**Revised Recovery Plan for the Houston Toad**
**(*Anaxyrus* [=*Bufo*] *houstonensis*)**

U.S. Fish and Wildlife Service
Southwest Region
Albuquerque, NM

May 2022

AMY LUEDERS Digitally signed by AMY LUEDERS
Date: 2022.05.17 13:11:23 -06'00'

Approved:______________________________________________

Regional Director, Southwest Region
U.S. Fish and Wildlife Service

Date: ______________________________

**Disclaimer**

Recovery plans delineate such reasonable actions as may be necessary, based upon the best scientific and commercial data available, for the conservation and survival of listed species. Plans are published by the U.S. Fish and Wildlife Service (USFWS) or National Marine Fisheries Service (NMFS), sometimes prepared with the assistance of recovery teams, contractors, State agencies and others. Recovery plans do not necessarily represent the views, official positions, or approval of any individuals or agencies involved in the plan formulation, other than the USFWS or NMFS. They represent the official position of the USFWS or NMFS only after they have been signed by the Regional Director (USFWS) or Assistant Administrator (NMFS). Recovery plans are guidance and planning documents only; identification of an action to be implemented by any public or private party does not create a legal obligation beyond existing legal requirements. Nothing in this plan should be construed as a commitment or requirement that any Federal agency obligate or pay funds in any one fiscal year in excess of appropriations made by Congress for that fiscal year in contravention of the Anti-Deficiency Act,31 U.S.C. 1341, or any other law or regulation. Approved recovery plans are subject to modification as dictated by new findings, changes in species status, and the completion of recovery actions.

Prepared by Charles Hermann and Hannah Gilbreath, U.S. Fish and Wildlife Service, Austin Ecological Services Field Office.

Recommended Citation: U.S. Fish and Wildlife Service. 2022. Revised recovery plan for the Houston toad (*Anaxyrus* [=*Bufo*] *houstonensis*). U.S. Fish and Wildlife Service, Albuquerque, New Mexico.

An electronic copy of this final recovery plan will be made available at: [Species Profile for Houston toad(Bufo houstonensis) (fws.gov)]

**Table of Contents**

**1.0 Introduction** ........ **1**

**2.0 Species Description and Needs** ........ **1**

2.1 Morphological Description ........ 1

2.2 Taxonomy ........ 2

2.3 Life History ........ 2

2.3.1 Diet ........ 2

2.3.2 Reproduction ........ 3

2.3.3 Sex Ratio ........ 4

2.3.4 Juvenile Survivorship ........ 4

2.3.5 Dispersal and Movement ........ 5

2.3.6 Allee Effects ........ 5

2.3.7 Population Dynamics ........ 6

2.4 Resource Needs of Individuals ........ 7

2.4.1 Geology and Soils ........ 7

2.4.2 Forests ........ 7

2.4.3 Herbaceous Vegetation ........ 10

2.4.4 Water ........ 10

2.5 Habitat Types ........ 11

2.5.1 Aquatic Habitat ........ 11

2.5.2 Terrestrial Habitat ........ 11

**3.0 Species Current Condition and Stressors** ........ **13**

3.1 Range and Distribution ........ 13

3.2 Captive Propagation and Population Supplementation ........ 16

3.3 Stressors ........ 16

3.3.1 Habitat Loss and Degradation (Factor A) ........ 17

3.3.2 Disease and Predation (Factor C) ........ 26

3.3.3 Small Population Size and Isolation (Factor E) ........ 27

3.3.4 Drought and Climate Change (Factor E) ........ 30

**3.4 Resiliency, Redundancy, and Representation** ........ **36**

3.4.1 Resiliency .......... 36
3.4.2 Redundancy .......... 36
3.4.3 Representation .......... 37
3.4.4 Conclusions .......... 37
**4.0 Recovery Program .......... 38**
4.1 Recovery Goal, Strategy, and Objectives .......... 38
4.1.1 Recovery Goal .......... 38
4.1.2 Recovery Strategy .......... 38
4.1.3 Recovery Objectives .......... 39
**4.2 Objective and Measurable Recovery Criteria .......... 41**
4.2.1 Downlisting Criteria .......... 41
4.2.2 Delisting Criteria .......... 42
**5.0 Recovery Implementation .......... 43**
5.1 Site-specific Recovery Actions .......... 43
5.1.1 Priority 1 Actions .......... 44
5.1.2 Priority 2 Actions .......... 44
5.1.3 Priority 3 Actions .......... 45
5.2 Estimated Time and Costs to Achieve Recovery .......... 45
**6.0 Literature Cited .......... 47**
**7.0 Appendix 1. Responses to Public Comments .......... 62**

## 1.0 Introduction

The Endangered Species Act of 1973 (ESA), as amended (16 U.S.C. 1531 *et seq.*) establishes policies and procedures for identifying, listing, and protecting species of wildlife and plants thatare endangered or threatened with extinction. Recovery is defined as the process by which listed species and their ecosystems are restored and their future is safeguarded to the point that protections under the ESA are no longer needed (NMFS and USFWS 2018). Recovery plans are advisory documents developed to provide site-specific management actions; objective, measurable recovery criteria; and estimates of time and cost to recovery.

The Houston toad (*Anaxyrus houstonensis*; formerly *Bufo houstonensis*) was listed as an endangered species on October 13, 1970 under the Federal Endangered Species Preservation Act of 1966 (35FR 16047), and the species' endangered status was continued under the ESA. The USFWS designated critical habitat in portions of Bastrop and Burleson counties, Texas on January 31, 1978 (43 FR 4022). The Houston toad is assigned a recovery priority number of 2C,meaning the species faces a high degree of threat, but has a high potential for recovery. The original recovery plan for the Houston toad was approved in August 1984 (USFWS 1984). On November 28, 2011, the USFWS issued a 5-year status review that concluded no change in classification of the Houston toad was needed (USFWS 2011). On July 6, 2018, the USFWS issued another 5-year status review concluding that the evaluation of threats affecting the species and the analysis in the 2011 5-year review remain an accurate reflection of the species' status as endangered (USFWS 2018).

A Recovery Implementation Strategy (RIS), defining the stepped-down activities needed to implement the recovery actions identified in this Recovery Plan, will be developed in coordination with recovery partners. The RIS will describe how the recovery actions will be coordinated with our partners and how costs and periods are estimated. As a separate document from this Recovery Plan, the RIS may be modified if new information reveals thatexpected results are not being achieved, therefore maximizing flexibility of recovery implementation.

## 2.0 Species Description and Needs

### 2.1 Morphological Description

Houston toads are generally brown and speckled, although individual coloration can vary considerably from light brown or red to gray to purplish gray with a variable number of dark brown or black spots (Sanders 1953, p. 29; Forstner 2003, p. 8). The Houston toad's underside is usually pale with small, dark spots. The toad's legs are banded with dark pigment (Sanders 1953, pp. 29, 31), and two dark bands extend from each eye down to the mouth. A white stripe that can vary in pigmentation density extends down the middle of the back (Sanders 1953, pp. 29, 31), but it can also be absent in some individuals.

Males and females are similar in appearance, although females are typically larger and bulkier than males. Males have dark throats, which appear bluish when distended (Sanders 1953, p. 31). Adult Houston toads are 5 to 8 centimeters (cm) (2 to 3 inches [in]) long (Forstner 2003, p. 8) and are covered with raised patches of skin that resemble warts (Sanders 1953, p. 32). Although Houston toads are similar in appearance to the closely related Gulf Coast toad (*Incilius nebulifer,* formerly

*B. nebulifer* [populations of this species were formerly assigned to the species *B. valliceps*]) and Woodhouse's toad (*A. woodhousii*), these species can be discerned by physical and genetic characteristics (Forstner 2003, pp. 8-9; Hillis et al. 1984, pp. 57-60).

## 2.2 Taxonomy

The Houston toad was first described by Sanders in 1953 (pp. 25-47) based on specimens collected from the area of Houston, Texas. Sanders (1953, pp. 25-47) provided a strong argument for the unique morphological aspects that distinguished the Houston toad from other toad species such as the American toad (*B. americanus*). Brown (1971, p. 188) demonstrated that the call of *B. houstonensis* differed from that of *B. americanus*, and subsequent studies on *Bufo* phylogeny continued to support the Houston toad as a unique and distinct species (Sandersand Cross 1964, pp. 248, 253-254; Pauly et al. 2004, pp. 2,522-2,523).

Frost et al. (2006, p. 363) proposed a taxonomic change for all anuran (i.e., frog and toad) species whereby historical, subgeneric names are elevated to full generic status. Under this proposed taxonomy, *B. houstonensis* would become *Anaxyrus houstonensis*. Several publications, however, have argued against the Frost et al. (2006, p. 363) proposal, stating that the name changes are arbitrary and do not reflect the evolutionary history of American anuran species. Forstner and Dixon (2011, pp. 30-31) recommended retaining the *Bufo houstonensis* nomenclature pending additional data, analysis, and systematic interpretation by the taxonomic community. We will refer to the Society for the Study of Amphibians and Reptiles and their North American Standard English and Scientific Names Database as the best available scientific review on Houston toad taxonomy, which suggests the appropriate nomenclature for the speciesis *Anaxyrus houstonensis*.

McHenry and Forstner (2009, p. 80) found little gene flow among Houston toad populations at distances greater than 4 kilometers (km) (2.5 miles [mi]), though some mitochondrial DNA haplotypes were found throughout the Houston toad's range. Those researchers also found that overall genetic diversity in the Houston toad was high (McHenry and Forstner 2009, p. 80). This suggests that, despite minimal habitat connectivity resulting in low gene flow (McHenry and Forstner 2009, p. 80), genetic diversity has seemingly been maintained throughout the species' range (McHenry and Forstner 2009, p. 81).

This high level of genetic diversity may be due to the age of the Houston toad as a species, whichis likely hundreds of thousands or at least tens of thousands of years old (McHenry and Forstner 2009, p. 81). Throughout this time in its evolutionary history, new haplotypes and alleles likely arose. In addition, Houston toad population sizes and habitat connectivity within its range were likely much greater up until recent decades (McHenry and Forstner 2009, pp. 80-81; Forstner and Dixon 2011, p. 28). It is speculated that Houston toad populations could have occurred close enough to each other to generate gene flow among them (McHenry and Forstner 2009, p. 81), allowing the genetic diversity in the species to persist.

## 2.3 Life History

### 2.3.1 Diet

Houston toads feed on a variety of insects and other invertebrates. Bragg (1960, p. 106) reported that captive Houston toads favored many small to medium-sized carabids (i.e., ground beetles), several small beetles of unknown families, several diptera (i.e., flies), green lacewings, and many types of small moths. Houston toad tadpoles are known to ingest pine pollen and the jelly envelopes of recently hatched Houston toad eggs (none were observed eating eggs before they hatched) [Hillis et al. 1984, p. 67]. Tadpoles remain on the bottom of the ponds during the day, and at night, they feed on material attached to vegetation in water and along the pond's edge (Hillis et al. 1984, p. 67). Once they leave the pond after metamorphosis, juvenile Houston toadspresumably feed on small invertebrates found on the forest floor, which is typical of toad species (Clarke 1974, pp. 141-146).

2.3.2 Reproduction

The Houston toad is an "aggregative" and "explosive" breeder, appearing in large numbers at breeding ponds where males chorus to attract females and compete with each other to breed overa period of a few nights throughout the breeding season (Wells 1977, p. 666; Jacobson 1989, p. 377; Price 2003, p. 1). Chorusing can begin as early as January (Dixon 1982, p. 4; Hillis et al. 1984, pp. 60-61). Houston toads typically breed from late January to June (Kennedy 1962, p.240; Dixon 1982, pp. 4-6; Hillis et al. 1984, pp. 60-61) with a peak in reproductive activity inMarch, depending on weather conditions (Swannack 2007, p. 67). Reported egg-laying dates in the field range from February 18 to June 26 (Kennedy 1962, p. 240; Hillis et al. 1984, p. 61; Jacobson 1989, p. 375; Dixon et al. 1990, p. 18).

Historically, breeding was believed to be triggered in part by rainfall and warm night temperatures (Kennedy 1962, p. 240; Dixon 1982, p. 6; Price 1992, p. 5; Price 2003, p. 2). However, chorus formation is delayed until heavy rains abate (Price 2003, p. 2). Other factors, such as humidity (i.e., greater than 70 percent), cloud cover, wind speed, subsurface soil temperature and moisture, and moon phase may also play a role in the timing of chorusing activity (Brown et al. 2013 pp. 303-321; Hillis et al. 1984, pp. 61-62; Dixon et al. 1990, pp.5-9; Price 1992, p. 1; Price 2003, p. 2; Swannack et al. 2009, p. 154). For example, Houston toads do not generally call during the 7- to 10-day period prior to a full moon unless cloud cover obscures the moon during this time (Price 2003, p. 2). Recently, temperatures greater than 16° Celsius (°C) (60.8°Fahrenheit [°F]), precipitation greater than 0 millimeters (mm)/day, and a change in barometric pressure less than -0.07 mm of mercury (in) have been identified as thresholds that provide the greatest detection probability of chorusing male Houston toads (MacLaren 2019, p. 40).

Once males reach a breeding pond, they often call from the pond's edge in shallow water or within several feet of the pond's edge. On some nights during the Houston toad's breeding season, males may be present but not chorusing at breeding ponds (Kennedy 1962, p. 241). Theygenerally move throughout the pond during a given night, while female Houston toads often reach the breeding pond beginning at sunset and continuing up to several hours after sunset (Hillis et al. 1984, p. 65). Eggs are fertilized externally. The male clasps the female with his front legs as part of mating in a process referred to as "amplexus." During amplexus,the male fertilizes the eggs upon their deposition by the female. Hillis et al. (1984, p. 65) observed Houston toad mating pairs in amplexus for several hours, and sometimes until the following night, before eggs were deposited.

This species tends to concentrate its reproductive efforts into producing large numbers (e.g., hundreds or thousands) of eggs, which are laid in strings (i.e., egg strands) in the breeding pond (Greuter 2004, p. 15). The eggs hatch into tadpoles that metamorphose into juvenile toadlets approximately 60 to 65 days after their deposition (Hillis et al. 1984, p. 66). Following metamorphosis, juvenile Houston toads move into the surrounding terrestrial habitats where they grow and develop into adults (Greuter 2004, pp. 32-33).

2.3.3 Sex Ratio

Amphibians are commonly found to have a male-biased sex ratio, which is generally assumed to be somewhat inaccurate because males can be more easily detected during chorusing. However, Swannack and Forstner (2007, pp. 386-392) demonstrated that male-biased sex ratios of Houston toads available for reproduction are not a result of differential detection, but rather a consequence of delayed maturation with differential mortality in female Houston toads (Swannack and Forstner 2007, p. 391). That is, because females reach sexual maturity in two years, as opposed to one year in males (Quinn and Mengden 1984, pp. 190-191; Swannack and Forstner 2007, pp. 387, 391), more females than males are likely to die before they can reproduce. This increases the necessity of conservation measures that influence female Houston toad survivorship (Swannack and Forstner 2007, p. 392).

2.3.4 Juvenile Survivorship

Immediately after Houston toad juveniles emerge from their natal ponds beginning in mid-April (Swannack et al. 2009, p. 150), they tend to concentrate at the pond's edge within 3 to 5 meters (m) (10 to 16 feet [ft]) and remain there for 1 to 3 weeks (Greuter 2004, pp. 58, 69). One consequence of this emergence strategy is that all of the juveniles are crowded into a narrow zone at the water's edge for this period of about 1 to 3 weeks. At no other time are there as many Houston toads in one location as during this initial post-emergence period (Forstner and Dixon 2011, p. 20). Juveniles have been shown to remain within a 50 m (164 ft) radius oftheir natal pond for at least 13 weeks (Greuter 2004, p. 70).

Postmetamorphic juvenile survivorship may be lower near permanent water bodies (Forstner 2003, p. 10) because they are more likely to harbor predators, such as birds, mammals, snakes, turtles, fish, aquatic invertebrates, and bullfrogs (Quinn and Ferguson 1983, p. 6;) and potential competitors, such as the Woodhouse's toad and Gulf Coast toad (Hillis et al. 1984, p. 69). Juvenile Houston toads are likely most susceptible to predation by red-imported fire ants (*Solenopsis invicta*) when they first emerge from the water (Freed and Neitman 1988, pp. 455-456;Brown et al. 2011, p. 138) particularly within open areas, as percentage of canopy cover is strongly inversely related to fire ant captures (Brown et al. 2012a, pp. 142-149; Greuter 2004, pp. 66-67).

A lack of canopy cover may also increase the likelihood of desiccation (i.e., drying out of a living organism) [Greuter 2004, p. 66]. Livestock usage of permanent water bodies and feral hog (*Sus scrofa*) activity can also negatively affect the quality of habitat along the pond's edge, including arthropod composition and water quality parameters including water temperature, nutrient levels, and pH. (Brown et al. 2012b, pp 78-85; Forstner 2001, p. 3; Forstner 2003, p. 10). The presence of livestock or feral hogs also increases the chance of direct mortality by crushing Houston toads emerging from the water (Bull 2009, p. 243). Therefore, restriction of livestock and feral hog access to potential Houston toad breeding sites through fencing and habitat restoration of these areas, where needed, may enhance juvenile survivorship.

For many pond-breeding amphibians, about 5 percent of eggs survive to metamorphosis (Semlitsch 2003, p. 20). In fact, Greuter (2004, pp. 29-30) calculated Houston toad juvenile survivorship (from the egg stage to metamorphosis) to be 4.73 percent. Greuter (2004, pp. 30, 74) also estimated survival from egg to 13 weeks post-emergence to be 4 percent and linearly extrapolated a survivorship of only 0.03 percent by the first year of age. Subsequent simulation modeling work by Swannack et al. (2009, p. 157) refined juvenile survivorship estimates to a range between 0.75 percent and 1.05 percent.

### 2.3.5 Dispersal and Movement

For many pond-breeding anurans, juveniles are thought to be the main units of dispersal, providing the majority of connectivity among ponds (Semlitsch 2000, p. 621; Bull 2009, p. 245; Funk et al. 2005, p. 15; Semlitsch 2008, pp. 262-263). Networks of ponds and individuals dispersing among these ponds are essential to maintaining viable populations of pond-breeding amphibians (Semlitsch 2003, p. 15).

Houston toads have been observed exhibiting generally high site fidelity both within a breeding season and among multiple years, with occasional long-distance movements (Vandewege et al. 2013, pp. 439-442). Adult Houston toads have been found to move over a kilometer within a breeding season between breeding ponds (Price 2003, p. 7). The longest published juvenile Houston toad dispersal distance was 1.34 km (0.8 mi) in five weeks (Vandewege et al. 2012, p. 117), although another juvenile was observed to disperse 3.7 km over a several-week period (Forstner pers. comm. 2021). Another study found an adult 950 m (3,117 ft) from its natal pond where it was marked 1-2 years earlier as a juvenile (Swannack 2007, p. 64). Dispersal, particularly of juveniles, has been observed in areas that are considered to have “unsuitable” soils, and therefore movement of Houston toads and their presence on the landscape is not limited to areas considered “suitable” (Forstner pers. comm. 2021). Subsequently, an updated habitat suitability assessment is needed and is currently underway in 2022.

During peak activity periods from February to April, Houston toads have been described as “vagrant,” with significant overland movement occurring (Yantis and Price 1993, pp. 5–6). Historically, adult Houston toads have been observed moving as far as 490 m (1,608 ft) in 24 hours (Yantis and Price 1993, p. 5) and have been recorded moving up to 1.85 km (1.15 mi) in one breeding season through suitable habitat (Price 2003, pp. 6–7). There is a significant difference in the rates of movement between males and females, with females more likely to move farther from potential breeding ponds (Swannack 2007, p. 33; McHenry and Forstner 2009, pp. 76-77).

Houston toad movement has not been tracked outside of the breeding season. However, multi-year trapping and tracking studies (Swannack 2007, pp. 10-66) have shown that most adults remain within 200 m (656 ft) of their breeding pond during the post-breeding season (Swannack 2007, p. 63). There is evidence reported in Forstner and Bohannon’s (2019) annual report to the USFWS of the continued findings of year-round juvenile activity on the Griffith League Ranch. Detections of juveniles, using pitfall traps, occurred in June, July, September, and October of 2019.

### 2.3.6 Allee Effects

Although the detection of Houston toad chorusing provides an indication of population trends at particular sites or on a regional scale, chorusing itself is not necessarily an indicator of successful reproduction or population stability. Male Houston toads are regularly found chorusing at ponds or other aquatic sites with no females present (i.e., chorusing ponds). Furthermore, egg strands are often found in ponds from which no juvenile toads ever emerge (i.e., breeding ponds) due to a variety of reasons. It is rare to find ponds in which Houston toad chorusing actually leads to reproduction and the successful emergence of juveniles (emergence ponds) (Forstner and Dixon 2011, p. 22).

"Allee effect" has been defined as a positive relationship between any component of individual fitness (the ability to survive and reproduce) and either numbers or density of individuals of the same species (Stephens et al. 1999, p. 186). In other words, an Allee effect refers to the phenomenon where reproduction and survival rates of individuals increase with increasing population density. For example, large aggregations of male toads may influence female attendance during breeding choruses (Pfennig et al. 2000, p. 73). Gaston et al. (2010, p. 3) identified mate-finding Allee effects in the Houston toad by determining that larger breeding choruses lead to successful emergence of juveniles (recruitment) significantly more often than smaller breeding choruses. However, other factors may also contribute to these results. For example, overall toad density may be so low in a given area that females are not within a distance at which they can audibly detect male chorusing, especially if there are fewer males chorusing (Gaston et al. 2010, p. 4). We therefore consider chorus size to be one aspect of anuran biology in which Allee effects may occur, but this warrants more research.

### 2.3.7 Population Dynamics

Many amphibian populations, especially those living in relatively isolated habitat patches, exist as a metapopulation. A metapopulation is an assemblage of local populations, called subpopulations, that are interconnected through gene flow, local extinctions (i.e., extirpations), and recolonizations. The key to metapopulation connectivity is dispersal capacity, which provides the linkages among subpopulations by way of individuals dispersing from one local subpopulation to others (Semlitsch 2003, p. 15; Revilla et al. 2004, p. 149).

Within metapopulations, different ecological processes (e.g., immigration, emigration, and extirpations) occur at three spatial levels: (1) the local subpopulation level at which individuals move and interact with one another, (2) the metapopulation level at which individuals move from one local subpopulation to another, and (3) the species level, which comprises the entire geographic range of the species (Allendorf and Luikart 2007, p. 366). At the local level, subpopulations may be extirpated, while the metapopulation persists. Metapopulations on opposite ends of the species' range do not exchange individuals, but they remain part of the same genetic species because of movement among intermediate metapopulations (Allendorf and Luikart 2007, p. 366).

Metapopulation structure can have profound implications for the persistence of a species, because a species that exists as a metapopulation can spread the risk of extinction across many subpopulations (Hanski 1998, p. 42). Thus, it is unlikely that catastrophes such as disease or wildfire would affect all of the subpopulations simultaneously and cause extinction of the entire metapopulation. Even if local subpopulations were extirpated, individuals dispersing from another subpopulation may recolonize the sites later. Because survival at a larger scale depends on recolonization of individuals from other areas, large-scale disruption of populations at the landscape level can result in a serious decline in functioning metapopulations (Dodd and Smith 2003, p. 106).

The Houston toad's population structure appears to fit the definition of a metapopulation (Semlitsch 2003, p. 15; Akçakaya et al. 2007, p. 65), because it appears to have evolved as a dynamic system of linked subpopulations in somewhat geographically isolated patches that are interconnected through patterns of gene flow (McHenry and Forstner 2009, p. 81; Vandewege et al. 2013, pp. 435-443). In some areas within the Houston toad's range, what were once subpopulations of larger metapopulations are now isolated from each other due to urbanization, high-traffic roads, and pastures. Some of these landscape changes may be reversible in that isolated subpopulations may still become part of a greater metapopulation. In other cases, the changes may be so extensive that geographic reconnection may no longer be an option.

### 2.4 Resource Needs of Individuals

Houston toad habitat is generally characterized as rolling uplands covered with pine and/or oak forests underlain by deep sandy soils. Although Houston toads are associated with forests and sandy soils (Kennedy 1962, p. 241; Brown 1971, p. 196), they may also breed in and move across sparsely wooded and even cleared, open areas (Dixon et al. 1990, p. 20). Because Houston toads are ectotherms (i.e., species that depend on environmental heat sources to control their body temperatures) and their skin is highly vulnerable to desiccation, they become dormant during harsh weather conditions, such as winter cold (i.e., hibernation) and summer heat and drought (i.e., estivation). They seek protection during these periods by burrowing into sand or hiding under rocks, leaf litter, logs, or in abandoned animal burrows (Hillis et al. 1984, pp. 64-65; Swannack 2007, p. 33). Houston toads spend a majority of their time in terrestrial habitat for sheltering, feeding, and dispersal, which is common among semi-aquatic amphibians (Semlitsch and Bodie 2003, pp. 1221–1222).

