U.S. FISH AND WILDLIFE SERVICE SPECIES ASSESSMENT AND LISTING PRIORITY ASSIGNMENT FORM

Scientific Name:

Truncilla macrodon

Common Name:

Texas Fawnsfoot

Lead region:

Region 2 (Southwest Region)

Information current as of:

03/04/2015

Status/Action

___ Funding provided for a proposed rule. Assessment not updated.

___ Species Assessment - determined species did not meet the definition of the endangered or threatened under the Act and, therefore, was not elevated to the Candidate status.

___ New Candidate

_X_ Continuing Candidate

___ Candidate Removal

> ___ Taxon is more abundant or widespread than previously believed or not subject to the degree of threats sufficient to warrant issuance of a proposed listing or continuance of candidate status
>
> ___ Taxon not subject to the degree of threats sufficient to warrant issuance of a proposed listing or continuance of candidate status due, in part or totally, to conservation efforts that remove or reduce the threats to the species
>
> ___ Range is no longer a U.S. territory
>
> ___ Insufficient information exists on biological vulnerability and threats to support listing

___ Taxon mistakenly included in past notice of review

___ Taxon does not meet the definition of "species"

___ Taxon believed to be extinct

___ Conservation efforts have removed or reduced threats

___ More abundant than believed, diminished threats, or threats eliminated.

Petition Information

___ Non-Petitioned

_X_ Petitioned - Date petition received: 10/15/2008

90-Day Positive:12/15/2009

12 Month Positive:10/06/2011

Did the Petition request a reclassification? **No**

For Petitioned Candidate species:

Is the listing warranted(if yes, see summary threats below) **Yes**

To Date, has publication of the proposal to list been precluded by other higher priority listing? **Yes**

Explanation of why precluded:

We find that the immediate issuance of a proposed rule and timely promulgation of a final rule for this species has been, for the preceding 12 months, and continues to be, precluded by higher priority listing actions (including candidate species with lower LPNs). During the past 12 months, the majority our entire national listing budget has been consumed by work on various listing actions to comply with court orders and court-approved settlement agreements; meeting statutory deadlines for petition findings or listing determinations; emergency listing evaluations and determinations; and essential litigation-related administrative and program management tasks. We will continue to monitor the status of this species as new information becomes available. This review will determine if a change in status is warranted, including the need to make prompt use of emergency listing procedures. For information on listing actions taken over the past 12 months, see the discussion of Progress on Revising the Lists, in the current CNOR which can be viewed on our Internet website (http://endangered.fws.gov/).

Historical States/Territories/Countries of Occurrence:

- **States/US Territories**: Texas
- **US Counties**:County information not available
- **Countries**:Country information not available

Current States/Counties/Territories/Countries of Occurrence:

- **States/US Territories**: Texas
- **US Counties**: Austin, TX, Brazoria, TX, Brazos, TX, Burleson, TX, Burnet, TX, Colorado, TX, Falls, TX, Fayette, TX, Fort Bend, TX, Grimes, TX, Limestone, TX, Matagorda, TX, Robertson, TX, San Saba, TX, Waller, TX, Washington, TX, Wharton, TX
- **Countries**:Country information not available

Land Ownership:

One Texas fawnsfoot population occurs in a State designated no-harvest sanctuary. The remaining populations occur in the Colorado or Brazos River systems adjacent to private land.

Lead Region Contact:

DIV OF ENDNGRD SPECIES AND HAB CONSERV, Nathan Allan, 512-490-0057, nathan_allan@fws.gov

Lead Field Office Contact:

Biological Information

Species Description:

The Texas fawnsfoot is a small, relatively thin-shelled freshwater mussel that can reach 60 mm (2.4 in) in length but is usually much smaller (Howells 2010d, p. 2). The shell is long and oval, generally free of external sculpturing, with external coloration that varies from yellowish- or orangish-tan, brown, reddish-brown, to smokygreen with a pattern of broken rays or irregular blotches (Howells 2010d, p. 2). The nacre (inside of the shell) is bluish-white or white and iridescent posteriorly (Howells 2010d, p. 2).

Taxonomy:

The Texas fawnsfoot was first described as Unio macrodon by Lea in 1859 and was subsequently placed in the genus Margaron by Lea in 1870 and then moved to Plagiola by Simpson (1900, p. 605). Ultimately the species was placed in the genus Truncilla by Strecker (1931, pp. 63, 65). The Texas fawnsfoot is recognized by the Committee on Scientific and Vernacular Names of Mollusks of the Council of Systematic Malacologists, American Malacological Union (Turgeon et al. 1998, p. 37), and we recognize it as a valid species.

Habitat/Life History:

Since Texas fawnsfoot were not found alive for many years, very little information is available about its habitat preferences. In the past only Texas fawnsfoot shells and recently dead individuals were occasionally found along rivers following drought-related dewatering or bank deposition after high floods. These shells and recently dead individuals indicated that the Texas fawnsfoot occurs in flowing water, as it was never found in ponds, lakes, or reservoirs, suggesting that it is intolerant of deep, low-velocity waters created by artificial impoundments (Howells 2010d, p. 3). The recently discovered live population in the Brazos River indicates that the species occurs in rivers with soft, sandy sediment with moderate water flow (Randklev and Lundeen 2010, p. 1; Randklev et al. 2010a, p. 298; Johnson 2011, p. 1). There is no specific information on age, size of maturity, or host fish use for Texas fawnsfoot. However, other species in the genus Truncilla parasitize freshwater drum (Aplodinotus grunniens) (OSUM 2011f, p. 1), and it is likely the Texas fawnsfoot does as well. Freshwater drum are ubiquitous throughout the range of Texas fawnsfoot (Hubbs et al. 2008, p. 53).

Adult freshwater mussels are filter-feeders, siphoning algae, bacteria, detritus, microscopic animals, and dissolved organic matter (Fuller 1974, pp. 221–222, Silverman et al. 1997, p. 1862; Nichols and Garling 2000, p. 874–876; Christian et al. 2004, p. 109). For their first several months, juvenile mussels feed using cilia (fine hairs) on the foot to capture suspended as well as depositional material, such as algae and detritus (Yeager et al. 1994, pp. 253–259). Mussels tend to grow relatively rapidly for the first few years, and then slow appreciably at sexual maturity, when energy presumably is being diverted from growth to reproductive activities (Baird 2000, pp. 66–67). Mussels are extremely long lived, living from two to several decades (Rogers et al. 2001, p. 592), and possibly up to 200 years in extreme instances (Bauer 1992, p. 427).

Most mussel species, including Texas fawnsfoot, have distinct forms of male and female. During reproduction, males release sperm into the water column, which females draw in through their siphons. Fertilization takes place internally, and the resulting eggs develop into specialized larvae (called glochidia) within the female’s modified gill pouch (called marsupia) for four to six weeks. The females will then release matured glochidia individually, in small groups, or embedded in larger mucus structures called conglutinates. Glochidia are obligate parasites (cannot live independently of their hosts) on fish and attach to the gills or fins of appropriate host species where they encyst (enclose in a cyst-like structure) and feed off of the host’s body fluids (Vaughn and Taylor 1999, p. 913) and develop into juvenile mussels weeks or months after attachment (Arey 1932, pp. 214–215). The glochidia will die if they fail to find the appropriate host fish, attach to a fish that has developed immunity from prior infestations, or attach to the wrong location on a host fish (Neves 1991, p. 254; Bogan 1993, p. 299). Mussels experience their primary opportunity for dispersal and movement within the stream as glochidia attached to a host fish (Smith 1985, p. 105). Upon release from the host, newly transformed juveniles drop to the substrate on the bottom of the stream. Those juveniles that drop in unsuitable substrates die because their immobility prevents them from relocating to more favorable habitat. Juvenile freshwater mussels burrow into interstitial substrates and grow to a larger size that is less susceptible to predation and displacement from high flow events (Yeager et al. 1994, p. 220). Throughout the rest of their life cycle, mussels generally remain within the same small area where they released from the host fish.

Historical Range/Distribution:

The Texas fawnsfoot is endemic to the Brazos and Colorado Rivers of central Texas (Howells et al. 1996, p. 143; Randklev et al. 2010a, p. 297). From the 1960s to the 1990s, malacologists working in central Texas found few individuals and few new population locations (Howells 2010d, p. 6). Historical records suggest the Texas fawnsfoot inhabited much of the Colorado River, from Wharton County upstream as far as the North Fork Concho River in Sterling County, as well as throughout the Concho, San Saba, and Llano Rivers and Onion Creek within the Colorado River basin (Howells 2010d, p. 4; Randklev et al. 2010b, p. 24). In the Brazos River, the species occurred from Fort Bend County upstream to the lower reaches of the Clear Fork Brazos River in Shackelford County, as well as in the Leon River, Little River, San Gabriel River, Deer Creek, and Yegua Creek (Howells 2010d, pp. 4–5; Randklev et al. 2010b, p. 24). Species reports from the Trinity River and other east Texas locations are of misidentified fawnsfoot (Truncilla donaciformis) (Howells 2010d, p. 4).

Current Range Distribution:

Until recently, relatively few Texas fawnsfoot have been documented since the species was first described in1859, and few live individuals have been found in recent decades (Randklev et al. 2010a, p. 297). All individuals found in recent decades were considered flood deposited on gravel bars and near death just prior to collection (Randklev et al. 2010a, p. 297), therefore, preventing information from being gathered about population size, preferred habitat, and other parameters. It was not until 2008 when the first live population of Texas fawnsfoot was discovered in the Brazos River near its confluence with the Navasota River (Randklev et al. 2010a, p. 297). A second larger population was found in 2009 in the Colorado River (Johnson 2009, p. 1; Burlakova and Karatayev 2010a, p. 17). Evidence of other remnant populations have also been found in the Clear Fork Brazos River, San Saba River, and Deer Creek.

Colorado River System

The Texas fawnsfoot has been eliminated from almost all of the Colorado River system. Live individuals were found in the upper and lower mainstem Colorado River in 2012 and 2009 respectively, and the only other evidence of current occurrence of Texas fawnsfoot in the Colorado River basin is in the San Saba River, where a population persists.

