

**Comal Springs Dryopid Beetle  
(*Stygoparnus comalensis*)  
5-Year Status Review:  
Summary and Evaluation**

**U.S. Fish and Wildlife Service  
Austin Ecological Services Field Office  
Austin, Texas  
May 21, 2024**

## 5-YEAR REVIEW

**Species reviewed:** Comal Springs dryopid beetle (*Stygoparnus comalensis*)

### TABLE OF CONTENTS

1.0	GENERAL INFORMATION.....	1
1.1	Reviewers:.....	1
1.2	Purpose of 5-Year Reviews:.....	1
1.3	Methodology used to complete the review: .....	1
1.4	Background: .....	2
1.4.1	FR Notice citation announcing initiation of this review:.....	2
1.4.2	Listing history: .....	2
1.4.3	Associated Rulemakings:.....	2
1.4.4	Review History: .....	2
1.4.5	Species' Recovery Priority Number at start of 5-year review:.....	2
1.4.6	Recovery Plan or Outline.....	2
2.0	REVIEW ANALYSIS .....	3
2.1	Distinct Population Segment (DPS) policy (1996):.....	3
2.2	Updated Information and Current Species Status .....	3
2.2.1	Biology and Habitat .....	3
2.2.1.1	New information on the species' biology and life history: .....	3
2.2.1.2	Abundance, population trends (e.g. increasing, decreasing, stable), demographic features (e.g., age structure, sex ratio, birth rate, seed set, germination rate, age at mortality, mortality rate, etc.), or demographic trends:.....	5
2.2.1.3	Genetics, genetic variation, or trends in genetic variation (e.g., loss of genetic variation, genetic drift, inbreeding, etc.):.....	6
2.2.1.4	Taxonomic classification or changes in nomenclature:.....	6
2.2.1.5	Spatial distribution, trends in spatial distribution (e.g. increasingly fragmented, increased numbers of corridors, pollinator availability, etc.), or historic range (e.g. corrections to the historical range, change in distribution of the species' within its historic range, etc.):.....	6
2.2.1.6	Habitat or ecosystem conditions (e.g., amount, distribution, and suitability of the habitat or ecosystem): .....	7
2.2.1.7	Other:.....	9
2.2.1.8	Conservation Measures: .....	10

2.2.2	Five-Factor Analysis (threats, conservation measures, and regulatory mechanisms):	13
2.2.2.1	Present or threatened destruction, modification or curtailment of its habitat or range:	13
2.2.2.2	Overutilization for commercial, recreational, scientific, or educational purposes:	22
2.2.2.3	Disease or predation: .....	22
2.2.2.4	Inadequacy of existing regulatory mechanisms: .....	23
2.2.2.5	Other natural or manmade factors affecting its continued existence: .....	25
2.3	Synthesis.....	27
3.0	RESULTS .....	28
3.1	Recommended Classification: .....	28
3.2	New Recovery Priority Number (indicate if no change; see 48 FR 43098): .....	28
3.3	Listing and Reclassification Priority Number, if reclassification is recommended (see 48 FR 43098): .....	29
4.0	RECOMMENDATIONS FOR FUTURE ACTIONS .....	29
5.0	REFERENCES .....	30

**5-YEAR REVIEW**  
**Comal Springs dryopid beetle (*Stygoparnus comalensis*)**

**1.0 GENERAL INFORMATION**

**1.1 Reviewers:**

**Lead Regional or Headquarters Office:**

Vanessa Burge, Recovery Biologist, Southwest Regional Office, Albuquerque, New Mexico, [vanessa\\_burge@fws.gov](mailto:vanessa_burge@fws.gov)

**Lead Field Office:**

Amelia Hunter, Fish and Wildlife Biologist, Austin Ecological Services Field Office, Austin, Texas, [amelia\\_hunter@fws.gov](mailto:amelia_hunter@fws.gov)

**Cooperating Field Office(s):**

Not Applicable

**Cooperating Regional Office(s):**

Not Applicable

**1.2 Purpose of 5-Year Reviews:**

The U.S. Fish and Wildlife Service (Service or USFWS) is required by section 4(c)(2) of the Endangered Species Act (ESA) to conduct a status review of each listed species once every 5 years. The purpose of a 5-year review is to evaluate whether or not the species' status has changed since it was listed (or since the most recent 5-year review). Based on the 5-year review, we recommend whether the species should be removed from the list of endangered and threatened species, be changed in status from endangered to threatened, or be changed in status from threatened to endangered. Our original listing as endangered or threatened is based on the species' status considering the five threat factors described in section 4(a)(1) of the ESA. These same five factors are considered in any subsequent reclassification or delisting decisions. In the 5-year review, we consider the best available scientific and commercial data on the species and focus on new information available since the species was listed or last reviewed. If we recommend a change in listing status based on the results of the 5-year review, we must propose to do so through a separate rule-making process including public review and comment.

**1.3 Methodology used to complete the review:**

The USFWS provides notice of status reviews via the *Federal Register* and requests new information on the status of the species (e.g., life history, habitat conditions, and threats). Data for this status review were solicited from interested parties through a *Federal Register* notice announcing this review on May 5, 2021 (86 FR 23976). The Austin Ecological Services Field Office conducted this review and considered both new and previously existing information from federal and state agencies, municipal and county governments,

non-governmental organizations, academia, and the public. The primary sources of information used in this analysis was the final rule listing the Comal Springs dryopid beetle as endangered (62 FR 66295), revised critical habitat ruling for the Comal Springs dryopid beetle (78 FR 63100), research published in scientific journals, and unpublished reports and data.

#### **1.4 Background:**

##### **1.4.1 FR Notice citation announcing initiation of this review:**

86 FR 23976 May 5, 2021

##### **1.4.2 Listing history:**

###### Original Listing

**FR notice:** 62 FR 66295

**Date listed:** December 18, 1997

**Entity listed:** Comal Springs dryopid beetle (*Stygoparnus comalensis*)

**Classification:** Endangered

###### Revised Listing, if applicable

**FR notice:** Not Applicable

**Date listed:** Not Applicable

**Entity listed:** Not Applicable

**Classification:** Not Applicable

##### **1.4.3 Associated Rulemakings:**

Critical habitat for Comal Springs dryopid beetle was revised on November 22, 2013, in areas of occupied, spring-related aquatic habitat with designations for surface and subsurface critical habitat (78 FR 63100). The original critical habitat designation encompassed only surface critical habitat and did not include any designation for subsurface critical habitat (72 FR 39248). Springs, associated streams, and underground spaces immediately inside of or adjacent to springs, seeps, and upwellings are the primary components of the physical or biological features essential to the conservation of this species (50 CFR 17.95; 78 FR 63120).

##### **1.4.4 Review History:**

Not Applicable

##### **1.4.5 Species' Recovery Priority Number at start of 5-year review:**

1C

##### **1.4.6 Recovery Plan or Outline**

**Name of plan or outline:** Not Applicable

**Date issued:** Not Applicable

**Dates of previous plans/amendment or outline, if applicable:** Not Applicable

## **2.0 REVIEW ANALYSIS**

Section 4 of the ESA (16 U.S.C. 1533) and its implementing regulations (50 CFR part 424) set forth the procedures for determining whether a species meets the definition of “endangered species” or “threatened species.” The ESA defines an “endangered species” as a species that is “in danger of extinction throughout all or a significant portion of its range,” and a “threatened species” as a species that is “likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range.” The ESA requires that we determine whether a species meets the definition of “endangered species” or “threatened species” due to any of the five factors described below.

Section 4(a) of the Act describes five factors that may lead to endangered or threatened status for a species. These include: A) the present or threatened destruction, modification, or curtailment of its habitat or range; B) overutilization for commercial, recreational, scientific, or educational purposes; C) disease or predation; D) the inadequacy of existing regulatory mechanisms; or E) other natural or manmade factors affecting its continued existence.

The identification of any threat(s) does not necessarily mean that the species meets the statutory definition of an “endangered species” or a “threatened species.” In assessing whether a species meets either definition, we must evaluate all identified threats by considering the expected response of the species, and the effects of the threats—in light of those actions and conditions that will ameliorate the threats—on an individual, population, and species level. We evaluate each threat and its expected effects on the species, then analyze the cumulative effect of all of the threats on the species as a whole. We also consider the cumulative effect of the threats in light of those actions and conditions that will have positive effects on the species—such as any existing regulatory mechanisms or conservation efforts. The Service recommends whether the species meets the definition of an “endangered species” or a “threatened species” only after conducting this cumulative analysis and describing the expected effect on the species now and in the foreseeable future.

### **2.1 Distinct Population Segment (DPS) policy (1996):**

Not Applicable

### **2.2 Updated Information and Current Species Status**

#### **2.2.1 Biology and Habitat**

##### **2.2.1.1 New information on the species’ biology and life history:**

*Background*

The Comal Springs dryopid beetle (*Stygoparnus comalensis*) is the only subterranean-adapted member of the family Dryopidae (Insecta: Coleoptera) (Barr and Spangler 1992, pp. 40-41). The first Comal Springs dryopid beetles were collected in 1987 in Comal County, Texas, from Comal Springs and later discovered at Fern Bank and Sessom springs in Hays County, Texas (Barr and Spangler 1992, p. 41; Barr 1993, pp. 31, 53-55; Kosnicki and Julius 2019, p. 3). This is the first 5-Year Review since the species' listing in 1997.

### *Biology*

Unique morphological distinctions include vestigial (i.e., poorly developed and non-functioning) eyes and wings and eight-segmented antennae (Barr and Spangler 1992, p. 47). Adult Comal Springs dryopid beetles have a slender body with a length of 3-3.7 millimeters (mm) (0.12-0.16 inches (in)) and are unable to swim (Barr and Spangler 1992, p. 47; Nowlin et al. 2022, p. 20). Adults respire through a plastron (i.e., small, hydrophilic hairs that diffuse oxygen from the water into the body), limiting them to habitats with high dissolved oxygen (Brown 1987, p. 260; Barr and Spangler 1992, pp. 43-49; Yee and Kehl 2015, p. 1011).

Larvae lack eyes, are elongate, cylindrical, and yellowish-brown in color, with wedge-shaped teeth (i.e., tridentate) with a fusiform (i.e., round) head (Barr and Spangler 1992, pp. 44, 49). Larvae develop a terrestrial breathing apparatus called spiracles to breathe air, unlike other Coleopteran larvae that use anal gills to breathe in water (Barr and Spangler 1992, p. 50). Mature larvae are approximately 6-8 mm (0.24-0.31 in) long (Barr and Spangler 1992, p. 49).

### *Life History*

Comal Spring dryopid females in captivity produce several clutches of eggs over many months with a maximum capacity of 10-14 eggs, independent of body size (Kosnicki and Julius, 2019 pp. 12-13). The most productive captively held female was estimated to potentially produce up to 130 eggs in her lifetime, but fecundity estimates could not be ascertained (Kosnicki and Julius 2019, p. 13).

Under captive conditions, eggs require two to three months to incubate above water before hatching with a 22 percent hatching success (Kosnicki and Julius 2019, p. 13). It is unknown if eggs can hatch underwater or if humid conditions are necessary for development (Kosnicki and Julius 2019, p. 20). It is uncertain how eggs laid in subterranean voids can access air spaces to reach the next life stage and if those spaces are available underground.

A study of Comal Springs dryopid beetle larva observed early instar individuals burrowing into conditioned poplar wood dowels and sycamore leaves to hide, with later instar larvae observed excavating trenches into the dowel, which

served as both a food source and shelter (Kosnicki and Julius 2019, pp. 7, 15-18). A single Comal Springs dryopid beetle larva was produced and grew from approximately 2-10 mm (0.08-0.40 inch (in)) in length over nine months, suggesting development of larvae may only take one year (Fries et al. 2004, p. 10; Kosnicki and Julius 2019, p. 4). Larvae are estimated to have six instars (i.e., molts), with an average of 22.4 days per instar (Kosnicki and Julius 2019, p. 16). The pupal stage for this species has not been observed (Kosnicki and Julius 2019, pp. 1, 20). Likewise, eclosion (i.e., hatching) and associated environmental cues, if they exist, have not been researched.

Some wild caught adult Comal Springs dryopid beetles have survived in captivity for 11 to 21 months, but the lifespan of this species remains unknown (Barr and Spangler 1992, p. 51; Fries et al. 2004, p. 10). There is no research on survival rates of wild surface or subterranean aquatic locations of this species and if they differ (Barr 1993, p. 52). A beetle that lived for a year in captivity experienced a decrease in plastron surface area to the time of death, hypothesizing abrasion of the setae (i.e., bristle-like hairs) occurred or aging (Fries et al. 2004, p. 10).

**2.2.1.2 Abundance, population trends (e.g. increasing, decreasing, stable), demographic features (e.g., age structure, sex ratio, birth rate, seed set, germination rate, age at mortality, mortality rate, etc.), or demographic trends:**

Little is known about limiting factors that may impact the abundance and distribution of the Comal Springs dryopid beetle. Current abundance estimates only include samples collected at the surface.

Fluctuations in the numbers of dryopid beetles and larvae have been observed by researchers for reasons that remain unknown. However, it is established that droughts can lead to a reduction in springflow, prompting the species to seek shelter and preferred water quality further down in the aquifer. Conversely, during periods of record-high springflows, the beetles may be dislodged into surface waters downstream due to their slow and fragile nature (Barr 1993, p. 54). This non-swimming, flightless aquatic beetle faces limited opportunities for expanding its range. This species is rarely collected, likely because its preferred habitat is challenging to sample (BIO-WEST, Inc. 2007, p. 39; Gibson et al. 2008, p. 77).

Drift and kick netting surveys in the 1990s resulted in the collection of just 10 adults during a month sampling period and only four larvae at a subset of the sites sampled (Barr and Spangler 1992, pp. 41, 51; Barr 1993, pp. 54, 41). Fewer dryopid beetle individuals were captured when flows and aquifer levels increased (i.e., as measured at San Antonio reference well, J-17) (Barr 1993, p. 55). Most species were collected at low-volume springs (i.e., spring runs 2 and 4

at Comal Springs and Fern Bank Springs) compared to the high-volume spring run 1 and 3 at Comal Springs (Barr 1993, p. 55).