#### 2.4.1 Geology and Soils

Current and historical Houston toad populations occur along two geologic formations dominated by sandy soils (Figure 1). The northern band runs through Bastrop, Lee, Burleson, Milam, Robertson, and Leon counties and includes the Carrizo, Queen City, Reklaw, Sparta, and Weches Formations. The southern band runs through Lavaca, Colorado, and Austin counties and includes the Willis and Goliad Formations (Forstner 2003, p. 3). It is not clear if the Houston toad requires sandy soils to persist in an area or if its distribution is correlated with sandy soils because these soils within the Houston toad's range typically support forests. Either way, it is likely that both sandy soils and the vegetation they support are key components to defining the Houston toad's habitat (Forstner and Dixon 2011, p. 37).

#### 2.4.2 Forests

Amphibians overall can be found in many different types of habitats. Some amphibian species have adapted to survive in forests. The association between forests and certain amphibian species hasbeen well-established (Fahrig et al. 1995, p. 181; Findlay and Houlahan 1997, pp. 1,004-1,006; Semlitsch 1998, pp. 1,116-1,117; Knutson et al. 1999, pp. 1,443-1,444). As an essential component of amphibian habitats, forests help stabilize temperatures, moderate evaporation rates of aquatic habitats, contribute and recycle organic matter, and support diverse plant and animal communities (Knutson et al. 1999, pp. 1,443-1,444). Forests also function as a "life zone" for amphibians like the Houston toad, which Semlitsch (1998, p. 1,117) describes as habitat that is critical for feeding, growing, sheltering, and maturation as well as survival of the entire juvenile and adult breeding populations.

Most Houston toadlocations are in, or very near, forested patches of habitat (Buzo 2008, p. 65; Forstner and Dixon 2011, p.37), and canopy cover appears to be a necessary component of the species' habitat. Those locations outside of currently forested areas were documented historically (i.e., prior to 1990) and were likely within woodlands or forested habitat at the time they were recorded (Buzo2008, pp. 66-67; Forstner and Dixon 2011, p. 37). Though primarily found in canopied habitat, telemetry data has also shown that Houston toads move along drainages within pastures, if some canopy cover is present (Swannack 2007, p. 67; Forstner and Dixon 2011, p. 37).

Not only does canopy cover provide essential habitat for the Houston toad, the loss of forested habitat can lead to a variety of threats. For example, red-imported fire ants,which threaten Houston toad survival, are known to select for open and edge habitats (Porter et al. 1988, p. 916; Stiles and Jones 1998, pp. 343-344; Brown et al. 2012a, p. 146). In addition, hybridization and competition between the Houston toad and the Woodhouse's toad occurs primarily along habitat edges where forests have been cleared (USFWS 1994, p. 78). Thus, habitat areas with greater canopy cover and less edge may reduce red-imported fire ant predation pressure and decrease the threat of hybridization and competition with other toad species with overlapping ranges.

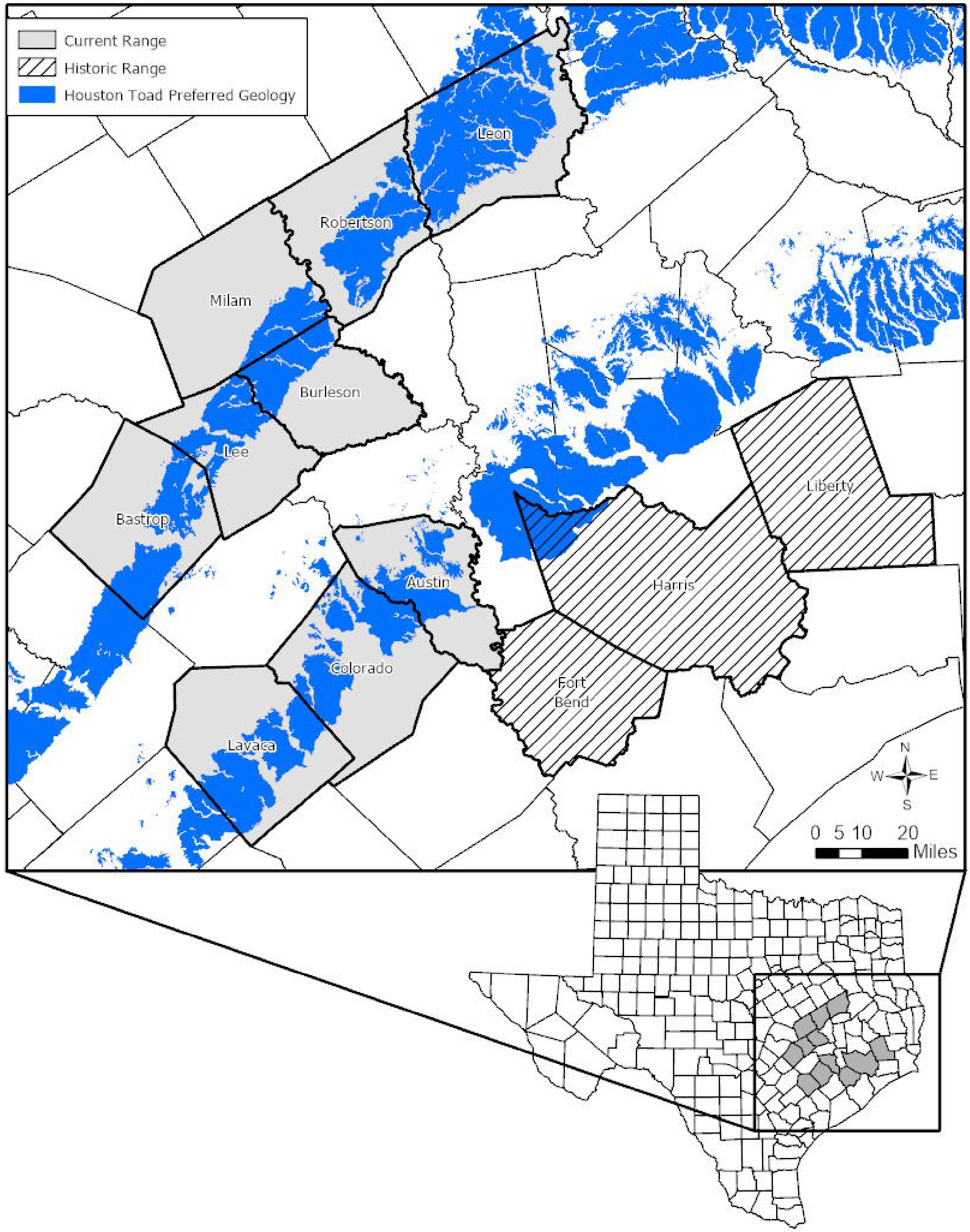


Figure 1: Geological formations (blue) associated with Houston toad current (gray) and historical (hatched) ranges.

The amount and type of canopy cover beneficial for Houston toad survival is uncertain. It is unclear what percentage of canopy cover is necessary to allow Houston toads to persist in an area, as the species has been observed in areas with relatively low overstory, grading from an open woodland with considerable herbaceous plant growth (forbs) into closed canopy gallery forests with 100 percent cover (Forstner and Dixon 2011, p. 37).

It is possible that the species is adaptable to a wide variety of overstory vegetation types. Tree species typically found within Houston toad habitat vary, but often include loblolly pine (*Pinus taeda*), post oak (*Quercus stellata*), blackjack oak (*Q. marilandica*), and/or sandjack oak (*Q. incana*) [Forstner 2003, p. 4]. Although the Houston toad does not appear to be tied to the presence of a particular tree species, pine is dominant in the Lost Pines region of Bastrop County(Thomas 1977, p. 4), which once supported large populations of Houston toads (Hillis et al. 1984, p. 70).

2.4.3 Herbaceous Vegetation

Herbaceous vegetation on the forest floor plays an important role in Houston toad habitat, as it supports native arthropod species (Harris 1984, p. 19) that comprise the Houston toad's food supply (Bragg 1960, p. 106; Clarke 1974, pp 141-146). Studies have shown that canopy cover allowing light to penetrate the forest floor can result in increased herbaceous plant diversity (Halls and Schuster 1965, pp. 282-283). The diversity of the arthropod community has been shown to increase with increasing plant diversity (Siemann etal. 1998, p. 738). In addition, increases in arthropod density and biomass have been correlated with increases in the biomass of herbaceous vegetation in prairie ecosystems (Kirchner 1977, p. 1,342). Therefore, we assume that the availability of herbaceous vegetation on the forest floor can influence the amount of arthropods available as a food source for Houston toads within their habitats. The availability of herbaceous vegetation and its specific impacts to the Houston toad and its prey present an area for possible future research.

2.4.4 Water

Water is an essential component of the Houston toad's habitat. Rainfall has been shown to stimulate breeding (Kennedy 1962, p. 240; Price 1992, pp. 1, 5), movement (Quinn et al. 1984, p. 4; Swannack 2007, p. 33), and foraging (Swannack 2007, p. 33). Houston toads are known to breed in small pools of water and ephemeral ponds (Kennedy 1962, p. 241; Brown 1971, p. 190; Forstner 2003, p. 10). They also have been heard calling from or have been captured in ditches, lakes, puddles in roads, moist areas in yards, flooded pastures, potholes, streams, stock tanks, and permanent ponds (Forstner 2001, p. 2; Forstner 2003, p. 10). Survival of eggs, tadpoles, and emerging juveniles may be low in permanent water bodies because they are more likely to harbor predators (Forstner 2003, p. 10), such as birds, mammals, snakes, turtles, fish, aquatic invertebrates, and bullfrogs (*Rana catesbiana*) (Ferguson et al. 2008, p. 452) and potential competitors and hybridizers, such as Woodhouse's and Gulf Coast toads (Hillis et al. 1984, p. 57). However, permanent water bodies can provide breeding habitat during breeding seasons in which many intermittent bodies of water may be desiccated.

Permanent water bodies also have an increased probability of livestock usage (Forstner 2003, p.10), which can negatively influence the quality of habitat along the edges of breeding ponds (Forstner 2001, p. 3; Forstner 2003, p. 10). Livestock wading and defecation can prevent vegetation from establishing around the pond's perimeter, and result in high levels of nitrogen (from urine and manure), increased turbidity, decreased water quality, and an overall adverse environment for amphibian egg and tadpole development (Knutson et al. 2004, p. 677; Schmutzer et al. 2008, p. 8). Elevated ammonia, nitrate, and nitrite levels are known to affect amphibian embryo and larvae survival and larval body size (Jofre and Karasov 1999, pp. 1,808- 1,810). Livestock wading into breeding areas leads to habitat alteration in the form of vegetation loss and soil compaction at the pond's edge that deters Houston toad breeding activity (Forstner 2001, p. 3). It may also result in the destruction of egg clutches and mortality of tadpoles, juveniles, and adults (Bull 2009, p. 243).

## 2.5 Habitat Types

### 2.5.1 Aquatic Habitat

Adult Houston toads require aquatic habitats to breed and reproduce. Rainfall is essential in preventing desiccation of potential breeding sites. These breeding habitats are usually composed of standing or still water, as found in a pond or wetland (Forstner and Dixon 2011, p. 39). Houston toads are known to breed in small pools of water and ephemeral ponds (Kennedy 1962, p. 241; Brown 1971, p. 190; Forstner 2003, p. 10). They also have been heard calling from or have been captured in ditches, lakes, puddles in roads, moist areas in yards, flooded pastures, potholes, streams, stock tanks, and permanent ponds (Forstner 2001, p. 2; Forstner 2003, p. 10). The presence of water during and after breeding is required for egg deposition, egg hatching, tadpole development, and emergence of tadpoles from a breeding site. Water is necessary for successful emergence, although not all chorusing events result in successful emergence (Forstnerand Dixon 2011, p. 21).

### 2.5.2 Terrestrial Habitat

Terrestrial habitat is used by the Houston toad for sheltering, feeding, and dispersal. This habitat is often overlooked in amphibian conservation (Semlitsch and Bodie 2003, p. 1221), but is important for the persistence of pond-breeding amphibians because these habitats are where amphibians spend the majority of their life cycles (Semlitsch 1998, p 1,116; Semlitsch 2000, p. 624). Habitat used for feeding and sheltering can be defined as canopied habitat with the appropriate geologic features and sandy soils discussed above. Ideal habitat will have a high diversity of herbaceous cover to support native arthropods (Siemann et al. 1998, p. 738), which comprise most of the Houston toad's diet (Bragg 1960, p. 106; Clarke 1974, pp 141-146). However, juvenile toads have been observed dispersing across non-suitable habitat, and therefore their possible presence on the landscape should be considered (Forstner, pers. comm. 2021)

There is little to no information on the home range size of Houston toads. Swannack (2007, pp. 67 and 106) did not find this species beyond 200 m (656 ft) from a breeding pond using radio telemetry within the breeding season. However, adult Houston toads have been documented moving 1.85 kilometers (1.15 mi) within a breeding season, and juveniles have been found to move 1.3 km (0.8 mi) over a five-week period (Price 2003, pp. 6–7; Vandewege et al. 2012 p. 117), with another juvenile dispersing 3.7 km over a several-week period (Forstner pers. comm. 2021). Research is needed to determine the extent of Houston toad home ranges, as there are no published papers on the subject.

There is a myriad of literature on the home range of Bufonids in North America and movement from breeding ponds. Distances very greatly among studies and species of toad: *B. bufo* (500 m

(1,640 ft), 0.67-2.46 ha (1.7-6.1 ac); Daversa et. al. 2012, pp. 662-663) *A. americanus* (400-1000 m (1,312-3,281 ft), 0.07 ha (0.17 ac); Forester et. al. 2006, pp.63-64), *A. boreas boreas* (218-721 m (715-2,365 ft), 13.8 ha (34 ac); Muths 2003, p. 162; 100 m (328 ft), 1.74 ha (4.32 ac); Goates et. al. 2007, pp. 478, 480), and *A. boreas* (581-1105 m (1,906-3,625 ft); Bartelt et. al. 2004, p. 460). Home ranges are often multinuclear (i.e., toads use multiple spatially separated areas) and toads will use narrow corridors of habitat to reach activity centers (Indermaur et al. 2009, p. 64; Forester et al. 2006, p. 66). Patch distribution of shelter and prey along with inter- and intra-specific competition among individuals may affect the size of a home range (Indermaur et al. 2009, pp. 67-68). If habitat isfragmented and patchy around a body of water, the core area and home range may be larger because of decreased resources (Indermaur et al. 2009, pp. 67-68).

Maintaining dispersal habitat is critical for the persistence of anuran species, especially in fragmented and disturbed landscapes (Semlitsch 2008, p. 265; Walston and Mullin 2008, p. 141). Houston toad dispersal habitat is comprised of the corridors through which unidirectional movements of juvenile and adults take place (McHenry and Forstner 2009, p. 83), creating a matrix of suitable habitat connecting breeding ponds. Movement and dispersal habitat is necessary for population survival, recruitment, immigration, genetic exchange, and maintaining the metapopulation dynamics of anuran populations (Reading et al. 1991, pp. 210–211; Rothermel and Semlitsch 2002, pp. 1330–1331; Funk et al. 2005, p. 15; Semlitsch 2008, pp. 264–265; Indermaur et al. 2009, p. 69).

Forests are a necessary component of the Houston toad's ecosystem because they maintain dispersal corridors (Welsh 1990, pp. 315-317; deMaynadier and Hunter 1999, p. 448; Gibbs 1998, pp. 265-268; Knutson et al. 1999, p. 1,444). Drainages and forested habitats are the most likely corridor routes for dispersing Houston toads because they provide moisture that can prevent desiccation. Hillis et al. (1984, pp. 66-67) observed Houston toad adults and juveniles using gulleys leading to ponds, and telemetry data have also shown that adults use drainages for dispersal (Swannack 2007, p. 67). Juvenile pond-breeding amphibians including *A. americanus* emigrating from experimental ponds have been shown to select closed-canopy forested habitat over open fields or partially closed canopy forests (deMaynadier and Hunter 1999, p. 446; Rothermel and Semlitsch 2002, p. 1,330). Walston and Mullin (2008, p. 144) also monitored movement patterns of newly metamorphosed amphibians including *A. americanus* and found that dispersing juveniles selected areas with greater forested habitats to move through rather than habitats with both forested and open areas. Microhabitat conditions within interior forest habitats, where soil moisture is greater and temperatures are less variable, are likely more hospitable to amphibians than are open habitats or areas along a forested edge (Knutson et al. 1999, pp. 1,443-1,444; Gibbs 1998, pp. 265-268).

Houston toads are explosive breeders (Wells 1977, pp. 667-669; Jacobson 1989, p. 377; Price 2003, p. 1), which results in a high number of juveniles at individual breeding sites. Due to an abundance of juveniles at individual sites, juveniles may have to leave suitable habitat to find new suitable habitat (Bull 2009, p. 245). Though ideal dispersal habitat includes forested areas and/or drainages that connect breeding habitat, Houston toads can move through a variety of habitat types that may not be thought of as "classic" Houston toad habitat. For example, Houston toads have been observed moving along drainages within pastures, if some canopy cover is present (Swannack 2007, p. 67; Forstner and Dixon 2011, p. 37). A dispersing juvenile toad will likely have to move through a mosaic of habitat types to reach new, suitable habitat in an increasingly fragmented landscape.

## 3.0 Species Current Condition and Stressors

### 3.1 Range and Distribution

The historical range of the Houston toad encompassed portions of the following 12 Texas counties: Austin, Bastrop, Burleson, Colorado, Fort Bend, Harris, Lavaca, Lee, Leon, Liberty, Milam, and Robertson (Figure 2; Hillis et al. 1984, p. 57; Yantis 1989, p. 2; 1990, p. 2; Forstner and Dixon 2011, p. 33). The current Houston toad range has been reduced to two bands distributed across portions of nine counties within the Post Oak Savannah Ecoregion. Currently occupied counties in the northern band are Bastrop, Burleson, Lee, Leon, Milam, and Robertson. Currently occupied counties in the southern band are Austin, Colorado, and Lavaca. Several populations of Houston toads have not been observed since they were first discovered, and it appears likely that the species is extirpated from Fort Bend, Harris, and Liberty counties (Forstner 2003, p. 8; Forstner and Dixon 2011, pp. 33-34).

The majority of the Houston toad's current range is located on private lands. Bastrop County is the only county within the species' range that contains public or protected lands known to support Houston toads. These lands include Texas Parks and Wildlife Department's Bastrop and Buescher State Parks, the Boy Scouts of America's Griffith League Ranch, and lands owned by the Lower Colorado River Authority and University of Texas. The last report of Houston toads in each county is shown in Table 1. The drought of the 1950s is often suggested as the cause of extirpation around Houston, along with the rapid development of the area (Forstner and Dixon 2011, p. 21). Continued rapid development across the Houston toad's range is the biggest stressor for this species. Houston toads may also soon be extirpated from Lee County, given population trends and habitat loss observed since 2000 (Forstner and Dixon 2011, p. 34). Additionally, the 2011 Bastrop County Complex Fire burned a total of 13,893 hectares (ha) [34,330 acres (ac)] of land, impacting Houston toad populations and associated habitat in the area (Lost Pines Recovery Team 2011, pp. 1-211).

Determining the size and status of Houston toad populations is problematic due to the difficulty of detecting this species during its non-breeding season and lack of techniques to track individuals from the egg, tadpole, or toadlet (i.e., juvenile) stage to adulthood, or to accurately estimate the age of wild-caught adults. Most Houston toad surveys are conducted during its breeding season when the species is most active and adult male Houston toads are vocalizing at breeding ponds. As a result, surveys of chorusing males provide potential breeding locality information. Multiple surveys at the same sites over several years can provide useful trend information for the species, but accurate populations estimates are difficult to ascertain due to detection difficulties.

Because the number of individuals at a breeding pond can be very small, and environmental conditions that help stimulate breeding activity can be unpredictable, Houston toads can be overlooked during surveys. Even when environmental conditions appear to be suitable for breeding activity, male Houston toads may be present, but not chorusing, at ponds. Multiple visits over several years are often necessary to determine whether Houston toads are present in any particular area. An abundance estimate at the Griffith League Ranch was calculated in the 2010 breeding season using mark-recapture methodology, estimating between 241 to 365 adult individuals (Duarte et al. 2011, pp. 207-215). Further mark-recapture efforts in the future at Griffith League Ranch and elsewhere across the range would be informative.

Table 1. Last observation of a Houston toad across the species' historical range.

| Geologic Band | County | Last Year Observed |
| --- | --- | --- |
| **Northern** | Bastrop | 2020 |
| | Robertson | 2019 |
| | Leon | 2019 |
| | Lee | 2017 |
| | Burleson | 2011 |
| | Milam | 2007 |
| **Southern** | Austin | 2019 |
| | Lavaca | 2013 |
| | Colorado | 2013 |
| | Harris | 1970s |
| | Fort Bend | 1960s |
| | Liberty | 1950s |

Species experts have provided a wide range of estimates for Houston toad subpopulation and census sizes throughout the years. Only Bastrop County has been surveyed consistently from year to year since the 1970s; therefore, most population estimates refer to Houston toad numbers in this county. In the 1980s, surveyors reported observing 30 to 1,000 Houston toads per breeding pond (Hillis et al. 1984, pp. 61, 70). Thereafter, estimates of 2,000 Houston toads in all of Bastrop County were reported (USFWS 1994, p. 63). Forstner (2003, p. 20) estimated the number of Houston toads in Bastrop County to be between 100 and 200 individuals (Forstner and Dixon 2011, p. 18).

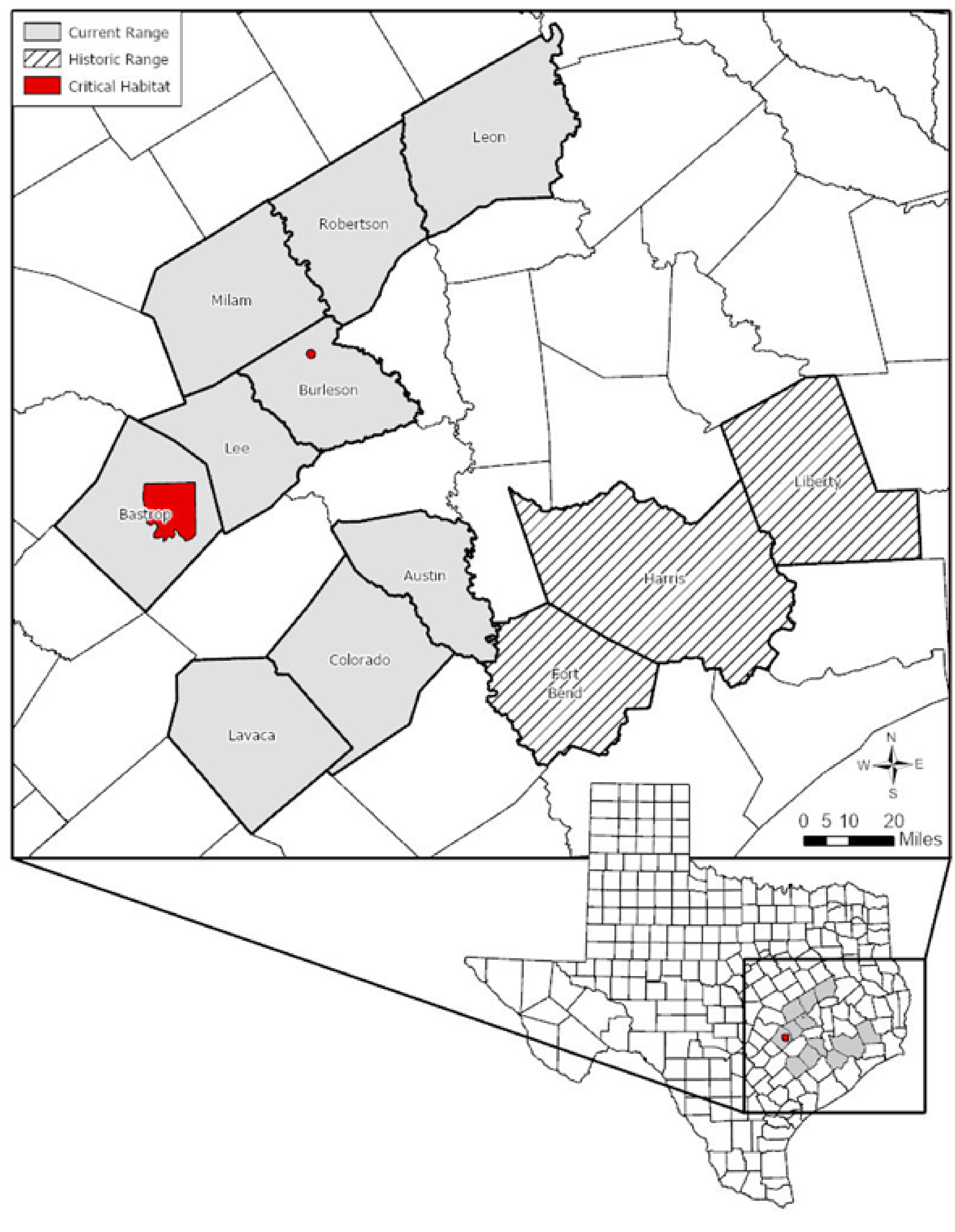


Figure 2: Houston toad current (gray) and historical (hatched) range with designated critical habitat (red).

