Fountain Darter
(*Etheostoma fonticola*)

5-Year Review:
Summary and Evaluation

U.S. Fish and Wildlife Service
Austin Ecological Services Field Office
Austin, Texas
March 30, 2021

5-YEAR REVIEW

Species reviewed: Fountain darter (*Etheostoma fonticola*)

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5-YEAR REVIEW
Fountain darter (*Etheostoma fonticola*)

1.0 GENERAL INFORMATION

1.1 Reviewers (list primary reviewers of species information below)

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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 (Act) 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 Act. 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 Service 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 March 20, 2008 (73 FR 14995) and March 19, 2019 (85 FR 15795). 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 fountain darter as endangered (35 FR 16047), the recovery plan (Service 1996, entire), amendment to the recovery plan (Service 2019b, entire), research published in scientific journals, and unpublished reports and data.

1.4 Background:

The purpose of this 5-year review is to ensure that the fountain darter has the appropriate level of protection under the Act. This review documents a determination by the Service as to whether the status of this species has changed since the time of its listing. This review also provides updated information on the current threats, ongoing conservation efforts, and the priority needs for future conservation actions.

The fountain darter is approximately 2.54 centimeters (cm) [1 inch (in)] long and is mostly reddish brown and occurs in Spring Lake, the San Marcos River downstream to the confluence with the Blanco River, and in the Comal River in Hays and Comal counties, Texas (Service 1996, pp. 30-33).

1.4.1 FR Notice citation announcing initiation of this review:

73 FR 14995 and 85 FR 15795

1.4.2 Listing history

<u>Original Listing</u>
FR notice: 35 FR 16047
Date listed: October 13, 1970 and received federal protection with the passage of the Endangered Species Act in 1973
Entity listed: Fountain darter (*Etheostoma fonticola*)
Classification: Endangered

1.4.3 Associated rulemakings:

On July 14, 1980, the Service designated critical habitat in Spring Lake and its outflow and the San Marcos River downstream to 0.8 kilometer (km) [0.5 mile (mi)] past Interstate 35 (45 FR 47355).

1.4.4 Review History:

The Service published a final rule to list this species as endangered on October 13, 1970 (35 FR 16047) due to threats to the quality and quantity of aquifer and spring water the fountain darter depends on. Then on July 14, 1980, the Service conducted a comprehensive habitat status review when designating critical habitat, but only in the San Marcos spring system, not at Comal Springs (45 FR 47355). There have been two other status reviews conducted for the fountain darter, both as part of recovery plans covering this and other spring dependent species collocated with the fountain darter (Service 1985, entire; Service 1996, entire). There have been no other status reviews conducted since the 1996 recovery plan.

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

2C

1.4.6 Recovery Plan or Outline

Name of plan or outline: San Marcos and Comal Springs and Associated Aquatic Ecosystems (Revised) Recovery Plan
Date issued: February 14, 1996; Amendment 1 issued December 6, 2019
Dates of previous revisions, if applicable: April 8, 1985

2.0 REVIEW ANALYSIS

2.1 Application of the 1996 Distinct Population Segment (DPS) policy

2.1.1 Is the species under review a vertebrate?

Yes

2.1.2 Is the species under review listed as a DPS?

No

2.2 Recovery Criteria

2.2.1 Does the species have a final, approved recovery plan containing objective, measurable criteria?

Yes. The revised recovery plan issued on February 14, 1996, established objective, measurable downlisting criteria only. Objective, measurable delisting criteria were subsequently established in the December 6, 2019, recovery plan amendment to satisfy the Service's Agency Priority Goal of ensuring all recovery plans have quantitative criteria for what constitutes a recovered species. The amendment serves as a supplement to the existing, 1996 recovery plan.

2.2.2 Adequacy of recovery criteria.

2.2.2.1 Do the recovery criteria reflect the best available and most up-to date information on the biology of the species and its habitat?

Yes. The 2019 amendment to the recovery plan considers additional data obtained from annual fountain darter sampling conducted by BIO-WEST (2017), and recommendations from State and local species experts at Texas Parks and Wildlife Department (TPWD) and the Service's San Marcos Aquatic Resources Center (SMARC).

2.2.2.2 Are all of the 5 listing factors that are relevant to the species addressed in the recovery criteria (and is there no new information to consider regarding existing or new threats)?

Yes.

2.2.3 List the recovery criteria as they appear in the recovery plan, and discuss how each criterion has or has not been met, citing information

The fountain darter will be considered for downlisting, from endangered to threatened, when the following conditions have been achieved (Service 1996, pp. 53-57):

Downlisting Criterion 1 – Adequate flows and water quality are assured to continue from the San Marcos and Comal Springs downstream through their respective rivers and channels, even in a drought of record, at a level that will sustain the species.

Downlisting Criterion 2 – Captive, breeding populations of both the Comal and San Marcos populations are being maintained in such a way that genetic integrity of each species is assured and there are suitable stocks for reintroductions or supplementations should a catastrophe eliminate or drastically reduce numbers in their native ecosystems.

Downlisting Criterion 3 – All measures identified in this plan to remove or minimize "local" threats have been successfully implemented (e.g., impacts from nonnative species, recreation, habitat alteration, or local water quality problems).

Downlisting Criterion 4 – Healthy, self-sustaining populations of both populations exist throughout their historic ranges in both the Comal and San Marcos systems and are being maintained. Whether this has been attained should be evaluated based on the criteria that follow:

- Monitoring of fountain darters and submergent vegetation in both the San Marcos and Comal systems should be conducted annually to verify acceptable populations are being maintained.
- Methods used to sample fountain darters should be similar to those used by the Service in their Comal and San Marcos habitat and flow requirements study, i.e., use of drop nets and underwater observation.
- Fountain darter numbers and densities by microhabitat type should occur in densities similar to or greater than that described by the Service in the Comal in 1993 and in the San Marcos in 1994 (work in progress: Habitat and Flow Requirements Study for the Comal and San Marcos Systems. The Service's Austin Ecological Services Office).
- Areal coverage of submergent vegetation by species (including filamentous algae, mosses, and higher plants) should be monitored annually (in July or August) and should not be significantly different from the submergent plant community described in 1993 and 1994 as characterized in studies conducted by the Service, TPWD, and cooperators.

The fountain darter will be considered for delisting when the following criteria are met (Service 2019b, pp. 7-8):

Delisting Criterion 1 – The long-term daily average discharge in the Comal River exceeds 225 cubic feet per second (cfs) for 50 years including the drought of record, and the minimum daily average flow is not less than 30 cfs. In the San Marcos River, the long-term daily average discharge exceeds 140 cfs for 50 years including the drought of record, and the minimum daily average flow is not less than 45 cfs. The duration of minimum daily average flows in both rivers must not exceed six months and must be followed by three months of 80 cfs or greater.

Delisting Criterion 2 – The populations are equal to or greater than 500,000 individuals in the both the Comal and San Marcos river systems consecutively for 30 years (based on a Service approved sampling design).

Delisting Criterion 3 – The mean weekly water temperature is less than or equal to 76 degrees Fahrenheit for 50 years. Water temperature will be measured at eight to ten representative sites including sites in Landa Lake, the Comal River Old Channel, the Comal River New Channel, Spring Lake, and downstream of Spring Lake, in 15 minute intervals using U.S. Geological Survey (USGS) NFM protocols and procedures. The specific locations will be developed by the Service with input by local scientists and river managers.

Delisting Criterion 4 – Dissolved oxygen measured as the daily minimum at a height of 15 cm above the river bed in six designated sites (three in Landa Lake and three in Spring Lake) exceeds 4.0 mg/L for 95 percent of the time over 50 years. Additionally, dissolved oxygen as measured above must exceed 2.0 mg/L 100 percent of the time.

Status of Completion:

Downlisting Criterion 1 – **Partially complete.** The Edwards Aquifer Regional Implementation Program Habitat Conservation Plan (EARIP HCP) was finalized in 2012 and covers incidental take of fountain darters and seven other species for groundwater withdrawal, recreation, and other activities through 2028 (EARIP HCP 2012, entire). This HCP includes measures to minimize and mitigate impacts and contribute to the recovery of the fountain darter (EARIP HCP, p. 4-43) and addresses a variety of aquifer management issues, including ensuring spring flow during a repeat of the drought of record (EARIP HCP, pp. 4-52 - 4-55, 4-58-4-62).

The EARIP HCP (2012, pp. 5-18-5-19, 5-26, 5-36, 5-41-5-44) includes measures to monitor water quality, and to minimize and mitigate threats to water quality. The Edwards Aquifer Authority (EAA) has implemented a water quality protection program and the City of San Marcos has added regulations to protect water quality in the recharge zone (EARIP HCP 2012, p. 3-39). Expanded water quality monitoring indicates high water quality in the Comal and San Marcos ecosystems (EAA 2019a, pp. 11, 26). However, the recharge and contributing zones to the Edwards Aquifer continue to experience rapid human population growth and conversion of natural habitat to development, which continue to threaten water quality (see section 2.3.2.1 for more information). Much of the contributing zone also is not under the same regulations to protect water quality (see section 2.3.2.4 for more information on inadequacy of existing regulations).

More information on spring discharge is discussed in Delisting Criterion 1 below. Local water quality is addressed in Downlisting Criterion 3 below. Water temperature and oxygen are addressed in Delisting Criteria 3 and 4 below.

Downlisting Criterion 2 – **Partially complete.** Large numbers of wild caught fountain darters collected from different portions of the San Marcos and Comal rivers are maintained in captivity (Service 2019a, pp. 35-37). The number of fountain darters in captivity should assure a suitable genetic stock is available if a reintroduction can occur quickly. However, it is uncertain whether extended captive breeding without supplementation of wild stock would maintain the genetic diversity in subsequent generations of captive fountain darters. Extended periods of captive breeding may be necessary if immediate reintroduction cannot occur due to impacted habitat or if multiple reintroductions are necessary to successfully reestablish a wild population. Performing genetic analyses on captively bred darters would provide information on whether genetic diversity in the captive population is maintained in successive filial generations and could inform a population management plan. New research indicates that the Comal and San Marcos populations are not genetically distinct populations and it is unnecessary to maintain a Comal stock to ensure that sufficient genetic stock is available for reintroduction (see section 2.3.1.3 for more information on genetics). In addition, a disease, which may be largemouth bass virus but has atypical symptoms for the virus, is currently preventing successful collection of new Comal stock from being collected (Service 2019a, p. 37; see section 2.3.2.3 for more information on disease). If similar disease issues were to occur in the San Marcos stock, this could prevent meeting the goals for the captive population in the future.

Downlisting Criterion 3 – **Partially complete.** Many measures have been taken to remove and minimize local threats through the EARIP HCP (2012). Note that many measures are ongoing and are contingent on the implementation of the EARIP HCP which is permitted though 2028. Thus, the continuation of the removal and minimization measures depend upon a new or renewed EARIP HCP in 2028.

Nonnative Species

Nonnative species continue to be a threat for fountain darters. However, fountain darter populations were stable from 2000-2015 (Perkins et al. 2018, p.2), which would indicate that the impacts of nonnative species on fountain darters are currently under control. See sections 2.3.1.6 and 2.3.2.3 for updated information on the impacts of nonnative species.

Management of nonnative organisms in the Comal and San Marcos rivers is part of the EARIP HCP. For the Comal River, this includes management of harmful nonnative animals (EARIP HCP 2012, pp. 5-16-5-17, 5-19), and monitoring and management of the trematode *Centrocestus formosanus* (EARIP HCP 2012, p. 5-18). For the San Marcos River, this includes management of nonnative plants (EARIP HCP 2012, pp. 5-27-5-28, 5-37), and harmful nonnative and predator species (EARIP HCP 2012, pp. 5-28-5-29, 5-37). The plan also has measures to reduce nonnative species introductions (EARIP HCP 2012, pp. 5-19, 5-26, 5-37) and to restore native riparian vegetation

(EARIP HCP 2012, pp. 5-18-5-19, 5-41) and native aquatic vegetation (EARIP HCP 2012, pp. 5-12-5-14). Nonnative vegetation decreased from 2000-2015 at most locations in the Comal and San Marcos rivers that are covered by the EARIP HCP, although it remains high in the Old Channel in the Comal River (Perkins et al. 2018, p. 45). The City of New Braunfels also executed a contract with BIO-WEST, Inc., Texas State University, and the U.S. Fish and Wildlife Service San Marcos National Fish Hatchery and Technology Center (SMARC) in 2013 to survey nonnative host species and gill parasites in the Comal River, and to develop a gill parasite monitoring and reduction program if needed. A preliminary study found that removing host snails was an effective method of controlling the densities of gill parasites in the Comal River (Service and BIO-WEST 2011, pp. 5-8). See section 2.3.2.3 for more information on disease and predation by nonnative species.

