Species Status Assessment Report for *Eryngium sparganophyllum* Arizona Eryngo

Flowering Arizona eryngo at Lewis Springs, Arizona.
Photo by Theresa Condo, Bureau of Land Management, September 20, 2019.

Version 1.0
November 2020
Lower Colorado Basin Region
United States Fish and Wildlife Service
Arizona Ecological Services Office
Tucson, Arizona

This document was prepared by Erin Fernandez with assistance from Susan Oetker, Rachel Williams, Vance Wolf, and Julie Crawford of the U.S. Fish and Wildlife Service. Valuable input was provided by Steve Blackwell, Desert Botanical Garden; Julia Fonseca, Pima County; La Cebadilla Estates; Yue "Max" Li, University of Arizona; Elizabeth Makings, Arizona State University; Robert Massatti, U.S. Geologic Survey; José Jesús Sánchez Escalante, University of Sonora; Marisa Rice, Pima County; Jeffrey Simms, Bureau of Land Management; Karen Simms, Pima County. We thank Mike Dick for assistance with creating maps for this document.

Suggested reference:

United States Fish and Wildlife Service. 2020. Species status assessment report for *Eryngium sparganophyllum* (Arizona eryngo). United States Fish and Wildlife Service, Tucson, Arizona.

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Eryngium sparganophyllum
Arizona Eryngo
Prepared by the
United States Fish and Wildlife Service

EXECUTIVE SUMMARY

This species status assessment reports the results of the comprehensive status review for *Eryngium sparganophyllum* (Arizona eryngo) and provides a thorough account of the species' overall viability and extinction risk. Arizona eryngo is an herbaceous perennial flowering plant in the Apiaceae, or carrot family and occurs in spring-fed aridland cienegas of the International Four Corners Region (i.e., Arizona, New Mexico, Sonora, Chihuahua).

To evaluate the biological status of the Arizona eryngo both currently and into the future, we assessed a range of conditions to allow us to consider the species' resiliency, redundancy, and representation (together, the 3Rs). Arizona eryngo needs multiple resilient populations distributed widely across its range, to maintain its persistence into the future and to avoid extinction. Many factors influence the resiliency of a population in response to stochastic events. The primary factors that we identified, however, are population abundance, recruitment, occupied area, soil moisture, and sunlight. As we consider the future viability of the species, higher overall species viability is generally associated with more populations with high resiliency that are distributed across the known range of this species.

Arizona eryngo is known historically from six sites. It has been extirpated from two known sites (one site in Arizona and one site in New Mexico), but remains extant at the other four sites (two in Arizona [Lewis Springs and La Cebadilla], one in Sonora [Rancho Agua Caliente], and one in Chihuahua [Ojo Vareleño]). Given the historical distribution of functional aridland cienegas, however, it is likely that Arizona eryngo populations were historically more abundant, occurred closer to one another, and were more connected (through pollination and seed dispersal) than they are currently. The remaining populations are isolated from one another, and as of 2018 to 2020, estimates indicate there are 56 to 30,422 individuals per population. We have assessed Arizona eryngo levels of resiliency, redundancy, and representation currently and into the future by ranking the condition of each population. Rankings are a qualitative assessment of the relative condition of occupied cienegas based on the knowledge and expertise of Service staff, as well as reports, papers, and consultation with experts.

Our analysis of the past, current, and future influences on what Arizona eryngo needs for long-term viability revealed that there are two influences that pose the largest risk to future viability of the species: water loss (groundwater withdrawal and water diversion) and invasion of nonnative and woody plant species, both of which are exacerbated by drought and warming caused by climate change. These influences reduce the availability of moist soils and outcompete Arizona eryngo for sunlight and space, thereby reducing the quantity and quality of habitat for the species. Water loss and invasion of plant species, as well as conservation efforts, are carried

forward in our assessment of the future conditions of Arizona eryngo populations and the viability of the species overall.

If populations lose resiliency due to the risks they face, they are more vulnerable to extirpation, with resulting losses in representation and redundancy. Given our uncertainty regarding 1) how climate will change in the future, which in turn will have an effect on the severity of future periods of drought and warming; 2) the amount of water withdrawals and water diversions that will occur in the future; and 3) whether nonnative and woody plants will be managed or allowed to spread, we have forecasted what Arizona eryngo may have in terms of resiliency, redundancy, and representation under two plausible future scenarios: Scenario 1: Continuation; and Scenario 2: Increased Effects. A third conservation planning scenario is included in Appendix 2. These future scenarios forecast the viability of Arizona eryngo over the next 10 and 30 years. Scenario 1, or the Continuation scenario, evaluates the condition of Arizona eryngo if there are no increases in risks to the populations from what exists today. Scenario 2, or the Increased Effects scenario, evaluates the response of the species to changes in risks, including increased levels of climate change, groundwater withdrawal and water diversions, and invasion of nonnative and woody plant species. Scenario 3, or the Conservation Planning scenario (Appendix 2), explores possible conservation strategies that if implemented, could improve current conditions.

Resiliency of Arizona eryngo populations depends on future availability of moist soil in cienega habitats with open sun conditions. We expect the four extant Arizona eryngo populations to experience changes to these aspects of their habitat in different ways under the different scenarios. We projected the expected future resiliency, representation, and redundancy of Arizona eryngo based on the events that would occur under each scenario (Table ES-1).

In 30 years, under Scenario 1 – Continuation, we would expect viability of Arizona eryngo to be characterized by lower levels of resiliency, representation, and redundancy than it has currently. No populations would be in high condition, one would remain in moderate condition, two would be in low condition, and three would be extirpated (i.e., one would become extirpated and two would remain extirpated).

In 30 years, under Scenario 2 – Increased Effects, we would expect viability of Arizona eryngo to be characterized by lower levels of resiliency, representation, and redundancy than it has currently. No populations would be in high condition, one would remain in moderate condition or decrease to low condition, one would be in low condition, one would be on the edge between low and extirpated, and three would be extirpated (i.e., one would become extirpated and two would remain extirpated). Only one population (in moderate condition) would have a greater than a 60% chance of persisting beyond 30 years.

A Species Status Assessment summary for Arizona eryngo is provided in Table ES-2.

Table ES-1. Arizona eryngo population conditions in 30 years under each scenario.

	Population Condition		
Population	**Current Condition**	**Scenario 1- Continuation**	**Scenario 2- Increased Effects**
La Cebadilla	**Moderate**	**Moderate**	**Moderate / Low**
Lewis Springs	**Moderate**	**Low**	**Low / Ø**
Rancho Agua Caliente	**Low**	**Low**	**Low**
Ojo Vareleño	**Low**	**Ø**	**Ø**
Las Playas	**Ø**	**Ø**	**Ø**
Agua Caliente	**Ø**	**Ø**	**Ø**

Table ES-2. Species Status Assessment summary for Arizona eryngo.

3Rs	Needs	Current Condition	Future Condition (Viability)
Resiliency (Large populations able to withstand stochastic events)	• Spring-fed cienega wetlands in the International Four Corners area (Arizona, New Mexico, Sonora, Chihuahua) • Moist, alkaline, organic soils • Full sunlight	• 4 of 6 known populations are extant in Arizona, U.S. and Sonora and Chihuahua, Mexico. • 2 of 6 known populations extirpated from New Mexico and Arizona. • Population Status: ○ 2 moderate resiliency ○ 2 low resiliency	Projections based on future scenarios in 30 years: • **Continuation**: Threats continue on current trajectory. 1 of 4 populations is extirpated. Resiliency of 1 population drops from moderate to low. Resiliency of the other 2 populations remain with moderate and low resiliency. • See Table ES-1 for other scenarios.
Representation (Genetic and ecological diversity to maintain adaptive potential)	• Maintenance of genetic diversity across the remaining 4 extant populations. • Maintenance of remaining 4 extant populations in each area of unique ecological diversity.	• Genetic and ecological representation in each of the 4 extant populations, all of which occur in unique river basins. • Extant populations are currently widely separated, likely resulting in genetic differentiation among them; it is likely that populations were historically more widespread and connected.	Projections based on future scenarios in 30 years: • **Continuation:** 1 area of representation in Mexico is lost due to the extirpation of a population. The other 3 areas of representation are maintained. • See Table ES-1 for other scenarios.
Redundancy (Number and distribution of populations to withstand catastrophic events)	• Multiple populations in each area of genetic and ecological representation	• Each of the 4 areas of representation only have 1 population each for redundancy.	Projections based on future scenarios in 30 years: • **Continuation**: 3 of 4 areas of representation continue to have only one population each for redundancy. 1 population is extirpated. • See Table ES-1 for other scenarios.

Table of Contents

EXECUTIVE SUMMARY iii
CHAPTER 1. INTRODUCTION 1
CHAPTER 2. INDIVIDUAL NEEDS – LIFE HISTORY AND BIOLOGY 5
2.1. Taxonomy and Genetics 5
2.2. Morphology 6
2.3. Life History: Phenology (Seasonal Changes), Reproduction, Lifespan 8
2.5. Resource Needs (Habitat) of Individuals 11
Cienegas 11
Groundwater and Winter Precipitation 12
Moist Organic Soils in Cienegas 13
Sunlight 14
Disturbance and competition reduction 14
Presence of Pollinators 14
Table 2.1. Life History and resource needs of Arizona eryngo. 16
CHAPTER 3. POPULATION AND SPECIES NEEDS 17
3.1. Historical and Current Range, Distribution, Abundance, and Population Site Description 17
Las Playas, New Mexico, United States (Extirpated) 19
Agua Caliente, Arizona, United States (Extirpated) 21
La Cebadilla, Arizona, United States (Extant) 24
Lewis Springs, Arizona, United States 29
Rancho Agua Caliente, Sonora, Mexico 36
Ojo Vareleño, Chihuahua, Mexico 40
3.2. Needs of Arizona eryngo 46
3.2.1. Population Resiliency 46
3.2.2. Species Representation 50
3.2.3. Species Redundancy 50
CHAPTER 4. CURRENT CONDITIONS 52
4.1. Introduction 52
4.2. Current Population Resiliency 52

4.3. Current Species Representation 55
4.4. Current Species Redundancy 55
CHAPTER 5. INFLUENCES ON VIABILITY 57
5.1. Physical loss and alteration of cienega habitat 57
5.2. Water loss 59
Groundwater withdrawal 60
Spring modification 61
Water diversion 61
Drought and warming 61
5.3. Change in Vegetation at Cienegas 63
5.4. Direct Harm and Mortality 64
5.5. Summary 65
CHAPTER 6. VIABILITY AND FUTURE CONDITIONS 67
6.1. Introduction 67
6.2. Future Scenarios and Considerations 68
Climate considerations 70
6.3. Viability (Resiliency, Redundancy, and Representation) 71
6.3.1. Scenario 1 – Continuation 71
6.3.2. Scenario 2 – Increased Effects 76
6.4. Status Assessment Summary 80
Literature Cited 82
APPENDIX 1. Evaluating Causes and Effects for Arizona Eryngo 1-1
APPENDIX 2. VIABILITY UNDER A CONSERVATION PLANNING SCENARIO 2-1

CHAPTER 1. INTRODUCTION

The Species Status Assessment (SSA) framework (FWS 2016, entire) is an analytical approach to assess the species needs, current status, and future status of a species using the best available information. The SSA Framework uses the conservation biology principles of resiliency, redundancy, and representation (collectively known as the "3Rs") as a lens to evaluate the current and future condition of the species. The result is an SSA Report that characterizes species' ability to sustain populations in the wild over time (viability) based on the best scientific understanding of current and future abundance and distribution within the species' ecological settings. The intent is for the SSA Report to be easily updated as new information becomes available and to support all functions of the U.S. Fish and Wildlife Service (FWS; we) Endangered Species Program from Candidate Assessment to Listing to Consultations to Recovery. As such, the SSA Report will be a living document upon which other documents, such as listing rules, recovery plans, and 5–year reviews, would be based if the species warrants listing under the Endangered Species Act (ESA).

Eryngium sparganophyllum is an herbaceous perennial flowering plant in the Apiaceae, or carrot family (Hooker 1897, p. 42; Stromberg et al. 2019, p. 8). Arizona eryngo is a cienega (or wetland) obligate known historically from six sites: three sites in Arizona and one site in New Mexico, United States (U.S.); and one site in Sonora and one site in Chihuahua, Mexico (Sánchez Escalante et al. 2019, pp. 16-17; Stromberg et al. 2019, pp. 3-8). It likely historically occurred at additional cienegas, as discussed in various sections below (e.g., 2.5, 3.1). As detailed below, it has been extirpated from two sites (one site in Arizona and one site in New Mexico), but remains extant at the other four sites (two in Arizona, one in Sonora, and one in Chihuahua) (Sánchez Escalante et al. 2019, pp. 16-17; Stromberg et al. 2019, pp. 4-5). Some individual plants have been reintroduced to an historical site (one of the sites from which Arizona eryngo was extirpated) in Arizona (Stromberg et al. 2019, pp. 10).

New Mexico

1) **Las Playas population**: Extirpated. Arizona eryngo historically occurred at Playas or Las Playas Springs, east of the Animas Mountains in Hidalgo County, but, despite surveys, has not been found since 1851 and is assumed extirpated in that state (Sivinski 2018, p. 21; Stromberg et al. 2019, p. 4).

Arizona

1) **Agua Caliente population**: Extirpated but reintroduced. Arizona eryngo historically occurred at the Agua Caliente Ranch east of Tucson in Pima County (Stromberg et al. 2019, p. 5). The property is now owned by Pima County and experimental reintroductions occurred in 2016-2019 with mixed success. Additional augmentation is expected in the near future (Stromberg et al. 2019, p. 5, 10).
2) **La Cebadilla population**: Extant. Arizona eryngo occurs in the La Cebadilla Cienega near the Tanque Verde Wash east of Tucson in Pima County (Stromberg et al. 2019, p. 5). The cienega is located on lands owned by La Cebadilla Estates and the Pima County Regional Flood Control District.
3) **Lewis Springs population**: Extant. Arizona eryngo occurs in the Lewis Springs Cienega near the San Pedro River in Cochise County (Stromberg et al. 2019, p. 5). The cienega is

located within the San Pedro Riparian National Conservation Area managed by the Bureau of Land Management.

Sonora, Mexico

1) **Rancho Agua Caliente population**: Extant. Arizona eryngo occurs in the Cienega Agua Caliente on the privately-owned Rancho Agua Caliente east of Esqueda in the municipality of Nacozari de García (Sánchez Escalante et al. 2019, p. 16; Stromberg et al. 2019, p. 7).

Chihuahua, Mexico

1) **Ojo Vareleño population**: Extant. Arizona eryngo occurs at a privately-owned hot springs spa, El Ojo Vareleño, located northwest of Casas Grandes in the municipality of Casas Grandes (Sánchez Escalante et al. 2019, p. 9; Stromberg et al. 2019, pp. 6-7).

Reports of the species further south in the Mexican states of Durango, Jalisco, Nayarit, Zacatecas, Michoacan, and Guerrero are likely not valid because the herbarium specimen from Durango, Mexico, is morphologically different from northern specimens (Stomberg et al. 2019, p. 7). Additionally, a report of the species occurring in Zacatecas, Nayarit, and Jalisco lacks supporting herbaria records (Stromberg et al. 2019, p. 7); and specimens collected from Michoacán and Guerrero appear to be a distinct taxon due to differences in flower color, habitat, elevation, and flowering time (Stromberg et al. 2019, p. 8). For the purposes of this assessment these reports are not considered to represent the species.

On April 9, 2018, the FWS received a petition from the Center for Biological Diversity, requesting that *Eryngium sparganophyllum* be listed as endangered or threatened and critical habitat be designated for this species under the Act. On April 26, 2019, the FWS published a 90-day finding (84 FR 17768) concluding that the petition presented substantial scientific or commercial information indicating that listing of the Arizona eryngo may be warranted. This SSA Report for Arizona eryngo is intended to provide the biological support for the decision on whether or not to propose to list the species as threatened or endangered under the ESA and, if so, where to propose designating critical habitat. Importantly, the SSA Report does not result in a decision by the FWS on whether this species should be proposed for listing as a threatened or endangered species under the ESA. Instead, this SSA Report provides a review of the available information strictly related to the biological status of Arizona eryngo. The listing decision will be made by the FWS after reviewing this document and all relevant laws, regulations, and policies, and the results of a proposed decision will be announced in the *Federal Register,* with appropriate opportunities for public input.

For the purposes of this SSA, we are analyzing impacts to populations. Also, for the purpose of this SSA, we define a population as all Arizona eryngo occurring within the same cienega or cienega complex and within the distance pollinators can travel. Populations of Arizona eryngo consist of approximately 56 to over 30,422 plants (Li 2020b, p. 1; Sánchez Escalante et al. 2019, p. 17, Stromberg et al. 2019, p. 6). Currently, we are aware of the four extant populations discussed above (La Cebadilla, Lewis Springs, Rancho Agua Caliente, and Ojo Vareleño). At La Cebadilla and Lewis Springs, Arizona eryngo occur in distinct patches referred to as colonies (Li 2020a, p. 1), which we consider a subunit of a population.

For the purpose of this assessment, we generally define viability as the ability of Arizona eryngo to sustain populations in natural systems over time. Using the SSA framework (Figure 1.1), we consider what the species needs to maintain viability by characterizing the status of the species in terms of its resiliency, redundancy, and representation (Wolf et al. 2015, entire).

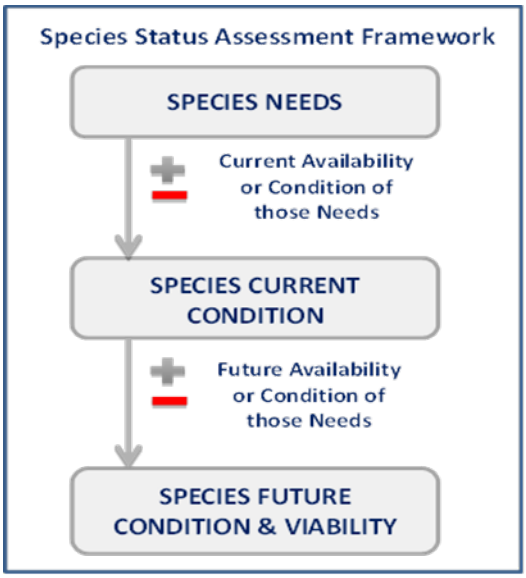


Figure 1.1 Species Status Assessment framework

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

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

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

To evaluate the biological status of Arizona eryngo into the future, we assessed a range of possible future conditions to allow us to consider the species' resiliency, redundancy, and representation. This SSA Report provides a thorough assessment of biology and natural history and assesses demographic risks, stressors, and limiting factors in the context of determining the viability and risks of extinction for the species going forward.

The format for this SSA Report includes: (1) this introduction (Chapter 1); (2) the life history, biology, and resource needs of individuals (Chapter 2); (3) the historical and current distribution of Arizona eryngo and a framework for determining the distribution of resilient populations across its range for species viability (Chapter 3); (4) current condition of the species (Chapter 4); (5) the likely causes of the current and future status of the species and stressors that affect the species' viability (Chapter 5); and (6) a description of species viability in terms of resiliency, redundancy, and representation (Chapter 6). This document is a compilation of the best available scientific and commercial information and a description of past, present, and likely future risk factors to Arizona eryngo.

CHAPTER 2. INDIVIDUAL NEEDS – LIFE HISTORY AND BIOLOGY

In this chapter we provide basic biological information about Arizona eryngo, including its taxonomic history, genetics, morphological description, and known life history traits. We then outline the resource needs of Arizona eryngo individuals. Here we report those aspects of the life history of Arizona eryngo that are important to our analysis in determining the viability of the species as it relates to resiliency, representation, and redundancy.

2.1. Taxonomy and Genetics

Eryngium sparganophyllum is an herbaceous perennial flowering plant in the Apiaceae, or carrot family (Wooton and Standley 1915, 475-478; Hooker 1897, p. 42). Arizona eryngo is one of about 250 species in the genus worldwide (Calviño et al. 2008, p. 1130); it is one of 30 *Eryngium* species native to the U.S. (with an additional two in the U.S. that are naturalized), and one of five known from Arizona, although one (*E. phyteumae*) has not been seen since 1882 (Calviño personal communication April 5, 2020). Arizona eryngo was first described by botanist William Hemsley and illustrated by Matilda Smith in Hooker's Icones Plantarum (Hooker 1897, p. 42) from the specimens collected by Charles Wright at Las Playas, New Mexico (the type locality) in 1851 (Stromberg et al. 2019, p. 4; Wooton and Standley 1915, p. 478; Hooker 1897, p. 42).

The currently accepted classification (Calviño and Downie 2007, p. 1; Calviño et al. 2008, p. 1129, ITIS 2020) is:

Kingdom: Plantae, plants
Subkingdom: Viridiplantae, green plants
Infrakingdom: Streptophyta – land plants
Superdivision: Embryophyta
Division: Tracheophyta, vascular plants
Subdivision: Spermatophytina
Class: Magnoliopsida
Superorder: Asteranae
Order: Apiales
Family: Apiaceae
Subfamily: Saniculoideae
Tribe: Saniculeae
Genus: Eryngium L. – eryngo
Subgenus: Monocotyloidea
Species: *Eryngium sparganophyllum* Hemsl. – Arizona eryngo

To our knowledge, there are no population genetic or phylogeographic studies on Arizona eryngo. However, some information about the phylogenetic position of the species, and ploidy level is available, that may eventually help to understand the genetic diversity of the species. Based on phylogeny, the species falls within a clade named "North American monocotyledonous" within *Eryngium* subgenus Monocotyloidea (Calviño et al. 2008, p. 1129). That clade, includes all North American species of *Eryngium* sampled in that study with a monocotyledonous habit. These plants are characterized by the possession of sessile, generally

linear, parallel-veined leaves and a well-developed cauline axis (erect and with several internodes). Most of them are polyploids, with conspicuous involucral bracts (Calviño et al. 2008, p. 1145).

Chromosome counts of Arizona eryngo indicate that the species is polyploid (Bell and Constance, 1966; n=16, tetraploid). Also, nrDNA ITS sequence analyses showed that the accession of Arizona eryngo showed evidence of ITS sequence additivity at several nucleotide sites, as inferred by overlapping peaks on electropherograms from both forward and reverse sequencing runs (Calviño et al. 2008, 1146). These results, suggest that Arizona eryngo might had an allopolyploid origin.

With regard to genetic diversity of Arizona eryngo, given 1) the large distance between extant populations (greater than 90 kilometers [km]; 56 miles [mi], see section 3.1 below) that decreases the likelihood of pollination between populations, 2) the hypothesized high rate of clonality of at least one population (Lewis Springs) (see section 2.3 below), and 3) the extirpation of two historical populations and overall fragmentation of the species' distribution, it is possible that genetic diversity within populations may be relatively low and genetic variability among populations relatively high. As such, and for this SSA, it is currently assumed that there is lower genetic diversity within populations and higher genetic variability between populations, however, genetic analyses are necessary to confirm this.

Genetic studies will help elucidate patterns of within and among population genetic diversity, as well as the ramet (clone) to genet (distinct genetic individuals) ratio of populations. In addition, genetic analyses may reveal how long it has been since the populations exchanged gene flow (i.e., how genetically unique the populations are), how the contemporary population size compares to past population sizes (e.g., prior to landscape development and other disturbances), and inbreeding in contemporary populations. Understanding these factors would help scientists and managers make accurate estimates of effective population size (e.g., effective population sizes can be overestimated when ramets are mistaken for genets; Tependino 2012, p. 945), as well as help define management units for the species (e.g., determine which populations are genetically similar enough such that they may be considered a single unit).

2.2. Morphology

Arizona eryngo is an herbaceous perennial dicot that grows to a height of about 1.5 meters (m) (~5 feet [ft]) with long, linear, parallel-veined leaves that emerge from a basal rosette (Stromberg et al. 2019, p. 3, Makings 2013, p. 74) (Figure 2.1). The plant is conspicuous when flowering (Makings 2013, p. 74) in June through September (Stromberg et al. 2019, p. 8; New Mexico Rare Plants 2013, p 1). The flowers are cream-colored and clustered in dense heads at the end of the branching, scapose inflorescences (Stromberg et al. 2019, p. 3; Makings 2013, p. 74). The flower heads are ovoid or ovoid-oblong and are 12-25 millimeters (mm) (0.47-0.98 inch [in]) long and 10-15 mm (0.39-0.59 in) wide, with several ovate or lanceolate basal bracts and similar, but smaller bractlets within the head that barely exceed to the length of the fruits (New Mexico Rare Plants 2013, p 1). The fruit, a schizocarp splitting into two mericarps, is ovoid and 3-4 mm (0.12-0.16 in) long (Stromberg et al. 2019, p. 8; New Mexico Rare Plants 2013, p 1). Root depth

is uncertain, but roots grow to at least 20 cm and likely beyond (Li personal communication December 11, 2019) (Figure 2.2).

Figure 2.1. Arizona eryngo in flower on August 15, 2018 at La Cebadilla Springs, Arizona (photo credit: Jeff Simms 2018).

Figure 2.2. Arizona eryngo roots extending beyond 20 cm (photo credit: Yue "Max" Li 2019).

2.3. Life History: Phenology (Seasonal Changes), Reproduction, Lifespan

Arizona eryngo grown in nurseries can flower in their first year. At natural sites, plants flower from June to September (Stromberg et al. 2019, p. 8; New Mexico Rare Plants 2013, p 1). Dry fruits ripen in September and October (Li 2020, p. 2; AGFD 2019, p. 2; Stromberg et al. 2019, p. 8). Stromberg et al. (2019, p. 8) studied plants at Lewis Springs and found that mature plants in 2018 produced an average of 1.75 flowering stalks, each with an average of 3.4 inflorescences per stalk (up to 12 inflorescences per stalk had been observed in prior years). In 2014, they found that each inflorescence contained an average of 96 flowers and therefore, given the two seeds per fruit, estimated that an individual plant could produce several hundred seeds per season. They reported that the observed number of flowering stalks was considerably lower at Lewis Springs in 2018 than in prior years, as surface soils were subjectively drier, with saturated conditions detected only when excavating several centimeters (cm) into the wetland soils. Li (2019, p. 8), based on his observations of the species at La Cebadilla, also hypothesizes that flowering is determined by soil moisture availability and temperature (i.e., summer warmth).

Aboveground, plants dieback partially or completely in the winter months such that almost no green or very little green aboveground structure can be seen (Li 2020, p. 9).

While little is known about the reproductive strategy/ecology of Arizona eryngo, it is likely that pollinators are required for cross-pollination in this species. Pollinators do not seem to be lacking and abundant animal activity on the flowers is readily observed (Li, p. 8; J. Simms 2019, p. 1, Stromberg et al. 2019, p. 8). Another *Eryngium* similar in appearance to Arizona eryngo, *E. yuccifolium* (rattlesnake master) is xenogamous species (transfer of pollen grains from the anther to the stigma of a different plant) with temporal dioecism (Molano-Flores 2001, p. 5). Temporal dioecism is a synchronized flowering sequence that allows pollen to be shed before any stigma becomes receptive, minimizing geitonogamous pollinations (the fertilization of a flower by pollen from another flower on the same or a genetically identical plant) and maximizing outcrossing (Molano-Flores 2001, p. 5).