During the 2012 survey season, approximately 100 male toads were detected range-wide. In 2013, about 30 Houston toads were detected, and in 2014 about 85 Houston toads were detected. In each year after the catastrophic Bastrop County Complex Fire of 2011, the species was detected within the burn area, indicating it was not eliminated from the landscape, though still vulnerable to extirpation. Numbers of Houston toad detections had not returned to levels prior to the Bastrop County Complex Fire, as of 2019 (Forstner and Bohannon 2019, p. 11).

### 3.2 Captive Propagation and Population Supplementation

In 2007, the Houston Zoo established a head-starting program to raise Houston toads through the most vulnerable life stages to supplement wild populations. Between 2007 and 2014, a captive assurance colony was established at the Houston and Fort Worth Zoos, and head-started juveniles and adult Houston toads were released into existing wild populations. In 2013, it was decided that it would be more productive and efficient to produce mass quantities of eggs to supplement wild populations rather than head start toads. From 2013 to 2020, the total number of eggs released increased from roughly 150,000 to 1,000,000, as husbandry methodology was refined (Table 2). In 2019, a captive assurance colony was established at the San Marcos Fish Hatchery. The fish hatchery produced and released about 10,000 eggs in 2020, their first breeding season.

Table 2. Total number of eggs released to supplement wild populations by year and county. These are rough estimates based on egg strand size, as it would be impossible to count each individual egg.

| Year | Total Eggs Released | County |
|---|---|---|
| 2013 | 50,000 | Bastrop and Leon |
| 2014 | 150,000 | Austin and Bastrop |
| 2015 | 550,000 | Bastrop |
| 2016 | 750,000 | Bastrop |
| 2017 | 900,000 | Bastrop |
| 2018 | 1,000,000 | Bastrop |
| 2019 | 1,000,000 | Bastrop |
| 2020 | 900,000 | Bastrop |
| 2021 | 700,000* | Bastrop |

*Approximately 23,000 of this number was comprised of tadpoles rather than eggs.

### 3.3 Stressors

The ESA describes five factors that may lead to endangered or threatened status for a species. These include: A) the present or threatened destruction, modification, or curtailment of its habitat or range; B) overutilization for commercial, recreational, scientific, or educational purposes; C) disease or predation; D) the inadequacy of existing regulatory mechanisms; or E) other natural or manmade factors affecting its continued existence. The primary threats to the Houston toad include habitat loss and degradation (Factor A), predation (Factor C), small population size and isolation, and drought and climate change (Factor E).

### 3.3.1 Habitat Loss and Degradation (Factor A)

Habitat loss in the form of destruction, modification, and curtailment of habitat have long been considered the most significant and immediate threats facing the Houston toad (Forstner and Dixon 2011, p. 44). These threats can have the following effects or stressors on amphibian species, including the Houston toad:

- Direct mortality (Reh and Seitz 1990, p. 247; Fahrig et al. 1995, p. 181; Carr and Fahrig 2001, p. 1,071; Dodd and Smith 2003, p. 106; Cushman 2006, p. 232)
- Reduction in population sizes (Fahrig et al. 1995, p. 181; Fahrig 1997, p. 603)
- Decreased mobility or movement, including dispersal, through an area (Gibbs 1998, p. 267; Cushman 2006, p. 232; Popescu and Hunter 2011, p. 1293)
- Population isolation and restricted gene flow (interference with metapopulation dynamics) [Reh and Seitz 1990, p. 247; Cushman 2006, p. 233]
- Loss of breeding sites or access to breeding sites (Vos and Chadron 1998, p. 54)
- Reduction in food availability (Porter and Savignano 1990, p. 2,101)
- Increased exposure to pollutants (Cushman 2006, p. 232)
- Elimination of shelter and the ability to escape harsh weather conditions (Dodd and Smith 2003, p. 106)
- Increased vulnerability to predators and competitors (Gibbs 1998, p. 267)
- Increased vulnerability to pathogens and disease (Cushman 2006, p. 232)
- Increased exposure to red-imported fire ants (Cushman 2006, p. 232)
- Increased likelihood of hybridization with other toad species (Rhymer and Simberloff 1996, pp. 83-84; Forstner and Dixon 2011, p. 29)
- Increased susceptibility to stochastic events (Dodd and Smith 2003, p. 106)
- Increased vulnerability to climate change (Cushman 2006, p. 232; Donald and Evans 2006, p. 213)

Although there are distinct differences between habitat destruction, alteration, and fragmentation on the landscape level, it is difficult to determine which of these processes is causing specific effects to Houston toad populations at any given time. This is partly because multiple sources of these threats are occurring concurrently within the Houston toad's range. All three processes may be caused by anthropogenic sources, such as urbanization, logging, and agricultural practices. Habitat loss and habitat fragmentation typically occur together (Fahrig 1997, p. 603), although fragmentation is often considered a secondary effect of habitat destruction, and habitat amount has been hypothesized as the most important factor (Fahrig 2013, pp. 1649-1663). As such, the various sources and effects of habitat destruction, alteration, and fragmentation are discussed below.

Habitat destruction is defined by Dodd and Smith (2003, p. 98) as the complete elimination of a localized or regional ecosystem leading to the loss of its former biological function. The effects of habitat loss with regard to population extinctions have been shown to be more significant than those of habitat fragmentation (Fahrig 1997, p. 607). In some instances, habitat destruction can be partially reversed through restoration. However, most destroyed habitats will never again function as natural ecosystems because the logistics, expense, and continued expansion of the human population make it infeasible (Dodd and Smith 2003, pp. 98-99). For example, when forests or other upland terrestrial habitats are paved and converted to parking lots or housing and commercial developments, the habitat is completely removed, leaving no opportunity for restoration. Conversion of forested areas to agricultural or improved pastures, timber harvesting, and mineral production can also result in habitat loss with varying potential for restoration.

Habitat destruction has been documented within the Houston toad's range. Buzo (2008, pp. 1- 93) used a geographical information system (GIS) to model the habitat suitability for the Houston toad. Using aerial imagery from Buzo's study, Forstner and Dixon (2011, pp. 19, 35, 44) noted significant losses of 16 and 11 percent of high suitability Houston toad habitat from 1999 to 2005 in both Lee and Bastrop counties, respectively. Such habitat loss has beenthe result of the conversion to housing, agricultural pastures, or other unsuitable landscapes (Forstner and Dixon 2011, p. 44).

Altered or degraded habitats are those in which ecosystem function has been adversely affected, although not totally or permanently (Dodd and Smith 2003, p. 99). Sources of habitat alteration may have fewer habitat impacts to the Houston toad. These sources may include, but are not limited to fire suppression, wildfires, and livestock damage to breeding habitat (discussed under section 4.1.4 below).

Habitat fragmentation can be defined as the disruption of a once large continuous block of habitat into less continuous habitat (Franklin et al. 2002, p. 20), which usually occurs through habitat loss (Franklin et al. 2002, p. 23). This is primarily caused by human disturbances, such as land clearing and conversion of vegetation from one type to another (Franklin et al. 2002, p. 20). Diminishing habitat sizes and connectivity cause problems for animal populations, as the genetic exchange of individuals is reduced or even stopped (Reh and Seitz 1990, p. 240). In addition, amphibians existing in fragments of habitat are subject to adverse effects from (1) edge effects (deMaynadier and Hunter 1998, p. 350; Houlahan and Findlay 2003, p. 1,007), (2) barriers to movement (Reh and Seitz 1990, p. 247), and (3) isolation and subsequent changes to demographic parameters, such as decreased survivorship and loss of genetic viability(Reh and Seitz 1990, pp. 240, 244-245; Dodd and Smith 2003, p. 99).

"Edge effects" are changes to the plant and animal communities where different habitats meet or where habitat meets developed areas, such as pavement. The length and width of the edge, as well as the contrast between vegetation communities or a vegetation community and a developed area, all contribute to the level of impacts to species (Harris 1984, pp. 74-82). Some types of edge effects include increases in solar radiation, changes in soil moisture due to elevated levels of evapotranspiration, wind buffering (Ranney et al. 1981, p. 69), changes in nutrient cycling and the hydrological cycle (Saunders et al. 1991, p. 20-22), and changes in the rate of leaf litter decomposition (Didham 1998, pp. 400-401). These edge effects alter plant communities, which in turn affect the associated animal species. Vegetation that is within 2 m (6.6. ft) from an edge can be visibly affected within days (Lovejoy et al. 1986, pp. 258-259).

Edges often allow enough disruption for invasive or exotic species to gain a foothold where the native vegetation may have previously prevented their spread (Saunders et al. 1991, p. 24: Suarez et al. 1998, p. 2,047, Meiners and Pickett 1999, p. 265). The invasion of red-imported fire ants, an aggressive predator (see the "Disease and Predation" sections below) and threat to the Houston toad (USFWS 1994, p. 76), is known to be aided by "any disturbance that clears a site of heavy vegetation and disrupts the native ant community" (Porteret al. 1988, p. 916). Edges favor the proliferation of red-imported fire ants, which can result in increased predation on Houston toads and competition with native arthropod species (Porter and Savignano 1990, p. 2,101), which comprise the Houston toad's prey base (Bragg 1960, p. 106).

Habitat fragmentation can also directly affect animal species with regard to movement. Edges can act as a barrier to distribution and dispersal patterns of birds and mammals (Yahner 1988, pp.336-337; Hansson 1998, p. 61). Increases in predation (Suarez et al. 1998, p. 2,053) and competition for food sources (Hanski 1995, p. 217) also occur in the edge of habitat fragments. In addition, organisms require necessary behaviors and body size to navigate various barriers to dispersal, including agriculture, and non-vegetated and hard surfaces, such as developments and roadways (Saunders et al. 1990, p. 23). These barriers, as well as dense grazing grasses (Yantis 1989, p. 6), can inhibit or cease movement for the Houston toad, (discussed below under the "*Fire Suppression and Wildfire*" and"*Agriculture Production*" sections.)

As habitat patches become isolated from similar surrounding habitat, rare species that depend on the habitat patch are more likely to become extirpated (Harris 1984, pp. 80-81). Even small amounts of habitat fragmentation (such as paved roads less than 10 ft (3 m) wide can prevent dispersal and effectively isolate populations of amphibians (van Gelder 1973, p. 94; Reh and Seitz 1990, p. 247; Yanes et al. 1995, p. 217; Findlay and Houlahan 1997, pp. 1,003-1,004; Gibbs 1998, p. 267; Vos and Chardron 1998, p. 54; Knutson et al. 1999, p. 1,438). Burke and Nol (1998, p. 101) also found that small forest fragments had significantly lower numbers of invertebrates in the leaf litter than larger fragments, which could adversely affect Houston toad feeding.

Currently, remaining Houston toad populations are all widely scattered, small, and disconnected (Forstner and Dixon 2011, p. 29). However, Houston toad population genetic analyses indicate strong, relatively recent connectivity among populations(McHenry and Forstner 2009, pp. 80-81). Significant genetic variation remains among Houston toads in the Bastrop area (McHenry and Forstner 2009, pp. 72, 80; Forstner and Dixon 2011, p. 28). Consequently, Houston toad populations that existed in large, generally contiguous habitat patches enabled gene flow within and among those habitat patches (McHenry and Forstner 2009, p. 81). Small populations of organisms are known to lose genetic variation over time (Lacy 1987, p. 144). Given the rapid habitat loss and population declines experienced by this species in recent decades, genetic variation is likely to decrease without human intervention.

3.3.1.1 Urbanization

Urbanization, along with associated effects of development, is one of the most pressing threats to native species (Wilcove et al. 1998, pp. 607, 612-613; Marzluff and Rodewald 2008, p. 3) and has been identified as the leading factor in the endangerment of nearly 300 species in the continental United States (Czech et al. 2000, pp. 596, 599). Construction of development projects (e.g., single- or multi-family housing, commercial buildings, and paved roadways) often entails the partial or complete mechanical removal of natural vegetation, and potentially topsoil, from a site (Theobald et al. 1997, p. 26; Zipperer 2011, pp. 188-189) followed by replacement with built structures, impervious cover, and/or non-native, managed landscaping (McKinney 2002, pp. 884, 886;

McKinney 2008, p. 168). Once completed, such urban landscape features can have long-term impacts on surrounding natural communities (Theobald et al. 1997, pp. 27-28, 31-33). Compared to some other anthropogenic drivers of species decline (e.g., agriculture, forestry, or grazing), the impacts of urbanization on native habitats are more persistent, resulting in highly modified sites with decreased potential for maintenance or re-establishment of native species (Rebele 1994, p. 177; Theobald et al. 1997, p. 33; Huxel and Hastings 1999, p. 312; Marzluff and Ewing 2001, p. 281; McKinney 2002, pp. 883-886, 889; Hansen et al. 2005, pp. 1,899-1,900).

Urban development can reduce native animal and plant species richness and abundance through the direct destruction and removal of natural habitat and degradation of habitat remaining near development (Paul and Meyer 2001, pp. 348-353; McKinney 2002, pp. 885-886; Riley et al. 2005, pp. 1901-1905; Price et al. 2006, pp. 439-440; O'Driscoll et al. 2010, pp. 630-631; Aronson et al. 2014, pp. 5-7). Sites cleared of natural vegetation can experience rapid deficits inthe resources (e.g., food or shelter) native animal species require for survival (Rebele 1994, p. 177; McKinney 2002, pp. 885-886). Urbanization also tends to favor a subset of animal and plant species (e.g., non-native species) tolerant of human activity or that prefer disturbed habitats(Rebele 1994, p. 176; Theobald, et al. 1997, p. 27; McKinney 2002, pp. 887-888; McKinney 2006, p. 2480). These species often replace less tolerant species (e.g., habitat specialists) in the urbanized landscape, leading to an overall homogenization of animal and plant species diversity (Marzluff and Ewing 2001, pp. 283-285; Holway and Suarez 2006, pp. 322-323; Devictor et al. 2007, pp. 747, 749; McKinney 2006, pp. 249-254; Olden et al. 2006, pp. 268-269; Marzluff and Rodewald 2008, p. 6). This loss of diversity and shift in plant and animal communities towards habitat generalists and tolerant species could shift habitat conditions to be less suitable for the Houston toad.

The rapid development of the Austin-Round Rock Metropolitan Area poses one of the greatest threats to the Houston toad. Expansion of human populations to nearby communities is of concern for western portions of the Houston toad's range. Table 3 depicts potential human population growth projections for counties occupied by extant Houston toad populations from 2020 to 2050 (Texas Demographic Center 2020). Bastrop County is projected to see the greatest increase in human population over the next 30 years (Texas Demographic Center 2020). Bastrop County hosts the most robust population of Houston toads, with the majority of egg release supplementation efforts occurring there. Other counties with extant Houston toad populations are projected to see moderate human population growth or declines.

Table 3: Human population projections (2020-2050) for counties with extant Houston toad populations (TexasDemographic Center 2020).

| County | Geologic Band | Population 2020 | Population 2050 |
|---|---|---|---|
| Bastrop | North | 86,105 | 125,002 |
| Lee | North | 17,595 | 18,309 |
| Burleson | North | 17,718 | 18,278 |
| Milam | North | 24,635 | 22,222 |
| Robertson | North | 16,888 | 16,940 |
| Leon | North | 17,707 | 19,131 |
| Lavaca | South | 20,735 | 30,647 |
| Austin | South | 30,402 | 33,391 |
| Colorado | South | 21,273 | 20,596 |

The adverse effects of urbanization on Houston toads are likely due to a combination of factors. The construction of buildings and associated infrastructure leads to permanent habitat loss of breeding, feeding, and sheltering sites (Forstner and Dixon 2011, p. 44). Urbanization also includes forest conversion to sod-forming turf grass lawns and other nonnative vegetation, soil compaction, erection of privacy fencing, introduction of imported topsoil, and pesticide application. Red-imported fire ants can be brought into areas through imported topsoil and nursery plants. They may also increase in intensity and distribution due to land clearing and development (see "Disease and Predation" below).

The terrestrial changes to the habitat brought on by urban development will likely inhibit Houston toad mobility and dispersal. This can affect survival of the Houston toad, as mobility and dispersal are necessary for (1) access to food and breeding sites; (2) protection from predators, (3) protection from extreme weather conditions; and (4) genetic exchange (Dodd and Smith 2003, pp. 104-106). These changes can also lead to a reduction in the diversity and abundance of the invertebrate communities the Houston toad feeds on (Haskell 2000, p. 60) and the direct mortality of Houston toads during site clearing, preparation, and construction from vehicular traffic on roads (Bull 2009, pp. 243, 245).

3.3.1.2 Roadways

One of the greatest impacts that roadways have on amphibians is the number of individuals killed by motor vehicle traffic (Forman and Alexander 1998, p. 213). Amphibians appear to be especially vulnerable to traffic mortality as they readily attempt to cross roads, but because theyare small and slow moving, drivers do not easily avoid them (Carr and Fahrig 2001, p. 1,076). The highest rates of road mortality for amphibians occur where roads are located in the vicinity of a wetland or pond where reproduction takes place and where roads cross areas of juvenile dispersal (deMaynadier and

Hunter 1995, p. 244; Andrews et al. 2006, p. 124).

Traffic density has been found to be negatively correlated with abundance of roadside populations of frogs and toads (Fahrig et al. 1995, p. 181). It is rare to find dead Houston toads on a roadway that have not already been consumed by red-imported fire ants or other animals, but they have been discovered occasionally (Paul Crump, Houston Zoo, pers. comm. 2010, p. 1; Shawn McCracken, The Tadpole Organization, pers. comm. 2012, p. 1). Vehicular strikes maybe a more significant issue for the Houston toad than other amphibians since it is already a rare species.

Road construction also fragments habitat and can act as a barrier to dispersal and genetic exchange among individuals (Reh and Seitz 1990, pp. 244-245), which is critical to maintaining population viability within Houston toad metapopulations. This may be due to amphibians' behavioral avoidance of moving into inhospitable areas (Russell et al. 2003, pp. 149-150; Semlitsch et al. 2008, p. 288). It could also be due to other factors, such as changes in microclimatic conditions near roads, increased predation along a road's edge, and mortality from roadway traffic (Reh and Seitz 1990, p. 240; Fahrig et al. 1995, p. 179). Abundance and diversity of macroinvertebrate soil fauna as well as leaf litter depths have been shown to be reduced close to roads constructed in forests (Haskell 2000, p. 60). Declines in faunal abundance and leaf litter depths have been observed as far as 100 m (328 ft) into the forest from a road (Haskell 2000, p. 60).

The construction of roadways can negatively affect the Houston toad in a variety of other ways. Removal of forested habitat for road construction can result in isolation of breeding ponds (Vos and Chadron 1998, p. 51) and decreased wetland biodiversity (Findlay and Houlahan 1997, pp. 1,003-1,004). Other road-related factors, such as pollutants in road runoff, exhaust emissions, vibrations, and noise may affect toads by either causing direct mortality or interrupting behavior (Fahrig et al. 1995, p. 181; Bull 2009, p. 243, 245). Roads can also constitute a hindrance to movement in forest-inhabiting species (Mader et al. 1990, pp. 214-215).

3.3.1.4 Agriculture

Portions of the Houston toad's range have been highly modified by agricultural practices (USFWS 1994, p. 33). Agriculture production contributes to Houston toad habitat loss and alteration through the following activities:

- Conversion of forests to pasture or cropland
- Plowing and mowing, which can result in direct mortality of Houston toads
- Alteration of breeding habitat by increasing the number of permanent water bodies on the landscape (Gaston et al. 2010, p. 5) and decreasing water quality in potential breeding ponds (Knutson et al. 2004, p. 677; Schmutzer et al. 2008, p. 2,620)
- Application of herbicides, pesticides, and fertilizers (Knutson et al. 1999, p. 1,444)
- Edge effects from conversion of forested habitat to agricultural lands

Perhaps the most conspicuous threat of agriculture production to Houston toad is the direct loss of forested habitat through deforestation activities necessary to create pastures and cropland.
After forested habitat known to be occupied by robust Houston toad populations was cleared for agriculture in Lee County, Houston toads were no longer detected there (McHenry and Forstner 2009, p. 17). It has also been shown that agricultural practices, such as cattle production, can have

negative effects on amphibians by decreasing water quality through deposition of nitrogenous waste and altering vegetation that reduces availability of food and cover (Schmutzeret al. 2008, pp. 8-9).

Grazing can change the age distribution and species composition of native vegetation (Bolen and Robinson 1999, p. 297), which may affect food and cover availability for Houston toads. Often, cattle production can lead to the conversion of native vegetation to improved pastures of Bermudagrass or Bahiagrass (*Paspalum notatum*), which are commonly used for grazing in the southern United States (Looper et al. 2006, p. 117). These dense, sod-forming grasses can inhibit Houston toad mobility (Yantis 1989, p. 6). Overgrazing can also lead to soil erosion, which can result in changes to moisture retention on the forest floor and runoff into ponds and streams (Belsky et al. 1999, p. 420). Excessive runoff can increase sediment loading and turbidity and decrease water quality (such as dissolved oxygen) within Houston toad breeding sites, which can affect tadpole foraging and survival (Belsky et al. 1999, p. 420).

Houston toad breeding ponds located within agricultural areas are at risk of disturbance from livestock wading and defecation. These activities can prevent vegetation from establishing around the pond's perimeter, and result in high levels of nitrogen (from urine and manure), increased turbidity, decreased water quality, and an overall adverse environment for amphibian egg and tadpole development (Knutson et al. 2004, p. 677; Schmutzer et al. 2008, p. 8). Elevated ammonia, nitrate, and nitrite levels are known to affect amphibian embryo and larvae survival and larval body size (Jofre and Karasov 1999, pp. 1,808-1,810).

Livestock wading into breeding areas leads to habitat alteration in the form of vegetation loss and soil compaction at the pond's edge that deters Houston toad breeding activity (Forstner 2001, p. 3). Trampling by cattle was reported as a primary source of mortality of Western toads (*Anaxyrus boreas*) (Bull 2009, p. 243). It is reasonable to assume that trampling may also result in the destruction of egg clutches as well as mortality of tadpoles and adults in and around water sources.

3.3.1.5 Oil, Natural Gas, and Mining Activities

The installation of oil and gas wells, associated roadways, pipelines, staging areas, and well drilling activities can result in fragmentation and habitat loss (including breeding site destruction). Direct impacts to the Houston toad can also occur during installation from trenching or construction in inhabited areas and trapping toads in open trenches or pits. Breeding sites can also be destroyed by these activities.

In addition to oil and gas production, mining operations (including lignite, gravel, and sand) can also result in severe, if not total, habitat loss in areas occupied by the Houston toad. The most direct effect on wildlife species from mining is the destruction or displacement of species in areas of excavation and piling of mine wastes (MINEO Consortium 2000, p. 20). However, the most significant impact of a mining project on the Houston toad is likely its effects on water quality and availability of water resources within areas surrounding the mining operation, because of its potential to affect Houston toads within a larger area than just the footprint of the mining project. Many mining operations remove groundwater prior to surface excavations to lower the underlying water table in a process referred to as "dewatering." Impacts from dewatering mayinclude reduction or elimination of surface water flows in riparian areas, springs, and other wetland areas (MINEO Consortium 2000, pp. 16-17, 20) that serve as Houston toad breeding habitat. Some mining activities can affect the underlying aquifer either through dewatering or by leaching minerals into it. Dixon (1982, p. 8) identified the following possibleimpacts from lignite mining:

- Dewatering may draw down surface waters and dry out the subsurface moisture in areas where the Houston toad occurs.
- Dewatering may reduce the carrying capacity of permanent surface ponds or ephemeral pools by drawing down subsurface moisture and affecting breeding sites.
- Leaching of sulphur and weak carbonic acids from the mine may result in poor water quality downstream in areas used as habitat by the Houston toad.

