm long, loosely tó tightly spaced. Calyx not conspicuously glandular-punctate, lacking stalked glands, tube at anthesis 4-8 mm long, calyx at fruit maturity 7.5-10 mm long. Corolla deep lavender to reddish violet, spotted or streaked inside with purple, puberulent or tomentulose to subglabrous. Nutlets (few available) 3-3.3 mm long, surface smooth (Cantino, P. D. 1982)."

Rayjacksonia aurea

Rayjacksonia aurea (Gray) R.L. Hartman & M.A. Lane, commonly known as Houston Camphor-daisy or Houston tansyaster is a member of the Asteraceae family. Houston Camphor-daisy is Texas endemic, which historically has been found in Houston and Galveston Counties (Poole et al. 1996). It is considered a pioneer species preferring areas mostly void of competition such as roadsides and prairie openings. Soil preferences include but are not limited to Gessner loam, Wockley fine sand loam, and Clodine loam (Mahler, WM. F. 1981). *R. aurea* is an annual persisting for a single growing season. Blooms are yellow with flowering occurring between October and December. It is described as "20–100 cm, herbaceous. Leaf blades linear to linear-oblanceolate, mid-cauline 1–3(–4) mm wide. Heads on short, sometimes bracteate peduncles, not surpassed by distal leaves. Involucres 4–7 × 10–15 mm. Phyllaries in 4–5 series, tightly appressed, strongly unequal, apices erect to slightly spreading, ca. 1 mm wide, herbaceous. Ray florets 14–19; corollas 6.5–9.5 mm. Disc florets: corolla tubes ± equaling limbs. 2n = 12 (eFlora)".

Houston Camphor-daisy is considered critically imperiled in Texas by NatureServe. Threats consist of development around the Houston area and invasive species. Being a pioneer species make it a poor competitor during later successional stages (Poole et al. 1996).

Salvia pentstemonoides

Salvia pentstemonoides Kunth & Bouché, orth. var. is commonly known as Big Red Sage, is a member of the Lamiaceae family. Big Red Sage is a robust perennial that grows up to 48in tall and 36in wide. "It is noted for its long summer bloom of tube-shaped, 2-lipped, dark rose-red to burgundy-red flowers (each to 1 1/2" long) that bloom in spikes atop stiff stems typically growing 3' (less frequently to 5') tall (Salvia pentstemonoides)". Flowers grow 1.5-2in long growing in a raceme arrangement (Laura). Endemic to the Edwards Plateau it prefers moist soils such as banks of streams in limestone outcrops, drainage areas, and seepage slopes. Grows in soil composition such as medium loam, clay loam, Limestone based and Calcareous (Poole et al). Can withstand a wide range of PH in the soil but prefers a PH greater than 7.2. Big sage grows best in partial sunlight, however with enough moisture can withstand full sun (Plant Database). Blooming occurs from June to October and provide food for butterflies and hummingbirds (Plant database). It is considered critically imperiled in Texas; however it has had considerable success being grown in gardens (Poole et al).

Streptanthus bracteatus

Streptanthus bracteatus Gray, commonly known as Bracted Twistflower, is a member of the family Brassicaceae. It is described as "Annuals or biennials; (glaucous); usually glabrous, (sometimes pedicels pubescent). Stems often branched distally, (2.3-) 4.5-12 dm. Basal leaves not rosulate; long-petiolate; blade oblanceolate to spatulate, 5-25 cm, margins laterally lobed to irregularly dentate. Cauline leaves: blade oblong to ovate, 3-15 cm × 15-80 mm (smaller distally as bracts), base auriculate to amplexicaul, margins entire or shallowly dentate. Racemes bracteate throughout, (proximal most bracts leaflike, distalmost much reduced). Fruiting pedicels divaricate-ascending, 7-19 mm, (glabrous or puberulent). Flowers: calyx campanulate; sepals (ascending to suberect), 8-12 mm, (not saccate basally), not keeled, (inner pair apiculate); petals purplish, 14-19 mm, blade 7-12 × 5-7 mm, margins not crisped, claw 6-8 mm, (slender), much narrower than blade; stamens tetradynamous; filaments: median pairs (distinct), 6-8 mm, lateral pair 4-6 mm; anthers (all) fertile, 4-6 mm; gynophore 1-2 mm. Fruits divaricate ascending, smooth, straight, flattened, 8-14.5 cm × 2.5-4 mm; valves each with prominent midvein; replum straight; ovules 48-80 per ovary; style 1-3.5 mm; stigma 2-lobed. Seeds oblong, 3-4 × 2-3 mm; wing 0.5-0.7 mm wide at apex, continuous (eFlora)".

S. bracteatus is an annual plant persisting for a single growing season. Blooming occurs from May through July. Blooms are a lavender color with alternating purple sepals. The bee species Megachile comata has been observed pollinating *S. bracteatus*. Seed dispersal is the main method for recruitment (Dieringer, G. 1991). *S. bracteatus* is found growing in the shade of oaks and junipers with some form of protection often given by undergrowth like shrubs (Dieringer, G. 1991). However in a recent study they found that *S. bracteatus* grows better in less shaded and covered areas. This implies that the species has had to settle for less optimal habitat in order to avoid predation or destruction of some form (Fowler, N.L., Center, A., Ramsey, E.A. 2012). Soils are often associated with limestone including well drained gravelly clays and clay loams (Dieringer, G. 1991).

Bracted Twistflower is endemic to the Texas hill country specifically Medina, Travis, and Uvalde Counties with only 15 known populations (Dieringer, G. 1991). It is considered S1 critically imperiled by NatureServe. Suppression of fire is considered a likely factor in the decline of this species; because they are being outcompeted by perennials that would normally be held back by frequent fires (Fowler, N.L., Center, A., Ramsey, E.A. 2012).

Symphyotrichum puniceum

Symphyotrichum puniceum* var. *scabricaule (Shinners) Nesom, commonly known as Purple-stem Aster, is a member of the family Asteraceae. It is described as "100–250(–300) cm. Stems usually densely and uniformly hirsute, sometimes less so and in lines distally. Leaves: faces ± con-colorous, without dark, distinct reticulum, adaxial with distinctly impressed main veins (giving rough appearance); array leaves reduced in size relative to mid cauline. 2n = 16 (eFloras. 2008)." Found in east Texas seepage bogs (Martinez, M. 1997). Flowering occurs from September through November.

Most populations of the species are found in east Texas bogs with possible occurrences in LA, MS, and AL (eFloras 2008). Sources varied between a Texas endemic and possibly being found in these other states. It is considered S1 critically imperiled in the state of Texas. No ranking has been established for LA, MS, or AL. Possible threats are the destruction of bogs and change in water flow in the low-lying wetlands where this species is found (Martinez, M. 1997).

Trillium pusillum var. texanum

Commonly known as Texas Trillium, is a member of the family Liliaceae. Texas Trillium has white to light pink flowers. As a member of the Liliaceae family it has no leaves but 3 brackets beneath the flowers. Texas Trillium is a low growing flow that utilizes rhizomes to create colonies. "It is the only trillium species in Texas with numerous stomata (specialized cells which open and close to regulate gas and water movement into/out of the plant) on upper and lower surfaces of its bracts Arlington." "Scapes 10-30 cm tall. Bracts leaflike, subsessile to shortly petiolate, narrowly elliptic to lanceolate to oblanceolate, 6-8 x 1.3-1.9 cm; apices obtuse to rounded. Flowers borne on pedicels 2-4 cm long, odor, if present, not known; sepals lanceolate to narrowly elliptic, 1.7-3.0 x 0.35-0.7 cm, usually ca. one-fourth longer than the petals, ascending to horizontal, green; petals narrowly lanceolate to lanceolate, white, fading to pink to reddish in age, 2.0-2.6 x 0.5-0.9 cm, apices acute to acuminate. Ovaries with distinct styles about as long as the ovaries; stigmas about as long as the styles. Fruit trianguloid-ovoid, 6-ridged at the apex (near the persistent styles)" (Singhurst et al.). The Species Trillium pusillum has several subvarieties. Studies show that differentiation among the varieties can be done through the examination of pollen grains. Trillium pusillum var. texanum has the smallest pollen grain of the species T. pusillum (Timmerman-Erskine et al). Texas Trillium is a perennial monocot (Trillium texanum Buckley). Reproduction occurs mainly through rhizomes. Flowering occurs from March through April (Factsheet US).

Texas Trillium grows in forested areas with high levels of moisture. Found mostly in far east Texas and western Louisiana. Considered diminutive it grows and flowers before most of the surrounding vegetation. Trillium is susceptible to competition from more vigorous plants such as Japanese honeysuckle and Chinese privet (Factsheet LA). It "occurs across thirteen counties in East Texas and into northwestern Louisiana (Caddo Parish). In Texas, twenty sites have been recorded across at least 6,000 square miles" (Arlington). *Trillium pusillum* var. *texanum* is considered imperiled in Texas and Louisiana by NatureServe.

References

Almost Eden Plants. "Correll's False Dragonhead, Obedient Plant". Available https://www.almostedenplants.com/shopping/products/10236-corrells-false-dragonhead-obedientplant/#:~:text=Like%20most%20other%20Physostegias%2C%20Correll's,dark%20purple%20to

Arlington, Texas Ecological Services Field Office. (2017, August). *Texas screwstem*. Texas screwstem - US Fish and Wildlife Service. Retrieved October 6, 2021, from https://www.fws.gov/southwest/es/arlingtontexas/pdf/Texas%20Screwstem_Fact%20Sheet_20170926.pdf.