The patterns of seed dispersal, germination percentages, and the rates of seedling establishment in the wild are not known (AGFD 2019, p. 2; Stromberg et al. 2019, p. 8). Arizona eryngo seeds are large and heavy and therefore are not likely to fall far from the mother plant. The height and the swaying of the inflorescence suggests that seeds may be dispersed by wind, but only short distances. Barbs around the seeds, however, likely function as hooks that may enable dispersal via attachment to mammals and birds (Blackwell et al. personal communication May 8-11, 2020).

We are unaware of any information available regarding the seedbank of Arizona eryngo, although the recruitment of Arizona eryngo as a result of removal of other plant species indicates that there might be a long lasting seed bank in the soil in Lewis Springs and that vigorous growth of other plant species may be limiting the recruitment of Arizona eryngo. *E. yuccifolium* (rattlesnake master), is very abundant in the seedbank (Molano-Flores 2001, p. 5).

Arizona eryngo seeds exhibit morphophysiological dormancy (Wolkis et al. 2020, p. 1). Seed germination of Arizona eryngo (collected from La Cebadilla) under nursery conditions, without dormancy breaking treatments, was 31% (Stromberg et al. 2019, p. 8). Physiological dormancy can be broken using cold stratification or application of gibberellic acid (Wolkis et al. 2020, p. 7, Stromberg et al. 2019, p. 8). After subjecting seeds to low temperature (4 degrees Celsius) and moisture (wet paper towel) for 80 days, germination of 72% was reached (Li 2020, p. 10). Seeds will germinate in the dark (i.e., cold stratifying seeds in a dark refrigerator) (Blackwell et al. personal communication May 8-11, 2020). Seeds were collected from Lewis Springs in September 2019, but despite using the same aforementioned germination methods, seeds did not germinate initially (Blackwell personal communication March 18, 2020). Attempts to germinate seeds from Lewis Springs have continued and resulted in some limited germination.

The species also reproduces vegetatively via rhizomes (underground stems) thus indicating ramet (clone) production (Stromberg et al. 2019, p. 8). Each clone has a unique basal stem, and multiple clones can form a clustered aggregate that resembles an individual plant (Li 2020, p. 2). Of the 29 juveniles sampled in 2018 at Lewis Springs, two were excavated and determined to be ramets (Stromberg et al. 2019, p. 8). Makings (Makings personal communication September 5, 2019) hypothesizes that much of the Lewis Springs population is clonal, with mature individuals

likely sending out ramets. It is hypothesized that ramets are produced during drier periods (Li 2019, p. 8; Stromberg et al. 2019, p. 8). Clonal integration (clones that remain connected) can help plants growing in patchy environments to deal with drought stress (Zhang et al. 2012, p. 7). High seedling mortality was observed at La Cebadilla in late spring/early summer 2020, likely because Arizona eryngo roots could not grow fast enough to follow the rapid drop in groundwater levels in late May to early June (Li personal communication August 17, 2020). This observation suggests that seedling recruitment may be episodic, with greater recruitment success in wetter years. When the plant is growing in dense patches, as in Figure 2.1, identifying individual plants (genet versus ramet) is difficult and this may affect population estimates of the species.

The lifespan and lifetime reproductive potential of Arizona eryngo is unknown (AGFD 2019, p. 1; Stromberg et al. 2019, p. 8). The species is hypothesized to be a long-lived perennial that can live well over 10 years (Blackwell personal communication December 10, 2019). In a nursery setting, as of December 2019, individuals are still alive and doing well that were germinated in December 2014/January 2015, making the minimum documented lifespan 5 years. These 5-year old nursery plants have flowered but are a fraction of the size of the adult plants in the wild at La Cebadilla, indicating the nursery plants are still young (Blackwell personal communication December 10, 2019). Importantly, because the species is clonal, genet age is difficult to measure in the wild, but continuous vegetative reproduction of genets may lead to a very long lifespan (i.e., maximum longevity of some clonal trees is thousands of years) (deWitte and Stocklin 2010, pp. 859, 862; Blackwell personal communication December 10, 2019). Another *Eryngium*, *E. maritimum*, a declining perennial clonal species native to the coastal littoral zone in Northern Europe, the Middle East, and North Africa (and naturalized in Australia and North America), is thought to have a genet lifespan of several decades (Isermann and Rooney 2014). High developmental plasticity (i.e., high ability to adapt to and cope with changes in its environment) at the root level of *E. maritimum* leads to clonal growth and an efficient survival and relatively long lifespan of individuals (Andersone et al. 2010, p. 509). *E. yuccifolium* is also considered long-lived.

No diseases have been documented in Arizona eryngo at cienegas, however, nursery plants experienced high mortality and severe disease symptoms as *Fusarium* strains attacked heat stressed individuals in 2020 (Li 2020c, p. 1). Plants recovered from the fungal disease after being moved to greenhouse with lower daytime temperatures (Li 2020c, p. 1).

While we currently know little about the demographic parameters (e.g., survival, growth, and fecundity) of Arizona eryngo, research currently being conducted by Dr. Yue "Max" Li with a FWS section 6 research grant should help us better understand the life history and demography of the species. Additionally, seed has been collected from populations at La Cebadilla and Lewis Springs. Some of the seed is being stored at the Desert Botanical Garden seed bank; and part of the seed has been, and continues to be, grown at the Desert Botanical Garden and Pima County Nursery for outplanting and research purposes. To maintain separate genetics, seeds from the two populations are being held separately and plants from each population will not be allowed to cross-pollinate. Research on nursery plants should also improve our understanding of species.

2.5. Resource Needs (Habitat) of Individuals

Arizona eryngo requires perennially moist, organic alkali soils found in spring-fed cienegas supported by adequate groundwater (Figure 2.3). Plants grow best in full sun in areas with few nonnative plant species, limited woody vegetation, or other vegetation that may shade or otherwise outcompete them. While the species reproduces asexually, pollinators are likely needed for sexual reproduction necessary to maintain genetic diversity. These resource needs are discussed below and summarized in Table 2.1.

Cienegas

Arizona eryngo is a habitat specialist and only occurs in spring-fed cienega wetlands of Arizona, New Mexico (now extirpated), Sonora, and Chihuahua at elevations ranging from 825 to 1,492 m (Stromberg et al. 2019, pp, 9, 14). Four of six of the spring-fed cienegas were/are thermal springs (Agua Caliente, Arizona; Las Playas, New Mexico; Rancho Agua Caliente, Sonora; and Ojo Vareleño, Chihuahua).

The term cienega is defined differently by various authors (e.g. NatureServe accessed 11-8-2019; Stromberg 1993, p. 2; Hendrickson and Minckley 1985, p. 131). While the term cienega has been used to describe various aquatic systems, NatureServe (accessed 11-8-2019) applies the term to North American Warm Desert, freshwater spring-fed wetlands, with potential saline margins (from high evaporation) occurring below 2,000 m elevation. Hendrickson and Minckley (1985, pp. 131, 133-134) apply the term to mid-elevation (1,000-2,000 m) freshwater wetlands associated with perennial springs and headwater streams, with permanently saturated, highly organic, reducing soils located in semidesert grassland or Madrean evergreen woodland. Stromberg (1993, p. 2) suggests cienegas are a wetland type found throughout the southwest that include warm-temperate riverine marshlands of southern Arizona semidesert grasslands at elevations between 1,100 and 1,500 m (3,609 and 4,921 ft). Cole and Cole (2015, p. 2) define cienegas as freshwater or alkaline wet meadows with shallow-gradient, permanently saturated soils in otherwise arid landscapes that support lush meadow grasses and explain that cienegas occur because geomorphology forces water to the surface.

Most cienegas are associated with springs (complex ecosystems in which groundwater reaches the earth's surface; Stevens and Meretsky 2008, p. 3) and are low gradient wetlands that serve to slow water and trap organic materials and nutrients (Sivinski and Tonne 2011, p. 1; Hendrickson and Minckley 1985, pp. 133-134). Spring-dominated cienegas are maintained by fault lines crossing aquifers and/or the intersection of wetland sites with shallow aquifers overlaying a deeper, impervious layer, both of which allow for groundwater to be forced to the surface (Minckley et al. 2013a, p. 214; Johnson et al. 2016, pp. 80-81). Cienegas are often found in the upper reaches of small drainages or above river channels in a variety of surrounding vegetation communities, and thus are protected from scouring floods (Sivinski and Tonne 2011, p. 2). Dominant vegetation in cienegas includes grasses, *Carex* spp. (sedges), *Cyperus* spp. (flatsedges), and *Eleocharis* spp. (spikerush; Stromberg et al. 2017, p. 8; Hendrickson and Minckley 1985, p. 136). Cienega vegetation decomposes annually, leading to the layers of organic peats and fine-textured silts that are trapped during occasional flood flows.

Functional cienegas were much more common prior to the late 1800s (Brunelle et al. 2018, p. 2; Cole and Cole 2015, p. 36; Fonseca 1998, p. 111; Hendrickson and Minckley 1985, p. 131). Recent estimates of cienega abundance in the International Four Corners Region of the Southwest (Arizona, Sonora, New Mexico, and Chihuahua) vary from hundreds to thousands and the number increases as new information is gathered (Cole and Cole 2015, p. 36). Many of these cienegas retain some ecological function or are restorable, while others are so compromised that there is no prospect for their restoration (Cole and Cole 2015, p. 36; Sivinski 2018, p. 4). In addition to the reduced abundance of cienegas, the remaining cienegas are greatly reduced in size and due to many being severely incised, they are more like creeks than marshes (Cole and Cole 2015, p. 36). Greater than 95% of the historical area of cienegas is now dry (Cole and Cole 2015, p. 36). Given the historical distribution of functional aridland cienegas, it is highly likely that Arizona eryngo populations were historically more abundant, occurred closer to one another, and were more connected (through pollination) than they are currently.

Groundwater and Winter Precipitation

Cienegas have water tables at or near the ground surface (Norman et al. 2019, p. 4) and are therefore maintained by the discharge of groundwater from relatively shallow aquifers. These groundwater aquifers, in turn, are typically recharged by infiltration of precipitation, at both a regional scale and within ephemeral streams along mountain fronts (Pool 2005, p.1). Winter precipitation dominates as an overall recharge source because precipitation produced by frontal storms is typically longer in duration and less intense and evaporation and transpiration rates are lower during winter months (Guido 2008, p. 4; Serrat-Capdevila et al. 2007, p. 50; Wahi et al. 2008, pp. 420-421; Pool 2005, p. 3). Summer precipitation is produced primarily by monsoonal thunderstorms that can be of greater intensity than winter frontal storms, but generally contribute less to groundwater recharge because precipitation is shorter in duration, storms are localized, and evaporation and transpiration rates are high (Serrat-Capdevila et al. 2007). Infiltration of summer streamflow, however, can be an important source of recharge in some locations due to variable interannual precipitation, hydrology, and/or lithology (Eastoe and Wright 2019, p. 17; Baille et al. 2007).

Johnson et al. (2016, p. 3) succinctly explain that "the wetland water balance describes water inflows, outflows and changes in groundwater storage in the wetland. Wetland inflow comes directly from groundwater and indirectly from precipitation. Wetland outflows include evapotranspiration, groundwater discharge to surface water, and groundwater withdrawals from wells, which became a significant anthropogenic impact to groundwater storage starting in the mid-20th century." A decline in groundwater inflow (recharge) or increase in groundwater outflow (discharge) (e.g., from groundwater withdrawal, drought, increased evapotranspiration) can lead to reductions and disruptions in springflow, or elimination of springs and wetlands altogether (Johnson et al. 2016, p. 52).

The water source of Lewis Springs Cienega is supplied by mountain front recharge to the local aquifers, as opposed to monsoonal surface flows (Baillie et al. 2007, p. 7; Stromberg et al. 2019, p. 6). Lewis Springs' water is a mixture of Huachuca and Mule Mountains groundwater (Meixner 2018). The percentage of water from each mountain range supplying Lewis Springs varies depending on values used in the calculation, but regardless, sources of water from both

east (Mule Mountains) and west (Huachuca Mountains) of the San Pedro River are important to Lewis Springs (located on the east side of the river) (Meixner 2018).

The water source of La Cebadilla Cienega groundwater at La Cebadilla discharges from gneiss (a foliated rock formed by regional metamorphism) at the mountain front (Olson 1982, p. 101). The water, from an aquifer confined by the Catalina detachment fault, is likely thousands of years old on the basis of comparison with similar groundwater in the area (Eastoe personal communication December 16, 2019). Cross section and water quality information suggest there are two water sources for the Agua Caliente Spring in Arizona: 1) alluvial water from Agua Caliente Wash recharge and shallow mountain front tributary alluvium; and 2) deep thermal artesian water from deep connected bedrock fractures (Postillion et al. 2014, p. 1).

Moist Organic Soils in Cienegas

Arizona eryngo occurs in perennially moist, alkaline, organic soils typical of cienegas. Analysis of soils at La Cebadilla revealed they are high in organic matter, saline, alkaline, and have salts on soil surfaces in the seasonally dry periphery (Stromberg et al. 2019, p. 6, 14). In addition to having approximately 20% organic matter, soils at La Cebadilla have approximately 50% silt and clay (Wolkis 2016, p. 80). Simms (2018, p. 16) additionally reported that La Cebadilla soils are a Silty Clay Loam with 60-75% Silt; 25-40% Clay; and 0-20% Sand. Soils with a higher clay and organic content hold water longer (Fonseca 2018, p. 7, A. Simms 2019, p. 16). The soils at Lewis Springs and Rancho Agua Caliente are also alkaline (Stromberg et al. 2019, pp. 6-7).

Arizona eryngo has been documented in standing water up to 2 cm to soil that is dry at the surface but saturated several centimeters into the soil (Stromberg et al. 2019, pp. 6, 8). It is hypothesized that flowering is determined, in part, by soil moisture availability (i.e., plants do not flower in drier conditions when the plants are more stressed) and that ramets are produced during drier periods (Li 2019, p. 8; Stromberg et al. 2019, p. 8). Some standing water may be needed for breaking seed dormancy. Seedling recruitment may be episodic, with greater recruitment success in wetter years. Soils must remain sufficiently moist for successful seedling recruitment, particularly in the hottest/driest time of the year (normally May/June).

Spatial distribution of Arizona eryngo within cienegas appears to be associated with water availability, with drier conditions favoring the growth of trees that outcompete the species, and very wet conditions (i.e., perennially standing water) favoring the growth of bulrush (*Schoenoplectus americanus*) that similarly outcompetes Arizona eryngo (Li 2019, p. 4). Arizona eryngo reestablishment efforts at Agua Caliente Park suggest that the amount of water available influences plant growth more than soil type soil type at the site (A. Simms 2019, p. 38). In a nursery setting, plants are grown in conditions such that some moisture is always available (Blackwell personal communication December 10, 2019), but where associated plants do not reduce light availability. Further research is needed on the optimal amount, duration, and seasonal timing of soil moisture to support Arizona eryngo flowering and seedling establishment.

In summary, Arizona eryngo requires perennially moist to saturated soils and likely some standing water for breaking seed dormancy. Soils in cienegas where the species occurs are organic and alkaline. While various observations (e.g., at plant nurseries and reestablishment

sites) suggest the species may be able to grow in other soil types, soils that are high in clay and organic matter have higher water-holding capacity which is critical for Arizona eryngo.

Sunlight

Arizona eryngo favors open sun conditions (Stromberg et al. 2019, p. 9). At La Cebadilla Cienega, Arizona eryngo is more abundant in open areas than in areas shaded by riparian trees (e.g., Fremont cottonwood [*Populus fremontii*], velvet mesquite [*Prosopis velutina*], and Arizona ash [*Fraxinus velutina*]); in open sun, Arizona eryngo had average cover of about 56%, compared to about 14% under canopy cover (Stromberg et al. 2019, p. 5). Colony boundaries at most sites (i.e., La Cebadilla, Lewis Springs, and Ojo Vareleño) are defined by the presence of native vegetation (e.g., bulrush, baccharis [*Baccharis* sp.], trees) and nonnative vegetation (e.g., Johnsongrass [*Sorghum halepense*], giant cane/reed [*Arundo donax*]) (Li 2019, p. 1; J. Simms 2019, entire; Sánchez Escalante et al. 2019, p. 10). Plants observed in November 2019 and January 2020 under tree (Arizona ash) canopy at La Cebadilla showed a reduction in flowering that year and leaves appeared less upright (more prostrate) and etiolated compared to nearby Arizona eryngo in sunnier conditions (Li 2020a, p. 11). It is likely that some of this wilting may have be attributed to drying of soils due to transpiration of the ash trees, and not entirely to shade produced by ash trees.

Disturbance and competition reduction

Many plant species require periodic disturbance to remove competing vegetation and maintain sunlight levels needed for germination and growth, or increase available nutrients required for flowering and seed development. Prior to European arrival, fire was likely the dominant source of disturbance (in and surrounding cienegas) that helped maintain open canopies (i.e., exclude woody plants) and promote the growth of grass species, (Cole and Cole 2015, p. 32). Fire suppression after European arrival contributed to the loss and alteration of cienegas (Cole and Cole 2015, p. 2). Other sources of disturbance may include floods, grazing, water fluctuations, and wind.

It appears that Arizona eryngo is generally outcompeted by native vegetation (*Schoenoplectus* spp. and woody plants) and nonnative, invasive species, as described above. Under appropriate conditions (e.g., soils that dry on the surface for part of the year and have standing water for part of the year), however, Arizona eryngo can persist with dense surrounding native vegetation. But without disturbance to create space in such dense native vegetation, seedling establishment appears nearly impossible and ramet production is favored. At Lewis Springs, disturbance of wetland vegetation (shallow holes dug next to Carsonite markers) seems to have created space and allowed for establishment of Arizona eryngo in moist areas where vegetation is normally too dense for self-establishment through seed dispersal or from the seedbank (i.e., isolated Arizona eryngo were found growing in the area disturbed by installation of the markers) (J. Simms 2019, pp. 22-23). More information on the most effective and practicable form of disturbance to promote seedling establishment is needed.

Presence of Pollinators

While reproductive strategy/ecology Arizona eryngo has not been studied, it is likely that pollinators are required for cross-pollination and gene flow in this species. In species where cross-pollination is required, this helps maintains genetic diversity. While Arizona eryngo

reproduces asexually, clonality and isolation of populations may lead to lower genetic diversity (as a result of processes like genetic drift) within and increase genetic separation among populations (Pluess and Stocklin 2004, p. 2013), leading to greater risk of extirpation (through reduced fitness and ability to adapt to changing environmental conditions). As described above, little is known about sexual reproduction of Arizona eryngo, but pollinators do not seem to be lacking and abundant animal activity on the flowers is readily observed (Li, p. 8; J. Simms 2019, p. 1, Stromberg et al. 2019, p. 8). Stromberg et al. (2019, p. 8) has documented arachnids, dragon and damselflies, grasshoppers and katydids, mantids, ant lions, true bugs, beetles, ants, bees, wasps, butterflies, moths, flies, and hummingbirds, interacting with Arizona eryngo, although the success of pollination visitors remains unknown.

Figure 2.3. Example of Arizona eryngo habitat at the La Cebadilla Cienega, Arizona (FWS photo taken July 2, 2019).

Table 2.1. Life History and resource needs of Arizona eryngo.

Life Stage	**Resource Needs (Habitat)**
All stages	Spring-fed aridland cienega wetlands (which are groundwater dependent systems) with perennially moist, alkaline, organic soils. Full Sun.
Seed	Saturated soil or soil with some standing water combined with winter (cold) temperature to break seed dormancy, and then moist soil in warm temperature plus space (bare ground) to allow for germination. Space achieved through disturbance.
Juvenile (ramet or seedling)	Moist soil with some drying on soil surface for part of the year may be necessary to reduce competition with bulrush and possibly other species. Soils must remain sufficiently moist for successful seedling recruitment, particularly in the hottest/driest time of the year (normally May/June).
Adult	Moist soil with some drying on soil surface for part of the year to reduce competition. Likely pollinators for sexual reproduction.

CHAPTER 3. POPULATION AND SPECIES NEEDS

In this chapter, we consider the historical distribution of Arizona eryngo, its current distribution and abundance, and what the species needs for viability. We first review the historical and current information on the range, distribution, abundance, and ecology of the species. We next review the conceptual needs of the species, including population resiliency, redundancy, and representation to support viability and reduce the likelihood of extinction.

3.1. Historical and Current Range, Distribution, Abundance, and Population Site Description

Arizona eryngo is known historically from six sites: three sites in Arizona and one in New Mexico in the U.S., and one site in Sonora and one site in Chihuahua in Mexico (Sánchez Escalante et al. 2019, pp. 16-17; Stromberg et al. 2019, pp. 3-8) (Figure 3.1). Given the historical distribution of functional aridland cienegas, however, it is likely that Arizona eryngo populations were historically more abundant, occurred closer to one another, and were more connected (through pollination) than they are currently. The species has been extirpated from one site in Arizona and one site in New Mexico but remains extant at the other four sites (two in Arizona, one in Sonora, and one in Chihuahua). Additionally, efforts are underway to reintroduce the species to the historical site in Arizona from which it was extirpated (Agua Caliente) and to introduce the species to a new site (Historic Canoa Ranch in Pima County, Arizona) within its general historical range. A handful of plants now exist at these sites, but these efforts have not yet been successful at establishing viable populations. With the exception of the reintroduced plants at Agua Caliente, which is about 6 km from the La Cebadilla population, other populations are about 90 to 335 km (56 to 208 mi) apart from one another. Historical and current populations are discussed in greater detail below and Table 3.1 provides summarized information on these populations. In general, more information is available regarding the sites in Arizona because they have been the subject of various studies.

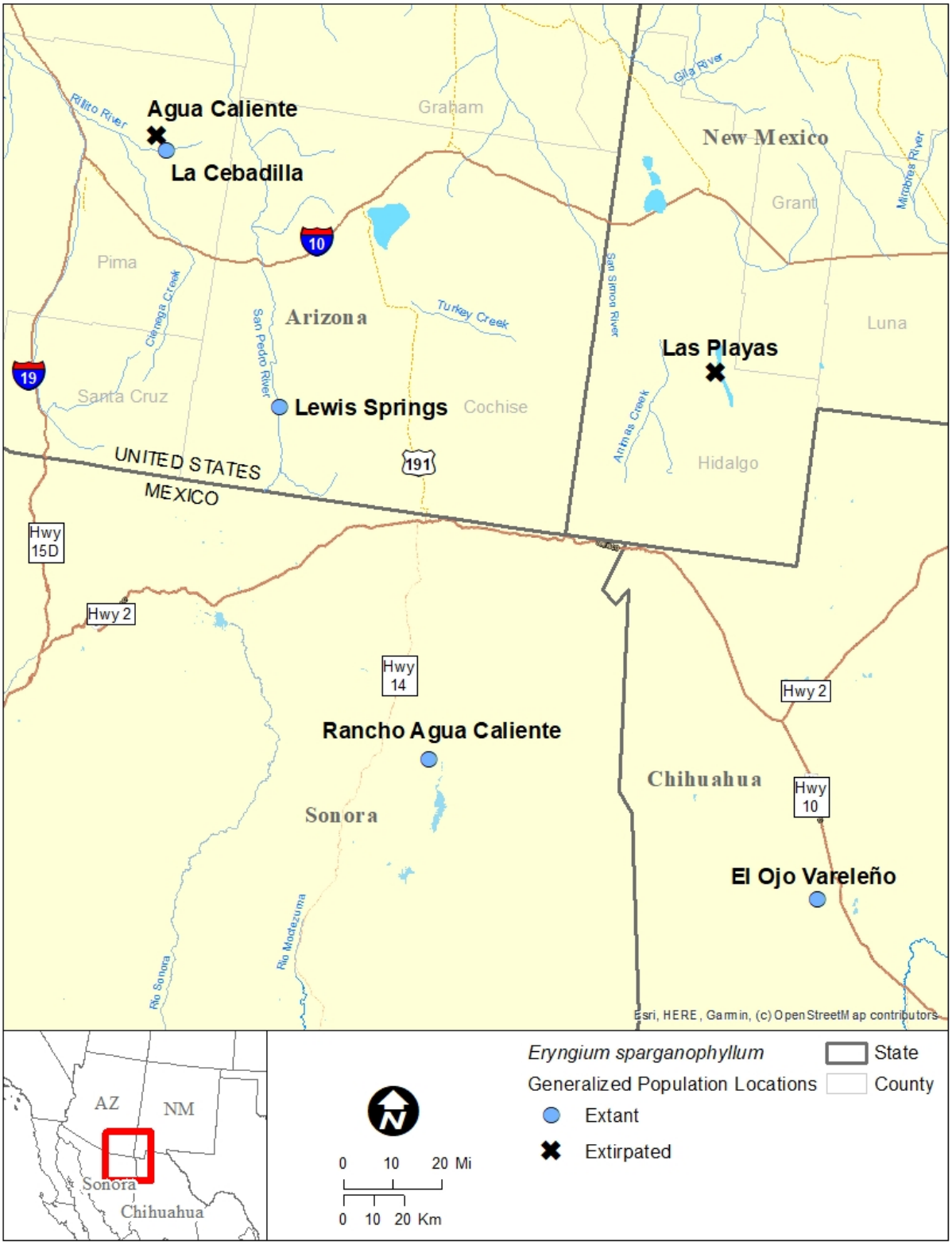


Figure 3.1. Historical and current locations of Arizona eryngo in the United States and Mexico.

Las Playas, New Mexico, United States (Extirpated)

Arizona eryngo (the type locality) historically occurred at Playas or Las Playas Springs in the Playas Basin (which is a closed basin), east of the Animas Mountains in Hidalgo County (Figure 3.2), but has not been found since 1851 and is assumed extirpated in that state (Sivinski 2018, p. 21; Stromberg et al. 2019, p. 4). It is unknown when specifically, the species was extirpated from the site, but the springs were diminished and Las Playas was found primarily dry by the mid to late-1950s (Sivinski 2018, p. 27; Stromberg et al. 2019, p. 5). The cienega at Las Playas is now considered dead (Sivinski 2018, p. 8) due to agricultural and industrial (i.e., copper mining) dewatering (Stromberg et al. 2019, p. 5).