Furthermore, the physical destruction of habitat that occurs during mining operations often results in the release of chemicals into the surrounding terrestrial and breeding habitat (MINEO Consortium 2000, p. 20). This can lead to habitat degradation and an increased exposure of the Houston toad to contaminants.

3.3.1.6 Timber Harvesting

Timber harvesting is a common form of land alteration that is associated with the loss and modificationof forested habitat and has caused declines in amphibian populations (Petranka et al. 1994, p. 142; deMaynadier and Hunter 1998, pp. 348-349; Ash 1997, p. 986-987; Knapp et al. 2003, pp. 759-760; Semlitsch et al. 2009, p. 860). The heavy machinery used in timber harvesting activities may directly kill amphibians (Knapp et al. 2003, 760). Forestry practices can also alter the microclimate of the forest floor (Keenan and Kimmins 1993, pp. 123-124; Chen et al. 1999, p. 293) and increase edge effects (deMaynadier and Hunter 1998, p. 341). deMaynadier and Hunter (1998, p. 350) found that many microhabitat features (small-scale physical habitat requirements) are directly affected by the intensity of timber harvesting. Such features includelitter depth and type, canopy cover, understory vegetation density, and abundance of cover refugia.

Clearcutting is the forestry practice in which most or all trees in an area are cut down. This practice can be particularly harmful to amphibian species, as it alters the fundamental structure of a forest by removing canopy and exposing the forest floor to more sunlight and wind. This, in turn, leads to a warmer, drier microclimate on the soil surface (Keenan and Kimmins 1993, p. 124; Chen at al. 1999, p. 295). Changes in microclimate can result in decreased availability of soil invertebrate prey species (Haskell 2000, p. 62). Clear-cuts can also act as significant barriers to amphibian dispersal (Popescu and Hunter 2011, p. 1,291), which can negatively affect population viability.

Some forestry practices (alternative methods to clearcutting), which involve the removal of onlya portion of the canopy (50 percent or less), are believed to minimize negative effects to amphibian populations (Semlitsch et al. 2009, p. 860). Although Knapp et al. (2003, p. 760) found little difference in salamander abundances following removal of canopy in clear-cuts compared to areas where alternative timber harvesting methods were used and less of the canopy was removed, lower overall abundances were found in clear-cuts. Total area of habitat disturbance from the creation of roads and machinery trails is greater when using alternative forestry practices to remove less canopy, since larger areas must be disturbed to obtain the same amount of timber as could be obtained from clear-cut areas. (Semlitsch et al. 2009, p. 860; Knappet al. 2003, p. 760). Thus, there exists a tradeoff between a smaller, intense disturbance from clearcutting, and alternative methods, which can disturb larger areas with less intensity (Semlitsch et al. 2009, p. 860), The intensity of logging activities within the Houston toad's range varies considerably from year to year, and largely depends on timber sale values and availability of timber in eastern Texas. Logging has occurred within the Houston toad's range at various times throughout the last century, and very little old growth forest remains. As demonstrated by other amphibian species (Ash 1997, p. 988; Knapp et al. 2003, p. 759-760), the Houston toad may recolonize areas that have been logged as the forest regenerates. However, this is only likely if sufficiently large Houston toad populations occur nearby.

3.3.1.7 Other Landscape Changes

Other alterations of the landscape have threatened the continued existence of this species. An increase in the number of permanent livestock ponds or tanks within the Houston toad's range over the last 100 years has likely contributed to the species' decline (Gaston et al. 2010, p. 5). Forstner and Dixon (2011, p. 22) reported over 1,700 water bodies within designated critical habitat in Bastrop County alone. Therefore, both quantity and quality (particularly the number of days per year standing water is present in a pond) of current breeding habitat is dramatically different from what existed during the evolutionary history of this species (Gaston et al. 2010, p. 5). With increasing pond density, fewer male Houston toads are available per pond to chorus each night (Gaston et al. 2010, p. 5), with approximately 1 pond per 161 ha (400 ac) representing the ideal pond density. Thus, the sheer number of potential Houston toad chorusing sites available on the landscape has reduced the chorusing magnitude needed to attract females to potential breeding sites (Gaston et al. 2010, p. 5; see "Allee Effects" discussion above). This has likely contributed to a decline in overall reproduction (Forstner and Dixon 2011, pp. 21-22).

More than 60 years of fire suppression has also considerably altered the forested habitat within the Houston toad's range (Lost Pines Recovery Team 2011, p. 203; Forstner and Dixon 2011, p.41). Fire suppression can increase the growth of understory plants and the encroachment of woody invasive species, such as yaupon (*Ilex vomitoria*) (USFWS 1994, p.33). A legacy of fire suppression in a forest ecosystem increases the probability of catastrophic fire and associated changes in forest structure and composition (Pilliod et al. 2003, p. 171). Within the Houston toad's range, long-term fire suppression has altered the structure and composition of current woodland habitats, as characterized by an excessive accumulation of dead wildland fuels (e.g., leaves and woody debris) and increased tree and shrub densities (Lost Pines Recovery Team 2011, p. 203).

These unnaturally heavy fuel loads combined with historic drought conditions supported uncommonly intense and expansive wildfires in Bastrop County, Texas in September 2011 (Lost Pines Recovery Team 2011, p. 203). The results of burn severity analyses indicate that 49 percent of the burned area experienced a stand-replacing fire (a fire in which most or all of the overstory trees were killed) (Lost Pines Recovery Team 2011, p. 203). The most considerable effects to the Houston toad from wildfires are the adverse changes to its habitat. The loss of understory vegetation, surface debris (e.g., leaf litter and logs), and canopy cover can lead to increased exposure to temperature extremes and predation from lack of cover, loss of habitat availability, and reduced dispersal and foraging capabilities.

Soil erosion, which is a typical occurrence following wildfires (Kocher et al. 2009, p. 3), can affect Houston toad breeding habitat by decreasing water quality in ponds. Direct mortality to the Houston toad resulting from wildfires is thought to be low, as amphibians have been shownto survive fire by moving under the soil (Russell et al. 1999, p. 375) or seeking cover within the burrows of other animals (Russell et al. 1999, p. 375).

Prescribed burning is an important tool that can be used to reduce hazardous fuel loads (Agee and Skinner 2005, pp. 86-87), and, depending on the prescribed treatment, can leave some tree canopy and other vegetative cover (Agee and Skinner 2005, p. 84). Studies conducted in Houston toad habitat found evidence that herpetofauna species do not appear to be particularly vulnerable to direct mortality from either low-intensity prescribed burns or even high-intensity wildfires including the Lost Pines wildfire (Brown et al. 2011, p. 142; Brown et al. 2014, pp. 192-205). Fire benefits amphibians not only through long-term habitat changes, but also through short-term changes, such as reduced predator pressure (Brown et al. 2011, p. 142). However, indirect effects of wildfire can include prey reduction, overstory tree thinning, and water quality (Brown et al. 2014, p. 201). Research on the effects ofprescribed burning activities on the Houston toad, its habitat, and its prey base is needed.

3.3.2 Disease and Predation (Factor C)

*Batrachochytrium dendrobatidis* causes a fungal disease called chytridiomycosis that is responsible for killing amphibians worldwide (Daszak et al. 2000, pp. 445-446). It has been detected in Houston toads (Gaertner et al. 2010, p. 457) and in other amphibians occurring within the Houston toad's range (Gaertner et al. 2009, pp. 184-187), but thus far, Houston toads appear to be asymptomatic for the disease. Ranaviruses are also diseases known to cause mortality in amphibians (Gray et al. 2009, pp. 243-266). One Ranaviral infection of the spotted chorus frog (*Pseudacris clarkii*) was recently documented in Texas (Torrence et al. 2010, p. 67), but has not yet been documented in the Houston toad.

Chlamydosis is another disease that has been reported to occur among both wild and captive populations of amphibian species and is caused by the pathogen *Chlamydophila* sp. (Densmore and Green 2007, p. 237). In 2012 and 2013, captive Houston toads at the Houston Zoo experienced increased mortality due to dermatitis caused by a fungus, bacterium, or co-morbidities (Romano Noregia et al. 2022). *Chlamydia pneumoniae* has caused mortality within the captive breeding colony at the Houston Zoo (Fratzke et al 2019, p. 789). Mycobacteria have been detected in lesions in the captive toad colony, however not all lesions were caused by mycobacteria, and the presence within the captive colony does not threaten the wild populations with a new pathogen, as these bacteria are also present in the wild (Vemulapally et al. 2021, pp. 503-514). We have no data to indicate if impacts from any of these diseases may increase in the wild in the future, and therefore, whether disease is a significant threat affecting the species.

Predators of the Houston toad include water snakes (*Nerodia* sp.), bullfrogs (*Rana catesbeiana*), raccoons (*Procyon lotor*), and various species of carnivores (e.g., skunks and foxes) [Freed and Neitman 1988, p. 455; Ferguson et al. 2008, p. 452]. Red-imported fire ants are also known to prey on newly metamorphosed Houston toad toadlets (Freed and Neitman 1988, pp. 455-456), as well as the invertebrate community (Porter and Savignano 1990, p. 2,103)that is believed to be an important part of the food base for the Houston toad (Bragg 1960, p. 106).

The red-imported fire ant is an invasive species that predominately inhabits the south and southeast regions of the United States (Callcott and Collins 1996, pp. 241-242). Once introduced into an area, the red-imported fire ant can negatively affect a wide range of native vertebrate and invertebrate species (Porter and Savignano 1990, pp. 2,103-2,104; Allen et al. 1994, pp. 52-55;

Todd et al. 2008, pp. 544-545; Epperson and Allen 2010, p. 61). This species can also reduce the abundance and diversity of native arthropods through competition and predation (Porter and Savignano 1990, pp. 2,103-2,104; Epperson and Allen 2010, p. 61), thus altering the possible available prey for the Houston toad. Red-imported fire ants dominated ant assemblages recruiting to U.S. sampling stations (i.e., baits), occurring at 97% of sites versus 68% of sites in South America (Porter et al. 2007, p. 375). These population densities are due to a number of factors, including the U.S. lack of diverse contingent natural enemies to modulate populations of red-imported fire ants, with only a small number of native natural enemies (Jouvenaz et al. 1977, pp. 277-279; Oi and Valles 2009, p. 240; Pereira 2004, p. 42; Porter et al. 1997, p. 376; Valles et al. 2004, p. 154; Yang et al. 2010, pp. 3313-3315).

A major driver of red-imported fire ant invasion into natural communities in the southeastern U.S. is anthropogenic habitat disturbance (Stiles and Jones 1998, pp. 338-339; Taylor et al. 2003, p. 8; Todd et al. 2008, p. 545; LeBrun et al. 2012, pp. 891- 893. The clearing of vegetation and soil disturbances that accompany conversion of natural habitat to human land uses create conditions that favor red- imported fire ant dispersal and colony establishment (Stiles and Jones 1998, pp. 339-340; Brown et al. 2012a, p. 146). Disturbances that accompany urban development can reduce native ant species richness and abundance, providing opportunities for red-imported fire invasion. Urban development and road construction also increases the probability that adjacent undisturbed natural habitat will be invaded by red- imported fire ants (Forys et al. 2002, pp. 30-31).

Small amphibians, such as the Houston toad, that move through or inhabit open microhabitats with little shade can become vulnerable to foraging red-imported fire ants (Todd et al. 2008, p. 545). Red-imported fire ants prefer to colonize in areas characterized by disturbance (Tschinkel 1988, p. 78; Todd et al. 2008, p. 545) and can use roads and power line cuts as expansion corridors (Stiles and Jones 1998, pp. 339-344). In fact, Brown et al. (2012a, p. 146) demonstratedthat the number of red-imported fire ant captures decreased with increasing canopy cover within Houston toad habitat, and red-imported fire ant captures do not occur in areas with 80 percent or greater canopy cover. The threat imposed on the Houston toad by this invasive predator likely exacerbates the negative effects caused by large-scale habitat alteration, such as forest clear-cutting (Todd et al. 2008, p. 544).

### 3.3.3 Small Population Size and Isolation (Factor E)

The historic distribution of the Houston toad appears to be naturally small as the result of specific habitat requirements for breeding and development. Small, sedentary species with restricted distributions, specialized habitat niches, and narrow climatic tolerances are especially sensitiveto changes in habitat conditions (Welsh 1990, p. 317; deMaynadier and Hunter 1998, p. 349). These natural restrictions make them particularly vulnerable to the negative effects of human-induced changes that result in habitat loss, degradation, and fragmentation (Hillis et al. 1984, p.70; Findlay and Houlahan 1997, pp. 1,006-1,007; Semlitsch 2002, pp. 622-623).

Extinction risk depends strongly on factors contributing to stochasticity (Melbourne and Hastings 2008, p. 100), including demographic and environmental stochasticity. Demographic stochasticity comes from the chance events of birth and death of individuals. While individuals in a population may have the same probability of giving birth or dying, how many offspring theyactually produce or when they die will differ by chance (Melbourne and Hastings 2008, p. 100). Environmental stochasticity occurs due to fluctuations in environmental factors (such as temperature), which affect population-level fluctuations in birth and death rates (Melbourne and Hastings 2008, p. 100).

Melbourne and Hastings (2008, p. 100) report that in small populations, demographic stochasticity increases extinction risk due to coincidental deaths and unsuccessful births of individuals (higher number of deaths and unsuccessful births than expected by chance) that cannot be overcome by the sheer number of individuals in the population. At small population levels, the effects of demographic stochasticity alone greatly increase the risk of localextinctions (Van Dyke 2008, p. 218). In contrast, environmental stochasticity increases extinction risk over a broader range of population sizes by affecting the entire population simultaneously (Melbourne and Hastings 2008, p. 100). Environmental stochasticity generally has smaller impacts on small populations compared to demographic stochasticity (Melbourneand Hastings 2008, p. 102).

The Houston toad may be susceptible to threats associated with small population size and impacts from stochastic events. True population size estimates have not been generated for this species, but as few as 12 individuals were detected during rangewide surveys in a single breedingseason in 2011 (Dr. Michael Forstner, Texas State University, pers. comm. 2011, p. 1). Small population sizes can also act synergistically with other traits of the Houston toad (such as being ahabitat specialist and having a limited distribution) to greatly increase risk of extinction (Davies et al. 2004, p. 270). Stochastic events from either environmental factors or demographic factors are heightened threats to the Houston toad because of its limited range and small population sizes (Melbourne and Hastings 2008, p. 100).

Small populations that are largely isolated from one another provide little opportunity for natural recolonization if any of these factors result in a local extirpation event. Although habitat modeling has indicated that there are several large continuous patches of suitable Houston toad habitat remaining (Buzo 2008, p. 67), it also revealed significant losses of suitable habitatand isolation of habitat patches, particularly within Bastrop and Lee Counties (Buzo 2008, p. 68; Forstner and Dixon 2011, pp. 5, 19-20). Small areas of suitable, forested habitat within the Houston toad's range limit the number of individuals that can be supported.

Genetic factors also play a large role in influencing the long-term viability of small populations. Conservation genetics research has demonstrated that long-term inbreeding depression (a pattern of reduced reproduction and survival as a result of genetic relatedness) can occur within small populations (Frankham 1995, p. 796; Latter et al. 1995, p. 294; Van Dyke 2008, pp. 155–156). Inbreeding depression contributes to further population decline and reduced reproduction and survival in small populations and can contribute to a species' extinction (Van Dyke 2008, pp. 172–173). Small populations may also suffer a loss of genetic diversity, reducing the ability of these populations to evolve in response to changing environmental conditions, such as climate change (Visser 2008, pp. 649-655; Traill et al. 2010, pp. 29-30).

Studies across taxonomic groups have found that both the demographic and genetic (including evolutionary) constraints on populations require sizes of at least 5,000 adult individuals to ensure long-term persistence (Traill et al. 2010, p. 30). Populations below this number are considered small and at increased risk of extinction. It is also important to note that this general estimate does not take into account species-specific ecological factors that may affect extinction risk, such as specialized habitat niches and sensitivity to changes in habitat conditions. Evidence from integrated work on population dynamics shows that setting conservation targets at only a few hundred individuals does not properly account for the synergistic impacts of multiple threats facing a population (Traill et al. 2010, p. 32).

A more recent review of the literature recommended setting minimum effective population sizes at 1,000 in order to maintain genetic diversity in the long-term (Frankham et al. 2014, p. 59). Effective population size is the size of an idealized population that would experience the same magnitude of genetic drift (random change in genetic variation) as the actual population of interest. Effective population sizes ($N_e$) can be converted to adult population sizes (N) if the $N_e$/N ratio for the species is known (Frankham et al. 2014, p. 60); unfortunately, $N_e$/N has not been estimated for the Houston toad. However, Frankham et al. (2014, p. 60) report that the average $N_e$/N across species is between 0.1 and 0.2, which yields recommended adult population sizes between 5,000 and 10,000. Therefore, until $N_e$ estimates for the Houston toad are available, we conclude that viable population sizes need to be greater than 5,000 adults. As discussed above, small populations are vulnerable to stochastic demographic factors, stochastic environmental factors, and genetic factors.

3.3.3.1 Hybridization

Hybridization is another threat to small and isolated populations. The Houston toad has been found to hybridize with Woodhouse's toad and the Gulf Coast toad (Kennedy 1962, p. 244;Brown 1971, p. 186; Hillis et al. 1984, p. 57). Although the extent and frequency to which hybridization with other toad species may be occurring are unknown, Houston toads have maintained genetic continuity that is discrete and separate from other toad species within its range (McHenry and Forstner 2009, p. 69; Forstner and Dixon 2011, p. 13). Hybridization between the Houston toad and the Woodhouse's toad occurs primarily along habitat edges where forests have been cleared and permanent ponds have replaced ephemeral pools (USFWS 1994, p. 78). Although these two species have breeding seasons that overlap at least partially, the Woodhouse's toad is commonly found in more open habitat (non-forested areas, such as irrigated fields, golf courses, and urban parks) (AmphibiaWeb 2011a, p. 2). Protection of forested habitat and ephemeral breeding sites is therefore likely to decrease the threat of hybridization with the Woodhouse's toad.

Kennedy (1962, p. 244) experimentally produced viable (although developmentally reduced) hybrids of Houston toads and Gulf Coast toads, which also have overlapping ranges. Although the Houston toad has a narrower breeding season than the Gulf Coast toad (Forstner and Dixon 2011, p. 51), the breeding seasons of the two species coincide for several months out of the year(Hillis et al. 1984, pp. 60-61; AmphibiaWeb 2011b, p. 2). Unlike the Houston toad, the Gulf Coast toad is well adapted to a wide variety of habitats (AmphibiaWeb 2011b, pp. 1-2) and to urban environments in particular (Kennedy 1962, p. 245). The Gulf Coast toad also tends to prefer permanent breeding ponds rather than the more temporary (i.e., ephemeral) ponds typically used by the Houston toad (Thomas 1977, p. 7) so some degree of habitat partitioning also occurs between these two species. Elimination or modification of ephemeral breeding sites or clearing of forested habitat may increase the threat of hybridization with the Gulf Coast toad.

3.3.3.2 Competition

Interspecific competition, competition between species for one or more of the same limited resources (food, sunlight, water, soil, nutrients, or space), is another threat to small, isolated populations. Given their overlapping ranges and similar life history requirements, both the

Woodhouse's toad and the Gulf Coast toad compete with Houston toads for resources (Thomas 1977, p. 7). Where forested habitat has been modified to more open habitats, such changes can lead to the displacement of the Houston toad from an area entirely. For instance, Brown (1971, pp. 186-187) documented the occurrence of Woodhouse's toad and Houston toad hybrids at a site in Bastrop County. In a re-examination of Brown's 1971 study site, Hillis et al. (1984, p. 69) found only Woodhouse's toad, and no Houston toads. Notably, thearea had been cleared during the intervening years.

3.3.4 Drought and Climate Change (Factor E)

Drought is another factor threatening Houston toads. Historically, the species has persisted in the face of extremely intense droughts, even by the standard of the drought of record in Texas in the 1950s(Cook et al. 2007, p. 96; Forstner and Dixon 2011, p. 42). Resilience to drought has likely decreased as a consequence of reduced Houston toad subpopulations, ruptured connectivity, and the related consequences to small populations (Forstner and Dixon 2011, p. 42). Therefore, although this species has historically persisted through drought, it may be less resilient to extreme drought events in the future.

More recently, a one and a half year period between spring of 2008 and fall of 2009, severe to exceptional drought conditions occurred in the central Texas region within the Houston toad's range (Figure 3; U.S. Drought Monitor 2020). A few years later, another year of severe to exceptional drought occurred between spring of 2011 and spring of 2012 (Figure 3; U.S. Drought Monitor 2020). Severe drought means that wildfire danger is severe, burn bans are implemented, wildlife may move into populated areas, and soil is hard (U.S. Drought Monitor 2020). Extreme drought means an increased risk of large wildfires, severe fish, plant, and wildlife loss reported, and soil has large cracks with very low soil moisture (U.S. Drought Monitor 2020). Exceptional drought means an extreme sensitivity to firedanger, widespread tree mortality is reported, most wildlife species' health and populations are suffering, and exceptional water shortages are noted across surface water sources (U.S. Drought Monitor 2020). Drought conditions can also cause low soil moisture and decreased pond levels due to high evaporation rates (LCRA 2011, p. 1)

In March 2011, during what is typically the peak of the Houston toad's breeding season, central Texas received less than 0.25 cm (0.10 in) of rainfall, making it the fourth driest March in the region since 1856 (LCRA 2011, p. 1). This drought resulted in no toads detected on the Griffith League Ranch in 2011, likely negatively impacted survivorship, and the Lost Pines fire (Duarte et al. 2014, p. 365-369; Duarte et al. 2011, p. 207-215). Since 2011, Houston toad numbers have not recovered to pre-drought levels (Forstner and Bohannon 2019, p. 11)

Direct effects of drought on this species include desiccation, loss of breeding sites, and loss of eggs or tadpoles resulting from pond evaporation or complete water loss (U.S. Fish and Wildlife1994, p. 33; Forstner and Dixon 2011, p. 42). As drought severity increases, predators and livestock tend to concentrate at the remaining water bodies (Forstner and Dixon 2011, pp. 42- 43). Drought may be a significant issue for the Houston toad, one that is exacerbated by highly fragmented and degraded habitats and low population numbers from which the species cannot rebound after the drought stress ends.

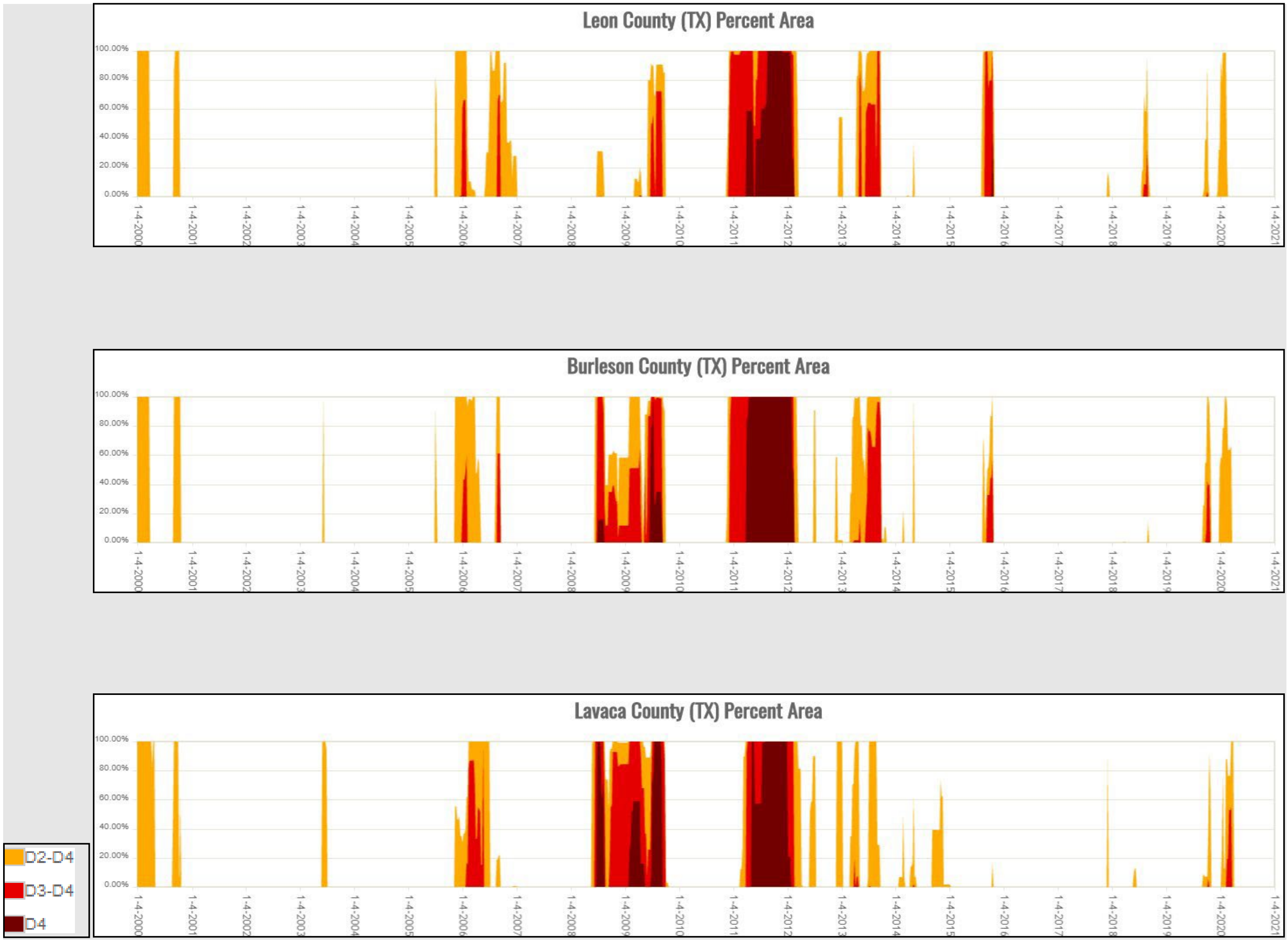


Figure 3. Percent area of Leon, Burleson, and Lavaca counties that experienced severe, extreme, or exceptional drought between 2000 and 2020.In the legend, D2-D4 represents severe, extreme, and exceptional drought, D3-D4 represents extreme and exceptional drought, and D4 represents only exceptional drought. Graphs courtesy of the U.S. Drought Monitor (U.S. Drought Monitor 2020).