Arlington, Texas Ecological Services Field Office. (n.d.). *Correll's False Dragonhead*. Retrieved September 30, 2021.

Arlington, Texas Ecological Services Field Office. (n.d.). *Texas Trillium*. Retrieved September 30, 2021.

Blackwell, W. H. (1964). Synopsis of the 23 Species of Asclepias (Asclepiadaceae) in Tamaulipas and Nuevo Leon Including Two New Species, Asclepias Bifida and Asclepias Prostrata. *The Southwestern Naturalist*, *9*(3), 171–180. https://doi.org/10.2307/3669574

Brown, B. A., Tomaino, A., & Strong, A. (1985). NatureServe Explorer 2.0. Retrieved October 23, 2021, from https://explorer.natureserve.org/Taxon/ELEMENT_GLOBAL.2.161715/Streptanthus_bracteatus.

Brown, B., Poole, Maybury, & Morse, L. (1985, January 31). NatureServe Explorer 2.0. Retrieved October 18, 2021, from https://explorer.natureserve.org/Taxon/ELEMENT_GLOBAL.2.133975/Liatris_cymosa.

Canne-Hilliker, J., & Hays, J. (1993). *Agalinis navasotensis*. Flora of North America. Retrieved October 22, 2021, from http://beta.floranorthamerica.org/Agalinis.

Canne-Hilliker, J.M., and M.L. Dubrule. (1993). A new species of Agalinis (Scrophulariaceae) from Grimes County, Texas. Sida 15(3): 425-440.

Cantino, P. D. (1982). A MONOGRAPH OF THE GENUS PHYSOSTEGIA (LABIATAE). Contributions from the Gray Herbarium of Harvard University, 211, 1–105. http://www.jstor.org/stable/41764739

Cardinale, B.J., Srivastava, D.S., Duffy, J.E., Wright, J.P., Downing, A.L., Sankaran, M. and C. Jouseau (2006). Effects of biodiversity on the functioning of trophic groups and ecosystems. Nature 443: 989-992.

Convention on Biological Diversity (CBD). (2020). Zero Draft of post-2020 biodiversity framework, Secretariat of the Convention on Biological Diversity, CBD/WG2020/2/3. Kunming, China.

Correll, D. S. (1966). Some Additions and Corrections to the Flora of Texas-II. *Brittonia*, *18*(4), 306–310. https://doi.org/10.2307/2805147

Dieringer, G. (1991). Pollination Ecology of *Streptanthus bracteatus* (Brassicaceae): A Rare Central Texas Endemic. The Southwestern Naturalist 36(3): 341–343. https://doi.org/10.2307/3671686

Duffy, J.E. (2009). Why Biodiversity is important to the functioning of real-world ecosystems. Frontiers in Ecology and the Environment 7(8): 437-444.

eFloras (2008). Published on the Internet http://www.efloras.org [accessed 23 October 20021] Missouri Botanical Garden, St. Louis, MO & Harvard University Herbaria, Cambridge, MA

eFloras. (n.d.). *Eriocaulon koernickianum in Flora of North America*. Flora of North America. http://www.efloras.org/florataxon.aspx?flora_id=1&taxon_id=222000064.

El-Hage, A., & Moulton, D. W. (1998, October). Evaluation of Selected Natural Resources in Parts of Loving, Pecos, Reeves, Ward, and Winkler Counties, Texas. Retrieved October 22, 2021, from https://tpwd.texas.gov/publications/pwdpubs/media/pwd_rp_t3200_1050c.pdf.

Flora of North America. (n.d.). *Rock quillwort* . Isoëtes lithophila in Flora of North America @ efloras.org. Retrieved October 12, 2021, from http://www.efloras.org/florataxon.aspx?flora_id=1&taxon_id=250076858.

Fowler, N.L., Center, A. & Ramsey, E.A. (2012) Streptanthus bracteatus (Brassicaceae), a rare annual woodland forb, thrives in less cover: evidence of a vanished habitat?. Plant Ecol 213: 1511–1523. https://doi.org/10.1007/s11258-012-0109-2

Hill, S. (2003). Conservation assessment for twining screwstem (Bartonia paniculata) (Michx.) Muhl. USDA Forest Service, Eastern Region. http://beta.floranorthamerica.org/Agalinis_navasotensis

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem services (IPBES). (2018). In: The IPBES assessment report on land degradation and restoration. Secretariat of the

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Bonn, Germany, p. 744.

Johnston, M. C. (1964). Cyperus Onerosus M. C. Johnston, Sp. Nov. *The Southwestern Naturalist*, *9*(4), 308–310. https://doi.org/10.2307/3669700

Keeney, T.M. (1967). Flora and ecological relationships of the easternmost extension of the Oakville Formation of Texas. M.A. thesis, Sam Houston State Collage.

Lady Bird Johnson Wildflower Center. (2014). *Asclepias prostrata*. Plant Database . Retrieved October 5, 2021, from https://www.wildflower.org/plants/result.php?id_plant=ASPR9.

Ladyman, J.A.R. and Patricia Gegick. (2001). Status of Lepidospartum Burgessii (Burgess broomshrub or gypsum broomscale). In: Southwestern Rare and Endangered Plants. Proceedings of Third Conference. RMRS-P-23. USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO. p. 116-127.

Laura. (2016, September 5). *Salvia penstemonoides, big Red Sage*. N. Central Chapter NPSOT. https://www.txnativeplants.org/salvia-penstemonoides-big-red-sage/.

Locklear, J. H. (2017). ENDEMIC PLANTS OF THE CENTRAL GRASSLAND OF NORTH AMERICA: DISTRIBUTION, ECOLOGY, AND CONSERVATION STATUS. Journal of the Botanical Research Institute of Texas, 11(1): 193–234. https://www.jstor.org/stable/26549465

Loreau, M., Naeem, S. & Inchausti, P. (eds.) (2002). Biodiversity and Ecosystem Functioning. Synthesis and Perspectives. Oxford University Press, Oxford, UK.

Lowry, P. P., & Jones, A. G. (1984). Systematics of Osmorhiza Raf. (Apiaceae: Apioideae). Annals of the Missouri Botanical Garden, 71(4), 1128–1171. https://doi.org/10.2307/2399249

MacRoberts, M. H., & MacRoberts, B. R. (2005). Status and management of *Eriocaulon koernickianum* (Eriocaulaceae) in Texas. *Phytologia 87*(3): 179–203. https://www.biodiversitylibrary.org/page/12995371#page/42/mode/1up.

Mahler, WM. F. (1981). NOTES ON RARE TEXAS AND OKLAHOMA PLANTS. SIDA, Contributions to Botany, 9(1), 76–86. http://www.jstor.org/stable/41966589

Martinez, M. (1997). *Symphyotrichum puniceum var. scabricaule*. NatureServe Explorer 2.0. Retrieved October 23, 2021, from https://explorer.natureserve.org/Taxon/ELEMENT_GLOBAL.2.138241/Symphyotrichum_puniceum_var_scabricaule.

Morse, L. E., Carr, B., & Poole, J. (1996). Agalinis calycina. Retrieved October 3, 2021, from https://explorer.natureserve.org/Taxon/ELEMENT_GLOBAL.2.137626/Agalinis_calycina.

Mouillot, D., D. R. Bellwood, C. Baraloto, J. Chave, R. Galzin, M. Harmelin-Vivien, M. Kulbicki, S. Lavergne, S. Lavorel & N. Mouquet (2013) Rare species support vulnerable functions in high-diversity ecosystems. *PLoS biology,* 11**,** e1001569.

Ness, H. (1899). A new species of Laciniaria. Bull. Torrey Botanical Club 26: 21-22

New Mexico Rare Plant Technical Council. (1999). New Mexico Rare Plants. Albuquerque, NM: New Mexico Rare Plants Home Page. https://nmrareplants.unm.edu (Latest update: 03 Oct 2021)

Nixon, E. S., & Ward, J. R. (1981). DISTRIBUTION OF “SCHOENOLIRION WRIGHTII” (LILIACEAE) AND “BARTONIA TEXANA” (GENTIANACEAE). *SIDA, Contributions to Botany*, *9*(1), 64–69. http://www.jstor.org/stable/41966587

Ogle, Y., Maybury, K., Logan, J., & Gravuer, K. (1996, January 22). *Eriocaulon koernickianum*. https://explorer.natureserve.org/Taxon/ELEMENT_GLOBAL.2.152415/Eriocaulon_koernickianum.

Phillips, T., Reid, C., & Singhurst, J. (2006, November 16). *Physostegia longisepala*. NatureServe Explorer 2.0. Retrieved October 20, 2021, from https://explorer.natureserve.org/Taxon/ELEMENT_GLOBAL.2.129193/Physostegia_longisepala.

Plant database. Lady Bird Johnson Wildflower Center - The University of Texas at Austin. (2014, July). https://www.wildflower.org/plants/result.php?id_plant=SAPE15.

Poole, J. M., & Maybury. (1984, September 27). *Cyperus onerosus*. NatureServe Explorer 2.0. Retrieved October 22, 2021, from https://explorer.natureserve.org/Taxon/ELEMENT_GLOBAL.2.133286/Cyperus_onerosus

Poole, J. M., W. R. Carr, D. M. Price and J. R. Singhurst. (2007). Rare plants of Texas. Texas A & M University Press. College Station, Texas. 640 pp.