Surveys in 2003 collected an average of 0.3 beetles/day at spring runs 1-3 of Comal Springs (Fries et al. 2004, pp. 6-7). At Fern Bank Springs, no subterranean species were caught at the pool or hillside sites (Gibson et al. 2008, p. 76). The species has been confirmed at Fern Bank Springs in 2003, when a single larva was collected after 398 hours of sampling spring orifices with drift nets (Gibson et al. 2008, p. 77). A more recent sampling effort from a spring emanating from the bluff of the Blanco River adjacent to the spring property suggested dryopid beetles at this site are productive with 31 adults and eight larvae collected (Nowlin et al. 2022, pp. 8, 15, 24). Additionally, the species was also captured at Sessom Springs in Hays County but have not been detected since 2017 (USFWS 2017, pp. 20-21, 24; Clough 2022, p. 1).

#### **2.2.1.3 Genetics, genetic variation, or trends in genetic variation (e.g., loss of genetic variation, genetic drift, inbreeding, etc.):**

Population structure suggests genetic differentiation between the three major spring ecosystems (i.e., Comal, Sessom, and Fern Bank springs) occupied by the species with no evidence of recent gene flow (Nowlin et al. 2022, pp. 12-13, 23-24). This variation is not associated with their feeding niche, trophic ecology, or morphology (Nowlin et al. 2022, p. 4).

#### **2.2.1.4 Taxonomic classification or changes in nomenclature:**

Dryopidae (Insecta: Coleoptera) is a family of long-toed water beetles distributed worldwide except for Australia and Antarctica with approximately 300 species (Yee and Kehl 2015, p. 1029). In North America, there are five genera and 13 described species of dryopids (Shepard 2002, p. 122). The Comal Springs dryopid beetle is the only subterranean adapted member of this family and is the only species in the genus *Stygoparnus* (Barr and Spangler 1992, pp. 40-41).

#### **2.2.1.5 Spatial distribution, trends in spatial distribution (e.g. increasingly fragmented, increased numbers of corridors, pollinator availability, etc.), or historic range (e.g. corrections to the historical range, change in distribution of the species' within its historic range, etc.):**

Comal Springs dryopid beetles are groundwater obligate invertebrates and spring endemics that have not been observed outside of spring ecosystems. This suggests that individuals of the species are not distributed throughout the aquifer and may be confined to small areas once at the surface (62 FR 66295). The species occurs in the aquifer at distances up to 110 meters (m) (360 feet (ft)) from spring outlets, somewhere within the groundwater-surface water interface (78 FR 63103). Additionally, they are more frequently caught at low-flow

springs like Fern Bank Springs and spring runs 2 and 4 at Comal Springs and terrestrial margin seeps, compared to higher-flow springs like spring runs 1 and 3 at Comal Springs.

The first Comal Springs dryopid beetles were discovered in 1987 in Comal County, Texas, specifically at spring run 2 in Comal Springs (Barr and Spangler 1992, p. 41). Since then, specimens have been identified at various locations within Comal Springs, including spring runs 1, 3, 4, 5, and 7 at Comal Springs, the western shoreline and Spring Island areas of Landa Lake (i.e., impounded section of the Comal Springs system), Panther Canyon well (i.e., a shallow well 110 m (360 ft) upslope of Comal Springs) (Barr 1993, pp. 31, 53-55; BIO-WEST, Inc. 2004, p. 34; Fries et al. 2004, pp. 9, 14-15; Gibson et al. 2008, pp. 76-77).

Additionally, two locations in Hays County, Texas have been identified: Sessom Springs and Fern Bank Springs (32 km (20 mi) northeast of Comal Springs), specifically at the easternmost orifice (i.e., "hill 3") and Cove Spring (Barr 1993, pp. 31, 53-55; BIO-WEST, Inc. 2004, p. 34; Fries et al. 2004, pp. 9, 14-15; Gibson et al. 2008, pp. 76-77; Kosnicki and Julius 2019, p. 3).

#### **2.2.1.6 Habitat or ecosystem conditions (e.g., amount, distribution, and suitability of the habitat or ecosystem):**

Comal Springs dryopid beetle adults inhabit subterranean spaces associated with springs issuing from the Edwards Aquifer, and their association with the surface can only be hypothesized (Barr and Spangler 1992, p. 52). Specific habitat requirements for this species are unknown given the difficulty of humans accessing their subsurface habitat (Gibson et al. 2008, p. 77). It is also unknown if this species can re-enter the subterranean aquifer once it has emerged or been discharged from springs (Barr 1993, p. 52). Specific springflow requirements and the breadth of subterranean habitat this species uses are unknown; habitat management relies on assuring historical conditions are maintained within the natural habitat for the species (LBG-Guyton and Associates et al. 2004, pp. C-4–C-5).

Comal Springs dryopid beetles are collected from the clear headwater spring orifices consisting of coarse sand and angular cobbles or along seeps of the terrestrial margin where soil, fallen leaves, and rocks line the surface 5-31 centimeters (cm) (2-12 in) deep (Barr and Spangler 1992, p. 41). Roots and organic debris associated with the aquifer and spring outlets may act as substrate for growth of microorganisms for food and may provide shelter (Gibson et al. 2008, p. 77; 77 FR 64274). They are attracted to flowing water sources in captive settings, working against the flow to stay near a food source (Kosnicki and Julius 2019, pp. 11, 19).

They have not been observed feeding on leaf litter fragments, but greater than 75 percent of their diet is derived from terrestrial organic matter (Barr and Spangler 1992, p. 51; Nair et al. 2021, pp. 240, 242; Nowlin et al. 2022, pp. 16-19). Comal Springs dryopid beetle adults feed on photosynthetic (i.e., terrestrial) organic matter energy sources (e.g., biofilms) scraped from surfaces such as rocks, wood, and vegetation and not periphyton-based organic matter; detritus, leaf litter, and decaying roots (Simon et al. 2003, p. 2404; Hutchins et al. 2016, pp. 1536, 1538; Nowlin et al. 2017, pp. 16-18; Nair et al. 2021, pp. 240, 242). A co-occurring species, the Comal Springs riffle beetle (*Heterelmis comalensis*), derives most of its food from the same organic matter sources, but has a less than or equal to 1 percent niche overlap with the dryopid beetle at Comal Springs (Nair et al. 2021, p. 244). Larvae are presumed to occupy moist soils along the margins of surface aquatic habitats and are presumed to have the capacity to inhabit air-filled pockets within the ceilings of the spring orifices where organic debris may serve as shelter and act as substrate for growth of microorganisms on which it feeds (Barr and Spangler 1992, pp. 41, 51-52).

The principal habitat at Comal Springs (spring runs) maintains a fairly stable water temperature (20.7°Celsius (°C) (69.3°Fahrenheit (°F)), specific conductivity (579-587 micro siemens/centimeter (µs/cm)), and dissolved oxygen (5.1-5.2 milligram per liter [mg/L]), with few detections of contaminants (BIO-WEST, Inc. 2021, p. 18; EAA 2013, p. 62; EAA 2018, p. 5; EAA 2021a, pp. 27-36, 45-47). Conditions further down in Landa Lake and Spring Island are typically warmer (23.9 °C [75°F]) (BIO-WEST, Inc. 2021b, p. 18).

However, total dissolved solids and conductivity at Comal Springs have trended upward since the 1970s, but are stabilizing, while nitrates have doubled (median concentration 2 mg/L) since the 1970s (Musgrove et al. 2016, pp. 462, 465, 467; EPA 2023a, unpaginated, EPA 2023b, unpaginated). These changes in water quality in streams and groundwater correspond with increases in impervious cover over a watershed (Kaushal et al. 2005, p. 13518; Baker et al. 2019, pp. 6494–6495; Castaño-Sánchez et al. 2020, p. 6). These water quality parameter changes may be a long-term indication of urbanization that has already occurred across the recharge zone.

Information for habitat conditions at Fern Bank Springs are incomplete due to lack of access. The best available information indicates that the shallow spring waters at Fern Bank Springs are neutral (pH 7.2) shallow waters, water temperature averaging 21°C (70°F), supersaturated with oxygen (6.8-7.4 mg/L; 98-100 percent saturation), and are relatively constant (Barr 1993, p. 40; Fries et al. 2004, pp. 4, 13).

The surface of Sessom Springs is covered with concrete along a road, and access to the water emerging from the aquifer is facilitated through PVC piping hammered into the spring openings for sampling. This unique infrastructure,

coupled with the concrete overlay, not only raises questions about the beetles' potential habitat, as they have been observed to also reside at the surface in other spring environments, but also means that there is a notable reduction of terrestrial organic matter compared to a more natural riparian area. According to one report, adult beetles at Sessom Springs occupy a much more limited area compared to other populations of the species (Nowlin et al. 2022, pp. 4, 16). Water quality has not been documented at Sessom Springs. While the springs are likely fed by regional groundwater flow, the possibility of contributions from surface water flows, possibly comprising Sessom Creek water with known higher non-point source contaminant levels upstream of the springs, adds an additional layer of uncertainty regarding this site (Loiácomo 2019, p. 42; EAA 2022, pp. 24, 52-53).

#### **2.2.1.7 Other:**

##### *Biological Constraints and Needs*

The Comal Springs dryopid beetle occurs in a limited range at a small number of localities with little or no ability to disperse between or beyond these localities. These characteristics make them susceptible to local extirpation and extinction (McKinney 1997, p. 499; O'Grady et al. 2004, p. 514). A severe drought or water contamination event could eliminate many or all the existing populations. Having a high number of individuals of the species at a site provides no protection against extinction due to stochastic events. Dispersal beyond their extant range is unlikely, given the isolated nature of the spring headwater system dynamics and aquifer hydraulic connectivity that limit movement of individuals.

The areas inhabited by individuals of the species can be protected through localized conservation measures (e.g., intact riparian zones, springflow protection measures); however, the groundwater that provides water quality and quantity for the species can originate a significant distance from these habitats, and efforts that protect or conserve groundwater may be variable in their success and implementation. Although some of the threats can be adequately addressed, the inherent problems associated with narrow endemics in isolated habitats will always be present. Even with the most effective management and recovery plans in place, the species remains vulnerable to devastating stochastic events such as floods or droughts that could eliminate the species.

##### *Fern Bank Springs Private Ownership*

Fern Bank Springs is privately-owned, located 8 km (5 mi) east of Wimberley, Texas off a bank of the Blanco River at an elevation of 235 m (770 ft) (Barr 1993, p. 39). Fern Bank Springs discharges from a cave and the stream cascades into a manmade pool and continues down the bluff into the Blanco River just upstream of the Edwards Aquifer recharge zone (Fries et al. 2004, p. 8; Gibson

et al. 2008, p. 76; Johnson et al. 2012, pp. 79-80). The property is relatively undeveloped, and access is rarely granted to researchers (Barr 1993, p. 39). Thus, evaluation of habitat conditions, current population or demographic data, documented changes in land-use activities, or ability to conduct future recovery actions and activities are not achievable at this time.

#### **2.2.1.8 Conservation Measures:**

##### *Groundwater Quantity*

The Edwards Aquifer Authority (EAA) is charged with protecting terrestrial and aquatic life, domestic and municipal water supplies, the operation of existing industries, and the economic development of the entire Edwards Aquifer (Chapter 626, Laws of the 73rd Texas Legislature, 1993). Aquifer management since these rules were implemented have been successful at controlling groundwater withdrawals to maintain springflows. By EAA estimates, Comal Springs would have likely ceased flowing during the 2014 drought period without current regulations (EAA 2015, p. 62). Currently, these regulations have been effective in managing the Edwards Aquifer and reducing the risk of substantial declines in spring flows at Comal and San Marcos Springs.

Another important conservation measure is implementation of the City of San Antonio's Edwards Aquifer Protection Program (Stone and Schindel 2002, pp. 38-39; City of San Antonio 2023, pp. 3, 6). In 2000, the voters of San Antonio passed Proposition 3, a \$65 million sales tax initiative, to fund the acquisition (i.e., fee-simple and conservation easements) of open space to protect the contributing and recharge zones of the aquifer in Bexar County (Romero 2018 p. 2). Protection of open space has the potential to reduce the impacts of development (e.g., run-off from impervious cover, fertilizer applications, and wastewater) on maintain aquifer recharge (Reilly and Carter 2018, pp. 3-2, 3-6; Romero 2018, pp. 5-6). That program was re-approved in 2005, 2010, and 2015 with additional funds to acquire open space (Reilly and Carter 2018, pp. 1-3-1-5). The effort was later expanded to acquire lands in Medina and Uvalde counties that contain larger portions of the contributing and recharge zones (Romero 2018, pp. 5-6, 8). The dedicated sales tax expired in 2021 with 97,124 hectares (ha) (240,000 acres (ac)) acquired under the Edwards Aquifer Protection Program (Siglo Group 2022, pp. 51-52). The City of San Antonio recently approved an alternative funding stream to support land acquisitions through the commitment of \$100 million over ten years (City of San Antonio 2023, pp. 3, 6).

##### *Groundwater Quality*

There are several laws and regulations to protect water quality that apply to the Edwards Aquifer. The Federal Safe Drinking Water Act of 1974, as amended, regulates pollution and sedimentation of public drinking water sources,

including the Edwards Aquifer. This legislation mandates enforcement of drinking water standards established by the Environmental Protection Agency. The Texas Commission on Environmental Quality (TCEQ) is responsible for enforcement of these standards in Texas. Under the authority of the Texas Administrative Code (TAC) (30 TAC § 213), the TCEQ regulates activities having the potential for polluting the Edwards Aquifer and hydrologically connected surface streams through the Edwards Aquifer Protection Program or “Edwards Rules.” The Edwards Rules require several water-quality protection measures for new development occurring in the recharge zone and portions of the contributing zone of the Edwards Aquifer. The TCEQ also prohibits facilities such as municipal solid waste landfills and waste disposal wells from being built in the recharge or transition zones.