Recreation

A study conducted by Halff Associates Inc. in 2010 for the EARIP HCP (2012, Appendix L, p. 75) investigated the impacts of recreation. High use areas had erosion along the river banks and litter. Sediment and turbidity caused by recreation could also impact habitat. In the Comal River, paddle boats on Landa Lake negatively impacted fountain darter habitat by impacting vegetation (EARIP HCP 2012, Appendix L, p. 75). Most recreation along the Comal River occurred downstream of the confluence of Old Channel and Landa Lake. The study recommended monitoring of recreation in higher quality habitat in the upper reaches of the Comal River. Recreation in the San Marcos River also negatively impacted vegetation (EARIP HCP 2012, Appendix L, pp. 62, 77-79), and thus negatively impacted fountain darter habitat. Fountain darters reproduce by adhering eggs to aquatic plants (Phillips et al. 2011a, entire). Impacts to vegetation that supports fountain darter eggs could affect breeding success. The restriction of recreational use in Spring Lake likely lessens the impacts of recreation on fountain darter habitat in Spring Lake.

The EARIP HCP (2012) includes several measures to minimize impacts of recreation by the City of New Braunfels (EARIP HCP 2012, pp. 5-14-5-16), City of San Marcos (EARIP HCP 2012, pp. 5-23-5-27), and Texas State University-San Marcos (formerly Southwest Texas State University; EARIP HCP 2012, pp. 5-29 5-33, 5-37). These measures limit recreation in some of the higher quality habitat in Spring Lake and Landa Lake, improve bank stabilization and decrease bank erosion, manage aquatic vegetation, reduce turbidity and sedimentation, and seek to educate river users. Recreation continues to cause some vegetation disturbance in both rivers and contributes to seasonal variation in vegetation cover (BIO-WEST 2019a, p. 25, 26, 30; BIO-WEST 2019b, pp. vi, 17, 20, 21, 27, 30).

To promote conservation of listed species and minimize the impacts of recreational activities on such species and their habitats, Texas Parks and Wildlife Department (TPWD) designated a State Scientific Area encompassing a 3.2 km (2 mi) segment of the San Marcos River effective July 8, 2012 [Texas Administrative Code (TAC) Title 31, Part 2, Chapter 57, Subchapter K, Section 57.910]. This designation includes habitat utilized by the fountain darter. This newly enacted regulation may provide some conservation value to the species by limiting impacts from recreation during periods of low flow in the San Marcos River. A State Scientific Area will also be established in the Comal River (EARIP HCP 2012, pp. 5-14, 5-41).

Habitat alteration

Measures to minimize and reduce habitat alteration due to recreation and nonnative organisms is discussed above. Dams have allowed sediment to accumulate in both the San Marcos and Comal rivers. The City of San Marcos will remove sediment during low flow periods (EARIP HCP 2012, pp. 5-26-5-27, 5-33, 5-35). Repair of culverts and valves that control flow into the Old Channel and New Channel of the Comal River occurred in 2014 as part of the EARIP HCP (2012, pp. 5-10 to 5-12). These repairs should reduce scouring and protect and restore native vegetation. In addition to measures that minimize impacts of habitat alteration, the EARIP HCP includes several measures for habitat restoration, which has been ongoing (EARIP HCP 2012, pp. 5-12-5-14, 5-18-5-19, 5-41). Although habitat restoration itself can impact darters by causing changes to water quality and native substrates, as well as loss of breeding substrates, these effects are short-term (Service 2012, p. 115). Overall habitat restoration should enhance habitat suitability by restoring native vegetation types that support fountain darter breeding, feeding, and sheltering activities.

The San Marcos City Council voted to remove Cape's Dam in the San Marcos River in 2016, which was projected to improve fountain darter habitat (Hardy and Raphelt 2015, entire). However, the City of San Marcos Historic Preservation Commission voted to recommend designating the dam as a historical landmark, which was then voted against by the San Marcos Planning and Zoning Commission in 2018 (City of San Marcos 2018, pp. 2-3). Currently, the City of San Marcos is partnering with Hays County to either remove or repair the dam.

Local water quality problems

Notable measures have been taken to minimize local water quality problems. The cities of San Marcos and New Braunfels maintain a hazardous household waste program (EARIP HCP 2012, p.5-43). The City of San Marcos permits septic systems to prevent subsurface pollutants being introduced into the spring ecosystem (EARIP HCP 2012, p. 5-42). Golf courses are covered under the EARIP HCP and both cities have also developed golf course management plans that include Integrated Pest Management Plans and reduce impacts to covered species, including fountain darters (EARIP HCP (2012, pp. 5-19-5-20, 5-36). The EAA has collected water quality data since 1968 and continues to do so as part of the EARIP HCP (2012, pp. 5-41 to 5-42) expanded water quality monitoring program to include stormwater runoff and additional surface and groundwater monitoring around Landa Lake and the Comal River, and Spring Lake and the San Marcos River. Water quality reports and expanded water quality reports are provided annually by the EAA and generally indicate good water quality in the San Antonio segment of the aquifer and in the areas of the San Marcos and Comal rivers where fountain darters occur (EAA 2019a, p. 12; EAA 2019b, pp. 2, 10).

Significantly, coal tar sealants, which contribute to polycyclic aromatic hydrocarbons (PAHs) in stormwater runoff (Mahler et al. 2012, entire), were banned by the EAA in 2012 in the recharge zone of the San Marcos and Comal spring ecosystems (EAA rule §713.703). The City of San Marcos also passed a coal tar ban in 2016 which protects additional fountain darter habitat in the San Marcos River from surface water runoff with high levels of PAHs. Downstream habitat outside of boundaries of the EAA regulated area in the Comal River could still be impacted by coal tar sealants, although the EAA intends to work with local government to encourage bans on coal tar sealants (EARIP HCP 2012, pp. 5-43-5-44). As part of expanded water quality monitoring, fish tissues were analyzed from the Comal and San Marcos rivers to detect the presence of several pollutants that could bioaccumulate (EAA 2019a, p. 2, 5). No PAHs were detected in the fish tissues (EAA 2019a, p. 27). The following chemicals exceeded the 12 meals/month EPA cancer health endpoint fish consumption value: arsenic in largemouth bass from Spring Lake and lower San Marcos River, arsenic in *Gambusia* from Spring Lake (EAA 2019a, p. 28), polychlorinated biphenyl in largemouth bass from Spring Lake and the lower San Marcos River, and *Gambusia* from the lower San Marcos River (EAA 2019a, p. 27).

Both municipalities have developed stormwater management plans. The City of New Braunfels established a stormwater management plan in 2014 (Lockwood, Andrews & Newman, Inc. 2014, entire), and is also developing a Watershed Protection Plan along with the EAA, the Guadalupe Blanco River Authority, and stakeholders to decrease bacteria in the Comal River. The City of San Marcos completed its Stormwater Master Plan in 2018 (Lockwood, Andrews & Newman, Inc and Halff Associates 2018, entire). Both cities also have hotlines to report spills or other water quality concerns.

This section does not focus on systemwide water quality. Refer to Downlisting Criterion 1 for a discussion of water quality, Delisting Criterion 1 for a discussion of adequate flow, Delisting Criterion 3 for water temperature, and Delisting Criterion 4 for dissolved oxygen.

Downlisting Criterion 4 – **Partially complete.** Annual monitoring reports of fountain darters and submergent vegetation are conducted annually with approved methodology for the EARIP HCP (2012, p. 6-4) and use drop nets and underwater observation. Note that the Habitat and Flow Requirements Study associated with this criterion was not completed; thus densities reported by TPWD and funded in part by the Service (Linam 1993, p. 11; Linam et al. 1993, p. 346) are being used for comparison for the Comal River and are below for reference. A study examining fountain darter density from 2000-2007 found higher densities in all vegetation types than were reported by previous studies (BIO-WEST 2007, p. 35). These higher densities are used to determine the goals for fountain darter densities used in the EARIP HCP (2012, pp. 4-10, 4-30) and have been met in all vegetation types except for bryophytes (Perkins et al. 2018, p. 111). Habitat conditions prior to the recovery plan may not have been optimal, although it is possible that differences in sampling locations may also contribute to these differences. Linam (1993, p. 12) found that the density of fountain darters varied by section of the San Marcos River. A comparison of fountain darter densities is in Tables 1 and 2.

Vegetation was described for the Comal River in the summer of 1990 by Linam et al. (1993, p. 345). Vegetation estimates for this time period differ from the habitat goals in the EARIP HCP (BIO-WEST and Watershed Systems Group 2016a, p. 67), which were based on the EAA variable flow study (BIO-WEST 2007) and modified in 2016. The modifications in 2016 were due to flooding that scoured vegetation in some areas, removal of nonnative species from habitat goals, and the feasibility of the goals in some areas (BIO-WEST and Watershed Systems Group 2016a, entire). The methodologies for each of these is also different, and thus not directly comparable. Linam et al. (1993, p. 342-344) sampled quadrats (i.e., cells) of vegetation that totaled 161,322 square meters (m^2) [1,736,456 square feet (ft^2)] Linam sampled cross-channel transects that were placed at 200 meter (m) intervals starting from Landa Lake, New Channel, and Old Channel. There was not sampling below Torrey Dam due to observations of poor fountain darter habitat. At each transect, two rows of 100 m^2 (1,076 ft^2) cells were stretched across the water, and vegetation type was identified in each cell. A calculation was then made to extrapolate the area represented by each vegetation throughout the river system. The San Marcos River was not sampled for amount of vegetation coverage.

Monitoring for the EARIP HCP comprehensively evaluates areal vegetation coverage in specific reaches of the rivers (BIO-WEST 2019a, p. 5; BIO-WEST 2019b, p. 6). In the Comal River, reaches include a subsection of Landa Lake, Old Channel, New Channel, Upper Spring run, and downstream near the confluence with the Guadalupe River (BIO-WEST 2007, p. 8). These reaches are approximately 45,400 m^2 (488,682 ft^2, K. Kollaus personal communication). In the San Marcos River, reaches included areas near the Spring Lake Dam, City Park, and north of I-35 (EARIP HCP 2012, p. 4-25). These reaches are approximately 17,100 m^2 (184,063 ft^2, K. Kollaus personal communication). Vegetation sampling has occurred annually since 2000 (BIO-WEST 2007, p. 13) and excludes vegetation stands of less than 0.5 m^2. A comparison of vegetation goals for each study is in Table 3.

Table 1. Comparison of goals for densities of fountain darters (number per m^2) by vegetation type in the Comal River. Data is from 1990 (Linam et al. 2013) and the EARIP HCP (BIO-WEST and Watershed Systems Group 2016a).

Vegetation	1990 Observed*	Goal EARIP HCP*
Bryophyta	–	20
Cabomba	1.44	7
Ceratopteris†	0.54	–
Chara sp.	2.15	–
Filamentous Algae	4.99	–
Justicia americana	0.18	–
Ludwigia sp.	0.88	7
Ludwigia sp./filamentous algae	1.74	–
Potamogeton	0	3.3
Sagittaria	–	1
Vallisneria	0.21	1
No vegetation	0.26	–

* Vegetation type (–) not reported by study
† Nonnative species

Table 2. Comparison of goals for densities of fountain darters (number per m^2) by vegetation type in the San Marcos River. Data is from 1990 (Linam 1993) and the EARIP HCP (BIO-WEST and Watershed Systems Group 2016b).

Vegetation	1990 Observed*	Goal EARIP HCP*
Cabomba	–	7
Egeria	0.66	–
Hydrilla veticillata†	0.6	–
Hydrocotyle	–	4
Ludwigia sp.	0.95	7
Potamogeton	0.35	5
Rhizoclonium	8.61	–
Sagittaria	–	1
Vallisneria	0.15	–
Zizania	0	5
No vegetation	0.1	–

* Vegetation type (–) not reported by study
† Nonnative species

Table 3. Comparison of goals for vegetation types for fountain darters (number of m^2). For Linam et al. (1993), the vegetation estimate includes vegetation where fountain darters were and were not found in quadrats. The EARIP HCP estimates are aerial coverage and did not evaluate the presence of fountain darters in all of the vegetation identified. Methodologies varied across study and are not directly comparable. The area surveyed in 1990 by Linam et al. (1993) is larger and more even across the river. The area surveyed by the EARIP HCP (BIO-WEST and Watershed Systems Group 2016a, b) is smaller and comprehensively samples representative reaches. See the text below for more information.