Our analyses under the ESA include consideration of ongoing and projected changes in climate. The terms “climate” and “climate change” are defined by the Intergovernmental Panel on Climate Change (IPCC). The term “climate” refers to the mean andvariability of different types of weather conditions over time, with 30 years being a typical period for such measurements, although shorter or longer periods also may be used (IPCC 2014b, pp. 119-120). The term “climate change” thus refers to a change in the mean or variability of one or more measures of climate (for example, temperature or precipitation) that persists for an extended period, typically decades or longer, whether the change is due to natural variability, human activity, or both (IPCC 2014b, pp. 119-120).

According to the IPCC (2014a, p. 2), “Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. It is very likely that from 1950 to 2012 cold days and nights have become less frequent, and hot days and hot nights have become more frequent on a global scale (IPCC 2013, p. 4). It is likely that the frequency and intensity of heavy precipitation events has increased over North America (IPCC 2013, p. 4).

With regard to our analysis for the Houston toad, downscaled projections in Texas are available. Based on downscaling global models of climate change, Texas is expected to receive up to 20 percent less precipitation in winters and up to 10 percent more precipitation in summers (Jiang and Yang 2012, p. 238). However, most regions in Texas are predicted to become drier as temperatures increase (Jiang and Yang 2012, pp. 240-242). Extreme droughts in Texas are now much more probable than they were 40 to 50 years ago (Rupp et al. 2012, pp. 1,053-1,054).

Downscaled climate projections for the Houston toad range were obtained from the U.S. Climate Resilience Toolkit (U.S. Federal Government, 2018). Using the observed average annual daily maximum temperature between 2007-2013 (2010 +/- 3 years), projections indicate that the average annual daily maximum temperature will increase in the northern band of the Houston toad range from 26.4°C (79.5°F) to 28.1°C (82.5°F), and from 27.2°C (80.9°F) to 28.9°C (84.1°F) in the southern band of the range, under low emissions, by 2050 (Representative Concentration Pathway [RCP] 4.5) (Figure 4; Table iii; U.S. Federal Government, 2018). Under high emissions (RCP 8.5), average daily temperature will increase from 26.4°C (79.5°F) to 28.6°C (83.5°F) in the northern band of counties, and from 27.2°C (80.9°F) to 29.6°C (85.2°F) in the southern band by 2050 (Figure 4; Table iii; U.S. Federal Government, 2018).

Number of days with a maximum temperature above 37.8°C (100°F) are projected to increase from an average observed 21.6 days, from 2007-2013 (2010 +/- 3 years), to 38.7 days in the northern counties of the Houston toad range, and from 16.5 days to 40.2 days in the southern counties, under low emissions (RCP 4.5)by 2050 (Figure 5; Table iv; U.S. Federal Government, 2018). Under high emissions (RCP 8.5), the northern counties are projected to increase from 21.6 days to 50.8 days, and the southern counties are projected to increase from 16.5 days to 53.3 days by 2050 (Figure 5; Table iv; U.S. Federal Government, 2018). To put those numbers of days into perspective, the severe to exceptional droughts that occurred in 2009 and 2011 had 49.2 and 64.1 days, respectively, with a maximum temperature above 37.8°C (100°F) in Bastrop County.

The Bastrop Complex Fire occurred in 2011, with 64.1 days having a maximum temperature above 37.8°C (100°F). With increased annual daily temperatures and increased number of days with a maximum temperature greater than 37.8°C (100°F), there will likely be increased drought, higher probability of catastrophic fire, and decreased surface water and moisture available. The presence of water is necessary for breeding, juvenile development, and juvenile and adult movement and dispersal (Forstner and Dixon 2011, pp. 6, 20-21, 49-50). Dryer and hotter conditions could result in less successful breeding, recruitment, and reduced dispersal.

Within the Houston toad's range, it is possible that alteration of rainfall patterns together with habitat loss may decrease the partitioning of chorusing periods currently in place between Houston toads and other toad species (Forstner and Dixon 2011, p. 50). Thus, climate change could result in an increase in the likelihood of hybridization events (Forstner and Dixon 2011, p.50). One effect of climate change will likely be the redistribution of species' ranges as they track moving climate envelopes (Donald and Evans 2006, p. 213). In fragmented landscapes, the shift of species' ranges may be inhibited because they will be incapable of moving across the landscape in a series of extinctions and recolonizations (Donald and Evans 2006, p. 213). In addition, because this species is known to persist only within the sandy soils of two bands of a particular geologic formation, there may be further limitations on the Houston toad's ability to adapt and redistribute into new areas

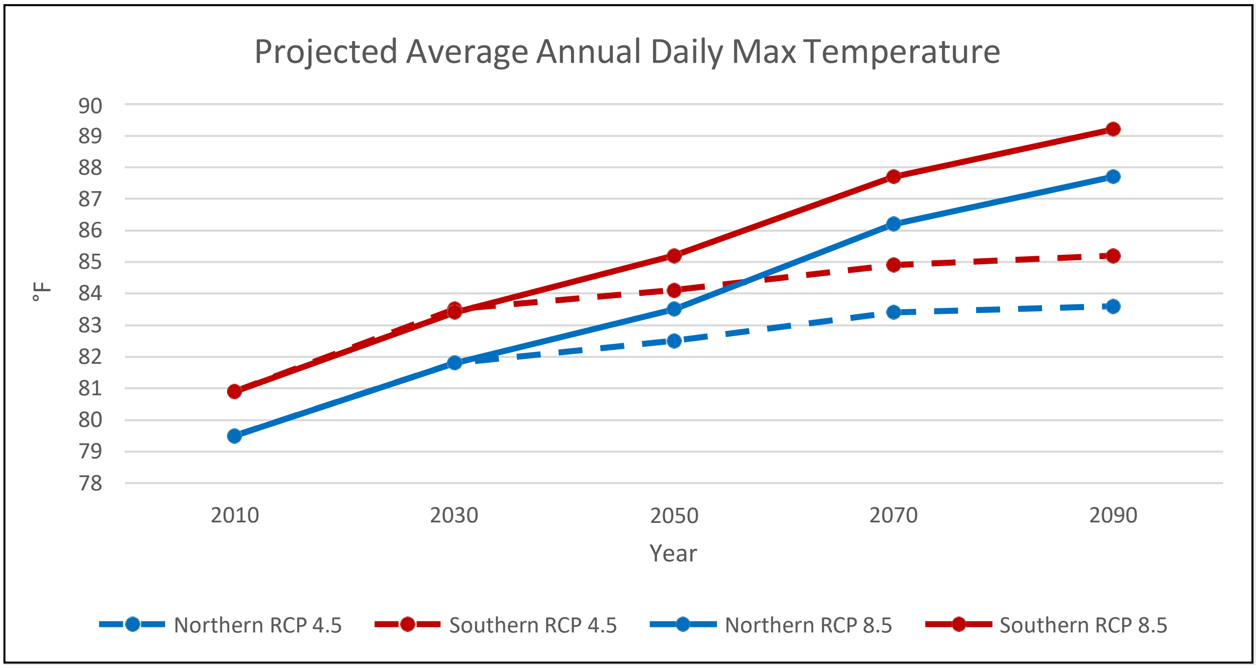


Figure 4. Average annual daily maximum temperature, in degrees Fahrenheit, projected under low (RCP 4.5) and high (RCP 8.5) emissions scenarios for the northern counties (blue lines) and southern counties (red lines) of the Houston toad range between 2010 and 2090. Dashed lines represent the low emissions (RCP 4.5) scenarios and solid lines represent the highemissions (RCP 8.5) scenarios. The points are the average of the average annual daily maximum temperatures across the northern or southern counties of the Houston toad range (U.S. Federal Government, 2018, Table iii).

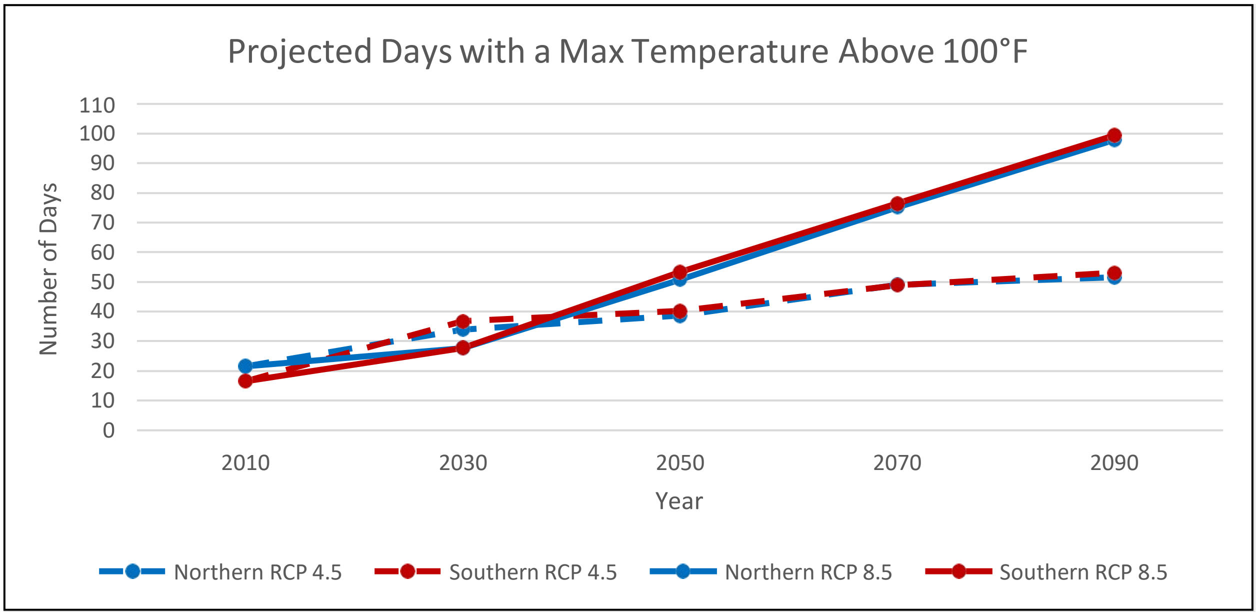


Figure 5. Number of days per year above 100°F (37.8°C) projected under low (RCP 4.5) and high (RCP 8.5) emission scenarios for the northern counties (blue lines) and southern counties (red lines) of the Houston toad range between 2010 and 2090. Dashed lines represent the low emissions (RCP 4.5) scenarios and solid lines represent the high emissions (RCP 8.5) scenarios. The points are the average of the number of days per year above 100°F (37.8°C) across the northern and southern counties of the Houston toad range (U.S. Federal Government, 2018, Table iv).

## 3.4 Resiliency, Redundancy, and Representation

### 3.4.1 Resiliency

Resiliency is the ability of a population to withstand stochastic events. We can measure resiliency based on metrics of population health (e.g., habitat size or population connectivity). Healthy populations are more resilient and better able to withstand disturbances such as random fluctuations in birth rates (i.e., demographic stochasticity), variations in rainfall (i.e., environmental stochasticity), random fluctuations in genetic variation (i.e., genetic drift), or the effects of anthropogenic activities. Houston toads exist in a metapopulation structure; therefore, current conditions will evaluate the three R's in the context of metapopulations.

The Houston toad population viability analysis (PVA) conducted by Hatfield et al. (2004, pp. 294-296) indicated that a relatively low probability of extinction (i.e., less than 5 percent per 100 years) may be achieved for a metapopulation if the following circumstances exist: (1) multiple Houston toad subpopulations are protected and managed, (2) each subpopulation has habitat sufficient to support several thousand one-year-old and older female Houston toads, and (3) dispersal among the subpopulations occurs either through natural corridors or through artificial means, such as translocation.

A metapopulation with three interconnected subpopulations that each support at least 1,000 adult females drops probability of extinction in 100 years to near zero (Hatfield et al. 2004, p. 296). We therefore consider a metapopulation resilient if it consists of at least three subpopulationsthat each support at least 1,000 adult females per subpopulation. The three subpopulations must be connected by suitable habitat to allow for dispersal of juveniles and adults, maintaining the ability to recolonize if a subpopulation is extirpated. The Hatfield model demonstrated a subpopulation often resulted in a high probability of extinction with a one percent juvenile survivorship, and a low probability of extinction with a two percent juvenile survivorship (Hatfield et al. 2004, p. 294). A resilient metapopulation should thus have at least two percent juvenile survivorship; however, the overall stability and growth of populations as a whole should remain the quantitative goal (TPWD 2021).

### 3.4.2 Redundancy

Redundancy is the ability of a species to withstand catastrophic events. Redundancy protects species against the unpredictable and highly consequential events for which adaptation is unlikely. In short, it is about spreading the risk. Redundancy is best achieved by having multiple metapopulations widely distributed across the species' range. Having multiple metapopulations reduces the likelihood that all metapopulations are affected simultaneously, while having widely distributed metapopulations reduces the likelihood of metapopulations possessing similar vulnerabilities toa catastrophic event. Given sufficient redundancy, single or multiple catastrophic events are unlikely to cause the extinction of a species. Thus, the greater redundancy a species has, the more viable it will be. Furthermore, the more metapopulations and the more diverse or widespread that these metapopulations are, the more likely it is that the adaptive diversity of the species will be preserved. Having multiple metapopulations distributed across the range of the species will help preserve the breadth of adaptive diversity, and hence, the evolutionary flexibility of the species.

Historically, most Houston toad subpopulations maintained broad connectivity through forested corridors and possibly along drainage systems (McHenry and Forstner 2009, p. 83; Forstner and Dixon 2011, pp. 28-29, 41). In contrast, the subpopulations remaining today are small, widely scattered, and disconnected (Forstner and Dixon 2011, p. 29; McHenry and Forstner 2009, p. 81). It is currently unknown how many Houston toad subpopulations remain, but not much connectivity remains between them (McHenry and Forstner 2009, p. 81). Recolonization of extirpated locations is unlikely to occur without human assistance. Because subpopulations are not currently widely distributed across the historic species range, the ability to withstand catastrophic events is limited due to the limited ability to spread the risk of a catastrophic event.

### 3.4.3 Representation

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

Maintaining representation in the form of genetic or ecological diversity is important to maintain the Houston toad's capacity to adapt to future environmental changes. Despite the species' current limited gene flow as a result of low mobility and minimal habitat connectivity, multiple DNA haplotypes have been found throughout the Houston toad's range, and overall genetic diversity has been described as high for Houston toads in Bastrop County (McHenry and Forstner 2009, p.80). It is likely that Houston toad metapopulation sizes and habitat connectivity within its range weremuch greater up until recent decades (McHenry and Forstner 2009, pp. 80-81; Forstner and Dixon 2011, p. 28). Therefore, it is speculated that Houston toad metapopulations, which were also much greater in size during previous decades, could have occurred close enough to each other to generate gene flow among them (McHenry and Forstner 2009, p. 81), allowing the genetic diversity in the species to persist.

The Houston toad has likely lost genetic diversity as subpopulations have been extirpated throughout its range. As such, maintaining the remaining representation in the form of genetic diversity in both the northern and southern portions of its range may be important to its capacityto adapt to future environmental change.

### 3.4.4 Conclusions

The recovery of the Houston toad has been hampered by increasing habitat loss stemming from urbanization, agriculture, and energy development. Historically, this species has been able to persist through catastrophic events, but increased fragmentation and habitat loss have lowered the resiliency and redundancy of the Houston toad. Decreased resiliency and redundancy hampered the ability to withstand stochastic and catastrophic events, resulting in significant decreases in numbers following severe to exceptional drought between 2008 and 2011 along with catastrophic fire events.

Captive propagation efforts have helped to boost Houston toadnumbers, but future resiliency, redundancy, and representation are affected by continued habitat loss.

## 4.0 Recovery Program

### 4.1 Recovery Goal, Strategy, and Objectives

#### 4.1.1 Recovery Goal

Our recovery goal is to ensure the conservation and long-term viability of the Houston toad inthe wild such that the species no longer requires protections under the ESA.

#### 4.1.2 Recovery Strategy

The purpose of the Houston toad recovery strategy is to present a recommended approach for recovery that will address the threats to the species and reduce them to a point such that the viability of the Houston toad can be maintained. We define viability as the ability of a species to persist and maintain populations in the wild over time. We use the conservation principles of resiliency (i.e., the ability of a population to withstand environmental and demographic stochasticity and disturbance) redundancy (i.e., the ability of a species to withstand catastrophic events; spreading risk among multiple populations to minimize the potential loss of the species from catastrophic events), and representation (i.e., the ability of a species to adapt to changing environmental conditions over time, via the range of genetic and ecological variation found within the species), to better inform our view of what contributes to the Houston toad's viability and how best to conserve the species.

The recovery vision for the Houston toad is:

- *Resiliency:* Resilient Houston toad subpopulations, within metapopulations, are conserved in sufficient number and distribution to ensure the species' long-term viability. That is, there are sufficient numbers of subpopulations in each metapopulation to support recovery from stochastic events in the environment (e.g., normal variation in rainfall and temperature, storms, and small-scale fire). Maintaining resilient subpopulations will require protecting sufficient quantity of high-quality habitats that are interconnected, while reducing or managing stressors at those sites.

- *Redundancy:* Resilient Houston toad metapopulations occur in sufficient number and distribution to guard against catastrophic events (e.g., catastrophic fire, widespread drought, and disease) extirpating portions of the species' adaptive diversity or leading to extinction of the species as a whole.

- *Representation:* Houston toad metapopulations occur across its range to maintain evolutionary drivers such as gene flow and natural selection. Maintaining the existing genetic and ecological diversity of Houston toad metapopulations will conserve the species'ability to adapt to future changes in its physical (e.g., habitat, climate) and biological (e.g., predators, competitors, diseases) environment.

### 4.1.3 Recovery Objectives

The primary objectives of the recovery effort for the Houston toad involve acquiring, protecting, enhancing, restoring, and managing habitat within multiple management units, and implementing population restoration efforts such that multiple, resilient metapopulations with the appropriate genetic and ecological diversity are distributed throughout the species' range.

We have identified six management units across the Houston toad's current range that are essential to the survival and recovery of the species (Figure 6). These management units encompass portions of all nine Texas counties where the Houston toad is currently extant and represent areas most likely to encapsulate at least one metapopulation. Boundaries were drawn using the geologic formations Houston toads are frequently associated with (Carrizo, Queen City, Reklaw, Sparta, Weches, Willis, and Goliad) (Forstner 2003, p. 3), Houston toad observations, and physical boundaries or disturbances, such as rivers or farms. The geologic formations were primarily used to draw the boundaries because they support the sandy soils that Houston toads prefer and have historically contained a majority of the Houston toad observations. Houston toad observations, physical boundaries, and disturbances were used to refine the boundaries around geologic formations because some areas were pasture or farmland.

Specific recovery objectives include:

1. Conserve and protect at least 30,351 ha (75,000 ac) of suitable habitat through a combination of land acquisition, conservation easements, or other conservation mechanisms appropriate to the land status, for the Houston toad to maintain its metapopulation structure across its range.

2. Continue to increase the abundance of Houston toad populations to reach and exceed 1000 females per metapopulation through support and expansion of the captive propagation program (through, for example, the Houston Zoo, Fort Worth Zoo, Dallas Zoo, and San Marcos Aquatic Resource Center) to produce over one million Houston toad eggs per year to supplement protected habitat and reverse declining populations.

3. Restore and maintain protected habitat to increase the carrying capacity and reduce threats to a level that will not hinder the continued viability of the species.

4. Maintain connectivity between metapopulations either through natural dispersal corridors or translocations.

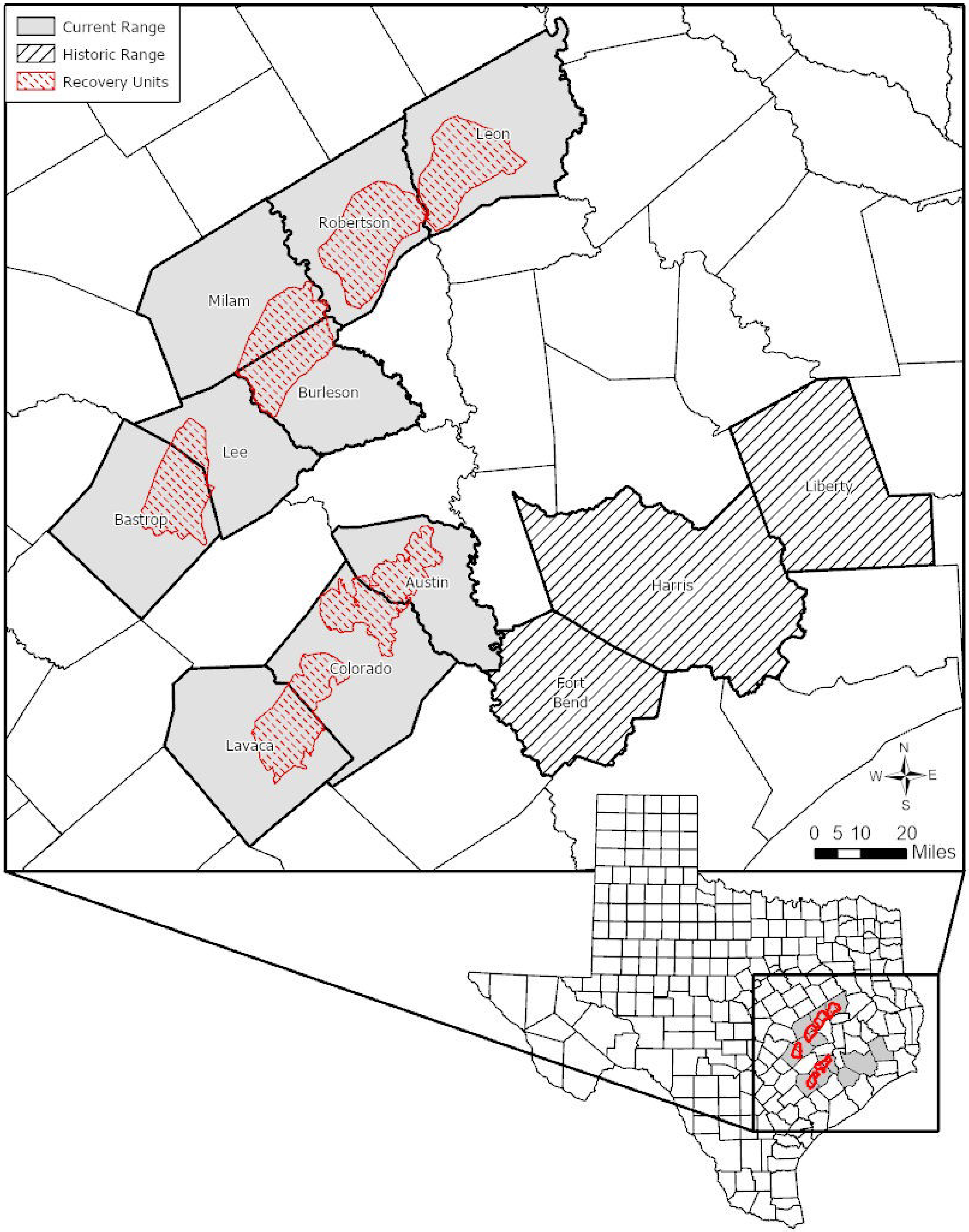


Figure 6: Houston toad current (gray) and historical (hatched) range with management units (red).