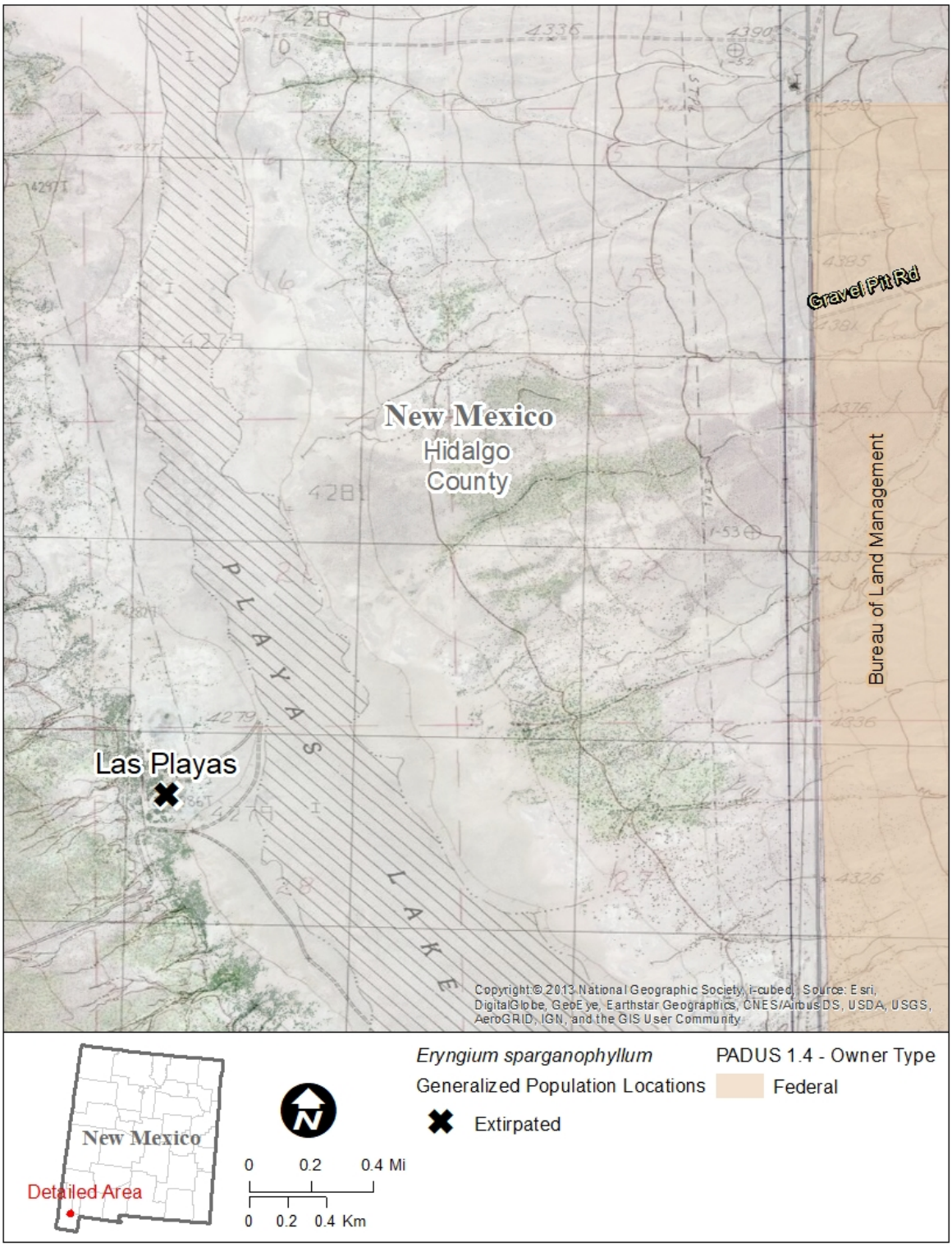


Figure 3.2. Generalized location of the extirpated Las Playas Springs Arizona eryngo population in New Mexico, United States.

Agua Caliente, Arizona, United States (Extirpated)

Arizona eryngo historically occurred at the Agua Caliente Ranch east of Tucson in Pima County, within the Santa Cruz River Basin (Stromberg et al. 2019, p. 5) (Figure 3.3). This population was extirpated in the mid-1900s, likely due to multiple manipulations of the site's hydrology, topography, and vegetation (Stromberg et al., p. 5; SWCA 2002, pp. 11-12, C-5). Some of these manipulations include spring modification and pond impoundment. Two springs (a hot spring and a cold spring) were blasted in the 1930s and again in the 1960s to increase water flow for resort development. Instead, the blasting significantly reduced water flow (Friends of Agua Caliente 2020, entire). Additionally, many wells occur within one mile of Agua Caliente Park, including the Pima County on-site well (used to support Pond 1), which tap the same artesian aquifer that is the source of the spring at Agua Caliente. As a result of spring modification, groundwater pumping, and drought the flow rate from the springs has varied from as high as 500 gallons per minute historically, to an immeasurable seep in recent years (Pima County 2020, entire, Postillion et al. 2014, p. 1).

While the sources and pathways of the spring water are not fully understood, rainfall and snow in the Catalina Mountains contribute to the flow (Pima County 2020, entire). Cross section and water quality information suggest there are two water sources for the Agua Caliente Spring: 1) alluvial water from Agua Caliente Wash recharge and shallow mountain front tributary alluvium; and 2) deep thermal artesian water from deep connected granitic and gneissic bedrock fractures (Postillion et al. 2014, p. 1). Due to winter rains in 2018 and 2019, the spring was flowing at about 35 gallons per minute in January 2020 (Friends of Agua Caliente 2020, entire). Photos of the site that show wetland areas still existed in 1960; however, the extent of wetland was curtailed by 1971 likely due primarily to impoundment of Pond 1.

The property was historically used for various purposes, including military, agricultural, and ranching, as well as a health spa, but is now owned by Pima County Natural Resources, Parks and Recreation and managed as a regional park (Friends of Agua Caliente 2020, entire). Restoration of one of the ponds (Pond 1) began in 2019 and was completed in 2020 (Pima County 2020). This pond is maintained by pumped groundwater, but soil sealant was used during the restoration to reduce seepage and conserve water. As part of the restoration, select palm trees (*Phoenix* spp.) and invasive cattails (*Typha* spp.) were removed to encourage growth of native species and a small wetland on the northwest side of Pond 1 was created (Pima County 2020, entire). Agua Caliente currently supports areas with a range of soil moisture (from standing water to dry soils) and sunlight conditions (from open sun to highly shaded) (see Figures 3.3 to 3.5).

Experimental reintroductions of Arizona eryngo occurred in 2017-2018 (Figures 3.4 and 3.5) using plants grown in a nursery with seeds collected from La Cebadilla (Fonseca 2018, entire; Stromberg et al. 2019, p. 5, 10). The initial reintroduction effort (2017: 20 plants) had limited success due to javelina damaging young plants and placement of the plants at sites where they experienced water stress (Fonseca 2018, entire). The second effort (2018: 15 plants) had improved success, but a number of plants were eaten by gophers (Li 2019, p. 6) or died of other causes. More recent reintroductions have resulted in the establishment of additional plants, including in the small wetland and wildlife island of Pond 1; however, efforts have not yet resulted in the establishment of a viable Arizona eryngo population.

Figure 3.3. Generalized location of the extirpated Agua Caliente Arizona eryngo population in Arizona, United States.

Figure 3.4. Reintroduced Arizona eryngo at Agua Caliente in Arizona, United States (FWS photo taken July 2, 2019).

Figure 3.5. Reintroduced Arizona eryngo at Agua Caliente (Pond 1) in Arizona, United States (Photo credit: Karen Simms, Pima County, photo taken in 2018).

La Cebadilla, Arizona, United States (Extant)

Arizona eryngo occurs in the La Cebadilla Cienega adjacent to the Tanque Verde Wash east of Tucson in Pima County, within the Santa Cruz River Basin (Stromberg et al. 2019, p. 5) (Figure 3.6). The cienega is located on lands owned by La Cebadilla Estates and the Pima County Regional Flood Control District; the majority of plants occur on the privately-owned portion of the cienega. About 1/3 of the 1.2 ha (12,300 m^2; 2.96 acres) cienega provides suitable habitat for Arizona eryngo (Stromberg et al. 2019, p. 6) (Figure 3.7). In 2019, Arizona eryngo was documented in a number of colonies with a total spatial extent of 4,488 m^2 (1.11 acres) (Li 2020, p. 1). Some colony boundaries are defined by the presence of bulrush and tree canopy (Li 2019, p. 1).

The Arizona eryngo population is estimated to be 30,422 genets or aggregates with a 95% confidence interval of the population size, according to the boostrapping estimation, of (19,289, 43,469) genets at Lewis Springs (Li 2020b, p. 1). (Li 2020b, p. 1). As described in section 2.3, each clone has a unique basal stem, and multiple clones can form a clustered aggregate that resembles an individual plant (Li 2020a, p. 2). Li (2020a, p. 2, 2020b, p. 1) refers to such an "individual plant" as a clonal aggregate or genet, which is the basic unit of Arizona eryngo population size. Stromberg et al. (2019, p. 6) estimated Arizona eryngo population size at La Cebadilla in the low thousands (calculated using the estimated spatial extent of 4,494 m^2 and assumption of a minimum of one plant per 2 m^2 quadrat). Further study indicates that the mean

number of individuals per $1m^2$ (in 30 established study plots) was 6.7, which explains why Stromberg et al.'s (2019) estimate was lower. While this is the largest of the four extant populations, the plants occur in a very confined space and remain tied to the fate of the cienega.

The La Cebadilla Cienega occurs within Arizona Upland subdivision of Sonoran Desert Scrub at about 825 m (2,707 ft) in elevation. The climate is semiarid with a mean annual temperature of 20 degrees C and mean annual precipitation of 337 mm (13.27 in) (Stromberg et al. 2019, p 5; Wolkis 2016, p. 35). At this site, Arizona eryngo is primarily associated with *Eleocharis palustris, Muhlenbergia asperifolia, Schoenoplectus americanus*, and *Anemopsis californica*. Other associates of Arizona eryngo at La Cebadilla Cienega were *Almutaster pauciflorus, Distichlis spicata, Eustoma exaltatum, Juncus balticus* and *Sisyrinchium demissum* (Stromberg et al. 2019, p. 6).

Soils at La Cebadilla are high in organic matter, saline, alkaline, and have salts on soil surfaces in the seasonally dry periphery (Stromberg et al. 2019, p. 6, 14). Arizona eryngo occurs here in saturated soils, with moisture ranging from about 2 cm of standing water to dry on the surface (but moist beneath) (Stromberg et al. 2019, p. 6). Groundwater at La Cebadilla discharges from gneiss at the mountain front (Olson 1982, p. 101). The water, from an aquifer confined by the Catalina detachment fault, is characterized by high sulfate and fluoride content and low values of $\delta^{18}O$ and δD (parameters related to the ratios of stable oxygen and hydrogen isotopes) (Olson 1982, p. 115). It is likely thousands of years old on the basis of comparison with similar groundwater in the area (Eastoe personal communication December 16, 2019).

The homeowners association of La Cebadilla Estates manages the cienega (the portion not owned by the Pima County Regional Flood Control District) and nearby La Cebadilla Lake (also referred to as a pond, to the west of the cienega). The homeowners association of La Cebadilla Estates manages their portion of the cienega as common property for the common use and enjoyment of its members (La Cebadilla Estates 2005, entire). The spring is located on the western edge of the cienega and a concrete spring box diverts some water to sustain the lake (Fonseca 2019, p. 2; Stromberg et al. 2019, p. 5). A berm is present on the south margin of the cienega and appears in aerial photographs dating back to 1941 (Fonseca 2019, p. 1).

The Pima County Flood Regional Control District acquired a floodprone lot (Figure 3.6) in 1986 from Pima County, who acquired the lot earlier from La Cebadilla Estates. Since 1986, the lot has been managed as natural open space with passive recreational uses such as hiking and equestrian use allowed (Rice personal communication December 6, 2019). Since 2015, the La Cebadilla property has been managed under their Land Stewardship Program, with the mission of protecting natural resources. Additionally, in 2017, the property was included as potential mitigation land under Pima County's Multi-species Conservation Plan, and a Restrictive Covenant was recorded which further limits development or other potentially damaging uses, and protects natural resources on the property (Rice personal communication December 6, 2019; Fonseca personal communication December 16, 2019).

Based on comparisons of historical (dating back to 1941) and recent imagery, the cienega appears to have been altered by increased presence of trees, bank erosion and pasture grading, utility construction, and removal of livestock in favor of subdivision development (Fonseca

2019, p. 3). Historical images indicate that the cienega was more extensive in 1941, with fewer trees on some margins of the cienega and no forest on the southern margin of the cienega (Fonseca 2019, p. 1). Aerial imagery in 1966 (Figure 3.8) indicates more *Prosopis* (mesquite) presence on the western margins of the cienega that were not present in 1941 (Fonseca 2019, p. 2). Due to the encroachment of woody vegetation, this site has varied sunlight conditions, ranging from highly shaded to fairly open (Figures 3.7 to 3.8).

A spring survey report considers La Cebadilla well protected today, with good aquifer functionality and quality (Stevens 2012, p. 4). However, the aquifer supporting the La Cebadilla springs could be in danger from numerous private wells (including the Tanque Verde Guest Ranch) producing water from the aquifer that feeds the springs (Eastoe and Fonseca personal communication December 17, 2019). It is unknown how well connected the fractures hosting the water are at depth (i.e., how quickly pumping a mile or two away from the springs might affect the springs themselves) (Eastoe personal communication December 17, 2019). The shrinking extent of the cienega may be evidence for aquifer depletion (Fonseca personal communication December 17, 2019). In addition to groundwater use, aquifer depletion could also result from increased evapotranspiration of tree cover (mesquite and cottonwood) apparent in Figures 3.6 and 3.8 (Fonseca personal communication December 17, 2019).

Stream channel adjustments may also affect the cienega. Aerial images of Tanque Verde Creek (Figure 3.6) show a meander about 60 meters east of the cienega approaching the site. Over time this adjustment can be expected to reach the cienega. The amount of time will depend largely on the recurrence interval of large flood events (Simms personal communication April 6, 2020). There is a small stream/wash adjacent to the cienega that may have affected the cienega through overbanking and contributing to the groundwater table (Fonseca personal communication April 6, 2020). How this wash currently contributes to or affects the cienega may warrant investigation.

Encroachment of native shrubs and trees (i.e., woody vegetation) poses a risk to the open, moist cienega habitat (Stevens 2012, p. 4) favored by Arizona eryngo. Arizona ash trees are invading the cienega, shading out Arizona eryngo (Li 2020b), and causing them to wilt likely due the hyper transpiration rate of ash trees. Select removal of small ash trees is currently being planned and will consider the needs of other unique or rare species using the site (e.g., yellow-billed cuckoos). Nonnative bermudagrass (*Cynodon dactylon*) occurs in the dry southern end of Arizona eryngo habitat should be monitored to assess its potential effect on Arizona eryngo. La Cebadilla Estates and the Pima County Regional Flood Control District are committed to the conservation of the unique ecological diversity of La Cebadilla cienega, including Arizona eryngo.

Figure 3.6. Generalized location of the La Cebadilla Arizona eryngo population in Arizona, United States.

Figure 3.7. Arizona eryngo at La Cebadilla Cienega in Arizona, United States (FWS photo taken July 2, 2019). Arizona eryngo is the broader-leafed plant interspersed throughout the cienega area of the photograph.

Figure 3.8. January1966 aerial photograph of La Cebadilla Cienega, Arizona (Fonseca 2019).

<u>Lewis Springs, Arizona, United States</u>
Arizona eryngo occurs in the Lewis Springs Cienega just to the east of the San Pedro River in Cochise County (Figure 3.9), within the San Pedro River Basin (Stromberg et al. 2019, p. 5), more specifically within the Sierra Vista Subwatershed of the Upper San Pedro Basin (Gungle et al. 2016, p. 3). The cienega is located within the San Pedro Riparian National Conservation Area (SPRNCA) managed by the Bureau of Land Management (BLM). The San Pedro riparian area, containing about 40 miles of the upper San Pedro River, was designated by Congress as a NCA in 1988. The primary purpose for the designation is to conserve, protect, and enhance the desert riparian ecosystem, a rare remnant of what was once an extensive network of similar riparian systems throughout the Southwest.

The Lewis Springs Complex has five groundwater outflows and is comprised of multiple elongated wetlands generally oriented northwest-southeast along a slope, totaling 1.22 ha (3.02 acres) (Table 3.1) (Li 2020, p. 1, J. Simms 2019, entire; Stromberg et al. 2019, p. 6; Radke

2013). Stromberg et al. (2019) reported that five wetlands appear present on aerial view; however, from the ground, eight wetlands have been mapped (Radke 2013; J. Simms 2019). As of September 2019, four of the eight wetlands support Arizona eryngo (J. Simms 2019, entire). Within these four wetlands, Arizona eryngo occurs in six colonies with discrete boundaries, the spatial extent of which is about 438 m^2 in 2019 (Li 2020, p. 1) (Table 3.1). The population size of Arizona eryngo was estimated in 2020 to be 1,813 genets, with a 95% confidence interval of the population size, according to the boostrapping estimation, of (1092, 2614) genets at Lewis Springs (Li 2020b, p. 1). The population was estimated in 2018 to be 1,275 plants, including juveniles and reproductively mature plants (Stromberg et al. 2019, p. 6) (Figures 3.9 and 3.10). The decrease in estimates likely reflects differences in sampling methods rather than an actual decrease of 205 plants in the population.

In 2005, there were approximately 15 springs and seeps in the wetland complex (some marked by Carsonite posts); however, as of 2019, some of the wetland patches appear to be drying, with soil drier at several sites than it had been in 2005 (J. Simms 2019, entire). In 2019, sites supporting Arizona eryngo range from dry on the surface to having some standing water. The water source of Lewis Springs Cienega is supplied by mountain front recharge (westward flow from the Mule Mountains and eastward flow from the Huachuca Mountains) to the local aquifers, as opposed to monsoonal surface flows (Baillie et al. 2007, p. 7; Stromberg et al. 2019, p. 6). Although this population occurs on lands managed for conservation purposes, groundwater pumping in the area, up to several kilometers away, may be affecting the regional groundwater flow to the wetlands along the San Pedro River, including Lewis Springs (Stromberg et al. 2019, p. 9).

The Lewis Springs Complex occurs within Chihuahuan desert scrub at about 1,219 m in elevation and the soils are alkaline (Stromberg et al. 2019, pp. 6, 14). At this site, Arizona eryngo is primarily associated with *Andropogon glomeratus, Juncus balticus, Lythrum californicum* (California loosestrife), *Muhlenbergia asperifolia* (scratchgrass muhly), and *Schoenoplectus americanus*. Other associates include *Almutaster pauciflorus*, *Anemopsis californica*, *Asclepias subverticillata*, *Carex praegracilis*, *Helianthus anuus*, and *Lobelia cardinalis* (Stromberg et al. 2019, p. 6). *S. americanus* also occurs at Lewis Springs (Radke 2013).

At this site, nonnative Johnsongrass is aggressively invading and appears to be suppressing Arizona eryngo, particularly in the drier areas (soil surface dry) of the wetlands (J. Simms 2019, p. 22, Li 2020, p. 2) (Figures 3.10 - 3.12). Also, in the drier areas, *Baccharis* sp. is moving slowly into the wetlands and also appears to be suppressing Arizona eryngo as none was found growing in the understory of the *Baccharis* sp. (J. Simms 2019, p. 6; Li 2019, p. 1). In the wetter areas of the wetlands where the soil is saturated and surface water is generally present, native species *Eleocharis palustris* and bulrush appear to suppress Arizona eryngo (Li 2020, p. 2). In areas with intermediate wetness where the soil surface is moist, but the soil is not necessarily saturated, native species *L. californicum* and *M. asperifolia* are found intermingled with Arizona eryngo (Li 2020, p. 2). This site has varied sunlight conditions, ranging from fairly open to highly shaded due to the encroachment of *Baccharis* sp. and Johnsongrass (Figures 3.10 to 3.12).

BLM is committed to the conservation of Lewis Springs and Arizona eryngo. BLM has conducted some removal of Johnsongrass Arizona eryngo colonies 1 and 2 at Lewis Springs in June 2020. Removal was conducted using electric weed-eaters, and, where there was Arizona eryngo, hand-pulling of Johnsongrass was employed. Many young Arizona eryngo were noted growing beneath the Johnsongrass. BLM is planning for additional removal of Johnsongrass and removal of baccharis shrubs at Lewis Springs, as well as establishment of additional populations and/or subpopulations of Arizona eryngo at suitable sites within Lewis Springs and the SPRNCA.

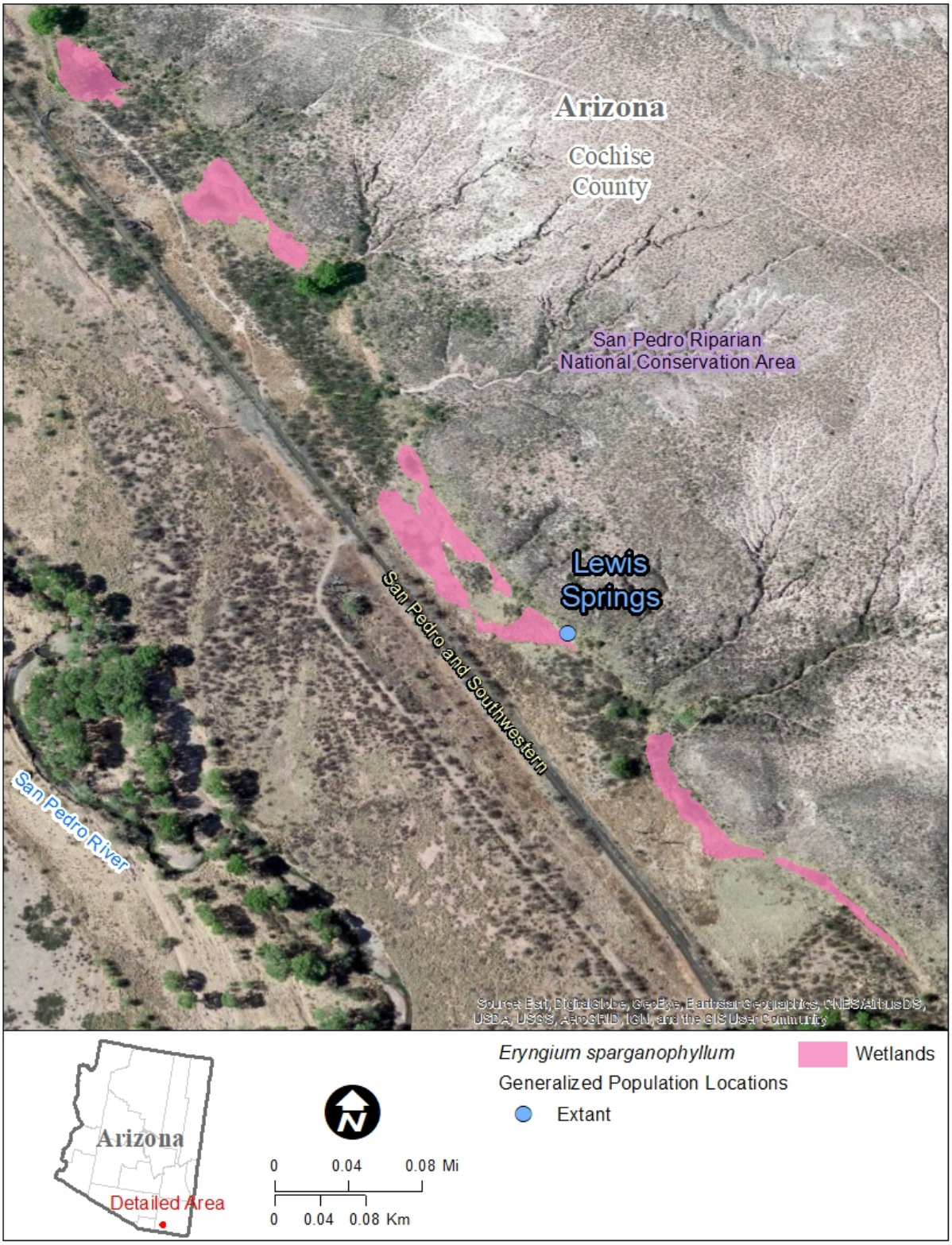


Figure 3.9. Generalized location of the Lewis Springs Arizona eryngo population in Arizona, United States (FWS). Wetland extent was mapped in 2013 (Radke 2013).

Table 3.1. Area of 8 cienegas and Arizona eryngo (ERSP) colonies at Lewis Springs, Arizona.

Lewis Springs Complex	**Area of Cienega (m^2)[1]**	**ERSP present 2019[2]**	**Area of ERSP (m^2) 2019[2]**	**ERSP present 2013[1]**	**Notes[2&3]**
Cienega 1*	769	Yes (colonies 1 & 2)	103.5; 115	Yes	Johnsongrass and baccharis invading; poor soil moisture conditions observed
Cienega 2	2,064	Yes (colony 3)	133.4	Yes	Johnsongrass and *Baccharis* sp. invading
Cienega 3	1,052	No	NA	Yes	
Cienega 4	162	No	NA	No	
Cienega 5	3,804	Yes (colonies 4 and 5)	84.55 and point location only	Yes	Colony 5 only includes 2 individuals clustered at one point where a hole was dug when a Carsonite post was placed in June 2005
Cienega 6	647	Yes	0.94	Yes	Arizona eryngo only growing at Carsonite post where a hole was dug in June 2005
Cienega 7	2,023	No	NA	No	Site dominated by *Schoenoplectus* spp.
Cienega 8	1,700	No	NA	Yes	Site dominated by *Eleocharis* sp. (spikerush) and mesquite invading on the lower areas
TOTAL	**12,221**		**438**		
[1]Radke 2013; [2]Li 2019; [3]J. Simms 2019; *cienegas numbered from the south to north					

Figure 3.10. Arizona eryngo (flowering in the foreground; note the Johnsongrass in background) at Lewis Springs in Arizona, United States (FWS photo taken September 20, 2019).

Figure 3.11. Collecting seed from Arizona eryngo (flowering in the foreground; note the Johnsongrass in background and left of photo) at Lewis Springs in Arizona, United States (FWS photo taken September 20, 2019).

Figure 3.12. Johnsongrass invasion near and at Lewis Springs in Arizona, United States (FWS photo taken September 20, 2019). The dense Johnsongrass in the foreground is near a railroad grade with disturbed soils. The cienega is on the mid-slope.

Rancho Agua Caliente, Sonora, Mexico

Arizona eryngo occurs in the Agua Caliente Cienega on the privately-owned Rancho Agua Caliente east of Esqueda in the municipality of Nacozari de García (Sánchez Escalante et al. 2019, p. 16; Stromberg et al. 2019, p. 7) (Figure 3.13). Rancho Agua Caliente is an active cattle ranch. The cienega is within the Bavispe River Basin at the base of the Sierra El Tigre (Stromberg et al. 2019, p. 7). Based on aerial photographs, the cienega appears to be about 5 ha (Stromberg el al. 2019, p. 7); however, it may only be about 1.5 ha (Sanchez Escalante personal communication September 20, 2019), or that may be the area that is still functional as a cienega. Currently, we do not have information on the source of water supplying the springs or the amount of groundwater use at this site.

This cienega is the only known site for Arizona eryngo in Sonora. Rancho Agua Caliente is a historical locality of Arizona eryngo, but no historical population estimates are available. In 2018, hundreds of Arizona eryngo, including juveniles, were distributed along the marsh where the spring flows within a nearly 1 ha area (Sánchez Escalante et al. 2019, p.16; Sánchez Escalante personal communication October 3, 2019) (Figures 3.14, 3.15). Sánchez Escalante et al. (2019, p.16) report that the habitat is somewhat disturbed by cattle, but that the Arizona

eryngo is in very good condition (Figure 3.15 shows cattle manure amidst juvenile plants). The estimated area occupied by Arizona eryngo is larger than the other sites, while the population estimate is quite low, thus indicating a sparse or patchy distribution pattern compared to La Cebadilla or Lewis Springs. Further study at this site will help improve our understanding of population size and distribution.