In the mainstem Colorado River, the Texas fawnsfoot historically occurred from Wharton County upstream into the headwaters (Randklev et al. 2010c, p. 4; OSUM 2011e, p. 1). Surveys throughout the upper Colorado River between 1993 and 2009 yielded only one dead individual found in 1999 in San Saba County when the entire river was dewatered and all mussels were eliminated from the area (Howells 2000a, pp. 25–26; 2009, p. 17). There was no other evidence of Texas fawnsfoot in the upper Colorado River (Howells 1994, pp. 20–21, 29; 1996, pp. 20–21, 23; 1997a, pp. 27, 31, 34–35; 1998, p. 10; 2000a, p. 27; 2002a, p. 6; 2004, p. 7; Burlakova and Karatayev 2010a, p. 16) until, Randklev (Pers. Comm. 2012) located a live individual downstream from the confluence of the San Saba River. Presence/absence surveys further downstream in San Saba and Lampasas Counties found recent dead to long dead Texas fawnsfoot shells but no live individuals in 2013 (Service Files, 2013). It is likely that a small population may persist in this section of the upper mainstem Colorado River, since it is downstream of the Texas fawnsfoot population in the San Saba River.

In the lower Colorado River in Colorado County, several old shells of Texas fawnsfoot were found at several sites in 1996 (Howells 1997a, p. 35), and, subsequently in 2009, two live individuals were discovered (Johnson 2011, p. 1). Later that year, this site was revisited, and the population was estimated to be approximately 2,800 individuals, with individuals ranging in size from 21 to 38 mm (0.8–1.5 in) (Burlakova and Karatayev 2010a, p. 17), indicating that reproduction and recruitment was occurring. This large population of Texas fawnsfoot was not located during three survey trips in the spring and summer of 2012. This population may have been lost during the 2009 and 2011 drought. However, two live individuals along with several recently dead shells were located downstream of that site in 2012 and 2013 (Service Files, 2012; Service Files 2013). The Service also found recently dead to long dead shells at one additional site in Colorado County and one site in Wharton County in 2013 (Service Files, 2013).

Texas fawnsfoot were not known to occur in the San Saba River si until a single live individual was collected in 2011 (Burlakova and Karatayev 2011, p. 6). Six additional live mussels were found at a different site later that year (Burlakova and Karatayev 2012a, p. 11; Burlakova and Karatayev 2012b, p. 17). Additional surveys yielded 16 Texas fawnsfoot of various ages collected at the site (Randklev 2011b, p. 1), indicating a persistent, recruiting population. The population size of Texas fawnsfoot throughout San Saba River has been estimated to be approximately 18,995 individuals (Burlakova and Karatayev 2012b, p. 17).

Texas fawnsfoot is presumed extirpated from the remainder of the Colorado River basin. Although historical records exist in the North Concho, Concho, and Llano Rivers and in Onion Creek (Randklev et al. 2010c, p. 4), numerous surveys of these streams indicate the extirpation of the species in these streams (Howells 1994, pp. 5–6; 1995, pp. 22–25, 28–29; 1996, pp. 21–22; 1998, pp.14–17; 1999, pp. 15–16; 2000a, pp. 23, 25; 2001, p. 27; 2005, p. 9; Burlakova and Karatayev 2011, p. 6).

Brazos River System

In the Brazos River system, the Texas fawnsfoot persists in the mainstem Brazos River, Clear Fork Brazos River, Navasota River, and possibly in Deer Creek. The species has been extirpated from the Leon River, Little River, San Gabriel River, and Yegua Creek.

In the mainstem Brazos River, the Texas fawnsfoot historically occurred throughout the length of the river, from Palo Pinto County downstream to Fort Bend County (Randklev et al. 2010c, pp. 2–4;

Burlakova and Karatayev 2010b, p. 1; OSUM 2011e, p. 1). While the species appears to have retained its range through the length of the Brazos River, occurrences are represented by very few live or recently dead individuals.

In the upper Brazos River in Palo Pinto and Parker Counties, two live individuals were found at each of two sites in 1996, as well as numerous recently dead shells (Howells 1997a, pp. 16, 17). A survey in 2000 yielded no evidence of Texas fawnsfoot in this area (Howells 2001, p. 19); however, reports from mussel watch volunteers stated that recently dead shells were found below Possum Kingdom Dam in Palo Pinto County (TPWD 2013, p. 23). Nearby, in Somervell County, four recently dead individuals were found in the mainstem Brazos River in 1996 (Howells 1997a, pp. 18–19. In 2007, only one old shell was found in the same area (Burlakova and Karatayev 2010b, p. 1). Further downstream in McLennan County, two live Texas fawnsfoot were located in 2011 (Randklev 2012). Surveys in Milam and Falls Counties have not yielded any evidence of Texas fawnsfoot, indicating the species may have been extirpated from this section of the Brazos River (Howells 1995, p. 17; 1999, pp. 12–13).

In the middle Brazos River, Texas fawnsfoot persists in low numbers in the vicinity of Brazos, Washington, and Grimes Counties. One live individual and several recently dead shells were found in 1994 (Howells 1996, pp. 17–18; TPWD 2013, p. 47), representing the first live collection of the species anywhere since the 1970s. In 1999, numerous recently dead Texas fawnsfoot of mixed sizes and ages were found at several sites in Burleson and Brazos Counties (Howells 2000a, pp. 21–22), indicating a recruiting population existed in the area. Several live individuals and recently dead Texas fawnsfoot have been documented in the same sections of the river during repeated surveys in 2000, 2003, 2006-2008, and 2011 (Howells 2001, p. 22; Karatayev and Burlakova 2008, p. 7; Howells 2009, p. 17; TPWD 2013, p. 40). In the mainstem Brazos River adjacent to the confluence of Yegua Creek, in Brazos and Washington Counties, 15 more live mussels were found during 2011 survey efforts (Randklev 2012). More surveys were conducted in the same general area in late 2012, where a total of 53 individuals were located (Randklev 2012, pers. comm.). The Service sampled same general area in 2014 and collected several fresh dead to long dead shells, indicating that the species continues to persist within Brazos, Burleson, Washingon, and Grimes Counties (Service Files, 2014).

The first account of a living population of Texas fawnsfoot (animals living in situ rather than deposited on or near the banks by floods) occurred in 2008 in the lower Brazos River near its confluence with the Navasota River (Randklev et al. 2010a, p. 297). Ten live individuals were collected, and all were small, indicating successful reproduction and recent recruitment. An additional Texas fawnsfoot was found in this area in 2011 (Randklev 2011a, p. 1). In 2006, one live and three recently dead Texas fawnsfoot were collected in Austin and Waller Counties making it the furthest downstream collection in the mainstem of Brazos River at the time (Karatayev and Burlakova 2008, p. 39). In 2012, a total of 57 live individuals were found at three different locations within Austin and Waller Counties (Randklev 2012, pers. comm.). Further downstream, in Austin and Fort Bend Counties, a total of 14 live mussels were found in late 2012, and even further downstream, another 14 live Texas fawnsfoot at several locations within Fort Bend County, making it the furthest downstream collection in the mainstem of the Brazos River on record in recent years (Randklev 2012, pers. comm.).

Texas fawnsfoot was first discovered in the Navasota River in 2011, when three individuals were found in Brazos and Grimes Counties (Randklev 2011a, p. 1). Previous surveys had not yielded evidence of the species in this river (Howells 2001, p. 23).

A recently dead Texas fawnsfoot was collected from Deer Creek, a tributary to the Brazos River in Falls County, in 2006 (Burlakova and Karatayev 2010b, p.1), despite previous surveys that yielded no evidence of the species (Howells 1999, p. 12).

Additionally, a Texas fawnsfoot population persists in the Clear Fork Brazos River. Recently dead Texas fawnsfoot have been collected in several locations along the length of the river, in Shackelford, Stephens, and Young Counties during 2010 survey efforts (Randklev et al. 2010c, p. 4; Randklev 2011, pers. comm.). Surveys conducted for the proposed Cedar Ridge Reservoir during late summer 2011, revealed over 264 fresh dead to recently dead Texas fawnsfoot in an 8-mile section of Clear Fork River, in Shackelford and Throckmorton Counties (Draft - Cedar Ridge Reservoir Project, December 2011, pp. 1–19). It was also reported that this section of the river stopped flowing due to severe drought conditions in 2011(Draft - Cedar Ridge Reservoir Project, December 2011, pp. 1–19); therefore, the status of this population is unknown.

Several other tributaries to the Brazos River that historically contained Texas fawnsfoot appear to no longer support the species after numerous surveys reveal no living or dead individuals, including the Leon River (Howells 1994, pp. 18–20; 1997a, pp. 19–20), the Little River (Howells 1997a, pp. 22–23), the San Gabriel River (Howells 1997a, p. 23), and Yegua Creek (Howells 1997a, pp. 24, 25–26; 1999, p. 14; 2001, p. 22; 2004, p. 6).

Population Estimates/Status:

Based on historical and current data, the Texas fawnsfoot has declined rangewide and is now known from only seven populations. The species has been extirpated from nearly all of the Colorado River basin and from much of the Brazos River basin. Of the populations that remain, only the lower Colorado, San Saba, and Brazos River populations are likely to be stable and recruiting; the remaining populations are disjunct and restricted to short stream reaches.

Threats

A. The present or threatened destruction, modification, or curtailment of its habitat or range:

The decline of mussels in Texas and across the United States is primarily the result of habitat loss and degradation (Neves 1991, pp. 252, 265; Howells et al. 1996, pp. 21–22). Chief among the causes of mussel decline in Texas are the effects of impoundments, sedimentation, dewatering, sand and gravel mining, and chemical contaminants (Neck 1982a, pp. 33–35; Howells et al. 1996, pp. 21–22; Winemiller et al. pp. 17–18). These threats are discussed below.

Impoundments

A major factor in the decline of freshwater mussels across the United States has been the large-scale impoundment of rivers (Vaughn and Taylor 1999, p. 913). Dams are the source of numerous threats to freshwater mussels: They block upstream and downstream movement of species by blocking host fish movement; they eliminate or reduce river flow within impounded areas, thereby trapping silts and causing sediment deposition; and dams change downstream water flow timing and temperature, decrease habitat heterogeneity, and affect normal flood patterns (Layzer et al. 1993, pp. 68–69; Neves et al. 1997, pp. 63–64; Watters 2000, pp. 261–264; Watters 1996, p. 80). Within reservoirs (the impounded waters behind dams), the decline of freshwater mussels has been attributed to sedimentation, decreased dissolved oxygen, and alteration of resident fish populations (Neves et al. 1997, pp. 63–64; Pringle et al. 2000, pp. 810–815; Watters 2000, pp. 261–264). Dams significantly alter downstream water quality and stream habitats (Allan and Flecker 1993, p. 36; Collier et al. 1996, pp. 1, 7) resulting in negative effects to tailwater (the area downstream of a dam) mussel populations (Layzer et al. 1993, p. 69; Neves et al. 1997, p. 63; Watters 2000, pp. 265–266). Below dams, mussel declines are associated with changes and fluctuation in flow regime, scouring and erosion of stream channels, reduced dissolved oxygen levels and water temperatures, and changes in resident fish assemblages (Williams et al. 1992, p. 7; Layzer et al. 1993, p. 69; Neves et al. 1997, pp. 63–64; Pringle et al. 2000, pp. 810–815; Watters 2000, pp. 265–266). Numerous dams have been constructed throughout the Colorado and Brazos River systems within the range of Texas fawnsfoot (Stanley et al. 1990, p. 61).