## 4.2 Objective and Measurable Recovery Criteria

### 4.2.1 Downlisting Criteria

The following are objective, measurable downlisting criteria:

**Downlisting Criterion 1**

A total of 12,141 ha (30,000 ac) of forested Houston toad habitat is conserved through a combination of land acquisition, conservation easements, or other conservation mechanisms appropriate to the land status, to prevent future development to minimize habitat destruction, modification, and fragmentation. The protected habitat must occur within two of the six management units (6,070 ha (15,000 ac) in each) and contain at least three large, (at least 2,023 ha (5,000 ac) areas of suitable Houston toad habitat to minimize edge effects (e.g., reduced threat from fire ants, hybridization, and competition). These undisturbed areas within each management unit mustbe interconnected by dispersal corridors to reduce threats of small population size and isolation and contain suitable breeding habitat consisting of approximately 1 pond per 81-162 ha (200-400 ac).

> *Justification:* The Houston toad population viability analysis (PVA) conducted by Hatfield et al. (2004) indicates that for a metapopulation to achieve a relatively low probability of extinction (i.e., less than 5 percent per 100 years), multiple Houston toad subpopulations[1] that are protected and managed must exist within that metapopulation.
>
> Historically, both Bastrop State Park and Griffith League Ranch have supported robust subpopulations of Houston toads, with Bastrop State Park consisting of about 1,700 ha (4,200 ac) of forested habitat, while the Griffith League Ranch consisted of about 1,902 ha (4,700 ac) of forested habitat until the Bastrop County Complex Fire in 2011. Using Bastrop State Park and Griffith League Ranch as historical models, we consider 2,023 ha (5,000 ac) of undisturbed habitat to be a sufficiently large area to support robust subpopulations of Houston toads.
>
> Conserving multiple, large habitat areas will facilitate establishment of a metapopulation structure within each management unit, thus increasing species redundancy and making the Houston toad better able to withstand catastrophic events such as drought and wildfire. These large habitat areas will also maintain and improve Houston toad dispersal, recruitment, and survival and thus increase subpopulation resiliency.

[1]Hatfield et al. (2004, p. 293) analyzed data from a mark-recapture study at Bastrop State Park for this PVA. Therefore, they recommended two to three subpopulations are protected and managed for Bastrop County to prevent extirpation.

**Downlisting Criterion 2**

Two or more management units have established Houston toad metapopulations, each consisting of at least three interconnected subpopulations (see Downlisting Criterion 1 above). Each metapopulation must support a minimum of 1,000 adult female Houston toads, as documented by annual surveys for five consecutive years. Counting egg strands the morning following a Houston toad breeding event can be used as a method to measure female abundance, if needed, due to the difficulties of documenting females.

> *Justification:* In addition to protected and managed subpopulations, the Houston toad PVA (Hatfield et al. 2004) also indicates that a metapopulation must have habitat sufficient to support several thousand adult female Houston toads, and dispersal among the subpopulations must occur for the metapopulation to achieve a low probability of extinction. Results of the PVA indicate that there is not a substantial difference in the probability of extinction between a carrying capacity of 1,000 adult females and 5,000 adult females in a simulation that included three interconnected subpopulations (i.e., within a metapopulation) with dispersal either through natural corridorsor through artificial means, such as translocation.
>
> Establishment of multiple Houston toad metapopulations by supplementing populations through captive breeding will increase the species' redundancy, and a minimum of 1,000 females within each metapopulation will allow for Houston toad abundance and gene flow to increase within and between subpopulations, thus reducing the threat of small population size and isolation. Larger subpopulations will be better able to withstand demographic and environmental stochasticity (resilience), and increased genetic diversity will enable the species to adapt to both near-term and long-term changes in its physical andbiological environments (representation).

4.2.2 Delisting Criteria

The following are objective, measurable delisting criteria:

**Delisting Criterion 1**

At total of 30,351 ha (75,000 ac) of forested Houston toad habitat (including the 12,141 ha (30,000 ac) required for Downlisting Criterion 1), is conserved through a combination of land acquisition, conservation easements, or other conservation mechanisms appropriate to the land status, and protected from future development to further minimize habitat destruction, modification, and fragmentation. The protected habitat must occur within five of the six management units (6,070 ha (15,000 ac) in each) and contain sufficiently large (at least 2,023 ha (5,000 ac) areas of suitable Houston toad habitat to minimize edge effects (e.g., reduced threat from fire ants, hybridization, and competition). These undisturbed areas within each management unit must be interconnected by dispersal corridors toreduce threats of small population size and isolation.

> *Justification:* See justification for Downlisting Criterion 1 above. Protecting and conservingmultiple large, undisturbed habitat areas within each of five management units will further increase species redundancy and subpopulation resiliency, thus

contributing to the Houston toad's overall viability.

**Delisting Criterion 2**

Five or more management units have established self-sustaining Houston toad metapopulations, each consistingof at least three interconnected Houston toad subpopulations (see Delisting Criterion 1 above). Each metapopulation must also support a minimum of 1,000 adult female Houston toads, asdocumented by annual surveys over five consecutive years. Counting egg strands the morning following a Houston toad breeding event can be used as a method to measure female abundance, if needed, due to the difficulties of documenting females.

*Justification:* See Downlisting Criterion 2 (above). Results of the Houston toad PVA indicate that there is a considerably lower extinction probability when three Houston toad subpopulations are modeled as opposed to one or two subpopulations (Hatfield et al. 2004). Establishing five or more genetically diverse Houston toad metapopulations across the range of the species will further increase species redundancy and representation, thus contributing to the Houston toad's overall viability.

**Delisting Criterion 3**

All established Houston toad metapopulations (see Delisting Criterion 2) must also have at least two percent juvenile Houston toad survivorship within each subpopulation, as documented by annual monitoring over five consecutive years.

*Justification:* The Houston toad PVA demonstrated a subpopulation with at least 1,000 adult females often resulted in a high probability of extinction when a one percent juvenile survivorship was modeled, and a low probability of extinction when a two percent juvenile survivorship was used (Hatfield et al. 2004, p. 294). Ensuring a two percent juvenile survivorship within each subpopulation will further increase subpopulation resiliency, thus contributing to the Houston toad's overall viability.

## 5.0 Recovery Implementation

### 5.1 Site-specific Recovery Actions

The recovery of the Houston toad will be accomplished through the site-specific management actions outlined below, and will require concerted cooperation among Federal, State, and local agencies, private landowners, and other stakeholders. We assign priorities to each action; note that actions within an action group may have different priorities. Priority 1 actions must be taken to prevent extinction or to prevent the species from declining irreversibly in the foreseeable future. Priority 2 actions must be taken to prevent a significant decline in population size or habitat quality, or some other significant negative impact. Priority 3 actions are all other actions that are necessary for the species' full recovery. The assignment of priorities does not imply that some recovery actions are of low importance, but instead implies that lower priority items may be deferred while higher priority items are being implemented. Table 4 indicates the linkage between threats, the recovery actions that address them, their priorities, and the recovery criteria they contribute to. The

RIS will describe in greater detail how these actions will be coordinated and scheduled.

5.1.1 Priority 1 Actions

1. *Conserve, Restore, and Protect Habitat (addresses Factor A):* Conserve and protect habitat through, for example, Safe Harbor Agreements, conservation banks, Section 6 non-traditional land acquisition, and expansion of current preserves (e.g., Bastrop State Park) within the six management units (Figure 6). Identify areas that could be ideal for conservation and restoration opportunities. Restore habitat using the habitat management guidelines (U.S. Fish and Wildlife Service, 2017).

2. *Captive Propagation and Supplementation (addresses Factors A, C, and E)*: This may include a multi-year supplementation plan. Increase the size of captive populations and the production of eggs and tadpoles for release or add captive populations at one or more additional zoos or other facilities to increase population supplementation capacity.

3. *Outreach and Private Land Engagement (addresses Factors A and E)*: Coordinate with recovery partners to host workshops and outreach events with an emphasis on actionable items. These efforts will focus on private landowners with Houston toad habitat or populations present on their property to achieve consistent and long-term engagement with private lands.

4. *Establish a Monitoring Program (addresses Factors C and E)*: Monitor areas known to support Houston toads and areas where toads have been supplemented. Standardized monitoring will include surveys for adult females; calculations of juvenile survivorship; and evaluation of habitat conditions.

5. *Research (addresses Factors A and E)*: Research topics may include, within the six management units (Figure 6), juvenile movement and dispersal, adult toad home range size, population viability analysis, resistance to dispersal and movement through varying habitat types, effective engagement with landowners, and a revised suitable habitat model.

5.1.2 Priority 2 Actions

1. *Expand Monitoring (addresses Factors C and E)*: Identify and survey areas likely to support Houston toads that have not or are not normally surveyed, and survey counties without confirmed observations of Houston toads thathave suitable habitat adjacent to counties in the current known range.

2. *Community Education (addresses Factors A and E)*: Coordinate and plan with recovery partners to host education-based workshops, outreach events, and social media to increase the awareness of the general public.

3. *Identify Effective Habitat Management Strategies (addresses Factors A, C, and E)*: Assess effectiveness of restoration and management of Houston toad habitat, including:

yaupon removal, tree planting and thinning, prescribed fires, native grass restoration, fire ant control and eradication, and feral hog control and eradication within the management units (Figure 6). Adjust the habitat management guidelines as appropriate (U.S. Fish and Wildlife Service, 2017).

### 5.1.3 Priority 3 Actions

*Effective Planning and Coordination (addresses Factors A, C, and E):* Coordinate andplan with recovery partners, implement and review Recovery ImplementationStrategies, track recovery implementation progress and success, and implement adaptive management.

Table 4. Houston toad threats, recovery actions that address them, and the associated recovery criteria.

| ESA Listing Factors | Threat | Recovery Actions | Downlisting Criteria | Delisting Criteria |
|---|---|---|---|---|
| Factor A: The present or threatened destruction, modification, or curtailment of its habitat or range. | Agriculture, energy development, urbanization, and other landscape changes | All | 1 | 1 |
| Factor C: Disease or predation. | Red-imported fire ants | 2, 3, 4, 7, 8 | 1, 2 | 1, 2, 3 |
| Factor E: Other natural or manmade factors affecting its continued existence. | Isolation/small population size | 2, 3, 4, 5, 8 | 1, 2 | 1, 2, 3 |
| Factor E: Other natural or manmade factors affecting its continued existence. | Climate change and drought | 3, 4, 8 | 1 | 1 |

## 5.2 Estimated Time and Costs to Achieve Recovery

If all actions are fully funded and implemented as outlined, including full cooperation of partners, we expect the status of the Houston toad to improve such that we can achieve downlisting within 20 years and achieve delisting as soon as 30 years. Projecting cost estimates obtained in 2020, the total estimated cost associated with implementing recovery actions for delisting the Houston toad, including land acquisition costs, is $424,425,600 (Table 5). Recovery action time and cost estimates are further broken down into intermediate steps by fiscal years. These costs include those borne by Federal, State, and local government agencies, as well as other institutions, universities, and organizations with an interest in recovering the Houston toad.The cost estimates provided are not intended to indicate a specific budget but are provided solely to assist in planning. The Houston toad RIS will provide more detailed time and cost estimates andidentify the potential responsible parties for implementing the specific on-the-ground activities needed to complete these actions over the estimated 30 years to achieve recovery.

Table 5. Time and cost estimates to implement recovery actions. *Note: Total Estimated Cost for the Action Conserve, Restore, and Protect Habitat includes costs of potential land acquisition and associated restoration.*

| **Priority** | **Action** | **Action Description (with ESA Listing Factor Addressed)** | **Estimated Time (Years)** | **Total Estimated Cost ($)** | **Estimated Cost by Fiscal Years 1-5 ($)** | **Estimated Cost by Fiscal Years 6-10 ($)** | **Estimated Cost by Fiscal Years 11-15 ($)** | **Estimated Cost by Fiscal Years 16-20 ($)** | **Estimated Cost by Fiscal Years 21-25 ($)** | **Estimated Cost by Fiscal Years 26-30 ($)** |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | Conserve, Restore, and Protect Habitat (Factor A) | 30 | 418,625,000 | 69,770,833 | 69,770,834 | 69,770,834 | 69,770,834 | 69,770,834 | 69,770,834 |
| 1 | 2 | Captive Propagation and Supplementation (Factors A, C, E) | 30 | 3,450,000 | 575,000 | 82,500 | 1,150,000 | 575,000 | 143,750 | 143,750 |
| 1 | 3 | Establish a Monitoring Program (Factors A, C, E) | 10 | 1,000,000 | 500,000 | 500,000 | 0 | 0 | 0 | 0 |
| 1 | 4 | Outreach and Private Land Engagement (Factors A, E) | 30 | 150,000 | 25,000 | 25,000 | 25,000 | 25,000 | 25,000 | 25,000 |
| 1 | 5 | Research (Factors A, C, E) | 15 | 500,000 | 166,667 | 166,667 | 166,667 | 0 | 0 | 0 |
| 2 | 6 | Expand Monitoring (Factors A, E) | 20 | 200,000 | 0 | 0 | 50,000 | 50,000 | 50,000 | 50,000 |
| 2 | 7 | Community Education (Factor A) | 30 | 100,000 | 15,000 | 25,000 | 35,000 | 10,000 | 10,000 | 5,000 |
| 2 | 8 | Identify Effective Management Strategies (Factors A, C) | 30 | 300,000 | 75,000 | 75,000 | 75,000 | 25,000 | 25,000 | 25,000 |
| 3 | 9 | Effective Planning and Coordination (Factors A, C, E) | 30 | 100,000 | 16,766 | 16,766 | 16,766 | 16,766 | 16,766 | 16,766 |
| | | | **Total:** | **424,425,600** | | | | | | |

## 6.0 Literature Cited

Agee, J.K. and C.N. Skinner. 2005. Basic principles of forest fuel reduction treatments. Forest Ecology and Management 211: 83-96.

Akçakaya, H.R., G. Mills, and C.P. Doncaster. 2007. The role of metapopulations in conservation in D.W. Macdonald and K. Service, editors. Key topics in conservationbiology. Blackwell Publishing, Oxford, U.K., pages 64-84.

Allen, C.R., S. Demarais, and R.S. Lutz. 1994. Red imported fire ant impact on wildlife: an overview. The Texas Journal of Science 46: 51-59.

Allendorf, F.W. and G. Luikart. 2007. Conserving global biodiversity? Conservation and the genetics of populations. Conservation Genetics 9: 437-438.

AmphibiaWeb. 2011a. Information on amphibian biology and conservation: *Bufo woodhousii*. Berkeley, California: AmphibiaWeb. Available at: http://amphibiaweb.org/cgi-bin/amphib_query?where-genus=Bufo&where-species=woodhousii. Date Accessed: December 5, 2011.

AmphibiaWeb. 2011b. Information on amphibian biology and conservation: *Bufo nebulifer*. Berkeley, California: AmphibiaWeb. Available at: http://amphibiaweb.org/cgi-bin/amphib_query?where-genus=Bufo&where-species=nebulifer. Date Accessed:December 5, 2011.

Andrews, K.M., J.W. Gibbons, and D.M. Jochimsen. 2006. Literature synthesis of the effects of roads and vehicles on amphibians and reptiles. Federal Highway Administration (FHWA), U.S. Department of Transportation, Report No. FHWA-HEP-08-005. Washington, D.C. 151 pp.

Aronson, M.F.J., F.A. La Sorte, C.H. Nilon, M. Katti, M.A. Goddard, C.A. Lepczyk, P.S. Warren, N.S.G. Williams, S. Cilliers, B. Clarkson, C. Dobbs, R. Dolan, M. Hedbom, S. Klotz, J. Louwe Kooijmans, I. Kühn, I. MacGregor-Fors, M. McDonnell, U. Mörtberg, P.Pyšek, S. Siebert, J. Sushinsky, P. Werner, and M. Winter. 2014. A global analysis of the impacts of urbanization on bird and plant diversity reveals key anthropogenic drivers. Proceedings of the Royal Society B 281: 20133330.

Ash, A.N. 1997. Disappearance and return of Plethodontid salamanders to clearcut plots in the southern Blue Ridge Mountains. Conservation Biology 11: 983-989.

Bartelt, P.E., C.R. Peterson, and R.W. Klaver. 2004. Sexual differences in the post-breeding movements and habitats selected by western toads (*Bufo boreas*) in southeastern Idaho. Herpetologica 60: 455-467.

Belsky, A.J., A. Matzke, and S. Uselman. 1999. Survey of livestock influences on stream and riparian ecosystems in the western United States. Journal of Soil and Water Conservation 54: 419-431.

Bolen, E.G. and W.L. Robinson. 1999. Wildlife Ecology and Management. Fourth Edition. Prentice Hall. Upper Saddle River, New Jersey.

Bragg, A. N. 1960. Feeding in the Houston toad. Southwestern Naturalist 5: 106.

Brown, D. J., A. Duarte, I. Mali, M. C. Jones, and M. R. J. Forstner. 2014. Potential impacts of a high severity wildfire on abundance, movement, and diversity of herpetofauna in the Lost Pines Ecoregion of Texas. Herpetological Conservation and Biology 9:192–205.

Brown, D.J., B. DeVolld, and M.R.J. Forstner. 2012a. Fire ants in Houston toad habitat: annual activity and responses to canopy cover and fire. Journal of Fish and Wildlife Management 3:142-149.

Brown, D.J., J.T. Baccus, D.B. Means, M.R.J. Forstner. 2011. Potential positive effects of fireon juvenile amphibians in a southern USA pine forest. Journal of Fish and Wildlife Management 2: 135-145.

Brown, D. J., M. C. Jones, J. Bell, and M. R. J. Forstner. 2012b. Feral hog damage to endangered Houston toad (Bufo houstonensis) habitat in the Lost Pines of Texas. Texas Journal of Science 64:73−88.

Brown, D. J., T. M. Swannack, and M. R. J. Forstner. 2013. Predictive models for calling and movement activity of the endangered Houston toad. American Midland Naturalist 169:303−321.

Brown, L. E. 1971. Natural hybridization and trend toward extinction in some relict toad populations. Southwestern Naturalist 16: 185-199.

Bull, E. L. 2009. Dispersal of newly metamorphosed and juvenile western toads (*Anaxyrusboreas*) in northeastern Oregon, USA. Herpetological Conservation and Biology 4: 236-247.

Burke, D.M. and E. Nol. 1998. Influence of food abundance, nest-site habitat, and forest fragmentation on breeding ovenbirds. The Auk 115: 96-104.

Buzo, D. 2008. A GIS model for identifying potential breeding habitat for the Houston toad (*Bufo houstonensis*). Master of Science. Texas State University, Department of Biology.

Callcott, A.A. and H.L. Collins. 1996. Invasion and range expansion of imported fire ants (Hymenoptera: Formicidae) in North America from 1918-1995. The Florida Entomologist 79(2): 240-251.

Carr, L.W. and Fahrig, L. 2001. Effect of road traffic on two amphibian species of differing vagility. Conservation Biology 15: 1071-1078.

Chen, J., S.C. Saunders, T.R. Crow, R.J. Naiman, K.D. Brosofske, G.D. Mroz, B.L. Brookshire,and

J.F. Franklin. 1999. Microclimate in forest ecosystem and landscape ecology. Bioscience 49: 288-297.

Clarke, R.D. 1974. Food habits of toads, genus *Bufo* (Amphibia: Bufonidae). AmericanMidland Naturalist 91: 140-147.

Cook E.R., R. Seager, M.A. Cane, and D.W. Stahle. 2007. North American drought: reconstructions, causes, and consequences. Earth Science Reviews 81: 93-134.

Cushman S.A. 2006. Effects of habitat loss and fragmentation on amphibians: a review and prospectus. Biological Conservation 128: 231-240.

Czech, B., P.R. Krausman, and P.K. Devers. 2000. Economic associations among causes ofspecies endangerment in the United States. BioScience 50(7): 593-601.

Daszak, P., A.A. Cunningham, A.D. Hyatt. 2000. Emerging infectious diseases of wildlife –threats to biodiversity and human health. Science 287: 443-449.

Daversa, D. R., E. Muths, and J. Bosch. 2012. Terrestrial Movement Patterns of the Common Toad (*Bufo bufo*) in Central Spain Reveal Habitat of Conservation Importance. Journal of Herpetology 46:658–664.

Davies, K.F., C.R. Margules, and J.F. Lawrence. 2004. A synergistic effect puts rare,specialized species at greater risk of extinction. Ecology 85: 265-271.

deMaynadier, P. G., and M.L. Hunter Jr. 1995. The Relationship between Forest Management and Amphibian Ecology: A Review of the North American Literature. Environmental Reviews. 3:230-261.

deMaynadier, P.G. and M.L. Hunter Jr. 1998. Effects of silvicultural edges on the distribution and abundance of amphibians in Maine. Conservation Biology. 12(2):340-352.

deMaynadier, P.G. and M.L. Hunter Jr. 1999. Forest canopy closure and juvenile emigration by pool-breeding amphibians in Maine. Journal of Wildlife Management 63: 441-450.

Densmore, C.L. and D.E. Green. 2007. Diseases of Amphibians. ILAR Journal 48: 235-254.

Devictor, V., R. Julliard, C. Couvet, A. Lee, and F. Jiguet. 2007. Functional homogenizationeffect of urbanization on bird communities. Conservation Biology 21(3): 741-751

Didham, R. 1998. Altered leaf-litter decomposition rates in tropical forest fragments. Oecologia 116: 397-406.

Dixon, J.R., N.O. Dronen, J.C. Godwin, and M.A. Simmons. 1990. Final Report: The amphibians, reptiles, and mammals of Bastrop and Buescher State Parks: with emphasison the Houston toad (*Bufo houstonensis*) and the short-tailed shrew (*Blarina* sp.). Submitted to Texas Parks and Wildlife Department. Austin, Texas.

Dixon, J.R. 1982. Distribution and habitat of the Houston toad, *Bufo houstonensis*, in thevicinity of Camp Swift Military Reservation. USDI-OSM, 35 pp.

Dodd, C.K. and L.L. Smith. 2003. Habitat destruction and alteration. Historical trends and future prospects for amphibians. Pages 94-112 in Semlitsch, R.D., editor. Amphibian Conservation. Smithsonian Institution Press. Washington, DC.

Donald, P.F. and A.D. Evans. 2006. Habitat connectivity and matrix restoration: the wider implications of agri-environment schemes. Journal of Applied Ecology 43: 209-218.

Duarte, A., D. J. Brown, and M. R. J. Forstner. 2014. Documenting extinction in real time: rapid decline of the endangered Houston toad on a primary recovery site. Journal of Fish and Wildlife Management 5:363−371.

Duarte, A., D. J. Brown, and M. R. J. Forstner. 2011. Estimating abundance of the endangered Houston toad on a primary recovery site. Journal of Fish and Wildlife Management 2:207−215.

Epperson, D.M. and C.R. Allen. 2010. Red imported fire ant impacts on upland arthropods in southern Mississippi. American Midland Naturalist 163: 54-63.

Fahrig, L. 1997. Relative effects of habitat loss and fragmentation on population extinction. The Journal of Wildlife Management 61: 603-610.

Fahrig, L. and J. Pedlar, S. Pope, P. Taylor, and J. Wegnar. 1995. Effect of road traffic on amphibian density. Biological Conservation, 73: 177-182.

Fahrig, L. 2013. Rethinking patch size and isolation effects: The habitat amount hypothesis. Journal of Biogeography, 4: 1649–1663.

Ferguson, A.W., F.W. Weckerly, J.T. Baccus, and M.R.J. Forstner. 2008. Evaluation of predator attendance at pitfall traps in Texas. Southwestern Naturalist 53: 450-457.

Findlay, C. and J. Houlahan. 1997. Anthropogenic correlates of species richness in southeastern Ontario wetlands. Conservation Biology 11: 1,000-1,009.

Forester, D.C., J.W., Snodgrass, K. Marsalek, and L. Zachary. 2006. Post-breeding dispersaland summer home range of female American toads (*Bufo americanus*). Northeastern Naturalist 13: 59-72.

Forman, R.T.T. and L.E. Alexander. 1998. Roads and their major ecological effects. AnnualReview of Ecology and Systematics 29: 207-231.

Forstner, M.R.J. 2001. Houston toad survey results and summary report for the Griffith League Ranch, Bastrop County, TX. 3 pages.