Discharge from non-point residential or agricultural sources is one of the primary sources of pollution in the Edwards Aquifer. Texas has an extensive program for the management and protection of water that operates under State statutes and the Federal Clean Water Act. The Program includes regulatory programs such as the following: Texas Pollutant Discharge Elimination System, Texas Surface Water Quality Standards, and Total Maximum Daily Load Program (under Section 303(d) of the Clean Water Act).

The TCEQ’s Texas Pollutant Discharge Elimination System program regulates discharges of pollutants to Texas surface water. Through the Pollutant Discharge Elimination System program, the TCEQ authorizes the discharge of stormwater and non-stormwater to surface waters in Texas associated with storm sewer systems and construction sites, which must meet the requirements of the Edwards Rules.

A watershed protection plan was accepted in 2018 by TCEQ for the Dry Comal Creek and Comal River Watershed by the City of New Braunfels. Dry Comal Creek has not met state water quality standard for bacteria, and the watershed protection plan is intended to address and reduce the elevated bacteria levels through management (TCEQ 2020, p. 1). Another watershed protection plan for the Upper San Marcos River was approved in 2018 by TCEQ. The watershed protection plan addresses the impairment of the Upper San Marcos River due to elevated total dissolved solids, and proactively addresses bacteria, nutrients, sediment, and future growth scenarios for the watershed (TCEQ 2018, p. 1).

The EAA has additional regulations (EAA rule 713) that apply to the recharge zone and five miles upgradient of the recharge zone. Much of the contributing zone occurs outside of the EAA jurisdiction (EARIP HCP 2020, pp. 1-4, 1-5) and is not subject to these regulations. New development in the Edwards Aquifer recharge, transition, or contributing zones is reviewed by the TCEQ Edwards Aquifer Protection Program (30 TAC § 213.1). For the contributing zone, the rule covers activities that disturb more than two hectares (five acres) in Medina, Bexar, Comal, Kinney, Uvalde, Hays, Travis, and Williamson counties

(30 TAC § 213.20). The contributing zone in Bandera, Kerr, and Kendall counties does not have additional protections under either program.

Several other entities also have measures to protect groundwater from contamination including the EAA's Aboveground Storage Tank Program, Agricultural Secondary Containment Assistance Program, and Abandoned Well Program among others (EAA 2022, entire). The San Antonio Water System implements several water quality protection measures including development regulations (i.e., Aquifer Quality Protection Ordinance No. 81491) for properties over the contributing and recharge zones, review of building permits and master development plans, regulation of underground storage tanks, commercial/industrial compliance, and an abandoned well program (San Antonio Water System 2022, unpaginated).

In addition to these state and federal regulations, a significant number of local regulations to protect water quality were implemented by the City of San Marcos, City of New Braunfels, EAA, and Texas State University as part of the Edwards Aquifer Recovery Implementation Program Habitat Conservation Plan (EARIP HCP; see sub-section below). Texas Water Code (Chapter 36) allows groundwater districts, but not cities, to regulate groundwater, including groundwater quality. However, cities can regulate pollution at the surface that ultimately impacts groundwater quality.

#### *Habitat Conservation Plan*

The Edwards Aquifer Recovery Implementation Program Habitat Conservation Plan (EARIP HCP) was finalized in 2013, amended in 2020, and covers incidental take of these species for groundwater withdrawal, recreation, and other activities through 2028 (EARIP HCP 2020, entire). Permittees to the plan include the EAA, City of San Antonio acting through the San Antonio Water System, City of New Braunfels, City of San Marcos, and Texas State University (National Research Council 2015, pp. 25–26). The EARIP HCP includes activities to minimize and mitigate impacts and contribute to the recovery of the eleven Covered Species and addresses a variety of aquifer management issues, including ensuring springflow during a repeat of the drought of record (Payne et al. 2019, p. 200; EARIP HCP 2020, pp. 4-57–4-59, 4-62–4-66). Long-term commitments to protect listed species in the Edwards Aquifer beyond the HCP and the term of its associated section 10(a)(1)(b) permit are not currently in place. However, a new habitat conservation plan is expected in 2028.

The current EARIP HCP biological goal that centers on water quality for the Comal Springs dryopid beetle is: “Not exceed a 10 percent deviation (daily average) from historically recorded water quality conditions (long-term average) in the Edwards Aquifer as measured issuing from the spring openings at Comal Springs”; there are no habitat-centered biological goals or biological objectives specific to this species.

A captive refugia and associated research is funded by the EARIP HCP through a contract (Contract # 16-822-HCP) with two USFWS facilities in San Marcos and Uvalde, Texas (EARIP HCP 2020 p. 5-3). The contract was established to protect species left vulnerable to extirpation throughout a significant portion of their range due to a limited geographic distribution of the population and will preserve the capacity for these species to be re-established in the event of the loss of population due to a catastrophic event, such as the unexpected loss of springflow or a chemical spill. Research activities expand knowledge on habitat requirements, biology, life histories, and effective reintroduction techniques for the species.

## **2.2.2 Five-Factor Analysis (threats, conservation measures, and regulatory mechanisms):**

### **2.2.2.1 Present or threatened destruction, modification or curtailment of its habitat or range:**

#### *Water Quantity*

A primary threat to the habitat of the Comal Springs dryopid beetle is the potential loss of springflows and reduced water quantity underground brought on by groundwater withdrawals from the southern segment of the Edwards Aquifer. Springflows at Comal, Sessom, and Fern Bank springs ecosystems are tied inseparably to water usage for the southern segment of the Edwards Aquifer. Groundwater pumping to meet municipal, industrial, and irrigation uses, is a widely recognized threat to the persistence of subsurface and surface groundwater-dependent ecosystems (Danielopol et al. 2003, pp. 109-112; Eamus et al. 2016, pp. 317, 333-335; Mammola et al. 2019, pp. 645-646). Removal of groundwater from an aquifer leads to water level decline, especially if discharge of groundwater significantly exceeds recharge (Theis 1940, pp. 278-280; Alley et al. 2002, pp. 1,986; Foster and Chilton 2003, pp. 1,961-1,962). Declining aquifer levels can result in springflow decline or failure, loss of stream and creek base-flow, and/or drying of water-filled caverns (Springer and Stevens 2009, pp. 9-10; Eamus et al. 2016, pp. 316-318, 333-335).

If not replenished through recharge, groundwater discharged through wells and springs is removed from aquifer storage (i.e., total amount of water in aquifer), and with absent or much reduced recharge, persistent groundwater removal would initially lead to decline and/or cessation in springflows (Lindgren et al. 2004, p. 41). Like other karst aquifers, water levels of the Edwards Aquifer fluctuate with recharge (i.e., distribution, amount, and intensity of rainfall) and discharge (i.e., wells or springs) (Petitt and George 1956, p. 49; Buszka 1987, pp. 24-27; Maclay 1995, pp. 48, 52; Worthington et al. 2003, p. 4; Lindgren et al. 2004 pp. 40-41, 45). Prolonged dry periods result in declines in aquifer, but water levels rebound rapidly with return of precipitation (Petitt and George 1956, p. 49). Groundwater pumping has exceeded recharge multiple times with

water levels rebounding with increased rainfall (Petitt and George 1956, p. 49). The longest period was the drought of record (a three-year period when aquifer recharge was at its lowest recorded level) during the mid-1950s (Arnow 1959, pp. 27-29). At one point, Comal Springs stopped flowing from June 13 through November 3, 1956, during the drought of record (Puente 1976, p. 22; Barr 1993, p. 61).

In the early 1990s, federal litigation (i.e., *Sierra Club vs. Secretary of the Interior* [No. MO-91-CA-069] United States District Court for the Western District of Texas) resulted in the creation of the EAA in 1993 by the State of Texas to manage groundwater withdrawals (i.e., by nonexempt wells) from the southern segment and limit Edwards Aquifer pumping authorized through permits (National Research Council 2015, pp. 24-26; Hardberger 2019, pp. 193-194; Payne et al. 2019, p. 199). During the 2007 legislative session, the Texas Legislature increased the annual maximum amount of pumping that could be authorized by permits to 705,551 megaliters (572,000 acre-feet) and directed the EAA to adopt and enforce a "Critical Period Management" plan establishing targeted withdrawal reductions during times of drought to achieve the water, species, and species habitat conservation goals established in the agency's enabling legislation (80th Texas Legislature, 2007, Senate Bill 3). Aquifer management since these rules were implemented have been successful at reducing groundwater withdrawals, but currently do not account for future droughts that may be worse than the drought of record. The Stage V Critical Period Management that currently exists is also tied to the Edwards Aquifer Recovery Implementation Program Habitat Conservation Plan (EARIP HCP) but could be subject to change after species recovery.

Springflows have been protected at Comal Springs during recent droughts in the 2000s and 2010s because of groundwater pumping restrictions from the EAA during periods of drought. During the 2008-2009 drought, springflows remained at sufficient levels to maintain resiliency for the EARIP HCP's Covered Species (above 2.3 cubic meters per second ( $m^3/s$ ) (80 cubic feet per second (cfs)) (USGS station 08169000). By EAA estimates, Comal Springs likely would have gone dry during the 2014 drought without the enforcement of Critical Period Management (EAA 2015, pp. 1, 62).

The former owner of Fern Bank Springs, spanning from the 1800s to 2009, asserted that the springs never ran dry, even during the drought of record (EARIP HCP 2020, p. 3-30). The best data currently available does not show any variation in the springflow of Fern Bank Springs, indicating it is a perennial spring. However, it is important to note that this site lacks a gauge and is only sporadically monitored for discharge (Barr 1993, p. 39).

Sessom Springs, another ecosystem where the Comal Springs dryopid beetle is present with an established population, lacks comprehensive monitoring data for its springflow. Unfortunately, the absence of such data makes it challenging to

determine the current status of the habitat. The uncertainty surrounding the springflow data for Sessom Springs emphasizes the need for further investigation to assess and safeguard the habitat of the Comal Springs dryopid beetle in this particular ecosystem.

The potential impact of extended periods of low flow and drying conditions on the Comal Springs dryopid beetle remains unclear. This uncertainty is primarily attributed to the limited availability of life history and abundance data. One hypothesis suggests that if adult females lay eggs at the surface, the negative effects of drying may be more pronounced (Barr 1993, pp. 61-62). Nevertheless, uncertainties persist regarding the species' egg-laying behavior and the environmental cues involved, such as whether it occurs underground or on the surface (Section 2.2.1.1).

While a repeat drought of record has not occurred, modeling indicates that the Critical Period Management plan during Phase II of the EARIP HCP will maintain springflows above 0.85 m<sup>3</sup>/s (30 cfs) at Comal Springs and above 1.3 m<sup>3</sup>/s (45 cfs) at San Marcos Springs during a drought of record. However, the plan is currently unable to return springflows at either spring system to 2.3 m<sup>3</sup>/s (80 cfs) within six months (EARIP HCP 2020, pp. 4-58, 4-66). Future droughts may also be more severe than the drought of record, and current aquifer management does not account for this.

Groundwater will continue to be a source of water in the future as city populations increase. Predicted water demands for the four counties within the San Antonio pool (i.e., Hays, Comal, Bexar, Medina) are projected to increase by 48 percent in the year 2070, insufficient to fulfill using existing supplies (Texas Water Development Board 2021, p. A-2–A-3). Strategies identified by the State of Texas and Groundwater Conservation Districts for these counties are contingent on funding and infrastructure availability (Texas Water Development Board 2021, entire).

Springflows needed to sustain resilient populations are species-specific and contingent on habitat use and requirements. The biological opinion (USFWS 2013, p. 129) associated with the EARIP HCP concluded that the issuance of the Incidental Take Permit for the EARIP HCP is not likely to jeopardize the continued existence of the Comal Springs dryopid beetle or destroy or adversely modify their designated critical habitat. Modeled springflows for conditions during Phase II project Comal Spring flows to remain at approximately 1.4 m<sup>3</sup>/s (50 cfs) during a repeat drought of record (USFWS 2013, pp. 32, 91, 100), greater than the springflows during the drought of record when it ceased for four months in 1956.

Springflows for the Comal Springs dryopid beetle were not included in the 1995 recovery plan or quantitative delisting criteria. The springflows affecting the Comal Springs dryopid beetle and its habitat may differ from other surface

species. For example, at 0.9 m<sup>3</sup>/s (30 cfs) at spring runs 2 and 3 of Comal Springs do not provide surface habitat for invertebrates (EAHCP 2020, pp. 4-97-4-98). The USFWS determined that 0.9 m<sup>3</sup>/s (30 cfs) during a repeat drought of record is not likely to jeopardize the Comal Springs dryopid beetle (USFWS 2013, p. 129). Water from Panther Canyon well, seeps along the western shoreline of Landa Lake, and within upwellings near Spring Island are expected to continue providing habitat during low flow conditions within the Comal Springs ecosystem.

Despite surviving the drought of record during the mid-1950s without being extirpated, the Comal Springs dryopid beetle likely suffered adverse effects from unregulated aquifer pumping during that drought period due to their aquatic nature when the springs remained dry for several months (Arnow 1959, pp. 27-29; Barr 1993, pp. 61-62). Additionally, it is reasonable to expect that populations of the species may be stranded and extirpated by receding groundwater. The Comal Springs dryopid beetle could be even more negatively impacted if adults are restricted to the vicinity of spring openings because of the potential terrestrial requirements of the immature stages (Barr 1993, pp. 61-62).

Moreover, for the other two populations of Comal Springs dryopid beetles at Fern Bank and Sessom springs, there is great uncertainty regarding the impacts of extended cessation of springflows. The unique ecological conditions of these habitats further complicate predictions, as they may have different hydrological dynamics compared to the main Comal Springs habitat. This lack of data poses significant challenges in understanding the vulnerabilities of these populations to changes in water quantity.

In summary, the potential cessation of springflows poses a significant concern for the Comal Springs population, given their need for consistent water sources. Additionally, this dryopid beetle is not likely adapted to surviving long periods of drying or stagnation (depending on the duration and severity), especially if the current water management plan for the Edwards Aquifer accommodating the water quantity needs of the Comal Springs dryopid beetle were to cease.