The Rancho Agua Caliente Cienega occurs within desert-scrub like thornscrub at about 940 m in elevation and the soils are alkaline (Stromberg et al. 2019, pp. 6, 14). At this site, Arizona eryngo is associated with various plant species, including *Eleocharis parishii*, *Juncus bufonius*, *Schoenoplectus americanus*, *Almutaster pauciflorus*, *Sisyrinchium demissum*, and *Pluchea salicifolia* (Sánchez Escalante et al. 2019, p.16). Based on photos, it appears that Rancho Agua Caliente currently supports areas with a range of soil moisture (from standing water to dry soils) and open sun conditions (see Figures 3.13 to 3.16). It is possible that disturbance by cattle at this site creates open sun conditions favored by Arizona eryngo.

Figure 3.13. Generalized location of the Rancho Agua Caliente Arizona eryngo population in Sonora, Mexico (FWS).

Figure 3.14. Arizona eryngo at Rancho Agua Caliente, Sonora in 2018 (photo credit: Sánchez Escalante et al. 2019, p. 42).

Figure 3.15. Arizona eryngo juveniles at Rancho Agua Caliente, Sonora in 2018 (photo credit: Sánchez Escalante 2019). Note the livestock manure amidst the juvenile plants.

Figure 3.16. Arizona eryngo at Rancho Agua Caliente, Sonora in 2018 (photo credit: Sánchez Escalante 2019). Note the open sun conditions.

Ojo Vareleño, Chihuahua, Mexico

Arizona eryngo occurs at a privately-owned hot springs spa, El Ojo Vareleño, located northwest of Casas Grandes in the municipality of Casas Grandes in Chihuahua (Sánchez Escalante et al. 2019, p. 9; Stromberg et al. 2019, pp. 6-7) (Figures 3.17 and 3.18). The site is within the San Miguel River Basin at the base of the Piedras Verdes Mountains (Stromberg et al. 2019, p. 6). It is a historical locality of Arizona eryngo, but no historical population estimates exist. The extent of the cienega is currently about 1 ha and supports about 56 adult plants (Sánchez Escalante et al. 2019, p. 17) that occupy an area of about 750 m^2 (Sánchez Escalante personal communication October 3, 2019). No juveniles were documented.

Ojo Vareleño occurs at about 1,490 m in elevation and the soils are alkaline (Sánchez Escalante et al. 2019, pp. 10, 27). At this site, other native plants associated with moist alkaline soils occur, including *Cirsium wrightii*, *Andropogon glomeratus*, *Ageratum corymbosum*, *Typha domingensis*, *Almutaster pauciflorus* and *Anemopsis californica*. Many nonnative plant species also occur, with a particularly aggressive invasion of nonnative giant reed (Sánchez Escalante et al. 2019, pp. 10) (Figure 3.19). Based on photos, it appears that Ojo Vareleño currently supports areas with a range of soil moisture (from standing water to dry soils) and sunlight conditions (from open sun to highly shaded) (see Figures 3.17 to 3.19). Giant reed invasion at the site is creating conditions with high amounts of shade and little to no space for other plants.

Springflow is collected in concrete spa ponds (Sánchez Escalante et al. 2019, pp. 28), which likely affects the natural hydrology of the site.

The municipality of Casas Grandes is interested in installing a pipeline from the spring at El Ojo Vareleño to supply water to the Universidad Tecnológica de Casas Grandes. The landowners, interested in the protection of the natural resources on their land, including the conservation of Arizona eryngo and *C. wrightii*, are opposed to the proposed water diversion (Sánchez Escalante et al. 2019, pp. 10). Currently, we do not have information on the source of water supplying the springs or the amount of groundwater use at this site.

Figure 3.17. Generalized location of the Ojo Vareleño Arizona eryngo population in Chihuahua, Mexico (FWS).

Figure 3.18. Arizona eryngo in flowing water at Ojo Vareleño, Chihuahua, Mexico in 2019 (photo credit: J. Sánchez Escalante).

Figure 3.19. Nonnative giant reed (tall plant in the background) invading the cienega at Ojo Vareleño in Chihuahua, Mexico (photo credit: Sánchez Escalante et al. 2019, p. 30).

Reports of the species further south in the Mexican states of Durango, Jalisco, Nayarit, Zacatecas, Michoacan, and Guerrero are likely not valid (Stromberg et al. 2019, p. 7-8) and for the purposes of this assessment are not considered to represent the species. See Stromberg et al. 2019 for a detailed discussion of the species in relation to these states.

While it is possible that other natural population of the Arizona eryngo exist, given that the species is obvious (tall with conspicuous flowers and locally abundant) and that most cienegas, particularly ones still extant in Arizona and New Mexico, have been surveyed (AGFD 2019, p. 7), it is unlikely that new populations will be found.

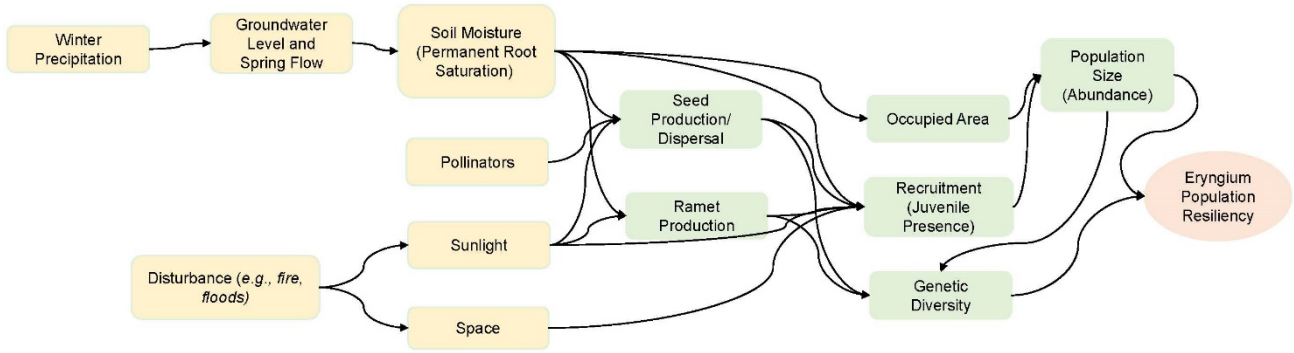
Table 3.1. Historical and current Arizona eryngo populations in the U.S. and Mexico (created with data from Li 2020, p. 1; Stromberg et al. 2019, pp. 4-8, 14; and Sanchez 2019, p. 17).

Name of population	Location	River Basin	County, State and Country	Elevation (m)	First collected	2019 Status	2019 Land ownership	Estimated population size and spatial extent
Las Playas Springs	East of the Animas Mountains	Playas (a closed basin)	Hidalgo, New Mexico, U.S.	1,420	1851 (type locality)	Extirpated, unknown extirpation date	Private	NA
Agua Caliente	East of Tucson at the base of Santa Catalina Mountains	Santa Cruz	Pima, Arizona, U.S.	884	1908	Extirpated	Pima County Natural Resources, Parks, and Recreation; Agua Caliente Regional Park	Some plants were reintroduced in 2016-2020; but a viable population has not yet been established
La Cebadilla Cienega	West of Tanque Verde Wash, east of Tucson	Santa Cruz	Pima, Arizona, U.S.	825	2001	Extant	La Cebadilla Estates; and Pima County Regional Flood Control District	2020: 30,422; 4,488 m^2
Lewis Springs	East of the San Pedro River	San Pedro	Cochise Arizona, U.S.	1,219	2003	Extant	Bureau of Land Management San Pedro Riparian National Conservation Area	2020: 1,813; 438 m^2
Rancho Agua Caliente	Rancho Agua Caliente Cienega, base of the Sierra El Tigre	Rio Bavispe	Nacozari de García, Sonora, Mexico	940	1980	Extant as of 2018	Private	2018: 100s of plants; 9,000 m^2
Ojo Vareleño	Northwest of Casas Grandes, base of the Piedras Verdes Mountain	Mimbres	Casas Grandes, Chihuahua, Mexico	1,492	1982	Extant as of 2018	Private	2019: 56 adult plants; 750 m^2

3.2. Needs of Arizona eryngo

As discussed in Chapter 1, for the purpose of this assessment, we define viability as the ability of the species to sustain populations in the wild over time (in this case, 30 years). While we do not know the lifespan or generation length of Arizona eryngo, it has been suggested that it can live over 10 years. Therefore, we chose 30 years to encompass multiple generations and environmental variation (e.g., drought cycles). Using the SSA framework, we describe the species' viability by characterizing the status of the species in terms of its resiliency, redundancy, and representation. In this section we analyze what the species needs in terms of population resiliency and species representation and redundancy.

3.2.1. Population Resiliency



For Arizona eryngo to maintain viability, its populations or some representative portion thereof must be resilient (i.e. withstand stochastic events arising from spatially and temporally random factors, as well as normal fluctuations in the environment). Stochastic events that have the potential to affect Arizona eryngo generally include annual and more extreme fluctuations in water availability during episodes of prolonged drought, floods, among others. A number of factors influence the resiliency of Arizona eryngo populations, including abundance, recruitment, and occupied area. Influencing those factors are elements of Arizona eryngo habitat that determine whether populations can grow to maximize habitat occupancy, thereby increasing the resiliency of populations. These factors and habitat elements are discussed below and shown in Figure 3.20.

Figure 3.20. Factors influencing Arizona eryngo population resiliency.

Population Resiliency Factors

While there are multiple factors that can affect population resiliency of Arizona eryngo, we focused on those factors that influence the population and for which we have some data. The population resiliency factors listed below are the population-level influences we use in our assessment of the current and future condition of the populations.

Abundance – Larger plant populations have a lower risk of extinction than smaller populations (Menges 2000, p. 78). In contrast, small populations are less resilient and more vulnerable to the

effects of demographic, environmental, and genetic stochasticity and have a higher risk of extinction than larger populations (Matthies et al. 2004, p. 481, 485). Small populations may experience increased inbreeding, loss of genetic variation, and ultimately a decreased potential to adapt to environmental change (Matthies et al. 2004, p. 481). When rare plant populations are very small (<100 individuals), they may suffer from inbreeding depression (Maschinski and Albrecht 2017, p. 392). Furthermore, fewer pollinators visit plants in small and isolated populations, which may lead to reduced pollination and lowered fecundity (Matthies et al. 2004, p. 482). Leimu et al. (2006) report that the strength and direction of the relationships between plant population size, fitness, and genetic variation may depend on different plant characteristics, especially life-span, mating system and rarity. For example, shorter-lived plants may be more susceptible to the negative genetic consequences of reduced population size (Leimu et al. 2006 p. 943), as well as environmental stochasticity (Matthies et al. 20014, p. 486). Additionally for shorter-lived plants, small populations are much more susceptible to extinction than populations with greater than 1,000 individuals (Matthies et al. 2004, p. 485). While we suspect Arizona eryngo is not short-lived (see section 2.3), we provide this example to stress the importance of better understanding characteristics of this species to manage for its resiliency.

For populations of Arizona eryngo to be resilient, abundance should be high enough that local stochastic events do not eliminate all individuals, allowing the overall population to recover from any one event. A greater number of individuals in a population increases the chance that a portion of the population will survive. The necessary abundance or minimum viable population size for Arizona eryngo is unknown; however, estimations can be attained from literature. For example, Pavlik (1996, p. 137; Figure 6.3) recommends Minimum Viable Population (MVP) sizes ranging from 50 individuals (lower end) to 2,500 individuals (upper end) for the conservation of rare plants, depending on various life-history characteristics of the taxon.

MVP is defined as the number of individuals required to have a specified probability of persistence over a given period of time (Brook et al. 2006, p. 375). For example, MVP might be defined as the population size (N) at which the probability of persistence over the next 100 years is 95% (Thompson 1991, p. 6). Mace and Lande (1991, p. 151) categorize species as Vulnerable when there is a 10% probability of extinction within 100 years (or conversely, when the probability of persisting 100 years is less than 90%).

In looking at Pavlik's (1996, p. 137) Figure 6.3, Arizona eryngo meets criteria for both the upper and lower ends of the MVP spectrum. On the lower end of the spectrum, Arizona eryngo is a perennial and has common ramet production. However, on the upper end of the spectrum, it is an herbaceous plant. The other criteria are unknown for Arizona eryngo. Therefore, based on our current understanding of the species, as well as minimum rare plant population sizes called for in the literature, an initial minimum viable population (MVP) of 1,225 may be needed to achieve resiliency for Arizona eryngo. An MVP of 1,225 is derived from the following calculation: 2500-50 / 2 = 1,225, where Arizona eryngo life history characteristics indicate that the species falls somewhere around Pavlik's (1996, p. 137) half-way mark of the MVP scale.

Determinations of MVP usually take into account the effective population size, rather than total number of individuals; 10 genetically identical individuals (for example, clones or ramets) would have an effective population size of 1. In the case of Arizona eryngo, we have estimates of abundance of individuals for each population, but do not know the effective population size. For

example, we do not know the ramet to genet ratio (future genetic studies should be conducted to determine this), however, it has been suggested that the species is highly clonal. In the case where genetic analysis has not been done to determine ramet to genet ratios, Tependino (2012) suggests adjusting the stem counts of rare clonal species to include the positive numerical effect of ramets which would result in the reduction of current population estimates by 25-50%. Therefore, to account for the clonal nature of Arizona eryngo, to estimate our final MVP, we add 50% to the estimated MVP of 1,225 (based on Pavlik 1996), to give us about **1,840** plants (=1,225 + 612.5=1,837.5 rounded to the nearest 10). There are still many life history characteristics and other variables that we need to more fully understand to best determine MVP size to achieve resiliency. In the absence of more specific information regarding MVP for Arizona eryngo, we are using this more general MVP based on species characteristics. We recognize the limitations of using a generic MVP and will update our MVP estimate as more information on the species and more accurate methods for determining MVP become available.

Recruitment – Resilient Arizona eryngo populations must also reproduce and produce sufficient amounts of seedlings and ramets such that recruitment equals or exceeds mortality. However, the necessary recruitment needed for a self-sustaining population is unknown. Ideally, we would know key demographic parameters of the plant (i.e., survival, life expectancy, lifespan, the number of genets and ramets) to estimate the percentage of juveniles required in a population to achieve population stability or growth. It would also be beneficial to know the percentage of seedlings (produced through sexual reproduction) needed to maintain a sufficiently genetically diverse and resilient population. Because we currently do not know any of these parameters, we are using the presence of juveniles as an important demographic factor influencing resiliency.

Current population size and abundance reflects previous influences on the population and habitat, while reproduction and recruitment reflect population trends that may be stable, increasing or decreasing in the future. For example, a large, dense population of Arizona eryngo that contains mostly old individuals may be able to withstand a single stochastic event over the short-term, but it is not likely to remain large and dense into the future, as there are few young individuals to sustain the population over time. A population that is less dense but has many young individuals may be likely to grow denser in the future, or such a population may be lost if a single stochastic event affects many seedlings at once.

Occupied Area – Resilient Arizona eryngo populations must occupy cienegas large enough such that stochastic events and environmental fluctuations that affect individual plants or colonies do not eliminate the entire population. Repopulation through seed dispersal and germination and ramet production within the cienega can allow the population to recover from these events.

Larger functional cienegas are likely to support larger populations of Arizona eryngo and more likely to provide patches of suitable habitat when small stochastic events and environmental fluctuations occur. For example, during drought years, areas closer to spring seeps and possibly areas with natural depressions (i.e., topographic variation) may remain moister throughout the year than areas farther away from seeps and slightly higher in elevation. Conversely, during years with heavy rainfall, slightly higher elevation areas may retain moist soils that are not inundated year round, providing suitable habitat for the species.

While we do not know the historical size of cienegas that supported Arizona eryngo, it is likely that they were larger. As described in Section 2.5., in addition to the reduced abundance of cienegas in the range of species, remaining cienegas are greatly reduced in size and greater than 95% of the historical area of cienegas is now dry (Cole and Cole 2015, p. 36). Imagery indicates that La Cebadilla Cienega was once larger than it is currently (Fonseca 2019, p. 1). Rancho Agua Caliente, Sonora appears to be 5 ha in aerial photographs (Stromberg et al. 2019, p. 7), however, it may be functionally smaller now (i.e., Sánchez Escalante reported that from the ground it appears to be 1.5 ha; Sánchez Escalante personal communication September 20, 2019). Ojo Vareleño Cienega is currently about 1 ha; however, it was thought to also be larger in the past (Sánchez Escalante personal communication September 20, 2019).

Given that the historical size of most cienegas was larger, we assume the area occupied by Arizona eryngo was also historically larger. Areas currently occupied by Arizona eryngo range from about 438 m^2 to 9,000 m^2 (Table 3.1). Based on historical and current estimates of cienega size and area occupied by Arizona eryngo and our assumption that larger cienegas have the ability to support larger populations of Arizona eryngo, we approximate that a resilient Arizona eryngo population should occupy greater than 10,000 m^2 (1 ha) within a functional cienega. Human land use is, in some cases, directly controlling the size of cienegas and will have consequences for the overall resiliency of the species.

Habitat Elements that Influence Resiliency

Similar to population resiliency, there are multiple habitat factors that can affect resiliency of Arizona eryngo. Here we focus on important habitat factors for which we have some data. It is important to note that Arizona eryngo are only found in spring-fed cienegas with organic, alkaline, moist soils, as discussed in Chapter 2. The habitat factors below (soil moisture and sunlight) are discussed in the context of such habitat (i.e., a site with moist soil and sunlight alone is not considered habitat for Arizona eryngo, rather sites with moist soil and full sun within appropriate cienegas are the context of the discussion below).

Soil Moisture – Resilient Arizona eryngo need moist soils year round. We do not know the amount of soil moisture that is needed, but the species is a cienega obligate and grows in what can be considered the margins of wetlands. Based on studies and expert opinion, soil should be moist year round immediately beneath the surface, even during drought years. The surface of the soil should be dry at times and standing water should also be present at times. Saturated soil or soil with some standing water combined with winter temperatures (cold) are needed to break see dormancy. Moist soil combined with warm temperatures are needed for seed germination. If the soil becomes too dry, other more drought tolerant species (e.g. *Baccharis*, *S. halepense*) are likely to encroach and outcompete Arizona eryngo, or if it becomes very dry such that the roots are not in moist soil, the plant is likely to die. If the soil is inundated with water (such that there is standing water on the surface) for too long, other species (e.g., bulrush) that grow more aggressively in mesic conditions are likely to outcompete Arizona eryngo. Additional studies could help quantify soil moisture requirements of Arizona eryngo.

Sunlight **–** Resilient Arizona eryngo requires full sun, as discussed in Chapter 2. Under canopy cover of trees, the species grows less densely and flowering is reduced. Tall native (e.g., *Schoenoplectus* spp., *Baccharis* spp.) and nonnative vegetation (e.g., Johnsongrass, giant reed)

appear to outcompete and suppress growth of Arizona eryngo. While these species may compete with Arizona eryngo for sunlight, water, and nutrients, lack of sunlight may be a primary factor driving the absence or decreased abundance of Arizona eryngo.

In summary, habitats with appropriate levels of soil moisture and sunlight are considered to contribute to resiliency, while those habitats with levels outside of the appropriate ranges are considered to provide less resiliency.

3.2.2. Species Representation

Maintaining representation of genetic and ecological diversity is important to maintain the capacity of Arizona eryngo to adapt to future environmental changes. There are currently known to be four extant Arizona eryngo populations within four river basins (Santa Cruz, San Pedro, Rio Bavispe, Mimbres) of three states, one in the U.S. and two in Mexico. (Note that these watersheds are at the Hydrologic Unit Code (HUC)-6 level, or watershed 6th level). Genetic analyses of this species have not been conducted within or among populations, however, populations are currently widely separated (ranging from about 90 to 335 km apart; 56 to 208 mi), making cross-pollination highly unlikely. In addition, the two populations in Arizona are larger than the two populations in Mexico. Therefore, genetic differentiation among populations is likely and the larger populations may contain higher genetic diversity compared to the smaller ones (Allendorf et al. 2013). Because two known populations have been extirpated, and possibly more that are unknown, it is likely that the species has already lost genetic diversity. As such, maintaining representation of the genetic diversity across the remaining four extant populations may be critical to preserving the capacity of Arizona eryngo to adapt to future environmental change.

With regard to ecological diversity, Arizona eryngo currently occupies cienega habitats in four different river basins in varying ecological settings. While cienegas supporting Arizona eryngo share many characteristics (as discussed in section 2.5), the cienegas vary with regard to surrounding vegetation community, some of the associated plant species, presence and abundance of nonnative invasive species, as well as native shrubs and trees that may shade Arizona eryngo, soil moisture, and elevation (see section 3.1. for site descriptions). They inevitably vary in other ways that have not yet been measured or for which we have not yet found information (e.g., annual precipitation, temperature, soil composition, aquifer function). Such ecological diversity could help the species survive future environmental changes, such as warming temperatures or decreased precipitation from climate change. At a minimum, we need to retain resilient populations in each area of representation throughout the current range of the species to maintain the capacity of Arizona eryngo to adapt environmental changes over time.

3.2.3. Species Redundancy

To ensure redundancy, multiple resilient Arizona eryngo populations distributed throughout its range are needed. The more populations, and the wider the distribution of those populations, the more redundancy the species will exhibit. Redundancy reduces the risk that a large portion of the species' range will be negatively affected by a catastrophic natural or anthropogenic event at a given point in time. Species that are well-distributed across their historical ranges are considered less susceptible to extinction and more likely to be viable than species confined to small portions of their ranges (Carroll et al. 2010, entire). Given the historical distribution of

functional aridland cienegas, it is likely that Arizona eryngo populations were historically more abundant, occurred closer to one another, and were more connected (through pollination and seed dispersal) than they are currently. Due to the historical loss of cienegas, spring modification, and spring extinction through groundwater withdrawal, Arizona eryngo populations are currently isolated from one another, and repopulation of extirpated locations is unlikely to occur without human assistance in some areas, and impossible to imagine in wetlands that have been irreversibly changed.

Because populations are currently isolated, a localized threat such as ground water withdrawal, spring modification, or a high intensity wildfire would affect only those populations near, or within the watershed of, the activity. However, regional drought and climate change could affect multiple, or all, populations throughout the plant's range. At a minimum, we need to retain each population across four river basins throughout the species' range to minimize impacts from catastrophic events. Because there is currently only one population within each representation area, increasing the number of populations within each area would be important to increase redundancy.

CHAPTER 4. CURRENT CONDITIONS

4.1. Introduction

In this chapter we consider the current conditions of Arizona eryngo in terms of population resiliency, redundancy, and representation. The available information indicates that four of six (or 67%) known historical Arizona eryngo populations are extant across four river basins in southern Arizona and northern Mexico. As of 2020, population estimates in Arizona indicate there are 30,422 plants at La Cebadilla and 1,813 plants at Lewis Springs. Population estimates in Mexico indicate there are 56 individuals in one population in Chihuahua and 100s of plants occurring in one population in Sonora.

4.2. Current Population Resiliency

Methodology

To summarize the overall current conditions of Arizona eryngo populations, we sorted them into three categories (high, moderate, and low) based on the population/distribution factors (abundance, recruitment [measured by juvenile presence], and occupied area) and habitat factors (soil moisture and sunlight) discussed in Chapter 3 (see section 3.2.1 Population Resiliency) (Tables 4.1 and 4.2). We also included in the table known populations that have been extirpated to show the entire current condition of the species. We assigned a numerical value to the condition categories, High=3, Moderate=2, Low=1, and Extirpated =0, so we could calculate an overall score (for the current condition of each population).

The current condition category is a qualitative estimate based on the analysis of the three populations and distribution factors and two habitat factors. In determining the current condition of each population, we capped the condition category by abundance, meaning that a population could not fall into a higher current condition category than the category of its abundance because, to some degree, abundance already reflects habitat elements that are currently influencing the populations.

Table 4.3 displays the presumed ranges of probabilities of persistence of a population with a given current condition category over 30 years. These ranges were not calculated; instead, they serve to communicate what we mean when we describe the current condition of a population.

Table 4.1. Population and habitat characteristics used to create condition categories in Table 4.2.

	Population / Distribution Factors			**Habitat Factors**	
Condition category (Probability of persistence over 30 years)	**Abundance**	**Recruitment**	**Occupied Area**	**Soil Moisture**	**Full Sun**
HIGH	>1840 plants	Juveniles present	> 1 ha (10,000 m^2)	Soil moist year-round immediately beneath surface. Soil dry on surface sometimes. Standing water occurs periodically, but does not persist year round.	Full sun; no encroachment of plants that shade out Arizona eryngo.
MODERATE	800 - 1840 plants	Juveniles present	0.4 to 1 ha (4,000 - 10,000 m^2)	Soil moist immediately beneath soil surface, but surface mostly dry or mostly under water.	Little encroachment of plants that shade out Arizona eryngo.
LOW	50 - 799 plants	Juveniles present	200 to <4,000 m^2	Soil moist immediately beneath soil surface, but surface almost always dry or almost always with standing water.	Some encroachment of plants that shade out Arizona eryngo.
FUNCTIONALLY EXTIRPATED (Ø)	0 - 49 plants	No juveniles present	<200 m^2	Soil seasonally dry at or below root depth; or always with standing water.	More encroachment of plants such that Arizona eryngo are in more shade than sun.

Table 4.2. Resiliency of Arizona eryngo populations. Information used to determine the states of these factors are discussed above in section 3.1, describing each population.

	Population / Distribution Factors			Habitat Factors		
Population	**Abundance (Individuals)**	**Recruitment (Juvenile Presence)**	**Occupied Area (m^2)**	**Soil Moisture**	**Sunlight**	**Current Condition**
La Cebadilla	**30,422**	**Yes**	**4,488**	**Moderate**	**Moderate**	**Moderate**
Lewis Springs	**1,813**	**Yes**	**438**	**Moderate**	**Moderate**	**Moderate**
Rancho Agua Caliente	**100s**	**Yes**	**9,000**	**Moderate**	**High**	**Low**
Ojo Vareleño	**56**	**No**	**750**	**Low**	**Low**	**Low**
Las Playas	**Ø**	**Ø**	**Ø**	**Ø**	**Unknown**	**Ø**
Agua Caliente	**Ø**	**Ø**	**Ø**	**Moderate**	**Moderate**	**Ø**

Table 4.3. Presumed probability of persistence of current condition categories.