Forstner, M. R. J. 2003. Final Technical Report. Final report of the 2003 Bastrop County coordinated Houston toad surveys. Submitted to Bastrop County Citizen's Workgroup.12 pages.

Forstner, M.R.J. and J.R. Dixon. 2011. Houston toad (*Bufo houstonensis*) 5-year review: summary and evaluation. Final Report for Section 6 project E-101. Submitted to TexasParks and

Wildlife Department and U.S. Fish and Wildlife Service.

Forstner, M.R.J. and A.M.A. Bohannon. 2019. Houston toad 2019 chorusing survey for Bastrop County and the Lost Pines Habitat Conservation Plan. Monitoring report for Bastrop County. 14 pp.

Forys, E.A., C.R. Allen, and D.P. Wojcik. 2002. Influence of the proximity and amount of human development and roads on the occurrence of the red-imported fire ant in the lowerFlorida Keys. Biological Conservation 108: 27-33.

Frankham, R., C.J.A. Bradshaw, and B.W. Brook. 2014. Genetics in conservation management: revised recommendations for the 50/500 rules, red list criteria and population viability analyses. Biological Conservation 170: 56-63.

Frankham, R. 1995. Effective population size/adult population size ratios in wildlife: a review. Genetic Research 66: 95-107.

Franklin, A.B., B.R. Noon, and T.L. George. 2002. What is habitat fragmentation? Studies In Avian Biology 25: 20-29.

Fratzke A, Howard LL, Tocidlowski ME, Armién A., Oliveira, F. Ritchie B., Berlin, E. Snook, E. 2019. Chlamydia pneumoniae Polioencephalomyelitis and Ganglionitis in Captive Houston Toads (*Anaxyrus houstonensis*). Veterinary Pathology. 56: 789-793.

Freed, P.S. and K. Neitman. 1988. Notes on predation on the endangered Houston toad, *Bufo houstonensis*. The Texas Journal of Science 40: 454-455

Frost, D.R., T. Grant, J. Faivovich, R.H. Bain, A. Haas, C.F.B. Haddad, R.O. De Sa, A. Channing, M. Wilkinson, S. C. Donnellan, C.J. Raxworthy, J. A. Campbell, B.L. Blotto, P. Moler, R.C. Drewes, R.A. Nussbaum, J.D. Lynch, D.M. Green, and W.C. Wheeler. 2006. The amphibian tree of life. Bulletin of the American Museum of Natural History 297: 1-291.

Funk, W.C., A.E. Greene, P.S. Corn, and F.W. Allendorf. 2005. High dispersal in a frog species suggests that it is vulnerable to habitat fragmentation. Biology Letters 1:13-16.

Gaertner, J.P., M.A. Gaston, D. Spontak, M.R.J. Forstner, and D. Hahn. 2009. Seasonal variation in the detection of *Batrachochytrium dendrobatidis* in a Texas population of Blanchard's cricket frog (*Acris crepitans blanchardi*). Herpetological Review 40: 184-187.

Gaertner, J., D. McHenry, M.R.J. Forstner, D. Hahn. 2010. Annual variation of *Batrachochytrium dendrobatidis* in the Houston toad (*Bufo houstonensis*) and a sympatriccongener (*Bufo nebulifer*). Herpetological Review 41: 456-459.

Gaston, M.A, A. Fuji, F.W. Weckerly, and M.R.J. Forstner. 2010. Potential component allee effects and their impact on wetland management in the conservation of endangered anurans. PLoS ONE 5: 1-6.

Gibbs, J.P. 1998. Distribution of woodland amphibians along a forest fragmentation gradient. Landscape Ecology 13: 263-268.

Goates, M.C., K.A. Hatch, and D.L. Eggett. 2007. The need to ground truth 30.5 m buffers: acase study of the boreal toad (*Bufo boreas*). Biological Conservation 138: 474-483.

Gray, M.J., D.L. Miller, and J.T. Hoverman. 2009. Ecology and pathology of amphibian Ranavirues. Diseases of Aquatic Organisms 87: 243-266.

Greuter, K.L. 2004. Early juvenile ecology of the endangered Houston toad, *Bufo houstonensis* (Anura: Bufonidae). Texas State University, San Marcos, Texas.

Halls, L.K. and J.L. Schuster. 1965. Tree-herbage relations in pine-hardwood forests of Texas. Journal of Forestry 63: 282-283.

Hansen, A.J., R.L. Knight, J.M. Marzluff, S. Powell, K. Brown, P.H. Gude, and K. Jones. 2005. Effects of exurban development on biodiversity: patterns, mechanisms, and research needs. Ecological Applications 15(6): 1893-1905.

Hanski, I. 1998. Metapopulation dynamics. Nature 396: 41-49.

Hanski, I. 1995. Effects of landscape pattern on competitive interactions. Pages 203-224 in Hansson L., L. Fahrig, and G. Merriam (eds.). Mosaic Landscapes and Ecological Processes. Springer, Dordrecht. https://doi.org/10.1007/978-94-011-0717-4_9

Hansson, L. 1998. Local hot spots and their edge effects: small mammals in oak-hazel woodland. Oikos 81: 55-62.

Harris, L. 1984. The fragmented forest: island biogeography theory and the preservation ofbiotic diversity. University of Chicago Press. Chicago, Illinois.

Haskell, D.G. 2000. Fauna of the southern Appalachian Mountains. Conservation Biology 14:57-63.

Hatfield, J.S., A.H. Price, D.D. Diamond, and C.D. True. 2004. Houston toad (*Bufo houstonensis*) in Bastrop County, Texas: need for protecting multiple subpopulations. Pages 292-298 in Akçakaya, H.R., M.A. Burgman, Kindvall, O., C.C. Wood, P. Sjögren-Gulve, J.S. Hatfield, and M.A. McCarthy, editors. Species Conservation Management: Case Studies. Oxford University Press. New York, New York. 552 pp.

Hillis, D.M., A.M. Hillis, and R.F. Martin. 1984. Reproductive ecology and hybridization of the endangered Houston toad (*Bufo houstonensis*). Journal of Herpetology 18: 56-71.

Holway, D.A. and A.V. Suarez. 2006. Homogenization of ant communities in Mediterranean California: the effects of urbanization and invasion. Biological Conservation 127:319-326.

Houlahan, J.E. and C.S. Findlay. 2003. The effects of adjacent land use on wetland amphibian species richness and community composition. Canadian Journal of Fisheries and Aquatic Sciences 60: 1078-1094.

Huxel, G.R. and A. Hastings. 1999. Habitat loss, fragmentation, and restoration. Restoration Ecology 7(3): 309-315.

Indermaur, L., M. Gehring, W. Wehrle, K. Tockner, and B. Naef-Daenzer. 2009. Behavior-Based Scale Definitions for Determining Individual Space Use: Requirements of TwoAmphibians. The American Naturalist 173: 60–71.

IPCC. 2013. Climate change 2013: the physical science basis. Contribution of working group I to the fifth assessment report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

IPCC. 2014a. Climate change 2014: Synthesis report. Contribution of working groups I, II, and III to the fifth assessment report of the Intergovernmental Panel on Climate Change [core writing team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

IPCC. 2014b. Annex II: Glossary [Mach, K.J., S. Planton, and C. von Stechow (eds.)]. In: Climate change 2014: Synthesis Report. Contribution of working groups I, II, and III to the fifth assessment report of the Intergovernmental Panel on Climate Change [core writing team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, pp. 117-130.

Jacobson, N.L. 1989. Breeding dynamics of the Houston toad. Southwestern Association of Naturalists 34: 374-380.

Jiang, X. and Z.L. Yang. 2012. Projected changes of temperature and precipitation in Texasfrom downscaled global climate models. Climate Research 53: 229-244.

Jofre, M.B. and W.H. Karasov. 1999. Direct effect of ammonia on three species of North American anuran amphibians. Environmental Toxicology and Chemistry 18:1,806-1,812.

Jouvenaz, D.P., G.E. Allen, W.A. Banks, and D.P. Wojcik. 1977. A survey for pathogens of fire ants, Solenopsis spp., in the southeastern United States. The Florida Entomologist 60(4): 275-279.

Keenan, R.J. and J.P. Kimmins. 1993. The ecological effects of clear-cutting. Environmental Reviews 1: 121-144.

Kennedy, J.P. 1962. Spawning season and experimental hybridization of the Houston toad, *Bufo houstonensis*. Herpetologica 17: 239-245.

Kirchner, T.B. 1977. The effects of resource enrichment on the diversity of plants andarthropods in a shortgrass prairie. Ecology 58: 1,334-1,344.

Knapp, S.M., C.A. Haas, D.N. Harpole, and R.L. Kirkpatrick. 2003. Silvicultural practices on terrestrial salamander abundance. Conservation Biology 17: 752-762.

Knutson, M.G., J.R Sauer, D.A. Olsen, M.J. Mossman, L.M. Hemesath, M.J. Lanoo. 1999. Effects of landscape composition and wetland fragmentation on frog and toad abundancein Iowa and Wisconsin, U.S.A. Conservation Biology 13: 1,437-1,446.

Knutson, M.G., W.B. Richardson, D.M. Reineke, B.R. Gray, J.R. Parmelee, and S.E. Weick. 2004.

Agricultural ponds support amphibian populations. Ecological Applications 14: 669-684.

Kocher, S., R. Harris, and G. Nakamura. 2009. Recovering from wildfire: a guide for California's forest landowners. Recovering from Wildfire ANR Publication 8386. 12 pp.

Lacy, R.C. 1987. Loss of genetic diversity from managed populations: interacting effects ofdrift, mutation, immigration, selection, and population subdivision. Conservation Biology 1: 143-158.

Latter, B.D.H., J.C. Mulley, D. Reid, and L. Pascoe. 1995. Reduced genetic load revealed byslow inbreeding in Drosophila melanogaster. Genetics 139: 287-297.

LCRA (Lower Colorado River Authority). 2011. Lower Colorado River Authority: droughtupdate Issue 2. Retrieved June 4, 2012. 3 pp.

LeBrun, E.G., R.M. Plowes, and L.E. Gilbert. 2012. Imported fire ants near the edge of their range: disturbance and moisture determine prevalence and impact of an invasive socialinsect. Journal of Animal Ecology 81: 884-895.

Looper, M.L, R. Flores, G.E. Aiken, C.F. Rosenkrans, and D.K. Brauer. 2006. Forage availability and nutritive composition of bahiagrass and bermudagrass grazed by steerswith or without steroid implants. AAES Research Series 545: 117-119.

Lost Pines Recovery Team. 2011. Bastrop County complex fire Lost Pines Region resources assessment & response report. 247 pp.

Lovejoy, T. E., R. 0. Bierregaard, Jr., A. B. Rylands, J. R. Malcolm, C. E. Quintela, L. H. Harper, K. S. Brown, Jr., A. H. Powell, G. V. N. Powell, H. 0. R. Shubart, and M. B. Hays. 1986. Edge and other effects of isolation on Amazon forest fragments. Pages 257-285 in M. E. Soul6, editor. Conservation biology: the science of scarcity and diversity. Sinauer Associates, Sunderland, Massachusetts, USA. 328 pp.

MacLaren, A. R. 2019. Re-evaluating the reproductive ecology of the endangered Houston Toad (*Bufo* [=*Anaxyrus*] *houstonensis*) using automated audio monitoring techniques (Unpublished dissertation). Texas State University, San Marcos, Texas. 112 pp.

Mader, H.J., Schell, C. and Kornacker, P. 1990. Linear barriers to arthropod movements in the landscape. Biological Conservation. 54: 209-222.

Marzluff, J.M. and A.D. Rodewald. 2008. Conserving biodiversity in urbanizing areas: nontraditional views from a bird's perspective. Cities and the Environment 1(2): 1-27.

Marzluff, J.M. and K. Ewing. 2001. Restoration of fragmented landscapes for the conservationof birds: a general framework and specific recommendations for urbanizing landscapes. Restoration Ecology 9(3): 280-292.

McHenry, D.J. and M.R.J. Forstner. 2009. Houston toad metapopulation assessment and genetics: data necessary for effective recovery strategies in a significantly fragmentedlandscape. Final Report for Section 6 project E-76. Submitted to Texas Parks and Wildlife Department and U.S. Fish and Wildlife Service.

McKinney, M.L. 2008. Effects of urbanization on species richness: a review of plants andanimals. Urban Ecosystems 11: 161-176.

McKinney, M.L. 2006. Urbanization as a major cause of biotic homogenization. Biological Conservation 127: 247-260.

McKinney, M.L. 2002. Urbanization, biodiversity, and conservation. BioScience 52(10): 883-890.

Meiners, S.J. and S.T.A. Pickett. 1999. Changes in community and population responses acrossa forest-field gradient. Ecography 22: 261-267.

Melbourne, B.A. and A. Hastings. 2008. Extinction risk depends strongly on factorscontributing to stochasticity. Nature 454: 100-103.

MINEO Consortium. 2000. Part 2 Review of potential environmental and social impact ofmining. Contract IST-1999-10337. 28 pp.

Muths, E. 2003. Home range and movements of boreal toads in undisturbed habitat. Copeia 1:160-165.

O'Driscoll, M., S. Clinton, A. Jefferson, A. Manda, and S. McMillan. 2010. Urbanization effects on watershed hydrology and in-stream processes in the southern United States.Water 2: 605-648.

Oi, D.H. and S.M. Valles. 2009. Fire ant control with entomopathogens in the USA. Pages 237-257 In Hajek, A.E., T.R. Glare, and M. O'Callaghan, editors. Use of Microbes forControl and Eradication of Invasive Arthropods. Springer. 366 pp.

Olden, J.D., N.L. Poff, and M.L. McKinney. 2006. Forecasting faunal and floral homogenization associated with human population geography in North America.Biological Conservation 127: 261-271.

Paul, M.J. and J.L. Meyer. 2001. Streams in the urban landscape. Annual Review of Ecologyand Systematics 32: 333-365.

Pauly, G.B., D.M. Hillis, and D.C. Cannatella. 2004. The history of a Nearctic colonization: molecular phylogenetics and biogeography of the Nearctic toads (*Bufo*). Evolution 58:2517-2535.

Pereira, R.M. 2004. Occurrence of Myrmicinosporidium durum in red imported fire ant,*Solenopsis invicta*, and other new host ants in eastern United States. Journal of Invertebrate Pathology 86: 38-44.

Petranka, J.W., M.P. Brannon, M.E. Hopey, and C.K. Smith. 1994. Effects of timber harvestingon low elevation populations of southern Appalachian salamanders. Forest Ecology and Management 67: 135-147.

Pfennig, K.S., K. Rapa, and R. McNatt. 2000. Evolution of male mating behavior: male spadefoot toads preferentially associate with conspecific males. Behavioral Ecology andSociobiology 48: 69-74.

Pilliod, D.S., R.B. Bury, E.J. Hyde, C.A. Pearl, and P.S. Corn. 2003. Fire and amphibians inNorth America. Forest Ecology and Management 178: 163-181.

Popescu, V.D., and M.L. Hunter. 2011. Clear-cutting affects habitat connectivity for a forest amphibian by decreasing permeability to juvenile movements. Ecological Applications21: 1283-1295.

Porter, S.D., S.M. Valles, T.S. Davis, J.A. Briano, L.A. Calcaterra, D.H. Oi, and R.A. Jenkins. 2007. Host specificity of the microsporidian pathogen *Vairimorpha invictae* at five field sites with infected Solenopsis invicta fire ant colonies in northern Argentina. Florida Entomologist 90: 447-452.

Porter, S.D., D.F. Williams, R.S. Patterson, and H.G. Fowler. 1997. Intercontinental differences in the abundance of *Solenopsis* fire ants (Hymenoptera: Formicidae); escape from natural enemies? Environmental Entomology 26(2): 373-384.

Porter, S.D. and S.A. Savignano. 1990. Invasion of polygyne fire ants decimates native ants and disrupts arthropod community.  Ecology. 71(6): 2095-2106.

Porter, S.D., B. Van Eimeren, and L.E. Gilbert. 1988. Invasion of red imported fire ants (Hymenoptera: Formicidae): Microgeography of competitive replacement. Annals of the Entomological Society of America 81: 913-918.

Price, A. H. 1992. Houston toad (*Bufo houstonensis*) status survey. Texas Parks and Wildlife Department. Austin, Texas. 11 pages.

Price, A.H. 2003. The Houston toad in Bastrop State Park 1990-2002: a narrative. Open-filereport 03-0401, Texas Parks and Wildlife Department.

Price, S.J., M.E. Dorcas, A.L. Gallant, R.W. Klaver, and J.D. Wilson. 2006. Three decades of urbanization: estimating the impact of land-cover changes on stream salamander populations. Biological Conservation 133: 436-441.

Quinn, H. and G. Ferguson.  1983.  Release program for captive-raised and wild-caught Houston toads (*Bufo houstonensis*). Progress report for work completed from February through June 1983.  Presented to U.S. Fish and Wildlife Service, Office of Endangered Species.

Quinn, H. R., G. Ferguson, A. Barrass. 1984. Release program for captive-raised and wild- caught Houston toads *Bufo houstonensis*. Progress report for work completed through June 1984. Submitted to U.S. Fish and Wildlife Service.

Quinn, H. and G. Mengdon. 1984. Reproduction and growth of *Bufo houstonensis* (Bufonidae) Southwestern Naturalist 29:189-195.

Ranney, J.W., M.C. Bruner, and J.B. Levenson. 1981. The importance of edge in the structure and dynamics of forest islands. Pages 67-95 in Burgess, R.L. and D.M. Sharpe, editors.Forest

Island Dynamics in Man-Dominated Landscapes. Springer Verlag, New York. 311 pp.

Reading, C. J., J. Loman, and T. Madsen. 1991. Breeding pond fidelity in the common toad, *Bufo bufo*. Journal of Zoology 225: 201–211.

Rebele, F. 1994. Urban ecology and special features of urban ecosystems. Global Ecology and Biogeography Letters 4: 173-187.

Reh, W. and A. Seitz. 1990. The influence of land use on the genetic structure of populations ofthe common frog *Rana temporaria*. Biological Conservation 54: 239-249.

Revilla, E., T. Wiegand, F. Palomares, P. Ferreras, and M. Delibes. 2004. Effects of matrix heterogeneity on animal dispersal: from individual behavior to metapopulation-level parameters. The American Naturalist 164: 130-153.

Rhymer, J.M., and D. Simberloff. 1996. Extinction by hybridization and introgression. Annual Review of Ecology and Systematics 27: 83-109.

Riley, S.P.D, G.T. Busteed, L.B. Kats, T.L. Vandergon, L.F.S. Lee, R.G. Dagit, J.L. Kerby, R.N. Fisher, and R.M. Sauvajot. 2005. Effects of urbanization on the distribution and abundance of amphibians and invasive species in southern California streams. Conservation Biology 19(6): 1894-1907.

Rothermel, B.B. and R.D. Semlitsch. 2002. An experimental investigation of landscaperesistance of forest versus old-field habitat to emigrating juvenile amphibians. Conservation Biology 16: 1,324-1,332.

Romano Noriega, J., Oliveira, F., Crump, P.S., Tocidlowski, M.E., Howard, L.L. 2022. Medical management of dermatitis-associated morbidity and mortality in endangered Houston toads (*Anaxyrus houstonensis*). Vet Record Case Reports e275

Rupp, D.E., P.W. Mote, N. Massey, C.J. Rye, R. Jones, and M.R. Allen. 2012. Did human influence on climate make the 2011 Texas drought more probable? Bulletin of the American Meteorological Society 93: 1041-1067.

Russell, R.E., R.K. Swihart, and Z. Feng. 2003. Population consequences of movementdecisions in a patchy landscape. Oikos 103: 142-152.

Russell, K.R., D.H. Van Lear, and D.C. Guynn, Jr. 1999. Prescribed fire effects on herpetofauna: review and management implications. Wildlife Society Bulletin. 27: 374-384.

Sanders, O.T. 1953. A new species of toad, with a discussion of morphology of the bufonidskull. Herpetologica 9: 25-47.

Sanders, O. and J.C. Cross. 1964. Relationships between certain North American toads asshown by cytological study. Herpetologica 19: 248-255.

Saunders, D.A., R.J. Hobbs, and C.R. Margules. 1991. Biological consequences of ecosystem fragmentation: a review. Conservation Biology 5: 18-32.

Suarez, A.V., D.T. Bolger, and T.J. Case. 1998. Effects of fragmentation and invasion on nativeant communities in coastal southern California. Ecology 79: 2041-2056.

Schmutzer, A.C., M.J. Gray, E.C. Burton, and D.L. Miller. 2008. Impacts of cattle on amphibian larvae and the aquatic environment. Freshwater Biology 53: 2,613-2,625.

Semlitsch, R.D. 1998. Biological delineation of terrestrial buffer zones for pond-breeding salamanders. Conservation Biology 12: 1,129-1,133.

Semlitsch, R.D. 2000. Principles for management of aquatic-breeding amphibians. Journal of Wildlife Management 64: 615-631.

Semlitsch, R.D. 2002. Critical elements for biologically based recovery plans of aquatic-breeding amphibians. Conservation Biology 16: 619-629.

Semlitsch, R.D. 2003. Conservation of pond-breeding amphibians in R.D. Semlitsch, editor. Amphibian conservation. Smithsonian Institution, Washington, pages 8-23.

Semlitsch, R. D. 2008. Differentiating Migration and Dispersal Processes for Pond-Breeding Amphibians. The Journal of Wildlife Management 72: 260–267.

Semlitsch, R.D., B.D. Todd, S.M. Blomquist, A.J.K. Calhoun, J.W. Givvons, J.P. Gibbs, G.J. Graeter, E.B. Harper, D.J. Hocking, M.L. Hunter, D.A. Patrick, T.A.G. Rittenhouse, and

B.B. Rothermel. 2009. Effects of timber harvest on amphibian populations: understanding mechanisms from forest experiments. BioScience 59: 853-862.

Semlitsch, R.D. and J.R. Bodie. 2003. Biological criteria for buffer zones around wetlands and riparian habitats for amphibians and reptiles. Conservation Biology 17: 1219-1228.

Siemann, E., D. Tilman, J. Haarstad, and Mark Ritchie. 1998. Experimental tests of the dependence of arthropod diversity on plant diversity. The American Naturalist 152: 738-750.

Stephens, P.A., W.J. Sutherland, and R.P. Freckleton. 1999. What is the allee effect? Oikos 87:185-190.

Stiles, J.H. and R.H. Jones. 1998. Distribution of the red imported fire ants, *Solenopsis invicta*,in road and powerline habitats. Landscape Ecology 335: 335-346.

Swannack, T. 2007. Ecology of the Houston toad (Bufo houstonensis). Ph.D. Texas A&M University, Department of Wildlife and Fisheries Sciences.

Swannack, T.M. and M.R.J. Forstner. 2007. Possible cause for the sex-ratio disparity of the endangered Houston toad (*Bufo houstonensis*). The Southwestern Naturalist 52: 386-392.

Swannack, T.M., W.E. Grant, and M.R.J. Forstner. 2009. Projecting population trends of endangered amphibian species in the face of uncertainty: a pattern-oriented approach. Ecological Modeling 220: 148-159.

Taylor, S.J., P.S. Sprouse, and F. Hutto. 2003. A survey of red imported fire ant (*Solenopsis* *invicta*) distribution and abundance at Fort Hood, Texas. Illinois Natural History Survey, Center for Biodiversity Technical Report 2003(26): 1-42.

Texas Demographic Center. 2020. Texas Population Projections Data Tool. Retrieved on May3, 2020 from https://demographics.texas.gov/.

Theobald, D.M., J.R. Miller, and N.T. Hobbs. 1997. Estimating the cumulative effects of development on wildlife habitat. Landscape and Urban Planning 39: 25-36.

Thomas, R.A. 1977. The endangered Houston toad (*Bufo houstonensis*). Final Report to the U.S. Fish and Wildlife Service. 11 pages.

Todd, B.D., B.B. Rothermel, R.N. Reed, T.M. Luhring, K. Schlatter, L. Trenkamp, and J.W. Gibbons. 2008. Habitat alteration increases invasive fire ant abundance to the detrimentof amphibians and reptiles. Biological Invasions 10: 539-5456.

Torrence, S.M, D.E. Green, C.J. Benson, H.S. Ip, L.M Smith, and S.T. McMurry. 2010. A new ranavirus isolated from *Pseudacris clarkii* tadpoles in playa wetlands in the southern high plains, Texas. Journal of Aquatic Animal Health 22: 65-72.

Traill, L.W., B.W. Brook, R.R. Frankham, and C.J.A. Bradshaw. 2010. Pragmatic population viability targets in a rapidly changing world. 143: 28-34.