Vegetation	**1990 Observed Comal***	**EARIP HCP Goal Comal***	**EARIP HCP Goal San Marcos***
Bryophyta	1,027	6,400	–
Cabomba	20,602	3,205	190
Ceratopteris†	431	–	–
Chara sp.	1,565	–	–
Egeria	9	–	–
Filamentous Algae	16,389	–	–
Hydrilla veticillata†	19	–	–
Hydrocotyle	–	–	110
Justicia americana	2,258	–	–
Ludwigia sp.	33,636	1,450	300
Ludwigia sp./filamentous algae	2,171	–	–
Nuphar luteum	1,257	–	–
Potamogeton	2,800	25	1,900
Sagittaria	18	3,550	650
Vallisneria	25,328	12,500	–
Zizania	–	–	3,050
No vegetation	53,573	–	–
Total area surveyed	161,322	45,422	17,144

* Vegetation type (–) not reported by study

† Nonnative species

In spite of methodological differences, there is some evidence of vegetation changes over time. For example, in 1990, *Cabomba* accounted for 20% of the estimated area in Landa Lake (Linam et al. 1993, p. 345), but was only 2.5% in the representative reach goal within Landa Lake for the EARIP HCP (BIO-WEST and Watershed Systems Group 2016a, p. 67). It is possible that there higher numbers of *Cabomba* occur in areas of Landa Lake outside of the representive reach. *Sagittaria* was not found in Landa Lake in 1990 (Linam et al. 1993, p. 345), but accounted for approximately 10% of the vegetation goal for Landa Lake in the EARIP HCP (BIO-WEST and Watershed Systems Group 2016a, p. 67). Historical flooding occurred in the San Marcos River in 2015 and scoured large amounts of aquatic vegetation (BIO-WEST 2016b, pp. vi, 48). Current vegetation is discussed below in section 2.3.1.6.

Delisting Criterion 1 – **Not complete.** The minimum daily average flow for the Comal River (USGS Gage 08169000) was below 0.85 cubic meters per second (m^3/s) [30 cubic feet per second (cfs)] during parts of July and August of 1984, with a minimum daily average flow of 0.74 m^3/s (26 cfs) on 7/18/1984 and 7/24/1984. Daily average flow increased above 2.27 m^3/s (80 cfs) in October 1984 and remained above 2.27 m^3/s (80 cfs) until July 1989. The Comal River had a daily average discharge of 8.89 m^3/s (314 cfs) and daily median discharge of 8.78 m^3/s (310 cfs) from 1970-2019. For the San Marcos River (USGS Gauge 08170500), the minimum daily average flow was lowest at 1.81 m^3/s (64 cfs) on 9/18/1984, and was never less than 1.27 m^3/s (45 cfs) during the 50 year time period. From 1970-2019, the daily average discharge was 5.15 m^3/s (182 cfs) and daily median discharge was 4.81 m^3/s (170 cfs). There has not been a repeat of the drought of record.

The primary means of insuring water flow is through the Edwards Aquifer Recovery Implementation Program Habitat Conservation Plan (EARIP HCP 2012). During the 2008-2009 drought, spring flows remained above 2.27 m^3/s (80 cfs) in the Comal and San Marcos rivers (USGS Gauges 08169000 and 08170500) even though flows decreased to near the drought of record level of 0.31 m^3/s (11 cfs) for the Barton Springs segment of the aquifer [0.37 m^3/s (13 cfs) on 9/4/2009, USGS Gauge 08155500]. The EARIP HCP (2012, p. 4-56) anticipates that its flow-related measures will achieve a long-term daily average of 5.55 m^3/s (196 cfs) at Comal Springs, not the 6.37 m^3/s (225 cfs) in this criterion. For both Comal and San Marcos springs, the EARIP HCP also projects that the management objective of three months of 2.27 m^3/s (80 cfs) or greater will not be achieved following lower flow periods (EARIP HCP 2012, pp. 4-54 ,4-61). An adjustment to the EAA Voluntary Irrigation Suspension Program Option in 2019 should ensure that Comal Springs maintains at least 0.85 m^3/s (30 cfs) daily average minimum during a drought of record (Blanton & Associates, pp. viii, 34, 48).

Another consideration is future climate. The flow models for Comal and San Marcos springs do not consider climate change, such as droughts that could surpass the drought of record. Climate downscaling for San Antonio projects an increase in extreme weather events (Sharif 2018, pp. 10-12). A recent study predicts megadroughts in Texas more severe than have been seen for the past thousand years, and that these will occur before 2100 (Nielsen-Gammon et al. 2020, entire). Droughts worse than the drought of record occurred as recently has the 1600s and are not uncommon in the region (EARIP HCP 2012, p. 3-13). 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.

Delisting Criterion 2 – **Not complete.** Fountain darter population estimates from 1993 were 168,078 with a confidence interval of 114,178 to 254,100 for the Comal River (Linam et al. 1993, pp. 341, 345). The San Marcos River was estimated to be 45,900 with a confidence interval of 15,900 to 107,700 (Linam 1993, p. 4), but did not include Spring Lake. The number of darters from 2002-2010 was estimated to vary from 58,562 to 471,315 in the San Marcos River, excluding Spring Lake (EARIP HCP 2012, p. 4-127). Population estimates including Spring Lake would likely be much higher (EARIP HCP 2012, p. 3-58). Spring Lake is not sampled by drop netting, but dip net and benthic transects indicate high abundance of darters there (BIO-WEST 2019b, p. 33). Data from the EAA indicates that darter abundance was stable from 2000-2015, though declined slightly in the San Marcos from 2006-2015 (Perkins et al. 2018, p. 2). The population estimates of fountain darters in the Comal River in representative reaches were 32,829-147,358 (EARIP HCP, p. 4-76-4-77). Population estimates for the entire Comal River would be higher but were not calculated.

During a drought of record, the EARIP HCP modeled a significant reduction in the number of fountain darters, with approximately 40,000 remaining in the Comal system (EARIP HCP 2012, p. 4-84) and 30,000 remaining in the San Marcos River (EARIP HCP 2012, p. 4-128).

It is difficult to convert monitoring data to population estimates as indicated by the large confidence intervals in some studies (EARIP HCP 2012, p. 3-58). While a rough estimate can be calculated using existing monitoring data and was done for the EARIP HCP (2012 pp. 4-83, 4-127), extrapolating a population wide estimate based on a few representative areas assumes that fountain darter density is the same throughout each river. Monitoring data indicates that habitat quality and reproduction is higher upstream than downstream (see sections 2.3.1.1 and 2.3.1.2 for more information). Additional data is also needed to assess the capture probability of fountain darters for the methods used. Thus, recent data does not exist to accurately evaluate this criterion.

Delisting Criterion 3 – **Not complete.** Continuous temperature monitoring has not occurred for 50 years at eight to ten representative sites. The EAA and BIO-WEST have monitored temperature since 2000. During this time period, temperatures have exceeded 24°Celsius (°C) [76°Fahrenheit (°F)] in the Comal River at Lower Landa Lake, Old Channel and New Channel. USGS monitoring data for the Comal River (Station 08169000) from 1996 indicates that New Channel exceeded 24 °C (76 °F) in July 1996, with the average weekly temperature reaching 25.8 °C (78.5 °F). The temperature also exceeded 24 °C (76 °F) in the San Marcos River, although this was further downstream than the critical habitat (EAA and BIO-WEST monitoring data).

Delisting Criterion 4 – **Not complete.** Daily dissolved oxygen monitoring has not occurred for 50 years at six representative sites. The EAA and BIO-WEST have monitored dissolved oxygen since 2013 at five sites and added four additional sites from 2016-2018. At Rio Vista, dissolved oxygen fell to 1.92 milligrams per liter (mg/L) [1.60 x 10^{-5} pounds per gallon (lb/gal)] on 7/27/2016, but otherwise recorded dissolved oxygen met this criteria during this timeframe (EAA and BIO-WEST monitoring data). All sites exceeded 4.0 mg/L (3.3 x 10^{-5} lb/gal) for over 99 percent of the time.

2.3 Updated Information and Current Species Status

2.3.1 Biology and Habitat

2.3.1.1 New information on the species' biology and life history:

A full description of the fountain darter's biology and life history information was provided in the 1996 Recovery Plan (Service 1996, pp. 30-36). Since the revised recovery plan was finalized in 1996, a few studies have generated new information on the species' biology and life history. They are summarized below.

Data collected during a variable flow study suggests that fountain darter reproduction may be tied to habitat quality (BIO-WEST 2007, pp. 35-37). Data on fountain darter size from several sample reaches suggest year-round reproduction in areas of high-quality habitat in both the Comal and San Marcos systems near Landa Lake and Spring Lake, and a strong spring peak in reproduction (with limited reproduction in summer and fall of most years) in areas of lower quality habitat farther downstream.

Phillips et al. (2011a, entire) examined egg deposition in seven probable microhabitat types in the San Marcos River (*Rhizoclonium*, *Potamogeton illinoensis*, waterthyme, *Hydrilla verticillata*, *Ludwigia repens*, *Sagittaria platyphylla*, and endangered *Zizania texana*) and in laboratory trials with six artificial habitats. In the wild, significantly more eggs were found on filamentous algae *Rhizoclonium* with *L. repens*, *S. platyphylla*, *and Z. texana* also supporting eggs. Phillips et al. (2011a, pp. 1392, 1394, 1396) also noted more eggs were deposited on plants growing in sand than silt substrate.

Several laboratory studies have investigated the impacts of water temperature on darter reproduction (Brandt et al. 1993; Bonner et al. 1998; McDonald et al. 2007). The most recent work determined that reproduction is negatively impacted above 24 °C (75.2 °F), with almost no reproduction above 26 °C (78.8 °F, McDonald et al. 2007, pp. 311, 314-316).

The diet of fountain darters was examined by dissecting fish from five areas of the Comal River (Bergin 1996, entire). The taxa found in more than 10% of gut contents included Copepoda, Cladocera, Amphipoda, Diptera, Ephemeroptera, and Ostracoda (Bergin 1996, p. 9). Diet also varied with fountain darter size; Copepoda and Cladocera were more consumed by small darters, Ephemeroptera and Diptera by intermediate size darters, and Amphipoda by large darters

(Bergin 1996, pp. 8, 10). Laboratory studies investigating the impact of turbidity on fountain darters found that turbid water negatively impacts foraging behavior (Swanbrow Becker et al. 2016, entire).

2.3.1.2 Abundance, population trends (e.g., increasing, decreasing, stable), demographic features (e.g., age structure, sex ratio, family size, birth rate, age at mortality, mortality rate, etc.), or demographic trends:

Most recent work on population trends for fountain darters has been performed by BIO-WEST, which has surveyed for fountain darters since 2000 (Perkins et al. 2018, pp. 58-86). The number of darters from 2002-2010 was estimated to be 58,562 to 471,315 in the San Marcos River, excluding Spring Lake (EARIP HCP 2012, p. 4-127). Population estimates including Spring Lake would likely be much higher (EARIP HCP 2012, p. 3-58). Spring Lake is not sampled by drop netting, but dip net and benthic transects indicate high abundance of darters there (BIO-WEST 2019b, p. 33). The population estimates of fountain darters in the Comal River in representative reaches were 32,829-147,358 (EARIP HCP 2012, pp. 4-76-4-77). Population estimates for the entire Comal River would be higher, but were not calculated. Estimating the population size of fountain darters is difficult and often results in large confidence intervals (EARIP HCP 2012, pp. 3-57-3-58). Different sampling methods have also been used in different studies that may prevent direct comparison of population estimates.

Annual biological reports for the EARIP HCP do not estimate the population size of fountain darters. Instead, the density of fountain darters by vegetation type is reported (see section 2.2.3, Downlisting Criterion 4), as well as the normalized population to determine whether fountain darter abundance is increasing or decreasing. Abundances from drop nets were stable in both the San Marcos and Comal rivers from 2000-2015, though dip net data showed a slight decrease in abundance in the San Marcos system (Perkins et al. 2018, p. 2). An evaluation of data from 2000-2015 found the most important predictors of variation in fountain darter abundance were dominant vegetation, site location, water depth, and year (Perkins et al. 2018, pp. 58-59, 63-64). These effects predicted more variation in the Comal River than in the San Marcos River, although less than half of the variance in fountain darter abundance was explained by these variables at all sites. Visual observations found that darter density was positively correlated to the percent of vegetation cover in Landa Lake (Perkins et al. 2018, p. 86). This report also found that the proportion of juveniles decreases downstream in both the Comal and San Marcos spring systems (Perkins et al. 2018, pp. 73-85). Small fountain darters are also more abundant in the spring than in the fall in both ecosystems (BIO-WEST 2019a, pp. 33, 35; BIO-WEST 2019b, p. 33, 37)

More recent data found that the spring and fall 2019 normalized population estimates for fountain darters for both Comal and San Marcos springs was within one standard deviation from the mean of the normalized population estimate for 2000-2019 (BIO-WEST 2019a, p. 33; BIO-WEST 2019b, p. 35).