### *Water Quality*

Water quality at Comal, Sessom, and Fern Bank springs ecosystems where the Comal Springs dryopid beetle is found are influenced by groundwater and surface water. These three spring ecosystems depend on groundwater flow from the southern segment of the Edwards Aquifer. This segment of the aquifer is fed by many stream systems that enter the aquifer through recharge features.

The Edwards Aquifer is vulnerable to contamination because the limestone and carbonate rocks are highly permeable and exposed at the surface in the recharge zone (Clark 2000, pp. 1-2, 8-9; Burri et al. 2019, p. 150). Contaminants, commonly linked to urban and suburban activities such as residential and

commercial development, industrial operations, transportation infrastructure, and waste disposal, tend to accumulate in higher concentrations within the shallow areas of recharge zones, especially in regions characterized by urban land uses (Wilson 2011, pp. 1-2; Lin and Gong 2016, pp. 384-385; Opsahl et al. 2018, p. 58).

There are currently no established groundwater quality standards for subterranean ecosystems, and the concentrations of pollutants that could harm subterranean species remain unclear (Hinsby et al. 2008, p. 10; Manenti et al. 2021, p. 2). However, subterranean fauna are likely to exhibit greater vulnerability to contaminants and a longer recovery period from stochastic events compared to surface fauna because of their inherent limitations, including a lack of adaptations to pollutants, isolation within their habitat, and restricted dispersal abilities, all of which render them sensitive to environmental disturbances (Hose 2005, p. 961; Di Lorenzo et al. 2019, pp. 293–294, 300; Hose et al. 2022, p. 2206).

Although water quality in the Edwards Aquifer is generally good, several studies have detected contaminants in groundwater from the southern segment including nitrates, herbicides, pesticides, and polycyclic aromatic hydrocarbons, among many others (Fahlquist and Ardis, 2004 pp. 7-8, 10; Johnson et al. 2009, pp. 10-13, 23-26, 31-35; Musgrove et al. 2014, pp. 67, 69-71; Opsahl et al. 2018, p. 58; Opsahl et al. 2020, pp. 17-30). For example, contaminants have exceeded public drinking water standards in springwater and surface water recharging the aquifer, including antimony, arsenic, lead, lithium, and tetrachloroethene (Johnson et al. 2009, p. 45). However, groundwater contamination has not been shown to be widespread or with large numbers of substances present in concentrations that exceed drinking water standards (Bush et al. 2000, pp. 1-2, 14-21; Fahlquist and Ardis 2004, pp. 7-8, 10; Johnson et al. 2009, 44, 47; Opsahl et al. 2018, p. 58; Opsahl et al. 2020, pp. 17-30; EARIP HCP 2020, pp. 3-40-3-42).

Some sources of water quality degradation include impervious cover and stormwater runoff, construction activities, recharge from irrigation return flow (i.e., water that is not lost from evapotranspiration on laws or to stream runoff), wastewater discharge, transportation infrastructure, and hazardous materials spills resulting from development within the watersheds that contribute flows to subterranean habitats (Passarello et al. 2012, pp. 29–34; Lapworth et al. 2012, entire).

Forested land with limited human disturbances contributes to high-quality recharge (Dudley and Stolten, 2003 pp. 11, 58; Shah et al. 2022, p. 120,396), while rural and exurban land uses contribute to groundwater contamination from leaking sewage, refuse dumping, and dead livestock (Sui et al. 2015, p. 21; Katz 2019, p. 565; EARIP HCP 2020, pp. 5-43). Septic systems are a likely source of nutrients (EARIP HCP 2020, p. 5-43; Sui et al. 2015, p. 21). Once a source of

pollution enters groundwater, it can be difficult if not impossible to track, intercept, and remediate because of karst conduit complexity (Humphreys 201,1 p. 297). Since water quality in the Edwards Aquifer is generally good, this indicates that local sources of water pollution can disproportionately affect water quality in portions of the aquifer.

Oil and gas transmission pipelines are another potential source of hazardous material spills on the contributing and recharge zones of the aquifer. The “development and production of oil, gas, or a geothermal resource within the jurisdiction of the Texas Railroad Commission” are not considered regulated activities “having the potential for polluting the Edwards Aquifer and hydrologically connected surface water in order to protect existing and potential uses of groundwater and maintain Texas Surface Water Quality Standards” (Texas Natural Resource Conservation Commission 1996, p. 1). Consequently, the construction and maintenance of these pipelines are not subject to guidance mitigating impacts to karst features such as voids, and development of these pipelines are not subject to the Edwards Aquifer rules (Texas Natural Resource Conservation Commission 1996, entire).

Abandoned groundwater wells are a source of potential contamination from shallow groundwater into subsurface habitat. Shallower wells (< 300 m [ $< 984$  ft]) are less likely than deeper wells to intercept older groundwater that received cumulative, diluted inputs of pollutants across the aquifer and therefore are more likely to intercept anthropogenic contaminants coming directly from the surface than deeper wells (Musgrove et al. 2014, pp. 69, 73). The EAA funds a needs-based abandoned well closure assistance program to assist well owners with proper well plugging in cooperation with San Antonio Water System to locate and plug abandoned wells (EAA 2021b, pp. 50-53). Likewise, former oil wells require maintenance decades after plugging (cement plugs in a steel pipe) and can blowout underground and break free under artesian pressure if not properly maintained (Gold 2022, entire).

Nitrogen is highly soluble and a threat to groundwater quality and a stressor to subterranean taxa (Castaño-Sánchez et al. 2020, pp. 6, 11; Banerjee et al. 2023, pp. 3–6). Panther Canyon well (State well number 6823302) recorded nitrate (2 mg/L) present in 2003 (Texas Water Development Board 2023, unpaginated). Nitrates and orthophosphate consistently emerge from spring run 1 at Comal Springs and are typically present at low concentrations (2 mg/L) (U.S. Geological Survey 2023, unpaginated). The current drought has significantly decreased flow, and thus dilution of contaminants are slowed at Comal Springs; recent data resulted in 3 mg/L of nitrate measured at spring run 2 at Comal Springs (West 2023, unpaginated). While safe for humans, it is unknown what effect these elevated nutrients will have over time within the aquifer food web, and if conditions would become more favorable for surface species to colonize further underground (Notenboom et al. 1994, pp. 482–484, 490; Opsahl et al. 2018, p. 3). The Comal Springs dryopid beetle’s environmental tolerances are

unknown, hindering quantitative assessments of this stressors' impact on its populations. Additionally, there are no established groundwater quality standards for subterranean ecosystems, making harmful impacts to the species from existing pollutant concentrations unclear (Hinsby et al. 2008, p. 10; Manenti et al. 2021, p. 2).

Volatile organic compounds have been detected at one spring ecosystem and generally these events are rare (Johnson and Schindel 2014, p. 21). There is one documented diesel spill (i.e., naphthalene) that occurred in 2000 at spring run 7 at Comal Springs (Ogden et al. 1986, p. 126; Gibson et al. 2008, p. 75). It is unknown what effect this had on the subterranean community.

Urban and agricultural land uses dominate the artesian zone in the southern segment. Low- to high-density urban development occurs across much of the former, while agriculture dominates the latter county. Land use across the southern segment of the Edwards Aquifer plays a major role in groundwater and surface water quality. The presence of agriculture, residential and commercial developments, industrial facilities, military installations, and transportation infrastructure are correlated with increased presence of many contaminants (Bush et al. 2000, pp. 6-9; Fahlquist and Ardis 2004, p. 7; Johnson et al. 2009, p. 46; Wilson 2011, pp. 1-2; Musgrove et al. 2014, pp. 69-71; Opsahl et al. 2018, p. 58; Opsahl et al. 2020, pp. 17-30).

To examine projected land-use changes in the urban centers intersecting Edwards Aquifer groundwater, we used the EPA's (2019, unpaginated) Integrated Climate and Land-Use Scenarios. These outputs produce spatially explicit projections of population and land-use that are based on the Intergovernmental Panel on Climate Change's Special Report on Emissions Scenarios. The combination of SSP5-RCP8.5 illustrates a higher population growth and higher emissions, and a faster rate of human population growth consistent with the Texas Demographic Center population projections for Bexar County and the San Antonio-New Braunfels Metropolitan Area (EPA 2017, pp. 34-35, 46; Texas Demographic Center 2022, unpaginated). Within the Edwards Aquifer artesian, recharge, and contributing zones (543,498 hectares [1,343,014 acres]), developed land-use classes are projected to grow from 21 percent in 2020 to 27 percent developed by 2050. When examining delineated areas at a finer scale around Comal and San Marcos springs using the Integrated Climate and Land-Use Scenarios, the area around Comal Springs is projected to increase in development from 66 percent to 82 percent developed and the San Marcos Springs area is projected to increase from 44 percent to 65 percent developed by 2050. These areas may be important to assess more immediate impacts from groundwater contamination. Alternatively, the area around Fern Bank Springs is not projected to have substantial changes in development use classes.

Based on the Integrated Climate and Land-Use Scenario results, projections of developed land-uses and population growth will continue to expand outward

outside of the major metropolitan areas. Over time, these alterations have the potential to affect recharge rates, leading to deteriorating groundwater quality as a result of heightened runoff from impervious surfaces in suburban and urban areas or septic systems that are poorly managed and prone to leakage in exurban areas (Berube et al. 2006, pp. 10, 38; Barkfield 2022, p. 2).

The U.S. Census Bureau (2020, unpaginated) ranked several of the counties in the recharge and contributing zones of Comal and San Marcos springs (adjacent to Sessom Springs in Hays County, Texas) among the fastest growing in the United States from April 2010 to July 2019: Hays County was the second fastest growing county with a 46.5 percent population increase, Comal County the fourth fastest growing county with a 43.9 percent population increase, and Kendall County the fifth fastest growing county with a 42.1 percent population increase. Since 2000, these three counties have doubled in population and have seen substantial associated development. Projections indicate that the human population of Bexar, Comal, Hays, and Kendall counties will continue to increase substantially over the next three decades.

Conversion of natural habitat to urban, suburban, and exurban development is likely to accompany this population growth. Under a high human population growth scenario, land use projections suggest that large areas west and north of Bexar County will be converted to increasingly more urbanized land-use classes by 2100 (EPA 2019, unpaginated). Much of the exurban and suburban development is postulated to occur outside of municipal boundaries in unincorporated areas of counties where land use regulations (e.g., restrictions on impervious cover) are non-existent (Siglo Group 2022, pp. 13-14). Run-off from existing and expanded impervious cover in sensitive areas of the aquifer could affect groundwater quality over time. New contaminant sources are expected to be added to the region as increased human populations and expanded development continues; many existing contaminant sources will persist.

Land-use changes, particularly increases in impervious cover, are known stressors to aquatic systems and are difficult to predict, model, and remediate (Sharp 2010, p. 3; Coles et al. 2012, p. 65). Future development in the recharge and contributing zones are likely to decrease water quality because of the increased risk of contamination entering the aquifer. Additionally, nitrate runoff from surface water recharge leads to increased nitrate concentrations in the aquifer, and concentrations over 1 mg/L are indicative of anthropogenic inputs, which have been recorded historically at Comal Springs and have doubled over the last 70 years (median concentration 2 mg/L) (Dubrovsky et al. 2010, p. 79; Musgrove et al. 2016, pp. 462, 465, 467; Castaño-Sánchez et al. 2020, p. 6). These changes in water quality in streams and groundwater correspond with increases in impervious cover over a watershed (Kaushal et al. 2005, p. 13518; Baker et al. 2019, pp. 6494–6495; Castaño-Sánchez et al. 2020, p. 6). These water quality parameter changes may be a long-term indication of urbanization that has already occurred across the recharge zone.

A review of research studies found that impacts to aquatic species are seen with impervious cover of 10 percent or more (Center for Watershed Protection 2003, p. 97). Although the studies were focused on stream systems, we assume that shallow groundwater habitats would have similar impacts because shallow groundwater ultimately flows into streams through discharge features. While physical parameters may be different (e.g., higher oxygen, lower temperatures, higher conductivity) in the shallow groundwater, pollutants entering both systems would be the same.

The EAA does not have explicit impervious cover limits in the recharge zone, with the intent that structural best management practices will protect water quality (Greater Edwards Aquifer Alliance 2010, p. 3). The TCEQ shares responsibility in protecting the Edwards Aquifer through impervious cover limits through a construction permit review process for development proposals of more than 20 percent impervious cover that includes structural best management practices (30 TAC § 213).

Hays County limits impervious cover to 15 percent within conservation lands on the recharge zone confined and limits impervious cover to 20 percent outside of the recharge zone (Hays County 2017 p. 204). Hays County also limits commercial property within the recharge zone not exceed 35 percent impervious cover or 65 percent if outside of the recharge zone (Hays County 2017 p. 207). Additionally, Comal County has goals to minimize impervious cover within the city of New Braunfels to limits of 26 percent per parcel (Design Workshop, Inc. 2012, pp. 4–5).

While the efforts to implement such limits are intended to help ameliorate at least some water quality impacts, these percentages are nonetheless higher than 10 percent, and each project approval does not account for the cumulative impact of combined impervious cover amounts within each county. Likewise, most lands over the contributing zone are not managed with land use regulations (e.g., impervious cover restrictions) (Siglo Group 2022, pp. 13–14).

#### *Habitat Disturbance- Flooding*

Surface habitat modification can occur as the result of flooding. Flash flooding is common throughout the Edwards Plateau (Woodruff and Wilding 2008, pp. 614-616). However, channel modification and the elimination of riparian zones can increase the severity of flooding (Schoof 1980, p. 697). Depending on the severity of floods, they can either deposit or increase suspended sediment loads over species habitat or scour substrate and vegetation from species habitat under high velocities (Griffin 2006, pp. 57-58, 61, 64; BIO-WEST, Inc. 2016, p. 26; BIO-WEST, Inc. 2019b, pp. 14, 17; Schwartz et al. 2020, pp. 12). It is possible that species may also be washed away in floods, though this has not been studied for the Comal Springs dryopid beetle. Record flooding occurred in the San Marcos River in 2015 and scoured large amounts of aquatic vegetation

(BIO-WEST, Inc. 2016, p. vi, 48). Floods have deposited finer sediments (e.g., silt) over invertebrate surface habitat at Comal and Sessom springs, reducing springflow and quality of habitat (BIO-WEST, Inc. 2002, p. 11; Gibson 2022, pers. comm.).