Population losses due to the effects of dams and impoundments have likely contributed more to the loss of diversity and abundance of freshwater mussels across Texas, including the Texas fawnsfoot, than any other factor. Stream habitat throughout nearly all of the range of Texas fawnsfoot has been affected by numerous impoundments, leaving generally short, isolated patches of remnant habitat between dams. Impoundments have resulted in profound changes to the nature of the rivers, primarily replacing free-flowing river systems with a series of large reservoirs.

There are no natural lakes within the range of the Texas fawnsfoot, nor has it ever been found in reservoirs. Surveys of the reservoirs on the Brazos and Colorado Rivers have been ongoing since at least 1992, and no evidence of live or dead Texas fawnsfoot has been found in any reservoir (Howells 1994, pp. 1–20; 1995, pp. 1–50; 1996, pp. 1–45; 1997a, pp. 1–58; 1998, pp. 1–30; 1999, pp. 1–34; 2000a, pp. 1–56; 2001, pp. 1–50; 2002a, pp. 1–28; 2003, pp. 1–42; 2004, pp. 1–48; 2005, pp. 1–23; 2006, pp. 1–106; Karatayev and Burlakova 2008, pp. 1–47; Burlakova and Karatayev 2010a, pp. 1–30; 2011, pp. 1–8), further indicating that this species is not tolerant of impoundments. Dams continue to fragment Texas fawnsfoot populations, and the downstream effects of dams are detrimental to their habitat.

Impoundments and numerous dams occur throughout the range of the Texas fawnsfoot. The majority of Nueces-Frio, Guadalupe-San Antonio, Colorado, and Brazos Rivers, as well as many tributaries, are now impounded. There are 74 major reservoirs and numerous smaller impoundments within the historical and current range of the Texas fawnsfoot. Thirty-one of the 74 major reservoirs are located within the Colorado River basin, and the remaining 43 reservoirs are located within the Brazos River basin. There are also eleven new reservoirs that have been recommended for development as feasible alternatives to meet future water needs within the Brazos River basin (Brazos G Regional Water Planning Group 2010, p. 4B.12–1). In addition, six new off-channel reservoirs are also being considered for future development (Brazos G Regional Water Planning Group 2010, p. 4B.13–2). At least one of the proposed reservoir sites on Clear Fork Brazos River in Shackelford, Haskell, and Throckmorton Counties is in the vicinity of where more than 264 fresh dead to recently dead and one live Texas fawnsfoot were found within and downstream of the proposed site in 2011 (Draft-Cedar Ridge Reservoir Project Fish and Mussel Surveys 2011, pp. 1–19). These, and numerous smaller dams, occur throughout the Colorado and Brazos River basins and have resulted in ongoing destruction and modification of Texas fawnsfoot habitat and the curtailment of its range.

Dams threaten freshwater mussels in several ways. First, they can prevent the movement of freshwater mussel host fish. The overall distribution of mussels is a function of the dispersal of their hosts (Watters 1996, p. 83). For example, Watters (1996, p. 80) found that the distributions of the fragile papershell (Leptodea fragilis) and pink heelsplitter (Potamilus alatus) in five midwestern rivers were determined by the presence of low-head dams. These dams were non-navigable (without locks), lacked fish ladders, and varied in height from 1 to 17.7 m (3 ft to 58 ft), and the host fish could not disperse through them. Although the distribution of mussels may depend on many ecological factors, the evidence presented in Watters (1996, pp. 79–85) illustrates that dams as small as 1 m (3 ft) high can limit the distribution of mussels. There are many dams that occur throughout the range of the Texas fawnsfoot that lack fish ladders and may be a barrier to the movement of fish hosts and, therefore, the distribution of mussels. Because the Texas fawnsfoot populations are all separated by dams of various sizes that are not passable by fish, the mussel is unable to disperse from its current occupied range through host fish migration.

Dams also alter aquatic habitat within the resulting impoundments. It is well documented that many mussel species that are adapted to flowing water stream environments do poorly in the altered aquatic conditions found within impoundments (Williams et al. 1992, p. 7; Vaughn and Taylor 1999, p. 913). Once a dam is constructed, the original river channel upstream remains intact but under much deeper water with much lower velocities. As water velocity decreases, water loses its ability to carry sediment; sediment falls to the substrate, eventually smothering mussels that cannot adapt to soft substrates (Watters 2000, p. 263). Over time, the original mussel species composition of the stream channel may be eliminated or changed in favor of silt tolerant species (Watters 2000, p. 264). The mussel community may be altered from one with many different species to a community dominated by one to several very common species (Neck 1982b, p. 174). The deep water in reservoirs is very cold and often devoid of oxygen and necessary nutrients (Watters 2000, p. 264). Cold water (less than 11 ° C (52 °F)) has been shown to stunt mussel growth (Hanson et al. 1988, p. 352). Because mussel reproduction is temperature dependent (Watters and O'Dee 1999, p. 455), it is likely that individuals living in the constantly cold hypolimnion in these channels may never reproduce, or reproduce less frequently (Watters 2000, p. 264). The same would be true for mussels living in coldwater discharges downstream of large impoundments (Watters 2000, p. 264). The inundation of stream habitat by impoundments is a likely cause of the reduction in the distribution of the Texas fawnsfoot. The presence of the impoundments has caused the permanent loss of Texas fawnsfoot habitat throughout its range.

Mussels downstream of impoundments are often affected through changes in fish host availability, water quality (particularly lower water temperatures), habitat structure, and stream channel scouring (Vaughn and Taylor 1999, p. 916). The release of cold water from the hypolimnion (deeper and colder layer of water in reservoirs) can decrease the occurrence of fish species adapted to warm water and increase the occurrence of fish species adapted to colder water (Edwards 1978, pp. 73–75). This changes the species composition of suitable host fish and may prevent mussels from completing an essential part of their reproductive cycle. This has been demonstrated by the extirpation of mussel species from several rivers on the eastern seaboard of the United States, which has been linked to the disappearance of appropriate host fish; the reintroduction of the host fish to rivers has enabled mussel species to recolonize areas (Kat and Davis 1984, p. 174). In addition, because mussel reproduction is temperature dependent (Watters and O'Dee 1999, pp. 455–456), it is likely that individual mussels living in cold waters downstream of dam releases may reproduce less frequently, if at all (Layzer et al. 1993, p. 69). Low water temperatures can also significantly delay or prevent metamorphosis (Watters and O'Dee 1999, pp. 454–455) and glochidial release, which is often triggered by water temperature (Watters and O'Dee 2000, p. 136).

In addition to the temperature of water released from dams, highly fluctuating, turbulent tailwaters devoid of sediment will scour the riverbed downstream of dams, rendering the area without mussel habitat (Layzer et al. 1993, p. 69). Depending on the use of the dam, water levels may fluctuate on a regular interval (for hydroelectric purposes) or at random (for flood control) (Watters 2000, p. 265). On the Colorado River, Inks Lake, Lake Marble Falls, Lake Buchanan, Lake Austin, Lake Travis, and Lady Bird Lake are each used for one or both of these purposes. Mortality of another rare mussel species in Texas, the Texas heelsplitter (Potamilus amphichaenus) was attributed to scheduled dewatering of the Neches River below B.A. Steinhagen Reservoir in east Texas (Neck and Howells 1994, p. 15).

In one study of the downstream effects of dams, Vaughn and Taylor (1999, p. 915) found a strong, gradual, linear increase in mussel species richness and abundance at sites on the Little River in Oklahoma downstream from Pine Creek Reservoir. Their research revealed that mussel species richness and total abundance did not begin to rebound until 20 km (12 mi) downstream of the impoundment and did not peak until 53 km (33 mi) downstream. They noted the most obvious difference since reservoir construction has been the alteration of the flow and temperature regimes, which gradually return to preimpoundment levels with downstream distance from the dam. These alterations appear to have produced an extinction gradient of mussels that is most severe near the dam (Vaughn and Taylor 1999, p. 915). We expect similar effects of the Texas fawnsfoot and other Texas mussels downstream of dams. For example, mussel habitat below the Possum Kingdom

Reservoir in the mainstem of the Brazos River did not stabilize until150 km (240 mi) below the dam (Yeager 1993, p. 68).

Dam construction also fragments the range of Texas fawnsfoot, leaving remaining habitats and populations isolated by the structures as well as by extensive areas of deep, uninhabitable, impounded waters. These isolated populations are unable to naturally recolonize suitable habitat that may be impacted by temporary but devastating events, such as severe drought, chemical spills, or unauthorized discharges. Dams impound river habitats throughout almost the entire range of the species. These impoundments have left short and isolated patches of remnant habitat, typically in between impounded reaches.

The widespread construction of dams throughout the range of Texas fawnsfoot has significantly altered stream habitat both upstream and downstream of the dams by changing fish assemblages, temperature, dissolved oxygen, and substrate. The effects of dams are ongoing, decades after construction. In addition, the construction of new reservoirs is also being considered within the species' range that could result in additional habitat loss. Because of this loss of habitat and its effects on the populations, we conclude that the effects of impoundments are a threat to the Texas fawnsfoot.

Sedimentation

Siltation and general sediment runoff is a pervasive problem in streams and has been implicated in the decline of stream mussel populations (Ellis 1936, pp. 39–40; Vannote and Minshall 1982, p. 4105; Dennis 1984, p. ii; Brim Box and Mossa 1999, p. 99; Fraley and Ahlstedt 2000, pp. 193–194). Specific biological effects on mussels from excessive sediment include reduced feeding and respiratory efficiency from clogged gills (Ellis 1936, p. 40), disrupted metabolic processes, reduced growth rates, increased substrate instability, limited burrowing activity (Marking and Bills 1979, pp. 208–209; Vannote and Minshall 1982, p. 4106), physical smothering, and disrupted host fish attractant mechanisms (Hartfield and Hartfield 1996, p. 373). The primary effects of excess sediment on mussels are sublethal, with detrimental effects not immediately apparent (Brim Box and Mossa 1999, p. 101).