Poole, J., & Texas Parks and Wildlife. (1997, December 1). *Osmorhiza mexicana ssp. bipatriata*. NatureServe Explorer 2.0. Retrieved October 20, 2021, from https://explorer.natureserve.org/Taxon/ELEMENT_GLOBAL.2.145274/Osmorhiza_mexicana_ssp_bipatriata.

Poole, J., Martinez, M., & Olivero, A. (1997, November 31). *Salvia penstemonoides Big Red Sage*. NatureServe Explorer 2.0. https://explorer.natureserve.org/Taxon/ELEMENT_GLOBAL.2.134863/Salvia_penstemonoides.

Poole, J., Maybury, K., Olivero, A., Strong, A., & Tomaino, A. (1996). *Rayjacksonia aurea*. NatureServe Explorer 2.0. Retrieved October 20, 2021, from https://explorer.natureserve.org/Taxon/ELEMENT_GLOBAL.2.133649/Rayjacksonia_aurea.

Poole, J., Maybury, K., Thunhorst, G., & Olivero, A. (1996, July 1). *Asclepias prostrata*. NatureServe Explorer 2.0. Retrieved October 5, 2021, from https://explorer.natureserve.org/Taxon/ELEMENT_GLOBAL.2.133366/Asclepias_prostrata.

Salvia penstemonoides. Salvia penstemonoides - Plant Finder. (n.d.). http://www.missouribotanicalgarden.org/PlantFinder/PlantFinderDetails.aspx?kempercode=c454.

Singhurst, J. R. (1996). The status of nine endangered plants of east texas: Historical, ecological, and phytogeographical notes (Order No. 1381490). Available from ProQuest Dissertations & Theses Global. (304355980). Retrieved from https://zeus.tarleton.edu/login?url=https://www.proquest.com/dissertations-theses/status-nine-endangered-plants-east-texas/docview/304355980/se-2?accountid=7078

Singhurst, J. R., Nixon, E. S., William F. Caldwell, & Holmes, W. C. (2002). The Genus Trillium (Liliaceae) in Texas. Castanea 67(3), 316–323. http://www.jstor.org/stable/4034353

Sivinski, R.C. (2011). Agalinis calycina (Leoncita false-foxglove): A Conservation Status Assessment. 2011 ESA Section 6 Progress Report Prepared for NM Energy, Minerals and Natural Resources Department and USDI-Fish & Wildlife Service, Region 2. [http://www.npsnm.org/wp-content/uploads/2012/09/S-6-Agalinis-calycina.pdf]

Strong, A. (2017). Flora Fact: Rock Lovers,Quillwort Grows in Enchanted Rock Vernal Pools. Texas Parks and Wildlife magazine. Online. Available: https://tpwmagazine.com/archive/2017/jan/scout3_florafact_quillwort/.

Strong, A., and P. S. Williamson. (2015). Data synthesis and species assessments to aid in determining future candidate or listed status for plants from the USFWS lawsuit settlements. Final Report as Required by The Endangered Species Program, Texas, Grant No. TX E-146.

Texas Parks and Wildlife Department (TPWD). (2021a). Species Protection Basics. Online.

https://tpwd.texas.gov/huntwild/wild/wildlife_diversity/nongame/listed-species/species-protection.phtml

Texas Parks and Wildlife Code. (2021). Title 5: Wildlife and Plant Conservation. Subtitle G: Plants. Chapter 88: Endangered Plants. Online. https://statutes.capitol.texas.gov/?link=PW

Theobald, D., I. Leinwand, J. Anderson, V. Landau & B. Dickson. (2019) Loss and fragmentation of natural lands in the conterminous US from 2001 to 2017. *The Center for American Progress and Conservation Science Partners. URL https://www.csp-inc. org/public/CSP Disappearing US Exec Summary,* 11819.

Timmerman-Erskine, M., Dute, R. R., & Boyd, R. S. (2002). The Trillium pusillum Michaux Complex (Trilliaceae): Analysis of Pollen and Leaf Epidermal Micromorphology. The Journal of the Torrey Botanical Society, 129(3), 175–186. https://doi.org/10.2307/3088768

Trillium texanum Buckley. USDA plants Database. (n.d.). Retrieved September 19, 2021, from https://plants.usda.gov/home/plantProfile?symbol=TRTE3.

TWC Staff. (2017, November 9). *Plant database*. Lady Bird Johnson Wildflower Center - The University of Texas at Austin. Retrieved September 30, 2021, from https://www.wildflower.org/plants/result.php?id_plant=PHCO17.

Watson, L., Uno, G., McCarty, N., & Kornkven, A. (1994). Conservation Biology of a Rare Plant Species, Eriocaulon kornickianum (Eriocaulaceae). American Journal of Botany 81(8): 980-986. doi:10.2307/2445291

Williams, C.R. and A. Manning. (2020). Comparison between two surveys of Physostegia correllii (Lamiaceae) in Travis County, Texas. Phytoneuron 2020-5: 1–7. Published 20 January 2020. ISSN 2153 733X

Chapter 2 Distribution models of 17 rare plant species of Texas

Introduction

Rare plant detection and predictive modelling require creative methods to locate and predict populations. Rare plant populations are difficult to detect without the use of extensive field surveys, which are often not logistically feasible. (Guisan et al. 2006). Rather than common survey methods, such as stratified random sampling, presence-only data, such as herbarium and observational citizen-science data is utilized. Herbarium and observational data is useful, but not complete or unbiased. Herbarium specimens and citicizen science data, sometimes exhibit uneven survey effort, and survey information is sometimes incomplete. Guided surveys based on niche characteristics yield better results than random sampling efforts (Guisan et al. 2006).

Species distribution models, hereafter referred to as SDMs, are often used to describe occurrence areas and determine habitat requirements of a given species (Marx & Quillfeldt 2018). SDMs are valuable resources when making conservation and management decisions for a given area, because they can determine areas with the highest likelihood of species occurrence or habitat quality. Species distribution models have become useful conservation tools because they provide detailed information of species distributions by relating species presence with environmental factors; they can determine areas with the highest likelihood of species occurrence or habitat quality (Elith et al. 2006). The emergence of multiple modeling methods allows researchers to choose the modeling technique that best fits the available species occurrence data as well as the investigation goal. The maximum entropy (Maxent) approach is ideal for modeling rare plant species because it allows the use of presence-only data without requiring known absence information (Elith et al. 2011, Phillips et al. 2017, (Støa et al. 2019). Maxent, a machine learning software, simulates "pseudo-absences" based on the background space in place of recorded known absences and compares the environmental predictor values to presence locations (Elith et al. 2011).

Conservation practices increasingly use SDMs for a multitude of reasons. Models assess risk of invasion success, aid in reserve selection, identify critical habitat locations, and guide in translocation or restoration of at-risk species (Guisan et al. 2013, Srivastava et al. 2019). However, it is often difficult to coordinate agency SDM theoretical knowledge and real-world management decisions. By undertaking case studies in which agencies apply model results in a given area, researchers can bridge the gap between the abstract and the applied (Guisan et al. 2013). Cross-validation methods may also reinforce this collaboration and allow SDMs to become widely implemented in habitat management. For rare or threatened species, it is especially important to build models at the appropriate scale and validate model performance so that conservation efforts are more efficient (Gogul-Prokurat 2011).

This project sought to bridge the gap between theory and practice. We, along with the Texas Department of Transportation and the Botanical Research Institute of Texas (BRIT), selected 17 species of rare plants (Chapter I of this report) within the state of Texas to develop distribution models. BRIT performed field surveys for 4 of the species utilizing the preliminary distribution models. The data obtained from these field survey were then utilized to validate our final models. Although these species have historical records, potential species distributions based on the available records are not fully documented.

The purpose of this project was three-fold: (1) to develop preliminary distribution models of identified rare plant species and understand the species-environment relationships for further improvising our models, (2) to provide probability based distribution maps to BRIT for guiding field surveys, and (3) develop improvised final models and validate the final models utilizing independent field survey data.

Materials and Methods

Study species and Occurrence data

We modeled distribution of 17 rare plant species in Texas. This study spanned across Texas (695,663 km^2) and beyond. Due to its extensive size, Texas contains a wide array of topographic, environmental and ecological variation resulting into 10 ecoregions in the state (TPWD 2021a). While occurrence data of a few species came exclusively from one respective ecoregion where they are primarily found, others were found in multiple ecoregions (Figure 1). Eight of the modelled 17 species were primarily found along the Texas borders. Though we developed a suite of models at Texas and ecoregion extents for the preliminary modeling purpose, we also developed our final models at the rectangular extent that encompassed the Texas boundary.