### *Recreation*

Historically, Comal Springs served as a recreational site. Researchers at spring run 2 observed negative effects on the habitat, as prohibited-use signs were ignored and not enforced (Barr 1993, p. 62). By 1992, the area faced heavy human traffic with activities like swimming and wading, resulting in low or no captures of Comal Springs dryopid beetles (Barr 1993, pp. 30, 62; Arsuffi et al. 1993, p. 22). Additionally, subterranean invertebrate diversity reached its lowest point between spring runs 1 through 3 during this period (Arsuffi 1993, p. 21). These historical recreational impacts may have had unknown consequences on the broader invertebrate community at that time. Currently, Comal Springs rules are enforced by park rangers. Unauthorized access to the spring runs are strictly prohibited, and individuals must obtain prior authorization from the park manager to access these areas for activities such as research and habitat restoration projects. Documentation must be provided on-site before any work is conducted at the springs.

#### **2.2.2.2 Overutilization for commercial, recreational, scientific, or educational purposes:**

Comal Springs dryopid beetle specimens are collected for scientific study and two refugia populations. Such collections which have not been documented to negatively impact total wild population numbers. At present, this species is not recognized for their commercial worth, and there is no evidence of overexploitation, making overutilization insignificant as a threat.

#### **2.2.2.3 Disease or predation:**

Fungi have not been observed on living Comal Springs dryopid beetles, but benign fungal parasites on *Dryops* beetle species have been documented (Brown 1987, p. 266). Filamentous fungi have been documented on deceased wild and captive Comal Springs dryopid beetle larvae and adults, but whether the fungi were the cause of the mortality or occurred post-mortem is uncertain (Worsham and Gibson 2022, pers. comm.).

The amount of predation that occurs in the wild has not been examined for this species. Blind, fragile subterranean species such as the Comal Springs dryopid beetle may be more susceptible to predation once the species enter surface waters (Brown 1987, p. 263; Barr 1993, pp. 63-64). Fishes compete for prey expelled from the aquifer at discharge features (e.g., spring openings). Researchers have seen Mexican tetras (*Astyanax mexicanus*), sunfish (*Lepomis*

sp.), and mosquitofish (*Gambusia* sp.) congregating at spring openings waiting for the driftnet to be removed and consuming the bycatch, including subterranean invertebrates (BIO-WEST, Inc. 2003, p. 42). Macroinvertebrates such as the Comal Springs dryopid beetle are a part of the food chain, and it is assumed any number of individuals removed from the listed macroinvertebrate populations through typical levels of predation are likely to be negligible.

#### **2.2.2.4 Inadequacy of existing regulatory mechanisms:**

Under this factor, we examine the stressors identified within the other factors as ameliorated or exacerbated by any existing regulatory mechanisms or conservation efforts. Section 4(b)(1)(A) of the ESA requires that the USFWS consider “those efforts, if any, being made by any State or foreign nation, or any political subdivision of a State or foreign nation, to protect such species...”. In relation to Factor D under the ESA, we interpret this language to require the USFWS to consider relevant Federal, State, and Tribal laws, regulations, and other such binding legal mechanisms that may ameliorate or exacerbate any of the threats we describe in threat analyses under the other four factors or otherwise enhance the species’ conservation. Our consideration of these mechanisms is described in detail within each of the threats or stressors to the Comal Springs dryopid beetle (see discussion under the other Factors). Much of the information under Section 2.2.2.1 should also be considered as relevant here because it is often the inadequacy of existing regulations that contributes to habitat loss and degradation for this species.

The recharge and contributing zones to the Edwards Aquifer continue to experience rapid human population growth and conversion of natural habitat to developed land-use types, which continues to threaten water quality. Much of the contributing zone is not under the same regulations to protect water quality as the recharge zone, even though much of the water that recharges the aquifer originates in the contributing zone. Regulatory mechanisms that protect water in the Edwards Aquifer are crucial to the future survival of the Comal Springs dryopid beetle. Federal, State, and local laws and regulations have improved water quality and quantity protection but could be insufficient to prevent ongoing impacts to the species and their habitats from water quality degradation, reduction in water quantity, and surface disturbance of spring sites, and are unlikely to prevent further impacts to the species in the future. Knowledge of the source, accumulation, and transport of these compounds in the aquifer are lacking and investigations into their effects on the habitat quality are necessary for the recovery of the Comal Springs dryopid beetle and for sustainable use of the aquifer (Danielopol et al. 2004, pp. 187-188; Opsahl et al. 2018, p. 2).

Under Texas Parks and Wildlife Code (Chapter 68) and TAC (31 TAC § 65.171-65.176), the Texas Parks and Wildlife Department is authorized to add species to the agency’s List of State Threatened and Endangered Nongame

Species and List of State Endangered, Threatened, and Protected Native Plants. The Comal Springs dryopid beetle is also state listed. The Texas Parks and Wildlife Department prohibits the taking, possession, transportation, or sale of any animal species that are state listed as threatened or endangered. State law prohibits commerce in threatened and endangered plants and prohibits collection of listed plant species from public land without a permit. However, prosecutions for these prohibited actions are rare and the burden of proof to prosecute is high, which can result in unauthorized take of state listed species. In addition, it is likely that at the time of recovery the species would no longer be state listed. Because Comal Springs dryopid beetle is conservation reliant, it would be expected that delisting would increase threats identified in the listing determination, unless there are other mechanisms to continue conservation efforts.

While the EAA was granted regulatory authority by the Texas Legislature, there have been several legal challenges to the EAA permitting program. For example, in court cases *Edwards Aquifer Authority v. Day* (2012, Supreme Court of Texas No. 08-0964) and *Edwards Aquifer Authority v. Bragg* (2013, Court of Appeals of Texas No. 04-11-00018-CV), courts awarded landowners compensation for groundwater permits that were denied by the EAA due to lack of historical usage. The ruling for *Edwards Aquifer Authority v. Day* by the Texas Supreme Court argued that there was no reason to treat groundwater differently than oil and gas and recognized groundwater as real property. In both cases, landowners owned the land prior to enactment of new groundwater pumping regulations. There remains a lack of clarity with Texas groundwater law that results in ongoing legal challenges regarding groundwater regulation, and these could impact the EAA's ability to regulate the aquifer in the future.

The EAA manages and issues permits for groundwater withdrawals within the Edwards Aquifer through conservation and drought management. The EAA's jurisdiction is limited to the Edwards Aquifer in Uvalde, Medina, Bexar, and portions of Comal, Guadalupe, Hays, and Caldwell counties. The contributing zone in Bandera, Kerr, and Kendall counties do not have additional protections under either program. Thus, the EAA's water quality regulations do not protect most of the contributing zone, which may ultimately reduce the water quality of the Edwards Aquifer.

As described above, TCEQ regulates activities that have the potential to pollute the Edwards Aquifer and hydrologically connected surface streams under the same Edwards Aquifer Protection Program or "Edwards Rules" and for the same counties. This means areas of the contributing zone do not have additional protections that could affect the amount and quality of recharge that enters the Edwards Aquifer, resulting in lower water quality protection for the aquifer and the Comal, Fern Bank, or Sessom ecosystems.

Likewise, this agency does not address development or other land use, impervious cover limitations, some nonpoint source pollution, or application of fertilizers and pesticides over the recharge zone (30 TAC § 213.31). Changes to how surface water and the Trinity Aquifer are managed are likely to change the amount that can be sustainably pumped from the Edwards Aquifer during drought conditions. For example, the Hays-Trinity Groundwater Conservation District also manages groundwater that influences the water at Sessom or Fern Bank springs ecosystems.

#### **2.2.2.5 Other natural or manmade factors affecting its continued existence:**

Global climate change is already affecting many regions' biodiversity, with stressors driven by increasing temperatures and extreme climatic events and will continue to in the near-term (Intergovernmental Panel on Climate Change 2023, pp. 5, 15). Over the last 115 years, the global averaged surface air temperature has increased by 1.0°C (1.8°F) with recent decades being the warmest in 1,500 years (Vose et al. 2017, pp. 186, 188). With the highly karstic permeability of the Edwards Aquifer, climate change and variability strongly influence this vulnerable aquifer that relies heavily on rainfall for recharge (Mace and Wade 2008, p. 659; Taylor et al. 2013, p. 312; Ding and McCarl 2019, p. 11; Nielsen-Gammon et al. 2020, p. 9). The Fourth U.S. National Climate Assessment (U.S. Global Change Research Program 2018, pp. 1,002-1,003) presents the Edwards Aquifer as a case study in vulnerability to climate change, citing the shallow karst aquifer as especially sensitive to climate change, and the regional population growth and development as exacerbating the effects of decreased water supply during droughts. While average rainfall is not projected to change significantly in central Texas, the distribution of precipitation is anticipated to change with more extreme droughts and extreme rain events (Geos Institute 2016, pp. 14-15).

Increasing temperatures will also create drier conditions due to increased evapotranspiration (Loáiciga and Schofield 2019, p. 224). Extreme droughts in Texas are more likely than they were 40-50 years ago (Rupp et al. 2012, p. 1,054; Nielsen-Gammon et al. 2020, entire). A recent study predicts megadroughts in Texas, more severe than have been seen for the past thousand years, that will occur before 2100 (Nielsen-Gammon et al. 2020, entire). Droughts worse than the drought of record occurred since the 1600s and are not uncommon in the region (Mauldin 2003, entire; Cleaveland et al. 2011, entire). It is not possible to ensure that there will be adequate flow to these springs without planning for more extreme droughts than the drought of record (Loáiciga and Schofield 2019, p. 236; Mace 2019, p. 212). The sustainable water yield for the Edwards Aquifer will decrease in a dry climate (EARIP HCP 2020, pp. 3-12, 3-31, 3-43; Loáiciga and Schofield 2019, pp. 223, 235-236) while human demand for groundwater will increase (EARIP HCP 2020, pp. 3-10-3-11), making it more challenging to balance groundwater use for human

needs and ecosystem function. In 2010, Texas set a record for lowest rainfall with similar conditions persisting until 2013 (Nielsen-Gammon 2012, p. 59; National Research Council 2015, p. 168). Heavy rainfall leading to floods may also become more common from extreme precipitation events and may result in increased habitat disturbance due to movement of materials and scouring.

Average air temperature in Texas has risen 1.5°C (2.7°F) since the early 1900s (National Oceanic and Atmospheric Administration 2022, unpaginated). Future air temperature changes will depend on the amount of future greenhouse gas emissions (U.S. Global Change Research Program 2018, p. 995). Based on current projections of greenhouse gas emissions, air temperature is projected to increase 2.0–2.8°C (3.6–5.1°F) by 2050, and 2.4–4.7°C (4.4–8.4°F) by 2100 for the southern Great Plains (U.S. Global Change Research Program 2018, p. 995). Projections by Sharif (2018, p. 4) predict a greater rise in air temperature by 2100, 2.7–5.6°C (5–10°F). Studies have not explicitly addressed groundwater temperature increases for the Edwards Aquifer. Based on other research into changes in groundwater temperature, it is reasonable to expect that groundwater temperature will increase as air temperature increases, with a possible lag in groundwater temperature increase (Mahler and Bourgeais 2013, p. 295). Groundwater temperature also increases with urbanization and vegetation removal (Benz et al. 2017, entire). This could further increase groundwater temperatures as more development occurs. Groundwater temperature typically increases with depth due to geothermal heat flow, although this also varies locally with other variables such as vertical groundwater flow (Bense and Kurylyk 2017, pp. 1, 8). This suggests that deeper water would not provide a long-term buffer to increasing temperatures.

Some subterranean-adapted species would likely be incapable of adapting to modified temperatures in the medium to long-term and less capable, due to restricted dispersal capabilities, to flee rising temperature conditions than surface-adapted species (Culver and Pipan 2009, pp. 207–208; Taylor et al. 2013, pp. 324–325; Mammola et al. 2019, p. 646). Subterranean-adaptations in ectothermic animals allow for small fluctuations in temperature, but increased temperatures due to climate change can affect subterranean diversity by altering mobilization of contaminants (i.e., change in recharge rates through the unsaturated zone) and disruption to biogeochemical processes (e.g., carbon and nitrogen cycle) (Kløve et al. 2014, p. 263; Castaño-Sánchez et al. 2020, p. 7). Water quality at the subsurface and surface is also likely to decrease with increased water temperature. Therefore, the adaptive capacity ectothermic animals have to environmental changes is presumed to be low.

Surface water temperature will also increase during warm months. Data from the EAA indicates greater temperature fluctuations downstream from the springs due to increased exposure time to ambient temperatures and runoff from rain events (BIO-WEST, Inc. 2019a, p. 20; BIO-WEST, Inc. 2019b, p. 16). Low spring discharge is also a mechanism that increases the water's exposure time to

ambient temperature. Thus, both future droughts and increased ambient temperature are likely to increase the surface water temperature. Thus, both future droughts and increased ambient temperature are likely to increase the surface water temperature. Continuous temperature data for the springs began in 2000, and groundwater temperature at Comal Springs is relatively constant (BIO-WEST, Inc. 2019b, p. 16). Continuous water temperature monitoring in the Comal River should indicate whether water temperatures rise in the future.

There is currently no information on whether increased temperatures can affect different life stages or reproduction of the Comal Springs dryopid beetle, or how quickly water temperature will change in their habitat into the future. For ectothermic animals (e.g., macroinvertebrates), overall vulnerability to climate change will depend on thermal sensitivity and how quickly their buffered environment changes (Pallarés et al. 2021, p. 487; Delić et al. 2022, p. 2). Species with similar tolerances and adaptive traits have no opportunity to migrate and are unlikely to successfully relocate due to its specific habitat requirements (Kløve et al. 2014, p. 263; Castaño-Sánchez et al. 2020, p. 7; Simčič and Sket 2021, entire; Becher et al. 2022, pp. 4–5). We are uncertain if this species could flee from undesirable conditions caused by catastrophic drought in their habitat. There could be voids that become de-watered, and we assume the species will make attempts to follow the water down into the aquifer as drying occurs.