Tschinkel, W.R. 1988. Distribution of the fire ants *Solenopsis invicta* and *S. geminate* (Hymenoptera: Formicidae) in northern Florida in relation to habitat and disturbance.Annals of the Entomological Society of America 81:76-81.

U.S. Drought Monitor. 2020. Time Series Tool. Retrieved on August 5, 2020 from https://droughtmonitor.unl.edu/.

U.S. Federal Government. 2018. U.S. Climate Resilience Toolkit Climate Explorer.Retrieved on August 1, 2020 from https://climate-explorer2.nemac.org.

U.S. Fish and Wildlife Service. 1984. Houston toad recovery plan. U.S. Fish and WildlifeService, Albuquerque, New Mexico. 73 pp.

U.S. Fish and Wildlife Service. 1994. Population and habitat viability assessment: Houston toad (*Bufo houstonensis*). Notes from workshop conducted by IUCN/SSC

Conservation Breeding Specialist Group in partial fulfillment of USFWS contract #94-172. Apple Valley, Minnesota.

U.S. Fish and Wildlife Service. 2011. Houston toad (*Bufo houstonensis)* 5-year review: Summary and evaluation. Austin Ecological Services Field Office, Austin, Texas. 23 pp.

US. Fish and Wildlife Service, 2017. Houston toad habitat management guidelines. Austin Ecological Services Field Office, Austin, Texas. pp. 1-13.

U.S. Fish and Wildlife Service. 2018. 5-Year review. Houston toad (*Anaxyrus* [formerly *Bufo*] *houstonensis)* 5-year review. Austin Ecological Services Field Office, Austin,Texas. 1 p.

Valles, S.M., C.A. Strong, P.M. Dang, W.B. Hunter, R.M. Pereira, D.H. Oi, A.M. Shapiro, and D.F. Williams. 2004. A picorna-like virus from the red-imported fire ant, *Solenopsisinvicta*: initial discovery, genome sequence, and characterization. Virology 328: 151-157.

van Dyke, F. 2008. Conservation biology: foundations, concepts, applications. Springer. Wheaton College, Illinois, USA. 477 pp.

van Gelder, J.J. 1973. A quantitative approach to the mortality resulting from traffic in apopulation of *Bufo bufo* L. Oecologia 13: 93-95.

Vandewege, M., D. Brown, and M. Forstner. 2012. *Bufo* (=*Anaxyrus*) *houstonensis* (Houstontoad) head-start juvenile dispersal. Herpetological Review 43: 117–118.

Vandewege, M. W., T. M. Swannack, K. L. Greuter, D. J. Brown, and M. R. J. Forstner. 2013. Breeding site fidelity and terrestrial movement of an endangered amphibian, the Houston toad (Bufo houstonensis). Herpetological Conservation and Biology 8:435−446.

Vemulapally S., Villamizar, A., Guerra, T. Tocidlowski, M.E., Spradley, M., Mays, S., Forstner, M.R.J., Hahn D. 2021. Mycobacteria in skin lesions and the habitat of the endangered Houston toad (*Anaxyrus houstonensi*s). Journal of Wildlife Diseases. 2021 57:503-514

Visser, M.E. 2008. Keeping up with a warming world; assessing the rate of adaptation toclimate change. Proceedings of the Royal Society B 275: 649-659.

Vos, C.C., and J.P. Chardon. 1998. Effects of habitat fragmentation and road density on the distribution pattern of the moor frog *Rana arvalis*. Journal of Applied Ecology 35: 44-56.

Walston, L.J. and S.J. Mullin. 2008. Variation in amount of surrounding forest habitat influences the initial orientation of juvenile amphibians emigrating from breeding ponds.Canadian Journal of Zoology 86:141-146.

Wells, K.D. 1977. The social behaviour of anuran amphibians. Animal Behaviour 25: 666-693.

Welsh, H. 1990. Relictual amphibians and old-growth forests. Conservation Biology 14: 309-319.

Wilcove, D.S., D. Rothstein, J. Dubow, A. Phillips, and E. Losos. 1998. Quantifying threats to imperiled species in the United States. BioScience 48(8): 607-615.

Yahner, R.H. 1988. Changes in wildlife communities near edges. Conservation Biology 2: 333-339.

Yanes, M., J.M. Velasco, and F. Suarez. 1995. Permeability of roads and railways tovertebrates: the importance of culverts. Biological Conservation 71: 217-222.

Yang, C., Y. Yu, S.M. Valles, D.H. Oi, Y. Chen, D. Shoemaker, W. Wu, and C. Shih. 2010. Loss of microbial (pathogen) infections associated with recent invasions of the redimported fire ant *Solenopsis invicta*. Biological Invasions 12: 3307-3318.

Yantis, J.H. 1989. Performance report. A state funded project, Nongame Wildlife Investigations, Job No. 78: Houston toad distribution and habitat status (*Bufohoustonensis*). Texas Parks and Wildlife Department, Austin TX.

Yantis, J.H. 1990. Performance report. A state funded project, Nongame Wildlife Investigations, Job No. 78: Houston toad distribution and habitat status (*Bufohoustonensis*). Texas Parks and Wildlife Department, Austin TX.

Yantis, J.H. and A.H. Price. 1993. Final Report. A state funded project, Nongame Wildlife Investigations, Job no. 8: Houston toad (*Bufo houstonensis*) status survey. Texas Parksand Wildlife Department, Austin TX.

Zipperer, W.C. 2011. The process of natural succession in urban areas. Pages 187-197 in Douglas, I., D. Goode, M. Houck, and R. Wang, editors. The Routledge Handbook onUrban Ecology. Routledge Taylor and Francis Group, London. 688 pp.

**7.0 Appendix 1. Responses to Public Comments**

| Name | Comment | USFWS Response |
|---|---|---|
| Texas Parks and Wildlife Department | Section 2.3.4 Juvenile Survivorship In the last paragraph on page 7 of this section, a list of survivorship estimates from various sources is included, but the estimates are in different units. Some are in percentages, and some are presumably in rates measured between 0 and 1, but it is unclear. TPWD recommends that the survivorship estimates be standardized into a common scale so that comparisons are clear. | Suggested change incorporated. |
| Texas Parks and Wildlife Department | Section 3.4.1 Population Resiliency In the third paragraph on page 39 of this section, a sentence reads "We consider a metapopulation to be resilient if it consists of at least three subpopulations that each support at least 1,000 adult females." It is not clear if this means the combined metapopulation will be considered resilient if the total is 1,000 females, or if each subpopulation needs 1,000 females to be considered resilient, and thus 3,000 females are needed for the total metapopulation. TPWD recommends clarifying this sentence. | Suggested change incorporated. |
| Texas Parks and Wildlife Department | Section 3.4.1 Population Resiliency At the end of the third paragraph on page 39, the Hatfield model is cited. The sentence reads, "A resilient metapopulation must have at least 2 percent juvenile survivorship." The model from the Hatfield et al. (2004) paper represents the best overall science for a population viability analysis (PVA), but some of the parameter estimates are outdated. For example, the fecundity estimates were taken from two older reports that reported clutch size to be 1773 eggs on average. Recent estimates of clutch size are larger; the Houston Zoo Captive Propagation Program | |

| Name | Comment | USFWS Response |
|---|---|---|
| | estimated between 3,000-5,000 eggs per clutch, but the toads in the program are large captive toads. No estimates of wild Houston toad egg masses have been made during this recent recovery effort. | |
| Texas Parks and Wildlife Department | Section 3.4.2 Species Redundancy At the end of the paragraph on page 40, the sentence reads "Because risks cannot be spread among multiple populations, the species likely has little ability to withstand catastrophic events." The meaning of this sentence is not clear. Although the Houston toad range is relatively small, encompassing only nine Texas counties currently, the scale of a typical catastrophe is generally much smaller. For example, the 2011 Bastrop County Complex Wildlife was a large and devastating fire that destroyed 35,000 acres of critical habitat, but it only affected part of one recovery unit. Populations in Robertson, Colorado, and Austin counties were unaffected by this same catastrophe. As such, it seems that, while all populations are likely in poor condition, there is more redundancy across the range than this statement implies. One catastrophe that might impact all populations somewhat equally are droughts. Therefore, the degree of redundancy might depend on the scale of the catastrophe and the likelihood of the catastrophe occurring. TPWD recommends clarifying this sentence. | Suggested change incorporated. |
| Texas Parks and Wildlife Department | Section 4.1.3 Recovery Objectives The second paragraph on page 40 states there are "six Texas counties where the Houston toad is extant." This should be changed to "nine Texas counties." | Number corrected. |

| Name | Comment | USFWS Response |
|---|---|---|
| Texas Parks and Wildlife Department | Section 4.1.3 Recovery Objectives Under the specific recovery objectives on page 42, the first one is to "Conserve and protect at least 75,000 acres of suitable habitat in perpetuity for the Houston toad to maintain its metapopulation structure across its range." Our interpretation of this objective is that USFWS intends this habitat to be purchased or placed under easement in perpetuity. If this interpretation is correct, this is an ambitious target. One important attribute of a good objective is that it be achievable, and it is unlikely that 75,000 acres of Houston toad habitat can be purchased out right or protected with conservation easements (i.e., "protected in perpetuity"). The cost of this would be extremely high for both the purchase and management of these properties. More importantly, if our interpretation of this is correct, this recovery objective leaves no role for private landowners who wish to retain ownership of their property, but manage the post oak savanna in a manner consistent with the needs of the Houston toad. If our interpretation is correct, then this objective effectively removes the programmatic Safe Harbor Agreement and the Lost Pines Habitat Conservation Plan from the suite of available recovery tools, as land enrolled in these programs is not protected permanently. The word "perpetuity" is what renders this objective potentially unachievable. TPWD recommends USFWS clarify what is meant by "perpetuity" and consider removing this perpetual requirement or perhaps reducing the amount required to be protected in perpetuity, such as a mix of lands protected in perpetuity and enrolled in long-term conservation agreements. | Suggested change incorporated. |

| Name | Comment | USFWS Response |
|---|---|---|
| | This would allow a mosaic of public, trust land, mitigation, and private lands to help restore Houston toad and would motivate and involve landowners to help with recovery. | |
| Texas Parks and Wildlife Department | Section 4.1.3 Recovery Objectives Under the specific recovery objectives on page 42, the second objective is to "Continue support and expand the capabilities of the four institutions participating in the captive propagation program. 11 This is not a recovery objective, rather this is an action that will hopefully lead to recovery. A more measurable recovery objective would be "Continue to increase the abundance of Houston toad populations up to and beyond 1,000 females per metapopulation. The support of the captive supplementation program, along with efforts to improve the survivorship of all life stages, would be the · actions necessary to achieve this objective. | Suggested change incorporated. |
| Texas Parks and Wildlife Department | Section 4.2.1 Downlisting Criteria Downlisting Criteria 1 on page 44 requires 30,000 acres of Houston toad habitat to be "conserved in perpetuity and protected from development." TPWD refers to the points made above about the need to be flexible with the approach of land conservation and consider removing "in perpetuity" from this criteria or consider reducing the amount required to be conserved in perpetuity to be some portion of the overall land conservation goal. | Suggested change incorporated. |

| Name | Comment | USFWS Response |
|---|---|---|
| Texas Parks and Wildlife Department | Section 4.2.1 Downlisting Criteria Downlisting Criteria 2 on page 44 requires that two or more recovery units support a Houston toad metapopulation and that "each metapopulation must also support a minimum of 1,000 adult female Houston toads, as documented by annual surveys for five consecutive years. By all historical accounts this is a very reasonable target but documenting the direct presence of females is often a difficult, if not impossible task. Most monitoring is focused on breeding males. Generally, there is a relationship between the number of males in chorus and the number of females that visit. Reproduction is usually confirmed by counting egg strings the morning after a Houston toad breeding event. Since females are difficult to count directly on surveys, TPWD recommends USFWS consider using egg string counts as a surrogate for female abundance. | Suggested change incorporated. |
| Texas Parks and Wildlife Department | Section 4.2.2 Delisting Criteria Delisting Criteria 1 on page 45 requires 75,000 acres of Houston toad habitat to be "conserved in perpetuity and protected from development." TPWD refers to the points made above about the need to be flexible with the approach of land conservation and consider removing the word perpetual from this criteria or consider reducing the amount required to be conserved in perpetuity to be some portion of the overall land conservation goal. | Suggested change incorporated. |
| Texas Parks and Wildlife Department | Section 4.2.2 Delisting Criteria Delisting Criteria 2 on pages 45 and 46 requires that 5 or more recovery units support a Houston toad metapopulation and that "each metapopulation must also support a minimum of 1,000 adult female Houston toads, as documented | Suggested change incorporated. |

| Name | Comment | USFWS Response |
| --- | --- | --- |
| | by annual surveys for five consecutive years. TPWD refers to previous comments recommending the use of egg strings as a surrogate for females for monitoring purposes. | |
| Texas Parks and Wildlife Department | Section 4.2.2 Delisting Criteria Delisting Criteria 3 on page 46 requires that "all established Houston toad metapopulations must also have at least two percent juvenile Houston toad survivorship within each subpopulation, as documented by annual monitoring over five consecutive years. For the reasons previously mentioned in comments on section 3.4.1 (Population Resiliency), TPWD believes it would be worthwhile to consider the impacts of increasing survivorship of other life stages or increasing fecundity (both likely outcomes of improved management of Houston toad habitat) to compensate for lower juvenile survivorship. The goal should be to ensure the overall viability of the Houston toad. | Suggested change incorporated. |
| Texas Parks and Wildlife Department | Section 5.1.2 Priority 2 Actions Education and outreach on page 4 7 are listed as a composite action when these are two very different activities with different goals and audiences. Education is a form of awareness-raising and seeks to impart knowledge about a subject (in this case the Houston toad) and is usually disconnected from a specific action request. Outreach, on the other hand, is an active process that is designed to provide information in a way that removes barriers motivates actions. The results of educational efforts for the Houston toad could result in long-term indirect benefits to the recovery of the species, whereas outreach, particularly when focused on private landowners with Houston toad habitat | Suggested change incorporated. |

| Name | Comment | USFWS Response |
|---|---|---|
| | present or even Houston toad populations on their properties, should result in short-term direct benefits to the recovery of the Houston toad. Outreach is an essential prerequisite to effectively implementing all the other priority recovery actions and therefore should be separate from education and moved into the Priority 1 Action category. Except for Bastrop State Park, there are no public lands with Houston toad habitat in any of the recovery units. Successful outreach and persistent engagement with private landowners on which all Houston toad habitat occurs needs to be a higher priority. | |
| Texas Parks and Wildlife Department | Section 5.2 Estimated time and costs to achieve recovery<br>Table 4 on page 49 outlines the costs to implement each of the recovery actions over the 30 years USFWS expects the recovery to be achieved. With the previously mentioned emphasis on "conserving and protecting habitat in perpetuity," it seems inconsistent to then downplay the costs of achieving that goal with a footnote explaining that the table excludes "costs of potential land acquisition. "USFWS calls for a landscape conservation approach for the Houston toad with delisting the Houston toad set to occur when 75,000 acres are in permanent conservation. The approximate cost of purchasing the land titles ($6,000 per acre) or easements ($3,000) on this acreage would be $225 million to $450 million dollars. Given that most of the post oak savanna is in a fire suppressed condition and needs to be restored to gain function and value for the Houston toad, a further $50 million will be needed for understory management ($650 per acre) and at least $30 million over 30 years for the | Suggested change incorporated. Estimated costs of land protection included in budget. |

| Name | Comment | USFWS Response |
| --- | --- | --- |
| | reinstatement and maintenance of the habitat with prescribed fire ($40 per acre, mean fire interval of five years). This brings the total cost to implement Priority Action 1 to between $304 million and $530 million. Removing the requirement for perpetual habitat protections or reducing the amount needed to achieve recovery, in combination with lands in long-term conservation agreements, will reduce both the cost of Houston toad recovery and the likelihood of it occurring. TPWD recommends that USFWS fully account for the costs of all the recovery actions that are required for downlisting and delisting. | |
| Glen Van Slyke | The Draft should be revised to include the best current survey estimate of the toad's population in each of the counties of its habitat, otherwise objective measurement of the effectiveness of the toad Recovery Plan is impossible. How many Houston toads exist that protection from extinction? The Draft admits that after the catastrophic Bastrop County Complex Fire, which burned the pine forest harboring the toad's largest known population in Bastrop State Park, "a total of 12 Houston toads were detected in extensive surveys in Austin, Bastrop, Burleson, Colorado, Lavaca, Lee and Milam counties, as well as Leon and Robertson counties." Ten years ago, only 12 toads could be found spread throughout these 9 counties. The last population count | The data to inform a population estimate in each county is not available, however survivorship of eggs have been estimated and are included in section 2.3.4 Juvenile Survivorship. More surveying and access to land across counties is necessary, and therefore would not be an accurate portrayal of the toad's status on the landscape. However, through outreach efforts, agreements with private landowners, grant agreements, and large scale partnerships, more information will be gathered on extant current populations of the toad and potential habitat. |

| Name | Comment | USFWS Response |
|---|---|---|
| | relied on in the Draft, located 85 toads in 2014. These toads must have all been found in only 5 of these counties (Austin, Bastrop, Robertson, Leon and Lee), because the Draft shows the last toad reported in the other 4 counties was in 2013 or earlier. (Table 1.). The "recovery objectives" and "recovery implementation" fail to explain how the six "management units" were mapped for conservation of suitable habitat other than to state they "encompass portions of all six Texas counties where the Houston toad is extant" and were based on geologic formations of sandy soil and boundaries of farms, pastures and rivers. There is no evidence that the Houston toad is still even extant in four of the counties containing two of the "management units". The last reports of the toad in these counties were in 2013 (Colorado, Lavaca), 2011 (Burleson) and 2007 (Milam). The Draft should be revised so that the "management unit" boundaries conform to currently observed toad populations. | |
| Glen Van Slyke | The "Recovery Implementation" actions are too vague to render allow their results to be objectively measurable. Priority Action 5.1.1.1 (Conserve, Protect and Restore Habitat) does not state the total minimum acreage of habitat or where it be, other than to state "within the six management units." Voluntary Safe Harbor Agreements, conservation banks, have not shown to be effective in preventing the toad's population decline. The Draft should be revised to conform to "Downlisting Criterion 1": "A total of 30,000 acres of forested Houston toad habitat is conserved in perpetuity and protected from further development." | Recovery implementation actions are intended to guide our actions in working towards Houston toad recovery. Both the programmatic Safe Harbor Agreement and conservation banking were implemented in recent years, and participation in both programs is increasing. This recovery plan also prioritizes continued public outreach and work with private landowners to increase participation and on the ground conservation. |

| Name | Comment | USFWS Response |
|---|---|---|
| Glen Van Slyke | The Recovery Action of "Captive Propagation and Supplementation" has no objective data or criteria to measure its effectiveness. The Draft should be revised to include information about the number of captive-bred eggs or toads that survived to adulthood. There is no benefit to transplanting eggs or young toads to habitats where the factors that caused the species endangerment. | While up to date survivorship rates are not available at this time, the primary reintroduction site saw record calling at ponds in 2021. Further habitat work and land acquisition is needed to for toad recovery as well, but captive propagation and reintroduction will continue to progress recovery. Captive propagation and reintroduction across the historical range will be necessary to achieve recovery to emulate the explosive breeding pattern of the Houston toad. Due to their current occurrences and population density on the landscape, this is not possible without reintroductions. However, egg strands and tadpole will only occur on lands deemed suitable through all necessary regulatory mechanisms. |
| Anonymous | Please protect the Houston Toads and help them to live in peace. And do not allow animals to be introduced to other locations, so that other animals won't fall into jeopardy. | Captive propagation and reintroduction across the historical range will be necessary to achieve recovery to emulate the explosive breeding pattern of the Houston toad. Due to their current occurrences and population density on the landscape, this is not possible without reintroductions. However, egg strands and tadpole will only be placed on lands deemed suitable through all necessary regulatory mechanisms. |

| Name | Comment | USFWS Response |
|---|---|---|
| Jean Publiee | usfws works with aphis, a massive nation wide killing organization. the odds are stacked against frogs so that i recommend we shut down the usda involvement with any animals and we form a new organization interested in preserving nature. this is not what usda does and so usfws is against animal lives as well. we have bad actors in govt and this is an example. protect the toad. protect all animal life, because humans are willin to kill it all for money. | The current status of the Houston toad is endangered under the Endangered Species Act. The Service works in accordance with its mission in working with others to conserve, protect, and enhance, fish, wildlife, plants, and their habitats for the continuing benefit of the American people. Under section 7 of the Endangered Species Act, federal agencies must consult the Service when any action the agency carries out, funds, or authorizes may affect either a species listed as threatened or endangered under the Act, or any critical habitat designated for it. |
| Eric Simandle | A cornerstone of Adaptive Management in Conservation Biology is the principle that management actions must be reviewed and assessed for effectiveness, and that those actions may be adjusted to improve effectiveness. Recovery objectives 2, 3, and 4 are not assessable and therefore not acceptable as “objectives”. Simply put, there is no objective criteria that would allow managers to determine success of an action, or if an objective was actually met. | Recovery Objective 2 has been edited to reflect a quantitative measure of progress for the criterion. Recovery objectives 3 and 4 will be measured through increased monitoring efforts and tracking habitat restoration projects. |

| Name | Comment | USFWS Response |
|---|---|---|
| Eric Simandle | Objective 2 calls for continued captive propogation. The Service does not appear to know how effective headstarting/captive propogation is, or is not forthcoming with those data in this document. How many of these propogules survive to adulthood out of the nearly 5 million that have been produced? How can a recovery objective include the continuance of a 15-year long captive propogation program that has never been assessed? There are no benefits to transplanting eggs or young to habitats where the factors that caused the species endangerment have not been rendered absent, or greatly reduced in severity. There has been no evidence presented that such a place exists in this document. There has been no evidence that the program is effective, either in its population-level results, or as a use of limited funding (that might be better used to acquire/manage habitat). This is the single largest budget item - at three times the dollar amount of any other action. At a minimum, evidence of effectiveness of the existing captive propagation is needed before it is included as an objective in the final Plan. | Recovery Objective 2 has been edited to reflect a quantitative measure of progress for the criterion. Recovery objectives 3 and 4 will be measured through increased monitoring efforts and tracking habitat restoration projects. Population thresholds of 1000 females per subpopulation in a metapopulation comprised of at least 3 subpopulations is considered resilient under this plan. While up to date survivorship rates are not available at this time, the primary reintroduction site saw record calling at ponds in 2021. Further habitat work and land acquisition is needed to for toad recovery as well, but captive propagation and reintroduction will continue to progress recovery. Existing estimates of survivorship are also included in 2.3.4 Juvenile Survivorship. Captive propagation and reintroduction across the historical range will be necessary to achieve recovery to emulate the explosive breeding pattern of the Houston toad. Due to their current occurrences and population density on the landscape, this is not possible without reintroductions. However, egg strands and tadpole will only occur on lands deemed suitable through all necessary regulatory mechanisms. Egg strands are not being places in habitat that cannot support toads, and all necessary regulatory mechanisms are followed to ensure the safety of the toads. |

| Name | Comment | USFWS Response |
|---|---|---|
| Eric Simandle | Objective 3 relies upon knowing "carrying capacity". It is not a reasonable biological expectation, that species such as anuran amphibians with boom and bust popuation size changes (e.g.,based on the failure or success of breeding), to ever attain "carrying capacity". The concept of "carrying capacity" is even less relevant in the metapopulation context where changing population sizes are expected. I suggest removing Objective 3 because it is misleading and portends to know what the "carrying capacity" is, and it uses the carrying capacity framework where it should not be applied (i.e., a dynamic system). | Carrying capacity can be defined as the total frequency of individuals within a community a habitat can sustain. Therefore, habitat restoration will eventually increase the capacity for individual toads sustained on the landscape. This can be measured by monitoring progress in habitat work and restoration, and eventual increased presence of toads on the landscape. |
| Eric Simandle | The determination of Critical Habitat is deficient in that common approaches in modern Conservation Biology were not brought to bear on the conservation of this toad. In the Draft Plan, there continues to be a fixation with sandy soils as a good indicator of habitat quality. Evidence is lacking for this claim, and, importantly, sand content of the soil is highly correlated with soil moisture ($r^2 > 0.90$), and is moderately correlated with other variables. As such, "sand" alone is not a reliable explanatory variable or predictor of Houston toad habitat suitability. I suggest that the Service a habitat suitability model, that can identify areas that may warrant protection, and guide land acquisitions based upon sound science. | Currently in 2022, the Service is funding a Section 6 project completing an updated habitat suitability assessment using species distribution modelling. This updated habitat suitability model will be used to adapt our recovery planning once complete and published. |