For the San Marcos River, the normalized population estimate incorporates an increase in Texas wild rice, which typically has a low density of fountain darters (BIO-WEST 2019b, pp. 34-35). The average of the normalized population estimate was lower than the long-term average in the San Marcos ecosystem (BIO-WEST 2019b, p. 35), and higher than the long-term average in the Comal ecosystem (BIO-WEST 2019a, p. 33).

Population modeling in the EARIP HCP projects that population size will decrease when spring flow decreases below 150 cfs in the San Marcos and Comal ecosystems (EARIP HCP 2012, pp. 4-77, 4-78, 4-122, 4-123). The EARIP HCP modeled the average fountain darter abundance to be highest at moderate spring flows in the San Marcos ecosystem (EARIP HCP 2012, pp. 4-125, 4-127). A scouring effect is expected in the San Marco ecosystem above 245 cfs that negatively impacts vegetation (EARIP HCP 2012, pp. 4-117, 4-118). Average fountain darter abundance was modeled to be highest at high spring flows in the Comal ecosystem (EARIP HCP 2012, pp. 4-82, 4-83). Modeling by the EARIP HCP accounted for variation in habitat quality in the spring systems at different flows based on estimates from the EAA Variable flow study (EARIP HCP 2012, pp. 4-69-4-73, pp. 4-116-4-121). Another study modeled effects of low flow on fountain darter populations and did not project negative impacts to fountain darter population dynamics until spring flows were below 98 cfs (Mora et al. 2013, p. 242). While this study did incorporate some impacts to habitat quality, it was not the same extent considered in the EARIP HCP.

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

In the 1950s, fountain darters were extirpated from the Comal River system (Service 1996, p. 32). From February 1975 through March 1976, 457 fountain darters collected from the San Marcos River were released into the headsprings area of the Comal River and into the old channel area that flows through the golf course (Schenck and Whiteside 1976, p. 700).

Olsen et al. (2016, entire) conducted genetic analyses on fountain darters to describe genetic population structure, assess if barriers like low-head dams impede gene flow, and determine if the reintroduction was sufficiently large to maintain genetic diversity. They found that the Comal population is descendent of the San Marcos population and that it may be sufficient to only use the San Marcos population for the captive refugia (Olsen et al. 2016, p. 1,403). There was not a clear result on the impact of dams on fountain darter genetics (Olsen et al. 2016, pp. 1,393, 1,398, 1,399). Finally, they determined that the 457 San Marcos River fish appear to have been insufficient to maintain the full array of genetic diversity present in the San Marcos River (Olsen et al. 2016, p. 1,403). A report using the same data recommended increasing the refugia population size to 1,000 individuals (Phillips et al. 2011b, p. 10). However, the analyses in Olsen et al. (2016) indicate the Comal fountain darter population was founded by approximately 49 darters, much lower than the 457 reintroduced (Olsen et al. 2016., pp. 1,393, 1,399, 1,403). Researching methods to increase the survival and reproduction of reintroduced fountain darters may allow fewer fish to be reintroduced while maintaining genetic diversity. No genetic analysis has been performed to assess how many individuals are needed to capture the genetic diversity of the wild population.

2.3.1.4 Taxonomic classification or changes in nomenclature:

There are no changes to this species taxonomic classification or changes to its nomenclature.

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

There is no new information on this species spatial distribution, trends in spatial distribution, historic range or distribution of the species within its historic range.

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

Fountain darters are more abundant in slower-moving areas of water. The presence of silt is an indicator of poor or less-preferred habitat (Phillips et al. 2011a, pp. 1,392, 1,396). Velocity was highest in areas with gravel substrate and lowest in areas with sand substrate (Phillips et al. 2011a, p.1,396). More eggs were found in areas with low velocity (Phillips et al. 2011a, p. 1,396).

It is important for fountain darters to have vegetated areas with dense cover close to the substrate to provide food, reproductive habitat, and refugia (EARIP HCP 2012, pp. 3-56-3-57). Fountain darter densities are generally lower in the San Marcos ecosystem than in the Comal ecosystem, likely due to the different vegetation densities within each system (BIO-WEST 2018, p. 33). Downlisting Criterion 4 and Table 1 discussed darter densities by vegetation type.

Alexander and Phillips (2012, entire) examined six habitats used by fountain darters in the San Marcos River: filamentous alga (*Rhizoclonium*), four native macrophytes (*Ludwigia repens*, *Potamogeton illinoensis*, S*agittaria platyphylla*, and *Zizania texana*, which is federally listed as endangered), and the exotic macrophyte *Hydrilla verticillata*. While fountain darters were found in all six habitats, *Rhizoclonium, Ludwigia repens,* and *Hydrilla verticillata* had the greatest densities of fountain darters (Alexander and Phillips 2012, p. 451). Note that fountain darter densities were not reported in the study. Alexander and Phillips (2012, p. 451) also noted size differences among the different habitats. For example, the smallest darters were in *Rhizoclonium* and the largest were in *Potamogeton illinoensis.* They deduced this was likely due to differences in current velocity among the different habitats.

Prey type also varies with vegetation. Native *Cabomba* contain the most fountain darter prey items (amphipods, true flies, mayflies, caddisflies, BIO-WEST 2019b, p. 32). While fountain darters were present at high densities in *H. verticillata* in the San Marcos River (Table 1), fountain darters eggs were not found on *H. verticillata* and this vegetation was used less than other vegetation types in a laboratory study (Phillips et al. 2011a, pp. 1,395-1,396).

While fountain darters can move between patches of vegetation, they appear to be highly resident fish and were documented moving a maximum of 95 m [312 feet (ft)] over a 26 day period in the Comal River, although only 7% of fish were observed moving greater than 35 m (115 ft, Dammeyer et al. 2013, pp. 1049, 1052, 1055). Site fidelity was higher in areas of low growing aquatic vegetation, such as algae or *Riccia fluitans* (a bryophyte, Danmeyer et al. 2013, pp. 1,052, 1,054). Fish were also more likely to move upstream (Danmeyer et al. 2013, pp. 1,053, 1,054) and toward areas of low growing aquatic vegetation (Danmeyer et al. 2013, pp. 1,052, 1,054).

Vegetation can be affected by spring flow, competition with nonnative aquatic plants, and predation by nonnative animals. The giant Ramshorn snail, a nonnative species that grazes on aquatic vegetation and thus can impact fountain darter habitat, has declined since the mid-1990s (EARIP HCP 2012, p-17). Texas wild rice, another endangered species endemic to the San Marcos River, is poor habitat for the fountain darter and has increased as a result of habitat restoration goals (EARIP HCP 2012, p. 4-16). However, vegetation goals should ensure suitable habitat for fountain darters for different parts of the San Marcos and Comal ecosystems if they are met (EARIP HCP 2012, pp. 4-4, 4-26).

The Comal River had abundant and stable vegetation in 2019, which contributed to good quality habitat for fountain darters (BIO-WEST 2019a, p. vii). The Upper Spring run was dominated by *Sagittaria* and had approximately double the coverage area as the biological goal, though other aquatic species were lower than the biological goal (BIO-WEST 2019a, p. 26). Landa Lake was dominated by *Vallisneria* followed by *Sagittaria*, and both were at or above the biological goal in the EARIP HCP, while other aquatic species were below it (BIO-WEST 2019a, p. 27). Old Channel vegetation was lower than the total coverage goals, though *Ludwigia* and *Hygrophila* were above the biological goal (BIO-WEST 2019a, p. 29). The Upper New Channel was dominated by *Hygrophila* followed by bryophytes and *Ludwigia* (BIO-WEST 2019a, p. 30). The Lower New Channel was dominated by *Cabomba* and *Hygrophila* and (BIO-WEST 2019a, p. 30) and together with the Upper New Channel meet the biological goals. Most areas had vegetation coverage that was close to the average of previous sampling years. However, the Upper New Channel had much greater than average vegetation, with 1,800 m^2 of vegetation in fall 2019 (BIO-WEST 2019a, p. 29). Since 2000, native vegetation has increased in most sampled reaches of the Comal River due to habitat restoration efforts (Perkins et al. 2018, pp. 42, 45).

Vegetation in the San Marcos River varied with pulse flows and seasonal disturbance due to recreation (BIO-WEST 2019b, p. vi). Increases in Texas wild rice resulted in a recalculation of normalized population estimates for fountain darter. Texas wild rice has not previously been sampled for fountain darters using drop nets, but it will be beginning in 2020 to refine the fountain darter population analysis (BIO-WEST 2019b, p. vi). Texas wild rice dominated vegetation at all three reaches sampled in the San Marcos River (BIO-WEST 2019b, pp. 19-22). Vegetation coverage was higher than average in the Spring Lake dam area due to the increase in wild rice (BIO-WEST 2019b, p. 19). The overall vegetation coverage in the City Park reach was not significantly different than average, although the increase in Texas wild rice in this area likely decreased the coverage of other species (BIO-WEST 2019b, p. 20). Nonnative *Hydrilla* also was not present in either of these areas as a result of habitat restoration activities (BIO-WEST 2019b, pp. 19-20). Vegetation coverage was also higher in the I-35 area than the historical average (BIO-WEST 2019b, p. 22). Recent floods and recreation in the San Marcos River have impacted vegetation in these reaches (BIO-WEST 2019b, pp. 17-21). Vegetation goals discussed in section 2.2.3 Delisting Criterion 1 are anticipated to be met by 2027 (BIO-WEST and Watershed Systems Group 2016b, p. 13).

2.3.1.7 Other

A summary of information on the Edwards Aquifer and springs in the San Antonio segment is provided in the EARIP HCP (2012, pp. 3-24 to 3-55). Several studies have further investigated the flow paths of water in the San Antonio segment of the Edwards Aquifer, which includes Comal and San Marcos springs. The EAA also is investigating the interconnectivity and groundwater flow between the Edwards and Trinity aquifers. Dye trace studies in northern Bexar County indicate a strong connection between the Trinity and Edwards aquifers (EARIP HCP 2012, p. 3-38). This information is relevant to conservation of the Comal and San Marcos ecosystems because the Trinity Aquifer does not have the same restrictions on groundwater withdrawals as the Edwards Aquifer.

Information about the groundwater flow paths is also important for accurately modeling spring flow. The groundwater divide between the San Antonio and Barton Springs segments of the Edwards Aquifer is dynamic, shifting based on the amount groundwater, which affects the hydraulic head at Onion Creek and the Blanco River (Smith et al. 2012, entire). During dry conditions, the groundwater divide moves south to the Blanco River, causing groundwater near San Marcos Springs to flow north (Smith et al. 2012, pp. 62-63). A USGS study investigating the source of water at San Marcos Springs determined that it was dominated by regional recharge, rather than local surface-water sources (Musgrove and Crow 2012, p. 2). Blanco River recharge contributed to San Marcos Springs discharge 0-28.9 percent during wet conditions (Musgrove and Crow 2012, p. 87).

Water in Comal Springs recharges regionally, primarily from Bexar and Medina counties, as well as locally in Comal County (EARIP HCP 2012, pp. 3-26, 3-27). Dye trace studies by EAA found that the flow path varies by spring orifice at Comal Springs, with some having more regional flow paths and others having larger contributions from localized, shallow flow paths.

2.3.1.8 Conservation Measures

The EARIP HCP includes measures to minimize and mitigate impacts to fountain darters from the covered activities such as groundwater pumping, which include monitoring and protection of water quality and quantity (also discussed above under the downlisting and delisting criteria), nonnative plant and animal removal, aquatic vegetation restoration and management, bank stabilization, and management of recreation (EARIP HCP 2012, summary p. 4-43). A captive refugia is funded by the EARIP HCP and maintained by the Service at facilities in San Marcos and Uvalde (EARIP HCP 2012, p. 5-3). Adaptive management is proposed to maintain adequate water temperature and aquatic vegetation, as well as determine the impacts of parasites, predators, nonnative species, and low flow on fountain darters (EARIP HCP 2012, summary pp. 6-15-6-17, 6-22-6-24).

2.3.2 Five-Factor Analysis (threats, conservation measures, and regulatory mechanisms)

2.3.2.1 Present or threatened destruction, modification or curtailment of its habitat or range:

The primary threats to fountain darters remain the quality and quantity of aquifer and spring water, including drought conditions and increased groundwater utilization resulting in reductions to or loss of spring flows. Some of the sources of water quality degradation include impervious cover and stormwater runoff, construction activities, wastewater discharge, transportation infrastructure, and hazardous materials spills resulting from development within the watersheds that contribute flows to fountain darter habitats. Water quantity degradation (i.e., reduction in spring flow) is often due to a lack of adequate rainfall; however, increased groundwater pumping can also reduce water quantity. A more detailed description of these threats can be found in the recovery plan (Service 1996, pp. 16-19).