The physical effects of sediment on mussel habitats are multifold and include changes in suspended material load; changes in streambed sediment composition from increased sediment production and runoff in the watershed; changes in the form, position, and stability of stream channels; changes in water depth or the width-to-depth ratio, which affects light penetration and flow regime; actively aggrading (filling) or degrading (scouring) channels; and changes in channel position that may leave mussels stranded (Brim Box and Mossa 1999, pp. 109–112). Increased sedimentation and siltation may explain, in part, why Texas fawnsfoot appear to be experiencing recruitment failure in some streams. Interstitial spaces (small openings between rocks and gravels) in the substrate provide essential habitat for juvenile mussels. When clogged with sand or silt, interstitial flow rates and spaces may become reduced (Brim Box and Mossa 1999, p. 100), thus reducing juvenile habitat availability. Juvenile freshwater mussels, including Texas fawnsfoot juveniles, burrow into interstitial substrates, making it particularly susceptible to degradation of this habitat.

Even in 1959, Colorado River was noted as having high sedimentation rates from agricultural activities (Soil Conservation Service 1959, pp. 56, 59). Approximately 40 percent of U.S. river miles do not meet Clean Water Act standards due to excessive sediment loads (Environmental Protection Agency (EPA) 2000, p. 1), with agricultural activities being the primary source of sediment in streams (Waters 1995, p. 170). In general, sedimentation, resulting from unrestricted access by livestock, has been shown to be a significant threat to many streams and their mussel populations (Fraley and Ahlstedt 2000, p. 193).

The dominant land use in the Colorado River basin is grazing (Hersh 2007, p. 11). Soil compaction from intensive grazing may reduce infiltration rates and increase runoff, and trampling of riparian vegetation increases the probability of erosion (Armour et al. 1994, p. 10; Brim Box and Mossa 1999, p. 103). Additionally, much of the Brazos River basin is grazed or farmed for row crops, which often contributes large amounts of sediment to the basin (Brazos River Authority 2007, p. 4). Reservoir construction in the upper portion of the basin has been attributed with the erosion and subsequent sedimentation of the lower river (USGS 2001, p. 30), as sediment-poor tailwaters scour the riverbanks below the dam and deposit sediment farther downstream. In 2004, sedimentation was high enough in the Brazos River below Possum Kingdom Reservoir to cause residents to raise concerns to the Brazos River Authority (Brazos River Authority 2006, p. 2), and elevated suspended sediment levels have been reported throughout the basin (Brazos River Authority 2006, p. 8).

Sedimentation may become an increasing threat to the Texas fawnsfoot in the Colorado and Brazos River basins as the Austin metropolitan area continues to expand. Activities associated with urbanization, such as road construction, increased impervious surfaces, and road construction can be detrimental to stream habitats (Couch and Hamilton 2002, p. 1). The City of Austin, population approximately 800,000 people (Austin City Connection 2011, p. 1) lies within the Colorado River basin, and 3.9 million people live within the Brazos River basin (Brazos River Authority 2007, p. 1). Both of these basins have undergone substantial urbanization providing sources of increased sediment runoff into habitats of the Texas fawnsfoot. Runoff from increased impervious surfaces increases sediment loads in streams and destabilizes stream channels (Pappas et al. 2008, p. 151). Impervious surfaces also result in channel instability by accelerating stormwater runoff, which increases bank erosion and bed scouring, thereby further increasing downstream sedimentation (Brim Box and Mossa 1999, p. 103). While erosion and sedimentation associated with road construction may be temporary, the existence of road crossings is shown to have ongoing impacts to mussel habitat. For example, in the Guadalupe River, road crossings were found to cause a long-term increase in sedimentation both upstream and downstream, as channel constriction reduced flow upstream, causing sediment deposition, and runoff from the road increased sedimentation downstream (Keen- Zebert and Curran 2009, p. 301). Urban development activities may also affect streams and their mussel fauna where adequate streamside buffers are not maintained and erosion from adjacent land is allowed to enter streams (Brainwood et al. 2006, p. 511).

The range of the Texas fawnsfoot receives sediment from increasing levels of sedimentation from agriculture, urbanization, and sand and gravel mining (discussed in section titled Sand and Gravel Mining); sedimentation is likely to continue to threaten the Texas fawnsfoot.

Dewatering

River dewatering can occur in several ways: anthropogenic activities such as surface water diversions and groundwater pumping, and natural events, such as drought. Surface water diversions and groundwater pumping can lower water tables, reducing river flows and reservoir levels. These actions can result in mussels stranded in previously wetted areas. This is a particular concern for Texas fawnsfoot within and below reservoirs, where water levels are managed for various purposes that can cause water levels in the reservoir or downstream to rise or fall in very short periods of time, such as when hydropower facilities release water during peak energy demand periods.

Drought can also severely impact Texas fawnsfoot populations. Central Texas, including the Colorado and Brazos River basins, experienced a major drought in the late 1970s (Lewis and Oliveria 1979, p. 243). Near record dry conditions in 2008 followed by a pattern of below-normal rainfall during the winter and spring of 2009 led to one of the worst droughts in recorded history for most of central Texas, including the range of the Texas fawnsfoot (Nielsen Gammon and McRoberts 2009, p. 2). This drought's severity was exacerbated by abnormally high air temperatures, a likely effect of climate change, which has already increased average air temperatures in Texas by at least 1 °C (1.8 °F) (Nielsen-Gammon and McRoberts 2009, p. 22). Instream flows throughout the Brazos River basin during this drought were significantly reduced (USGS 2011c, p. 1) and Texas fawnsfoot populations in areas with reduced water levels, such as in the Clear Fork Brazos River, may have been negatively affected.

Central Texas is currently experiencing another extreme drought, with rainfall between October 2010 and July 2011 being the lowest on record during those months (LCRA 2011c, p. 1). Many gravel bars that were surveyed in March and July were barely covered with water, large areas of the San Saba River were completely dry, and the situation got worse throughout the summer (Burlakova and Karatayev 2012b, p. 10). As the drought continued in the fall of 2011, many of the populations in San Saba River may no longer exist (Burlakova and Karatayev 2012b, p. 10); 2012 was dry as well (Service Files 2012), which may have further stressed any remaining populations.

According to the National Weather Service records for 2011, more than 77 percent of Texas is experiencing moderate to extreme drought (Burlakova and Karatayev 2012b, p. 16). Current climate model simulations suggest that the American southwest could experience a 60-year stretch of heat and drought unseen since the 12th century and that the region is likely to become drier and experience more frequent droughts, with changes accelerating toward the end of the century (Woodhouse et al. 2010, pp. 21283-21288). Droughts result in a decrease in water depth and flow velocity in streams inhabited by Texas fawnsfoot, which reduces the availability of food and dissolved oxygen and reduces survivability. As droughts persist, mussels face hypoxia, elevated water temperature and, ultimately, death due to stranding (Golladay et al. 2004, p. 501).

We do not know the extent of the impacts of stream dewatering on the Texas fawnsfoot; however, because several populations are small and isolated, the loss of numerous individuals at a site can have dramatic consequences to the population. Hydropower facilities, construction, and drought are occurring throughout the range of the Texas fawnsfoot; therefore, the effects of dewatering are ongoing and unlikely to decrease, resulting in significant threats to the Texas fawnsfoot.

Sand and Gravel Mining

Sand and gravel mining (removing bed materials from streams) has been implicated in the destruction of mussel populations across the United States (Hartfield 1993, pp. 136–138). Sand and gravel mining causes stream instability by increasing erosion and turbidity (a measure of water clarity) and causing subsequent sediment deposition downstream (Meador and Layher 1998, pp. 8–9). These changes to the stream can result in large-scale changes to aquatic fauna, by altering habitat and affecting spawning of fish, mussels, and other aquatic species (Kanehl and Lyons 1992, pp. 4–11).

The Brazos River has a long history of sand mining, particularly in the lower river, and channel morphology changes have been attributed to destabilization due to instream sand mining in the area (USGS 2001, p. 27). The removal of sand from within the river creates sediment traps during periods of high flow, which causes scouring and erosion downstream (USGS 2001, p. 27). One gravel dredging operation in the Brazos River was documented depositing sediment as far as 1.6 km (1 mile) downstream (Forshage and Carter 1973, p. 697). Accelerated stream bank erosion and downcutting of streambeds are common effects of instream sand and gravel mining, as is the mobilization of fine sediments during sand and gravel extraction (Roell 1999, p. 7).
Within the range of the Texas fawnsfoot, TPWD has issued permits for four current sand mining activities within the Brazos River (Austin, Bosque, and Fort Bend Counties) (TPWD 2004, p. 1; 2007b, p. 1, 2008b, p. 1; 2010b, p. 1). All of the permits allow for the repeated removal of sand and gravel at various locations within the Brazos River. The lower Brazos River, where these mining activities occur, contains one of the more numerous populations of Texas fawnsfoot.
In areas where repeated mining occurs, an upstream progression of channel degradation and erosion (called headcutting) can occur (Meador and Layher 1998, p. 8). Headcutting may move miles upstream in a zipper-like fashion as the upper boundary of the modified area collapses. Headcutting can be found within the majority of rivers and streams in Texas, including within the Texas fawnsfoot's current and historical range (Kennon et al. 1967, p. 22). Headcuts induced by sand and gravel mining can cause dramatic changes in streambank and channel shape that may affect instream flow, water chemistry and temperature, bank stability, and siltation (Meador and Layher 1998, p. 8), all of which are harmful to freshwater mussels. Mussels are particularly vulnerable to channel degradation and sedimentation processes associated with headcutting due to their immobility (Pringle 1997, p. 429).

In addition to headcutting, mines that are located near stream channels are subject to the gravel pit being captured by the stream during flood events or due to gradual channel migration (Simmang and Curran 2006, p. 1). For example, two gravel mines along the Colorado River downstream of Austin were inundated; one by stream channel migration in 1984, one by stream capture in 1991 (Simmang and Curran 2006, p. 1). Once captured by the mainstem river, gravel mines contribute large amounts of suspended sediment to the river, causing additional turbidity and sedimentation and further degrading mussel habitat.

