Risks of Atrazine Use to Federally Listed Endangered Barton Springs Salamanders (Eurycea sosorum)

Appendix D: Status and Life History of the Barton Springs Salamander

August 22, 2006

Appendix D
Status and Life History of the Barton Springs Salamander

D.1 Species Listing Status

The Barton Springs salamander was federally listed as an endangered species on May 30, 1997 (62 FR 23377-23392) by the U.S. Fish and Wildlife Service (USFWS or the Service) based on the following threats:

(1) degradation of the water quality in Barton Springs as a result of urban expansion,
(2) decreased quantity of water that feeds Barton Springs as a result of urban expansion,
(3) modification of the salamander's structural habitat,
(4) inadequacy of existing regulatory mechanisms to protect the salamander and lack of a comprehensive plan to protect the Barton Springs watershed from increasing threats to water quality and quantity, and
(5) the salamander's extreme vulnerability to environmental degradation because of its restricted range in an entirely aquatic environment.

USFWS is the branch of the Department of Interior responsible for listing endangered amphibians, such as the Barton Springs salamander. The extent to which any these threats is considered to predominate is unknown and presumably their cumulative effect may be of primary concern.

D.2 Description and Taxonomy

The Barton Springs salamander (Figure D.1) is a member of the Family Plethodontidae (lungless salamanders). Texas species within the genus *Eurycea* inhabit springs, spring-runs, and water-bearing karst formations of the Edwards Aquifer (Chippindale, 1993). These salamanders are aquatic and neotenic, meaning they retain a larval, gill-breathing morphology throughout their lives. Neotenic salamanders, including the Barton Springs salamander, do not metamorphose into a terrestrial form. Rather, they live their entire life cycle in water, where they become sexually mature and eventually reproduce.

Figure D.1. Barton Springs Salamander
(courtesy of Lisa O'Donnell; City of Austin Watershed Protection and Development Review Department)

The Barton Springs salamander was first collected from Barton Springs in 1946 (Brown, 1950; Texas Natural History Collection specimens 6317-6321). Adults grow to approximately 2.5 to 3 inches (63-76 mm) in total length. Adult body morphology includes reduced eyes and elongate, spindly limbs indicative of a semi-subterranean lifestyle. The head is relatively broad and deep in lateral view, and the snout appears somewhat truncate when viewed from above. Three bright red, feathery gills are present on either side of the base of the head. The coloration on the salamander's upper body varies from light to dark brown, purple, reddish brown, yellowish cream, or orange. The characteristic mottled salt-and-pepper color pattern on the upper body surface is due to brown or black melanophores (cells containing pigments called melanin) and silvery-white iridiophores (cells containing pigments containing guanine). The arrangement of these pigment cells is highly variable and can be widely dispersed in some Barton Springs salamanders, causing them to have an overall pale appearance. In other individuals, the melanophores may be dense, resulting in a dark brown appearance. The ventral side (underside) of the body is cream-colored and translucent, allowing some internal organs and developing eggs in females to be visible. The tail is relatively short with a well-developed dorsal (upper) fin and poorly developed ventral (lower) fin. The upper and lower mid-lines of the tail usually exhibit some degree of orange-yellow pigmentation. Juveniles closely resemble adults (Chippindale et al., 1993). Newly hatched larvae are about 0.5 inches (12 mm) in total length and may lack fully developed limbs or pigment (Chamberlain and O'Donnell, 2003).

D.3 Population Status and Distribution

The Barton Spring salamander has been found only at the four spring outlets that make up Barton Springs complex (Figure D.2). This species is considered to have one of the smallest geographical ranges of any vertebrate species in North America (Chippindale et al., 1993; Conant and Collins, 1998).

The salamander was first observed in Barton Springs Pool and Eliza Springs in the 1940s, Sunken Garden Springs in 1993 (Chippindale et al., 1993), and the intermittent Upper Barton Springs in 1997 (City of Austin, 1998).