An assessment by U.S. Geological Survey evaluated the projected future vulnerability through 2050 of the Comal Springs dryopid beetle and rated it as moderately vulnerable to climate change (Stamm et al. 2015, pp. 1, 40, 42, 47). Moderately vulnerable is defined as “abundance and/or range extent within geographical area assessed likely to decrease by 2050”. There is currently no information indicating whether increased temperatures would affect different life stages or reproduction of the Comal Springs dryopid beetle or how quickly groundwater temperature will change in the Edwards Aquifer in response to climate change at the surface. Without more information, it is unknown to what extent these temporally delayed changes to the aquifer would have on this dryopid beetle and if the species would have sufficient time and have appropriate traits to adapt. These are important factors that require more research globally to fully understand vulnerability of these aquifer ecosystems and their subterranean communities (Mammola et al. 2019, pp. 646–647; Hose et al. 2022, entire).

### **2.3 Synthesis**

There are currently three genetically isolated populations of the Comal Springs dryopid beetle in Texas. There is currently no recovery plan for the beetle and no species status assessment has fully evaluated the species viability. Available demographic data, captive refugia research, and the five-factor threats analysis (Section 2.2.2) are collectively not indicative of the need for a change in listing status recommendation for the Comal Springs

dryopid beetle. Comal Springs dryopid beetle populations rely on continuous management and protective measures to preserve habitat, prevent silt accumulation, manage groundwater pumping for optimal springflow, supply terrestrial organic matter for the food web, and maintain sufficient water availability and quality for overall ecosystem health. In conclusion, it is our recommendation that a change in classification is not warranted at this time.

### **3.0 RESULTS**

#### **3.1 Recommended Classification:**

**No change is needed**

#### **3.2 New Recovery Priority Number (indicate if no change; see 48 FR 43098):**

No Change Recommended; see 48 FR 43098, September 21, 1983 & 48 FR 51985, November 15, 1983 - Correction)

#### **Brief Rationale:**

Primary stressors for the Comal Spring dryopid beetle are loss of springflow and decreases in subsurface habitat due to drawdown of the Edwards Aquifer and reductions in water quality from development and land-use changes. Research suggests that contamination of groundwater has not been historically widespread, is at relatively low concentrations currently, and the subterranean ecosystems do not exhibit significant signs of degradation (Hutchins 2018, pp. 481–482). Current conservation, flow protection, and water quantity optimization measures in place have been effective in meeting biological objectives for the EARIP HCP’s Covered Species, including the Comal Springs dryopid beetle, under which the EARIP HCP and regulations are reducing groundwater withdrawal pressure (National Research Council 2018, p. 109).

Given the projected increases in development and climate change-induced droughts in South Central Texas, the associated impacts from these activities on groundwater quality and aquifer recharge into the future remains uncertain (Loáiciga and Schofield 2019, p. 224; National Oceanic and Atmospheric Administration 2022, unpaginated). The sustainable water output for the Edwards Aquifer could decrease in a dry climate while human demand for groundwater would increase, making it more challenging to balance groundwater use for human needs and ecosystem function, and thus, the Comal Springs dryopid beetle’s viability (Loáiciga and Schofield 2019, pp. 223, 235–236; EARIP HCP 2020, pp. 3-10–3-11, 3-12, 3-31, 3-43; Nielsen-Gammon et al. 2020, pp. 9–10).

In terms of viability (Smith et al. 2018, entire), the Comal Springs dryopid beetle occupies a restricted range of three genetically distinct populations as a narrow endemic species only occurring in the Edwards Aquifer and associated spring ecosystems and are highly susceptible to extinction from perturbations that would affect water quantity and quality in the Edwards Aquifer and ongoing management is needed to maintain resiliency. Further, the

absence of data to inform how these threats directly impact Comal Springs dryopid beetle populations precludes a more detailed assessment of these impacts. Thus, our analysis does not warrant a change in recommended classification or recovery priority number. Therefore, we recommend the Comal Springs dryopid beetle retain its classification as endangered due to its conservation-reliant status.

**3.3 Listing and Reclassification Priority Number, if reclassification is recommended (see 48 FR 43098):**

**Reclassification (from Threatened to Endangered) Priority Number:**

**Reclassification (from Endangered to Threatened) Priority Number:**

**Delisting (Removal from list regardless of current classification) Priority Number:**

**Brief Rationale:**

Not applicable

**4.0 RECOMMENDATIONS FOR FUTURE ACTIONS**

- Explore various sampling techniques or increase the frequency of sampling using existing methods to enhance the collection of Comal Springs dryopid beetles at Sessom Springs. This will contribute to a better understanding of this population's status and the overall health of the habitat.
- Conduct status surveys at the Fern Bank ecosystem in Hays County, Texas to assess the status and health of this population. We recommend that these surveys also introduce goals to improve habitat conditions through landowner cooperation if recommended or crucial to improve species' resiliency and preserve redundancy of this genetically distinct population.
- Incorporate habitat-centered biological goals and objectives during EARIP HCP renewal process to promote protection of suitable habitat quality and quantity and species resiliency.
- Conduct a comprehensive assessment, including a dye-tracing study, to delineate the watershed and groundwater flowpaths contributing to springflow at Sessom Springs. This will help determine the respective contributions of regional groundwater and/or local Sessom Creek flow, providing critical insights into water sources. Such analysis will enable targeted efforts to enhance water quality remediation and maintain springflows through best management practices, especially during drought conditions.
- Conduct survey efforts focused on sampling for the Comal Springs dryopid beetle at wells and springs between the three occupied spring ecosystems to inform patterns of genetic diversity and understand the lack of gene flow between these locations. This may be coupled with research to better understand groundwater basin connectivity between the Comal, Fern Bank, and Sessom springs ecosystems.
- Continue water quantity and quality monitoring at accessible spring and well sites within and the areas that recharge the occupied spring ecosystems for habitat quality.
- Conduct research to reduce sources of nitrate into the Comal ecosystem through coordination with agencies, public education, and other non-governmental organizations.

- Establish conservation easements or fund land purchases within the contributing and recharge zones of the Edwards Aquifer for the benefit of the Comal Springs dryopid beetle and to ensure adequate springflow is sustained through droughts. Additionally, a site-prioritization tool could be developed to support decision making about strategic land acquisitions.
- To the extent possible, prevent or reduce increases in impervious surfaces or clearing of forest within the recharge areas supporting the species.
- Continue captive propagation research:
  - Conduct ongoing research to enhance captive propagation techniques.
  - Develop the capacity to produce offspring on-demand, anticipating standard operating procedures to inform action for potential catastrophic events or extirpation in the wild.
  - Formulate a comprehensive reintroduction plan based on research findings, ensuring the ability to replenish populations as needed.

## 5.0 REFERENCES

- Alley, W.M., R.W. Healy, J.W. LaBaugh, and T.E. Reilly. 2002. Flow and storage in groundwater systems. *Science* 296: 1,985-1,990.
- Arnow, T. 1959. Ground-water geology of Bexar County, Texas. Texas Board of Water Engineers Bulletin 5911. 52 pp.
- Arsuffi, T. L. 1993. Status of the Comal Springs riffle beetle (*Heterelmis comalensis* Bosse, Tuff, and Brown), Peck's cave amphipod (*Stygobromus pecki* Holsinger), and the Comal Springs dryopid beetle (*Stygoparnus comalensis* Barr and Spangler). Report prepared for US Fish and Wildlife Service, Ecological Services Field Office, Austin, Texas. 36 pp.
- Baker, M.E., M.L. Schley, and J.O. Sexton. 2019. Impacts of Expanding Impervious Surface on Specific Conductance in Urbanizing Streams. *Water Resources Research* 55: 6482–6498.
- Banerjee, P., P. Garai, N. C. Saha, S. Saha, P. Sharma, and A. K. Maiti. 2023. A critical review on the effect of nitrate pollution in aquatic invertebrates and fish. *Water, Air, & Soil Pollution* 234(6):333.
- Barkfield, R. F. 2022. Infrastructure consequences of exurb growth in Texas. Texas A&M University, The Bush School of Government and Public Service, Mosbacher Institute White Paper Spring 2022, 11 pp.
- Barr, C.B. 1993. Survey for two Edwards Aquifer invertebrates: Comal Springs dryopid beetle *Stygoparnus comalensis* Barr and Spangler (Coleoptera: Dryopidae) and Peck's cave amphipod *Stygobromus pecki* Holsinger (Amphipoda: Crangonyctidae). 70 pp.
- Barr, C., and P.J. Spangler. 1992. A new genus and species of stygobiontic dryopid beetle, *Stygoparnus comalensis* (Coleoptera: Dryopidae), from Comal Springs, Texas. *Proc. Biol. Soc. Wash.* 105: 40–54.

- Becher, J., C. Englisch, C. Griebler, and P. Bayer. 2022. Groundwater fauna downtown – Drivers, impacts and implications for subsurface ecosystems in urban areas. *Journal of Contaminant Hydrology* 248:104021.
- Bense, V. and B.L. Kurylyk. 2017. Tracking the subsurface signal of decadal climate warming to quantify vertical groundwater flow rates. *Geophysical Research Letters* 44: 1-10.
- Benz, S.A., P. Bayer, and P. Blum. 2017. Identifying anthropogenic anomalies in air, surface and groundwater temperatures in Germany. *Science of the Total Environment* 584-585: 145-153.
- Berube, A., A. Singer, J.H. Wilson, and W.H. Frey. 2006. Finding exurbia: America’s fast-growing communities at the metropolitan fringe. The Brookings Institution, *On the Record*, Washington, D.C. 47 pp.
- BIO-WEST, Inc. 2002. Comal Springs riffle beetle habitat and population evaluation. Project 802, Task 13. BIO-WEST, Inc. Prepared for the Edwards Aquifer Authority, Variable Flow Study, 11 pp.
- BIO-WEST, Inc. 2003. Comprehensive and critical period monitoring program to evaluate the effects of variable flow on biological resources in the Comal Springs/River aquatic ecosystem. Final 2002 Annual Report. Edwards Aquifer Authority, 45 pp.
- BIO-WEST, Inc. 2004. Comprehensive and critical period monitoring program to evaluate the effects of variable flow on biological resources in the Comal Springs/River aquatic ecosystem. Final 2003 Annual Report. Edwards Aquifer Authority, 40 pp.
- BIO-WEST, Inc. 2007. Variable Flow Study: Seven years of monitoring and applied research. Prepared for Edwards Aquifer Authority, 70 pp.
- BIO-WEST, Inc. 2008. Comprehensive and critical period monitoring program to evaluate the effects of variable flow on biological resources in the Comal Springs/River Aquatic Ecosystem. Final 2007 Annual Report. BIO-WEST, Inc., Comal County, Texas. 41 pp.
- BIO-WEST, Inc. 2016. Habitat Conservation Plan Biological Monitoring Program. San Marcos Springs/River Aquatic Ecosystem 2016 Annual Report. Prepared for Edwards Aquifer Authority, 53 pp.
- BIO-WEST, Inc. 2019a. Habitat Conservation Plan Biological Monitoring Program. San Marcos Springs/River Aquatic Ecosystem 2019 Annual Report. Prepared for Edwards Aquifer Authority, 50 pp.
- BIO-WEST, Inc. 2019b. Habitat Conservation Plan Biological Monitoring Program. Comal Springs/River Aquatic Ecosystem 2019 Annual Report. Prepared for Edwards Aquifer Authority, 53 pp.

- BIO-WEST, Inc. 2021. Biological Monitoring Program Comal Springs/River Aquatic Ecosystem Annual Report. Prepared for Edwards Aquifer Authority, 52 pp.
- Bowles, D.E., C.B. Barr, and P.J. Spangler. 1993. Comal Springs spring run field data sheets and maps.
- Bowles, D.E., C.B. Barr, and P.J. Spangler. 1994. Comal Springs spring run field data sheets and maps.
- Brown, H.P. 1987. Biology of riffle beetles. *Annual Review of Entomology* 32: 253–273.
- Bush, P.W., A.F. Ardis, L. Fahlquist, and P.B. Ging. 2000. Water quality in south-central Texas 1996-98: U.S. Geological Survey Circular Report, C 1212. 32 pp.
- Burri, N.M., R. Weatherl, C. Moeck, and M. Schirmer. 2019. A review of threats to groundwater quality in the Anthropocene. *Science of The Total Environment* 684: 136–154.
- Bush, P.W., A.F. Ardis, L. Fahlquist, and P.B. Ging. 2000. Water quality in south-central Texas 1996-98: U.S. Geological Survey Circular Report 1212, 32 pp.
- Buszka, P.M. 1987. Relation of water chemistry of the Edwards Aquifer to hydrogeology and land use, San Antonio region, Texas. U.S. Geological Survey Water-Resources Investigations Report 87-4116. 100 pp.
- Castaño-Sánchez, A., G.C. Hose, and A.S.P.S. Reboleira. 2020. Ecotoxicological effects of anthropogenic stressors in subterranean organisms: A review. *Chemosphere* 244:125422.
- Center for Watershed Protection. 2003. Impacts of impervious cover on aquatic systems. Center for Watershed Protection, Ellicott City, MD.
- City of San Antonio. 2023. Capital improvements program FY2023 FY2028. 241 pp.
- Clark, A.K. 2000. Vulnerability of ground water to contamination, Edwards Aquifer recharge zone, Bexar County, Texas, 1998. Water-Resources Investigation Report 00-4149. U.S. Geological Survey, Austin, Texas. 9 pp.
- Cleaveland, M.K., T.H. Votteler, D.K. Stahle, R.C. Casteel, and J.L. Banner. 2011. Extended chronology of drought in South Central, Southeastern and West Texas. *Texas Water Journal* 2: 54–96.
- Clough, A. 2022. Comal Springs dryopid beetle refugia program. Available at: <https://storymaps.arcgis.com/stories/c5c96b7d26814b7dad9e55cee55196e7> (June 2, 2022).
- Coles, J.F., G. McMahon, A.H. Bell, L.R. Brown, F.A. Fitzpatrick, B.C. Scudder Eikenberry, M.D. Woodside, T.F. Cuffney, W.L. Bryant, K. Capiella, L. Fraley-McNeal, and W.P.