The Texas fawnsfoot population in the lower Brazos River may be currently affected by sand and gravel mining. These activities occur over a long period of time, destabilizing mussel habitat both upstream and downstream, which decreases the likelihood of recolonization after the activity has been completed. Therefore, the effects of sand and gravel mining are an ongoing threat to the Texas fawnsfoot and are expected to continue to occur throughout the range of the species.

Chemical Contaminants

Chemical contaminants are ubiquitous throughout the environment and are a major reason for the decline of freshwater mussel species nationwide (Richter et. al. 1997, p. 1081; Strayer et al. 2004, p. 436; Wang et al. 2007a, p. 2029). Chemicals enter the environment through both point and nonpoint discharges, including spills, industrial sources, municipal effluents, and agriculture runoff. These sources contribute organic compounds, heavy metals, pesticides, herbicides, and a wide variety of newly emerging contaminants to the aquatic environment. As a result, water quality can be degraded to the extent that mussel populations are adversely affected.

Chemical and oil spills can be especially devastating to mussels because they may result in exposure of a relatively immobile species to elevated concentrations that far exceed toxic levels. Acute and chronic exposure to oil spills in freshwater systems is largely understudied; therefore, little information is available on effects of oil spills on freshwater ecosystems (Harrel 1985, p. 223; Bhattacharyya et al. 2002, p. 205). Oil is retained much longer in marshes and other low-energy environments, such as slow-moving streams and rivers, than on wave-swept coasts (Bhattacharyya et al. 2002, p. 205). Oils have been found in sediments at low energy sites as much as 5 years after the occurrence of spills, and they may be released into the water column long after the initial spill. Oil may have various chronic effects on water-column and benthic (bottom-dwelling) species. These effects include sensory disruption, behavioral and developmental abnormalities, and reduced fertility (Bhattacharyya et al. 2002, p. 205). Oil spilled on the water surface may also limit oxygen exchange, coat the gills of aquatic organisms, and cause pathological lesions on respiratory surfaces, thereby affecting respiration in aquatic organisms. Effects of oil on freshwater mussels may result from oil settling on the sediment
surfaces and accumulating in the sediment. This can prevent invertebrate colonization (Bhattacharyya et al. 2002, p. 205). Complete recovery of benthic communities may be a matter of years, with communities in the meantime consisting solely of pollutant-tolerant organisms (Bhattacharyya et al. 2002, p. 205).

Examples of the exposure of Texas fawnsfoot to chemical contaminants include an event in 2010, crude oil overflowed from a failed storage tank into Keechi Creek in Leon County, a tributary to the

Navasota River (National Response Center 2010, p. 2). This location is upstream of one of the few remaining Texas fawnsfoot populations. These can occur from on site accidents (tank, pipeline spills) or from tanker truck accidents within watersheds occupied by Texas fawnsfoot. For example, oil has spilled into the Brazos River a number of times. As much as 320,000 L (84,000 gal) of crude oil was spilled in the Brazos River in Knox County in 1991 (Associated Press 1991, p. 1). In June 2010, flooding of holding ponds adjacent to oil drilling operations leaked oil into Thompson Creek and subsequently into the Brazos River (Lewis 2010, p. 1). Also, in July 2010, oil pipelines burst and released approximately 165 barrels of crude oil into the upper Brazos River (Joiner 2010, p. 1). Although no analyses were conducted of the specific effects of these spills on Texas fawnsfoot, we expect that if the mussels are exposed to even moderate levels of toxic chemical contaminants, such as crude oil, adverse effects (both direct mortality and indirect effects to food source availability) are likely to occur.

Exposure of mussels to persistent low concentrations of contaminants likely to be found in aquatic environments can also adversely affect mussels and their populations. Such concentrations may not be immediately lethal, but over time can result in mortality, reduced filtration efficiency, reduced growth, decreased reproduction, changes in enzyme activity, and behavioral changes to all mussel life stages (Naimo 1995, pp. 351–352; Baun et al. 2008, p. 392). Frequently, procedures that evaluate the ‘‘safe’’ concentration of an environmental contaminant (for example, national water quality criteria) do not have data for freshwater mussel species or do not consider data that are available for freshwater mussels (March et al. 2007, pp. 2066–2067, 2073). One chemical that is particularly toxic to early life stages of mussels is ammonia. Sources of ammonia include agricultural activities (animal feedlots and nitrogenous fertilizers), municipal wastewater treatment plants, and industrial waste (Augspurger et al. 2007, p. 2026), as well as precipitation and natural processes (decomposition of organic nitrogen) (Goudreau et al. 1993, p. 212; Hickey and Martin 1999, p. 44; Augspurger et al. 2003, p. 2569; Newton 2003, p. 2543). Therefore, ammonia is considered a limiting factor for survival and recovery of some mussel species due to its ubiquity in aquatic environments, high level of toxicity, and because the highest concentrations typically occur in mussel microhabitats (Augspurger et al. 2003, p. 2574). In addition, studies have shown that ammonia concentrations increase with increasing temperature and low-flow conditions (Cherry et al. 2005, p. 378; Cooper et al. 2005, p. 381), which may be exacerbated during low-flow events in streams.

In addition to ammonia, agricultural sources of chemical contaminants include two broad categories that have the potential to adversely affect mussel species: Nutrients and pesticides. High amounts of nutrients, such as nitrogen and phosphorus, in streams can stimulate excessive plant growth (algae and periphyton, among others), which in turn can reduce dissolved oxygen levels when dead plant material decomposes. Nutrient over-enrichment in streams is primarily a result of runoff of fertlizer and animal manure from livestock farms, feedlots, and heavily fertilized row crops (Peterjohn and Correll 1984, p. 1471). Over-enriched conditions are exacerbated by low-flow stream conditions, such as those experienced during typical summer season flows. Bauer (1988, p. 244) found that excessive nitrogen concentrations can be detrimental to the adult freshwater pearl mussel (Margaritifera margaritifera), as was evident by the positive linear relationship between mortality and nitrate concentrations. Also, a study of mussel life span and size (Bauer 1992, p. 425) showed a negative correlation between growth rate and high nutrient concentrations, and longevity was reduced as the concentration of nitrates increased. Juvenile mussels in interstitial habitats are particularly affected by depleted dissolved oxygen levels resulting from nutrient over-enrichment (Sparks and Strayer 1998, p. 133).

Mussels are also affected by metals, such as cadmium, chromium, copper, mercury, and zinc, which can negatively affect biological processes such as growth, filtration efficiency, enzyme activity, valve closure, and behavior (Keller and Zam 1991, p. 543; Naimo 1995, pp. 351–355; Jacobson et al. 1997, p. 2390; Valenti et al. 2005, p. 1244). Metals occur in industrial and wastewater effluents and are often a result of atmospheric deposition from industrial processes and incinerators. Studies have shown that copper can have toxic effects on glochidia and juvenile freshwater mussels (Wang et al. 2007a, pp. 2036– 2047; Wang et al. 2007b, pp. 2048– 2056). Because we know that copper contamination in water can lead to death of mussels and that theses above mentioned sources are within the Texas fawnsfoot distribution, we conclude that the copper may be adversely affecting Texas fawnsfoot.

Mercury is another heavy metal that has the potential to negatively affect mussel populations, and it is widely distributed in the environment. Mercury has been detected throughout aquatic environments as a product of municipal and industrial waste and atmospheric deposition from coal burning plants. Rainbow mussel (Villosa iris) glochidia have been demonstrated to be more sensitive to mercury than juvenile mussels, with the median lethal concentration value of 14 parts per billion (ppb) for glochidia, compared to 114 ppb for the juvenile life stages (Valenti 2005, p. 1242). The chronic toxicity tests conducted determined that juveniles exposed to mercury greater than or equal to 8 ppb exhibited reduced growth. Acute mercury toxicity was determined to be the cause of extirpation of a diverse mussel community for a 112 km (70 mi) portion of the North Fork Holston River in Virginia (Brown et al. 2005, pp. 1455– 1457). Mercury has been documented throughout Texas rivers, with particularly high concentrations in fish in the upper reaches of some of the rivers (Lee and Schultz 1994, p. 8). As with copper, we do not have information on the concentration of mercury that Texas fawnsfoot is being exposed to in these streams, but the higher than expected levels in fish indicate high mercury levels in the area, which may be adversely affecting Texas fawnsfoot.

Pesticides are another source of contaminants in streams. Elevated concentrations of pesticides frequently occur in streams due to pesticide runoff, overspray application to row crops, and lack of adequate riparian buffers. The timing of agricultural pesticide applications in the spring often coincides with the reproductive and early life stages of mussels, which may increase the vulnerability of mussels to pesticides (Bringolf et al. 2007a, p. 2094). Little is known regarding the effect of currently used pesticides to freshwater mussels even though some pesticides, such as glyphosate (active ingredient in Roundup®), are used globally. Recent studies tested the toxicity of glyphosate, its formulations, and a surfactant (MON 0810) used in several glyphosate formulations, to early life stages of the fatmucket (Lampsilis siliquoidea) (Bringolf et al. 2007a, p. 2094). Studies conducted with fatmucket juveniles and glochidia determined that the surfactant was the most toxic of the compounds tested and that fatmucket glochidia were the most sensitive organisms tested to date (Bringolf et al. 2007a, p. 2094). Roundup®, technical grade glyphosate isopropylamine salt, and isopropylamine were also acutely toxic to juveniles and glochidia (Bringolf et al. 2007a, p. 2097). These commonly applied pesticides may be adversely affecting Texas fawnsfoot populations.

The effects of other widely used pesticides, including atrazine, chlorpyrifos, and permethrin, on glochidia and juvenile life stages have also recently been studied (Bringolf et al. 2007b, p. 2101). Environmentally relevant concentrations (concentrations that may be found in streams) of permethrin and chlorpyrifos were found to be toxic to glochidia and juvenile fatmucket (Bringolf et al. 2007b, pp. 2104–2106). Commonly applied pesticides are a threat to mussels as a result of their widespread use. All of these pesticides are commonly used on agricultural lands throughout the range of the Texas fawnsfoot, which may be adversely affecting the species.