The water quality for the San Marcos and Comal spring ecosystems is dependent on the quality of water recharging the San Antonio segment of the Edwards Aquifer, as well as whether the water becomes contaminated underground. Although water quality in the Edwards Aquifer is generally good, some contaminants have been found in the aquifer and the streams that recharge it (EARIP HCP 2012, p. 4-41). Elevated nitrate levels and metals were detected in several wells sampled by EAA (EARIP HCP 2012, p. 4-41). Septic systems are a likely source of nutrients and septic system registration occurs in San Marcos

(EARIP HCP 2012, p. 5-42). Pesticides have also been detected by the Texas Commission on Environmental Quality (TCEQ) in water wells sampled for the Texas Groundwater Monitoring Program in all of the counties in the recharge and artesian zones for the Comal and San Marcos rivers (TCEQ 2015, p. 1). From 1996-2018, there were 56 groundwater contamination cases in Bexar County (TCEQ 2019, pp. 4-6), 5 in Comal County (TCEQ 2019, p. 11), 10 in Hays County (TCEQ 2019, p. 40), and 1 in Medina County (TCEQ 2019, p. 48). In spite of specific groundwater contamination cases, nonpoint source pollution is the most likely cause of most water quality problems (EARIP HCP 2012, p. 5-43).

The U.S. Census Bureau (2020b) ranked several of the counties in the recharge and contributing zones of Comal and San Marcos springs among the fastest growing in the United States from April 2010 to July 2019: Hays County was the second fasting growing county with a 46.5% population increase, Comal County the fourth fastest growing county with a 43.9% population increase, and Kendall County the fifth fastest growing county with a 42.1% 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. Bexar county is projected to increase 67% from 2,003,554 in 2019 (U.S. Census Bureau 2020a) to 3,353,060 in 2050 (Texas Demographic Center 2018). Comal County is projected to increase 149% from 156,209 in 2019 (U.S. Census Bureau 2020a) in 389,584 in 2050 (Texas Demographic Center 2018). Hays County is projected to increase 224% from 230,191 in 2019 (U.S. Census Bureau 2020a) to 746,149 in 2050 (Texas Demographic Center 2018). Kendall County is projected to increase 190% from 47,431 in 2019 (U.S. Census Bureau 2020a) to 137,844 in 2050 (Texas Demographic Center 2018). Conversion of natural habitat to urban, suburban, and exurban development is likely to accompany this population growth.

Nowak and Greenfield (2018, pp. 168-171) developed projections for urbanized land growth in the United States from 2010 to 2060. Texas is projected to gain the second highest amount of urbanized land in the country at 3,004,386 hectares (ha)[7,424,000 acres (ac)] over that 50-year period (Nowak and Greenfield 2018, p. 169). Percentage of urbanized land is projected to increase 10.1-25% from 2010-2060 in Hays and Comal Counties (Nowak and Greenfield 2018, p. 171). Percentage of urbanized land is projected to increase 25.1-37.7% from 2010-2060 in Bexar County (Nowak and Greenfield 2018, p. 171). Counties in the contributing zone are not projected to have as much growth. Percentage of urbanized land is projected to increase 1.1-5% from 2010-2060 in Kendall, Kerr, and Medina counties, and 0-1% in Bandera County (Nowak and Greenfield 2018, p. 171). Land use changes, particularly increases in impervious cover, are known stressors to aquatic systems (Coles et al. 2012, p. 65).

The Edwards Aquifer Protection Program by the City of San Antonio and EAA has protected 61,819 ha (152,759 ac) of land over the Edwards Aquifer (Reilly and Carter 2018, p. 3-7). In September 2020, the San Antonio City Council passed an ordinance to authorize the continuation of the program with $100 million funding commitment for the next 10 years (City of San Antonio Ordinance No. 2020-09-17-0647). The Nature Conservancy has also conserved approximately 120,000 ac of land over the Edwards Aquifer.

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 2012, p. 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 (TAC, Title 30, Part 1, Chapter 213). For the contributing zone, the rule covers activities that disturb more than two ha (five ac) in Medina, Bexar, Comal, Kinney, Uvalde, Hays, Travis, and Williamson counties (TAC, Title 30, Part 1, Chapter 213, Subchapter B). The contributing zone in Bandera, Kerr, and Kendall counties does not have additional protections under either program.

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 is not subject to guidance mitigating impacts to karst features such as voids, and development of these pipelines is not subject to the Edwards Aquifer rules (Texas Natural Resource Conservation Commission 1996, entire).

Spring flow in the Comal and San Marcos ecosystems depends on recharge to the aquifer, which varies with rainfall, as well as the amount of groundwater that is pumped. The EARIP HCP estimated that 76 to 95 percent of the Comal system fountain darter population (losses of 130,000 to 735,000 fountain darters) could be lost during a repeat of drought of record conditions (EARIP HCP 2012, p. 4-84). Similarly, under drought of record conditions, the EARIP HCP estimated the San Marcos River system may have losses of 50,000 to 450,000 fountain darters (EARIP HCP 2012, p. 4-128). Climate models predict that droughts worse than the drought of record are likely to occur in the 21st century (Nielsen-Gammon et al. 2020, entire, see section 2.3.2.5 below for more information on future climate). Using historical records to guide decision making of future climate is not reliable due to changing climate (Sharif 2018, pp. 2-3). A drought worse that the drought of record could reasonably be expected to increase the loss of fountain darters beyond of that expected for the drought of record and may jeopardize the existence of fountain darters in the wild (see section 2.3.2.5 below for information on future climate).

Another threat to fountain darters is modifications made to surface habitat. 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). Historical flooding occurred in the San Marcos River in 2015 and scoured large amounts of aquatic vegetation (BIO-WEST 2016b, p. vi, 48). Darter surveys in spring 2016 were lower than average and may be due to a delayed impact to the population from the 2015 floods (BIOWEST 2016a, p. 40; BIO-WEST 2016b, p. 37). Dams are another habitat modification that disrupts the ability of fountain darters to move upstream (Dammeyer et al. 2013, p. 1055). A study investigating whether barriers like low-head dams impede gene flow was inconclusive on the impacts of dams (Olsen et al. 2016, pp. 1393, 1398, 1399).

2.3.2.2 Overutilization for commercial, recreational, scientific, or educational purposes:

There is no evidence that fountain darters are overutilized. Collections occur for refugia established at the SMARC and Uvalde National Fish Hatchery to serve as a back-up population for the fountain darter from both the San Marcos and Comal springs systems (Service 2019a, p. 7). As of December 2020, there are 13 10(a)1(A) permits issued for fountain darters. Most of these permits are used by environmental consultants and researchers. Most permittees are not authorized to collect from the wild, except for a few voucher specimens. Impacts of recreation are addressed above in section 2.2.3, Downlisting Criterion 3.

2.3.2.3 Disease or predation:

Nonnative parasitic trematodes have been a focus of recent research on fountain darters. *Centrocestus formosanus* transmitted by nonnative snails infect fountain darters and are more likely to kill larval and juvenile fountain darters than adults in the laboratory (McDonald et al. 2006, entire). This could indicate that infected fountain darters are less likely to reach reproductive age. There was not a statistically significant difference in reproduction between darters that were infected with *C. formosanus* and those that were not in the laboratory (McDonald et al. 2007, p. 314). However, this study also assessed different temperature treatments (McDonald et al. 2007, pp. 312-313), and did not test for an interaction between temperature and parasite infection on reproduction, even though reproduction varied with temperature. Another study examined infected fish in the Comal River (Johnson et al. 2012, entire). There was a decrease in the cercariae density of *C. formosanus* from 2006-2010, which may be a natural decline after the initial invasion of this nonnative species (Johnson et al. 2012, pp. 111, 115). This parasite may also vary with the volume of water; it was found in higher concentrations in areas of low velocity and may be diluted by the volume of water (Cantu 2003, pp. 17-19). Thus, these parasites may increase in the environment during low flows and as a result, may also increase the infections in fountain darters. A preliminary study found that removing host snails was an effective method of controlling the densities of gill parasites in the Comal River (Service and BIO-WEST 2011, pp. 5-8).

Another trematode, *Haplorchis pumilio,* was recently determined to infect fountain darters (Huston et al. 2014, entire). It was determined that all 10 fountain darters collected were infected with *Haplorchis pumilio*, although infection intensity was considered low (Huston et al. 2014, p. 192). The authors speculated that the parasite was missed by other researchers due to its small size and atypical location for infection on the fin insertions and caudal peduncle (Huston et al. 2014, p. 189). Targeting large snail removal of *Tarebia granifera* in all areas, and removal of *Melanoides tuberculata* in areas with high densities of detritus and vegetation may be the most effective way to control the trematode infection in the wild (Tolley-Jordan and Chadwick 2019, p. 121).

Comal River fountain darters collected from the wild have had high mortality when brought into captivity since 2017 (Service 2019a, p. 40). Although the cause of the mortality is uncertain, this timeline corresponds with Comal fountain darters testing positive for largemouth bass virus (LMBV). Recently, survival of fountain darters collected from the Comal River was 90% for those that tested negative for LMBV versus 46.1% for those that tested positive (Service 2019a, p. 41). The symptoms exhibited by fish are not consistent with LMBV in other fish species. LMBV typically attacks the swim bladder, which is not present in fountain darters (Service 2018, p. 27). While this has impacted collections for the refugia population, the normalized population estimate of Comal fountain darters in 2019 was not significantly different than the population average for 2000-2019, indicating a stable population in the wild (BIO-WEST 2019a, p.33). Additional work is occurring at the captive refugia to determine the nature of the disease problems (Service 2020, p. 4). A study has been approved to examine whether LMBV can be transferred between fish in captivity. In addition, because it is possible that the polymerase chain reaction (PCR) primers for LMBV may amplify other DNA. DNA sequencing will be used to confirm that the pathogen is LMBV (L. Campbell personal communication).

A novel virus belonging to the *Aquareovirus A* genus was recently described in fountain darters (Iwanowicz et al. 2018, entire). The virus was found in healthy darters and at this time it’s unknown whether the virus is pathogenic and needs further investigation. In other fish species, aquareoviruses can be pathogens, and sometimes are pathogens circumstantially under stressful conditions.

There has been less research on the effects of predation of fountain darters. Foraging by nonnative armored catfish in the genus *Hypostomus* decreased the survival rate of fountain darter eggs from 92% to 23% in experimental aquaria (Cook-Hildreth 2008, pp. 27-28), with survival being higher with algae than without any vegetation. Conditions in natural ecosystems are likely to change these reported survival rates of eggs. Another study examining predation of eggs by native and nonnative snails found that both native and nonnative snails would consume fountain darter eggs in aquaria, with the amount consumed varying substantially by species (Phillips et al. 2010). The nonnative freshwater snail, *Marisa cornuarietis* consumed the most eggs (74.7%). Another study examined predation on adult fountain darters in outdoor raceways by red swamp crayfish (*Procambarus clarkii*) and largemouth bass at varying temperatures (Clark et al. 2017, entire). At 18ºC (64.4ºF) and 27ºC (80.6ºF), fountain darter mortality was lower when only exposed to red swamp crayfish, and was higher in raceways that had either exclusively largemouth bass or a combination of largemouth bass and red swamp crayfish (Clark et al. 2017, p. 295). However, at 22 °C (71.6 °F), fountain darter mortality was higher in the raceways where both largemouth bass and red swamp crayfish were present, and lower in the raceways that only had one species of predator (Clark et al. 2017, p. 295). The 22 °C (71.6 °F), treatment is the closest to the temperature experience by fountain darters in the wild and thus may be the closest to what occurs in natural ecosystems. However, natural ecosystems will have much more complex predator-prey interactions, with multiple prey types available and more potential mechanisms for predator avoidance by fountain darters. This study also did not detect an effect of vegetation on fountain darter mortality, though the authors suggested that changes to the experimental design in other studies may change this result (Clark et al. 2017, p. 295). In the wild, examination of 231 fish from the Comal ecosystem indicated that two fountain darters were consumed by largemouth bass (Perkins et al. 2018, p. 108-109). In the San Marcos system, examination of 200 fish indicated that one warmouth had consumed a fountain darter (Perkins et al. 2018, pp. 108, 110).

Antipredator behavior in fountain darters has been examined in response to visual and chemical cues of green sunfish, *Lepomis cyanellus* (Swanbrow Becker and Gabor 2012, entire). Fountain darters required both types of cues to exhibit an antipredator response (Swanbrow Becker and Gabor 2012, pp. 994, 998). Fountain darters also did not exhibit an antipredator response when vision was impaired by a semitransparent tint that prevented full visibility of green sunfish (Swanbrow Becker and Gabor 2012, pp. 994, 997, 998). This result could indicate that other visual impairments, such as turbid water, could reduce the antipredator response of fountain darters in the wild.