- Stack. 2012. Effects of urban development on stream ecosystems in nine metropolitan study areas across the United States. U.S. Geological Survey, Circular 1373, 138 pp.
- Culver, D.C., and T. Pipan. 2009. The biology of caves and other subterranean habitats. Oxford University Press, New York.
- Danielopol, D.L., M. Creuzé des Châtelliers, F. Moeszlacher, P. Pospisil, and R. Popa. 1994. Adaptation of crustacea to interstitial habitats. Academic Press, San Diego, California.
- Delić, T., P. Trontelj, V. Zakšek, A. Brancelj, T. Simčič, F. Stoch, and C. Fišer. 2022. Speciation of a subterranean amphipod on the glacier margins in South Eastern Alps, Europe. *Journal of Biogeography* 49(1):38-50.
- Design Workshop, Inc. 2012. New Braunfels stormwater management strategy. Phase I Report, 48 pp.
- Di Lorenzo, T., W.D. Di Marzio, B. Fiasca, D.M.P. Galassi, K. Korbel, S. Iepure, J.L. Pereira, A.S.P.S. Reboleira, S.I. Schmidt, and G.C. Hose. 2019. Recommendations for ecotoxicity testing with stygobiotic species in the framework of groundwater environmental risk assessment. *Science of The Total Environment* 681: 292–304.
- Ding, J., and B. A. McCarl. 2019. Economic and ecological impacts of increased drought frequency in the Edwards Aquifer. *Climate* 8(1):2.
- Dubrovsky, N.M., K.R. Burow, G.M. Clark, J.M. Gronberg, P.A. Hamilton, K.J. Hitt, D.K. Mueller, M.D. Munn, B.T. Nolan, L.J. Puckett, M.G. Rupert, T.M. Short, N.E. Spahr, L.A. Sprague, and W.G. Wilber. 2010. The quality of our nation's waters: Nutrients in the nation's streams and groundwater, 1992-2004. U.S. Geological Survey, Circular 1350. 174 pp.
- Dudley, N., and S. Stolten. 2003. Running pure: The importance of forest protected areas to drinking water. A report to the World Bank and WWF Alliance for Forest Conservation and Sustainable Use, 112 pp.
- EAA (Edwards Aquifer Authority) 2013. Hydrologic data report for 2011. Report No. 13-01, San Antonio, Texas, 73 pp.
- EAA (Edwards Aquifer Authority) 2015. Hydrologic data report for 2014. Report No. 15-01, San Antonio, Texas, 69 pp.
- EAA (Edwards Aquifer Authority) 2018. 2017 water quality summary. San Antonio, Texas, 6 pp.
- EAA (Edwards Aquifer Authority). 2021a. EAHCP annual expanded water quality monitoring report. Appendix F of 2021 Edwards Aquifer Authority Reports.

- EAA (Edwards Aquifer Authority). 2021b. Plugging away at the EAA. Edwards Aquifer Authority News Drop (Summer 2021):56. Retrieved on April 14, 2022, from: <https://user-qzm76pf.cld.bz/NewsDrop-Summer-2021/>.
- EAA (Edwards Aquifer Authority). 2022. Aquifer Protection. Retrieved on May 3, 2022, from: <https://www.edwardsaquifer.org/aquifer-protection/>.
- Eamus, D., B. Fu, A.E. Springer, and L.E. Stevens. 2016. Groundwater dependent ecosystems: classification, identification techniques and threats. Pages 313-346 in Jakeman, A.J., O. Barreteau, R.J. Hunt, J. Rinaudo, and A. Ross, editors. Integrated groundwater management: concepts, approaches, and challenges. Springer Open. 762 pp.
- EARIP HCP (Edwards Aquifer Recovery Implementation Program Habitat Conservation Program). 2020. Prepared by RECON, Environmental, Inc.; Hicks & Company; Zara Environmental, LLC; and BIO-WEST, Inc. 423 pp.
- EPA (U.S. Environmental Protection Agency). 2017. Updates to the demographic and spatial allocation models to produce Integrated Climate and Land Use Scenarios (ICLUS) (Final Report, Version 2). EPA/600/R-16/366F. Office of Research and Development U.S. Environmental Protection Agency, Washington, DC.
- EPA (U.S. Environmental Protection Agency). 2019. Integrated Climate and Land-Use Scenarios Version 2.1 Land Use Projections. Retrieved on September 16, 2022, from <https://www.epa.gov/gcx/iclus-downloads/>.
- Fahlquist, L., A.F. Ardis. 2004. Quality of water in the Trinity and Edwards Aquifers, south-central Texas, 1996-98: U.S. Geological Survey Scientific Investigations Report 2004-5201, 25 pp.
- Foster, S.S.D. and P.J. Chilton. 2003. Groundwater: the processes and global significance of aquifer degradation. *Philosophical Transactions of the Royal Society B* 358: 1957–1972.
- Fries, J.N., J.R. Gibson, and T.L. Arsuffi. 2004. Edwards Aquifer spring invertebrate survey and captive maintenance of two species. San Marcos National Fish Hatchery and Technology Center and Texas State University.
- Geos Institute. 2016. Hot enough yet? The future of extreme weather in Austin, Texas. Ashland, OR. 26 pp.
- Gibson, J.R., S.J. Harden, and J. Fries. 2008. Survey and distribution of invertebrates from selected springs of the Edwards Aquifer in Comal and Hays Counties, Texas. *Southwestern Naturalist* 53:74-84.
- Gibson, J.R. 2022. Phone call on invertebrate threats for species biological report. November 29.

- Gold, R. 2022, January 12. A forgotten oil well births a 100-foot geyser in West Texas. *Texas Monthly*. Retrieved on April 14, 2022, from: <https://www.texasmonthly.com/news-politics/west-texas-geyser-oil-well-chevron/>.
- Greater Edwards Aquifer Alliance. 2010. Permanent stormwater pollution prevention systems within the Edwards Aquifer Recharge Zone in Bexar County, Texas. An overview and assessment of current regulatory agency processes, 48 pp.
- Griffin, K.L. 2006. An Analysis of changes in Texas wild rice distribution following the 1998 flood of the San Marcos River, Texas. M.A. Geo. Thesis, Texas State University, 68 pp.
- Hardberger, A. 2019. Texas groundwater law and the Edwards Aquifer. Pages 189–197 *in* The Edwards Aquifer: The Past, Present, and Future of a Vital Water Resource. Geological Society of America.
- Hinsby, K., M.T. Condesso De Melo, and M. Dahl. 2008. European case studies supporting the derivation of natural background levels and groundwater threshold values for the protection of dependent ecosystems and human health. *Science of The Total Environment* 401: 1–20.
- Hose, G.C. 2005. Assessing the need for groundwater quality guidelines for pesticides using the Species Sensitivity Distribution Approach. *Human and Ecological Risk Assessment: An International Journal* 11: 951–966.
- Hose, G.C., A.A. Chariton, M.A. Daam, T. Di Lorenzo, D.M.P. Galassi, S.A. Halse, A.S.P.S. Reboleira, A.L. Robertson, S.I. Schmidt, and K.L. Korbel. 2022. Invertebrate traits, diversity and the vulnerability of groundwater ecosystems. *Functional Ecology* 36(9):2200-2214.
- Humphreys, W.F. 2011. *Management of Groundwater Species in Karst Environments*. Springer, Dordrecht, Netherlands.
- Hutchins, B.T. 2018. The conservation status of Texas groundwater invertebrates. *Biodivers. Conserv.* 27: 475–501.
- Hutchins, B.T., A.S. Engel, W.H. Nowlin, and B.F. Schwartz. 2016. Chemolithoautotrophy supports macroinvertebrate food webs and affects diversity and stability in groundwater communities. *Ecology* 97: 1530-1542.
- Intergovernmental Panel on Climate Change. 2023. Summary for policymakers. *Climate change 2023: Synthesis report*, pp. 1–34. IPCC, Geneva, Switzerland.
- Johnson, S., G. Schindel, and J. Hoyt. 2009. Water quality trends analysis of the San Antonio segment, Balcones Fault Zone Edwards Aquifer, Texas. Edwards Aquifer Authority Report No. 09-03.

- Johnson, S., and G.M. Schindel. 2014. Water quality trends analysis of the San Antonio Segment, Balcones Fault Zone Edwards Aquifer, Texas. 2014 Update. Edwards Aquifer Authority, 65 pp.
- Johnson, S., G. Schindel, G. Veni, N. Hauwert, B. Hunt, B. Smith, and M. Gary. 2012. Tracing groundwater flowpaths in the vicinity of San Marcos Springs, Texas. Report No. 12-03. Edwards Aquifer Authority in cooperation with Barton Springs Edwards Aquifer Conservation District and City of Austin Watershed Protection, 147 pp.
- Katz, B.G. 2019. Nitrate contamination in karst groundwater. Pages 756–760 *in* Encyclopedia of Caves. Academic Press. London, United Kingdom.
- Kaushal, S.S., P.M. Groffman, G.E. Likens, K.T. Belt, W.P. Stack, V.R. Kelly, L.E. Band, and G.T. Fisher. 2005. Increased salinization of fresh water in the northeastern United States. *Proc. Natl. Acad. Sci. U.S.A.* 102: 13517–13520.
- Kløve, B., P. Ala-Aho, G. Bertrand, J. J. Gurdak, H. Kupfersberger, J. Kværner, T. Muotka, H. Mykrä, E. Preda, P. Rossi, C. B. Uvo, E. Velasco, and M. Pulido-Velazquez. 2014. Climate change impacts on groundwater and dependent ecosystems. *Journal of Hydrology* 518:250–266.
- Kosnicki, E., and E. Julius. 2019. Life-history aspects of the Comal Springs dryopid beetle (*Stygoparnus comalensis*) and notes on life-history aspects of the Comal Springs riffle beetle (*Heterelmis comalensis*). BIO-WEST, Inc. Prepared for the Edwards Aquifer Authority, 61 pp.
- Lapworth, D. J., N. Baran, M. E. Stuart, and R. S. Ward. 2012. Emerging organic contaminants in groundwater: A review of sources, fate and occurrence. *Environmental Pollution* 163:287–303.
- LBG-Guyton Associates, BIO-WEST, Inc., Espey Consultants, Inc., and URS Corporation. 2004. Evaluation of Augmentation Methodologies in Support of In-Situ Refugia at Comal and San Marcos Springs, Texas, 1182 pp.
- Lin, Y. and X. Gong. 2016. Risk assessment of water pollution exposure to hazardous waste sites: a case study in Bexar County, Texas. *Papers in Applied Geography* 2(4): 383–394.
- Lindgren, R.J., A.R. Dutton, S.D. Hovorka, S.R.H. Worthington, and S. Painter. 2004. Conceptualization and simulation of the Edwards aquifer, San Antonio region, Texas: U.S. Geological Survey Scientific Investigations Report 2004–5277, 143 pp.
- Loáiciga, H. A., and M. Schofield. 2019. Climate variability, climate change, and Edwards Aquifer water fluxes. Pages 223-238 *In* The Edwards Aquifer: The past, present, and future of a vital water resource. Abbott, P.L. and C.M. Woodruff, Jr., editors. Geological Society of America. 312 pp.

- Loiácomo, D.J. 2019. Stormwater and non-point source pollutants in Sessom Creek, San Marcos, TX. Master of Science. Texas State University, 76 pp.
- Mace, R.E. 2019. The use of water from the Edwards Aquifers, Texas. Pages 207–212 *in* The Edwards Aquifer: The Past, Present, and Future of a Vital Water Resource. Geological Society of America.
- Mace, R.E. and S.C. Wade. 2008. In hot water? How climate change may (or may not) affect the groundwater resources of Texas, Texas, Gulf Coast Association of Geological Societies Transactions, v. 58, p.655-668.
- Mammola, S., P. Cardoso, D. C. Culver, L. Deharveng, R. L. Ferreira, C. Fišer, D. M. P. Galassi, C. Griebler, S. Halse, W. F. Humphreys, M. Isaia, F. Malard, A. Martinez, O. T. Moldovan, M. L. Niemiller, M. Pavlek, A. S. P. S. Reboleira, M. Souza-Silva, E. C. Teeling, J. J. Wynne, and M. Zagamajster. 2019. Scientists’ warning on the conservation of subterranean ecosystems. *BioScience* 69(8):641–650.
- Maclay, R.W. 1995. Geology and hydrology of the Edwards Aquifer in the San Antonio area, Texas. Geological Survey Water-Resources Investigations Report 95-4186, 54 pp.
- Mahler, B. J., and R. Bourgeois. 2013. Dissolved oxygen fluctuations in karst spring flow and implications for endemic species: Barton Springs, Edwards aquifer, Texas, USA. *Journal of Hydrology* 505:291–298.
- Manenti, R., B. Piazza, Y. Zhao, E. Padoa Schioppa, and E. Lunghi. 2021. Conservation studies on groundwaters’ pollution: Challenges and perspectives for stygofauna communities. *Sustainability* 13: 7030.
- McKinney, M.L. 1997. Extinction vulnerability and selectivity: combining ecological and paleontological views. *Annual Review of Ecology and Systematics* 28:495–516.
- Musgrove, M., and C.L. Crow. 2012. Origin and Characteristics of Discharge at San Marcos Springs Based on Hydrologic and Geochemical Data (2008–10), Bexar, Comal, and Hays Counties, Texas. 2012–5126. U.S. Geological Survey in cooperation with San Antonio Water System, Report, Bexar County, Comal County, Hays County, 94 pp.
- Musgrove, M., B.G. Katz, L.S. Fahlquist, C.A. Crandall, and R.J. Lindgren. 2014. Factors affecting public-supply well vulnerability in two karst aquifers. *Groundwater–Focus* 52: 63–75.
- Musgrove, M., S. P. Opsahl, B. J. Mahler, C. Herrington, T. L. Sample, and J. R. Banta. 2016. Source, variability, and transformation of nitrate in a regional karst aquifer: Edwards aquifer, central Texas. *Science of The Total Environment* 568:457–469.
- Nair, P., P.H. Diaz, and W.H. Nowlin. 2021. Interactions at surface–subterranean ecotones: structure and function of food webs within spring orifices. *Oecologia* 195:14.