Likelihood of Persistence:	**High**	**Moderate**	**Low**	**Functionally Extirpated**
Range of Presumed Probability of Persistence over ~30 years	**>90 – 100%**	**>60 – 90%**	**>10 – 60%**	**≤10%**
Range of Presumed Probability of Extirpation over ~30 years	**0 – ≤10%**	**10 – ≤40%**	**40 – ≤90%**	**≥90%**

Results

Two populations (La Cebadilla and Lewis Springs) fall into the moderate category, but overall La Cebadilla scores the highest and is the only population that has no factors in the low category and has abundance in the high category. Two populations (Ojo Vareleño and Rancho) fall into the low category, but overall Ojo Vareleño scores the lowest and is the only population that has no juvenile presence and whose factors all fall into the low category. The only population whose current condition category was capped by abundance was Rancho Agua Caliente, where population and habitat factors fall into the moderate to high range, with the exception of abundance, which falls in the low category.

4.3. Current Species Representation

We consider Arizona eryngo to currently have representation in the form of genetic diversity (see section 2.2 and 3.2.2.) and ecological diversity (see section 3.1 and 3.2.2), as it occurs at four isolated sites in separate river basins. The four populations and river basins of representation are: 1) the La Cebadilla population in the Santa Cruz River Basin, 2) the Lewis Springs population in the San Pedro River Basin, 3) the Rancho Agua Caliente population in the Rio Bavispe River Basin, and 4) the Ojo Vareleño population in the Mimbres Basin. The representation areas are approximately depicted in Figure 4.1. It is possible that representation boundaries could be adjusted in the future after further investigation of the genetic and ecological diversity of the species.

4.4. Current Species Redundancy

Currently, there are four extant Arizona eryngo populations rangewide; however, each of the four aforementioned representation areas, have one population each for redundancy (Figure 4.1). Requirements of the species may be specific enough that Arizona eryngo did not commonly occur at all historical cienegas in the International Four Corners Region, however, given the historical distribution of functional aridland cienegas, it is likely that Arizona eryngo populations were historically more abundant, occurred closer to one another, and were more connected (through pollination and seed dispersal) than they are currently. If further plantings at Agua Caliente are successful and a viable population can be sustained over time, this reintroduced population would add redundancy to the Santa Cruz River Basin representation area, within which the La Cebadilla population is extant. An introduction effort began in November 2019 at the Historic Canoa Ranch, owned and managed by Pima County Natural Resources, Parks and Recreation. Six plants were planted at the Canoa pond in 2019, and 12 more were planted in January 2020 at the newly constructed Canoa cienega. This site is also within the Santa Cruz River Basin representation area; therefore, if this introduction effort is successful in the long-term it will add further redundancy.

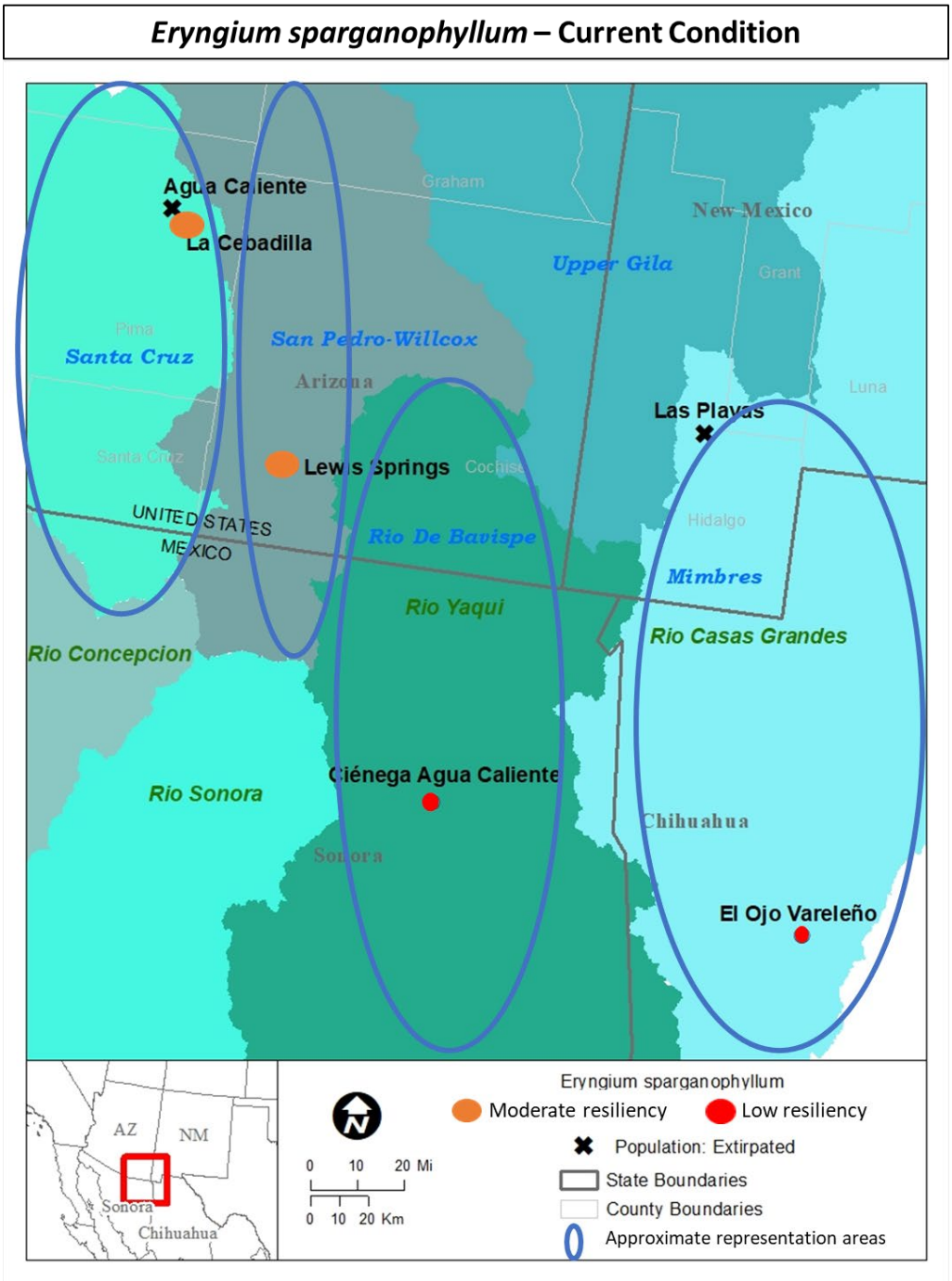


Figure 4.1. Current resiliency, redundancy, and representation of Arizona eryngo. Representation areas follow watershed boundaries (at the HUC-6 level) but are depicted on the map as blue polygons for visual simplification.

CHAPTER 5. INFLUENCES ON VIABILITY

In this chapter, we evaluate the past, current, and future influences that may affect what Arizona eryngo needs for long term viability. We analyzed these factors in detail using the tables in Appendix 1 in terms of causes and effects to the species. These tables analyze the pathways by which each influence affects the species, and each of the causes is examined for its historical, current, and potential future effects on the species' status. Current and potential future effects, along with current expected distribution and abundance, determine present viability and, therefore, vulnerability to extinction. We organized these influences around the stressors (i.e., changes in the resources needed by the Arizona eryngo) and discuss the sources of those stressors. Those risks that are not known to have effects on Arizona eryngo populations, such as overutilization for commercial and scientific purposes and disease, are not discussed in this SSA report.

While there are many complex influences on Arizona eryngo viability, the primary ones we have identified are 1) physical alteration of cienegas, 2) water loss, and 3) changes in vegetation. These are discussed below. Also discussed as a potential influence is direct harm or mortality due to herbivory or trampling.

5.1. Physical loss and alteration of cienega habitat

Functional cienegas were much more common prior to the late 1800s, as evidenced by pollen and fire records, General Land Office survey notes, and early trapper and settler diaries (Brunelle et al. 2018, p. 2; Cole and Cole 2015, p. 36; Fonseca 1998, p. 111; Hendrickson and Minckley 1985, p. 131). Estimates of cienega abundance in the International Four Corners Region of the Southwest (Arizona, Sonora, New Mexico, and Chihuahua) vary from hundreds to thousands and the number increases as new information is gathered (Cole and Cole 2015, p. 36; Sivinski 2018, entire). Many of these cienegas retain some ecological function or are restorable, while others are severely damaged (Cole and Cole 2015, p. 36; Sivinski 2018, p. 4).

For example, in a study of 60 cienegas of the Apache Highlands ecoregion (Arizona, New Mexico, and Sonora), 46 were extant, the others were dry or so altered they have lost their ecological function and no longer provide services such as water purification, flood control, nutrient cycling, etc. (Minckley et al. 2013a, p. 218). Of the 155 cienegas that Cole and Cole (2015, p. 36) identified in the International Four Corners Region, 87 (56%) are either dead or so severely compromised that there is no prospect for their restoration (Figure 5.1). [Sivinksi (2019, p. 14) defines "dead cienegas" as historical cienegas that no longer have groundwater at or near the ground surface and likely have water tables so severely depleted that restoration, given today's techniques and economics, is not feasible.] Sivinski (2018, p. 4) considered 114 of the 169 cienegas he documented in New Mexico to be still functional or restorable. In addition to the reduced abundance of cienegas in the International Four Corners Region, the remaining cienegas are greatly reduced in size and due to many being severely incised, they are more like creeks than marshes (Cole and Cole 2015, p. 36). Greater than 95% of the historical area of cienegas is now dry (Cole and Cole 2015, p. 36).

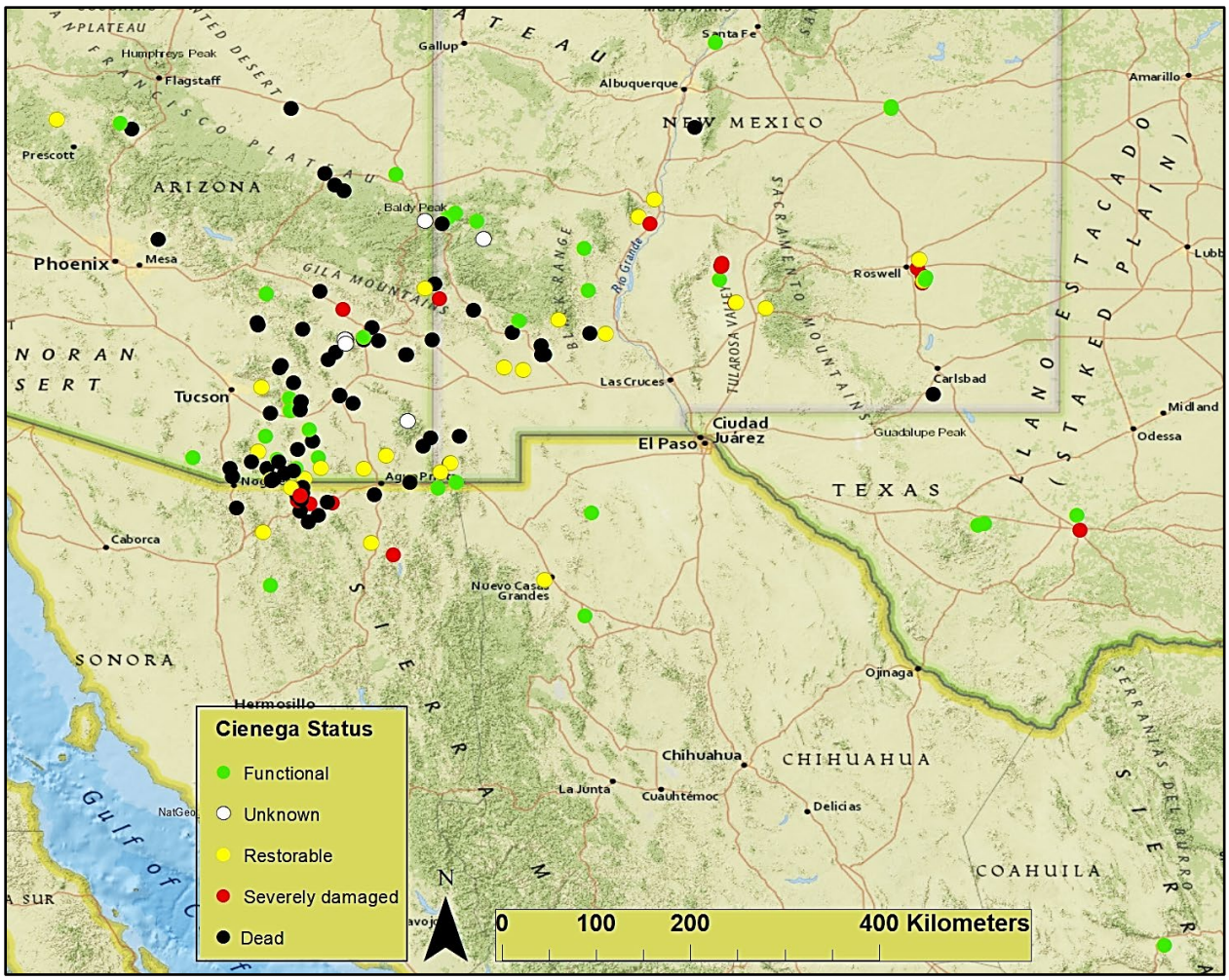


Figure 5.1. Map recreated from data provided by Dean Hendrickson; locations of 155 cienegas and their conditions in the international four corners region.

A number of complex factors, many of which are interrelated, led to the historical loss and degradation of cienegas and continue to contribute to this loss today. The primary factors that led to the historical physical loss and alteration of cienegas are discussed in this section, whereas, other factors are discussed in sections below. These primary factors include: a) intensive grazing of domestic livestock, b) the removal of beaver (*Castor canadensis*) from regional streams and rivers, and c) agricultural re-contouring (Cole and Cole 2015, p. 32; Minckley et al. 2013a, p. 214). Intensive overgrazing by sheep and cattle from the late 1500s to the late 1800s led to barren soil, erosion, headcutting (erosional feature in a stream which contributes to lowering the watertable of the surrounding system), increased frequency of or intensity of destructive floods, etc., all leading to the alteration or complete destruction (complete loss of ecological function) of cienegas (Cole and Cole 2015, p. 32; Minckley et al. 2013a, p. 214). Beaver dams, once numerous in range of Arizona eryngo, slowed water and created pools and wetlands along water courses; however, high levels of beaver trapping in the 1800s resulted in increased erosion and channel cutting of these once complex, shallow flatland watercourses (Cole and Cole 2015, p. 32; Gibson and Olden 2014, p. 395). Additionally, early settlers recontoured (e.g., diverted, dammed, channelized) cienegas for agricultural, mining, disease control and other purposes; this resulted in further channelization and concentrated flow thus greatly reducing the size of

cienegas (and further lowering the water table) (Cole and Cole 2015, p. 32; Minckley et al. 2013b, p. 78).

Six Arizona eryngo populations have been documented, but it seems highly likely that additional populations occurred at historical cienegas that have lost their ecological function due to physical alteration (see Figure 5.1 for an example of how much more abundant cienegas were in the past), such that populations were historically more abundant, occurred closer to one another, and were more connected (through pollination and seed dispersal) than they are currently. The four extant Arizona eryngo populations are now disjunct. While the physical alteration of cienegas likely decreased the amount of habitat available to Arizona eryngo in the past, possibly resulting in the elimination of historical populations, including Agua Caliente and Las Playas, these particular physical alterations likely have much less of a continuing effect on the four extant populations of Arizona eryngo. For example, currently no grazing is authorized at Lewis Springs and, to our knowledge, no grazing occurs at La Cebadilla and Ojo Vareleño. Trespass livestock could enter Lewis Springs and affect habitat. Based on 2018 and 2019 visits, there is no evidence of cattle using the site; however, evidence (i.e., scat and light trailing) of the presence of a trespass horse was found at the site, but not in specific areas occupied by Arizona eryngo. Cattle are present at Rancho Agua Caliente, Sonora and Sánchez Escalante et al. (2019, p.16) report that the habitat is somewhat disturbed by cattle. Livestock (e.g., livestock trailing and gathering) can trample vegetation and expose and compact soil resulting in habitat erosion and altered hydrological function, but the effects of livestock are dependent on many factors such as the intensity, duration, and timing of grazing. In the absence of other forms of disturbance (e.g., fire), it is also possible that selective, well-managed livestock grazing could create habitat disturbance and open sun conditions favoring Arizona eryngo seedling establishment. Research on this topic would help land managers implement livestock management practices that favor Arizona eryngo viability.

5.2. Water loss

Water loss in cienegas poses a significant threat to Arizona eryngo. Causes of water loss are complex, but the primary causes at cienegas historically or currently supporting Arizona eryngo are 1) groundwater pumping/withdrawal; 2) spring modification; 3) water diversion; and 4) drought caused by climate change. Groundwater pumping or withdrawal leads to reduced aquifer storage (or aquifer depletion) and no or reduced outflow from springheads. Modification of springhead(s) reduces or eliminates springflow. Water diverted from springheads reduces (or eliminates) the amount of water supporting the cienega. Drought and warming also reduce springflow and the amount of water in cienegas. Reduction in winter rain particularly leads to reduced aquifer recharge. Climate change is expected to exacerbate drought conditions, which may lead to a reduction in aquifer recharge and increased cienega drying.

Water loss in cienegas reduces the quantity and quality of habitat for Arizona eryngo. As discussed in section 2.5., Arizona eryngo requires moist soils and possibly some standing water for breaking seed dormancy. As water is lost from cienegas, soils become drier, creating inhospitable conditions for the species. Drying also creates conditions which can encourage woody and/or nonnative plant species encroachment. As discussed below in section 5.3, these species outcompete Arizona eryngo for sunlight and space.

Alteration of cienegas that resulted in their drying caused the extirpation of the species at two of the six cienegas historically supporting Arizona eryngo (Las Playas, NM and Agua Caliente, AZ) and all populations continue to be exposed to water loss; these are discussed below.

Groundwater withdrawal

The population at Las Playas was extirpated primarily due to groundwater pumping for agriculture and the Playas Smelter that caused the desiccation of the spring (Sivinski 2018, p. 27; Stromberg et al. 2019, p. 5). Lewis Springs, La Cebadilla, and Agua Caliente are exposed to groundwater withdrawal. The use of groundwater for agriculture, industry, and urban and rural development has enabled significant population growth in the arid Southwest. However, use of groundwater in the region that exceeds replenishment has consequences for many resources, including wetlands (Johnson et al. 2016, p. 53; Guido 2008, p. 1; Leake et al. 2008, p. 1). As explained in section 2.5., increased groundwater outflow (e.g., from groundwater withdrawal) can reduce or eliminate springflow, thereby eliminating wetlands altogether (Johnson et al. 2016, p. 52).

The largest municipalities in the Sierra Vista Subwatershed, within which Lewis Springs occurs, are Sierra Vista, Bisbee, Tombstone, and Huachuca City. Within these areas, the human population is increasing, as is development distributed in rural parts of the subwatershed (Leake et al. 2008, p. 1). This growing population is dependent on groundwater to meet its water consumption needs. Water outflow from the subwatershed, including water withdrawn by pumping, exceeds natural inflow (i.e., a negative water budget) to the regional aquifer within the subwatershed (Leake et al. 2008, p. 2). As a result, groundwater levels in parts of the subwatershed are declining and groundwater storage is being depleted. We note that Fort Huachuca is also situated in the Sierra Vista Subwatershed. Fort Huachuca's on-post population fluctuates in response to mission needs, but the installation's groundwater pumping has declined due to aggressive water conservation programs (FWS 2014, p. 19). The estimated annual water budget of the Sierra Vista Subwatershed from 2002 to 2012 was in deficit (Gungle et al. 2016, p. 32), but the deficit decreased due to reduced agricultural pumping, reduced municipal pumping (including reduction on Fort Huachuca), and enhanced recharge of treated effluent.

Groundwater pumping in the area of Lewis Springs, up to several kilometers away, may be affecting the regional groundwater flow to the wetlands along the San Pedro River, including Lewis Springs (Stromberg et al. 2019, p. 9). The continued decline of groundwater levels upgradient from perennial river reaches will eventually diminish the base flow of the San Pedro River and imperil the riparian ecosystem within the SPRNCA (Leake et al. 2008, p. 2). Even if groundwater pumping were to stop today and the groundwater-budget balance was positive for decades to come, the effects of pumping over the past century will eventually capture surface flow from the river (Gungle et al. 2016, p. 29). Simulated effects of groundwater withdrawal from the Upper San Pedro Basin were depicted as capture (i.e., the reduction of water available to connected streams, springs, and riparian trees dependent on groundwater) maps for withdrawal periods of 10 and 50 years, with water withdrawn at a constant rate (Leake et al. 2008, p. 14). The maps show greatest capture near the San Pedro River for both time periods, and an increase in capture between 10 and 50 years (Leake et al. 2008, p. 14). Lewis Springs is not identified on the map, but both the 10- and 50-year capture map (Figure 4B. in Leake et al. 2008, p. 11) show the area of Lewis Springs as being one of greatest capture. Additionally, there is a wildcat subdivision (i.e., when parcels of land are split into lots and developed without following the

state's typical subdivision regulations) "High Knolls" just to the east of Lewis Springs that may also affect Lewis Springs through the installation and use private wells, as well as through hardscaping, road, runoff, etc. (BLM personal communication April 2020).

The aquifer supporting the La Cebadilla springs could be in danger from numerous private wells (including the Tanque Verde Guest Ranch) producing water from the aquifer that feeds the springs (Eastoe and Fonseca personal communication December 17, 2019). It is unknown how well connected the fractures hosting the water are at depth (i.e., how quickly pumping a mile or two away from the springs might affect the springs themselves) (Eastoe personal communication December 17, 2019).

Agua Caliente spring is exposed to groundwater withdrawal. From 2000 to 2014, at least 12 wells were drilled within ½-mile of the Agua Caliente Spring. These wells tap bedrock artesian water, probably from the same aquifer source as the Pima County Agua Caliente well and spring. Pumping withdrawal combined with low watershed rainfall may be the cause severe reduction of Agua Caliente springflow (Postillion 2014, p. 3).

Currently, we do not have information on the source of water supplying the springs or about the amount of groundwater use at Rancho Agua Caliente or Ojo Vareleño.

Spring modification

The Arizona eryngo population at Agua Caliente, AZ was extirpated likely due to multiple manipulations of the site's hydrology, topography, and vegetation. These manipulations, include, but not limited to spring modification (i.e., the springs were blasted in the 1930s and again in the 1960s) that significantly decreased the water flow (Friends of Agua Caliente 2020, entire; Stromberg et al. 2019, p. 5), and pond impoundment.

Water diversion

The population at La Cebadilla has been exposed to water diversion for many decades; this diversion may have led to a reduction in the size of the cienega, but enough water still flows to maintain the cienega and support the largest documented population of Arizona eryngo (Fonseca 2019, p. 2; Stromberg et al. 2019, p. 5). Pound impoundment diverts water from the cienega at Agua Caliente; this was pronounced in the 1960s during subdivision construction and has continued since.

Less is known about water loss associated with the cienegas supporting Arizona eryngo in Mexico, but we are aware that the municipality of Casas Grandes is interested in installing a pipeline from the spring at El Ojo Vareleño to supply water to the Universidad Tecnológica de Casas Grandes. The landowners, interested in the protection of the natural resources on their land, including the conservation of Arizona eryngo and *C. wrightii*, are opposed to the proposed water diversion (Sánchez Escalante et al. 2019, pp. 10). Currently at Ojo Vareleño, springflow is collected in concrete spa ponds, which likely affects the natural hydrology of the site.

Drought and warming

All populations are exposed to drought and warming temperatures caused by climate change. Decreased precipitation and increased temperatures due to climate change will exacerbate declines in surface and groundwater levels, which will cause further drying of cienega habitat required by Arizona eryngo. Over the next century, the conservation of rare plants will need to

consider not only the effect of climate change on species and ecosystems, but also on understanding how other factors interact with climate change to influence species viability (Souther and McGraw 2014, p. 1463). Climate change is an important consideration in the analysis of the future threats to Arizona eryngo because of the direct impact to the plant, as well as the dewatering of its rare habitat. In our analysis of the future condition of Arizona eryngo, we consider climate change to be an exacerbating factor in the increase of water loss and vegetation changes in cienegas.

Climate change has already begun, and continued greenhouse gas emissions at or above current rates will cause further warming with broad implications for living organisms across the planet, and the habitat on which they depend (Intergovernmental Panel on Climate Change (IPCC) 2014, p. 8). Climate models indicate that the transition to a more arid climate is already underway and predict that in this century the arid regions of the southwestern U.S. will become drier (i.e., decreased precipitation) and warmer (i.e., increased surface temperatures), and have fewer frost days, decreased snow pack, increased frequency of extreme weather events (heat waves, droughts, and floods), declines in river flow and soil moisture, and greater water demand by plants, animals and humans (Garfin et al. 2013, pp. 5-6; Archer and Predick 2008, p. 23). Increasing dryness in the southwestern U.S. and northern Mexico is predicted to occur as early as 2021-2040 (Seager et al. 2007, p. 1181). Analyses of the southwestern U.S. using Coupled Model Intercomparison Project Phase 3 models, show consistent projections of drying, primarily due to a decrease in winter precipitation (Collins et al. 2013, p. 1080). For both Pima and Cochise counties, where the La Cebadilla and Lewis Springs populations occur, Climate Explorer (2020) shows that average daily maximum temperature, under both lower and higher emissions scenarios, will increase by mid-century.

Climate change over the 21st century is additionally projected to reduce renewable surface water and groundwater resources in most dry subtropical regions (IPCC 2014, p. 69). Serrat-Capdevila et al. 2007 (entire) modeled the effects of four climate change scenarios on the hydrology of the San Pedro basin. Groundwater extraction was maintained equal to the rate at the time of the study. Results indicate that over the next 100 years, groundwater recharge in the San Pedro basin will decrease 17-30%, depending on the climate scenario considered (Serrat-Capdevila et al. 2007, p. 63) and average annual base flow will be half the base flow in 2000. As the area gets drier, the San Pedro aquifer groundwater overdraft will become more severe as recharge declines and groundwater pumping increases (Meixner et al. 2016, p. 135).

Summary of water loss

In summary, water loss caused the extirpation of two of six known populations (Agua Caliente and Las Playas) and threatens the future viability of all extant populations. Both extant U.S. populations (Lewis Springs and La Cebadilla) are exposed to water loss through groundwater withdrawal, and one of these (La Cebadilla) is also exposed to spring diversion. Water diversion at La Cebadilla is likely not a primary threat to Arizona eryngo as a substantial portion of the cienega has been maintained even with decades of partial diversion. Groundwater withdrawal, particularly when exacerbated by climate change, is a primary threat to the survival of Arizona eryngo at Lewis Springs and La Cebadilla. Less is known about water loss associated with the two populations in Mexico, but spring diversion is proposed at one site supporting Arizona eryngo in Chihuahua (Ojo Vareleño) and it is likely that they are exposed to groundwater

withdrawal. All populations are exposed to drought and warming caused by climate change that puts them at risk, particularly when combined with groundwater withdrawal and diversion, as well as other influences discussed in this chapter.