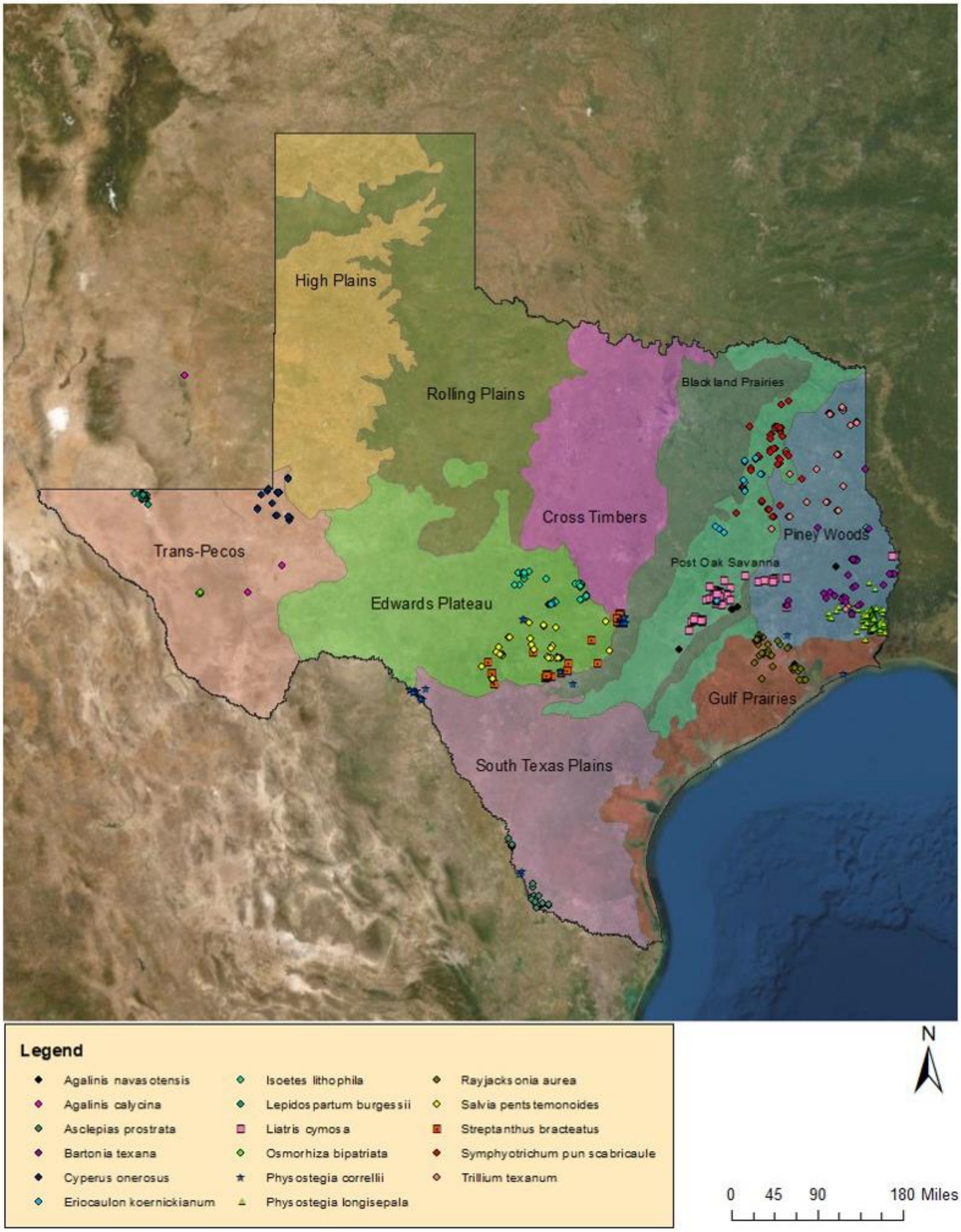

Figure 1 Locations of rare plants presence in Texas

We used georeferenced presence location data provided by an independent contractor (Marie Knipfer) and BRIT that was acquired through presence records of each species from herbaria databases, the Texas Parks and Wildlife Department, the Texas Natural Diversity Database, and citizen science records, such as those from iNaturalist. Historical data obtained from multiple unplanned surveys are prone to environmental bias and may exhibit higher degree of spatial autocorrelation (Araujo and Guisan 2006; Boakes et al. 2010). To avoid this, we filtered location data in such a way that no two presence locations were present in one 30 arc sec pixel, the resolution of our predictor variables. We did not include occurrences that lacked geographic coordinates. Most data points did not come from official surveys detailing both presence and absence locations; however, presence-only data is still useful for modeling purposes (Elith et al. 2006).

Environmental Variables

Three categories of environmental variables, including bioclimatic, solar radiation, and topographical variables (Table 3) were used in the preliminary model development (Fick and Hijman 2017, Worldclim2). These data were trimmed to three different extents- rectangular extent encompassing Texas, Texas boundary, and ecoregions extent based on ecoregions any particular species were observed within. Although many of these variables were correlated, we first retained all variables as variable selection may dependent on different modeling approaches (Warren and seifert 2011) and correlation depends on different background points selected by the algorithm based on the extent considered (Feng et al. 2019). Later, to reduce effects of collinearity, we tested for correlation among variables and only used those that were not strongly correlated ($r < 0.7$). Thus, we developed two sets of models (1) with all variables for preliminary models and (2) with uncorrelated variables for final models. However, models included a few variables exhibiting some degree of correlation as maxent is not very sensitive to correlated variables (Feng et al. 2019). Decisions regarding the variable inclusion or exclusion in the final models were based on biological relevance to the plant taxa and recommendations from available literature.

Table 3 Environmental predictor variables used in preliminary model development

Category	Variable
Bioclimatic	Annual Mean Temperature

	Mean Diurnal Range
	Isothermality
	Temperature Seasonality
	Max Temperature of Warmest Month
	Min Temperature of Coldest Month
	Temperature Annual Range
	Mean Temperature of Wettest Quarter
	Mean Temperature of Driest Quarter
	Mean Temperature of Warmest Quarter
	Mean Temperature of Coldest Quarter
	Annual Precipitation
	Precipitation of Wettest Month
	Precipitation of Driest Month
	Precipitation Seasonality
	Precipitation of Wettest Quarter
	Precipitation of Driest Quarter
	Precipitation of Warmest Quarter
	Precipitation of Coldest Quarter
Solar Radiation	Solar radiation values for each month (January – December) (12 variables total)
Topography	Soil
	Geology
	DEM
	NLCD

Preliminary Models Development

We employed a Maxent algorithm to predict probability of species potential distribution in Maxent ver 3.4.1 (Phillips et al. 2006). Maxent is a machine-learning software that is robust despite small sample sizes, and it utilizes presence-only data that does not require absence locations (Guisan et al. 2007, Gogol-Prokurat 2011). Maxent models nonlinear relationships between species presence locations and environmental variables (Thuiller et al. 2003). Maxent produces a continuous prediction of occurrences ranging from 0 to 1. We used default parameters settings i.e. regularization multiplier = 1, auto features, maximum iterations = 500, and convergence threshold = 10^{-5} for developing preliminary models. We ran 10 bootstrap replications using 25% test locations with a random seeding option so that each replication did not use the same set of test locations. We ran 5000 iterations of each model and applied a 10-percentile training presence threshold rule. Raw results were given on a logscale. These settings generated reasonably simple models that did not over-fit (Philips and Dudik 2008).

Model Evaluation

We used the area under the curve (AUC) of the receiver Operative Characteristics plot (ROC-plot) (Fielding and Bell 1997) for evaluating model performance (Gogul-Prokurat 2011; Radosavljevic and Anderson 2014; West et al. 2016) of the preliminary models. We focused on models with AUC values > 0.75, indicating that they performed better than a random model (AUC = 0.50) (Thuiller 2003, Philips et al. 2006; Franklin et al. 2009; Peterson et al. 2011). We assessed environmental variable contribution using jackknife analyses (Shcheglovitova and Anderson 2013).

Field Survey Methods: BRIT followed the following procedure for conducting field surveys;

Site Selection

A stratified random sampling design was used to collect field data on presence or absence of the four candidate species, *Trillium texanum, Eriocaulon koernickianum, Physostegia correllii,* and *Salvia pentstemonoides*. Suitability classes from the Maxent 1-km models were established following the criteria below, where the Lowest Presence Threshold (LPT) is equal to the minimum training presence threshold from the Maxent software for each species. The Maximum habitat suitability value (Max HSV) is equal to the highest habitat suitability value represented in the model for each species. Presence locations with high locational uncertainty (uncertainty buffer > 500 m) were excluded when determining LPT.

- Suitability Class 1 ranged from an HSV of 0 to the LPT. This class represents areas with the lowest likelihood of containing the species of interest.

- Suitability Class 2 ranged from the LPT (non-inclusive) to the midpoint between the LPT and the Max HSV (=50% Max HSV).
- Suitability Class 3 ranged from 50% Max HSV (non-inclusive) to the midpoint between 50% Max HSV and the Max HSV (=75% Max HSV).
- Suitability Class 4 ranged from 75% Max HSV (non-inclusive) to the Max HSV. This class represents areas with the highest likelihood of containing the species of interest.

The ranges for each suitability class are shown in Table 4 below.

Table 4 Habitat suitability values for each habitat suitability class

Taxon	*LPT*	*Max HSV*	*Habitat Suitability Class 1*	*Habitat Suitability Class 2*	*Habitat Suitability Class 3*	*Habitat Suitability Class 4*
Trillium texanum	*0.0112*	0.94403	0-0.0112	0.0112-0.47763	0.47763-0.71083	0.71083-0.94403
Eriocaulon koernickianum	*0.5925*	0.905772	0-0.5925	0.5925-0.74914	0.74914-0.82746	0.82746-0.905772
Physostegia correllii	*0.1292*	0.995316	0-0.1292	0.1292-0.56226	0.56226-0.77879	0.77879-0.995316
Salvia pentstemonoides	*0.0067*	0.949013	0-0.0067	0.0067-0.47783	0.47783-0.71342	0.71342-0.949013

The Raster model files were converted to polygons representing each Suitability Class. The sampling area was restricted to the area consisting of the minimum bounding geometry surrounding categories 2 through 4. If all known locations were not present within this area, a buffer equal to the distance from the edge of the minimum bounding geometry to the point was added. Known sites with high locational certainty (buffer <500 m) plus their associated locational uncertainty buffer were excluded from the sampling area. Urban areas and major highways were also excluded when generating roadside points. The resulting sampling polygons were overlaid with layers representing public areas (parks, natural areas, etc.) and roadside right of ways to restrict sampling to areas with public access.