The extent of the Barton Spring salamander's range within the Barton Springs Segment of the Edwards Aquifer, and the degree of subsurface connection among these spring populations is unknown. However, observations of salamanders actively swimming into high flow areas from the spring openings, including Main Springs in Barton Springs Pool (USFWS, 2005), and the discovery of a more cave-adapted species (Austin blind salamander, *Eurycea waterlooensis*), suggest that the Barton Springs salamander is not entirely subterranean (triglobotic). The Barton Springs salamander appears to reproduce primarily in subterranean areas (*i.e.,* within the aquifer). Although salamander larvae are present in surface water year-round, very few eggs have been observed on the surface (Chamberlain and O'Donnell, 2003).

D.3.1 Survey Results

The City of Austin initiated salamander surveys in (1) Barton Springs Pool in 1993, (2) Old Mill Springs and Eliza Springs in 1995, and (3) Upper Barton Springs in 1997 (City of Austin, 1998, City of Austin, 1993-2003, unpublished data). Due to the inaccessibility of the aquifer and spring orifices, survey counts reflect the number of individuals observed in the spring pools and spring runs rather than total population census estimates (City of Austin, 2005a). Survey methods have varied to some degree, mainly in Barton Springs Pool, where the survey area gradually shifted from transects to the immediate area around the spring outlets where salamanders are most abundant (USFWS, 2005).

The results of the adult and juvenile salamander survey data are depicted in Figures D.3 and D.4, respectively. From 1997 to 2005 (years in which there are survey data for all four springs), the mean number of adult salamanders observed per year at all four springs combined ranged between 5 and 80. Further examination of the data shows a marked increase in the number of observed adults and juveniles in Eliza Spring, relative to the other springs, from mid-2003 to 2005. From 1997 until 2003, the largest mean number of adult and juvenile salamanders (15 and 14, respectively) were observed in Barton Springs Pool, followed by Old Mill Spring (13 and 8, respectively). However, in 2004 and 2005, the largest average number of adult and juvenile salamanders were observed in Eliza Springs (252 and 91, respectively), followed by Barton Springs Pool (35 and 21, respectively).