2.3.2.4 Inadequacy of existing regulatory mechanisms:

To conserve fountain darters, action is needed on broad regional issues for water use and landscape level management, localized actions taken by municipalities and landowners that affect these systems, and species-specific or site-specific actions that directly affect the fountain darter (Service 1996, p. 1). This review discusses several conservation measures for fountain darters that were implemented as part of the EARIP HCP (2012) that is permitted until 2028. Long-term commitments to restore fountain darter habitat beyond the HCP and the term of its associated section 10(a)(1)(b) permit are not in place. Many of the measures that protect the fountain darter result from the species endangered status and may not continue if the species were delisted.

Regulatory mechanisms that protect water in the Edwards Aquifer are crucial to the future survival of this species. Federal, State, and local laws and regulations have improved water quality and quantity protection, but could be insufficient to prevent ongoing impacts to the fountain darter and its habitat 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.

Water Quality Regulations

To protect water quality, there are several laws and regulations 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 TCEQ is responsible for enforcement of these standards in Texas. Under the authority of the Texas Administrative Code (TAC, Title 30, Chapter 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 a number of water-quality protection measures for new development occurring in the recharge, transition, and portions of the contributing zones of the Edwards Aquifer. TCEQ also prohibits facilities such as municipal solid waste landfills and waste disposal wells from being built in the recharge or transition zones. However, in Bandera, Kerr, and Kendall counties, the contributing zone does not have additional protections under the Edwards Rules. Because surface water in these areas flows to the recharge zone and enters the Edwards Aquifer, this results in lower water quality protection for the aquifer and San Marcos and Comal springs.

The Edwards Rules were enacted to protect existing and potential uses of groundwater and maintain Texas Surface Water Quality Standards. Specifically, a water pollution abatement plan (WPAP) must be in order to conduct any construction related or post-construction activities on the recharge zone. The WPAP must include a description of the site and location maps, a geologic assessment conducted by a geologist, and a technical report describing, among other things, temporary and permanent best management practices (BMPs).

Permanent BMPs and measures identified in the WPAP are designed, constructed, operated, and maintained to remove 80% of the incremental increase in annual mass loading of the total suspended solids from the site. This results in some level of water quality degradation since up to 20% of total suspended solids are ultimately discharged from the site into receiving waterways. Separate Edwards Aquifer protection plans are required for organized sewage collection systems, underground storage tank facilities, and aboveground storage tank facilities. Regulated activities exempt from the requirements of the Edwards Rules are the installation of natural gas lines; telephone lines; water lines; and other utility lines that are not designed to carry and will not carry pollutants, storm water runoff, sewage effluent, or treated effluent from a wastewater treatment facility.

Temporary erosion and sedimentation controls are required to be installed and maintained for any exempted activities located on the recharge zone. Individual landowners who seek to construct single-family residences on sites are exempt from the Edwards Aquifer protection plan application requirements provided they do not exceed 20% impervious cover. Similarly, the Executive Director of the TCEQ may waive the requirements for permanent BMPs for multi-family residential subdivisions, schools, or small businesses when 20% or less impervious cover is used at the site.

The best available science indicates that measurable degradation of stream habitat and loss of biotic integrity occurs at levels of impervious cover within a watershed much less than this (Coles et al. 2012, p. 65). The TCEQ regulations do not address land use, impervious cover limitations, some nonpoint source pollution, or application of fertilizers and pesticides over the recharge zone (TAC, Title 30, Part 1, Chapter 213, Subchapter C).

Texas has an extensive program for the management and protection of water that operates under State statutes and the Federal Clean Water Act (CWA). It 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 CWA).

In 1998, the State of Texas assumed authority from the Environmental Protection Agency (EPA) to administer the National Pollutant Discharge Elimination System. As a result, the TCEQ's Texas Pollutant Discharge Elimination System (TPDES) program has regulatory authority over discharges of pollutants to Texas surface water, with the exception of discharges associated with oil, gas, and geothermal exploration and development activities, which are regulated by the Railroad Commission of Texas. In addition, stormwater discharges from agricultural activities are not subject to TPDES permitting requirements.

The TCEQ issues two general permits that authorize the discharge of stormwater and non-stormwater to surface waters in Texas associated with: (1) small municipal separate storm sewer systems (MS4) (TPDES General Permit #TXR040000) and (2) construction sites (TPDES General Permit #TXR150000). The MS4 permit covers small municipal separate storm sewer systems that were fully or partially located within an urbanized area, as determined by the 2000 Decennial Census by the U.S. Census Bureau, and the construction general permit covers discharges of storm water runoff from small and large construction activities impacting greater than 0.4 ha (1 ac) of land. In addition, both of these permits require new discharges to meet the requirements of the Edwards Rules.

To receive coverage under the MS4 general permit, a municipality must submit a Notice of Intent (NOI) and a copy of their Storm Water Management Program (SWMP) to TCEQ. The SWMP must include a description of how that municipality is implementing the seven minimum control measures. These measures include (1) public education and outreach; (2) public involvement and participation; (3) detection and elimination of illicit discharges; (4) construction site storm water runoff control (when greater than 0.4 ha (1 ac) is disturbed); (5) post-construction storm water management; (6) pollution prevention and good housekeeping for municipal operations; and (7) authorization for municipal construction activities (optional).

For coverage under a construction general permit, an applicant must prepare a stormwater pollution and prevention plan (SWP3) that describes the implementation of practices that will be used to minimize, to the extent practicable, the discharge of pollutants in storm water associated with construction activity and non-storm water discharges. For activities that disturb greater than 2 ha (5 ac), the applicant must submit a NOI to TCEQ as part of the approval process.

As stated above, the two general permits issued by the TCEQ do not address discharge of pollutants to surface waters from oil, gas, and geothermal exploration and geothermal development activities, stormwater discharges associated with agricultural activities, and from activities disturbing less than 2 ha (5 ac) of land. Despite the significant value the TPDES program has in regulating point source pollution discharged to surface waters in Texas, it does not adequately address all sources of water quality degradation, including non-point source pollution and the exceptions mentioned above, that have the potential to negatively impact the fountain darter.

To discharge effluent onto the land, the TCEQ requires wastewater treatment systems within the San Antonio Segment of the Edwards Aquifer recharge and contributing zones to obtain Texas Land Application Permits (TLAP) (Ross 2011, p. 7). Although these permits are designed to protect the surface waters and underground aquifer, studies have demonstrated reduced water quality downstream of TLAP sites (Mahler et al. 2011, pp. 34-35; Ross 2011, pp. 11-18). Ross (2011, pp. 18-21) attributes this to the TCEQ’s failure to conduct regular soil monitoring for nutrient accumulation on TLAP sites and the failure to conduct in-depth reviews of TLAP applications. A study by the USGS concluded that nitrate levels in the Barton Springs Segment of the Edwards Aquifer had shifted upward between 2001 and 2010 and was at least partially the result of an increase in the land application of treated wastewater (Mahler et al. 2011, pp. 34-35). Similar problems could occur if TLAP permitting increased in the San Antonio Segment of the Edwards Aquifer.

A watershed protection plan (WPP) 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 WPP is intended to address and reduce the elevated bacteria levels through management (TCEQ 2020, p.1). Another WPP for the Upper San Marcos River was approved in 2018 by TCEQ. The WPP addresses the impairment of the Upper San Marcos River due to elevated total dissolved solids, and also proactively addresses bacteria, nutrients, sediment, and future growth scenarios for the watershed (TCEQ 2018, p. 1).

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 EARIP HCP and are discussed under Downlisting Criteria 1 and 3 in section 2.2.3. 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. The EAA also does not have the authority to regulate the majority of the contributing zone including Bandera, Kerr, and Kendall counties. Thus, its water quality regulations do not protect the majority of the contributing zone, which may ultimately reduce the water quality of the Edwards Aquifer.

Water Quantity Regulations

Management of groundwater supply is typically deferred to states (Folger et al. 2018, p. 1). This may be due to the origin of groundwater laws in the 19th and early 20th centuries, before groundwater resources were well understood (Folger et al. 2018, p. 8). While groundwater resources are better understood now, groundwater laws in many areas have not been updated to reflect the connectivity of surface and groundwater though conjunctive management to manage groundwater and surface water together (Folger et al. 2018, p. 9). Texas adopted the “rule of capture” in 1904, which allows landowners to capture the groundwater beneath their land (Booth and Richard-Crow 2004, p. 19). In 1949, the Texas Legislature allowed for the formation of groundwater conservation districts, although these were still voluntary measures (Booth and Richard-Crow 2004, p. 20). The rule of capture is still viable in areas outside of groundwater conservation districts (Booth and Richard-Crow 2004, pp. 19-20), and is also sometimes the subject of lawsuits against groundwater conservation districts (see below). Under the authority provided by Texas Water Code (Chapter 36, Subsection 36.101), groundwater conservation districts may limit aquifer withdrawals under rules governed by Chapter 36 and by their enabling legislation to conserve, preserve, and protect groundwater or groundwater recharge, and to prevent waste of the groundwater resource or groundwater reservoirs in their jurisdiction as part of a comprehensive, approved groundwater management plan.

An underground water authority, the EAA, was created (Chapter 626, Laws of the 73rd Texas Legislature, 1993, as amended) to manage and issue permits for the withdrawal of groundwater from the Edwards Aquifer for the purposes of water conservation and drought management. The EAA was designated a special regional management district and charged with protecting terrestrial and aquatic life, domestic and municipal water supplies, the operation of existing industries, and the economic development of the State of Texas. The EAA is mandated to pursue all reasonable measures to conserve water; protect water quality in the aquifer; protect water quality of surface streams provided with spring flow from the aquifer; maximize the beneficial use of water available to be drawn from the aquifer; protect aquatic and wildlife habitat; protect threatened and endangered species under Federal or State law; and provide for instream uses, bays and estuaries.

The Texas Legislature directed the EAA in 1993 to limit Edwards Aquifer pumping authorized by permits to a maximum of 555,066,835 cubic meters (m^3) [(450,000 acre-feet (ac-ft)] per year, and to reduce that total to 493,392,742 m^3 (400,000 ac-ft) per year by December 31, 2007. During the 2007 legislative session, the Texas Legislature increased the annual maximum amount of pumping that could be authorized by permits to 705,551,621 m^3 (572,000 ac-ft) and directed the EAA to adopt and enforce a "Critical Period Management" (CPM) 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. By EAA estimates, Comal Springs most likely would have gone dry during the drought in 2014 without the new pumping regulations (EAA 2015, p. 62). Instead, the minimum daily flow in 2014 was 1.84 m^3/s (65 cfs) in August (EAA 2015, p. 1). However, future droughts are expected to become more severe and current aquifer management does not account for this (see section 2.3.2.5 below for discussion of future climate).

Even with authority granted by the Texas Legislature, there have been several legal challenges to the EAA permitting program. For example, in court cases EAA v. Day (2012, Supreme Court of Texas No. 08-0964) and EAA 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 EAA 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.

Changes to how surface water and the Trinity Aquifer are managed are both likely to change the amount that can be sustainably pumped from the Edwards Aquifer during drought conditions. The EAA jurisdiction is limited to the Edwards Aquifer in Uvalde, Medina, Bexar, and portions of Comal, Guadalupe, Hays, and Caldwell counties. The EAA does not have jurisdiction over the surface water that recharges the aquifer. The Trinity Aquifer is also not under EAA jurisdiction but can affect the water level of the Edwards Aquifer both through interconnectivity of the aquifers and through spring discharges that recharge the Edwards Aquifer (see section 2.3.1.7). For example, the Hays-Trinity Groundwater Conservation District also manages groundwater that influences the water at San Marcos Springs. Considerable drawdowns have also occurred over portions of the Trinity Aquifer. Groundwater production from Trinity Aquifer wells is used primarily for municipal, rural domestic, livestock, and vineyard cultivation demands (Hays Trinity Groundwater Conservation District 2016, p. 12). Intensive pumping in the Trinity Aquifer over the last several decades have caused declines in the water table, decreased well yields, and diminished baseflow to springs and streams (Bluntzer 1992, pp. 41-44).

2.3.2.5 Other natural or manmade factors affecting its continued existence:

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 to 50 years ago (Rupp et al. 2012, p. 1,054; Nielsen-Gammon et al. 2020, entire). The sustainable water yield for the Edwards Aquifer will decrease in a dry climate (EARIP HCP 2012, pp. 3-12, 3-31, 3-43; Loáiciga and Schofield 2019, pp. 223, 235-236) while human demand for groundwater will increase (EARIP HCP 2012, pp. 3-10-3-11), making it more challenging to balance groundwater use for human needs and ecosystem function. The EARIP HCP (2012, pp. 3-7-3-14) provides a more comprehensive discussion of the impacts of climate change on groundwater resources. Heavy rainfall leading to floods may also become more common and may result in increased habitat disturbance. Because submerged vegetation is critical to fountain darters (Service 1996, p. 33), habitat disturbance due to floods can negatively impact fountain darters (BIO-WEST 2019b, pp. 14, 17).