A potential, but undocumented, threat to freshwater mussels, including Texas fawnsfoot, are compounds referred to as ‘‘emerging contaminants’’ that are being detected in aquatic ecosystems at an increasing rate. These include pharmaceuticals, hormones, and other organic contaminants that have been detected downstream from urban areas and livestock production (Kolpin et al. 2002, p. 1202) and have been shown to affect fish behavior (TCEQ 2010b, p. 3). In samples of the Trinity River, for example, compounds such as antidepressants, antihistamines, blood pressure lowering medication, antiseizure medication, and antimicrobial compounds were all detected during a 2006 study (TCEQ 2010b, pp. 27–28). A large potential source of these emerging contaminants is wastewater being discharged through both permitted (National Pollutant Discharge Elimination System (NPDES)) and nonpermitted sites within the Colorado and Brazos River systems. Although streams within the range of Texas fawnsfoot have not been tested for these emerging contaminants, permitted discharge sites are ubiquitous in watersheds with Texas fawnsfoot populations, providing many opportunities for contaminants to impact the species.

A study in the Blanco River found that mussels may be adversely affected by sewage effluent (Horne and McIntosh 1979, p. 132). Ammonia levels below the outfall were three times higher than the levels above the outfall and were higher than recently determined toxicity values of ammonia for mussels (Augsperger et al. 2003, p. 2572). The river was nutrient-enriched for miles downstream, and mussels were less abundant below the outfall than above (Horne and McIntosh 1979, pp. 124–125, 132).

Texas Commission on Environmental Quality (TCEQ) data for 2010 indicated that 26 of the 98 assessed water bodies within Colorado River basin and 81 of approximately 124 assessed water bodies within Brazos River basin did not meet surface water quality standards and were classified as impaired water bodies (Texas Clean Rivers Program 2010a, p. 5; TCEQ 2010c, pp. 1–106). These water bodies were impaired with dissolved solids, nitrites, nitrates, bacteria, low dissolved oxygen, aluminum, sulfates, selenium, chloride, orthophosphorus, phosphorus, Chlorophyll a, and low pH associated with agricultural, urban, municipal, and industrial runoff. Of these, nitrites and low dissolved oxygen are known to be harmful to freshwater mussels. Agricultural pesticides and emerging contaminants are likely also present in streams inhabited by

Texas fawnsfoot. There are 53 wastewater treatment plants permitted to discharge more than one million gallons per day into the Brazos River basin (Valenti and Brooks 2008, p. 12); the outfalls of these treatment plants have not been tested to determine if they contain contaminants of note.

Releases of chemical contaminants, such as oil, ammonia, copper, mercury, nutrients, pesticides, and other compounds into the habitat of the Texas fawnsfoot are an ongoing threat to the Texas fawnsfoot. The species is vulnerable to acute contamination from spills, as well as chronic contaminant exposure, which has occurred and is expected to continue to occur throughout the range of the Texas fawnsfoot.

Summary of Factor A

The reduction in numbers and range of the Texas fawnsfoot is primarily the result of the long-lasting effects of habitat alterations such as the effects of impoundments, sedimentation, dewatering, sand and gravel mining, and chemical contaminants. Impoundments occur throughout the range of the species and have farreaching effects to riverine habitat both upstream and downstream of the dams. Both the Colorado and Brazos River systems have experienced a large amount of sedimentation from agriculture, instream mining, and urban development. Sand and gravel mining affects Texas fawnsfoot habitat by increasing sedimentation and channel instability downstream and by causing headcutting upstream. Chemical contaminants exceeding the standards developed to support aquatic life have been documented throughout the range of the species and may represent a significant threat to the Texas fawnsfoot. Based upon our review of the best commercial and scientific data available, we conclude that the present or threatened destruction, modification, or curtailment of its habitat or range is an immediate and ongoing threat of high magnitude to the Texas fawnsfoot.

B. Overutilization for commercial, recreational, scientific, or educational purposes:

The Texas fawnsfoot is not a commercially valuable species and has never been harvested in Texas as a commercial mussel species (Howells 2010b, p.12). Some scientific collecting occurs but is not likely to be a significant threat to the species because it occurs only rarely. However, handling mussels can disturb gravid females and result in glochidial loss and subsequent reproductive failure. Additionally, handling has also been shown to reduce shell growth across mussel species, including several species of Lampsilis (Haag and Commens-Carson 2008, pp. 505–506). Repeated handling by researchers may adversely affect Texas fawnsfoot individuals, but these activities are occurring rarely and are not likely to be a threat to populations. Handling for scientific purposes contributes to the long-term conservation of the species. We do not have any evidence of risks to the Texas fawnsfoot from overutilization for commercial, recreational, scientific, or educational purposes, and we have no reason to believe this factor will become a threat to the species in the future. Based upon the best scientific and commercial information available, we conclude that overutilization for commercial, recreational, scientific, or educational purposes does not pose a threat to the Texas fawnsfoot rangewide.

C. Disease or predation:

Disease

Little is known about disease in freshwater mussels. However, disease is believed to be a contributing factor in documented mussel die-offs in other parts of the United States (Neves 1987, pp. 11–12). Diseases have not been documented or observed during any studies of Texas fawnsfoot.

Predation

Raccoons will prey on freshwater mussels stranded by low waters or deposited in shallow water or on bars following flooding or low water periods (Howells 2010c, p. 12). Predation of Texas fawnsfoot by raccoons may be occurring occasionally, but there is no indication it is a significant threat to the status of the species. Some species of fish feed on mussels, such as common carp, freshwater drum, and redear sunfish, all of which are common throughout the range of Texas fawnsfoot (Hubbs et al. 2008, pp. 19, 45, 53). Common species of flatworms are voracious predators of newly metamorphosed juvenile mussels of many species (Zimmerman et al. 2003, p. 30). Predation is a normal factor influencing the population dynamics of a healthy mussel population; however, predation may amplify declines in small populations primarily caused by other factors.

Summary of Factor C

Disease in freshwater mussels is poorly known, and we do not have any information indicating it is a threat to the Texas fawnsfoot. Additionally, predation is a natural ecological interaction and we have no information indicating the extent of any predation is a threat to populations of Texas fawnsfoot. Based upon the best scientific and commercial information available, we conclude that disease or predation is not a threat to the Texas fawnsfoot.

D. The inadequacy of existing regulatory mechanisms:

The Act requires us to examine the adequacy of existing regulatory mechanisms with respect to threats that may place the Texas fawnsfoot in danger of extinction or increase its likelihood of becoming so in the future. Existing regulatory mechanisms that could affect threats to the Texas fawnsfoot include State and Federal laws such as the Texas Threatened and Endangered Species regulations, Texas freshwater mussel sanctuaries, State and Federal sand and gravel mining regulations, and regulation of point and non-point source pollution.

Texas Threatened and Endangered Species Regulations

On January 8, 2010, the Texas Parks and Wildlife Commission placed 15 species of freshwater mussels, including the Texas fawnsfoot, on the State threatened list (Texas Register 2010, pp. 6–10). Section 68.002 of the Texas Parks and Wildlife (TPW) Code and Section 65.171 of the Texas Administrative Code (TAC) prohibit the direct take of a threatened species, except under issuance of a scientific collecting permit. ‘‘Take’’ is defined in Section 1.101(5) of the TPW Code as collect, hook, hunt, net, shoot, or snare, by any means or device, and includes an attempt to take or to pursue in order to take. While this law protects individuals from take, it is difficult to enforce and does not provide any protection for Texas fawnsfoot habitat. Moreover, our assessment finds that the species is not threatened by take (see Factor B above). There are no State provisions under the Texas Threatened and Endangered Species Regulations for reducing or eliminating the threats (see Factor A above) that may adversely affect Texas fawnsfoot or its habitat. In addition, these State regulations do not call for development of a recovery plan that will restore and protect existing habitat for the species. For these reasons, we find that existing Texas regulatory mechanisms for State-listed threatened species are currently inadequate to protect Texas fawnsfoot and its habitat or to prevent further decline of the species.

Freshwater Mussel Sanctuaries

The TPWD has designated specific areas of streams and reservoirs as no harvest mussel sanctuaries (31 TAC, part 2, chapter 57, subpart B, Rule 57.157). The locations of the designated mussel sanctuaries were selected because they support populations of rare and endemic mussel species or are important for maintaining, repopulating, or allowing recovery of mussels in watersheds where they have been depleted. Unfortunately, mussel sanctuaries only restrict the harvest of mussels and do not address other activities that may affect mussels or their habitats. Therefore, these designations provide no regulatory mechanisms to protect Texas fawnsfoot from habitat alteration.

State Sand and Gravel Mining Regulations

The TPWD has been responsible for regulating the ‘‘disturbance of taking’’ streambed materials since 1911 (Meador and Layher 1998, p. 11) and has issued several permits for ongoing activities within the Texas fawnsfoot range (for more information on the effects of sand and gravel mining on Texas fawnsfoot, please refer to ‘‘Sand and Gravel Mining’’ under Factor A in Five-Factor Evaluation). Sand and gravel mining may be one of the least regulated of all mining activities (Meador and Layher 1998, p. 10).

Clean Water Act

The U.S. Army Corps of Engineers (USACE) retains oversight authority and requires a permit for gravel and sand mining activities that deposit fill into streams under section 404 of the Clean Water Act (33 U.S.C. 1251 et seq.). Additionally, a permit is required under section 10 of the Rivers and Harbors Act (33 U.S.C. 401 et seq.) for navigable waterways. However, many mining operations do not fall under these two categories. For example, nationwide permits are issued by the USACE for types of projects that are presumed to have minimal environmental impacts. However, projects permitted by nationwide permits, such as small mining operations, may have cumulative effects on aquatic species like the Texas fawnsfoot through increased sedimentation and channel instability.

Point source discharges of potential contaminants within the range of the Texas fawnsfoot have been reduced since the inception of the Clean Water Act, but this reduction may not provide adequate protection for filter-feeding organisms that can be affected by extremely low levels of contaminants (see ‘‘Chemical Contaminants’’ under Factor A). The EPA’s established water quality criteria may not be protective of mussels. Current water quality standards applied by EPA were established to be protective of aquatic life; however, freshwater mussels were not used to develop these standards (EPA 2005, p. 5), and current research reveals mussels to be more sensitive to many aquatic pollutants than the tested organisms (Augsperger et al. 2007, p. 2025). For example, Augspurger et al. (2003, p. 2572) and Sharpe (2005, p. 28) suggested that the criteria for ammonia may not be sufficient to prevent impacts to mussels under current and future climate conditions. In addition, chronic copper concentrations lethal to juvenile freshwater mussels have been shown to be less than the EPA’s 1996 chronic water quality criterion for copper (Wang et al. 2007b, pp. 2052–2055). Based on this information, the existing EPA water quality criteria may not be sufficient to prevent negative effects to the Texas fawnsfoot.