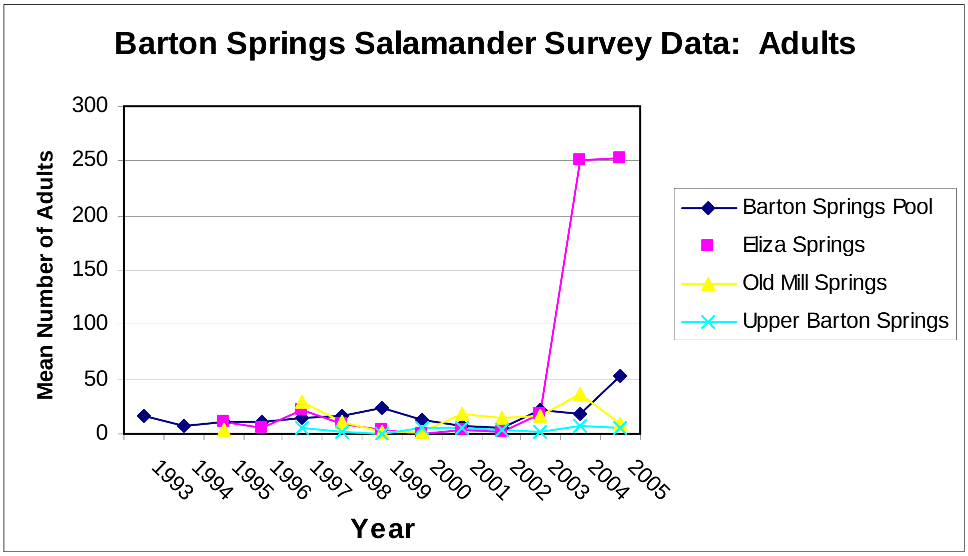

Figure D.3. Barton Springs Salamander Survey Data: Adults

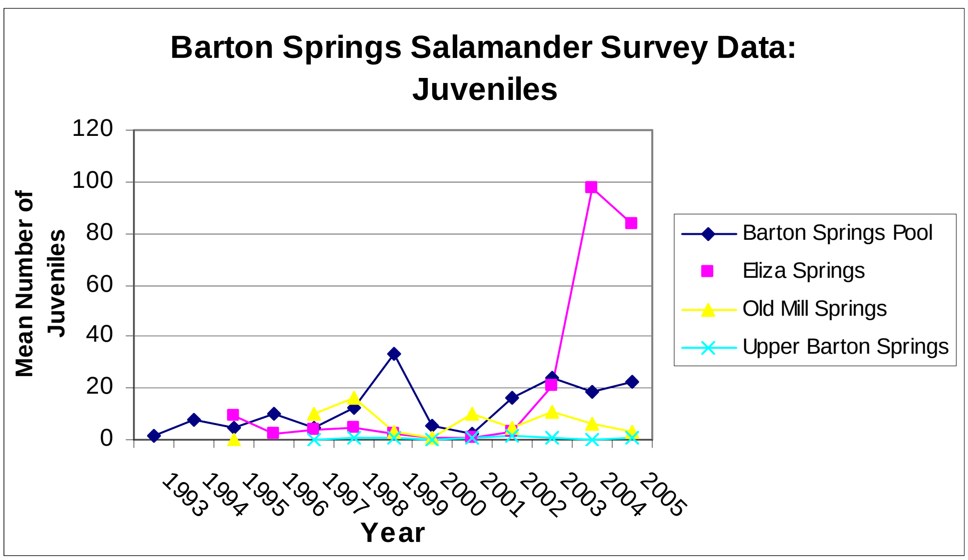

Figure D.4. Barton Springs Salamander Survey Data: Juveniles

Increased numbers of observed adult and juvenile salamanders in Eliza Springs from 2003 to 2005 are believed to be due to habitat restoration efforts, initiated in Eliza Springs by the City of Austin biologists in the fall of 2002 (City of Austin, 2003). Following habitat restoration, observed numbers of salamanders began to increase in July 2003. The habitat restoration efforts at Eliza Springs included removal of debris from the drainage infrastructure to increase flow across the bottom of the spring pool and allow for more natural flushing and draining of the spring ecosystem. Removal of fine sediment exposed a layer of gravel and cobble that had previously been obscured, making it available as habitat for the salamanders. Several species of native aquatic plants, including water primrose (*Ludwegia* sp.), rush (*Eleocharis* sp.), and water hyssop (*Bacopa* sp.) were also successfully transplanted from Barton Creek into Eliza Springs to serve as cover and promote invertebrate prey species. In addition, mosquitofish and crayfish, predators to the salamander, were removed from Eliza Springs. The net impact of the restoration efforts at Eliza Springs was the following: (1) to increase lateral water flow across the spring pool, thus reducing the amount of sediment and increasing the amount of loose rock substrate (habitat) available for the salamander and its forage base; and (2) to decrease the number of predators and other species that compete for available food. As a result of these efforts, mean numbers of adults and juveniles collected from Eliza Springs during 2004 increased by approximately 13-fold and 5-fold, respectively, as compared to total numbers collected during 2003. With the exception of an increase in the number of juvenile salamanders in Eliza Spring over the past two years, there does not appear to be any clear pattern in the number of young salamanders recorded by year or month over the past decade of survey results.

The majority of salamanders in Barton Springs Pool are found primarily in the immediate area of the spring outlets (USFWS, 2005). They have also been found to a lesser extent in the "beach" area, which includes an underwater concrete bench immediately adjacent to a pedestrian sidewalk on the north side of Barton Springs Pool. Salamanders are rarely seen in the deep end of the pool, which is often covered by sediment, or in the shallow end, which is almost entirely limestone and/or concrete, and thus not considered suitable habitat. Based on observations of salamanders in water depths ranging from <1 inch to >15 feet, it appears that water depth is not a determining factor in habitat selection. Although Barton Springs salamanders do not appear to have an obvious depth preference, constant water flow, stable temperatures, and rock substrates free of sediment are needed for suitable habitat. The survey area in Barton Springs Pool has gradually shifted from transects that included the beach and the deep end, to the intermediate area around the spring outlets where salamanders appear to be most abundant. Based on the comprehensive surveys conducted by the City of Austin and the Service, the number of estimated salamanders inhabiting the surface habitat in Barton Springs Pool may be negatively biased, with actual expected numbers of individuals that are three to five times greater than the number of individuals counted during the regular monthly surveys (City of Austin, 1998).