5.3. Change in Vegetation at Cienegas

Invasion of vegetation that shades out Arizona eryngo and dries soils poses a significant threat to the species. Changes in vegetation at cienegas are a result of many complex factors, however, primary among these are fire suppression, introduction of nonnative plant species, decreased flood events, and changes in hydrology and climate. Prior to the arrival of European settlers, burning by indigenous people was frequent enough to exclude most woody plants (e.g., *Celtis* spp., *Cephalanthus* spp., cottonwood, ash, willow [*Salix* spp.]) and suppress bulrush from cienegas and promote growth of grasses (Davis et al. 2002, p. 1; Cole and Cole 2015, p. 32). Extant cienegas now have less diversity of annual and disturbance-adapted native understory species, and an increase in native woody, clonal, and nonnative plants (Stromberg et al. 2017, p. 10). As water levels in cienegas decrease and CO_2 increases, woody plants invade without regular disturbance (e.g., fires, floods) to the system (Huxman and Scott 2007, p. 1). Shifts from herbaceous wetland vegetation to more deeply rooted riparian trees have been well documented at wetland with lowered water tables (Stromberg et al. 2019, p. 9). These woody plants not only shade out Arizona eryngo, but they can cause water level declines in cienegas through increased evapotranspiration, particularly in the summer (Johnson et al. 2016, p. 83).

Invasive nonnative plants (e.g., giant reed, Johnsongrass) are of concern because they often quickly colonize an area and aggressively compete with native species such as Arizona eryngo for sunlight, water, and nutrients. Giant reed is fast-growing, tall (can grow up to 6 m) perennial hydrophytic (water-loving) grass that grows in riparian areas, streams, irrigation ditches, and wetlands. It is an aggressive invader that rapidly spreads into a thick monoculture that outcompetes and shades out other vegetation (DiPietro 2002, p. 9; Frandsen 1997, p. 245). Giant reed is fire adapted and resprouts from extensive underground rhizomes even after very hot fires that kill native vegetation (DiPietro 2002, p. 9). Additionally, it uses large amounts of water, thereby reducing the amount of water available for native vegetation (DiPietro 2002, p. 10).

Johnsongrass is fast-growing, tall, invasive perennial grass that thrives in a variety of environments and climates (Peerzada et al. 2017, p. 2). It mostly grows at moist sites (e.g., irrigation canals, cultivated fields, field edges, pastures) and in Arizona it is known as a riparian weed in the Sonoran and Chihuahuan deserts. Johnsongrass impacts the growth of native plants due to the species strong competitive abilities (Peerzada et al. 2017, p. 4). It is difficult to control and has become resistant to herbicides, particularly glyphosate (Peerzada et al. 2017, p. 2).

At three of four cienegas supporting Arizona eryngo (Lewis Springs, La Cebadilla, and Ojo Vareleño), an increase in woody vegetation and nonnative plant species has been documented. This vegetation is outcompeting Arizona eryngo for sunlight, space, and water, likely causing a decrease in population size and extent at these sites. At Lewis Springs, nonnative Johsongrass is aggressively invading and appears to be suppressing Arizona eryngo, particularly in the drier areas of the wetlands (Li 2019, entire; J. Simms 2019, entire). Johsongrass has been present at this site since at least 2009, however, it possibly occurred earlier as Leenhouts et al. (2006, p.

116) documented it in nearby areas in the early 2000s. Also, in the drier areas of the wetlands, *Baccharis* sp. is moving slowly encroaching and also appears to be suppressing Arizona eryngo as none was found growing in the understory of *Baccharis* (Li 2019, entire; J. Simms 2019, entire). At La Cebadilla aerial imagery indicates that mesquite is invading the cienega, and cottonwood also appear to be shading out Arizona eryngo (Fonseca 2019, entire). Arizona ash trees are invading the cienega, shading out Arizona eryngo (Li 2020b), and causing them to wilt likely due the hyper transpiration rate of ash trees. Nonnative bermudagrass (*Cynodon dactylon*) occurs in the dry southern end of Arizona eryngo habitat, but it is unknown if bermudagrass is affecting Arizona eryngo. At Ojo Vareleño many nonnative plant species also occur, with a particularly aggressive invasion of giant reed that is likely invading Arizona eryngo habitat and outcompeting the species (Sánchez Escalante et al. 2019, p. 9-10). At Rancho Agua Caliente, no observations have been made with regard to changes in vegetation structure that may be affecting Arizona eryngo.

In summary, nonnative Johnsongrass and giant reed are likely to continue to aggressively invade Lewis Springs and Ojo Vareleño, respectively. If not controlled, these nonnative plant species may contribute to the near-term extirpation of Arizona eryngo populations at these sites. Woody vegetation encroachment at La Cebadilla and Lewis Springs is also likely to continue, but possibly at a slower rate than the invasion of nonnative plant species, putting Arizona eryngo populations at these sites at longer-term risk.

5.4. Direct Harm and Mortality

Livestock (e.g., cattle, horses) and native herbivores (invertebrate and vertebrate herbivores) may cause harm or mortality to Arizona eryngo through trampling, herbivory, or uprooting. We are uncertain to what extent livestock and native herbivores cause harm and mortality to plants, but they warrant some discussion. For example, some populations of *E. yuccifolium*, a species found primarily in undisturbed sites of tall-grass prairie, experience high level of flower and fruit herbivory by the larva of a Gelechiidae moth (*Aristotellia* sp.) (Molano-Flores 2001, p. 5). Floral herbivory damage of *E. yuccifolium* by a moth (*Coleotechnites eryngiella*; Gelechiidae) negatively affects floral visitation and larger floral displays tend to attract more visitors than smaller floral displays (Danderson and Molano-Flores 2010, p. 244). Cattle consume flowering *E. yuccifolium*, but appear not to eat *E. yuccifolium* with hardened flowers (La Gesse and Wiker 2008, p. 8).

Physical alteration of cienegas by livestock grazing is discussed above. Cattle are present at Rancho Agua Caliente, Sonora and have the potential to trample or eat Arizona eryngo. Photos from a site visit in 2018 show cattle manure amidst juvenile Arizona eryngo at this site. Because mature plants have large, fibrous leaves, cattle are more likely to consume young plants at an early growth stage. Some leaves in Figure 3.15 appear to be cut at the tips, but we are unclear of the cause of damage. At Lewis Springs, trespass cattle and horses could enter Lewis Springs and trample Arizona eryngo. Based on 2018 and 2019 visits, there is no evidence of cattle using the site. Evidence (i.e., scat and light trailing) of a trespass horse was found at the site, but it was not located in areas occupied by Arizona eryngo. To our knowledge, no livestock is present at La Cebadilla or Ojo Vareleño.

Many invertebrates have been observed on Arizona eryngo at La Cebadilla and Lewis Springs (Stromberg et al. 2019, p. 8; Li 2019, p. 2; Simms 2019, p. 1). Some of these invertebrates may

be floral herbivores, but do not appear to be of concern to the species. At the Agua Caliente reintroduction site in Arizona, javelina uprooted and killed young plants (it is uncertain if plants were eaten) and gophers ate young reintroduced plants (Fonseca 2018, p. 1; and Li 2019, p. 6). These vertebrate herbivores may harm plants at other sites, but this has not been documented. Saturated areas of cienegas may not provide suitable habitat for gophers, however, as cienegas become drier, gopher use and interaction with Arizona eryngo could increase. More observations and research will help confirm and clarify this potential relationship.

In summary, native and nonnative herbivores may harm Arizona eryngo, but they do not currently appear to pose a significant threat to the species. More research is warranted, particularly to determine to what extent seedlings and young plants are susceptible to vertebrate herbivory, as well as to what degree flower and seed herbivory by invertebrates has an effect on Arizona eryngo populations.

5.5. Summary

Our analysis of the past, current, and future influences on what Arizona eryngo needs for long-term viability revealed there are two that pose the largest risk to future viability: water loss (groundwater withdrawal and water diversion) and invasion of nonnative and woody plant species, both of which are exacerbated by drought and warming caused by climate change. These influences reduce the availability of moist soils and outcompete Arizona eryngo for sunlight and space, thereby reducing the quantity and quality of habitat for the species (Figure 5.2). Water loss and invasion of plant species, as well as management efforts, are carried forward in our assessment of the future conditions of Arizona eryngo populations and the viability of the species overall.

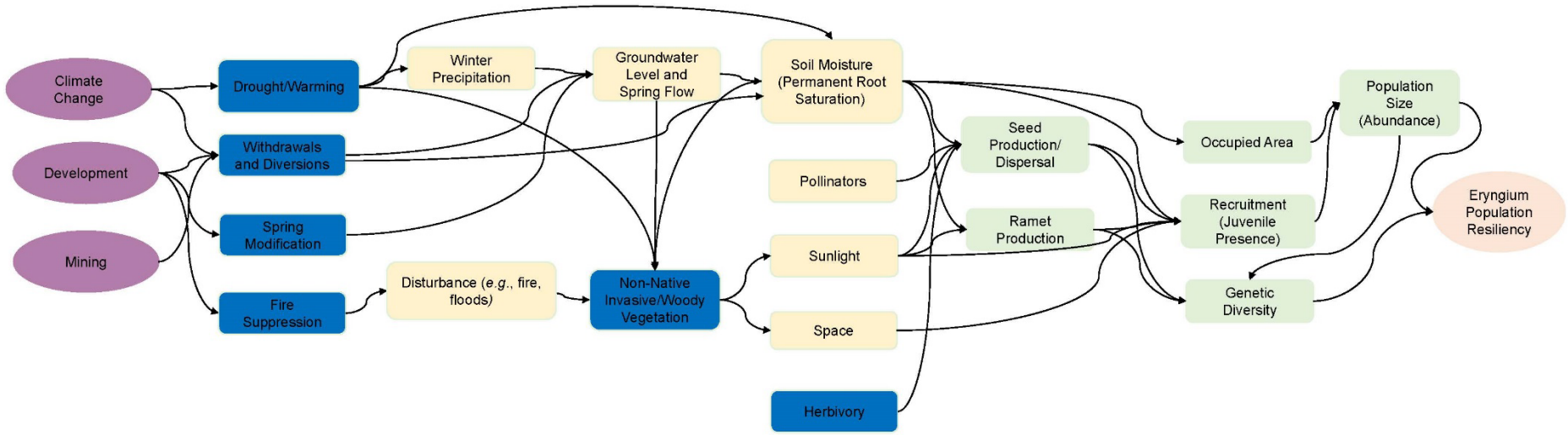


Figure 5.2. Sources of reduced soil moisture and increased competition for sunlight and space within Arizona eryngo populations.

CHAPTER 6. VIABILITY AND FUTURE CONDITIONS

This report has considered what Arizona eryngo needs for viability and the current condition of those needs (Chapters 2, 3, and 4), and we reviewed the risk factors that are driving the historical, current, and future conditions of the species (Chapter 5). In this chapter, we consider what those future conditions are likely to be and apply our forecasts to the concepts of resiliency, redundancy, and representation to assess the future viability of Arizona eryngo.

6.1. Introduction

The range of Arizona eryngo, which historically included New Mexico, has declined, with the species currently occupying southern Arizona and northern Sonora and Chihuahua. Four of six (or 67%) known historical Arizona eryngo populations are extant. Two populations (one in Arizona and one in New Mexico) have been extirpated, and it is highly likely that additional undocumented populations have been extirpated as well. In both instances of known extirpation, the loss of Arizona eryngo populations was associated with the drying of habitat that rendered it unsuitable for the species to persist. The remaining populations are isolated from one another, and as of 2018 to 2020, estimates indicate there are from approximately 56 to 30,422 individuals per population, with the population in Chihuahua being the smallest.

The effects of water loss from cienegas (e.g., from groundwater withdrawal, diversions), invasion of nonnative plant species, and encroachment of woody vegetation, and the exacerbating effects of drought and warming caused by climate change create varying levels of risk to Arizona eryngo into the future. Both smaller and larger Arizona eryngo populations face risks from anthropogenic sources, however, the smaller populations in Sonora and Chihuahua (both in the low condition) are more vulnerable to a single stochastic event, such as a severe drought year, which could eliminate the entire population. Smaller populations may also be more vulnerable to smaller stressors as such herbivory.

These risks, alone or in combination, could result in the extirpation of populations. The current isolation of populations prohibits natural recolonization, therefore, extirpation of one population would result in the permanent loss of the population and reduced species representation. Historically, the species, with a larger range of likely interconnected populations, would have been more resilient to stochastic events because even if some populations were extirpated by such events, they could be recolonized over time by dispersal from nearby surviving populations (for example, La Cebadilla and Agua Caliente). This connectivity would have made for a highly resilient species overall. Under current conditions, restoring that connectivity on a large scale may not be feasible due to the reduced number of functional aridland cienegas; however, improving the redundancy of populations within at least some of the areas of representation is feasible through the reintroduction and introduction of Arizona eryngo at suitable sites (e.g., Agua Caliente; Historic Canoa Ranch).

In summary, as a consequence of the current conditions of Arizona eryngo, the viability of the species now primarily depends on maintaining the remaining four isolated populations and restoring new populations where feasible.

6.2. Future Scenarios and Considerations

Because we have significant uncertainty regarding: 1) how climate will change in the future, which in turn will have an effect on the severity of future periods of drought and warming; 2) the amount of water withdrawals and water diversions that will occur in the future; and 3) whether nonnative and woody plants will be managed or allowed to spread, we have forecasted the resiliency, redundancy, and representation of Arizona eryngo under three plausible future scenarios (Scenario 1: Continuation; Scenario 2: Increased Effects; and Scenario 3: Conservation; Table 6.1). These future scenarios forecast the viability of Arizona eryngo over the next 10 and 30 years. We chose 10 years to evaluate what is likely to occur in the near term, and 30 years because this is within the range of available hydrological and climate change model forecasts and this incorporates multiple generations of Arizona eryngo.

For each future scenario, we describe the effects from the identified source/stressors that would occur in each population (Table 6.1). All of the scenarios involve some degree of uncertainty; however, they present a range of realistic and plausible future conditions. Each scenario is described in further detail below (Table 6.1), but in summary, Scenario 1, or the Continuation scenario, evaluates the condition of Arizona eryngo if there is no increase in risks to the populations from what exists today. In other words, those factors that are having an influence on populations of Arizona eryngo continue at current rates. Scenario 2, or the Increased Effects scenario, evaluates the response of the species to changes in risks, including the application of Representative Concentration Pathways (RCP) 8.5 predictions (note that RCP is explained in the following section), increased groundwater withdrawal and water diversions, and increased invasion of nonnative and woody plant species. Scenario 3, or the Conservation Planning scenario (Appendix 2), explores possible conservation strategies that if implemented, could improve current conditions, by slowing or halting declines in habitat and population conditions in 10 years, and in some cases, reversing declines to improve habitat and population conditions in 30 years.

Table 6.1. Future Scenario Descriptions by Source/Stressor and Conservation.

Source/Stressor	Water Loss	Increased Competition	Conservation
Source/Stressor described	Amount of water loss (through withdrawal and diversion). Number or severity of drought events. Level of increased temperature.	Amount of nonnative plant invasion. Amount of woody plant encroachment.	Level of implementation of conservation actions.
Scenario 1 Continuation	Water loss occurs at the same rate as the past 10 years. Number or severity of drought events continue similar to the past 10 years. Climate change follows a 4.5 emissions scenario.	Competition from nonnative and woody plants occurs at same rate as the last 10 years.	No new populations are found. Reestablishment efforts at Agua Caliente continue at the same level with limited success. Seed preservation continues. No management of nonnative and woody plants is implemented.
Scenario 2 Increased Effects	Water loss occurs at an increased rate. Number and severity of drought events increases. Climate change follows an 8.5 emissions scenario.	Competition from nonnative and woody plants increases.	No new populations are found. Reestablishment efforts at Agua Caliente continue at the same level with limited success. Seed preservation continues. No management of nonnative and woody plants is implemented.
Scenario 3 Conservation Planning (Appendix 2)	Water loss stabilizes or decreases compared to the last 10 years, due to actions including water conservation, riparian and cienega restoration, and groundwater recharge. Number or severity of drought events are similar to the past 10 years, but do not worsen. Climate change follows a 4.5 emissions scenario.	Competition from nonnative and woody plants is reduced due to management actions.	Sites in Mexico are revisited and additional plants are located or the populations are augmented. Reestablishment efforts at Agua Caliente are successful. Introductions at new sites successful. Nonnative plants are controlled and woody vegetation is managed (thinned or removed).

We examine the resiliency, representation, and redundancy of Arizona eryngo under each of these three plausible scenarios for each of the two time periods. Resiliency of Arizona eryngo populations depends on future availability of water and sunlight, among other resources

(discussed in Section 2.5), and how these habitat factors influence species abundance, recruitment, and the amount of habitat occupied. We expect the four extant Arizona eryngo populations to experience changes to these aspects of their habitat in different ways under the different scenarios. We projected the expected future resiliency of each population based on the events that would occur under each scenario. We then project an overall condition for each population based on these habitat and population factors. For these projections, populations in high (healthy) condition are expected to have high resiliency at that time period (i.e., they are at the high end of the abundance range, recruitment is successful, and they occupy habitat of sufficient size to allow for some expansion and contraction within a cienega without significantly affecting the overall viability of the population). Populations in high condition are expected to persist into the future (>90 % chance of persistence beyond 30 years), and have the ability to withstand stochastic events that may occur. Populations in moderate condition have less resiliency than those in high condition, but the majority (>60 – 90%) of these populations are expected to persist beyond 30 years. Populations in moderate condition are smaller in abundance and occupy smaller areas than those in high condition. Populations in low (unhealthy) condition have low resiliency and are not necessarily able to withstand stochastic events. As a result, they are less likely to persist beyond 30 years (>10 – 60%). Finally, populations are considered extirpated when they completely lack individuals, or functionally extirpated when they have very low numbers and no evidence of reproduction; these latter populations have very low resiliency and have less than or equal to a 10 % chance of persistence beyond 30 years.

Climate considerations

In section 5.2., we discussed the potential effects of drought and warming caused by climate change on Arizona eryngo. In this section, we briefly explain the two different climate change trajectories considered in the future scenarios for the species. The future scenarios include the effects of future climate change using emissions projected at 4.5 and 8.5 RCP scenarios contributed by the Working Group III to the Fifth Assessment Report and described in the most recent Synthesis Report of the Intergovernmental Panel on Climate Change (IPCC 2014, pp. 9, 22, 57). The IPCC Report describes four alternative trajectories for carbon dioxide emissions (RCPs) and the resulting atmospheric concentrations from the year 2000 to 2100 (van Vuuren et al. 2011, p. 5). For the purposes of our analysis, we chose one intermediate scenario (RCP4.5) and one scenario with very high greenhouse gas emission (RCP8.5) (IPCC 2014, p. 8). Scenarios with lower emissions than RCP 4.5 require human interventions, technologies, and mitigations to reduce emissions that are not currently plausible (NOAA 2020, p. 1).

Arizona eryngo future Scenario 1, the Continuation scenario, assumes RCP4.5, a medium stabilization scenario where CO_2 emissions continue to increase through mid-21st century, but then decline and atmospheric carbon dioxide concentrations are between 580 and 720 ppm CO_2 from 2050 to 2100, representing an approximate +2.5 ºC temperature change relative to 1861-80 (IPCC 2014, p. 9, Figure SPM.5). Future scenario 2 assumes RCP8.5 where atmospheric carbon dioxide concentrations are above 1000 ppm CO_2 between 2050 and 2100, representing an approximate +4.5 ºC temperature change relative to 1861-80 (IPCC 2014, p. 9, Figure SPM.5). The 2014 IPCC Synthesis Report projects global temperature change to 2100 (IPCC 2014, p. 8). A recent study suggests that, because of uncertainty in long-run economic growth rates, there is "a greater than 35% probability that emissions concentrations will exceed those assumed in the

most severe of the available climate change scenarios (RCP8.5)" by 2100 (Christensen et al. 2018, p. 5409).

For both RCP4.5 and RCP8.5, global mean surface temperature change for the end of the 21st century (2081-2100) is projected to likely exceed 1.5ºC, relative to 1850-1900 (IPCC 2014, p. 60). Under RCP8.5, global mean surface temperature change is projected likely to exceed 2.0ºC by 2100, perhaps as high as 4.8 ºC, relative to 1850-1900 (IPCC 2014, p. 60). Global mean surface temperature for the mid-century (2046-2065) is projected to increase under RCP4.5 and 8.5, but projections are lower than those for the end of the century (IPCC 2014, p. 60). For both Pima and Cochise counties, where the La Cebadilla and Lewis Springs populations occur, Climate Explorer (2020) shows that average daily maximum temperature, under both lower and higher emissions scenarios, will increase by mid-century. It is virtually certain that there will be more frequent hot and fewer cold temperature extremes over most land areas on daily and seasonal timescales, as global mean surface temperature increases (IPCC 2014, p. 58). In many mid-latitude and subtropical dry regions, mean precipitation will likely decrease, under the RCP8.5 scenario (IPCC 2014, p.60).

Climate change over the 21st century is additionally projected to reduce renewable surface water and groundwater resources in most dry subtropical regions (IPCC 2014, p. 69). In presently dry regions, the frequency of droughts will likely increase by the end of the 21st century under RCP8.5 regions (IPCC 2014, p. 69). Because of the influence of temperature on water, including evapotranspiration, climate change is expected to result in drier soils with less runoff (USGCRP 2017, pp. 232). Future human demand for water resources, due to human population growth and limitations of existing supply, is expected to interact with climate effects and exacerbate the effects of drought on water resources in Arizona.

6.3. Viability (Resiliency, Redundancy, and Representation)

This section reviews the viability of Arizona eryngo under two scenarios. The output of the Continuation and Increased Effects scenarios at each time step (0-10 and 10-30 years) and synopses of the effects to the populations over time are included below. The Conservation Planning scenario is presented in Appendix 2.

6.3.1. Scenario 1 – Continuation

Under Scenario 1, the Continuation scenario, those factors that are having an influence on populations of Arizona eryngo continue for the next 30 years at existing rates, current as of the preparation of this SSA report. Effects of the influences on Arizona eryngo are considered over the next 0-10 and 10-30 years. Water loss due to groundwater withdrawal, diversion, and drought, as well as nonnative plant invasion and woody plant encroachment continue to reduce cienega habitat for this species. Climate change, which is already occurring, follows a RCP4.5 emissions scenario, leading to additional water loss at all locations. Conservation efforts that are underway (e.g., Arizona eryngo reestablishment at Agua Caliente continues at the same level with limited success, such that a viable population is not established) will continue, but are not expanded.

6.3.1.1. Resiliency

La Cebadilla
Under the Continuation scenario, within 30 years La Cebadilla would experience a modest decrease in groundwater levels due to continued groundwater pumping and drought and warming as a result of climate change. Partial springflow diversion would continue to occur. As a result of decreased groundwater levels, springflow would diminish and woody vegetation encroachment would marginally increase, leaving somewhat less open sun, moist cienega habitat available for Arizona eryngo. Under the Continuation scenario, we would expect the La Cebadilla population to remain in moderate condition in 30 years.

Lewis Springs
Under the Continuation scenario, Lewis Springs would experience a moderate decrease in groundwater levels due to the effects of a combination of past, present, and future groundwater pumping (from continued human development in the Upper San Pedro River Basin), and drought and warming as a result of climate change. As a result of decreased groundwater levels, springflow would diminish and woody vegetation encroachment would increase, leaving less open sun, moist cienega habitat available for Arizona eryngo. Invasion of *S. halepense* would also continue, leaving less open sun habitat available for Arizona eryngo. Under the Continuation scenario, we would expect the Lewis Springs population to decline to low condition in 30 years.

Rancho Agua Caliente
Under the Continuation scenario, Rancho Agua Caliente would experience a modest decrease in groundwater levels due to groundwater pumping and/or drought and warming as a result of climate change. As a result of decreased groundwater levels, springflow would diminish, leaving less moist cienega habitat available for Arizona eryngo. Under the Continuation scenario, we would expect the Rancho Agua Caliente population to remain in low condition in 30 years.

Ojo Vareleño
Under the Continuation scenario, within 30 years, *A. donax* would completely invade the Ojo Vareleño, leaving no or extremely little open sun suitable cienega habitat available for Arizona eryngo. In this scenario, proposed water diversion does not occur, but other stressors, such as groundwater pumping and drought and warming as a result of climate change continue. Under the Continuation scenario, we would expect the Ojo Vareleño population to be extirpated in 30 years.

Table 6.2. Resiliency of Arizona eryngo populations under Scenario 1, Continuation from 0-10 years.

	Population / Distribution Factors			**Habitat Factors**		
Population	**Abundance (individuals)**	**Juvenile Presence**	**Occupied Area (m^2)**	**Soil Moisture**	**Full Sun**	**Continuation Condition**
La Cebadilla	**High**	**Yes**	**Moderate**	**Moderate**	**Moderate**	**Moderate**

Lewis Springs	Moderate	Yes	Low	Moderate	Moderate	Moderate
Rancho Agua Caliente	Low	Yes	Moderate	Moderate	High	Low
Ojo Vareleño	Low	No	Low	Low	Low	Low
Las Playas	Ø	Ø	Ø	Ø	Unknown	Ø
Agua Caliente	Ø	Ø	Ø	Moderate	Moderate	Ø

Table 6.3. Resiliency of Arizona eryngo populations under Scenario 1, Continuation from 10-30 years.

	Population / Distribution Factors			Habitat Factors		
Population	**Abundance (individuals)**	**Juvenile Presence**	**Occupied Area (m^2)**	**Soil Moisture**	**Full Sun**	**Continuation Condition**
La Cebadilla	Moderate	Yes	Moderate	Moderate	Moderate	Moderate
Lewis Springs	Low	Yes	Low	Low	Low	Low
Rancho Agua Caliente	Low	Yes	Moderate	Moderate	High	Low
Ojo Vareleño	Ø	Ø	Ø	Low	Ø	Ø
Las Playas	Ø	Ø	Ø	Ø	Unknown	Ø
Agua Caliente	Ø	Ø	Ø	Moderate	Moderate	Ø

6.3.1.2. Representation

In the Continuation scenario, the current level of representation in the U.S. may be maintained for 30 years, although the Lewis Springs population would become smaller and more vulnerable to extirpation and therefore there is a possibility of loss of that area of representation (San Pedro River Basin). The current level of representation in Mexico would decrease within 30 years because one area of representation (Ojo Vareleño in the Mimbres River Basin) would be lost.

6.3.1.3. Redundancy

Each of the four current representation areas have only one population each for redundancy. In the Continuation scenario, within 30 years, one of these populations (Ojo Vareleño) would be

lost and the other areas of representation would continue to have only one population each for redundancy.