A total of 50 randomly-generated points were selected for each taxon, with a minimum of 10 points selected in areas other than on roadside right of ways. A minimum of five random points were selected for each category (1 through 4), with the remaining points distributed throughout the categories, dependent on availability of publicly accessible sites within each category. A 1000 m buffer was used between sampling points to create independent sample plots.

Once points were selected, Google Earth aerial imagery was consulted to ensure the point was accessible and did not appear highly modified or developed. If a point was either not accessible or appeared highly modified, the point was excluded and the next randomly generated point was used. Permits or private landowner permission was obtained for each point when appropriate.

Field Surveys

Field surveys were completed in the Spring and Summers of 2020 and 2021 (Table 5). Each randomly generated point (~50 total per species) was surveyed for presence of the indicated species and assessed for dominant plant species present. Each randomly generated point was located in the field using a GPS unit and a 20-m^2 plot was established with the randomly generated point at the center. Plot size was 10-m x 2-m with the long side parallel to the road (if present). The plot and the immediate surrounding area were systematically searched for the indicated species. Search intensity was held constant by allowing a set amount of time and observers for searching. For *T. texanum,* and *P. correllii,* and *S. pentstemonoides,* 2 people searched for 10 minutes for a total of 20 minutes of search time. For *E. koernickanum* 2 people searched for 20 minutes for a total of 40 minutes of search time. The number of individuals of the species of interest and geographic coordinates of each individual plant of the species of interest occurring within the sample area were recorded. Associated dominant taxa were recorded within each plot following the 50/20 rule for dominants, where dominant taxa and their estimated percent coverage within the plot are listed beginning with the most abundant until the total cover for the listed species equals or exceeds 50%. Any additional taxa with a coverage of 20% or more within the plot are also included. Herbarium specimens were collected for the species of interest and associated dominant taxa for verification of species identification.

In addition to the randomly selected points, a minimum of three populations of known occurrence were visited for each species. Plots were established at each of these sites using the previously detailed methods.

Herbarium specimens were identified using floristic treatments appropriate to the region collected and plant family (Diggs et. al 1999; Diggs & Lipscomb 2006, 2014; Flora of North America Editorial Committee 1993+; Shaw 2012). Taxonomy follows World Flora Online (http://www.worldfloraonline.org/). Photographs for each collection were also posted to iNaturalist (iNaturalist.org). Herbarium specimens are deposited at the Botanical Research Institute of Texas Philecology Herbarium (BRIT), with sterile ecological vouchers stored in the BRIT Conservation Department.

Table 5 Field Survey Dates

Species	2020 Field Season (# points)	2021 Field Season (# points)
Trillium texanum	field season suspended due to Covid-19	March 4 to April 12, 2021 (50)
Eriocaulon koernickianum	June 1 to July 1, 2020 (32)	May 31 to June 16, 2021 (20)
Physostegia correllii	July 6 to August 13, 2020 (40)	July 13 to 15, 2021 (9)
Salvia pentstemonoides	July 7 to September 9, 2020 (54)	July 31 to August 1, 2021 (known sites only)

Data Analysis

The percent cover values for dominant taxa at known sites was averaged to have a single “known site” cover value for each species. The Bray-Curtis Dissimilarity equation was used to determine a dissimilarity value for each plot by comparing cover values for each species in each plot to the “known site” average data using the following equation:

$$BC_d = \frac{\sum |x_i - x_j|}{\sum (x_i + x_j)}$$

x_i = mean percent cover in known plots

x_j = percent cover in random plot

The Bray-Curtis Index was then calculated by subtracting the Bray-Curtis Dissimilarity from 1 and multiplying by 100 to give a similarity value for each plot ranging from 0 to 100, with a value of 0 signifying that there were no shared species between the random plots and the known sites.

All field validation data, including the location of each plot, the date surveyed, dominant species cover values for each plot, Bray-Curtis Index values, and the probability of occurrences extracted from the 1-km Maxent models are included in the attached data files: “Trillium_Data.xlsv”, “Eriocaulon_Data.xlsv”, “Physostegia_Data.xlsv”, and “Salvia_Data.xlsv” (Supplementary Data 1 submitted in digital format along with the final report).

The habitat suitability value for the GPS coordinates at the center of each plot (extracted from the model) was plotted against the Bray-Curtis Index and a linear regression analysis was performed to determine how well the model predicted the appropriate habitat for the target species. Linear regression analysis was also performed separately for data collected on roadside right-of-ways and in parks. Single factor ANOVA was conducted to compare the BCI of plots grouped by habitat suitability class for all the combined sites as well as individually for roadside right-of-ways and parks. A T-test was used to compare the BCI in plots with an HSV of greater than 0.5 to plots with an HSV of less than 0.5 as well as to compare plots with an HSV greater than or less than the LPT. The results of all analyses are presented as separate tabs in each species data spreadsheet.

Final Model Selection Procedure

Environmental variable selection: Quantitative and qualitative examination of the series of models developed using all environmental variables, as mentioned above, led us to decide on the variables we used for our final models. We considered avoiding multicollinearity (Gogol-Prokurat 2011; Connor et al. 2019, Sillero et al. 2021), examining variable contribution as depicted by the jackknife and bootstrapping analyses (Kafley et al. 2009; Shcheglovitova and Anderson 2013, Peterson and Cohoon 1999, Cobos et al. 2019), and identifying the variables that are more biologically meaningful for the taxa in consideration (O'Donnell and Ignizio 2012; Sillero et al. 2021). Finally, we selected 9 out of 19 Bioclimatic variables for building final models (Table 6).

We conducted series of modeling experiments utilizing varying level of model complexity. Maxent limit model complexity by regularization, smoothing the model and making it more regular, and thereby avoids overfitting (Phillips et al. 2006; Philips and Dudik 2008; Anderson and Gonzalez 2011; Elith et al. 2011). Regularization is a penalty for each term included in the model and for higher weights given to a term. We used five regularization multipliers – 0.1, 0.5, 1 (default), 5, and 10. Quantitative measure of model performance used to select the best model across different regularization multipliers, and within specific extent were AUC, a threshold-independent measure and TSS, a threshold dependent measure. AUC assesses overall model performance or discriminatory ability quantifying the probability that the model correctly ranks a random presence locality higher than a random background pixel (Phillips et al. 2006). In addition to the above AUC approach of model evaluation we also calculated maximum Kappa statistics and the True Skill Statistic (TSS) (Allouche et al. 2006) to assess accuracy of the distribution models.

We also evaluated model performance qualitatively by examining resulting predicted potential distribution maps visually (Anderson and Gonzalez 2011; Radosavljevic and Anderson 2014). For each of the regularization multipliers, we examined 1) whether the model exhibited any sign of overfitting to the environmental conditions found at training localities, and 2) details of the predictions in regions where strong differences were apparent among regularization multipliers. In addition to these, we also compared our predicted probability surface to other published coarse-scale distribution maps (Poole et al. 2007).

Table 6 Biolclimatic variables (in bold font) used for final model building

Code	Environmental Variables	Unit	Interpretation (Adopted from O'Donnell & Ignizio 2012)
Bio1	**Annual mean temperature**	°C	Approximates the total energy inputs for an ecosystem
Bio2	**Mean diurnal range** (mean of monthly max. and min. temp.)	°C	Provides information pertaining to the relevance of temperature fluctuation for different species
Bio3	**Isothermality** (Bio2/bio7)	-	Quantifies how large the day-to-night temperatures oscillate relative to the summer-to-winter oscillations- a species distribution may be influenced by larger or smaller temperature fluctuations within a month relative to the year and this predictor is useful for ascertaining such information
Bio4	Temperature seasonality	C of V	-
Bio5	**Maximum temperature of warmest month**	°C	Calculated by selecting maximum temperature values across all months within a given year- this information is useful when examining whether species distributions are affected by warm temperature anomalies throughout the year
Bio6	**Minimum temperature of coldest month**	°C	Calculated by selecting minimum temperature values across all months within a given year- this information is useful when examining whether species distributions are affected by cold temperature anomalies throughout the year
Bio7	**Temperature annual range** (Bio5-Bio6)	°C	This information is useful when examining whether species distributions are affected by ranges of extreme temperature conditions
Bio8	Mean temperature of wettest quarter	°C	-
Bio9	Mean temperature of driest quarter	°C	-
Bio10	Mean temperature of warmest quarter	°C	-
Bio11	Mean temperature of coldest quarter	°C	-
Bio12	**Annual precipitation**	mm	Sum of precipitation values of each of the 12 months in a year- it approximates the total water inputs and is therefore useful when ascertaining the importance of water availability to a species distribution
Bio13	**Precipitation of wettest month**	mm	The highest cumulative precipitation in the wettest month is useful if extreme precipitation

			conditions during the year influence species potential range
Bio14	**Precipitation of driest month**	mm	The highest cumulative precipitation in the the driest month is useful if extreme precipitation conditions during the year influence species potential range
Bio15	Precipitation seasonality (CV)	C of V	-
Bio16	Precipitation of wettest quarter	mm	-
Bio17	Precipitation of driest quarter	mm	-
Bio18	Precipitation of warmest quarter	mm	-
Bio19	Precipitation of coldest quarter	mm	-

Results and discussion

Preliminary Models

We developed preliminary models (Appendix I) using all available predictors. The goal for building preliminary models was to guide field surveys. Therefore, we allowed models to overfit so that high probability areas could be identified in order to distribute sample locations for the field survey. Models for all species had high AUC (AUC > 0.90) that indicated good discrimination between presence location and random background locations. These models provided baseline to determine sampling strategy for the field survey. We do not discuss these preliminary models further and focus our discussion later on final models. Preliminary models for four species selected for field surveys are briefly discussed below-

Eriocaulon koernickianum

This model was created using all of the environmental variables and serves as a preliminary diagnostic model. The model for Eriocaulon identified general known range of the species. The test AUC was 0.997 indicating that the test locations were correctly classified in the model. However, the maximum possible test AUC would be 0.978 if the test data was drawn from the maxent distribution itself. This metrics clearly indicated overfit of the model. Soil, mean temperature of driest quarter, geology, and precipitation seasonality contributed higher than 1% to the model. All remaining predictors contributed less than 1% or did not contribute at all. The environmental variable with highest gain when used in isolation was soil, which therefore appeared to have the most useful information by itself. The environmental variable that decreased the gain the most when it is omitted was soil, which therefore appeared to have the most information that isn't present in the other variables.