Nonpoint source pollution such as sedimentation and chemical contamination is considered a significant threat to Texas fawnsfoot habitat; however, the Clean Water Act does not adequately protect Texas fawnsfoot habitat from nonpoint source pollution, because most activities that cause nonpoint source pollution are not regulated under the Clean Water Act.

Summary of Factor D

Despite some State and Federal laws protecting the species and water quality, the Texas fawnsfoot continues to decline due to the effects of habitat destruction, poor water quality, contaminants, and other factors. The regulatory measures described above are not sufficient to significantly reduce or remove the threats to the Texas fawnsfoot. Based upon our review of the best commercial and scientific data available, we conclude that the lack of existing regulatory mechanisms is an immediate threat of moderate magnitude to the Texas fawnsfoot.

E. Other natural or manmade factors affecting its continued existence:

Natural and manmade factors that threaten the Texas fawnsfoot include climate change, population fragmentation and isolation, and nonnative species.

Climate Change

It is widely accepted that changes in climate are occurring worldwide (International Panel on Climate Change (IPCC) 2007, p. 30). Understanding the effects of climate change on the Texas fawnsfoot is important because the disjunct nature of the remaining Texas fawnsfoot populations, coupled with the limited ability of mussels to migrate, makes it unlikely that the Texas fawnsfoot can adjust its range in response to changes in climate (Strayer 2008, p. 30). For example, changes in temperature and precipitation can increase the likelihood of flooding or increase drought duration and intensity, resulting in direct effects to freshwater mussels like the Texas fawnsfoot (Hastie et al. 2003, pp. 40–43; Golloday et al. 2004, p. 503). Because the range of the Texas fawnsfoot has been reduced to isolated locations with low population numbers in small to medium sized rivers and streams, the Texas fawnsfoot is vulnerable to climatic changes that could decrease the availability of water or produce more frequent scouring flood events. Indirect effects of climate change may include declines in host fish populations, habitat reduction, and changes in human activity in response to climate change (Hastie et al. 2003, pp. 43–44).

For the next two decades, a warming of about 0.2 °C (0.4 °F) per decade is projected across the United States (IPCC 2007, p. 12), and hot extremes, heat waves, and heavy precipitation and flooding are expected to increase in frequency (IPCC 2007, p. 18). As with many areas of North America, central Texas is projected to experience an overall warming trend in the range of 2.5 to 3.3 °C (4.5 to 6 °F) over the next 50 to 200 years (Mace and Wade 2008, p. 656). Even under lower greenhouse gas emission scenarios, recent projections forecast a 2.8 °C (5 °F) increase in temperature and a 10 percent decline in precipitation in central Texas by 2080–2099 (Karl et al. 2009, pp. 123–124). Based on our current understanding of climate change, air temperatures are expected to rise and precipitation patterns are expected to change in areas occupied by the Texas fawnsfoot. Karl et al. (2009, p. 12) also suggests that climate change impacts on water resources in the southern Great Plains (including central Texas) are expected as rising temperatures and decreasing precipitation exacerbate an area already plagued by low rainfall, high temperatures, and unsustainable water use practices.

One preliminary study forecasting the possible hydrological impacts of climate change on the annual runoff and its seasonality in the upper Colorado River watershed was conducted by CH2M HILL (2008). In this initial evaluation, four modeling scenarios (chosen to represent a range of possible future climatic conditions) were each run under a 2050 and 2080 time scenario, producing annual surface water runoff estimates at multiple sites with stream gages in the Colorado River basin. For the 2050 scenarios, the results from all four climate change scenarios predicted significant decreases in annual runoff totals compared to historic averages (CH2M HILL 2008, pp. 7–30—7–32). For the 2080 scenarios, one model predicted increases in annual runoff; the other three 2080 scenarios predicted decreases in annual runoff (CH2M HILL 2008, pp. 7–30—7–33). The modeling efforts from this study focus on annual averages and cannot necessarily account for the seasonal variations in flooding events or long periods of drought. However, the study demonstrates the potential effects of climate change on surface water availability, which is forecasted to result in an overall decline in stream flows in the region where the Texas fawnsfoot occurs.

In summary, climate change could affect the Texas fawnsfoot through the combined effects of global and regional climate change, along with the increased probability of long-term drought. Climate change exacerbates threats such as habitat degradation from prolonged periods of drought, increased water temperature, and the increased allocation of water for municipal, agricultural, and industrial use. As such, climate change, in and of itself, may affect the Texas fawnsfoot, but the magnitude and imminence (when the effects occur) of the effects remain uncertain. Based upon our review of the best commercial and scientific data available, we conclude that the effects of climate change in the future will likely exacerbate the current and ongoing threats of habitat loss and degradation caused by other factors, as discussed above.

Population Fragmentation and Isolation

As with many freshwater mussels, several of the remaining populations of the Texas fawnsfoot are small and geographically isolated and thus are susceptible to genetic drift, inbreeding depression, and random or chance changes to the environment, such as toxic chemical spills (Watters and Dunn 1995, pp. 257–258), or dewatering. Inbreeding depression can result in death, decreased fertility, smaller body size, loss of vigor, reduced fitness, and various chromosomal abnormalities (Smith 1974, pp. 350). Despite any evolutionary adaptations for rarity, habitat loss and degradation increase a species' vulnerability to extinction (Noss and Cooperrider 1994, pp. 58–62). Numerous authors (including Noss and Cooperrider 1994, pp. 58–62; Thomas 1994, p. 373) have indicated that the probability of extinction increases with decreasing habitat availability. Although changes in the environment may cause populations to fluctuate naturally, small and low-density populations are more likely to fluctuate below a minimum viable population (the minimum or threshold number of individuals needed in a population to persist in a viable state for a given interval) (Gilpin and Soule 1986, pp. 25–33; Shaffer 1981, p. 131; Shaffer and Samson 1985, pp. 148–150).

Historically, the Texas fawnsfoot was widespread throughout much of the Colorado and Brazos River systems when few natural barriers existed to prevent migration (via host species) among suitable habitats. Construction of dams, however, likely destroyed many Texas fawnsfoot populations through drastic habitat changes and isolated the remnant populations from each other. The extensive impoundment of the Brazos and Colorado River basins has fragmented Texas fawnsfoot populations throughout these river systems.

For fertilization, Texas fawnsfoot females need an upstream male to release sperm; populations with few individuals reduce the likelihood that females will be exposed to sperm while siphoning. Therefore, recruitment failure is a potential problem for many small populations rangewide, a potential condition exacerbated by its reduced range and increasingly isolated populations. If downward population trends continue, further significant declines in total Texas fawnsfoot population size and consequent reduction in long-term survivability may soon become apparent. Small Texas fawnsfoot populations, including those in the Brazos River, Clear Fork Brazos River, Navasota River, and Deer Creek, may be below the minimum population size required to maintain population viability into the future. These populations are more vulnerable to extirpation since they are less likely to be able to recover through recruitment from events that reduce but do not extirpate populations.

Additionally, these small populations are more vulnerable to extirpation from stochastic (random) natural events, as the lack of connectivity among populations does not permit nearby populations to recolonize areas affected by intense droughts, toxic spills, or other isolated events that result in significant mussel die-offs. When species are limited to small, isolated habitats, as the Texas fawnsfoot is, they are more likely to become extinct due to a local event that negatively effects the population (McKinney 1997, p. 497; Minckley and Unmack 2000, pp. 52–53; Shepard 1993, pp. 354–357). While the populations' small, isolated nature does not represent an independent threat to the species, it does substantially increase the risk of extirpation from the effects of all other threats, including those addressed in this analysis, and those that could occur in the future from unknown sources.

Based upon our review of the best commercial and scientific data available, we conclude that fragmentation and isolation of small remaining populations of the Texas fawnsfoot are occurring and are ongoing threats to the species throughout all of its range. Further, stochastic events may play a magnified role in extirpation of small, isolated populations.

Nonnative Species

Various nonnative species of aquatic organisms are firmly established within the range of the Texas fawnsfoot and pose a threat to the species. Golden algae (Prymnesium parvum) is a microscopic algae considered to be one of the most harmful algal species to fish and other gill-breathing organisms (Lutz-Carrillo et al. 2010, p. 24). Golden algae was first discovered in Texas in 1985 and is presumed to have been introduced from western Europe (Lutz- Carrillo et al. 2010, p. 30). Since its introduction, golden algae has been found in Texas rivers and lakes, including two lakes in central Texas (Baylor University 2009, p. 1). Under certain environmental conditions, this algae can produce toxins that can cause massive fish and mussel kills (Barkoh and Fries 2010, p. 1; Lutz-Carrillo et al. 2010, p. 24). Evidence shows that golden algae probably caused fish kills in Texas as early as the 1960s, but the first documented fish kill due to golden algae in inland waters of Texas occurred in 1985 on the Pecos River in the Rio Grande basin (TPWD 2002, p. 1). The range of golden algae has increased to include portions of the Brazos and Colorado River basins, among others, and it has been responsible for killing more than 8 million fish in the Brazos River since 1981 and more than 2 million fish in the Colorado River since 1989 (TPWD 2010a, p. 1). Although actual mussel kills in Texas due to golden algae have not been recorded in the past, the toxin can kill mussels. Therefore, the elimination of host fish and the poisonous nature of the toxin to mussels make future golden algae blooms a threat to the Texas fawnsfoot.

An additional nonnative species, the zebra mussel (Dreissena polymorpha), poses a potential threat to the Texas fawnsfoot. This invasive species has been responsible for the extirpation of freshwater mussels in other regions of the United States, including the Higgin’s eye (Lampsilis higginsii) in Wisconsin and Iowa (Service 2006, pp. 9–10). Zebra mussels attach in large numbers to the shells of live native mussels and are implicated in the loss of entire native mussel beds (Ricciardi et al. 1998, p. 615). This fouling impedes locomotion (both laterally and vertically), interferes with normal valve movements, deforms valve margins, and essentially suffocates and starves the native mussels by depleting the surrounding water of oxygen and food (Strayer 1999, pp. 77–80). Heavy infestations of zebra mussels on native mussels may overly stress the animals by reducing their energy reserves. Zebra mussels may also filter the sperm and possibly glochidia of native mussels from the water column, thus reducing reproductive potential. Habitat for native mussels may also be degraded by large deposits of zebra mussel pseudofeces (undigested waste material passed out of the incurrent siphon) (Vaughan 1997, p. 11).