The Barton Springs Salamander Recovery Plan (USFWS, 2005) notes that numbers of salamanders at Old Mill Springs appear to be related to flow patterns and the presence of predatory fish. For example, a decrease in salamander numbers observed during the winter of 2002-2003 may have been due to the presence of Mexican tetras (*Asyanax mexicanus*), a non-native predatory fish (City of Austin, 2003). Review of the survey data also indicates a drop in numbers in Old Mill Springs in 2000, which is believed to be due to reduced water flow within the spring. According the City of Austin (2003), flow was extremely low in 2000; in fact, much of Old Mill Springs was dry in the spring/summer of 2000.

In 1997, biologists from the City of Austin and the USFWS discovered 14 adult salamanders at Upper Barton Springs, which flows intermittently. The number of salamanders found at this site in subsequent surveys has ranged from 0 to 14 (City of Austin, unpublished data). Given that salamanders are absent when this spring is dry, survey data indicate that salamander numbers are directly affected by surface flow. However, some monthly surveys at Upper Barton Springs have not found salamanders, even during periods when the spring was flowing (USFWS, 2005).

D.4 Habitat

All available information indicates that the Barton Springs salamander is restricted to the immediate vicinity of the four spring outlets of Barton Springs. Because the Barton Springs segment of the Edwards Aquifer and its contributing zone supply all of the water in the springs that make up the Barton Springs complex, the salamander may be affected by changes in water quality and quantity occurring in the Barton Springs watershed[1].

"Surface" habitat for the Barton Springs salamander refers to the spring pools and spring runs where the salamander is observed, as opposed to its potential subsurface aquifer habitat. The Barton Springs salamander experiences relatively stable aquatic environmental conditions. These conditions consist of perennially flowing spring water that is generally clear, has a neutral pH (~7), and cool average annual temperatures of 21 to 22 ºC (~70-72 ºF) (USFWS, 2005). As is typical of groundwater dominated systems, the springs exhibit a narrow temperature range (stenothermal). Flows of clean spring water with a relatively constant, cool temperature are essential to maintaining well-oxygenated water necessary for salamander respiration and survival (USFWS, 2005). Dissolved oxygen (DO) concentrations in Barton Springs average approximately 6 mg/L (USFWS, 2005) and are directly related to springflow. Higher DO concentrations occur during periods of high spring discharge (USFWS, 2005).

The subterranean component of the Barton Springs salamander's habitat may provide a location for reproduction, serve as refugium during high flow events or high sediment loads from surface sources in the surface habitat, and/or provide a migration pathway between the surface habitat areas (USFWS, 2005).

Based on the survey results, Barton Springs salamanders appear to prefer clean, loose substrate for cover. They are found primarily under boulder, cobble, and gravel substrates, but may also be found in the vicinity of aquatic plants, leaf litter, and woody debris (USFWS, 2005). In the main pool, City of Austin surveys indicate that salamanders are found primarily near the spring outlets. To a lesser extent, Barton Springs salamanders are also found in aquatic moss (*Amblystegium riparium*) that grows on bare rocks and on the walls surrounding Barton Springs Pool, Eliza Springs, and Old Mill Springs (City of Austin, 2003).