Physostegia Correllii

Model for Physostegia had test AUC 0.943 where the best possible test AUC could be 0.948 if test data was drawn from maxent distribution itself. The environmental variable with highest gain when used in isolation was land cover classes (nlcd), which therefore appeared to have the most useful information by itself. The environmental variable that decreased the gain the most when it is omitted was nlcd, which therefore appears to have the most information that isn't present in the other variables.

Salvia pentstemonoides

This model, like the 1-km resolution model for *T. texanum*, was developed using all of the listed environmental variables. The resulting map depicts potential habitat in central Texas, with some points of lower likelihood extending into north-central Texas outside of the Edwards Plateau. The testing data for this model had an AUC value of 0.993, indicating that this set of data fit the model better than randomly generated data. However, the maximum possible test AUC would be 0.986 if the test data was drawn from the maxent distribution itself. This discrepancy in AUC difference indicated overfit. Based on jackknife analyses, the model generated using testing data and the soil data had the greatest gain out of any of the other variables. Geology and the temperature seasonality (bio4) also seemed to indicate more gain than the other variables, but not as much as the soil variable.

Trillium texanum

This model was created using all of the environmental variables and serves as a preliminary diagnostic model. The resulting map depicts that potential habitat is most likely clustered in east Texas, which is the known range of this species. The testing data for this model had an AUC value of 0.969, indicating that the data fit the model better than randomly selected points would. The maximum possible test AUC would be 0.985 if the test data was drawn from the maxent distribution itself. Usually, a value this high is indicative of over-prediction; however, this value may be large simply because *T. texanum* has a relatively narrow range in which it is found compared to the extent used. For the testing data, models created using only the soil data, precipitation seasonality (bio15), or mean temperature of the driest quarter (bio9) had the greatest "gain" in regard to predicting potential habitat localities.

Field Survey Results (BRIT)

A total of 49 to 54 random points were visited for each species in the 2020 and 2021 field seasons. No plants were found of the species of interest at any random points. However, individual plants of the species of interest were observed at previously known locations. Approximately 429 *Trillium texanum* stems were observed in 4 unique populations, 69 of which were in flower; approximately 900 *Eriocaulon koernickianum* plants were observed in 5 unique populations; 121 *Physostegia correllii* plants were observed in 4 unique populations; and 18 S*alvia pentstemonoides* plants were observed in 4 unique populations. GPS coordinates for each population were recorded and are available in the "Plant Coordinates" tab for each species' data file.

The Bray-Curtis Index (BCI) values (Table 7, 8, 9, 10) represent how similar the dominant vegetation was at each random point to the pooled habitat data at the sites where plants of the species of interest were present. This score allows us to test the model's ability to predict the presence of potential habitat for the species, even if the species of interest were not present. BCI values range from 0 to 100, with 100 representing 100% similarity between plots.

All random plots for *Eriocaulon koernickianum* resulted in a Bray-Curtis Index of 0, indicating there was no overlap in species composition of dominant taxa between the known plots and the random plots. No additional analyses could be performed since there was no variation in BCI.

Table 7 Summary data by Habitat Suitability Class for Trillium texanum random plots.

	Habitat Suitability Class 1	***Habitat Suitability Class 2***	***Habitat Suitability Class 3***	***Habitat Suitability Class 4***
HSV range	0-0.0112	0.0112-0.47763	0.47763-0.71083	0.71083-0.94403
Total plots	9	10	16	15

Park plots	4	5	2	5
Roadside plots	5	5	14	10
Min BCI	0	0	23.02158273	0
Max BCI	65.04065041	65.04065041	57.55395683	69.90291262
# with BCI=0	3	2	8	3
Mean BCI	34.08525212	45.49448206	41.10959159	44.31853372

Table 8 Summary data by Habitat Suitability Class for Eriocaulon koernickianum random plots.

	Habitat Suitability Class 1	**Habitat Suitability Class 2**	**Habitat Suitability Class 3**	**Habitat Suitability Class 4**
HSV range	0-0.5925	0.5925-0.74914	0.74914-0.82746	0.82746-0.905772
Total plots	13	17	14	8
Park plots	2	6	2	0
Roadside plots	11	11	12	8
# with BCI=0	13	17	14	8

Table 9 Summary data by Habitat Suitability Class for Physostegia correllii random plots.

	Habitat Suitability Class 1	**Habitat Suitability Class 2**	**Habitat Suitability Class 3**	**Habitat Suitability Class 4**
HSV range	0-0.1292	0.1292-0.56226	0.56226-0.77879	0.77879-0.995316
total plots	23	12	9	5
park plots	9	2	6	3
roadside plots	14	10	3	2
Min BCI	0	0	0	0

Max BCI	20	14.28571429	10.71428571	18.75
# with BCI=0	9	6	5	3
Mean BCI	7.28397	5.305233328	4.531490015	6.607142857

Table 10 Summary data by Habitat Suitability Class for Salvia pentstemonoides random plots.

	Habitat Suitability Class 1	***Habitat Suitability Class 2***	***Habitat Suitability Class 3***	***Habitat Suitability Class 4***
HSV range	0-0.0067	0.0067-0.47783	0.47783-0.71342	0.71342-0.949013
Total plots	15	9	20	10
Park plots	8	4	4	1
Roadside plots	7	5	16	9
Min BCI	0	0	0	0
Max BCI	56	33.33333333	44	59.25925926
# with BCI=0	6	2	4	7
Mean BCI	18.3695	18.47044739	21.18021781	11.53721119

Linear Regression analysis between plot Habitat Suitability Value (HSV) and Bray-Curtis Index (BCI) was found to be insignificant for all species ($p>0.05$) including when data was analyzed separately for points on roadside right-of-ways and in parks (Figure 2, 3, 4). All ANOVA and T-test analyses were also insignificant (p>0.05) for all tests performed except the ANOVA conducted on the pooled *Trillium texanum* data grouped by Habitat Suitability Class (p=0.03689). The mean BCI for each of the classes were Class 1: 34.09, Class 2: 45.49, Class 3: 20.55, and Class 4: 44.32. The low relative mean in Class 3 likely accounts for the significance found in the ANOVA. Class 3 had 8 plots with a BCI of 0, significantly lowering the mean BCI within the class.

According to these analyses the Habitat Suitability Values found within the 1-km models for each species do not predict the vegetative community present on the ground. This is likely due at least in part to the discrepancy between the size of the grid cell in the model (1-km) and the size of vegetation plots used (20-m). The species of interest are often found in small pockets of ideal habitat in a larger matrix of unsuitable habitat. A smaller grid-cell model would likely improve the predictive power of the model in this situation.

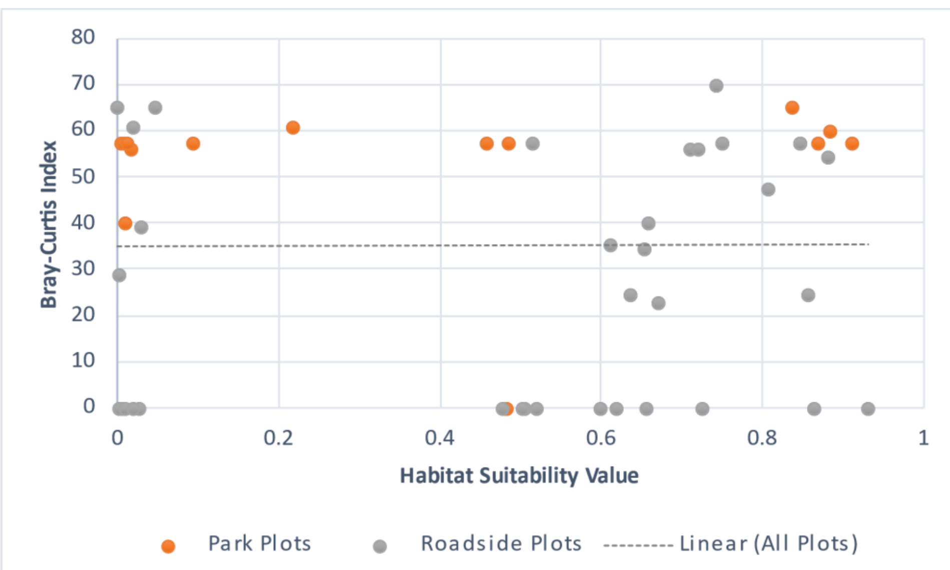

Figure 2 Diagram showing Habitat Suitability Value plotted against the Bray-Curtis Index for each of the random plots for Trillium texanum.