- National Oceanic and Atmospheric Administration. 2022. NOAA National Centers for Environmental Information. State climate summaries 2022: Texas. Available at: <https://statesummaries.ncics.org/chapter/tx/> (September 1, 2022).
- National Research Council. 2015. Review of the Edwards Aquifer Habitat Conservation Plan: Report 1. National Academies Press, Washington, D.C. 174 pp.
- Nielsen-Gammon, J., J.L. Banner, B.I. Cook, D.M. Tremaine, C.I. Wong, R.E. Mace, H. Gao, Z. Yang, M.F. Gonzalez, R. Hoffpauir, T. Gooch, and K. Kloesel. 2020. Unprecedented drought challenges for Texas water resources in a changing climate: What do researchers and stakeholders need to know? *Earth's Future* 8: 20.
- Nielsen-Gammon, J., S. Holman, A. Buley, S. Jorgensen, J. Escobedo, C. Ott, and J. Dedrick. 2021. Assessment of historic and future trends of extreme weather in Texas, 1900-2036. OSC-202101. Texas A&M University, Document, Office of the State Climatologist, Texas A&M University, College Station, Texas.
- Notenboom, J., S. Plénet, and M.-J. Turquin. 1994. Groundwater contamination and its impact on groundwater animals and ecosystems. Pages 477–500 in J. Gibert, D.L. Danielopol, and J.A. Stanford [eds.], *Groundwater ecology*. Academic Press. San Diego, California.
- Nowlin, W.H., D. Hahn, P. Nair, and F. Alfano. 2017. Evaluation of the trophic status and functional feeding group status of the Comal Springs riffle beetle. 148-15-HCP. Texas State University prepared for the Edwards Aquifer Authority, 30 pp.
- Nowlin, W.H., B.F. Schwartz, M.L.D. Worsham, and J. R. Gibson. 2016. Refugia research: development of husbandry and captive propagation techniques for invertebrates covered under the Edwards Aquifer habitat conservation plan. Texas State University and San Marcos Aquatic Resources Center prepared for the Edwards Aquifer Authority, 37 pp.
- Nowlin, W.H., C. Nice, W. Coleman, and B.F. Schwartz. 2022. Trophic ecology and population genetics of the endangered Comal Springs dryopid beetle (*Stygoparnus comalensis*). Report No. E-205-R-1. Texas State University and Edwards Aquifer Research and Data Center prepared for Texas Parks and Wildlife Department, 27 pp.
- O'Grady, J.J., D.H. Reed, B.W. Brook, and R. Frankham. 2004. What are the best correlates of predicted extinction risk? *Biological Conservation* 118:513-520.
- Ogden, A.E., R.A. Quick, and S.R. Rothermel. 1986. Hydrochemistry of the Comal, Hueco, and San Marcos Springs, Edwards Aquifer, Texas. Geological Society of America.
- Opsahl, S.P., M. Musgrove, B.J. Mahler, and R.B. Lambert. 2018. Water-quality observations of the San Antonio segment of the Edwards Aquifer, Texas, with an emphasis on processes influencing nutrient and pesticide geochemistry and factors affecting aquifer vulnerability. Scientific Investigations Report 2010-16. U.S. Geological Survey in cooperation with San Antonio Water System, 67 pp.

- Opsahl, S.P., Musgrove, M., and Mecum, K.E. 2020. Temporal and spatial variability of water quality in the San Antonio segment of the Edwards aquifer recharge zone, Texas, with an emphasis on periods of groundwater recharge, September 2017–July 2019: U.S. Geological Survey Scientific Investigations Report 2020–5033, 37 pp.
- Pallarés, S., R. Colado, M. Botella-Cruz, A. Montes, P. Balart-García, D.T. Bilton, A. Millán, I. Ribera, and D. Sánchez-Fernández. 2021. Loss of heat acclimation capacity could leave subterranean specialists highly sensitive to climate change. *Animal Conservation* 24(3):482-490.
- Passarello, M. C., J. M. Sharp, and S. A. Pierce. 2012. Estimating urban-induced artificial recharge: A case study for Austin, TX. *Environmental & Engineering Geoscience* 18(1):25–36.
- Payne, S., N. Pence, and C. Furl. 2019. The Edwards Aquifer Habitat Conservation Plan: Its planning and implementation. Pages 109–206 *in* The Edwards Aquifer: The Past, Present, and Future of a Vital Water Resource. Geological Society of America.
- Petitt, B.M., Jr. and W.O. George. 1956. Ground-water resources of the San Antonio area, Texas: a progress report on current studies. Texas Board of Water Engineers Bulletin 5608. Volume 1, 80 pp.
- Puente, C. 1976. Statistical analysis of water-level springflow, and stream data for the Edwards aquifer in south-central Texas: Open-File Report 76-393. U.S. Geological Survey, San Antonio, Texas, 59 pp.
- Reilly, F.J., Jr. and K.A. Carter. 2018. Program study and analysis services for the Edwards Aquifer Protection Program. Report for the City of San Antonio, Texas’ Parks and Recreation Department, 45 pp.
- Romero, F.S. 2018. San Antonio’s Edwards Aquifer Protection Program: overview and analysis. *Texas Water Journal* 1–15.
- Rupp, D. E., P. W. Mote, N. Massey, C. J. Rye, R. Jones, and M. R. Allen. 2012. Did human influence on climate made the 2011 Texas drought more probable? Explaining extreme events of 2011 from a climate perspective. *Bulletin of the American Meteorological Society* 93(7):1041–1067.
- San Antonio Water System. 2022. Aquifer Protection and Evaluation. Retrieved on January 12, 2023, from: [https://www.saws.org/protecting-our-environment/water-resource-compliance-protection/aquifer\\_protection/](https://www.saws.org/protecting-our-environment/water-resource-compliance-protection/aquifer_protection/).
- Schoof, R. 1980. Environmental impact of channel modification. *Water Resources Bulletin* 16(4): 697-701.

- Schwartz, B., W.H. Nowlin, T. Hardy, J. Jeong, and J. Wolfe, III. 2020. Sessom Creek sediment export study. Texas State University; Edwards Aquifer Research and Data Center; Texas A&M AgriLife Research, EAHCP proposal no. 160-17-TESS, San Marcos, TX. 7 pp.
- Shah, N.W., B.R. Baillie, K. Bishop, S. Ferraz, L. Högbom, and J. Nettles. 2022. The effects of forest management on water quality. *Forest Ecology and Management* 522: 120397.
- Sharif, H. 2018. Climate projections for the City of San Antonio. University of Texas at San Antonio, San Antonio, TX. 17 pp.
- Sharp, J.M. 2010. The impacts of urbanization on groundwater systems and recharge, 6 pp.
- Shepard, W.D. 2002. Dryopidae Billberg 1820. Pages 121–122 in R.H. Arnett, M.C. Thomas, P.E. Skelley, and J.H. Frank [eds.], *American Beetles, Volume II: Polyphaga: Scarabaeoidea through Curculionoidea*. CRC Press.
- Siglo Group. 2022. State of the Hill Country: 8 key conservation and growth metrics for a region at a crossroads, 60 pp.
- Simčič, T., and B. Sket. 2021. Ecophysiological responses of two closely related epigean and hypogean *Niphargus* species to hypoxia and increased temperature: Do they differ? *International Journal of Speleology* 50(2):111-120.
- Simon, K.S., E.F. Benfield, and S.A. Macko. 2003. Food web structure and the role of epilithic biofilms in cave streams. *Ecology* 84: 2395–2406.
- Smith, D.R., N.L. Allan, C.P. McGowan, J.A. Szymanski, S.R. Oetker, and H.M. Bell. 2018. Development of a species status assessment process for decisions under the U.S. Endangered Species Act. *Journal of Fish and Wildlife Management* 9: 302–320.
- Springer, A.E. and L.E. Stevens. 2009. Spheres of discharge of springs. *Hydrogeology Journal* 17(1):83-93.
- Stamm, J.F., M.F. Poteet, A.J. Symstad, M. Musgrove, A.J. Long, B.J. Mahler, and P.A. Norton. 2014. Historical and projected climate (1901–2050) and hydrologic response of karst aquifers, and species vulnerability in south-central Texas and western South Dakota. 2014–5089. U.S. Geological Survey in cooperation with the Department of Interior South-Central Climate Science Center, Scientific Investigations Report 59 pp.
- Stone, D., and G.M. Schindel. 2002. The application of GIS in support of land acquisition for the protection of sensitive groundwater recharge properties in the Edwards Aquifer of south-central Texas. *Journal of Cave and Karst Studies* 64: 38–44.
- Sui, Q., X. Cao, S. Lu, W. Zhao, Z. Qiu, and G. Yu. 2015. Occurrence, sources and fate of pharmaceuticals and personal care products in the groundwater: A review. *Emerging Contaminants* 1(1):14-24.

- Taylor, R. G., B. Scanlon, P. Döll, M. Rodell, R. van Beek, Y. Wada, L. Longuevergne, M. Leblanc, J. S. Famiglietti, M. Edmunds, L. Konikow, T. R. Green, J. Chen, M. Taniguchi, M. F. P. Bierkens, A. MacDonald, Y. Fan, R. M. Maxwell, Y. Yechieli, J. J. Gurdak, D. M. Allen, M. Shamsudduha, K. Hiscock, P. J.-F. Yeh, I. Holman, and H. Treidel. 2013. Ground water and climate change. *Nature Climate Change* 3(4):322–329.
- TCEQ (Texas Commission on Environmental Quality). 2018. Upper San Marcos River Watershed Protection Plan. TCEQ Nonpoint Source Program Fact sheet, 2 pp.
- TCEQ (Texas Commission on Environmental Quality). 2020. Dry Comal Creek and Comal River Watershed Protection Plan Implementation. TCEQ Nonpoint Source Program Fact sheet, 1 pp.
- Texas Demographic Center 2022. Texas Population Projections Program. Retrieved on July 28, 2023, from: <https://demographics.texas.gov/data/tpepp/projections/>.
- Texas Natural Resource Conservation Commission. 1996. Chapter 213 - Edwards Aquifer Rule Log No. 97105-213-WT.
- Texas Water Development Board. 2021. 2022 State Water Plan, 167 pp.
- Texas Water Development Board. 2023. Groundwater Database Report and Downloads. Retrieved on May 24, 2023, from: [http://www.twdb.texas.gov/groundwater/data/gw\\_dbrpt.asp/](http://www.twdb.texas.gov/groundwater/data/gw_dbrpt.asp/).
- Theis, C.V. 1940. The source of water derived from wells. *Civil Engineering* 10: 277–280.
- U.S. Census Bureau 2020. Estimates of the Components of Resident Population Change for Counties in Texas: April 1, 2010 to July 1, 2019. Retrieved on July 24, 2020, from <https://census.gov/>.
- USFWS (U.S. Fish and Wildlife Service). 2013. Biological and conference opinions for the Edwards Aquifer Recovery Implementation Program Habitat Conservation Plan-Permit TE-63663A-0 (Consultation No. 21450-2010-F-0110). Ecological Services Field Office, Austin, TX, 169 pp.
- USFWS (U.S. Fish and Wildlife Service). 2017. San Marcos Aquatic Resources Center annual station report, fiscal year 2017. 49 pp.
- U.S. Geological Survey. 2023. USGS Surface-Water Daily Data for the Nation. USGS 08168710 Comal Spgs at New Braunfels, TX. Available at: <https://waterdata.usgs.gov/monitoring-location/08168710> (February 28, 2023).
- U.S. Global Change Research Program. 2018. Impacts, risks, and adaptation in the United States. Pages 987–1035 *in* Fourth National Climate Assessment. Washington, D.C.

- Vose, R.S., D.R. Easterling, K. E. Kunkel, A.N. LeGrande, and M.F. Wehner. 2017. Temperature changes in the United States. U.S. Global Change Research Program, Washington, D.C.
- West, B. 2023. E-mail: “Edwards Aquifer Refugia Program Peck’s cave amphipod and Comal Springs riffle beetle collection TODAY.”
- Wilson, J.T. 2011. Assessment of selected contaminants in streambed- and suspended-sediment samples collected in Bexar County, Texas, 2007–09: U.S. Geological Survey Scientific Investigations Report 2011–5097, 57 pp.
- Woodruff, C.M. and L.P. Wilding. 2008. Bedrock, soils, and hillslope hydrology in the central Texas Hill Country, USA: implications on environmental management in a carbonate rock terrain. *Environmental Geology* 55: 605-618.
- Worsham, M.L.D., and J.R. Gibson. 2022. E-mail “*Stygobromus* diseases”. August 25.
- Worthington, S.R.H. 2003. Conduits and turbulent flow in the Edwards Aquifer. Report prepared for the Edwards Aquifer Authority. 42 pp.
- Yee, D.A., and S. Kehl. 2015. Order Coleoptera. Pages 1003–1042 in J.H. Thorp and A.P. Covich [eds.], *Ecology and general biology*. 4th edition. Elsevier/AP, Academic Press is an imprint of Elsevier. San Diego, California.

**U.S. FISH AND WILDLIFE SERVICE**

**5-YEAR REVIEW of Comal Springs dryopid beetle (*Stygoparnus comalensis*)**

**Current Classification:** Endangered

**Recommendation resulting from the 5-Year Review:**

No change needed

**Appropriate Listing/Reclassification Priority Number, if applicable:**

**FIELD OFFICE APPROVAL:**

**Lead Field Supervisor, Fish and Wildlife Service, Austin Ecological Services Field Office**

Approve \_\_\_\_\_