Historical records indicate a diversity of macrophytes once resided in Barton Springs Pool, including arrowhead (*Sagittaria platyphylla*), water primrose (*Ludwigia* spp.), wild celery (*Vallisneria americana*), cabomba (*Cabomba caroliniana*), water stargrass (*Heteranthera sp.*), southern naiad (*Najas guadalupensis*), and pondweed (*Potamogeton* sp.) (Alan Plummer Associates Inc., 2000 in USFWS, 2005). In 1992, the dominant

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[1] The "Barton Springs watershed" includes the contributing zone and recharge zone of the Barton Springs segment of Edwards Aquifer.

aquatic plant in the pool was the moss (*A. riparium*), an aquatic bryophyte ubiquitous in Central Texas springs. In addition to providing cover, moss and other aquatic plants harbor a variety and abundance of the aquatic invertebrates that salamanders eat.

During the 1980s and 1990s, the majority of aquatic macrophytes disappeared from the Barton Springs Pool (USFWS, 2005), leaving primarily unvegetated limestone substrate and sediment as habitat. The disappearance of the aquatic macrophytes in the deep end of the pool appears to have resulted from the combined effects of flooding, dredging, and the mechanical dragging of the deep end with chains for sediment removal (USFWS, 2005). However, it is unclear how these activities and the related disappearance of aquatic macrophytes in Barton Springs Pool may have affected the salamander numbers because they pre-dated the survey efforts, which were initiated in 1993.

In addition to restoration efforts for Eliza Springs (previously discussed in Section D.3.1), efforts to reintroduce endemic plant species in Barton Springs Pool were initiated by the City of Austin in 1993. At that time, aquatic vegetation in Barton Springs Pool was limited to two small patches of *Potamogeton*, one patch of *Sagittaria* in the far deep end of the pool, and areas of *Amblystegium* near the discharge points. *Sagittaria*, *Ludwigia*, and *Cabomba* have been introduced into Barton Springs Pool in June 1993 and again in the fall of 1994. It is not possible to gauge the effect of these activities on salamander numbers because there were no historical survey data. Aquatic macrophytes currently found in Barton Springs Pool are limited to *Sagittaria*. *Amblystegium* is also common on limestone surfaces in the general vicinity of the main springs and various side springs.

Salamanders are most frequently found around the main spring outflows, hidden within a 2-8 cm (0.8 – 3.1 inches) deep zone of gravel and small rocks overlying a coarse sandy or bare limestone substrate (USFWS, 2005). These areas are visibly clear of fine silt or decomposed organic debris and appear to be kept clean by flowing spring water during medium to high aquifer levels. Abundant prey species for the salamander also inhabit these areas. Piles of woody debris in the vicinity of the main springs provide habitat for the salamander, as well as its prey base, after floods, when normal habitat may be covered with sediment. Suitable habitat can increase or decrease depending on a number of factors including springflows, abundance of aquatic macrophytes, sedimentation rates, and frequency of floods.

In addition, pool cleanings may affect the salamander and its habitat. During the cleanings, full drawdowns of the pool (removal of 4-5 feet of water) are limited to four times/year, when spring discharge exceeds 53 cfs (cubic feet/second) and Barton Creek floods. For the past two years, the water level has been partially lowered (by 18-24") once per month when the flow exceeds 53 cfs. During this time, biologists clean sediment and debris from salamander habitat with garden hoses. Salamander habitat in Barton Springs Pool that is exposed during full drawdowns includes the area of fissures on the bedrock above the main spring outlets. The main spring outlets, which are located 10-16 feet below the top of the bedrock fissures, are not exposed during drawdowns as spring water continues to flow.

When discharge from Barton Springs Pool is lower than 54 cfs, the water level in Eliza Springs has the potential to drop below the surface substrate during a full drawdown. This is partially due to the presence of a concrete slab at the bottom of Eliza Springs, beneath the gravel and cobble. Flowing spring water into Eliza Springs must have adequate pressure to discharge through holes in the concrete bottom. When discharge is low and Barton Springs Pool is drawn down, the water level in Eliza Springs drops to below the surface substrate and salamanders are stranded at the surface. The habitat beneath this concrete slab is dark and sediment laden, and thus considered as poor habitat. In general, the water level in Old Mill Springs does not drop below the surface substrate when the Pool is drawn down, unless there is very low discharge from the aquifer.