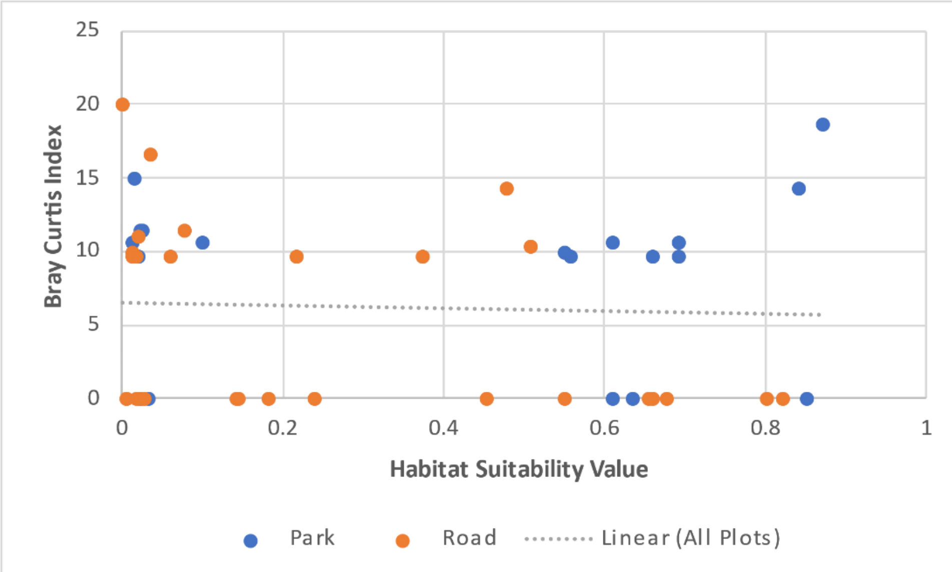

Figure 3 Diagram showing Habitat Suitability Value plotted against the Bray-Curtis Index for each of the random plots for Physostegia correllii.

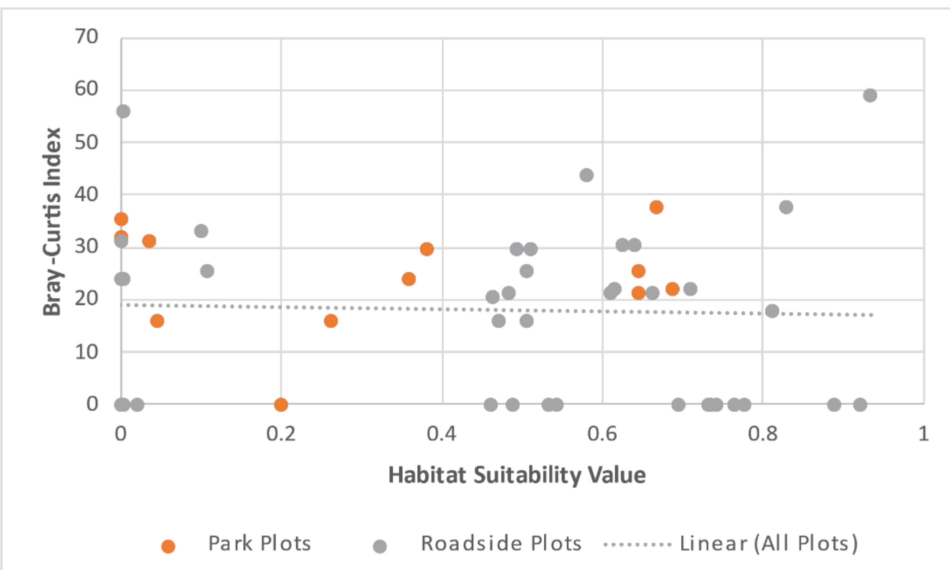

Figure 4 Diagram showing Habitat Suitability Value plotted against the Bray-Curtis Index for each of the random plots for Salvia pentstemonoides

Final Models

The final model outputs for all species except for *A. Calycina and O. Patriata*, with 3 and 2 occurrence locations respectively (Table 11), provided good results with the given set of data at varying level of model complexity. In all cases, the models had high discrimination ability with AUC > 0.90 indicating better than random predictions (Philips et al. 2006). Higher AUC of the models was generally achieved with increasing extent (Texas boundary models vs. Regional model, Appendix II & III) (Anderson and Raza 2010, Connor et al. 2019) and lower level beta multipliers that tend to overfit the data and generate overly complex models (Appendix IV) (Philips and Elith 2010; Anderson and Gonzalez 2011). Quantitative evaluation of our models complexity did not depict any sign of over-fitting. Difference between training and test AUC were consistently smaller across the species and levels of complexity (Radosavljevic and Anderson 2014). However, visual analyses of the predictive maps clearly indicated overfitting at lower regularization multipliers that produced visually unrealistic probability surface. This is probably because the complex model tends to fit the presence location more restrictively. Though in-depth experimental analyses for identifying optimum level of model complexity was not the scope of this study, our analyses suggest that default regularization multiplier setting produced reasonably better models than overly complex (regularization multiplier- 0.1 and 0.5) or overly simplistic (regularization multiplier- 5 and 10) models (Appendix V). In this report we append 2 sets of models that are fairly comparable and suggest them as the working models- 1) models built using default regularization parameter setting, 10 replicated boostrap runs with 25% random test percentage (Appendix III) models built using default regularization parameter setting and 5 replicated crossvalidation run type (Appendix VI) built at an extent of rectangle encompassing Texas boundary.

*Table 11 Occurrence locations of rare plant species Species available for modeling (*not modelled)*

Short name	Species long name	Number of presence locations (number after removal of duplicate points within the same grid cell)
A. calycina	*Agalinis calycina*	*36 (3)**
A. navasotensis	*Agalinis navasotensis*	61 (7)
A. prostrata	*Asclepias prostrata*	136 (21)
B. texana	*Bartonia texana*	104 (27)
C. onerosus	*Cyperus onerosus*	124 (18)
E. koernickianum	*Eriocaulon koernickianum*	44 (13)
I. lithophila	*Isoetes lithophila*	163 (33)
L. burgessii	*Lepidospartum burgessii*	80 (15)
L. cymosa	*Liatris cymosa*	116 (50)
O. bipatriata	*Osmorhiza bipatriata*	18 (2)*

P. corellii	*Physostegia correllii*	86 (21)
P. longisepala	*Physostegia longisepala*	356 (85)
R. aurea	*Rayjacksonia aurea*	185 (42)
S. pentstemonoides	*Salvia pentstemonoides*	157 (27)
S. bracteatus	*Streptanthus bracteatus*	203 (32)
S. puniceum	*Symphyotrichum puniceum*	169 (38)
T. pusillum	*Trillium pusillum*	177 (28)

Conclusions and recommendations

We modelled potential distribution of the 15 rare plant species for which the distribution models were not previously available till date. We modelled the distribution at three extents (rectangular region encompassing Texas boundary, within Texas boundary, and within ecoregion). As we did not have any ecological justification to choose specific extents, the goal was to model potential distribution at varying extents and identify the most plausible models. Though choosing ecoregion as an extent might seem ecologically meaningful, not all species were exclusively found in the specific ecoregion and there were many species that were found in either multiple ecoregions or along the boundary of different ecoregions (all species except *O. bipatriata, A. calycina* and *A. prostrata*). Therefore, we do not report ecoregion level models as we considered this extent as an arbitrary extent as others. However, we qualitatively investigated performances of these models to other models. Models were also built within Texas boundary extent, yet another arbitrary extent. We realize that few species (*A. prostrata, A. navasotensis, B. paniculata, C. onerosus, P. correllii, P. longisepala, T. Pusillum*) occur along the Texas boundary that are potentially distributed beyond the state boundary. Therefore, we considered a rectangular extent including Texas boundary as our extent for building final models.

We recommend using probability surface resulted from our models to delineate study extent for future survey efforts or modeling exercise. Thus, the future investigation should not rely on arbitrary extent but base the investigation within ecologically meaningful extent. Moreover, the resulted smaller extents from this study will also allow investigation to be conducted at fine spatial scale resolution. We emphasize fine spatial scale investigation for these rare plants that have specialized niches and might respond to fine spatial scale predictors better. Conner et al. (2019) demonstrates that models built at the small total extent with smaller possible grain sizes produce more accurate predictions but it was not the case when the extent was increased. We recommend choosing smallest grain size first and increasing the grain size to determine an optimal size that produces best model while setting fixed extent.