Air temperature in Texas has risen 1 °C (2 °F) since the early 1900s (Geos Institute 2016, p. 4). Future air temperature changes will depend on the amount of future greenhouse gas emissions (U.S. Global Change Research Program 2018, p. 995). There have been no new mechanisms that have effectively regulated greenhouse gas emissions, which are contributing to global climate change and associated modifications to fountain darter water quality and quantity. Since the recovery plan for the fountain darter was published in 1996, global carbon dioxide emissions increased by 40% by 2010 (Boden et al. 2010). However, governments and concerned organizations are trying to address climate change impacts on a global level. At the Paris Climate Conference held in December 2015, 195 countries adopted the first universal global climate agreement. This agreement presents a global action plan that is meant to limit global warming to below 2 °C by the end of the century (European Commission 2016).

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), with another study showing a higher range by 2100 of 2.7-5.6 °C (5-10 °F, Sharif 2018, p. 4). Studies have not explicitly addressed groundwater temperature increases for the Edward's 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 lead to further increases in groundwater temperature as more development occurs. Groundwater temperature typically increases with depth due to geothermal heat flow (Bense and Kurylyk 2017, p. 1), although this also varies locally with other variables such as vertical groundwater flow (Bense and Kurylyk 2017, p. 8). This suggests that deeper water would not provide a long-term buffer to increasing temperatures. More information is needed to understand how quickly water temperature will change in the Edwards Aquifer.

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 2019a, p. 20; BIO-WEST 2019b, p. 16). It should be noted that low spring discharge is 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. As discussed previously, water temperature increases beyond 24.4 °C (76 °F), could impact fountain darter reproduction. Water quality is also likely to decrease with increased water temperature, for example as dissolved oxygen decreases and microbial activity increases (Bates et al. 2008, p. 43). Continuous temperature data for the springs began in 2000, and groundwater temperature at Spring Lake and Comal Springs is relatively constant (BIO-WEST 2019a, p. 20; BIO-WEST 2019b, p. 16). Continuous water temperature monitoring in the Comal and San Marcos rivers should indicate whether water temperatures rise in the future.

The fountain darter has no opportunity to migrate and it is unlikely it could be successfully relocated due to its specific habitat requirements. Therefore, its capability to adapt to environmental changes from climate change is presumed to be low. An assessment by USGS rated the fountain darter as moderately vulnerable to climate change in part due to the narrow thermal tolerance of the species and projected decline in spring flows (Stamm et al. 2015, pp. 1, 40, 42, 47). One of the goals of current water planning is to ensure spring flows in San Marcos and Comal springs during a drought of record (EARIP HCP 2012, pp. 4-52 - 4-55, 4-58-4-62). However, a drought worse than the drought of record is included as an unforeseen circumstance in the EARIP HCP and would not require the commitment of additional groundwater resources to ensure the persistence of the fountain darter (EARIP HCP 2012, pp. 8-7-8-8). The EAA, Oklahoma State University, and the University of Texas-San Antonio are currently pursuing work to project effects of climate change on future groundwater levels (S. Storment personal communication).

2.4 Synthesis

The fountain darter continues to be at high risk of extinction due to the rapid rate of urbanization across the species' range, the ongoing threats of decreasing water quality and quantity in the aquifer systems on which it depends, and catastrophic spills. Rapid human population growth, increased water demands, and a warming climate with more frequent drought conditions continue to place increased stress on the limited water resources required by the fountain darter to meet its breeding, feeding, and sheltering needs. Although minimum groundwater flows should be maintained to conserve this species, given the anticipated effects of climate change, existing regulatory measures may not be enough to maintain spring flows in conditions worse than the drought of record. Therefore, we recommend the fountain darter remain listed as endangered.

3.0 RESULTS

3.1 Recommended Classification:

_____Downlist to Threatened
_____Uplist to Endangered
_____Delist *(Indicate reasons for delisting per 50 CFR 424.11):*
____ *Extinction*
____ *Recovery*
____ *Original data for classification in error*
__X__ No change is needed

3.2 New Recovery Priority Number

No change needed (2C)

Brief Rationale:

A Recovery Priority Number of 2C is indicative of a taxon with a high degree of threat, a high recovery potential, and the taxonomic standing of a species. Fountain darters continue to be threatened by water quality and water quantity stressors as a result of development and water withdrawals over the contributing and recharge zones of the San Antonio segment of the Edwards Aquifer.

4.0 RECOMMENDATIONS FOR FUTURE ACTIONS

- Revise the 1996 San Marcos & Comal Springs & Associated Aquatic Ecosystems (Revised) Recovery Plan when schedule permits to include recovery actions that incorporate new information and can be evaluated using the data currently collected for the species.

- Revise Downlisting Criterion 1. Because future climate is expected to become drier in the region, a plan for aquifer management based on the drought of record is not protective of more severe droughts that have been projected by scientific studies. Future climate modeling should be used reevaluate the amount of groundwater that can sustainably be withdrawn during dry conditions expected in the future and to better understand the relationship between future air temperature and water temperature in the San Marcos and Comal rivers.

- Revise Downlisting Criterion 4. Because current data collection occurs due to monitoring for the EARIP HCP (2012), it is recommended that the vegetation goals be adjusted to match the goals used in the EARIP HCP. The goals for darter densities should also be updated to reflect the densities that are used by the EARIP HCP (2012, pp. 4-10, 4-30).

- Meeting species-specific vegetation goals is less important for fountain darters than the total amount of coverage of high quality native aquatic vegetation to provide habitat for fountain darters. Thus, it would make sense to combine the species-specific goals for vegetation for a total areal coverage goal for native vegetation for each spring reach.

- Sample fountain darters outside of representative reaches to better assess overall population status.

- Increase reproduction in the captive refugia now that a large wild-caught stock exists in captivity. Create a genetics management plan to determine the minimum number of wild caught individuals necessary to maintain genetic diversity in captivity. Remove the requirement to maintain fountain darters from the Comal River based on genetic evidence that they are subset of the genetic diversity from the San Marcos River.

5.0 REFERENCES

Alexander M.L. and C.T. Phillips. 2012. Habitats used by the endangered fountain darter (*Etheostoma fonticola*) in the San Marcos River, Hays County, Texas. The Southwestern Naturalist 57(4): 449-452.

Bates, B.C., Z.W. Kundzewicz, S. Wu, and J.P. Palutikof, Eds. 2008: Climate change and water. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, Switzerland, 210 pp.

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.

Bergin, S.J. 1996. Diet of the fountain darter *Etheostoma fonticola* in the Comal River, Texas. Southwest Texas State University, San Marcos. 45 pp.

BIO-WEST. 2007. Variable flow study: seven years of monitoring and applied research. Prepared for Edwards Aquifer Authority, San Antonio, Texas, 70 pp.

BIO-WEST. 2016a. Habitat Conservation Plan Biological Monitoring Program. Comal Springs/River Aquatic Ecosystem 2016 Annual Report. Prepared for Edwards Aquifer Authority, San Antonio, Texas, 64 pp. plus Appendices.

BIO-WEST. 2016b. Habitat Conservation Plan Biological Monitoring Program. San Marcos Springs/River Aquatic Ecosystem 2016 Annual Report. Prepared for Edwards Aquifer Authority, San Antonio, Texas, 53 pp. plus Appendices.

BIO-WEST. 2017. Permit report for TE0371550-0 to Austin Ecological Services Field Office.

BIO-WEST. 2018. Habitat Conservation Plan Biological Monitoring Program. San Marcos Springs/River Aquatic Ecosystem 2018 Annual Report. Prepared for Edwards Aquifer Authority, San Antonio, Texas, 55 pp. plus Appendices.

BIO-WEST. 2019a. Habitat Conservation Plan Biological Monitoring Program. Comal Springs/River Aquatic Ecosystem 2019 Annual Report. Prepared for Edwards Aquifer Authority, San Antonio, Texas, 53 pp. plus Appendices.

BIO-WEST. 2019b. Habitat Conservation Plan Biological Monitoring Program. San Marcos Springs/River Aquatic Ecosystem 2019 Annual Report. Prepared for Edwards Aquifer Authority, San Antonio, Texas, 50 pp. plus Appendices.

BIO-WEST and Watershed Systems Group. 2016a. Submerged aquatic vegetation analysis and recommendations. Prepared for Edwards Aquifer Authority, San Antonio, Texas, 96 pp. plus Appendices.

BIO-WEST and Watershed Systems Group. 2016b. SAV Addendum and revised Appendix B. Prepared for Edwards Aquifer Authority, San Antonio, Texas, 15 pp. plus Appendices.

Blanton & Associates, Inc. 2020. Edwards Aquifer Habitat Conservation Plan 2019 Annual Report. Prepared on behalf of The Edwards Aquifer Habitat Conservation Plan and Permittees, 110 pp. plus Appendices.

Bluntzer, R.L. 1992. Evaluation of the ground-water resources of the Paleozoic and Cretaceous aquifers in the Hill Country of Central Texas: Texas Water Development Board Report 339. Austin, Texas. 130 pp.

Boden, T.A., G. Marland, and R.J. Andres. 2010. Global, regional, and national fossil fuel CO_2 emissions. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. doi 10.3334/CDIAC/00001_V2010.

Bonner, T.M., T.M. Brandt, J.N. Fries, and B.G. Whiteside. 1998. Effects of temperature on egg production and early life stages of the fountain darter. Transactions of the American Fisheries Society 127: 971-978.

Booth, M.J. and R. Richard-Crow. 2004. Regulatory dance: rule of capture and Chapter 36 District perspective. In 100 Years of Rule of Capture: From East to Groundwater Management, Mullican, W.F., III and S. Schwartz, eds. Texas Water Development Board Report 361, pp. 19-40.

Brandt, T.M., K.G. Graves, C. Berkhouse, T. Simon, and B.G. Whiteside. 1993. Laboratory spawning and rearing of the endangered fountain darter. The Progressive Fish-Culturist 55: 149-156.

Cantu, V. 2003. Spatial and temporal variation of *Centrocestus formosanus* in river water and endangered fountain darters (*Etheostoma fonticola*) in the Comal River, Texas. M.S. Thesis, Texas State University-San Marcos, 69 pp.

City of San Marcos. 2018. Meeting Minutes-Final. Planning and Zoning Commission. Tuesday, November 27, 2018, 7 pp.

Clark, M.K., K.G. Ostrand, and T.H. Bonner. 2017. Implications of piscine predator control on the federally listed fountain darter. Fish Management and Ecology 24: 292-297.

Coles, J.F., G. McMahon, A.H. Bell, L.R. Brown, F.A. Fitzpatrick, B.C. Eikenberry, M.D. Woodside, T.F. Cuffney, W.L. Bryant, K. Cappiella, L. Fraley-McNeal, and W.P. Stack. 2012. Effects of urban development on stream ecosystems in nine metropolitan study areas across the United States. Circular 1373. U.S. Geological Survey, 152 pp.

Cook-Hildreth, S.L. 2008. Exotic armored catfishes in Texas: reproductive biology, and effects of foraging on egg survival of native fishes (*Etheostoma fonticola*, endangered and *Dionda diaboli*, threatened). M.S. Thesis, Texas State University-San Marcos, 50 pp.

Dammeyer, N.T., C.T. Phillips, and T.H. Bonner. 2013. Site fidelity and movement *of Etheostoma fonticola* with implications to endangered species management. Transactions of the American Fisheries Society 142: 1,049–1,057

EAA. 2015. Hydrologic data report for 2014. Report No. 15-01, San Antonio, Texas, 69 pp. plus Appendices.

EAA. 2019a. Edwards Aquifer Habitat Conservation Plan Expanded Water Quality Report 2019, San Antonio, Texas, 45 pp. plus Appendices.

EAA. 2019b. Water Quality Summary 2019, San Antonio, Texas, 10 pp.

Edwards Aquifer Recovery Implementation Program. 2012. Edwards Aquifer Recovery Implementation Program Habitat Conservation Plan. November 2012. Prepared by RECON, Environmental, Inc.; Hicks & Company; Zara Environmental LLC; and BIO-WEST. 399 pp.

European Commission. 2016. Climate action, Paris Agreement, policy. European Commission, http: //ec.europa.eu/clima/policies/international/negotiations/paris_en#tab-0-0.

Folger, P., C.V. Stern, N.T. Carter, and M. Stubbs. 2018. The federal role in groundwater supply: overview and legislation in the 115th Congress. Congressional Research Service, R45259, 32 pp.

Geos Institute. 2016. Hot enough yet? The future of extreme weather in Austin, Texas. Ashland, Oregon, 26 pp.