D.5 Life History and Ecology

Information on the life history and ecology of the Barton Springs salamander, including diet, respiration, reproduction, longevity, diseases, and predators is provided in Sections D.5.1 through D.5.6.

D.5.1 Diet

Barton Springs salamanders appear to be opportunistic predators of small, live aquatic invertebrates (USFWS, 2005). Chippindale et al. (1993) found amphipod remains in the stomachs of wild-caught salamanders. The gastro-intestinal tracts of 18 adult and juvenile Barton Springs salamanders and fecal pellets from 11 adult salamanders collected from Eliza Springs, Barton Springs Pool, and Sunken Garden Springs contained ostracods, copepods, chironomids, snails, amphipods, mayfly larvae, leeches, and adult riffle beetles. The most prevalent organisms found in these samples were ostracods, amphipods, and chironomids (USFWS, 2005). The types of invertebrates found in the pools at Barton Springs are documented in the City of Austin’s Habitat Conservation Plan (1998).

D.5.2 Respiration

Primary respiration in neotenic salamanders is through the gills; however, a substantial amount of gas exchange occurs through the skin (Boutilier et al. 1992; Hillman and Withers 1979). They require moving water across their gills and bodies for respiration. Metabolic rates and oxygen consumption are highest in juveniles and decrease with increasing body size (Norris et al., 1963). Oxygenation of salamander eggs is critical to embryonic development since gas exchange and waste elimination occur through semipermeable membranes surrounding the embryo (Duellman and Trueb 1986).

D.5.3 Reproduction

Little is known about the reproductive biology of the Barton Springs salamander in the wild. The ability to view Barton Springs salamanders in their natural environment is limited because of the animal's propensity to inhabit interstitial spaces under rocks and subterranean environments. Therefore, information regarding the reproductive biology of the Barton Springs salamander is based primarily on captive breeding populations maintained by the City of Austin, and extrapolations from closely related species. Although some aspects of the reproductive biology may be affected by the artificial environment in which they are maintained, information collected on the captive breeding population represents the best available information. When field data are available, the differences and similarities between the wild and captive populations are compared.

Barton Springs salamanders are not sexually dimorphic; however, gravid females can sometimes be distinguished by the presence of eggs which are visible through the translucent skin of the underside. Recent studies with captive individuals indicate that salamander eggs are 1.5 to 2.0 mm (0.06 to 0.08 inches) in diameter when they are laid. Young larvae develop and hatch in approximately 16 to 39 days (USFWS, 2005). Captive raised female salamanders have developed eggs within 11 to 17 months after hatching. One male also displayed courtship behavior (tail undulation) at one year from hatching (Chamberlain and O'Donnell, 2003). At sexual maturity, salamanders are generally at least 50 mm in total length (Chamberlain and O'Donnell, 2003). No clear pattern of reproductive activity has been recorded in the field or in the laboratory. It appears that salamanders can reproduce year-round, based on observations of gravid females, eggs, and larvae throughout the year in Barton Springs (USFWS, 2005). No relationship between breeding activity and environmental factors has been established to date.

The captive breeding program has observed clutch sizes ranging from 5 to 39 eggs, with an average of 22 eggs based on 32 clutches; individual captive females have produced up to 6 clutches per year (Chamberlain and O'Donnell, 2003). Of the 34 egg-laying events at the Dallas Aquarium, clutch size ranged from 10 to 55 (Lynn Ables, Dallas Aquarium, pers. comm., 2000). Females may lay all or only a few of their eggs, and in some cases, females may reabsorb their unlaid eggs within a few weeks after egg-laying (Chamberlain and O'Donnell, 2003). Currently, specific cues and/or environmental factors associated with clutch size and timing of courtship and reproduction have not been identified (USFWS, 2005).