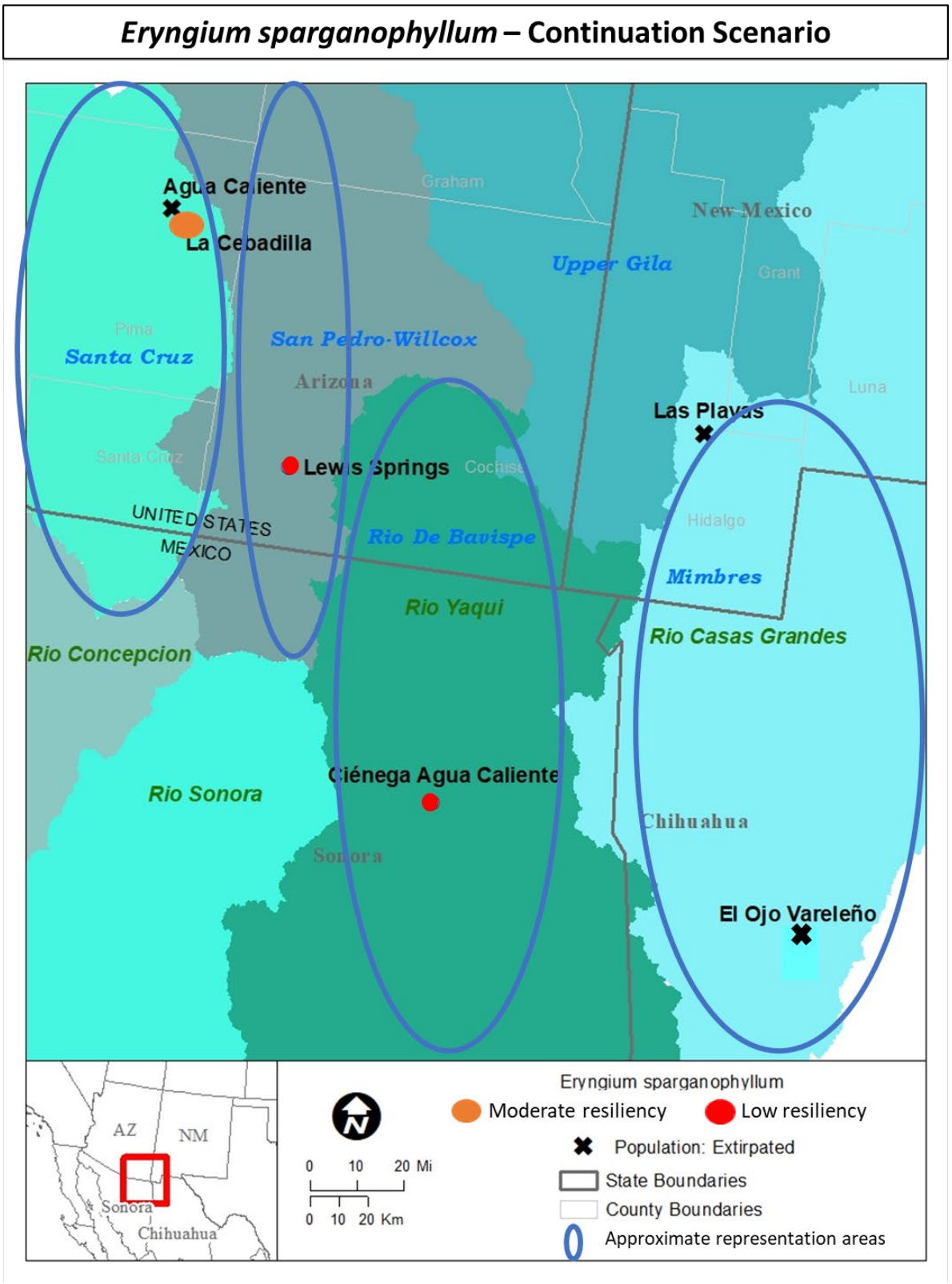


Figure 6.1. Resiliency, representation, and redundancy of Arizona eryngo under the Continuation scenario.

6.3.2. Scenario 2 – Increased Effects

Scenario 2, the Increased Effects scenario, examines increased risks to Arizona eryngo populations, with changes in climate projected at a higher (RCP8.5) emissions scenario, and with additional increases in other stressors, as detailed below. Conservation efforts that are underway (e.g., Arizona eryngo reestablishment at Agua Caliente continues at the same level with limited success, such that a viable population is not established) will continue, but are not expanded.

6.3.2.1. Resiliency

La Cebadilla

Under the Increased Effects scenario, within 30 years La Cebadilla would experience a moderate decrease in groundwater levels due to increased groundwater pumping and drought and warming as a result of climate change. Partial springflow diversion would continue to occur. As a result of decreased groundwater levels, springflow would diminish and woody vegetation encroachment would increase, leaving less open sun, moist cienega habitat available for Arizona eryngo. Under the Increased Effects scenario, we would expect the La Cebadilla population to possibly remain in moderate condition or decrease to low condition in 30 years. There is a lack of information regarding impacts to spring flow as a result of climate change, and water levels at La Cebadilla are relatively substantial compared to other sites, so this spring may be able to maintain moist soils for longer than other areas. Therefore, the future condition of this population depends on the relationship between groundwater levels and climate change in this area. As we find more information or more information becomes available on groundwater levels and use (current and projected), we will likely become more confident in our predictions regarding the future status of this population.

Lewis Springs

Under the Increased Effects scenario, within 30 years Lewis Springs would experience a large decrease in groundwater levels due to the effects of a combination of past, present, and future groundwater pumping (from increased human development in the Upper San Pedro River Basin), and drought and warming as a result of climate change. As a result of decreased groundwater levels, springflow would diminish and woody vegetation encroachment would increase, leaving less open sun, moist cienega habitat available for Arizona eryngo. Invasion of *S. halepense* would also continue, leaving much less open sun habitat available for Arizona eryngo. Under the Increased Effects Scenario, we would expect the Lewis Springs population to decline to low or functionally extirpated condition in 30 years. For example, if not completely extirpated, the population would decline such that abundance would be on the low end of the low category range, or within the functionally extirpated abundance range, as described in Table 4.1.

Rancho Agua Caliente

Under the Increased Effects scenario, within 30 years Rancho Agua Caliente would experience a moderate decrease in groundwater levels due to groundwater pumping and/or drought and warming as a result of climate change. As a result of decreased groundwater levels, springflow would diminish, leaving less moist cienega habitat available for Arizona eryngo. Under the Increased Effects scenario, we would expect the Rancho Agua Caliente population to remain in low condition in 30 years.

Ojo Vareleño
Under the Increased Effects scenario, springflow is diverted from the Ojo Vareleño cienega which leads to drying of cienega habitat. *A. donax* may decrease in this scenario due to water diversion. Other stressors, such as groundwater pumping and drought and warming as a result of climate change continue. Under the Increased Effects scenario, we would expect the Ojo Vareleño population to be extirpated in 30 years.

Table 6.4. Resiliency of Arizona eryngo populations under Scenario 2, Increased Effects from 0-10 years.

	Population / Distribution Factors			Habitat Factors		
Population	**Abundance (individuals)**	**Juvenile Presence**	**Occupied Area (m^2)**	**Soil Moisture**	**Full Sun**	**Increased Effects Condition**
La Cebadilla	High	Yes	Moderate	Moderate	Moderate	Moderate
Lewis Springs	Moderate	Yes	Low	Moderate	Moderate	Moderate
Rancho Agua Caliente	Low	Yes	Moderate	Moderate	High	Low
Ojo Vareleño	Low	No	Low	Low	Low	Low
Las Playas	Ø	Ø	Ø	Ø	Unknown	Ø
Agua Caliente	Ø	Ø	Ø	Moderate	Moderate	Ø

Table 6.5. Resiliency of Arizona eryngo populations under Scenario 2, Increased Effects from 10-30 years.

	Population / Distribution Factors			Habitat Factors		
Population	**Abundance (individuals)**	**Juvenile Presence**	**Occupied Area (m^2)**	**Soil Moisture**	**Full Sun**	**Increased Effects Condition**
La Cebadilla	Moderate	Yes	Moderate / Low	Moderate / Low	Moderate / Low	Moderate / Low
Lewis Springs	Low / Ø	Yes / No	Low	Low	Low	Low / Ø
Rancho Agua Caliente	Low	Yes	Moderate	Moderate / Low	High	Low
Ojo Vareleño	Ø	Ø	Ø	Ø	Low	Ø

Las Playas	**Ø**	**Ø**	**Ø**	**Ø**	**Unknown**	**Ø**
Agua Caliente	**Ø**	**Ø**	**Ø**	**Moderate**	**Moderate**	**Ø**

6.3.2.2. Representation

In the Increased Effects scenario, the current level of representation in the U.S. may be maintained for 30 years, although the Lewis Springs population would become smaller and more vulnerable to extirpation and therefore there is a possibility of loss of that area of representation (San Pedro River Basin). The current level of representation in Mexico would decrease within 30 years because one area of representation (Ojo Vareleño in the Mimbres River Basin) would be lost. Similar to U.S., the remaining population in Mexico, Rancho Agua Caliente, would become smaller and more vulnerable to extirpation and therefore there is a possibility of loss of all areas of representation in Mexico.

6.3.2.3. Redundancy

Each of the four current representation areas have only one population each for redundancy. In the Increased Effects scenario, within 30 years, one of these populations (Ojo Vareleño), and possibly a second (Lewis Springs) would be lost, and the other areas of representation would continue to have only one population each for redundancy.

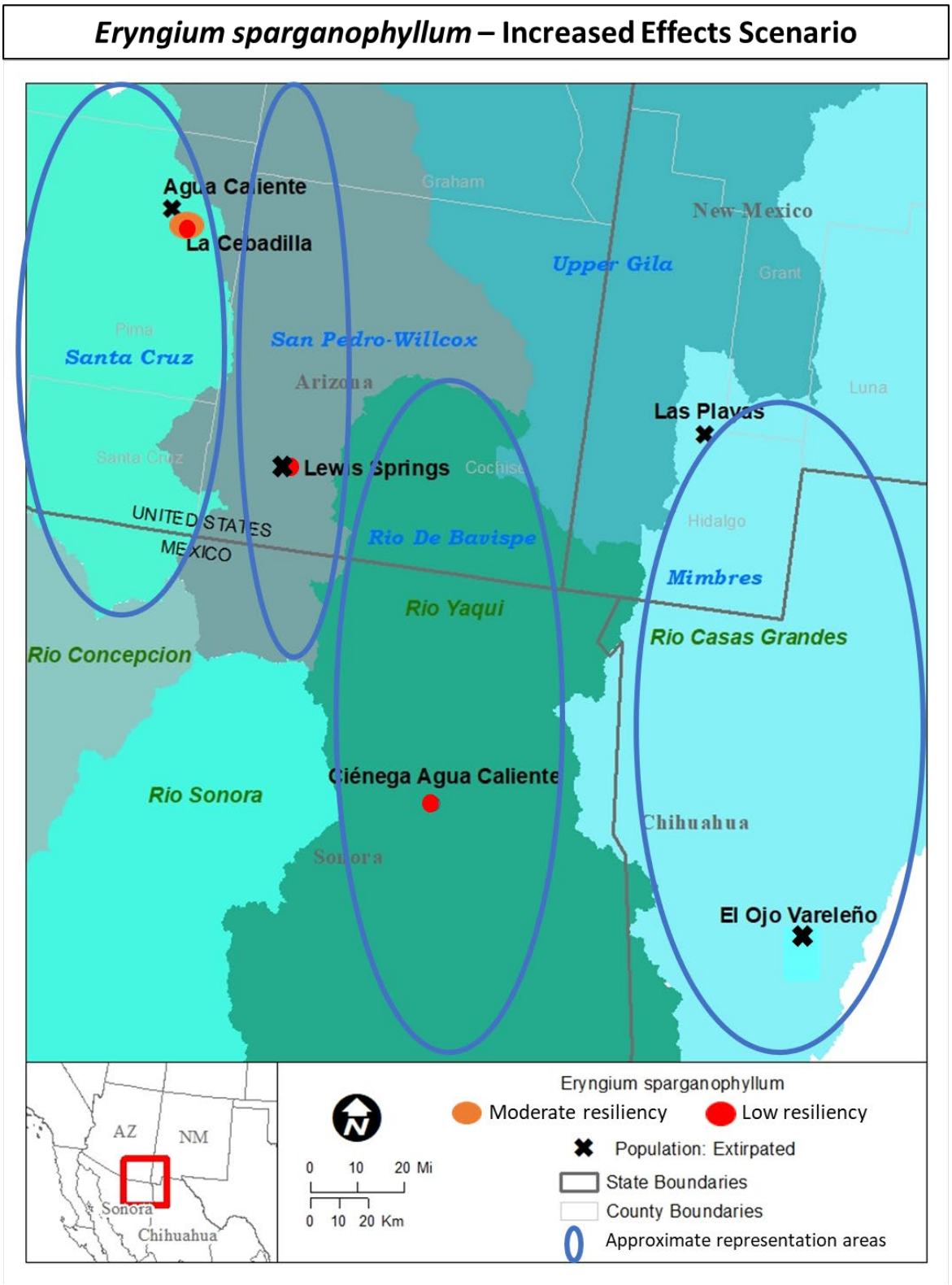


Figure 6.2. Resiliency, representation, and redundancy of Arizona eryngo under the Increased Effects scenario.

6.4. Status Assessment Summary

We used the best available information to forecast the likely future condition of Arizona eryngo. Our goal was to describe the viability of the species in a manner that will address the needs of the species in terms of resiliency, representation, and redundancy. We considered the possible future condition of the species, considering a range of potential scenarios that include important influences on the status of the species. Our results describe a range of possible conditions in terms of how many and where Arizona eryngo populations are likely to persist into the future (Tables 6.6, 6.7).

Table 6.6. Arizona eryngo population conditions under each scenario at 0-10 years.

	Population Condition		
Population	**Current Condition**	**Scenario 1- Continuation**	**Scenario 2- Increased Effects**
La Cebadilla	**Moderate**	**Moderate**	**Moderate**
Lewis Springs	**Moderate**	**Moderate**	**Low**
Rancho Agua Caliente	**Low**	**Low**	**Low**
Ojo Vareleño	**Low**	**Ø**	**Ø**
Las Playas	**Ø**	**Ø**	**Ø**
Agua Caliente	**Ø**	**Ø**	**Ø**

Table 6.7. Arizona eryngo population conditions under each scenario at 10-30 years.

	Population Condition		
Population	**Current Condition**	**Scenario 1- Continuation**	**Scenario 2- Increased Effects**
La Cebadilla	**Moderate**	**Moderate**	**Moderate / Low**
Lewis Springs	**Moderate**	**Low**	**Low / Ø**
Rancho Agua Caliente	**Low**	**Low**	**Low**
Ojo Vareleño	**Low**	**Ø**	**Ø**
Las Playas	**Ø**	**Ø**	**Ø**
Agua Caliente	**Ø**	**Ø**	**Ø**

Arizona eryngo faces a variety of risks from water loss, nonnative plant invasion, and woody plant encroachment. These risks play a large role in the future viability of Arizona eryngo. If populations lose resiliency, they are more vulnerable to extirpation, with resulting losses in representation and redundancy.

In 30 years, under Scenario 1 – Continuation, we would expect viability of Arizona eryngo to be characterized by lower levels of resiliency, representation, and redundancy than it has currently. No populations would be in high condition, one would remain in moderate condition, two would be in low condition, and three would be extirpated.

In 30 years, under Scenario 2 – Increased Effects, we would expect viability of Arizona eryngo to be characterized by lower levels of resiliency, representation, and redundancy than it has currently. No populations would be in high condition, one would remain in possibly remain in moderate condition or decrease to low condition, one would be in low condition, one would be on the edge between low and extirpated, and three would be extirpated. Only one population (in moderate condition) would have a greater than a 60% chance of persisting beyond 30 years.

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APPENDIX 1. Evaluating Causes and Effects for Arizona Eryngo

Template for Cause and Effects Evaluation

THEME: ?			
[ESA Factor(s): ?]	**Analysis**	Confidence / Uncertainty	Supporting Information
SOURCE(S)	*What is the ultimate source of the actions causing the stressor? Ie, Urban Development, Oil and Gas Development, Agriculture*	See next page for confidences to apply at each step.	Literature Citations, with page numbers , for each step. Use superscript to delineate which statement goes with which citation. These can be repeated per theme, but not within a theme.
- Activity(ies)	*What is actually happening on the ground as a result of the action? Be specific here.*		
STRESSOR(S)	*What are the changes in environmental conditions on the ground that may be affecting the species? For example, removal of nesting habitat, increased temperature, loss of flow*		
- Affected Resource(s)	*What are the resources that are needed by the species that are being affected by this stressor? Or is it a direct effect on individuals?*		
- Exposure of Stressor(s)	*Overlap in time and space. When and where does the stressor overlap with the resource need of the species (life history and habitat needs)? This is not the place to describe where geographically it is occuring, but where in terms of habitat.*		
- Immediacy of Stressor(s)	*What's the timing and frequency of the stressors? Are the stressors happening in the past, present, and/or future?*		
Changes in Resource(s)	*Specifically, how has(is) the resource changed(ing)?*		
Response to Stressors: - INDIVIDUALS	*What are the effects on individuals of the species to the stressor? (May be by life stage)*		
POPULATION & SPECIES RESPONSES	*[Following analysis will determine how do individual effects translate to population and species-level responses? And what is the magnitude of this stressor in terms of species viability?]*		
Effects of Stressors: - POPULATIONS [RESILIENCY]	*What are the effects on population characteristics (lower reproductive rates, reduced population growth rate, changes in distribution, etc)?*		

THEME: ?			
[ESA Factor(s): ?]	**Analysis**	Confidence / Uncertainty	Supporting Information
- GEOGRAPHIC SCOPE	*What is the geographic extent of the stressor relative to the range of the species/populations? In other words, this stressor effects what proportion of the rangewide populations?*		
- MAGNITUDE	*How large of an effect do you expect it to have on the populations?*		
SUMMARY	*What is the bottom line- is this stressor important to carry forward in your analysis, or is it only having local effects, or no effects?*		

This table of Confidence Terminologies explains what we mean when we characterize our confidence levels in the cause and effects tables on the following pages.

Confidence Terminology	Explanation
Highly Confident	We are more than **90% sure** that this relationship or assumption accurately reflects the reality in the wild as supported by documented accounts or research and/or strongly consistent with accepted conservation biology principles.
Moderately Confident	We are **70 to 90% sure** that this relationship or assumption accurately reflects the reality in the wild as supported by some available information and/or consistent with accepted conservation biology principles.
Somewhat Confident	We are **50 to 70% sure** that this relationship or assumption accurately reflects the reality in the wild as supported by some available information and/or consistent with accepted conservation biology principles.
Low Confidence	We are less than **50% sure** that this relationship or assumption accurately reflects the reality in the wild, as there is little or no supporting available information and/or uncertainty consistency with accepted conservation biology principles. Indicates areas of high uncertainty.

Evaluating Cause and Effects for Arizona eryngo

THEME: Anthropogenic Physical Alteration of Cienegas			
[ESA Factor(s): A]	**Analysis**	Confidence / Uncertainty	Supporting Information
SOURCE(S)	The source of anthropogenic physical alteration of cienegas comes from human activities for domestic, agricultural, and ranching needs.	Highly Confident	
- Activity(ies)	**Historical:** 1) Livestock (sheep and cattle) introduction : intensive overgrazing from sheep and cattle from the late 1500s to the late 1800s led to barren soil, erosion, headcutting (erosional feature in a stream which contributes to lowering the watertable of the surrounding system), increased frequency of or intensity of destructive floods, etc., all leading to the alteration or complete destruction (complete loss of ecological function) of cienegas. 2) Beaver Eradication: beaver dams, once numerous in range of Arizona eryngo, slowed water and created pools and wetlands along water courses; however, high levels of beaver (*Castor canadensis*) trapping in the 1800s further caused erosion and channel cutting of these once complex, shallow flatland watercourses. 3) Agricultural Recountouring: early settlers recontoured (e.g., diverted, dammed, channelized) cienegas for agricultural, mining, disease control and other purposes; this resulted in further channelization and concentrated flow thus greatly reducing the former size of cienegas (and further lowering the water table). 4) Other physical alterations: these include other alterations, such as railroads placed near cienegas, that altered hydrological function of cienegas. **Current:** 1) Livestock: cattle and horses can trample vegetation and expose and compact soil resulting in habitat erosion and altered hydrological function, but the effects of livestock are dependent on many factors such as the intensity, duration, and timing of grazing.	Highly Confident	Cole and Cole 2015, p. 32; Sivinski 2018, p. 6; Cole and Cole 2015, p. 32; Gibson and Olden 2014, p. 395; Guido 2008, p. 2, Minckley et al. 2013, p. 214
STRESSOR(S)	Drying and channelization of habitat for Arizona eryngo.	Highly Confident	
- Affected Resource(s)	Habitat quantity and quality (the amount of organic, moist, wetland soils) is reduced or eliminated in cienegas that have been physically altered.	Highly Confident	
- Exposure of Stressor(s)	Physical alteration of cienegas decreased the amount of habitat available to Arizona eryngo in the past, likely resulting in the elimination of undocumented populations. At cienegas that support extant populations of Arizona eryngo, some physical alterations are much less severe today and result in fewer effects to the species. The population at Lewis Springs continues to be affected by the presence of a railroad that alters the natural hydrology of the area. The population at La Cebadilla continues to be affected by the presence of a berm that alters the natural hydrology of the cienega. The population at Rancho Agua Caliente is exposed to cattle ranching which may result in some physical alterations (e.g., cattle may trample vegetation and expose and compact soil resulting in habitat erosion and altered hydrological function)	Moderately Confident	
- Immediacy of Stressor(s)	Severe physical alteration of cienegas in the past likely eliminated undocumented Arizona eryngo populations. At cienegas that support extant populations of Arizona eryngo, some physical alterations are less severe today and result in fewer effects to the species	Moderately Confident	
Changes in Resource(s)	Severe physical alteration of cienegas likely led to the loss of Arizona eryngo populations in the past. Continuing physical alteration (e.g., berm, railroad, houses, livestock) is less severe but may cause some changes in cienega hydrology that could reduce Arizona eryngo habitat quantity and quality	Moderately Confident	
Response to Stressors: - INDIVIDUALS	Fewer Arizona eryngo survive with less habitat available.	Highly Confident	
POPULATION & SPECIES RESPONSES			
Effects of Stressors: - POPULATIONS [RESILIENCY]	Populations at cienegas that have reduced ecological function due to physical alteration can be eliminated or reduced in size. The more severe the alteration, the more likely ecological function will be lost and populations will be eliminated. Less severe alterations may not eliminate populations, but may reduce population size due to decreased habitat quantity and quality. Smaller populations occuring over smaller areas have less resiliency than larger populations over larger areas. Furthermore, when populations are eliminated, genetic diversity is lost, extant populations become isolated, and repopulation of extirpated locations is unlikely to occur without human assistance.	Moderately Confident	

THEME: Anthropogenic Physical Alteration of Cienegas			
[ESA Factor(s): A]	**Analysis**	Confidence / Uncertainty	Supporting Information
- GEOGRAPHIC SCOPE	Historical: Physical alteration of cienegas leading to loss of ecological function historically occurred across the range of the Arizona eryngo. Current: Physical alteration (from cattle, berm, houses, railroad) that may lead to changes in ecological function of cienegas currently occurs at three of four sites that supports the species (Rancho Agua Caliente in Sonora and La Cebadilla and Lewis Springs in Arizona)	Moderately Confident	
- MAGNITUDE	Historical: Physical alteration of cienegas leading to loss of ecological function occurred across the range of the Arizona eryngo and likely eliminated populations. Current: Physical alteration from various sources (cattle, berm, houses, railroad) may somewhat reduce the ecological function of the cienega at Rancho Agua Caliente, La Cebadilla, and Lewis Springs, possibly resulting in lowered Arizona eryngo population abundance, but this has not been documented.	Somewhat Confident	
SUMMARY	Physical alteration of cienegas caused by historical activities led to the loss of or reduction in ecological function of cienegas. Such loss likely eliminated undocumented Arizona eryngo populations, possibly leading to the current isolation of populations and reduced genetic diversity. Currently, less severe physical alteration at sites that support extant E. sparanophyllum populations, namely Rancho Agua Caliente, La Cebadilla, and Lewis Springs may reduce cienega function, but this has not been documented.	Somewhat Confident	

THEME: Water loss from cienegas			
[ESA Factor(s): A]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
SOURCE(S)	The source of water loss from cienegas (from reducing, stopping, or diverting spring flow) comes from human activities for domestic, industrial, agricultural, and ranching needs, as well as decreased precipitation and increased temperatures resulting from climate change.	Highly Confident	
- Activity(ies)	1) Groundwater pumping: leads to reduced aquifer storage (or aquifer depletion) and no or reduced outflow from springheads. 2) Spring modification: modified springhead(s) reduce or eliminate springflow. 3) Water diversion: water diverted from springheads reduces the amount of cienega habitat. 4) Drought and warming caused by climate change: reduces spring flow and the amount of water in cienegas. Reduction in winter rain particularly leads to reduced groundwater recharge. Climate change is expected to exacerbate drought conditions, which may lead to less aquifer recharge.	Highly Confident	Sivinski 2018, p. 27; Fonseca 2019, p. 2; Stromberg et al. 2019, p. 5; http://friendsofaguacaliente.org/history/
STRESSOR(S)	Drying of habitat for Arizona eryngo.	Highly Confident	
- Affected Resource(s)	Habitat quantity (the amount of organic, moist, wetland soils) is reduced or eliminated in cienegas that have experienced water loss. Habitat quality is also reduced. Drier cienegas may be invaded by woody vegetation and nonnative species; however, this is discussed in Tab 3. Drier conditions may result in reduced flowering and sexual reproduction (asexual reproduction may still occur).	Highly Confident	
- Exposure of Stressor(s)	1) **Historical:** a) The population at Las Playas was extirpated due to groundwater pumping for agriculture and the Playas Smelter which caused the drying of the cienega; b) the population at Agua Caliente, AZ was extirpated due to spring flow diversion (to fill a pond), modification (i.e., the springs were blasted in the 1930s and again in the 1960s), and groundwater pumping that significantly decreased the water flow; c) the population at La Cebadilla has been exposed to water diversion for many decades; this diversion may have led to a reduction in the size of the cienega, but enough water still flows to the cienega to maintain it. 2) **Current and future**: a) the population at La Cebadilla continues to be exposed to water diversion and water diversion is proposed at the Ojo Vareleño population site; b) Lewis Springs and La Cebadilla are exposed to groundwater withdrawal and it is likely that the sites in Mexico are exposed to withdrawal as well; c) all populations are exposed to drought and warming caused by climate change.	Highly Confident	Sivinski 2018, p. 27; Agua Caliente, AZ: http://friendsofaguacaliente.org/history/ Sánchez Escalante et al. 2019, p. 10; Postillion 2014, p. 1
- Immediacy of Stressor(s)	Drying of cienegas caused by water use/loss led to the extirpation of 2 of 6 Arizona eryngo populations. The remaining 4 populations are exposed to continued water use, drought, and warming, with Lewis Springs and Ojo Vareleño appearing to be the most threatened. Groundwater withdrawal exacerbated by climate change is highly likely to affect springs at Lewis Springs and La Cebadilla. We do not know about groundwater withdrawal at Ojo Vareleño and Rancho Agua Caliente, but it is reasonable to assume human populations in the area are reliant on groundwater. As human populations grow, so will demand for water. This demand is likely to continue to be met, in part through the use of groundwater. It is unknown what the tipping point is for the springs at Lewis Springs and La Cebadilla is (i.e., how much groundwater can be pumped before causing spring to dry), but some drying of the springs at both sites has already been observed. Water loss caused by water diversion at La Cebadilla likely caused a reduction in the size of the cienega (Arizona eryngo) in the past. Some springflow will continue to be diverted at La Cebadilla, as it has been for many decades, but enough water currently flows to maintain the cienega. Water diversion will threaten the Arizona eryngo population at Ojo Vareleño in the future if the proposed diversion project is implemented. The exacerbating effects of drought and warming caused by climate change have already begun throughout the range of Arizona eryngo and will only worsen if we continue along the predicted trajectory of emissions and temperature increase.	Highly confident	Fonseca 1941
Changes in Resource(s)	Reduced or diverted spring flow results in drier soils thereby reducing habitat quantity and quality for Arizona eryngo. Eliminating springflow eliminates habitat.	Highly confident	
Response to Stressors: - INDIVIDUALS	Fewer Arizona eryngo will survive with less habitat available (i.e., plants will die in areas that become too dry). Arizona eryngo that continue to grow in areas that still retain some, but not ideal moisture, likely will not flower or produce fewer flowers. Seeds may not germinate without adequate moisture. Sexual reproduction will decline.	Highly confident	