Hardy, T.B. and N. Raphelt. 2015. Effects of changing height of Cape's Dam on recreation, Texas wild rice and fountain darter habitat in the San Marcos River, Texas. Watershed Systems Group, INC San Marcos, Texas, 36 pp.

Hays Trinity Groundwater Conservation District. 2016. Groundwater management plan. Dripping Springs, Texas. 74 pp.

Huston, D.C., M.D. Worsham, D.G. Huffman, and K.G. Ostrand. 2014. Infection of fishes, including threatened and endangered species by the trematode parasite *Haplorchis pumilio* (Looss, 1896) (Trematoda: Heterophyidae). BioInvasions Record 3(3): 189-194.

Iwanowicz, L.R., D.D. Iwanowicz, C.R. Adams, T.D. Lewis, T.M. Brandt, L.R. Sanders, and R.S. Cornman. 2018. Isolation, characterization and molecular identification of a novel aquareovirus that infects the endangered fountain darter *Etheostoma fonticola*. Diseases of Aquatic Organisms 130: 95-108.

Johnson, M.S., A. Bolick, M. Alexander, D. Huffman, E. Oborny, and A. Monroe. 2012. Fluctuations in densities of the invasive gill parasite *Centrocestus formosanus* (Trematoda: Heterophyidae) in the Comal River, Comal County, Texas, U.S.A. Journal of Parasitology 98(1): 111-116.

Linam, L.A. 1993. A reassessment of the distribution, habitat preference, and population size estimate of the fountain darter (*Etheostoma fonticola*) in the San Marcos River, Texas. In Conservation of the Upper San Marcos and Comal Ecosystems, Section 6 report,Texas Parks and Wildlife Department, 13 pp.

Linam, G.W, K.B. Mayes, and K.S. Saunders. 1993. A habitat utilization and population site estimate of fountain darters (*Etheostoma fonticola*) in the Comal River, Texas. Texas Journal of Science, 45(5): 341-348.

Loáiciga, H.A. and M. Schofield. 2019. Climate variability, climate change, and Edwards Aquifer water fluxes. In: The Edwards Aquifer: The Past, Present, and Future of a Vital Water Resource, pp. 223-238. Sharp, J.M., R.T. Green, G.M. Schindel, eds. Geological Society of America.

Lockwood, Andrews & Newman, Inc. 2014. City of New Braunfels Stormwater Management Plan, Texas, 82 pp.

Lockwood, Andrews & Newman, Inc. and Halff Associates. 2014. San Marcos Stormwater Master Plan, Texas, 16 pp.

Mahler, B.J. and R. Bourgeais. 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.

Mahler, B.J., M.L. Musgrove, C. Herrington, and T.L. Sample. 2011. Recent (2008-10) concentrations and isotopic compositions of nitrate and concentrations of wastewater compounds in the Barton Springs Zone, south-central Texas, and their potential relation to urban development in the contributing zone. U.S Geological Survey Scientific Investigations Report 2011-5018, 39 pp.

Mahler, B.J., P.C. Van Metre, J.L. Crane, A.W. Watts, M. Scoggins, and E.S. Williams. 2012. Coal-tar-based pavement sealcoat and PAHs: implications for the environment, human health, and stormwater management. Environmental Science and Technology 6(6): 3,039-3,045.

McDonald, D.L., T.H. Bonner, T.M. Brandt, and G.H. Trevino. 2006. Size susceptibility to trematode-induced mortality in the endangered fountain darter (*Etheostoma fonticola*). Journal of Freshwater Ecology 21(2): 293-299.

McDonald, D.L., T.H. Bonner, E.L. Oborny, Jr., and T.M. Brandt. 2007. Effects of fluctuating temperatures and gill parasites on reproduction of the fountain darter, *Etheostoma fonticola*. Journal of Freshwater Ecology 22(2): 311-318.

Mora, M.A., W.E. Grant, L. Wilkins, and H.-H. Wang. 2013. Simulated effects of reduced spring flow from the Edwards Aquifer on population size of the fountain darter (*Etheostoma fonticola*). Ecological Modelling 250: 235-243.

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. USGS Scientific Investigations Report 2012–5126, 94 pp.

Nielsen-Gammon, J.W., J.L. Banner, B.I. Cook, D.M. Tremaine, C.I. Wong, R.E. Mace, H. Goa, Z.-L. Yang, M.F. Gonzalez, R. Hoffpauir, T. Gooch, and K. Kloesel. 2020 (In press). Unprecedented drought challenges for Texas water resources in a changing climate: what do researchers and stakeholders need to know? AGU Advances.

Nowak, D.J. and E.J. Greenfield. 2018. U.S. urban forest statistics, values, and projections. Journal of Forestry 116(2): 164-177.

Olsen, J.B., A.P. Kinziger, J.K. Wenburg, C.J. Lewis, C.T. Phillips, and K.G. Ostrand. 2016. Genetic diversity and divergence in the fountain darter (*Etheostoma fonticola*): implications for conservation of an endangered species. Conservation Genetics 17: 1,393-1,404.

Perkins, J.S., E. Kosnicki, and J. Jackson. 2018. Analysis of the Comal Springs and San Marcos Springs long-term monitoring dataset. Edwards Aquifer Authority, San Antonio, Texas, 122 pp.

Phillips, C.T., M.L. Alexander, and R. Howard. 2010. Consumption of eggs of the endangered fountain darter (*Etheostoma fonticola*) by native and nonnative snails. The Southwestern Naturalist 55(1): 115-117.

Phillips C.T., M.L. Alexander, and A.M. Gonzales. 2011a. Use of macrophytes for egg deposition by the endangered fountain darter. Transactions of the American Fisheries Society 140(5): 1,392-1,397.

Phillips, C.T., J.K. Wenburg, C. Lewis, and J. Olsen. 2011b. Genetic diversity in the fountain darter *Etheostoma fonticola*. Final report presented to the Edwards Aquifer Recovery Implementation Program Steering Committee, San Antonio, Texas, 45 pp.

Reilly, F. and K.A. Carter. 2018. Program study and analysis services for the Edwards Aquifer Protection Program. San Antonio, Texas, 35 pp. plus Appendix.

Ross, D.L. 2011. Land-applied wastewater effluent impacts on the Edwards Aquifer. Report prepared for Great Edwards Aquifer Alliance and Save Our Springs Alliance. 35 pp.

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? In Explaining Extreme Events of 2011 from a Climate Perspective, pp. 1,052-1,054. Peterson, T.C., P.S. Stott, and S. Herring, S, eds. Bulletin of the American Meteorological Society, pp. 1041-1067.

Schenck, J.R., and B.G. Whiteside. 1976. Distribution, habitat preference and population size estimate of *Etheostoma fonticola*. Copeia 1976(4): 697-703.

Service (U.S. Fish and Wildlife Service). 1985. San Marcos recovery plan for San Marcos River endangered and threatened species-San Marcos gambusia (*Gambusia georgei*) Hubbs and Peden, fountain darter (*Etheostoma fonticola*) (Jordan and Gilbert), San Marcos salamander (*Eurycea nana*) Bishop, and Texas wild-rice (*Zizania texana*) Hitchcock: U.S. Fish and Wildlife Service, 109 pp.

Service (U.S. Fish and Wildlife Service). 1996. San Marcos & Comal Springs & associated aquatic ecosystems (revised) recovery plan. Southwest Region, Albuquerque, New Mexico, 93 pp. plus Appendices.

Service (U.S. Fish and Wildlife Service). 2012. Biological and conference opinions for the Edwards Aquifer Recovery Implementation Program Habitat Conservation Plan - Permit TE-63663A-0 (Consultation No. 21450-2010-F-0l 10). Southwest Region, Albuquerque, New Mexico, 169 pp.

Service (U.S. Fish and Wildlife Service). 2018. Implementation of the refugia program under the Edwards Aquifer Habitat Conservation Plan. Annual Report 2018. Contract No. 16-822-HCP. Southwest Region, Albuquerque, New Mexico, 73 pp.

Service (U.S. Fish and Wildlife Service). 2019a. Implementation of the refugia program under the Edwards Aquifer Habitat Conservation Plan. Annual Report 2019. Contract No. 16-822-HCP. Southwest Region, Albuquerque, New Mexico, 107 pp.

Service (U.S. Fish and Wildlife Service). 2019b. Amendment 1 - Recovery plan for *Zizania texana* (Texas wild-rice), fountain darter (*Etheostoma fonticola*) and Texas blind salamander (*Typhlomolge rathbuni*). Southwest Region, Albuquerque, New Mexico, 17 pp.

Service (U.S. Fish and Wildlife Service). 2020. 2020 EAHCP Refugia Work Plan. Southwest Region, Albuquerque, New Mexico, 26 pp.

Service (U.S. Fish and Wildlife Service) and BIO-WEST, Inc. 2011. Effectiveness of Host Snail Removal in the Comal River, Texas and its Impact on Densities of the Gill Parasite *Centrocestus formosanus* (Trematoda: Heterophyidae). 12 pp.

Sharif, H. 2018. Climate Projections for the City of San Antonio. San Antonio, Texas, 17 pp.

Smith, B.A., B.B. Hunt, and S.B. Johnson. 2012. Revisiting the hydrologic divide between the San Antonio and Barton Springs segments of the Edwards Aquifer: insights from recent studies. Gulf Coast Association of Geological Societies Journal 1: 55-68.

Stamm, J.F., M.F. Poteet, A.J. Symstad, M. Musgrove, A.J. Long, B.J. Mahler, and P.A. Norton. 2015. Historical and projected climate (1901–2050) and hydrologic response of karst aquifers, and species vulnerability in south-central Texas and western South Dakota: U.S. Geological Survey Scientific Investigations Report 2014–5089, 59 pp. plus Supplements.

Swanbrow Becker, L.J. and C.R. Gabor. 2012. Effects of turbidity and visual vs. chemical cues on anti-predator response in the endangered fountain darter (*Etheostoma fonticola*). Ethology 118: 994-1,000.

Swanbrow Becker, L.J., E.M. Brooks, C.R. Gabor, and K.G. Ostrand. 2016. Effects of turbidity on foraging behavior in the endangered fountain darter (*Etheostoma fonticola*). American Midland Naturalist 175: 55-63.

TCEQ. 2015. Texas Groundwater Monitoring Program Pesticide Sampling Sites. Water Wells Sampled or Analyzed by TCEQ (Thru August 2014). 1 p.

TCEQ. 2018. Upper San Marcos River Watershed Protection Plan. TCEQ Nonpoint Source Program Fact sheet, 2 pp.

TCEQ. 2019. Joint Groundwater Monitoring and Contamination Report – 2018. Prepared by the Texas Groundwater Protection Committee. 169 pp. plus Appendices

TCEQ. 2020. Dry Comal Creek and Comal River Watershed Protection Plan Implementation. TCEQ Nonpoint Source Program Fact sheet, 1 pp.

Texas Demographic Center. 2018. Texas population projections data tool. Data retrieved on July 24, 2020 at https: //demographics.texas.gov

Texas Natural Resource Conservation Commission. 1996. Chapter 213 - Edwards Aquifer; Rule Log No. 96114-213-WT. Texas Natural Resource Conservation Commission, 124 pp.

Texas Water Development Board. 2017. Water for Texas. 2017 State Water Plan. 133 pp.

Tolley-Jordan, L.R. and M.A. Chadwick. 2019. Effects of parasite infection and host body size on habitat associations of invasive aquatic snails: implications for environmental monitoring. Journal of Aquatic Animal Health 31: 121–128.

U.S. Census Bureau. 2020a. Estimates of the Components of Resident Population Change for Counties in Texas: April 1, 2010 to July 1, 2019. Excel spreadsheet accessed July 24, 2020. https: //census.gov

U.S. Census Bureau. 2020b. Resident Population Estimates for the 100 Fastest-Growing U.S. Counties with 10,000 or More Population in 2010: April 1, 2010 to July 1, 2019. Excel spreadsheet accessed July 24, 2020. https: //census.gov

U.S. Global Change Research Program. 2018. Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. Washington, DC, USA, 1,515 pp. doi: 10.7930/NCA4.2018

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.

U.S. FISH AND WILDLIFE SERVICE

5-YEAR REVIEW of the fountain darter (*Etheostoma fonticola*)

Current Classification: Endangered

Recommendation resulting from the 5-Year Review:

____ Downlist to Threatened
____ Uplist to Endangered
____ Delist
__X_ No change needed

Appropriate Listing/Reclassification Priority Number, if applicable: Not applicable

Review Conducted By: Donelle Robinson, Austin Ecological Field Service Office

FIELD OFFICE APPROVAL:

Lead Field Supervisor, Fish and Wildlife Service

Approve ADAM ZERRENNER Digitally signed by ADAM ZERRENNER Date: 2021.03.30 14:40:21 -05'00' Date ____________