Data regarding development and hatching of eggs are based almost exclusively on observations of the captive populations. In spite of relatively intensive survey efforts, only four eggs have been located in the wild. In four separate instances, a single egg was found near a spring orifice (USFWS, 2005). These observations combined with the visibility of the eggs to predators due to their lack of pigment (eggs are white) suggest the eggs are laid in the subterranean portion of the salamander's habitat. Eggs are laid singly and receive no parental care (USFWS, 2005). Hatching of eggs in captivity has occurred within 16 to 39 days after eggs have been laid (Chamberlain and O'Donnell, 2003). Hatching success of a clutch is variable (10 - 100%), with means ranging from 26 to 57 percent (Chamberlain and O'Donnell, 2003). Based on information summarized in USFWS (2005), egg mortality in captivity has been attributed to (1) fungus (Chamberlain and O'Donnell, 2002 and 2003), (2) hydra (small invertebrates with stinging tentacles)

(Lynn Ables, Dallas Aquarium, pers. comm., 2000), and (3) other factors, including infertility (Chamberlain and O'Donnell, 2003). Environmental conditions, water quality, adequate space, habitat heterogeneity, and food availability may also influence egg laying (Chamberlain and O'Donnell, 2003).

At hatch, juveniles measure 13 mm in total length (snout to tip of tail). After 4 months, juveniles ranged in total length from 13 to 38 mm (Chamberlain and O'Donnell, 2003). Growth rates in the wild, based on a limited mark-recapture dataset of 11 Barton Springs salamanders, ranged from 0.14 to 0.50 mm per day over a 30- to 57-day period (City of Austin, unpublished data). The available data suggest that Barton Springs salamanders could potentially reach full maturity within six months from hatching, although the sample size upon which these data are based is limited and additional research is warranted.

City of Austin biologists have generally found the first three months following hatching to be a critical period for juvenile survival (Chamberlain and O'Donnell, 2003). Of the 285 eggs laid in one breeding study, only 12 (4%) survived the first three months (Chamberlain and O'Donnell, 2003). Newly hatched larvae have sufficient yolk to sustain their nutritional needs for several days after hatch. Larvae feeding on prey items have been observed 11 to 15 days after hatching (Lynn Ables, Dallas Aquarium, pers. comm., 1999).

D.5.4 Longevity

The longevity of the Barton Springs salamander in the wild is unknown; however, salamanders in captivity have survived to at least 12 years (USFWS, 2005).

D.5.5 Diseases

A limited number of physiological infections have been reported in the wild for the Barton Springs salamanders. Adult Barton Springs salamanders have been infected with trematodes (*Clinostomum* sp.) that invaded tissue near the salamander's vent (Chamberlain and O'Donnell, 2002).

D.5.6 Predators

Predation on adult Barton Springs salamanders in the wild is expected to be minimal when adequate cover is available (USFWS, 2005). Most of the potential predators native to the Barton Springs ecosystem are opportunistic feeders, and predation is unlikely unless the salamanders become exposed. Crayfish (*Procambarus clarkii*) and other large predatory invertebrates may prey on salamanders or on their larvae and eggs (Gamradt and Kats, 1996). Crayfish have been reported to be extremely abundant at times, with an apparent "crayfish bloom" occurring in the spring of 1995, when thousands of crayfish were found throughout the pool (USFWS, 2006). Predatory fish found at Barton Springs include mosquitofish (*Gambusia affiinis*), longear sunfish (*Lepomis megalotis*), and largemouth bass (*Micropterus salmoides*). Mosquitofish have been known to prey on frog and salamander larvae in areas where the fish have been introduced (Gamradt and Kats, 1996; Goodsell and Kats, 1999; Lawler et al., 1999). Longear sunfish are known to prey on aquatic vertebrates, and largemouth bass are opportunistic predators that feed primarily on smaller fishes and crayfish. Mexican tetras are non-native fish and aggressive generalist predators that are occasionally found in Barton Creek, Barton Springs Pool, Upper Barton Springs, and Sunken Garden Springs (USFWS, 2005). In addition, green-throat darters (*Etheostoma lepidum*) have been known to prey upon small juvenile salamanders when no cover is available.

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