We tested the performance of different models under varying complexity. We investigated average training AUC and test AUC values of the replicated runs and average difference of average training and test AUC. While all models with varying level of complexity had acceptable training and test AUC, none of these metrics favored any specific level of complexity. True complexity of the environmental niche of any species is unknown and probably not possible to understand or model (Warren and Seifert 2011). In our case we used regularization multiplier values of 0.1, 0.5, 1, 5, and 10. We found that the distribution maps obtained from 01. And 0.5 regularization multipliers were too restricted and the maps obtained from 5, 10 level of regularization multipliers depicted unrealistically wider distribution potential. Therefore, we resorted to default regularization multiplier value 1 (Phillips and Dudik, 2008) that was determined based on tuning experiments using random partitioning of model training and evaluation data. We understand that selecting default regularization parameter may overestimate performance of the model by overfitting the data. But, visual examination of the distribution maps produced at default complexity was intuitive than other overfitted and underfitted models. Overfitted and underfitted models generally lacks model generality and thereby transferability (Peterson 2003, Araujo and Guisan 2006). While using default regularization parameter is questionable (Warren and Seifert 2011(Radosavljevic and Anderson 2014)) it has been extensively used (Morales, Fernández and Baca-González 2017) especially when transferability is not the goal of the modeling exercise. For future studies, we recommend using additional level of complexity and also use information criteria such as Bayesian information Criteria (BIC) or Alaike Information Criteria (AIC) for selecting the model in addition to AUC.

We believe that our models will be useful for future conservation and management of rare plant species in Texas. Though we append only selected models in this report we will submit all model outputs to TxDOT in digital format so that the agency can refer to more restrictive (overfitted models) or more simplistic (underfitted models) as all of those models also had better discrimination ability.

References

Allouche, O., Tsoar, A. and Kadmon, R. 2006. Assessing the accuracy of species distribution models: prevalence, kappa and the true skill statistic (TSS). Journal of Applied Ecology. 43(6):1223-1232.

Anderson, R. P. & A. Raza (2010) The effect of the extent of the study region on GIS models of species geographic distributions and estimates of niche evolution: preliminary tests with montane rodents (genus Nephelomys) in Venezuela. *Journal of Biogeography,* 37**,** 1378-1393.

Anderson, R.P. & Gonzalez, I., Jr (2011) Species-specific tuning increases robustness to sampling bias in models of species distributions: an implementation with Maxent. Ecological Modelling, 222, 2796– 2811.

Araujo, M. B. & A. Guisan (2006) Five (or so) challenges for species distribution modelling. *Journal of biogeography,* 33**,** 1677-1688.

Araujo, M.B. & Guisan, A. (2006) Five (or so) challenges for species distribution modelling. Journal of Biogeography 33: 1677–1688.

Boakes, E.H., McGowan, P.J.K., Fuller, R.A., Ding, C.-Q., Clark, N.E., O'Connor, K. & Mace, G.M. (2010) Distorted views of biodiversity: spatial and temporal bias in species occurrence data. PLoS Biology, 8, e1000385.

Cobos, M. E., A. T. Peterson, L. Osorio-Olvera & D. Jiménez-García (2019) An exhaustive analysis of heuristic methods for variable selection in ecological niche modeling and species distribution modeling. *Ecological Informatics,* 53**,** 100983.

Connor, T., A. Viña, J. A. Winkler, V. Hull, Y. Tang, A. Shortridge, H. Yang, Z. Zhao, F. Wang & J. Zhang (2019) Interactive spatial scale effects on species distribution modeling: The case of the giant panda. *Scientific reports,* 9**,** 1-14.

Diggs, G. Lipscomb, B. 2006 Illustrated Flora of East Texas, Vol 1. Botanical Research Institute of Texas Press.

Diggs, G. Lipscomb, B., O'Kennon, R. 1999. Shinners and Mahler's Illustrated Flora of North Central Texas. Botanical Research Institute of Texas Press.

Diggs, G., Lipscomb, B. 2014. The Ferns and Lycophytes of Texas. Botanical Research Institute of Texas Press.

Elith, J. et al. 2006. Novel methods improve prediction of species' distributions from occurrence data. Ecography. 29:129-151.

Elith, J., Phillips, S.J., Hastie, T., Dudik, M., Chee, M.D. and Yates, C,J. 2011. A statistical explanation of MaxEnt for ecologists. Diversity and Distributions. 17:43-57.

Feng, X., Park, D.S., Liang, Y., Pandey, R. and Papes, M. (2019). Collinearity in ecological niche modeling: Confusions and challenges. Ecology and Evolution 9: 10365-10376

Fick, S.E. and R.J. Hijmans, 2017. WorldClim 2: new 1km spatial resolution climate surfaces for global land areas. International Journal of Climatology 37 (12): 4302-4315.

Flora of North America Editorial Committee, eds. 1993+. Flora of North America North of Mexico [Online]. 22+ vols. New York and Oxford. http://beta.floranorthamerica.org.

Franklin, J. (2009). Mapping Species Distribution: Spatial Inference and Prediction. Cambridge University Press, Cambridge, UK.

Gogul-Prokurat M (2011) Predicting habitat suitability for rare plants at local spatial scales using a species distribution model. Ecological Applications. 21(1):33-47.

Guisan A et al (2006) Using niche-based models to improve the sampling of rare species. Conservation Biology. 20:501-511.

Guisan A., Zimmermann, N.E., Elith, J., Graham, C.H., Phillips, S. and Peterson, A.T. 2007. What matters for predicting the occurrences of trees: techniques, data, or species characteristics? Ecological Monographs. 77(4):615-630.

Guisan, A. et al. 2013. Predicting species distributions for conservation decisions. Ecology Letters. 16:1424-1435.

Kafley, H., Khadka, M. and Sharma, M. 2009. Habitat evaluation and suitability modelling of Rhinoceros unicornis in Chitwan National Park, Nepal: a geospatial approach. XIII World Forestry Congress Buenos Aires, Argentina, 18–23 October.

Marx M and Quillfeldt P (2018) Species distribution models of European Turtle Doves in Germany are more reliable with presence only rather than presence absence data. Scientific Reports. 8:16898.

Morales, N. S., Fernández, I. C. and Baca-González, V. (2017) MaxEnt's parameter configuration and small samples: are we paying attention to recommendations? A systematic review. *PeerJ,* 5**,** e3093.

Mouillot D et al (2013) Rare species support vulnerable functions in high-diversity ecosystems. PLOS Biology. Vol 11:Issue 5 plosbiology.org.

Peterson, A. T. & K. P. Cohoon (1999) Sensitivity of distributional prediction algorithms to geographic data completeness. *Ecological modelling,* 117**,** 159-164.

Peterson, A. T. (2003) Predicting the geography of species' invasions via ecological niche modeling. *The quarterly review of biology,* 78**,** 419-433.

Peterson, A.T., Soberon, R.G., Pearson, R.P., Anderson, E., Martinez-Meyer, M., Nakamura, and Araujo, M.B. (2011). Ecological Niches and Geographic Distributions. Princeton University Press, Pinceton, New Jersey, USA.

Phillips, S. J. et al. 2006. Maximum entropy modeling of species geographic distributions.

Ecological Modelling 190:231-259.

Phillips, S. and Dudik, M. 2008. Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. Ecography 32(2): 161-175.

Phillips, S. and Elith, J. 2010. POC plots: calibrating species distribution models with presence-only data. Ecology 91(8): 2476-2484.

Phillips, S.J., Anderson, R.P., Dudik, M., Schapire, R.E. and Blair, M.E. 2017. Opening the black box: an open-source release of Maxent. Ecography. 40:887-893.

Poole, J.M., Carr, W.R., Price, A.M. and Singhurst, J.R. (2007). Rare Plants of Texas. Texas A&M University Press, College Station. Pp 640.

Radosavljevic, A. & R. P. Anderson (2014) Making better Maxent models of species distributions: complexity, overfitting and evaluation. *Journal of biogeography,* 41 (4)**:** 629-643.

Shcheglovitova, M. & Anderson, R.P. (2013) Estimating optimal complexity for ecological niche models: a jackknife approach for species with small sample sizes. *Ecological Modelling*, **269**, 9– 17.

Shaw, R. 2012. Guide to Texas Grasses. Texas A&M University Press.

Srivastava, V., Lafond, V. and Griess, V.C. 2019. Species distribution models (SDM): applications, benefits and challenges in invasive species management. CAB Reviews. 14:1-13.

Sillero, N., S. Arenas-Castro, U. Enriquez-Urzelai, C. G. Vale, D. Sousa-Guedes, F. Martínez-Freiría, R. Real & A. M. Barbosa (2021) Want to model a species niche? A step-by-step guideline on correlative ecological niche modelling. *Ecological Modelling,* 456**,** 109671.

Støa, B., R. Halvorsen, J. N. Stokland & V. I. Gusarov (2019) How much is enough? Influence of number of presence observations on the performance of species distribution models. *Sommerfeltia,* 39**,** 1-28.

Texas Parks and Wildlife Department (2020) Texas Ecoregions. https://tpwd.texas.gov/education/hunter-education/online-course/wildlife-conservation/texas-ecoregions.

Texas Parks and Wildlife Department (TPWD). 2021a. Species Protection Basics. Online. https://tpwd.texas.gov/huntwild/wild/wildlife_diversity/nongame/listed-species/species-protection.phtml

Thuiller W., Araujo, M.B. and Lavorel, S. 2003. Generalized models vs. classification tree analysis: Predicting spatial distributions of plant species at different scales. Journal of Vegetation Science 14:669-680.

O'Donnell, M.S. and Ignizio, D.A. 2012. Bioclimatic predictors for supporting ecological applications in the conterminous United States. U.S. Geological Survey Data Series 691, 10p.

Warren, D.L. and Seifert, S.N. 2011. Ecological niche modeling in Maxent: the importance of model complexity and the performance of model selection criteria. Ecological applications 21(2): 335-342.

West, A.M., Kumar, S., Brown, C.S., Stohlgren, T.J. and Bromberg, J. (2016). Field validation of an invasive species Maxent model. Ecological Informatics 36:126-134.