THEME: Water loss from cienegas			
[ESA Factor(s): A]	Analysis	Confidence / Uncertainty	Supporting Information
POPULATION & SPECIES RESPONSES			
Effects of Stressors: - POPULATIONS [RESILIENCY]	Smaller populations occuring over smaller areas are less resilient than larger populations occurring over larger areas. Reduced sexual reproduction leads to decreased genetic diversity, which may reduce resiliency of a population over time.	Highly confident	
- GEOGRAPHIC SCOPE	Water loss from cienegas occurs througout the range of the species. Groundwater pumping and spring modification/diversion caused the extirpation of 2 of 6 known historical populations (1 in New Mexico and 1 in Arizona). It is likely that water loss from cienegas (due to physical alteration of ciengas which is dicussed in Tab 1) caused the extirpation of additional Arizona eryngo populations that were never documented. Water diversion has likely reduced the size La Cebadilla and may affect Ojo Vareleno in the future. Water loss due to groundwater pumping occurs throughout the range of the species. Water loss caused by drought and warming has and continues to affect all Arizona eryngo populations throughout the species' range.	Highly confident	
- MAGNITUDE	Water loss caused by groundwater pumping caused the extirpation of 1 Arizona eryngo population (1 out of 6 known historical populations) and water loss caused by groundwater pumping, exacerbated by drought and warming caused by climate change, is likely to cause the extirpation of most, if not all, Arizona eryngo populations in the future, if current trends continue. Water loss caused by various manipulations (including spring modification/diversion) caused the extirpation of 1 Arizona eryngo population (1 out of 6 known historical populations), but is not likely to affect current populations. Water loss caused by partial springflow diversion likely caused a reduction in the size of habitat supporting 1 Arizona eryngo population (1 out of 6 known historical populations).	Highly confident	
SUMMARY	Water loss from cienegas caused the extirpation of 2 of 6 known Arizona eryngo populations, and likely other undocumented populations. Continued water loss caused by groundwater pumping and drought and warming caused by climate change are likely to cause the extirpation of most Arizona eryngo populations in the future, if current trends continue.	Highly confident	

THEME: Changes in vegetation at cienegas			
[ESA Factor(s): A]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
SOURCE(S)	The source of vegetation changes (specifically encroachment of plants that shade out Arizona eryngo) at cienegas comes from human activities of fire suppression, nonnative plant introduction, and water use associated with domestic, agricultural, and ranching needs. There are many activities that result in changes in vegetation, however, we consider these three to be key with regard to Arizona eryngo.	Highly confident	
- Activity(ies)	1) Fire suppression: leads to woody plant and Schoenoplectus spp. encroachment into cienegas. These plants shade out Arizona eryngo. Prior to the arrival of European settlers, burning by indigenous people was frequent enough to exclude most woody plants and suppress Schoenoplectus spp. from cienegas and promote growth of grasses. 2) Nonnative plant introduction: leads to nonnative plant invasion into cienegas. These plants (e.g., Johnsongrass, giant reed) shade out and outcompete Arizona eryngo. 3) Water use (that causes changes in hydrology at cienegas): water use (e.g., groundwater withdrawal and declining water tables, spring modification, water diversion) that causes changes in hydrology are discussed in Tab 2. Changes in hydrology that cause drying can lead to encroachment of plants that shade out Arizona eryngo, including native woody plants such as Baccharis spp. and mesquie, and nonnative plants such as Johsongrass. Shifts from herbaceous wetland vegetation to more deeply rooted riparian trees have been well documented at sites with lowered water tables. The effects of water loss and soil drying are exacerbated by climate change (discussed on Tab 2).	Highly confident	Davis et al 2002, p. 1; Cole and Cole 2015, p. 32; Simms 2019, entire; Li 2019, entire; Sánchez Escalante et al. 2019, p. 9; Stromberg et al. 2019, p. 9;
STRESSOR(S)	Invasion and encroachment of plants that shade out and outcompete Arizona eryngo, which favors open sun conditions.	Highly confident	Stromberg et al. 2019, p. 9
- Affected Resource(s)	Sunlight and space are reduced in cienegas that experience encroachment of tall vegetation (e.g., woody vegetation, *Schoenoplectus* spp., nonnative species such as Johnsongrass and giant reed). Water level declines through increased evapotranspiration of woody vegetation.	Highly confident	
- Exposure of Stressor(s)	Encroachment of plants that shade Arizona eryngo has been documented at Lewis Springs, La Cebadilla, and Ojo Vareleño. 1) Lewis Springs: At this site, nonnative Johnsongrass is aggressively invading and appears to be suppressing Arizona eryngo, particularly in the drier areas of the wetlands. Also in the drier areas, Baccharis sp. is moving slowly into the wetlands and also appears to be suppressing Arizona eryngo as none was found growing in the understory of the Baccharis. 2) La Cebadilla: at this site, aerial imagery indicates that mesquite is invading the cienega, and cottonwoods and velvet ash (Fraxinus velutina) also appear to be shading out Arizona eryngo. 3) Ojo Vareleño at this site, many nonnative plant species also occur, with a particularly aggressive invasion of giant reed that is likely invading Arizona eryngo habitat and outcompeting the species. 4) Rancho Agua Caliente: at this site, no observations have been made with regard to changes in vegetation that may shade out Arizona eryngo.	Highly confident	Lewis Springs: Simms 2019, entire; Li 2019, entire. La Cebadilla: Fonseca 2019, entire. Ojo Vareleño: Sánchez Escalante et al. 2019, p. 9-10.
- Immediacy of Stressor(s)	The encroachment and invasion of plants that shade out Arizona eryngo have likely reduced habitat quantity and quality and population size at Lewis Springs, Ojo Vareleño, and La Cebadilla. Johsnongrass at Lewis Springs and giant reed at Ojo Vareleno are particularly agressive and are likely increasing at these sites. Johsnongrass has been documented at Lewis Springs for at least a decade and it is unknown how long giant reed has occurred at Ojo Vareleno. These nonnative plants will continue to reduce sunlight and space at Lewis Springs and Ojo Vareleño if not controlled. Woody vegetation encroachment at La Cebadilla and Lewis Springs appears to be limiting the extent of Arizona eryngo, but this encroachment is occuring more slowly compared to the invasion of nonnative species previously discussed.	Highly confident	

THEME: Changes in vegetation at cienegas			
[ESA Factor(s): A]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
Changes in Resource(s)	Rapid invasion of nonnative species (such as S. halepense and A. donax) and slower encroachment of woody vegetation have reduced space and exposure to sunlight for Arizona eryngo. In some cases, such as at La Cebadilla, Arizona eryngo still grow in the shade of woody vegetation, but show a substantial reduction in flowering. In other cases, Arizona eryngo is not growing in the shade of such vegetation and the extent of the Arizona eryngo has likely decreased as the other vegetation spreads further. Additionally, woody plants not only shade out Arizona eryngo, but they can cause water level declines in cienegas through increased evapotranspiration, particularly in the summer.	Highly confident	Li, University of Arizona, personal communication November 12, 2019; Johnson et al. 2016, p. 83
Response to Stressors: - INDIVIDUALS	Fewer Arizona eryngo survive with reduced habitat quantity (due to vegetation encroachment and invasion). Arizona eryngo that continue to grow in areas with limited encroachment of shade-producing vegetation produce fewer or no flowers, therefore limiting seed production and sexual reproduction. Arizona eryngo that grow in areas with woody vegetation that dries soil produce fewer flowers and recruitment of juveniles is likely low.	Highly confident	
POPULATION & SPECIES RESPONSES			
Effects of Stressors: - POPULATIONS [RESILIENCY]	Invasion and encroachment of plants that shade out Arizona eryngo are reducing the amount of Arizona eryngo habitat and likely causing a decline in numbers at 3 of 4 extant populations. Smaller populations occuring over smaller areas are less resilient than larger populations occurring over larger areas. Reduced flowering may lead to reduced sexual reproduction and lowered genetic diversity, which may reduce resiliency of a population over time.	Highly confident	
- GEOGRAPHIC SCOPE	Invasion and encroachment of plants that shade out Arizona eryngo have been documented at 3 of the 4 extant populations (Lewis Springs, La Cebadilla, and Ojo Vareleño).	Highly confident	
- MAGNITUDE	Two of 4 Arizona eryngo populations (Ojo Vareleño and Lewis Springs) are at nearer-term risk of extirpation due to invasion of nonnative species. La Cebadilla and Lewis Springs populations are at longer-term risk due to encroachment of woody species.	Moderately confident	
SUMMARY	Invasion and encroachment of plant species that shade out Arizona eryngo are likely to continue to cause a decline in the number of Arizona eryngo at existing sites if current trends continue. At Ojo Vareleño continued invasion of A. donax may rapidly contribute to the extirpation of this already small population. At Lewis Springs, continued invasion of S. halepense is likely to substantially reduce or possibly eliminate plants at some of the colonies.	Moderately confident	

THEME: Direct harm and mortality to plants from native and nonnative animal species			
[ESA Factor(s):]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
SOURCE(S)	The source of direct harm or mortality (from trampling, herbivory, uprooting) to Arizona eryngo comes from ranching needs and native herbivores However, we are uncertain to what extent trampling and herbivory cause harm and mortality to plants, but they warrant some discussion, particulary based on observations of other species in the genus Eryngium.	Highly confident	
- Activity(ies)	1) Livestock ranching: cattle, horses, and other livestock may trample or consume Arizona eryngo. 2) Native herbivores: javelina, gophers, invertebrates, and other herbivores may harm or cause mortality (uproot, damage, consume) to plants	Moderately confident for trampling and herbivory by livestock; Highly confident for herbivory by native herbivores	Cattle: La Gesse and Wiker 2008; Native herbivores Li 2019
STRESSOR(S)	Livestock and native herbivores may trample, uproot, or consume (whole or parts of the plant) Arizona eryngo.	Moderately confident	Cattle: La Gesse and Wiker 2008; Native herbivores: Li 2019
- Affected Resource(s)	Harm or mortality to plants.	Moderately confident	
- Exposure of Stressor(s)	The Arizona eryngo population at Rancho Agua Caliente may experience some effects from trampling or herbivory by cattle becuase it is an active cattle ranch. At Lewis Springs, the Arizona eryngo population could be exposed to trespass livestock, which have occassionally been documented there. Native vertebrate and invertebrate herbivores are present at all sites, but do not appear to cause extensive harm or mortality to plants. At the reintroduction site at Agua Caliente, AZ, native vertebrate herbivores killed young plants.	Moderately confident	Agua Caliente, Sonora: Sánchez Escalante, personal communication; Lewis Springs: personal observation 2018 and 2019; La Cebadilla: Stromberg et al. 2019, p. 8; Agua Caliente, AZ: Fonseca 2018,
- Immediacy of Stressor(s)	Native invertebrate and vertebrate herbivores are always present at all sites supporting Arizona eryngo and therefore, ongoing harm or mortality to plants may occur at low levels due to herbivory. Livestock, where they are present, may cause some ongoing, likely low level, harm or mortality Arizona eryngo,but evidence of this is limited.	Moderately confident	
Changes in Resource(s)	Some individual plants, particularly seedlings and young plants, may be damaged or killed by native and domestic vertebrate herbivores. Flower heads may be damaged by invertebrate herbivores.	Moderately confident	
Response to Stressors: - INDIVIDUALS	Fewer Arizona eryngo may survive and sexually reproduce. Plants that are completely consumed or dug up will not survive. Plants that are trampled or partially consumed may not flower or produce seeds.	Moderately confident	
POPULATION & SPECIES RESPONSES			
Effects of Stressors: - POPULATIONS [RESILIENCY]	Trampling and herbivory of Arizona eryngo may affect individual plants but there is no current evidence that these stressors are adversely affecting the resiliency of Arizona eryngo populations. Harm to or mortality of individual plants that are part of a smaller population (i.e., Ojo Vareleño, Rancho Agua Caliente) are more likely to affect the resiliency of these populations. If seedlings are eaten or trampled, recruitment will be lowered, possibly leading to lowered future abundance and lowered genetic diversity.	Moderately confident	

THEME: Direct harm and mortality to plants from native and nonnative animal species			
[ESA Factor(s):]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
- GEOGRAPHIC SCOPE	Native vertebrate and invertebrates occur throughout the species range. Cattle are currently ranched at Rancho Agua Caliente, Sonora; and a trespass horse has recently been documented at Lewis Springs. Native invertebrate and vertebrate herbivores are always present at all sites supporting Arizona eryngo	Highly confident	
- MAGNITUDE	Trampling and herbivory by livestock and native herbivores do not appear to currently be affecting Arizona eryngo on a population level.	Moderately confident	
SUMMARY	Trampling and herbivory by livestock and native herbivores do not appear to currently be affecting Arizona eryngo on a population level. Of all the populations, Rancho Agua Caliente has the greatest likelihood of being affected by livestock trampling and herbivory because the site is an active cattle ranch. That being said, cattle may help to maintain open sun conditions favored by Arizona eryngo. Further research on the possible effects of trampling and herbivory are warranted.	Moderately confident	

APPENDIX 2. VIABILITY UNDER A CONSERVATION PLANNING SCENARIO

Appendix 2 review the viability (Resiliency, Redundancy, and Representation) of Arizona eryngo under a Conservation planning scenario, as presented in Table 6.1 in Chapter 6. As with the other two scenarios (Continuation and Increased Effects) discussed in Chapter 6, the output of the Conservation planning scenario at each time step (0-10 and 10-30 years) and synopses of the effects to the populations over time are included below.

Viability (Resiliency, Redundancy, and Representation)

Scenario 3 – Conservation

Under Scenario 3, the Conservation scenario, a binational strategy to conserve Arizona eryngo is planned and implemented with cooperation of partners in the U.S. and Mexico. Scenario 3 follows a RCP4.5 climate change scenario, but also considers a number of conservation actions (see Table 6.1) that could be implemented in the next 30 years, and what improvements to Arizona eryngo and its habitat could be accomplished in the next 0–10 and 10-30 years. These positive conservation actions are not exhaustive, but if implemented, are expected to maintain and, in some cases, improve habitat and population conditions over the next 30 years. These actions would include:

- Reducing groundwater pumping through the implementation of water conservation activities;
- Increasing groundwater recharge;
- Ensuring no new springflow diversion;
- Monitoring and controlling of invasive nonnative plant species;
- Monitoring and selectively managing the encroachment of native woody vegetation (e.g., mesquite, baccharis);
- Revisiting sites in Mexico and locating additional Arizona eryngo plants, and/or augmenting existing populations with plants grown from seeds collected at the site, and/or establishing viable populations at new suitable sites in Mexico;
- Augmenting existing populations in the U.S.;
- Reintroducing Arizona eryngo to a historical site (Agua Caliente), such that a viable population is established;
- Introducing Arizona eryngo to at least two new suitable sites (e.g., Historic Canoa Ranch; another cienega within the SPRNCA; and/or other sites to be identified) within the general historical range of the species such that new viable populations are established; and
- Implementing selective disturbance to promote seedling establishment.
- Implementing other management actions to maintain and/or improve conditions of the cienegas, for the benefit of Arizona eryngo and other native species.
- Protecting habitat through conservation easements or other methods.

6.3.1.1. Resiliency

La Cebadilla

Under the Conservation Planning scenario, within 30 years groundwater levels would stabilize at La Cebadilla due to water conservation and recharge activities. Partial springflow diversion

would continue to occur, but would not increase. Woody vegetation would be selectively managed; some older/larger trees would be trimmed or removed, and younger/smaller trees would be removed regularly. These activities would lead to stabilized or increased springflow and a small increase in the amount of open sun, moist cienega habitat available for Arizona eryngo. Some selective disturbance would be implemented if needed to promote seedling establishment. Additionally, a new colony or subpopulation would be established near the La Cebadilla lake. Under the Conservation Planning scenario, we would expect the La Cebadilla population to improve to high condition in 30 years.

Lewis Springs
Under the Conservation Planning scenario, within 30 years groundwater levels would stabilize at Lewis Springs due to water conservation and recharge activities. Nonnative species would be monitored and managed. Aggressive control of Johnnsongrass would be implemented. Woody vegetation would be selectively managed; some older/larger trees and shrubs would be trimmed or removed, and younger/smaller trees and shrubs would be removed regularly. These activities would lead to stabilized or increased springflow and an increase in the amount of open sun, moist cienega habitat available for Arizona eryngo. Some selective disturbance would be implemented if needed to promote seedling establishment. Additionally, Lewis Springs wetlands with no or few Arizona eryngo plants would be augmented with additional plants. Under the Conservation Planning scenario, we would expect the Lewis Springs population to improve to high condition in 30 years.

Rancho Agua Caliente
Under the Conservation Planning scenario, within 30 years groundwater levels would remain stable at Rancho Agua Caliente due to water conservation and recharge activities. As a result, springflow would remain stable or increase, leading to a small increase in the amount of moist cienega habitat available for Arizona eryngo. If needed, the population would be augmented with additional Arizona eryngo plants. Livestock would be monitored and managed at levels compatible with Arizona eryngo conservation. Nonnative species would be monitored and managed as needed. Under the Conservation Planning scenario, we would expect the Rancho Agua Caliente population to improve to moderate condition in 30 years.

Ojo Vareleño
Under the Conservation Planning scenario, within 30 years no springflow diversion would occur and groundwater levels would remain stable at Ojo Vareleño due to water conservation and recharge activities. Nonnative species would be monitored and managed. Aggressive control of giant reed would also be implemented. These activities would lead to stabilized or increased springflow and an increase in the amount of open sun, moist cienega habitat available for Arizona eryngo. Some selective disturbance would be implemented if needed to promote seedling establishment. Additionally, the population would be augmented. Under the Conservation Planning scenario, we would expect the Ojo Vareleño population to improve to moderate condition in 30 years.

Table A.1. Resiliency of Arizona eryngo populations under Scenario 3, Conservation from 0-10 years.

	Population / Distribution Factors			Habitat Factors		
Population	**Abundance (individuals)**	**Juvenile Presence**	**Occupied Area (m^2)**	**Soil Moisture**	**Full Sun**	**Conservation Condition**
La Cebadilla	High	Yes	Moderate	Moderate	High	High
Lewis Springs	Moderate	Yes	Low	Moderate	Moderate	Moderate
Rancho Agua Caliente	Moderate	Yes	Moderate	Moderate	High	Moderate
Ojo Vareleño	Low	Yes	Low	Low	Low	Low
Las Playas	Ø	Ø	Ø	Ø	Unknown	Ø
Agua Caliente	Ø	Ø	Ø	Moderate	Moderate	Low

Table A.2. Resiliency of Arizona eryngo populations under Scenario 3, Conservation from 10-30 years.

	Population / Distribution Factors			Habitat Factors		
Population	**Abundance (individuals)**	**Juvenile Presence**	**Occupied Area (m^2)**	**Soil Moisture**	**Full Sun**	**Conservation Condition**
La Cebadilla	High	Yes	High	Moderate	High	High
Lewis Springs	High	Yes	Moderate	Moderate	High	High
Rancho Agua Caliente	Moderate	Yes	Moderate	Moderate	High	Moderate
Ojo Vareleño	Moderate	Yes	Moderate	Moderate	Moderate	Moderate
Las Playas	Ø	Ø	Ø	Ø	Unknown	Ø
Agua Caliente	Ø	Ø	Ø	Moderate	High	Moderate

6.3.1.2. Representation

In the Conservation Planning scenario, the current level of representation in the U.S. and Mexico would be maintained for 30 years.

6.3.1.3. Redundancy

Each of the four current representation areas have only one population each for redundancy, as of 2020. In the Conservation Planning scenario, within 30 years, the Santa Cruz River Basin representation area would gain redundancy with the successful reintroduction of a population at Agua Caliente and successful introduction of a population at the Historic Canoa Ranch, Arizona. The San Pedro River Basin representation area (and/or possibly other) would also gain redundancy with the successful introduction of a population at a suitable site, such as a restored cienega in the SPRNCA. Therefore, within 30 years, the Santa Cruz representation area would have three populations, the San Pedro representation area would have two populations for redundancy, and the other areas of representation would continue to have only one population each for redundancy.

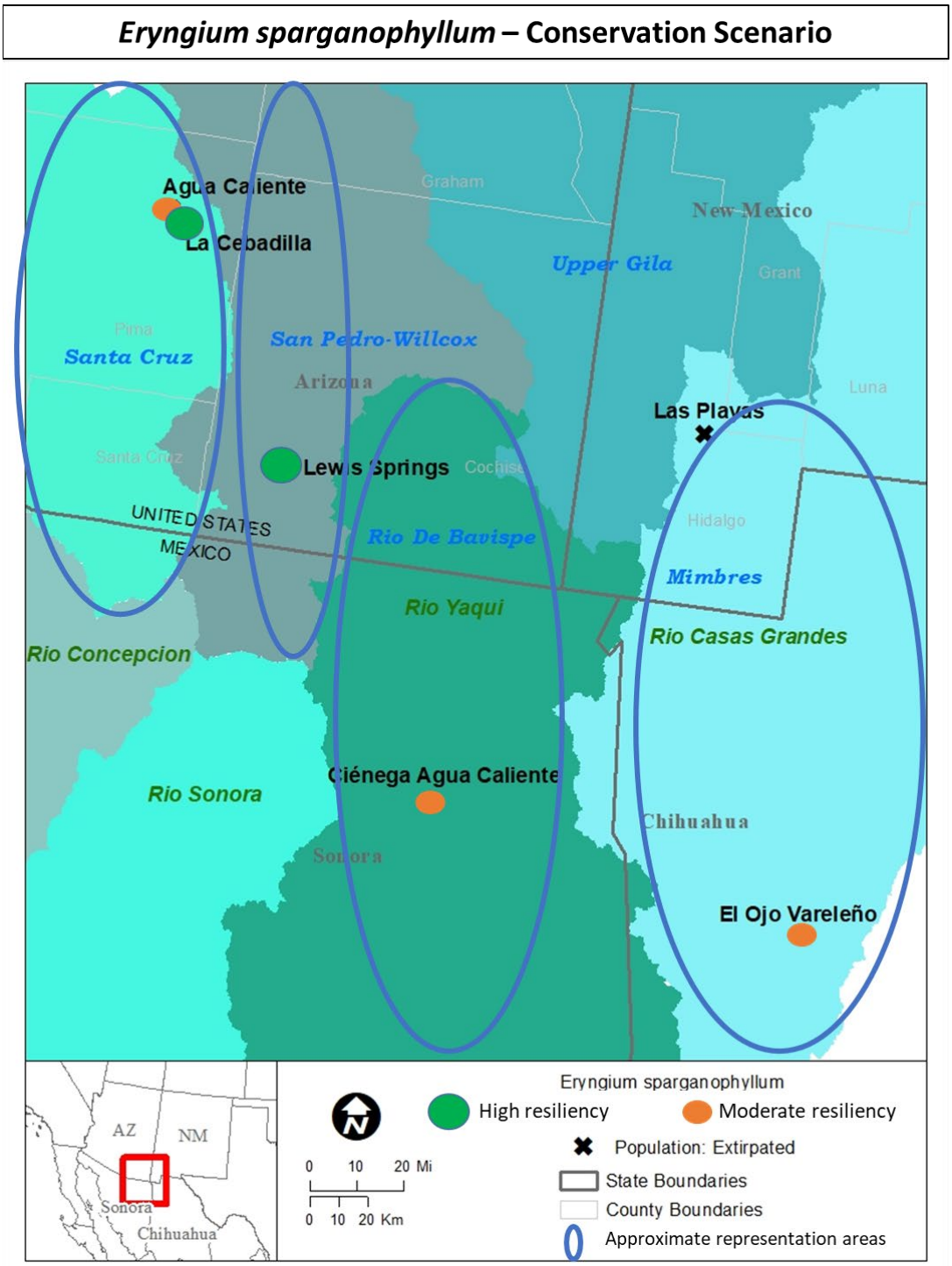

Figure A.1. Resiliency, representation, and redundancy of Arizona eryngo under the Increased Effects scenario. Note that the populations at new sites are not depicted because of the uncertainty with the site location.

In summary, under Scenario 3 – Conservation, we would expect viability of Arizona eryngo to be characterized by higher levels of resiliency and redundancy (in 10 and 30 years) than it exhibits under the current condition (Tables A.3. and A.4). Of the existing populations, two

would be in high condition and three would be in moderate condition. Additionally, the historical Agua Caliente population would be successfully reestablished and populations at two new sites would be successfully established. We anticipate all of the current populations to persist and one historical population to be successfully reintroduced such that redundancy in increased.

Table A.3. Arizona eryngo population conditions under each scenario at 0-10 years.

	Population Condition			
Population	**Current Condition**	**Scenario 1- Continuation**	**Scenario 2- Increased Effects**	**Scenario 3- Conservation**
La Cebadilla	**Moderate**	**Moderate**	**Moderate**	**High**
Lewis Springs	**Moderate**	**Moderate**	**Low**	**Moderate**
Rancho Agua Caliente	**Low**	**Low**	**Low**	**Moderate**
Ojo Vareleño	**Low**	**Ø**	**Ø**	**Low**
Las Playas	**Ø**	**Ø**	**Ø**	**Ø**
Agua Caliente	**Ø**	**Ø**	**Ø**	**Low**
New Populations	**None**	**None**	**None**	**1**

Table A.4. Arizona eryngo population conditions under each scenario at 10-30 years.

	Population Condition			
Population	**Current Condition**	**Scenario 1- Continuation**	**Scenario 2- Increased Effects**	**Scenario 3- Conservation**
La Cebadilla	**Moderate**	**Moderate**	**Moderate / Low**	**High**
Lewis Springs	**Moderate**	**Low**	**Low / Ø**	**High**
Rancho Agua Caliente	**Low**	**Low**	**Low**	**Moderate**
Ojo Vareleño	**Low**	**Ø**	**Ø**	**Moderate**
Las Playas	**Ø**	**Ø**	**Ø**	**Ø**
Agua Caliente	**Ø**	**Ø**	**Ø**	**Moderate**
New Populations	**None**	**None**	**None**	**2**