Zebra mussels are currently found within the range of the Texas fawnsfoot. A live adult zebra mussel was first documented in Lake Texoma on the Red River (on the north Texas border with Oklahoma) in 2009 (TPWD 2009a, p. 1). Since that time, additional zebra mussels have been reported from Lake Texoma, where they are now believed to be well established (TPWD 2009c, p.

1).In spring and summer of 2013, Texas Parks and Wildlife Department (TPWD) monitored 23 other Texas reservoirs and found that zebra mussels may be present in two additional reservoirs: Lake Worth and Joe Pool. No adult zebra mussels or veligers have been found in either of the aforementioned water bodies (TPWD 2013, p. 1). To date, Lake Texoma, Lake Ray Roberts, Lake Lewisville, Lake Bridgeport, Lake Lavon, Lake Belton, and Lake Waco reservoirs and Elm Fork of the Trinity River are known to harbor zebra mussels TPWD 2014, p. 1). Zebra mussels are likely to spread to many other Texas reservoirs through accidental human transport (Schneider et al. 1998, p. 789). Although zebra mussels tend to proliferate in reservoirs or large pools, released zebra mussel veligers float downstream and attach to any hard surface available, rendering downstream Texas fawnsfoot populations extremely vulnerable to attachment and fouling. Because zebra mussels are so easily introduced to new locations, the potential for zebra mussels to continue to expand in Texas and further invade the range of the Texas fawnsfoot is high. If this occurs, the Texas fawnsfoot is vulnerable to zebra mussel attachment and subsequent deprivation of oxygen, food, and mobility.

A molluscivore (mollusk eater), the black carp (Mylopharyngodon piceus) is a potential threat to the Texas fawnsfoot. The species has been commonly used by aquaculturists to control snails or for research in fish production in several States, including Texas (72 FR 59019, October 18, 2007). Black carp can reach more than 1.3 m (4 ft) in length and 150 pounds (68 kilograms (kg)) (Nico and Williams 1996, p. 6). Foraging rates for a 4-year old fish average 3 to 4 pounds (1.4 to1.8 kg) a day, indicating that a single individual could consume 10 tons (9,072 kg) of native mollusks over its lifetime (Mississippi Interstate Cooperative Resource Association (MICRA) 2005, p. 1). Black carp can escape from aquaculture facilities. For example, in 1994 30 black carp escaped from an aquaculture facility in Missouri during a flood. Other escapes into the wild by non-sterile carp are likely to occur. Because of the high risk to freshwater mussels and other native mollusks, the Service recently listed black carp as an injurious species under the Lacey Act (72 FR 59019, October 18, 2007), which prevents importations and interstate transfer of this harmful species, but does not prevent its release into the wild once it is in the State. If the black carp were to escape within the range of the Texas fawnsfoot, it would likely negatively affect native mussels, including the Texas fawnsfoot.

Based upon our review of the best commercial and scientific data available, we conclude that golden algae is an ongoing threat to the Texas fawnsfoot, and other nonnative species, such as zebra mussels and black carp, are a potential future threat to the Texas fawnsfoot that is likely to increase as these exotic species expand their occupancy within the range of the Texas fawnsfoot.

Summary of Factor E

The effects of climate change, while difficult to quantify at this time, are likely to exacerbate the current and ongoing threat of habitat loss caused by other factors, and the small sizes and fragmented nature of the remaining populations render them more vulnerable to extirpation. In addition, nonnative species, such as golden algae, currently threaten the Texas fawnsfoot, and the potential introduction of zebra mussels and black carp are potential future threats. Based upon our review of the best commercial and scientific data available, we conclude that other natural or manmade factors are immediate threats of moderate magnitude to the Texas fawnsfoot.

Conservation Measures Planned or Implemented :

The Texas fawnsfoot is listed as threatened by the TPWD in Texas and is a high priority species in the Texas Wildlife Action Plan 2005-2010 (TPWD 2005, p. 756). The Service, TPWD, academia, and other resource agencies have proposed and ongoing studies in Texas' river systems for Texas freshwater mussels, including the Texas fawnsfoot, observing life history parameters (including determination of ecological fish hosts), survivability of juveniles, monitoring habitat, and analyzing population dynamics. In addition, TPWD has established a Mussel Watch group.

The Service is currently working on forming and implementing the use of a Strategic Conservation Plan for Texas Freshwater Mussels that will result in additional conservation measures such as, best management practices, survey protocols, relocation protocols, and monitoring guidelines. The Service will be collaborating with other Federal, State, and non-governmental agencies during the formation and implementation of the Strategic Conservation Plan.

Summary of Threats :

This status review identifies threats to the Texas fawnsfoot attributable to Factors A, D, and E. The primary threat to the species is from habitat destruction and modification (Factor A) from impoundments, which scour riverbeds, thereby removing mussel habitat, decrease water quality, modify stream flows, and restrict fish host migration and distribution of freshwater mussels. Additional threats under Factor A include sedimentation, dewatering, sand and gravel mining, and chemical contaminants. Also, most of these threats may be exacerbated by the current and projected effects of climate change (discussed under Factor E). Threats to the Texas fawnsfoot are not being adequately addressed through existing regulatory mechanisms (Factor D). Because of the limited distribution of this endemic species and its lack of mobility, these threats are likely to lead to the extinction of the Texas fawnsfoot in the foreseeable future.

For species that are being removed from candidate status:

_____ Is the removal based in whole or in part on one or more individual conservation efforts that you determined met the standards in the Policy for Evaluation of Conservation Efforts When Making Listing Decisions(PECE)?

Recommended Conservation Measures :

Continued survey and monitoring efforts are needed throughout former and occupied sites to better define the species' distribution and status in the Colorado and Brazos River systems.

Continued biological and ecological research efforts are needed to identify host fish, spawning and brooding seasons, glochidia, and habitat and physiochemical parameters for the Texas fawnsfoot.

The Service will continue to work with TPWD, USGS, and others needed research in order to facilitate the conservation and preservation of the Texas fawnsfoot.

Long-term conservation measures need to be developed to facilitate and accomplish cooperative efforts between resource management agencies and private landowners. The development of a candidate conservation agreements (with assurances) with interested parties would initiate conservation for the Texas fawnsfoot.

The Service will continue working with resource management agencies and the Texas Department of Transportation (TxDOT) on developing best management practices for proposed adjacent/instream impacts specific to Texas water systems.

The Service will continue working with resource management agencies and academia on developing a drought contingency plan that will facilitate the management and monitoring of mussel populations that harbor species of concern (i.e. the Texas fawnsfoot) during times of drought.

The Service will continue working with resource management agencies, TxDOT, and academia on the development of standard mussel survey, relocation, and monitoring protocols, which would establish a commonality among the wide variety of methods currently being used in Texas and would establish a baseline of what kind of data needs to be collected while conducting surveys.

Priority Table

<table>
<tr><th>Magnitude</th><th>Immediacy</th><th>Taxonomy</th><th>Priority</th></tr>
<tr><td rowspan="6">High</td><td rowspan="3">Imminent</td><td>Monotypic genus</td><td>1</td></tr>
<tr><td>Species</td><td>2</td></tr>
<tr><td>Subspecies/Population</td><td>3</td></tr>
<tr><td rowspan="3">Non-imminent</td><td>Monotypic genus</td><td>4</td></tr>
<tr><td>Species</td><td>5</td></tr>
<tr><td>Subspecies/Population</td><td>6</td></tr>
<tr><td rowspan="6">Moderate to Low</td><td rowspan="3">Imminent</td><td>Monotype genus</td><td>7</td></tr>
<tr><td>Species</td><td>8</td></tr>
<tr><td>Subspecies/Population</td><td>9</td></tr>
<tr><td rowspan="3">Non-Imminent</td><td>Monotype genus</td><td>10</td></tr>
<tr><td>Species</td><td>11</td></tr>
<tr><td>Subspecies/Population</td><td>12</td></tr>
</table>

Rationale for Change in Listing Priority Number:

No change in priority number.

Magnitude:

We consider the threats that the Texas fawnsfoot faces to be high in magnitude. Habitat loss and degradation from impoundments, sedimentation, sand and gravel mining, and chemical contaminants are widespread throughout the range of the Texas fawnsfoot and profoundly affect its habitat. Remaining populations are small, isolated, and highly vulnerable to stochastic events.

Imminence :

We consider the threats to the Texas fawnsfoot as described under Factors A, D, and E in the Five-Factor Evaluation for Texas Fawnsfoot section to be imminent because these threats are ongoing and will continue in the foreseeable future. Habitat loss and destruction has already occurred and will continue as the human population continues to grow in central Texas. The Texas fawnsfoot populations may already be below the minimum viable population requirement, which would cause a reduction in the number of populations and an increase in the species' vulnerability to extinction. These threats are exacerbated by climate change, which will increase the frequency and magnitude of droughts. Therefore, we consider these threats to be imminent.

__Yes__ Have you promptly reviewed all of the information received regarding the species for the purpose of determination whether emergency listing is needed?

Emergency Listing Review

__No__ Is Emergency Listing Warranted?

Description of Monitoring:

The TPWD Mussel Watch group has been conducting surveys throughout Texas and found several fresh dead Texas fawnsfoot in the Colorado and Brazos River systems. The groups continued efforts along with historic data has sparked the interest of academia to further survey efforts in the Colorado and Brazos River systems where a couple of large, stable, reproducing populations were discovered and are now being closely monitored. These recent discoveries will likely lead to increased survey and monitoring efforts throughout Texas.

Indicate which State(s) (within the range of the species) provided information or comments on the species or latest species assessment:

Texas

Indicate which State(s) did not provide any information or comment:

none

State Coordination:

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Approval/Concurrence:

Lead Regions must obtain written concurrence from all other Regions within the range of the species before recommending changes, including elevations or removals from candidate status and listing priority changes; the Regional Director must approve all such recommendations. The Director must concur on all resubmitted 12-month petition findings, additions or removal of species from candidate status, and listing priority changes.

Approve: [signature] 06/12/2015
Date

Concur: [signature] 12/15/2015
Date

Did not concur: ______________________ ________
Date

Director's Remarks: