U.S. Fish and Wildlife Service

Biological Report for the Ozark Hellbender

(*Cryptobranchus alleganiensis bishopi*)

Ozark Hellbender; Photo: Jeffrey Briggler, Missouri Department of Conservation

Version 1.0

U.S. Fish and Wildlife Service
Missouri Ecological Services Field Office
Columbia, Missouri

March 2, 2020

ACKNOWLEDGEMENTS

This report was prepared by Trisha Crabill (Missouri Ecological Services Field Office) with assistance from Laura Ragan (Midwest Regional Office). We greatly appreciate the following individuals who provided information on the current status and threats of the Ozark hellbender: Dr. Jeffrey Briggler (Missouri Department of Conservation), Kelly Irwin (Arkansas Game and Fish Commission), Lauren Augustine (Saint Louis Zoo), Dr. Jeffery Ettling (Sedgwick County Zoo; previously Saint Louis Zoo), Mark Wanner (Saint Louis Zoo), Chris Davidson (U.S. Fish and Wildlife Service), Theresa Davidson (Mark Twain National Forest), Victoria Grant (Ozark National Scenic Riverways), and Alyssa Bangs (U.S. Fish and Wildlife Service).

Suggested citation: U.S. Fish and Wildlife Service. 2020. Biological report for the Ozark hellbender (*Cryptobranchus alleganiensis bishopi*). Version 1.0, March 2, 2020. Midwest Region, Bloomington, Minnesota. 81 pp.

EXECUTIVE SUMMARY

The Ozark hellbender (*Cryptobranchus alleganiensis bishopi*) is a large aquatic salamander inhabiting cool, fast-flowing streams and rivers in the Ozark Highlands of southern Missouri and northern Arkansas. As a result of drastic population declines, the U.S. Fish and Wildlife Service (Service) listed the Ozark hellbender in October 2011 as endangered under the Endangered Species Act of 1973, as amended (Act). This report summarizes the biology of the Ozark hellbender and provides a scientific assessment of the species' status and viability, including those factors that impact or are likely to impact the species. This report also informs a draft recovery plan for the Ozark hellbender (*Cryptobranchus alleganiensis bishopi*), which presents the criteria, actions, and estimated time and cost for recovery of the species, and a draft recovery implementation strategy, which provides an expanded narrative for recovery activities and an implementation schedule.

The Ozark hellbender historically occurred in portions of the White, Spring, Eleven Point, and Current rivers and some of their tributaries (Bryant Creek, the North Fork White River, and Jacks Fork River). Currently, populations of Ozark hellbenders are known to occur in Bryant Creek, the North Fork White River, the Eleven Point River, and the Current River, with some individuals possibly still present in the White River mainstem, Spring River, and Jacks Fork River.

Until the early 1970s, Ozark hellbenders were captured in large numbers where they were known to occur. However, by the late 1990s, populations throughout the range had declined by around 70% and no populations appeared to be stable. Most animals captured were large adults, and little recruitment was observed. Results from a population and habitat viability model in 2006 indicated that without management, the Ozark hellbender would be functionally extinct within 20 years. Extensive monitoring has been and continues to be conducted to monitor the status of Ozark hellbender populations. Results from these efforts indicate that all of the populations are still declining and that recruitment continues to be limited.

Though the exact cause(s) of the Ozark hellbender decline remains unclear, the primary factors thought to contribute to declines include habitat degradation, illegal collection, and disease. Additional potential factors include degraded water quality, predation by stocked native and non-native fish, and electrofishing. Extensive efforts have been initiated to help reverse or slow population declines and include population monitoring, captive propagation and augmentation, using nest boxes to augment nesting habitat, protecting populations and habitat, assessing and treating diseases, and numerous research investigations.

To assess the Ozark hellbender's current viability, we applied the conservation biology principles of resiliency, representation, and redundancy, in conjunction with an assessment of the threats acting on the species. Resiliency of the Ozark hellbender to stochastic events is considered to be low based on the loss of the Spring River population and the reduced health of the remaining 3 populations. Loss of the Spring River population also has reduced the Ozark hellbender's ability to withstand catastrophic events (redundancy) and to adapt to novel changes in environmental conditions (representation). Both measures have been further reduced due the poor health of the remaining 3 remaining populations. Because there are genetic differences among the existing populations, however, the Ozark hellbender may have some capacity to adapt to future changes in environmental conditions.

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CHAPTER 1. INTRODUCTION

The Ozark hellbender (*Cryptobranchus alleganiensis bishopi*) is a large aquatic salamander inhabiting cool, fast-flowing streams and rivers in the Ozark Highlands of southern Missouri and northern Arkansas. The species historically occurred in portions of the White, Spring, Eleven Point, and Current rivers and some of their tributaries (Bryant Creek, the North Fork White River, and Jacks Fork River). Until the early 1970s, Ozark hellbenders were captured in large numbers where they were known to occur. However, by the late 1990s, population throughout the range had declined by around 70% and no populations appeared to be stable (Wheeler et al. 2003).

As a result of the drastic population declines, the U.S. Fish and Wildlife Service (Service) listed the Ozark hellbender in October 2011 as endangered under the Endangered Species Act of 1973, as amended (Act)(USFWS 2011a). Since the listing, there have been several developments that provide a better understanding of the species'[1] status and potential factors contributing to declines, including completion of multiple scientific studies, updated population estimates, and successful head-starting of young and captive breeding of adults.

In order to utilize the new information for recovery planning and for other purposes, we have developed a Biological Report for the Ozark hellbender. In this report we 1) summarize the Ozark hellbender's biology and life history to provide an understanding of the ecological requirements of the species, 2) describe the species' current status, 3) summarize past and current threats thought to affect the Ozark hellbender's status, and 4) and assess the Ozark hellbender's current viability using the conservation biology principles of resiliency, representation, and redundancy (Shaffer and Stein 2000).

This report also informs a draft recovery plan for the Ozark hellbender (USFWS 2020b), which presents the criteria, actions, and estimated time and cost for recovery of the species, and a draft recovery implementation strategy (USFWS 2020a), which provides an expanded narrative for recovery activities and an implementation schedule. This Biological Report and the Recovery Implementation Strategy (when finalized) will be updated as necessary and will be available at https://ecos.fws.gov.

This Biological Report incorporates the best available scientific information, including published literature, unpublished reports, and input by species experts and others involved in Ozark hellbender conservation.

[1] Though the Ozark hellbender is a subspecies, in this report we use the term "species" when referring to it.

CHAPTER 2. SPECIES DESCRIPTION, TAXONOMY, DISTRIBUTION, AND ECOLOGY

Species Description

The Ozark hellbender is a large, strictly aquatic salamander endemic to streams of the Ozark Plateau in southern Missouri and northern Arkansas. Individuals have a large, keeled tail; small eyes; and a dorso-ventrally flattened body that enables movements in the fast-flowing streams they inhabit (Nickerson and Mays 1973a)(Fig. 2-1). Numerous fleshy folds along the sides of the body provide surface area for respiration, and adults may attain lengths of 11 to 22 inches (in)(29 to 57 centimeters)(cm)(Dundee and Dundee 1965, Johnson 2000). Hellbenders are long-lived and capable of living 25 to 30 years in the wild (Peterson et al. 1983). Females reportedly reach sexual maturity in 6 to 8 years (Nickerson and Mays 1973a; Peterson et al. 1983; Taber et al. 1975) and males in approximately 5 years (Taber et al. 1975).

The Ozark hellbender is distinguishable from the eastern hellbender (*Cryptobranchus alleganiensis alleganiensis*) by its smaller body size, dorsal blotches, increased skin mottling, heavily pigmented lower lip, smooth surfaced lateral line system, and reduced spiracular openings (openings where water is expelled out of the body)(Grobman 1943, Dundee 1971, Peterson et al. 1983, LaClaire 1993). Despite these distinguishing characteristics, the two subspecies are not easily or readily distinguishable absent the presence of both subspecies or when encountered outside of their subspecies' range.

Figure 2-1. An adult Ozark hellbender from the Current River. Photo credit: Jeffrey Briggler, Missouri Department of Conservation.

Taxonomy

The Ozark hellbender was originally described as *Cryptobranchus bishopi* by Grobman (1943) from a specimen collected from the Current River in Carter County, Missouri. Based on the slight morphological and ecological variation within the genus *Cryptobranchus*, Dundee and Dundee (1965) determined subspecies status for Ozark and eastern hellbenders as within the hellbender, *C. alleganiensis* complex *sensu lato* (which means, ''in the broad sense'' and is used when two subspecies are derived from a single species within a broader context). Some phenotypic and genetic differences between Ozark and eastern hellbenders exist (Grobman 1943, Dundee and Dundee 1965, Dundee 1971, Merkle et al. 1977, Shaffer and Breden 1989). However, recent studies indicate that populations of both subspecies comprise at least 8 distinct units and the two currently recognized subspecies may be paraphyletic (i.e., they include some, but not all of the descendants of the most recent common ancestor)(Sabatino and Routman 2009, Crowhurst et al. 2011, Tonione et al. 2011).

Within the Ozark hellbender subspecies (as it is currently recognized), a minimum of 3 genetic lineages have been identified: 1) North Fork White River/Bryant Creek, 2) Spring River, and 3) Eleven Point River/Current River (Sabatino and Routman 2009, Crowhurst et al. 2011, Tonione et al. 2011). Ozark hellbender populations in the Eleven Point and Current rivers cluster together genetically (Sabatino and Routman 2009, Crowhurst et al. 2011, Tonione et al. 2011). However, populations in these 2 rivers exhibit substantial genetic differentiation and are geographically isolated from each other, thus potentially constituting 2 separate genetic lineages (Crowhurst et al. 2011). In addition, results of Hime et al. (2017) indicate that the Ozark hellbender should be elevated to full species status. However, no proposed changes have been submitted for publication, and the Service will continue to use the nomenclature C. a. bishopi for the Ozark hellbender, which is the taxonomy currently recognized by the Committee on Standard English and Scientific Names (Crother et al. 2017).

Historical Range and Distribution

The Ozark hellbender is endemic to the White River drainage in southern Missouri and northern Arkansas (Johnson 2000), historically occurring in portions of the White, Spring, Black, Eleven Point, and Current rivers and some of their tributaries (Bryant Creek, the North Fork White River, and Jacks Fork River)(Fig. 2-2).

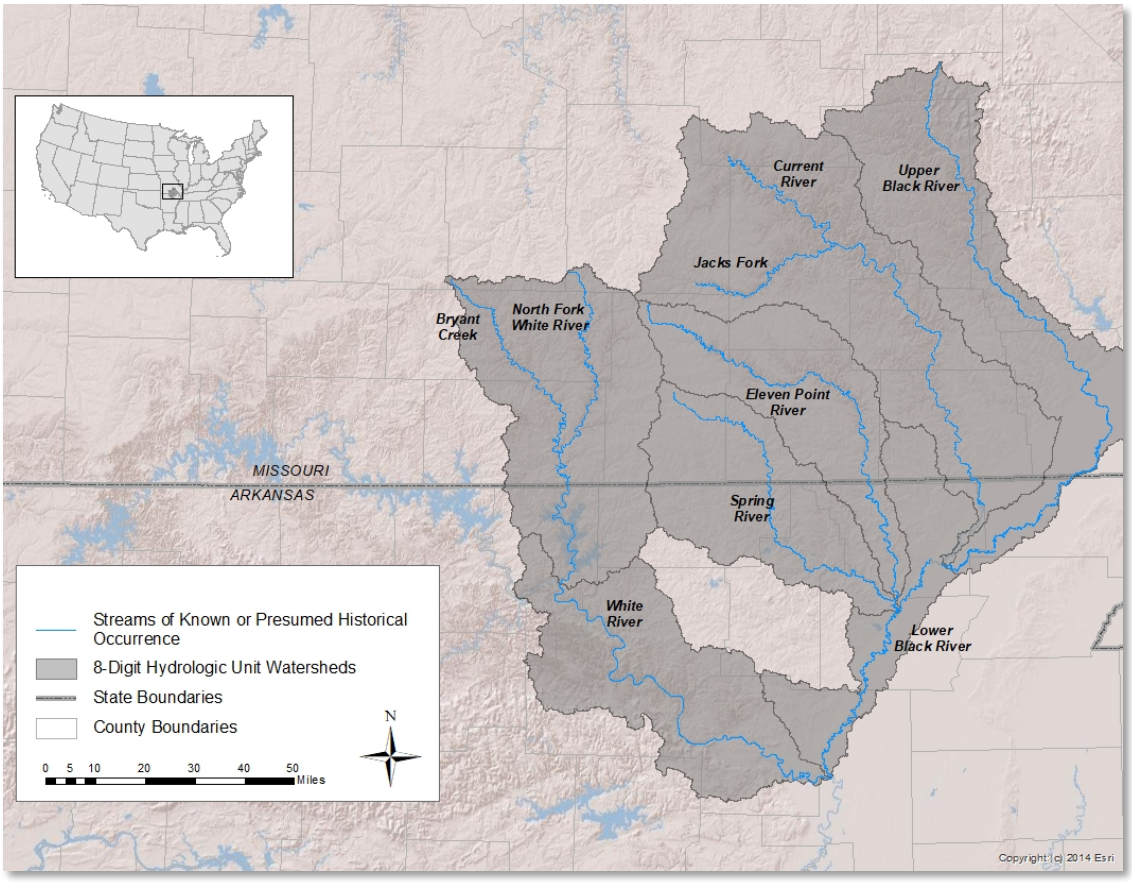

Figure 2-2. Rivers in which the Ozark hellbender presumably occurred. Because only one Ozark hellbender record exists from the Black River in Arkansas, it is unclear if the river was historically part of the species' range.

Life History

Below is a summary of the Ozark hellbender's life history. We do not provide a comprehensive review of available information, but rather information relevant to understanding the Ozark hellbender's status and how threats may be acting upon the species.

Adult and Juvenile Habitat

Adult Ozark hellbenders are frequently found beneath large rocks, typically limestone or dolomite, and in moderate to deep (less than 3 feet (ft)(1 meter (m) to 9.8 ft)(3 m) rocky, fast-flowing streams in the Ozark Plateau (Fobes and Wilkinson 1995, Johnson 2000). In spring-fed streams, Ozark hellbenders will often concentrate downstream of the spring where there is little water temperature fluctuation throughout the year (Dundee and Dundee 1965). Juvenile Ozark hellbenders, defined as sexually immature individuals that have undergone metamorphosis, appear to occupy similar habitat as adults, but can also occupy rocks smaller than those typically used by adults due to their smaller size.

Larval Habitat

Larval hellbenders are defined as individuals that have not undergone metamorphosis and still have their gills. Information on larval habitat is limited because larvae are difficult to detect and thus, constitute a small portion of hellbenders captured. Larvae appear to use the same habitat patches as adult hellbenders, but often use different microhabitat than the adults. For example, Nickerson and Mays (1973a) found larval hellbenders hiding beneath small stones in gravel beds or under large rocks similar to those occupied by adults. In another study, however, Nickerson and Krysko (2003) found eastern hellbender larvae in interstitial spaces in gravel beds. Other eastern hellbender studies indicate larval-sized hellbenders primarily utilize cobble and boulders for shelter (Nickerson et al. 2003; Freake and Hecht unpublished data, as cited in Hecht-Kardasz et al. 2012). The diet of larval hellbenders, consisting primarily of aquatic invertebrates (Pitt and Nickerson 2006) also implies their use of interstitial spaces as habitat.

Breeding and Nesting Habitat

Though observations of Ozark hellbenders breeding (e.g., several animals under one rock or in bedrock crevices) are scarce, eggs have been found more frequently in recent years based on a better understanding of nesting habitat and how to find the eggs (Briggler 2019a, pers. comm.). Based on these observations, breeding and nesting habitat appears to be similar to habitat used by adults outside of the breeding season. The main difference appears to be that nesting rocks are typically larger than other rocks used for refugia (Briggler 2019a, pers. comm.). Nesting rocks and bedrock crevices also need to be proximate to larval habitat, or movement corridors consisting of a series of rocks needs to be present so that larvae can transition to larval habitat with minimal exposure to predators.

Reproduction

Ozark hellbender individuals are thought to mature sexually at 5 to 8 years of age (Bishop 1941, Dundee and Dundee 1965), although the age of maturity could be greater with some individuals (Briggler 2014, pers. comm.). Males typically mature at a smaller size and younger age than females, and some sites are heavily male- or female-biased (Briggler 2015, pers. comm.). Female hellbenders are reported to sexually mature at a total length of 14.6 to 15.4 in (37 to 39 cm), or at an age of approximately 6 to 8 years (Nickerson and Mays 1973a, Taber et al. 1975, Peterson et al. 1983). Male hellbenders have been reported to reach sexual maturity at a total length of 11.8 in (30 cm), or at an age of approximately 5 years (Taber et al. 1975).

Breeding generally occurs between late September and late October (Johnson 2000, Briggler 2014, pers. comm.), although individuals in the Spring River were known to breed primarily in January (Peterson et al. 1989). Males typically prepare nests beneath large flat rocks or within bedrock crevices; however, egg clutches also have been found under submerged logs (Nickerson and Mays 1973a) and in mud banks (Peterson 1988). Ozark hellbenders mate via external fertilization, and instances of multiple paternity (fertilization of an egg clutch by multiple males) and maternity (ovipositing, or laying of eggs, by multiple females within one nest cavity) have been documented (Smith 1907, Ettling et al. 2013, Briggler 2019a, pers. comm). Clutch sizes vary from 150 to 350 eggs per female (Briggler 2014, pers. comm.), and eggs hatch after approximately 6 weeks (Smith 1907). It has been speculated that females may breed every 3 years on average (Briggler et al. 2007), but it may be more depending on resource availability (Briggler 2019a, pers. comm.). Not all eggs may be deposited during breeding, with some retained and later resorbed (Topping and Ingersol 1981).

Males provide parental care by rocking their body to increase oxygen and movement among eggs (Smith 1907, Settle et al. 2018) and by guarding the fertilized eggs from predation by fish, crayfish, and other hellbenders (Nickerson and Mays 1973a). Most hellbenders examined during the breeding season contained between 15 and 25 eggs in their stomachs (Smith 1907). Males frequently regurgitate eggs (King 1939, Pfingsten 1990), and females sometimes eat their own eggs while ovipositing them (Nickerson and Mays 1973a). It may be that hellbenders are more apt to consume eggs when other food resources are scarce, or perhaps males consume eggs containing fungus to keep fungus from spreading to other eggs, as behavior exhibited by giant salamanders (Okada et al. 2015).

Successful hatching of eggs and survivorship of larvae while in the nest may depend on the fitness of males as healthy males are better able to protect their nests from predators. Healthy males also have less incentive to consume their eggs for nutrition.

Figure 2-3. Ozark hellbender eggs protruding out of the entrance to a nest cavity. Photo credit: Jeffrey Briggler, Missouri Department of Conservation.

Feeding Habits

Ozark hellbender adults and subadults forage primarily on crayfish with small fish, aquatic insects, worms, snails, and other miscellaneous prey accounting for secondary items (Smith 1907, Nickerson and Mays 1973a, Petranka 1998). As noted under ***Reproduction***, hellbenders are also widely known to consume hellbender eggs (Smith 1907, Bishop 1941, Humphries et al. 2005) and occasionally other hellbenders (Groves and Williams 2014). Although there is little information on the diet of larval hellbenders, it is generally believed that aquatic insects comprise their primary food source. In one of the few studies on larval diet, Pitt and Nickerson (2006) found that the stomach of a larval eastern hellbender from the Little River in Tennessee exclusively contained aquatic insects. In Ozark hellbender streams, prey abundance is high and does not appear to be limiting populations (Briggler 2014, pers. comm.).

Water Conditions

Hellbenders are habitat specialists that depend on consistent levels of dissolved oxygen, temperature, and flow (Williams et al. 1981). The lower dissolved-oxygen levels found in warm or standing water do not provide for the hellbender's respiratory needs. In fact, hellbenders have been observed rocking or swaying in still, warm water (Williams et al. 1981) to increase their exposure to oxygen. Hutchison and Hill (1976) found that hellbenders exhibits a preferred mean water temperature of 52.9 °F (11.6 °C), 63.9 °F (17.7 °C), and 71.1 °F (21.7 °C) for individuals acclimatized to temperatures of 41 °F (5 °C), 59 °F (15 °C), and 77 °F (25 °C), respectively. Hutchison et al. (1973) found that the mean critical thermal maxima (the temperature at which animals lose their organized locomotory ability and are unable to escape from conditions that would promptly lead to their death) of Ozark hellbenders was 90.9 °F (32.7 °C) at 41 °F (5 °C) acclimation, 91.2 °F (32.9 °C) at 59 °F (15 °C), and 97.7 °F (36.5 °C) at 77 °F (25 °C).

Home Range and Movements

Adults are typically nocturnal, remaining beneath cover during the day and either actively foraging at night or opportunistically preying on crayfish and other items entering rock cavities. Long-term mark-recapture and monitoring studies conducted since 2001 indicate that there is little movement among sites (Briggler 2014, pers. comm; Irwin 2014, pers. comm.), consistent with Nickerson and May's (1973a) findings. Nickerson and Mays (1973a) also found limited movement within sites with 70% of recaptured individuals moving less than 100 ft (30 m) from their original point of capture (Nickerson and Mays 1973a). Home ranges for Ozark hellbenders tend to be small and average between 91.9 square feet (sq ft)(28 square meters)(sq m) and 265.7 sq ft (81 sq m)(Peterson and Wilkinson 1996, Bodinof et al. 2012a). Generally, males of both hellbender subspecies tend to have larger home ranges than females (Peterson and Wilkinson 1996, Burgmeier et al. 2011). Ozark hellbenders are territorial and are known to defend occupied cover rocks from other hellbenders (Nickerson and Mays 1973a).

During the breeding season, hellbenders may be active during the day (Nickerson and Mays 1973a, Noeske and Nickerson 1979, Briggler 2019a, pers. comm.) and may move more than during the non-breeding season (Blais 1996, Burgmeier et al. 2011). This increased movement and diurnal activity may increase exposure to predation and collection. Eastern hellbenders have also been reported to move many miles to reach breeding grounds in the fall (Alexander 1927), although the extent to which Ozark hellbenders may exhibit this behavior remains unclear. The increased movement among sites during the breeding season underscores the importance of maintaining connectivity among habitat patches to maintain gene flow and thus, genetic diversity.

Very little is known about larval hellbender movement. However, observations of larvae under nest rocks indicate that larvae leave the nest primary in late winter through early April when many predators are less active and that larvae appear to orient and move upstream (Briggler 2019a, pers. comm.). The timing of

when larvae leave the nest may depend on the availability of food resources in the nest, which in turn may be influenced by the size of the nest rock or bedrock cavity[1] (Briggler 2019b, pers. comm.). Larvae also tend to bury into gravel, both under nest rocks in the wild (Briggler 2015, pers. comm.) and in captivity (Wanner 2015, pers. comm.). Staff at the Saint Louis Zoo also have observed captive Ozark hellbender larvae swimming in the water column at night and under low light conditions (Wanner 2015, pers. comm.). Swimming in the water column could facilitate dispersal downstream if the larvae are carried downstream in the current.

Longevity and Survivorship

Hellbenders are long-lived, capable at least 29 years in captivity (Nigrelli 1954). In the wild, they are estimated to live 25-30 years (Peterson et al. 1983), with one individual in Missouri estimated to be at least 36 years old based on the number of years between captures on its size when first captured (Briggler 2019b, pers. comm.). Survivorship likely varies by life stage and may also vary between the sexes (Taber et al. 1975, Briggler et al. 2007). Appendix I contains survivorship estimates from various studies and for different life stages. Based on the studies identified in Appendix I, survivorship (for stable populations) may be estimated as: 10% for eggs to year 1, 10-40% from year 1 to 2, 50-75% from year 2 to 3, 50-75% annually from year 3 to 6, and 80-88% annually for hellbenders 6 years and older[2]. It should be noted that longevity and survivorship of Ozark hellbenders may be greater than those of eastern hellbenders because Ozark hellbenders have slower growth rates and prey abundance appears to be greater in streams occupied by Ozark hellbenders[3] (Briggler 2014, pers. comm.). Greater availability of prey would reduce the extent of foraging necessary, thus decreasing vulnerability of hellbenders to predation.

Known predators of hellbenders include large species of predaceous fish, turtles, and watersnakes (Nickerson and Mays 1973a). Other predators include mink, river otters, and raccoons (Briggler et al. 2007, Hecht et al. 2014, Briggler 2019a, pers. comm., Lipps 2019, pers. comm.).

[1] This speculation is based on observations while checking nest boxes of larvae nipping each other when resources are not available (Briggler 2019b, pers. comm.).

[2] Estimated survivorship rates from Peterson et al. (1983, 1988) are not included as these rates are likely substantially lower than actual survivorship rates. Peterson (1987) noted that in these studies, there was a significant difference in catchability of the sexes and age classes in one population for the following reasons: 1) hellbender detectability varied based on the habitat individuals occupied (e.g., turnable rocks vs. holes in bedrock or immovable boulders), 2) emigration of some individuals was not permanent, and 3) some rocks within the study area may not have been flipped. Therefore, there was likely a violation of the equal catchability assumption, which is an important assumption of the model used to generate survivorship estimates.

[3] While prey availability may be greater in Ozark hellbender streams, colder water temperatures likely reduce growth rates due to lower metabolic rates.

CHAPTER 3. CURRENT STATUS

Current Distribution

The Ozark hellbender historically occurred in portions of the White, Spring, Eleven Point, and Current rivers and some of their tributaries (Bryant Creek, the North Fork White River, and Jacks Fork River). In addition, there is a confirmed record of an Ozark hellbender from the Black River in Arkansas near the Independence-Jackson County line (LaClaire 1993).

Currently, populations of Ozark hellbenders are known to occur in Bryant Creek, the North Fork White River, the Eleven Point River, and the Current River. Some individuals may also still be present in the mainstem of the White River, Spring River, and Jacks Fork River (Briggler 2013, pers. comm.; Irwin 2013, pers. comm.). There may also be some movement into tributaries near the confluence of occupied streams. Due to the difficulty in detecting hellbenders in some habitats (areas with large boulders or with bedrock crevices), we consider the current range to consist of streams in which any hellbenders have been captured within 30 years, Thus, we consider the Ozark hellbender's current range to include Bryant Creek, the North Fork White River, the lower portion of the White River mainstem, the Spring River, the Eleven Point River, Jacks Fork River, and the Current River (Fig. 3-1). Though the Black River is presumed to be part of the Ozark hellbender's historical range, no additional hellbenders have been captured during surveys (Wheeler et al. 1999, Briggler 2008a, pers. comm.) and habitat no longer appears suitable (Briggler 2008a, pers. comm.; Irwin 2008a, pers. comm.).

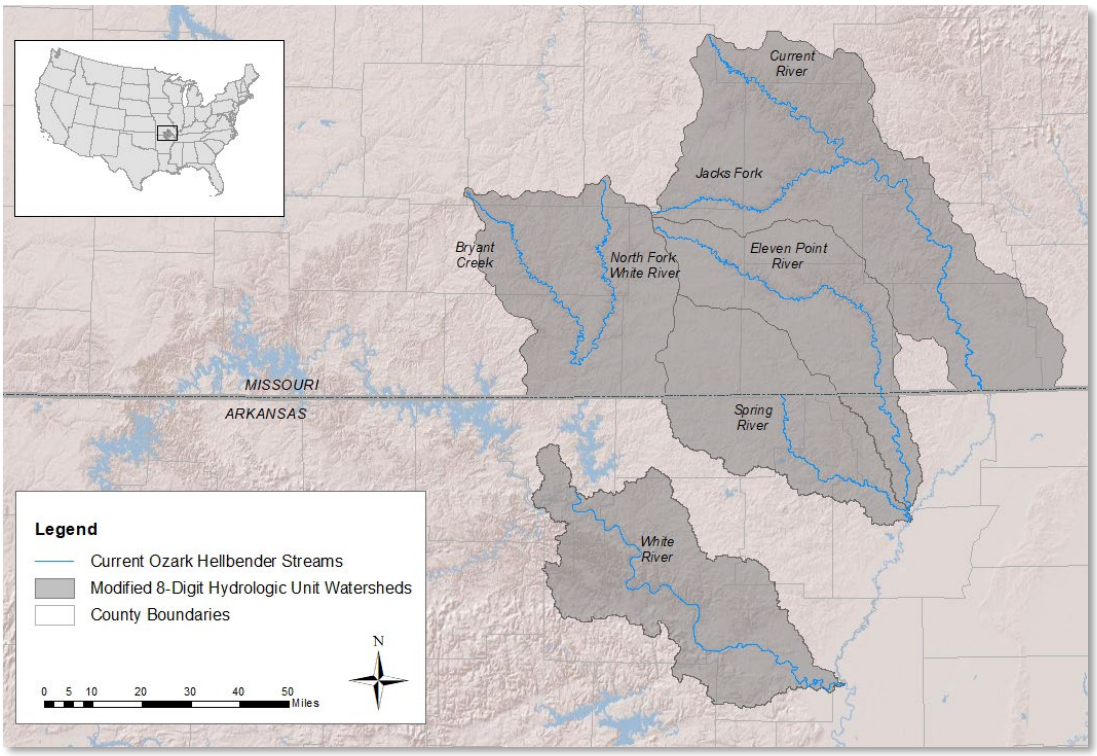

Figure 3-1. Streams in which the Ozark hellbender likely or possibly still occurs. Individuals occur in discrete habitat patches, rather than throughout the entirety of streams.

Population Abundance and Trends

A description of what is currently known about each Ozark hellbender population is provided below and summarized in Table 3-1. Though we do not consider the Black River to be part of the Ozark hellbender's current range, we provide a description of documented records, surveys conducted, and the availability of suitable habitat. Because it remains unclear how augmentation from captive breeding and head-starting is influencing population status, augmentation efforts are described separately in Chapter 5.

White River

There are only 2 Ozark hellbender records from the mainstem of the White River. In 1997, an Ozark hellbender was recorded in Baxter County, Arkansas (Irwin 2008a, pers. comm.). No hellbenders were found during a 2001 survey of the lower portion of the White River, but in 2003, an angler purportedly caught a specimen in Independence County, Arkansas (Wheeler 2007; Irwin 2008a, pers. comm.). There are also tentative detections of environmental DNA (eDNA) from the White River (Irwin 2019 pers. comm.). However, we do not know whether a viable population exists (or whether hellbenders are able to exist) in the mainstem of the White River, or if the individuals captured are members of a relic population that was separated from the North Fork White River population by Norfork Reservoir. Much of the potentially occupied hellbender habitat was destroyed by the series of dams constructed in the 1940s and 1950s on the upper White River, including Beaver, Table Rock, Bull Shoals, and Norfork Reservoirs. Additional eDNA testing is scheduled for 2020 (Irwin 2019, pers. comm.) and will provide a better understanding if individuals are still present in the White River.

North Fork White River

The North Fork White River historically contained a considerable Ozark hellbender population. Results of a mark-recapture study in 1973 indicated that there were approximately 1,150 hellbenders within a 1.7-mile (mi)(2.7-kilometer)(km) reach of the North Fork in Ozark County, Missouri, with an estimated density of one individual per 26.2 to 32.8 sq ft (8 to 10 sq m)(Nickerson and Mays 1973b). Ten years later, hellbender density in a 2.9-mi (4.6-km) section of the North Fork in the same county remained high, with estimated densities between one per 19.7 sq ft (6 sq m) and one per 52.5 sq ft (16 sq m)(Peterson et al. 1983). Though most captured individuals measured between 9.8 and 17.7 in (250 and 449 millimeters)(mm), some individuals represented a range of lengths from 6.8 to 21.7 in (172 to 551 mm), indicating that reproduction was occurring in this population. In a subsequent 1992 qualitative study in Ozark County, Missouri, 122 hellbenders were caught during 49 person-hours of searching the North Fork (Ziehmer and Johnson 1992). Those individuals ranged in length from 10 to 18 in (254 to 457 mm); no average length was included in the publication.

Until the 1992 study, the North Fork White River population appeared to be relatively healthy. However, in a 1998 study of the same reach of river that was censused in 1983 (Peterson et al. 1983) and that used the same collection methods, only 50 hellbenders were captured (Wheeler et al. 2003). These individuals ranged in length from 7.9 to 20.0 in (200 to 507 mm), with most measuring between 15.7 and 19.7 in (400 and 500 mm), and the average length was significantly greater than the average length of those collected 20 years earlier (Wheeler et al. 2003). This shift in length distribution was not a result of an increase in maximum length of individuals. Instead, there were fewer individuals collected in the smaller size classes, indicating lack of recruitment.

As a way to compare relative abundance of hellbenders in the late 1990s to historical numbers, Wheeler et al. (2003) obtained raw data used in the Peterson et al. (1983) study to calculate numbers of individuals caught per day. Other Ozark hellbender population studies not included in that conversion are converted here for further comparison of relative abundance between historical and more recent studies

(Ziehmer and Johnson 1992). For comparison purposes, one search day is defined as 8 hours of searching by 3 people (or 24 person-hours). However, converting person-hours to a search day metric may underestimate actual search effort and overestimate relative hellbender abundance since person-hours usually only include time spent in the water searching (as opposed to total number of hours spent on the river). It should also be noted that because search effort was not standardized among all studies, comparison of hellbender captures per search day is a general, rather than a quantitative, comparison. Using this metric for the North Fork White River population, approximately 55 hellbenders were caught per search day in 1983 (Peterson et al. 1983). In 1992, 60 hellbenders per search day were caught (Ziehmer and Johnson 1992), and in 1998, 17 hellbenders per search day were caught (Wheeler 2003).

Another comparison of Ozark hellbender captures between historical and recent years provides further evidence of a decline. A 16.2-mi (25-km) section of stream in the North Fork (overlapping with some sites sampled in the previous studies) was surveyed during 1969-1979 and again during 2005-2006 (Nickerson and Briggler 2007). Between 1969 and 1979, researchers caught 8 to 12 hellbenders per hour (64 to 96 hellbenders per search day); whereas in 2005 and 2006 researchers averaged 0.5 hellbenders per hour (4 hellbenders per search day)(Nickerson and Briggler 2007).

In 2009 a long-term monitoring protocol for Ozark hellbenders was implemented in Missouri by the Missouri Department of Conservation to identify changes in hellbender populations and inform management decisions. The goals of the monitoring were to 1) evaluate changes over time in the estimated percentage of habitat patches in each river occupied by Ozark hellbenders, 2) estimate abundance at a subset of sites (referred to as abundance sites), and 2) compare the size class distribution and body condition of captured hellbenders to those from the same river from the 1970s and 1980s (Bodinof et al. 2012c). The occupancy portion of the monitoring consists of presence/absence surveys in which randomly-selected sites are monitored to estimate the percentage of suitable habitat that is occupied. Surveying at each habitat is only conducted until a hellbender is observed; therefore, the number of animals captured does not represent the number of animals present. To assess body condition, a body index score was calculated based on the actual body mass of the individual captured compared to the predicted body mass (using historical body condition of Ozark hellbenders). During the 2009 surveys 64 Ozark hellbenders were encountered and captured 2009 surveys[1], and results from occupancy modeling indicated that an estimated 57-85% of the suitable hellbender habitat in the North Fork White River was occupied in 2009 (Bodinof et al. 2012c). Though standard errors for the occupancy estimates were large[2], the authors concluded that at least 30% of the suitable habitat patches in the North Fork White River was occupied in 2009 because hellbenders were captured at those sites (Bodinof et al. 2012c). In the 3 sites selected for abundance surveys (sites that are considered to harbor the majority of hellbenders in the population), the mean catch per unit effort was 0.63 hellbenders per person-hour (5 hellbenders per search day), with one site having a median[3] catch per person-hour of 1.3 hellbenders (10 hellbender per search day)(Bodinof et al. 2012c). The total length of captured individuals measured was 11.8 to 19.7 in (300-500 mm), and body condition was similar to that observed historically (Bodinof et al. 2012c). There was no evidence of recent recruitment and the number of hellbenders that had been previously captured and marked was relatively low (40%)(Bodinof et al. 2012c).

The Missouri Department of Conservation monitoring protocols were revised in 2012, and abundance monitoring was removed as one of the primary objectives (Bodinof Jachowski et al. 2012). In addition, the

[1] Because not all sites were surveyed and because surveying at occupancy sites only occurs until 1 hellbender is observed, these numbers do not represent the number of animals present in the population.

[2] The standard errors are not included in this report because there was a standard error estimate for each of the 3 occupancy estimates.

[3] Two separate crews surveyed each habitat patch used for abundance monitoring.

frequency of surveys on each river was increased to every 5 years to minimize disturbance to habitat from conducting surveys (Bodinof Jachowski et al. 2012). During the 2012 surveys, 20 Ozark hellbenders were encountered in the North Fork White River with 15 captured[1] (the other 5 individuals were observed with dive lights)(Bodinof Jachowski et al. 2012). Results from the occupancy modeling indicated that an estimated 64% (± 11%) of the suitable habitat in the North Fork White River was occupied by Ozark hellbenders in 2012 (Bodinof Jachowski et al. 2012). All of the hellbenders captured during the 2012 surveys were post-metamorphic individuals with most being mature adults (Bodinof Jachowski et al. 2012). However, one-third of the hellbenders captured were less than 11.8 in (300 mm) in total-length (Bodinof Jachowski et al. 2012), indicating successful recruitment has occurred within the past 4 to 7 years (Peterson et al. 1983). Catch per unit effort and the percentage of animals recaptured were not reported.

Standardized surveys have not been conducted since the 2012 sampling by the Missouri Department of Conservation. However, non-standardized sampling has been conducted to capture individuals for other studies. With the individuals captured, there has not been a noticeable change in their health in terms of amphibian chytrid fungus, abnormalities, or the size of individuals captured (Briggler 2019c, pers. comm.). Fertilized egg clutches are also typically found every year at multiple locations in artificial nest boxes and natural nests (see Chapter 5 for more information about nest boxes)(Briggler 2019c, pers. comm.). However, extreme flooding occurred the spring of 2017, resulting in record flooding (over a 500-year flood)(Heimann et al. 2018) that significantly impacted Ozark hellbender habitat (Briggler 2018). According to Briggler (2018), both the substrate and riparian zone of the North Fork White River was heavily damaged from the flooding. In some locations, massive movement of rocks occurred on the river bottom, resulting in deposition of piles of rocks at the downstream end of each site (Briggler 2018). Following the flood there has been a substantial reduction in the number of egg nests located, and all of the nest boxes were lost (Briggler 2019b, pers. comm.). Due to the severe impacts from the flooding, the population of Ozark hellbenders in the North Fork White River may have been reduced by over 50% (Briggler 2018).

Summary of the North Fork White River Population Status - The North Fork White River has been considered the stronghold of the species in Missouri, and the population inhabiting this river was considered stable by Ziehmer and Johnson (1992) and LaClaire (1993). Although fertilized egg clutches are typically found every year in nest boxes and natural nests, the collection of young individuals has become rare, indicating that there is little recruitment. Until the 2017 flood, however, there had been an increase in the number of young found at some sites, as well as an increase in the number of fertilized nests found, indicating that the population may be slightly recovering (Briggler 2019c). But the extreme flooding in 2017 significantly impacted Ozark hellbenders and their habitat, potentially reducing the population size by 50% (Briggler 2018).

Bryant Creek

Bryant Creek is a tributary of the North Fork in Ozark County, Missouri, which flows into Norfork Reservoir. Ziehmer and Johnson (1992) expected to find Ozark hellbenders in this stream during an initial survey, but none were captured or observed after 22 person-hours (0.9 search days). This apparent absence of the species conflicted with previous reports from Missouri Department of Conservation personnel and an angler who reported observations of relatively high numbers of hellbenders in Bryant Creek during the winter months (Ziehmer and Johnson 1992). A subsequent survey of the creek resulted in the capture of 6 hellbenders (Wheeler et al. 1999).

[1] Because not all sites were surveyed and because surveying at occupancy sites only occurs until 1 hellbender is observed, these numbers do not represent the number of animals present in the population.

As part of the long-term monitoring implemented in Missouri in 2009 by the Missouri Department of Conservation, occupancy surveys were conducted in Bryant Creek in 2009 (see North Fork White River for additional information on monitoring protocols). Three Ozark hellbenders were encountered[1], and results from occupancy monitoring indicated that an estimated 17-41% of the suitable hellbender habitat was occupied in 2009 (Bodinof et al. 2012c). Though standard errors for the estimates were large[2], the authors concluded that at least 6% of the suitable habitat patches in Bryant Creek was occupied in 2009 because hellbenders were captured at those sites (Bodinof et al. 2012c). There were no sites selected for abundance monitoring given the low number of individuals observed; thus, catch per unit effort was not calculated (Bodinof et al. 2012c). The total length of the 3 individuals captured ranged from 11.7 to 15.9 in (298 - 404 mm) Bodinof et al. 2012c). The mean body condition was similar to that observed historically, although the condition varied substantially among the 3 individuals (Bodinof et al. 2012c).

In 2012 the Missouri Department of Conservation long-term monitoring resulted in observations of 7 Ozark hellbenders with 6 of the individuals captured[3] (the other individual was observed with a dive light)(Bodinof Jachowski et al. 2012). All of the hellbenders captured during the 2012 surveys were post-metamorphic individuals with most being mature adults (Bodinof Jachowski et al. 2012). However, one individual captured was 13.1 in (332 mm) in total-length (Bodinof Jachowski et al. 2012), indicating successful recruitment had occurred within the past 5 to 7 years (Peterson et al. 1983). Of the habitat patches identified from Bryant Creek, 29% (± 32%) was estimated to be occupied in 2012 (Bodinof Jachowski et al. 2012). None of the 6 Ozark hellbenders captured has been previously captured and marked (Bodinof Jackowski et al. 2012). Catch per unit effort and the percentage of animals recaptured were not reported.

Standardized surveys have not been conducted since the 2012 sampling by the Missouri Department of Conservation. However, habitat was assessed following the historic flood in 2017 and there were no substantial changes to the substrate or riparian corridor (Briggler 2019c, pers. comm.).

Summary of the Bryant Creek Population Status - The Bryant Creek population is somewhat isolated from the North Fork White River population by the Norfork Reservoir, which could contribute to this population's apparent small size due to habitat fragmentation. Bryant Creek also has warmer temperatures and greater extremes in temperature than the North Fork White River due to less spring influence (Bodinof Jachowski et al. 2012). However a small number of animals do exist throughout Bryant Creek, and genetic analyses indicate that there is some movement of hellbenders between the Bryant Creek and the North Fork White River populations (Crowhurst et al. 2011). The reason for low abundance in Bryant Creek remains unclear, however, and it is unclear if the river ever contained a large population. The population is currently not considered to be viable on its own (Briggler 2008b, pers. comm.).

Black River

The Black River is presumed to be part of the historical range of the subspecies because Ozark hellbenders have been documented in several of its tributaries, including the Spring, Eleven Point, and Current rivers (Firschein 1951, Trauth et al. 1992). In addition, there is one documented record of an

[1] Because not all sites were surveyed and because surveying at occupancy sites only occurs until 1 hellbender is observed, these numbers do not represent the number of animals present in the population.

[2] The standard errors are not included in this report because there was a standard error estimate for each of the 3 occupancy estimates.

[3] Because not all sites were surveyed and because surveying at occupancy sites only occurs until 1 hellbender is observed, these numbers do not represent the number of animals present in the population.

Ozark hellbender in the Black River above its confluence with the Strawberry River on the Independence-Jackson County line (Arkansas) in 1978 (Irwin 2008a, pers. comm.). Because of the 1978 record, portions of the Black River in Missouri were surveyed in 1999 by researchers at Arkansas State University, but no hellbenders were observed (Wheeler et al. 1999). In 2004, Missouri Department of Conservation surveyed areas in Missouri that had been searched in 1999 by Wheeler et al. (1999), as well as areas not searched in 1999 that had anecdotal reports of hellbenders. No hellbenders were found during this 2-day survey and the habitat was considered less than ideal because it was predominantly composed of igneous rocks, which lack the cracks and crevices necessary for hellbender inhabitance.

Parts of the Black River, with suitable dolomite rock, might have contained a small population of Ozark hellbenders at one time before intensive agriculture was initiated in the area, resulting in sedimentation over suitable habitat (Briggler 2008a, pers. comm.; Irwin 2008b, pers. comm.). However, it does not appear to currently have conditions suitable for Ozark hellbenders due to the habitat changes. No population appears to currently be present in the Black River, but eDNA sampling has been conducted and results are forthcoming (Crabill 2019b, pers. comm.).

Spring River

The Spring River, a tributary of the Black River, flows from Oregon County, Missouri, south into Arkansas. Ozark hellbender populations have been found in the Spring River near Mammoth Spring in Fulton County, Arkansas (LaClaire 1993). In the early 1980s, 370 individuals were captured during a mark-recapture study along 4.4-mi (7-km) of stream south of Mammoth Spring (Peterson et al. 1988). Hellbender density at each of the 2 surveyed sites was fairly high (approximately one hellbender per 75.5 sq ft (23 sq m) and one per 364 sq ft (111 sq m), respectively). These individuals were considerably larger than hellbenders captured from other streams during the same time period, with 74% of Spring River hellbenders having a total length of more than 17.7 in (450 mm), with a maximum length of 23.6 in (600 mm)(Peterson et al. 1988). Although other factors may be involved in the observed length differences, it has been hypothesized that Spring River populations are genetically distinct from other hellbender populations. This speculation was upheld by the conclusions of a genetic study of the populations in the Spring, Eleven Point, and Current rivers (Kucuktas et al. 2001).

In 1991, surveyors searched 10 sites for hellbenders along a 16.2-mi (26-km) stream reach and observed 20 individuals during 41 person-hours (11.7 hellbenders per search day) over a 6-month period (Trauth et al. 1992). This 6-month survey included the 2 sites surveyed in the early to mid-1980s in which surveyors captured 370 hellbenders, along with 8 additional sites upstream and downstream (Peterson et al. 1988, Trauth et al. 1992). No size class information is available, although the large sizes of captures reported in Peterson et al. (1988) may be indicative of a population experiencing little recruitment.

Researchers with Arkansas State University surveyed the Spring River from autumn 2003 through winter 2004, performing 74 hours of search effort and found 14 Ozark hellbenders (4.5 hellbenders per search day)(Hiler et al. 2005). Nine of these animals exhibited severe physical abnormalities and were removed from the river to be housed at the Mammoth Spring National Fish Hatchery. All 9 died shortly thereafter, however, possibly due to water quality issues at the hatchery or from health issues that were observed when they were captured (i.e., lesions, raw limbs). Arkansas State University researchers found 4 individuals during a 2005 survey and 1 individual a 2006 survey (Trauth et al. 2007). Since then, no Ozark hellbenders have been captured in the Spring River, despite multiple surveys conducted by the Arkansas Game and Fish Commission (Irwin 2014, pers. comm.). Environmental DNA testing at various locations throughout the river is scheduled for 2020 (Irwin 2019, pers. comm.) and will provide a better understanding if individuals are still present in the Spring River.

Summary of the Spring River Population Status - Though once abundant in the Spring River, Ozark hellbenders have declined in the Spring River and individuals captured in the 2000's exhibited severe physical abnormalities. No Ozark hellbenders have been captured in the river since 2006, and it is unclear if any individuals remain.

Eleven Point River

The Eleven Point River, a tributary of the Black River that occurs in Missouri and Arkansas, has been surveyed several times since the 1970s. Wheeler et al. (2003) analyzed historical data and reported that in 1978, 87 Ozark hellbenders were captured in Oregon County, Missouri, over a 3-day period, yielding an average of 29 hellbenders per search day. From 1980 to 1982, 314 hellbenders were captured in the same area in 9 collection days, yielding an average of 35 hellbenders per search day; hellbender body lengths over that period ranged from 4.7 to 17.8 in (119 to 451 mm)(Wheeler et al. 2003). In 1988, Peterson et al. (1988) captured 211 hellbenders from the Eleven Point River and estimated hellbender density to be approximately one per 65.6 sq ft (20 sq m). Total lengths of these individuals ranged from 4.7 to 17.7 in (120 to 450 mm), with most between 9.8 and 13.8 in (250 and 350 mm). The average number of hellbenders captured per hour was 8.4 and 8.8 for the 2 sites sampled, or 67 and 70 hellbenders captured per search day (using the search day conversion method presented in the North Fork White River discussion). As noted previously, the abundance of hellbenders per search day is likely an overestimate and may be better approximated as 35-40 hellbenders per search day since the reported capture rates do not appear to be relative to the number of surveyors.

In 1998, Wheeler et al. (2003) captured 36 Ozark hellbenders over 4 days from the same localities as Peterson et al. (1988), for an average of 9 hellbenders per search day. These hellbenders were larger than those captured previously, with total lengths of 12.8 to 18.0 in (324 to 457 mm), and there were considerably fewer individuals in the smaller size classes. The same localities were surveyed again in 2005, with a total of 31 hellbenders captured, yielding an average of 2.6 hellbenders captured per search day. In Arkansas in 2005 and 2007, however, no more than 2 or 3 individuals were caught per search day (Irwin 2008a, pers. comm.). The catch per person-hour in 2005 was 1.1 hellbenders and in 2007, the capture rate was 0.9 hellbenders per person-hour (Irwin 2008a, pers. comm.).

As part of the long-term monitoring implemented in Missouri in 2009 by the Missouri Department of Conservation, occupancy surveys were conducted in the Eleven Point River in 2010 (see North Fork White River for additional information on monitoring protocols), and 18 Ozark hellbenders were encountered and captured (Bodinof et al. 2012d). Results from the occupancy monitoring indicated that an estimated 60-71% of the suitable hellbender habitat in the Eleven Point River in Missouri was occupied in 2010 (Bodinof et al. 2012d) Though standard errors for the occupancy estimates were large[1], the authors concluded that at least 41% of the suitable habitat patches in the Eleven Point River was occupied in 2010 because hellbenders were captured at those sites (Bodinof et al. 2012d). The results also indicated that patches where hellbenders have been detected in the previous 10 years were extremely likely to still be occupied, suggesting that extirpation of hellbenders from habitat patches does not appear to be occurring within a short time period (e.g., a decade)(Bodinof et al. 2012d). In the 5 sites selected for abundance surveys (sites that are considered to harbor the majority of hellbenders in the population), the mean catch per unit effort was 0.35 hellbenders per person-hour (Bodinof et al. 2012d). The total length of captured individuals measured was 11.9 to 18.9 in (302 - 480 mm), and body condition was similar to that observed historically (Bodinof et al. 2012d). However, size class distributions were

[1] The standard errors are not included in this report because there was a standard error estimate for each of the 3 occupancy estimates.

biased towards mature individuals and there was no evidence of recruitment (Bodinof et al. 2012d). In addition, the combined number of individuals captured at the abundance sites was low and previously tagged animals are continuing to be recaptured at relatively low rates[1] (39% of individuals)(Bodinof et al. 2012d).

In 2013 the Missouri Department of Conservation long-term monitoring in Missouri resulted in observations of 11 Ozark hellbenders with 9 captured[2] (the other individuals were observed with a dive light)(Kelly et al. 2013). Results from the occupancy modeling indicated that an estimated 41% (± 15%) of the suitable habitat patches in the Eleven Point River in Missouri was occupied by Ozark hellbenders in 2013 (Kelly et al. 2013). All of the hellbenders captured during the 2013 surveys were post-metamorphic individuals with most being mature adults, and the total length of captured individuals ranged from 15.4 to 17.7 (390 - 450 mm)(Kelly et al. 2013). Similar to results in 2010, the size class distribution was skewed towards large individuals, suggesting that recruitment in the Eleven Point River remains a problem for the population (Kelly et al. 2013). Catch per unit effort, body condition, and the percentage of animals recaptured were not reported.

Standardized surveys in Missouri have not been conducted since the 2013 sampling by the Missouri Department of Conservation. However, non-standardized sampling has been conducted to capture individuals for other studies. With the individuals captured in Missouri, there has not been a noticeable change in their health in terms of amphibian chytrid fungus, abnormalities, or the size of individuals captured (Briggler 2019c, pers. comm.). Though fertilized egg clutches are typically found every year in artificial nest boxes (see Chapter 5 for more information about nest boxes), natural nests are rarely found (Briggler 2019c, pers. comm.). No substantial damage occurred from the extreme flooding that occurred the spring of 2017 (Briggler 2019c, pers. comm.).

In Arkansas low numbers of Ozark hellbenders are observed during surveys and there have been no natural nests found, with only 1 egg clutch found in nest boxes to date (Irwin 2020, pers. comm.). Combined with the continued degradation of habitat (see Chapter 3), it appears that the portion of the population occurring in Arkansas is also continuing to decline (Irwin 2019, pers. comm.).

Summary of the Eleven Point River Population Status - The studies cited above indicate that the Eleven Point River population has experienced a substantial decline since the 1970s. Ozark hellbenders continue to be consistently found during surveys in the Eleven Point River and fertilized egg clutches are typically found every year in nest boxes (Briggler 2019c, pers. comm.). However, the collection of young individuals continues to be rare, indicating that there is little recruitment. Without recruitment, the population will continue to decline.

Current River

The Current River was not surveyed extensively until the 1990s. Nickerson and Mays (1973a) reported a large Ozark hellbender population in this stream, but no numbers were recorded. In 1992, Ziehmer and Johnson (1992) found 12 hellbenders in 60 person-hours in Shannon County, Missouri, or approximately 5 hellbenders per search day (using the same search day conversion as presented in the North Fork White River discussion). These individuals ranged in length from 4.5 in (115 mm) to more than 15.0 in

[1] It was noted by Bodinof et al. 2012d that it would be unreliable to use the sum of the number of animals captured at abundance sites to extrapolate abundance to the entire population.

[2] Because not all sites were surveyed and because surveying at occupancy sites only occurs until 1 hellbender is observed, these numbers do not represent the number of animals present in the population.

(380 mm)(maximum length was not reported), with most between 13.0 and 15.0 in (330 and 380 mm). In 1999, 14 hellbenders were collected over 3 collection days (approximately 5 hellbenders per search day), also in Shannon County, Missouri, and the individuals ranged from 14.8 to 20.3 in (375 to 515 mm) in length, with most between 17.7 to 19.7 in (450 to 499 mm)(Wheeler et al. 2003). The average size of individuals increased by nearly 4 in (100 mm), and the reported increase in length suggests that recruitment may be absent in this population. In 2005 and 2006, researchers found 22 hellbenders throughout the Current River in 100 hours of searching (equivalent to 5.2 hellbenders per search day).

As part of the long-term monitoring implemented in Missouri in 2009 by the Missouri Department of Conservation, occupancy surveys were conducted in the Current River in 2011 (see North Fork White River for additional information on monitoring protocols), and 58 Ozark hellbenders were encountered with 57 captured (Bodinof et al. 2012e). Results from the occupancy monitoring indicated that an estimated 40-63% of the suitable hellbender habitat in Missouri was occupied in 2011 (Bodinof et al. 2012e). Though standard errors for the occupancy estimates were large[1], the authors concluded that at least 17% of the suitable habitat patches in the Current River was occupied because hellbenders were captured at those sites (Bodinof et al. 2012e). The results also indicated that patches where hellbenders have been detected in the previous 10 years were extremely likely to still be occupied, suggesting that extirpation of hellbenders from habitat patches does not appear to be occurring within a short time period (e.g., a decade)(Bodinof et al. 2012e). In the 6 sites selected for abundance surveys (sites that are considered to harbor the majority of hellbenders in the population), the mean catch per unit effort was 0.56 hellbenders per person-hour (Bodinof et al. 2012e). The total length of captured individuals measured was 12.3 to 19.9 in (312-505 mm), and body condition was lower to that observed historically (Bodinof et al. 2012e). Size class distributions were biased towards mature individuals and there was no evidence of recruitment (Bodinof et al. 2012e). In addition, the combined number of individuals captured at the abundance sites was low and previously tagged animals are continuing to be recaptured at relatively low rates (21% individuals)(Bodinof et al. 2012e).

In 2014 the Missouri Department of Conservation long-term monitoring resulted in observations of 22 Ozark hellbenders with 7 captured[2] (the other individuals were observed with a dive light)(Kelly et al. 2014). Results from the occupancy modeling estimated that 36% (± 6%) of the suitable habitat patches in the Current River was occupied by Ozark hellbenders in 2014 (Kelly et al. 2014). All of the hellbenders captured during the 2014 surveys were post-metamorphic individuals and most were mature adults (Kelly et al. 2014). The total length of individuals ranged from 16.1 to 18.1 in (410 to 461 mm), and none were small enough to indicate recruitment in the previous 7-10 years (Kelly et al. 2014). Similar to results in 2011, the size class distribution was skewed towards large individuals, suggesting that recruitment in the Current River may be a problem for the population (Kelly et al. 2014). Catch per unit effort, body condition, and the percentage of animals recaptured were not reported.

Standardized surveys in Missouri have not been conducted since the 2014 sampling by the Missouri Department of Conservation. However, similar to the other populations, non-standardized sampling has been conducted to capture individuals for other studies. With the individuals captured in Missouri, there has not been a noticeable change in their health in terms of amphibian chytrid fungus, abnormalities, or the size of individuals captured (Briggler 2019c, pers. comm.). Following the historic flood in 2017, there were no substantial changes to the substrate or riparian corridor (Briggler 2019c, pers. comm.). Fertilized

[1] The standard errors are not included in this report because there was a standard error estimate for each of the 3 occupancy estimates.

[2] Because not all sites were surveyed and because surveying at occupancy sites only occurs until 1 hellbender is observed, these numbers do not represent the number of animals present in the population.

egg clutches are consistently found every year in artificial nest boxes (see Chapter 5 for more information about nest boxes) and in natural nests (Briggler 2019c, pers. comm.), and there appears to be high quality habitat for Ozark hellbenders. No substantial damage occurred from the extreme flooding that occurred in the spring of 2017 (Briggler 2019c, pers. comm.).

Summary of the Current River Population Status - Because extensive surveys were not conducted until the 1990s, no historical data are available. However, based on the number of individuals captured relative to the amount of available habitat, we presume that the population has declined. Similar to the North Fork White and Eleven Point rivers, collection of young individuals is rare, despite typically finding numerous fertilized egg clutches each year (Briggler 2019c, pers. comm.).

Jacks Fork

Jacks Fork River, a tributary of the Current River, was initially surveyed for Ozark hellbenders in 1992 (Ziehmer and Johnson 1992). Four hellbenders were collected over 66 person-hours, equating to roughly 1.5 hellbenders per search day. The individuals were large, ranging from 13.0 to 16.9 in (330 to 430 mm) in length. Though three Ozark hellbenders were found in the Jacks Fork River in 1999 (Briggler 2019a, pers. comm.), none were found during surveys in 2003, nor were any found in 2006 during 7 person-hours of searching (Phillips 2010, pers. comm.). However, in 2004, 3 dead Ozark hellbenders were found on the upper end of the river (Briggler 2019a, pers. comm.). It is unknown if these animals were introduced, or if they naturally occurred at the location. There was another Ozark hellbender captured by an angler in 2007. Given the difficulty in finding hellbenders when there are few individuals present, we presume that there may be a small number of Ozark hellbenders remaining in the Jacks Fork River.

A survey of all suitable habitat within the entire river was conducted in 2013; however, no individuals were found (Briggler 2019c, pers. comm.). Water samples were collected in 2019 for eDNA sampling and results are currently pending (Crabill 2019b, pers. comm.).

Table 3-1. Summary of population status for each river known to contain the Ozark hellbender.

River	Summary of Population Status
White River mainstem	It is unknown whether a viable population exists. There are only 2 Ozark hellbender records, and much of the potentially occupied habitat was destroyed by the construction of dams.
North Fork White River	Historically, abundance was high. However, between the early 1980s and late 1990s there was a substantial decline with a significant shift towards larger individuals. Subsequent surveys indicate that the population continues to decline, and historic flooding in 2017 may have reduced the population size by more than 50%.
Bryant Creek	A small number of animals are present and some movement likely occurs between this population and the North Fork White River population. This population is currently not considered to be viable on its own.
Black River	There is only one documented Ozark hellbender record in the Arkansas portion of the Black River. Though parts of the Black River may have contained a small population at one time, the river has limited suitable habitat and no population appears to be present.
Spring River	Abundance was historically high. However, animals captured in 2003-2004 exhibited severe physical abnormalities and died shortly after being transferred to captivity. No individuals have been captured since 2006 and the population is presumed to be functionally extirpated.
Eleven Point River	Though hellbenders are consistently found during surveys in both Missouri and Arkansas, the population appears have declined substantially from the 1970s and little recruitment is observed.
Current River	Because extensive surveys were not conducted until the 1990s, no historical data are available. Based on the number of individuals captured relative to the amount of available habitat, we presume that the population has declined.
Jacks Fork River	No individuals have been captured since 2007. We presume that a small number of animals may still be present.

Population Size Estimates

Ozark hellbender population sizes were first estimated in 2006 as part of a workshop to evaluate viability of the species (Briggler et al. 2007). Information considered in developing the estimates includes the number of hellbenders captured during surveys, recapture rate of marked individuals, size of habitat patches surveyed, and quality of habitat surveyed (Briggler et al. 2007). Populations sizes were estimated as 200 individuals for Bryant Creek and the North Fork White River, 10 individuals for the Spring River, 300 individuals for the Eleven Point River (both in Missouri and Arkansas), and 80 individuals for the Jacks Fork River and Current River[1] (Table 3-2)(Briggler et al. 2007).

Population sizes were estimated again in 2014 and were calculated by averaging the range of hellbender densities observed at habitat patches[2] and then multiplying this density by the total amount of available habitat in the river (i.e., the sum area of all habitat patches)(Briggler 2014, pers. comm.). The 2014

[1] These numbers represent age classes over one year of age.

[2] Regardless of size, some sites may support greater numbers of hellbenders due to a greater amount of cover rocks.

estimated population sizes were 550 individuals in the North Fork White River, 30 or less individuals in Bryant Creek, 180 individuals in the Eleven Point River (in Missouri only), 10 or less individuals in the Jacks Fork River, and 350 individuals in the Current River (Table 3-2)(Briggler 2014, pers. comm.). Though the number of individuals in the Eleven Point River in Arkansas is not included, these estimates indicate that at least 1,120 adult, wild[1] Ozark hellbenders were present throughout the species' range in 2014. It should be noted that the increase in the estimated population size does not necessarily reflect an actual increase in the population size, but rather a better understanding of the number of animals likely present (Briggler 2014, pers. comm.).

In 2019 population sizes were estimated using the same methods described for the 2014 estimations. The estimated population sizes for 2019 is 275 individuals in the North Fork White River, 30 or less individuals in Bryant Creek, 160 individuals in the Eleven Point River in Missouri, 150-200 individuals in the Eleven Point river in Arkansas, 10 or less individuals in the Jacks Fork River, and 350 individuals in the Current River (Table 3-2)(Briggler 2019c, pers. comm.; Irwin 2020, pers. comm.). The lower estimate for the North Fork White River population is due to the historic flooding that occurred in 2017. The flooding resulted in significant damage to the substrate and riparian zone of the river, likely reducing the population size by around 50% (Briggler 2018). The population estimate is also lower for the Eleven Point River in Missouri, with an estimated 160 individuals, 20 individuals less than the estimate for 2016. This reduction is based on non-standardized surveys conducted in 2014-2019 in which additional effort was needed to capture individuals at routinely surveyed sites (Briggler 2019c, pers. comm.). The combined estimates indicate that approximately 975 to 1,025 adult, wild[2] Ozark hellbenders are currently present throughout the species' range.

Table 3-2. Population size estimates from 2006 (Briggler et al. 2007), 2014 (Briggler 2014, pers. comm.), and 2019 (Briggler 2019c, pers. comm.) for the Ozark hellbender. Estimated population sizes pertain only to wild adults, and do not include larvae and subadults.

River	Estimated Population Size in 2006	Estimated Population Size in 2014	Estimated Population Size in 2019
White River mainstem	Not estimated	Not estimated	Not estimated
North Fork White River/Bryant Creek	200	580[a]	305[b]
Black River	Not estimated	NA	NA
Spring River	10	Not estimated	Not estimated
Eleven Point River	300	180[c]	250[d]
Current River/Jacks Fork River	80	360[e]	360[f]
Total	**590**	**1120**	**915**

[a] The estimated number of individuals in the North Fork White River is 550; while the estimated number in Bryant Creek is less than or equal to 30.

[1] Does not include individuals augmented through the propagation program.

[2] Does not include individuals augmented through the propagation program.

[b] The estimated number of individuals in the North Fork White River is 275; while the estimated number in Bryant Creek is less than or equal to 30. The reduction in the estimated population size of the North Fork White River is due to the severe impacts from flooding in 2017.

[c] Does not include individuals from Arkansas.

[d] The estimated number of individuals in the Eleven Point River in Missouri is 150; while the estimated number in the Eleven Point River in Arkansas is 100.

[e] The estimated number of individuals in the Current River is 350; while the estimated number in the Jacks Fork River is less than or equal to 10.

f The estimated number of individuals in the Current River is 350; while the estimated number in the Jacks Fork River is less than or equal to 10.

Limited Recruitment

As noted above, most Ozark hellbenders captured are large adults, and little recruitment is observed in the wild. Pfingsten (1990) cautioned that lack of detection of larval hellbenders could mean that larvae occupy a microhabitat that has yet to be surveyed. Whereas hellbender larvae can occupy different microhabitat than adults (e.g., cobble and gravel beds)(Nickerson and Mays 1973a), they also can be found in similar habitats and microhabitats as adults (Lipps 2010, pers. comm.; Phillips 2010, pers. comm.). When re-analyzing the data collected by Pfingsten for eastern hellbender populations in Ohio, Lipps and Pfingsten (Lipps 2010, pers. comm.) found strong evidence to reject the hypothesis that younger size classes (i.e., larvae) were occupying area not surveyed. Furthermore, there should be a replacement of smaller size classes of adult hellbenders (that are more detectable during surveys) if larvae are present but have a low detectability. Instead, there has been a significant shift towards larger individuals (Wheeler et al. 2003). This information indicates that the lack of larvae and juveniles in populations is not a function of survey technique, but instead reflects a true reduction in recruitment.

To evaluate if poor sperm health was limiting recruitment, Unger (2003) compared several measures of sperm production over 2 years between male Ozark and eastern hellbenders in Missouri to those of hellbenders from more stable eastern hellbender populations in other states. Though sperm counts were significantly lower for males from both Ozark and eastern hellbenders in Missouri, there were no significantly differences with respect to sperm viability and motility. From 2010 to 2016, Crabill and Briggler (2016 unpublished data) evaluated Ozark hellbender sperm health in individuals from the North Fork White, Eleven Point, and Current rivers. Results to date indicate that sperm health is high, as evidenced by high motility rates, viability rates, and sperm concentration (Crabill and Briggler 2016, unpublished data). Based on this information, it appears that sperm health is not a primary factor affecting recruitment.

Methods to find nests in the wild have improved and numerous Ozark hellbender nests are typically located each year (Briggler 2018, pers. comm.). Results of nest monitoring indicates that egg-hatching rates are high (Briggler 2018, pers. comm.), in turn indicating that successful fertilization is occurring. Though sample sizes are relatively low, there also does not appear to be high mortality during the subsequent weeks while larvae remain in the nest (Briggler 2018, pers. comm.). Thus, it appears the factor(s) affecting recruitment occur after larvae leave the nest.

Severe Physical Abnormalities

Ozark hellbender morphological aberrations over a 10-year period were investigated by Wheeler et al. (2002). Wheeler et al. (2002) obtained deformity data from hellbenders that were examined during population and distributional surveys in the Eleven Point River, North Fork White River, and Spring River dating back to 1990. They reported a variety of abnormal limb structures, including missing toes, feet, and limbs (Fig. 3-2). Additional abnormalities encountered include epidermal lesions, blindness, missing eyes,

and bifurcated limbs. Three hellbenders also were documented with tumors on their bodies in the Spring River in Arkansas.

In Ozark hellbenders sampled in 2004 in Missouri, 72% had abnormalities present (compared to 49% of eastern hellbenders sampled in Missouri)(Briggler 2007, pers. comm.). In 2006, abnormalities were observed on 90% of Ozark hellbenders surveyed from the Eleven Point River in Missouri, 73% from the Current River, and 67% from the North Fork White River (Briggler 2007, pers. comm.). By 2007 the prevalence and severity of abnormalities in Ozark hellbenders appeared to increase, often to a level that the animals are near death (for example, missing digits on all or most limbs, missing all or most limbs; Briggler 2007, pers. comm.). However, by 2015, the prevalence and severity of the physical abnormalities showed no increase, with 76% of captured individuals in Missouri from 2006-2015[1] exhibiting physical abnormalities (Briggler 2016). Subsequent sampling indicates that there has not been a continued increase in the percentage of individuals exhibiting abnormalities (Briggler 2019c, pers. comm.). However, the number of individuals captured since 2015 has been small since there has not been standardized surveys or intensive sampling to collect individuals for scientific studies. Thus, we cannot conclude definitively that there has not been a change in the percentage of individuals exhibiting physical abnormalities.

For the Spring River population, most, if not all, hellbenders collected in the late 1990s and 2000s had some type of major malformity or lesions (Davidson 2008, pers. comm.). In fact, a hellbender found in the Spring River in 2004 was missing all four feet and was covered in lesions and a fungal growth externally and inside its mouth; this animal died within 15 minutes of capture (Davidson 2008, pers. comm.).

The presence of these physical impairments (and the frequency with which they occur) is likely contributing to Ozark hellbender declines by reducing survivorship and reproduction. We assume that lesions on the feet and absence of appendages altogether reduces motility and foraging ability and possibly increases vulnerability of hellbenders to predators. Blindness or missing eyes likely also decreases survivability; while the overall stress imposed on affected individuals has the potential to reduce breeding activities and thus, decrease recruitment.

The exact cause of these physical abnormalities on Ozark hellbenders is yet to be determined. However, the current belief is that secondary bacterial and fungal infections are contributing factors (Briggler 2011a, pers. comm.). While these pathogens likely naturally occur on the animals, it appears that some unknown factor is increasing the hellbenders' susceptibility to these infections (see **Disease** in Chapter 4).

[1] The percentage of individuals exhibiting physical abnormalities was calculated for Ozark hellbenders captured from 2006-2015. Data are not available for individual years.

Figure 3-2. Photos representing physical abnormalities such as lesions (left) and necrotic limbs (right) observed on Ozark hellbenders. Photo credit: Trisha Crabill, U.S. Fish and Wildlife Service.

Low Genetic Diversity Within Populations

Although there is significant differentiation among Ozark hellbender populations, there appears to be relatively low level of genetic diversity within populations (Sabatino and Routman 2009, Crowhurst et al. 2011, Tonione et al. 2011), indicating a loss of genetic diversity. Genetic studies have repeatedly demonstrated very low genetic diversity in hellbender populations, which could contribute to the decline of the species through inbreeding depression (Kucuktas et al. 2001). The small size and isolation of the remaining populations of the Ozark hellbender further increase its vulnerability to extinction due to genetic drift, inbreeding depression, and random or chance events.

Quantity and Quality of Habitat

Described below is the estimated extent of suitable habitat within the rivers containing Ozark hellbenders (where available). Within these areas of suitable habitat, the quality of habitat varies, primarily due to the amount of sedimentation and bedload movement. Sedimentation is the deposition or accumulation of sediment, which can be in the form of small particles or larger particles such as gravel or cobble; whereas bedload movement is the transport of larger particles by rolling, skipping, or sliding along the bottom of the river. Both sedimentation and bedload movement are influenced by the gradient of the river and the extent of quality of riparian habitat[1] within the watershed because trees in the riparian corridor keep the stream channel narrow and flow velocity high, resulting in less sediment deposition. River gradient, the change in elevation over the length of the stream, influences sedimentation and bedload movement because the higher the gradient, the more velocity water has to transport sediment particles. Thus, sediment in higher gradient streams is more likely to be transported through hellbender habitat, rather than deposited on it. The quality of riparian habitat within the watershed influences sedimentation and bedload movement because watersheds with intact (vegetated) riparian corridors have less streambank erosion and maintain more stable stream channels. Therefore, there is less sediment entering the river system to be deposited or transported through the river. Sedimentation and resulting impacts to hellbenders, are described in further details in Chapter 4.

<u>White River</u>

The average gradient of the mainstem of the White River where Ozark hellbenders may be present is less than 2 ft per stream mi (0.4 m/stream km)[2], and a relatively large portion of the watershed is managed as part of the Ozark National Forest (see Chapter 5). There are 3 lock and dams within this portion of the White River that also likely also have an influence on flow velocity and the amount of sedimentation.

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[1] Riparian habitat is the habitat bordering a stream or river.

[2] Calculated using the National Hydrography Dataset Plus (NHD Plus) High Resolution.

According to Wheeler (2007), there is a vast amount of suitable hellbender habitat with extremely swift current in the portions of the river surveyed. However, the temperature at the surveyed sites drops far below the typical temperature of other Ozark hellbender rivers when water was released to generate hydroelectric power (Wheeler 2007), making the suitability of habitat questionable.

North Fork White River

A large portion of the North Fork White River watershed is managed as part of the Mark Twain National Forest (see Chapter 5) and riparian habitat within the forest boundaries is protected, reducing the amount of sedimentation entering the river. Water quality within the watershed is relatively good; however periodically high fecal coliform levels, nutrient loading, and sediment/gravel deposition are threats to water quality (Miller and Wilkerson 2001). According to Briggler (2019c, pers. comm.), the extent of suitable habitat for Ozark hellbenders is 25 mi (40 km) in the North Fork White River. Prior to the major flood event in 2017, there was some sedimentation and bedload movement In the North Fork White River. However, the sedimentation was not substantially degrading sites (Briggler 2019c, pers. comm.), likely due to the river's gradient which is 7.5 ft/stream mi (1.4 m/stream km) and as high as 10.4 ft/stream mi (2.0 m/stream km) (MDC 2013). During the 2017 flood, there was major bedload movement and changes to the habitat. Some new bedrock was exposed after the gravel was scoured way; while fine sediment settled in other areas (Briggler 2019c, pers. comm.).

Bryant Creek

The average gradient of the river is 5.8 ft/stream mi (1.1 m/stream km) and is up to 7.8 ft/stream mi (1.5 m/stream km) in some sections (MDC 2013). Water quality within the watershed is relatively good; however periodically high fecal coliform levels, nutrient loading, and sediment/gravel deposition are threats to water quality (Miller and Wilkerson 2001). The amount of suitable habitat in Bryant Creek is estimated to be 33 mi (53 km)(Briggler 2019c, pers. comm.). Though very little of the watershed is in public ownership or owned by conservation organizations (see Chapter 5), sedimentation does not appear to be a factor substantially influencing the quality of hellbender habitat (Briggler 2019c, pers. comm.).

Spring River

The Spring River has an average stream gradient of 4.6 ft (1.4 m) per stream mi[1], and the river is strongly influenced by springs, which also increase water velocity and keep fine sediment from settling over hellbender habitat. There is very little public land within the watershed (see Chapter 5). According to Wheeler (2007), the Spring River has sustained severe ecological perturbations, including sedimentation, encroachment of aquatic vegetation, modification of water flow, pollution in the form of non-point agricultural runoff and municipal wastewater, and intensive recreational use.

Eleven Point River

The average gradient for the portion of the Eleven Point River in Missouri is 5.4 ft/stream mi (1.0 m/stream km) and can be as high as 6.5 ft/stream mi (1.2 m/stream km)(MDC 2013). A large portion of the Eleven Point River watershed is part of the Mark Twain National Forest, and 48 mi (71 km) of the total 138 mi (222 km) are protected under the Wild and Scenic River Act (see Chapter 5), which means that development is limited within the river's riparian zone. Water quality within the Eleven Point watershed is relatively good; however, high fecal coliform levels, nutrient loading, and sediment and gravel deposition are the most severe threats to water quality. The amount of suitable hellbender habitat in the Eleven Point

[1] Calculated using the National Hydrography Dataset Plus (NHD Plus) High Resolution.

River (in Missouri only) is estimated to be 33 mi (53 km)(Briggler 2019c, pers. comm.), and sedimentation and bedload movement do not appear to substantially impact the quality of hellbender habitat in Missouri (Briggler 2019c, pers. comm.). In Arkansas, however, the quality of hellbender habitat is poor due to fine sediment smothering the habitat (Irwin 2019, pers. comm.). Sources of the fine sediment include soil erosion from indiscriminate land clearing (removal of riparian habitat and not using best management practices when clearing timber) and allowing livestock in riparian areas for long periods of time (Miller and Wilkerson 2000).

Current River

The Current River has an average gradient of 4.4 ft/stream mi (0.8 m/stream km) and can be as high as 8.7 ft/stream mi (1.6 m/stream km)(MDC 2013). There also is a strong spring influence which increases the water velocity downstream of each spring that helps to keep sediment from depositing over hellbender habitat. A large portion of the Current River watershed is managed by either the Mark Twain National Forest or the Ozark Scenic Riverways, with most of the river's riparian habitat protected from development (see Chapter 5). Overall water quality within the watershed appears to be relatively good (Wilkerson 2003). According to Briggler (2019c, pers. comm.), the extent of suitable habitat in the river for Ozark hellbenders is 124 mi (200 km). Although fine sediments are not a major problem in this river, a large amount of gravel is in the river system and continues to enter the Current River from tributaries. The quality of hellbender habitat appears to be improving near the upper end of the river now where the gravel has already passed through (Briggler 2019c, pers. comm.).

Jacks Fork River

The average stream gradient for the Jacks Fork River is 7.1 ft/stream mi (1.3 m/stream km) with the gradient as high as 8.6 ft/stream mi (1.6 m/stream km) in some sections (MDC 2013). A large portion of the riparian habitat immediately adjacent to the river is managed by the Ozark National Scenic Riverways, with much of the river's riparian habitat protected from development (see Chapter 5). However, water quality within the Jacks Fork Watershed has been negatively impacted by periodically high fecal coliform levels in the past (Wilkerson 2001). The amount of suitable hellbender habitat in the river is estimated to be 88 mi (142 km)(Briggler (2019c, pers. comm.), and according to Ziemer and Johnson (1992), there are many areas with large rocks, bedrock bottoms, and bedrock ledges that provide suitable hellbender habitat (but could not be surveyed).

CHAPTER 4. THREATS

In this biological report, we refer to factors negatively influencing the Ozark hellbender's viability as threats. Known and presumed threats to the Ozark hellbender are described below and analyzed in further detail in Appendix B in terms of the stressor associated with each threat, response of Ozark hellbender individuals, geographic scope, overall threat level, and management potential.

Habitat Degradation

One of the most likely causes of the decline of the Ozark hellbender in the White River system in Missouri and Arkansas is habitat degradation resulting from impoundments, sedimentation, ore and gravel mining, nutrient runoff, and nest site disturbance from recreational uses of the rivers (Williams et al. 1981, LaClaire 1993). The Ozark hellbender is a habitat specialists that depend on consistent levels of dissolved oxygen, temperature, and flow (Williams et al. 1981). Therefore, even minor alterations to stream habitat are likely to be detrimental to hellbender populations.

Impoundments

In the 1940s and 1950s, construction of multiple dams in the upper White River created Beaver, Table Rock, Bull Shoals, and Norfork lakes (Fig. 4-1). It is unknown if any Ozark hellbender populations occurred in the Upper White River because no surveys were conducted prior to construction of the dams. However, based on the presence of Ozark hellbenders in Bryant Creek and the North Fork White River and because 2 hellbenders have been recorded in the lower mainstem White River, we presume that at least some individuals were present in the lower mainstem White River. If present, Ozark hellbender populations downstream of the dams were likely extirpated due to hypolimnetic releases from the reservoir[1]. Hypolimnetic releases are cooler than normal stream temperatures because they are from a layer of water that is below the thermocline, and the water from this layer typically has reduced oxygen levels because it is non-circulating or does not ''turn over'' to the surface. The tail-water zones below dams also experience extreme water level fluctuations and scouring for several miles downstream. This can impact hellbender populations by washing out the pebbles and cobbles used as cover by juveniles and by creating unpredictable habitat conditions outside the Ozark hellbender's normal range of tolerance.

Ozark hellbender habitat upstream of the lakes was impacted because when a dam is built on a free-flowing stream, riffle and run habitats are converted to lentic (still), deep-water habitat. As a result, surface water temperatures tend to increase, and dissolved oxygen levels tend to decrease (Allan and Castillo 2007). Hellbenders depend upon highly vascularized lateral skin folds for respiration. Therefore, lakes and reservoirs are unsuitable habitat for Ozark hellbenders, because these areas have lower oxygen levels and higher water temperatures than do fast-flowing, cool-water stream habitats (Williams et al. 1981, LaClaire 1993). As stated above, it is unknown if any Ozark hellbender populations occurred in the Upper White River. However, Ozark hellbenders do occupy Bryant Creek and the North Fork White River population, and the portion of those streams impounded no longer provides habitat for the species.

The impoundments also affect upstream hellbender habitat by increasing sedimentation during periods of heavy rain because the flow of water is impeded by the presence of the reservoir. In 2008 and 2011, heavy rains and flooding resulted in an increase in water levels in excess of 10 to 15 feet (ft)(3 to 5 meters)(m) and significantly reduced flow velocity (Briggler 2011b, pers. comm.; Crabill 2011, pers. obs.).

[1] As noted in Chapter 3, there are 2 records from the mainstem White River.

Deposition of gravel from the 2008 flood event removed an estimated 30% of the available cover rocks and habitat at one of the most abundant Ozark hellbender sites; while flooding in 2011 removed an additional 50% of the habitat at this site (Briggler 2011b, pers. comm.). During high water levels, Ozark hellbenders at sites upstream of the reservoirs are also exposed to increased predation pressure by large predatory fishes. The increased water levels allow fish to expand upstream of the reservoir and have been observed in large numbers at upstream Ozark hellbender sites (Roberts 2011, pers. comm.). The increased abundance of large predatory fish, such as brown trout and striped bass, at sites upstream of Norfork Reservoir has even been noted by private landowners near these sites (Anononymous 2010, pers. comm.).

Lastly, the White River impoundments, as well as 3 lock and dams located on the White River, fragment hellbender habitat, blocking the flow of immigration and emigration between populations (Dodd 1997). The Norfork Lake largely separates individuals in Bryant Creek from the North Fork White River population, though some movement is thought to occur (Briggler 2019a).

Though smaller on scale, the Spring River also has several dams in the first few miles of the river. These dams were built during the early part of the 20th century for hydroelectric production. Although the dams only influence the flow regime of the river locally and do not cause many of the impacts described above, they likely impede, or at least reduce, hellbender movement among habitat patches.

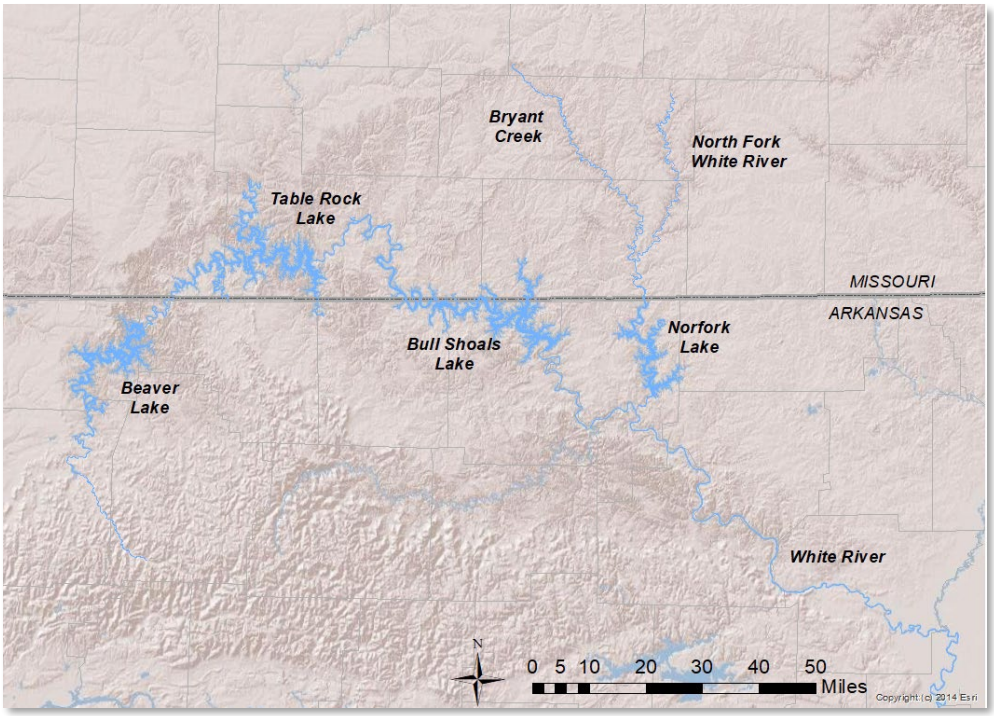

Figure 4-1. Lakes created on the White River in the 1940s and 1950s.

<u>Sedimentation and Altered Hydrology</u>

Sedimentation is another form of habitat degradation affecting Ozark hellbenders. Though Ozark streams are clear and cool, the streams have experienced accelerated erosion, gravel accumulation, and channel migration (Jacobson and Primm 1994), which has resulted in excessive sedimentation. Excessive stream

sedimentation (or siltation) results from soil erosion associated with upland activities (e.g., agriculture, forestry, mining, unpaved roads, road or pipeline construction, and general urbanization) as well as activities that can destabilize stream channels themselves (e.g., dredging or channelization, construction of dams, culverts, pipeline crossings, or other instream structures).

While historical timber clearing contributed to the large quantity of gravel currently in Ozark streams (Jacobson and Primm 1994), gravel dredging and poor land use practices are the current sources of cause soil erosion and stream sedimentation (Miller and Wilkerson 2000, Miller and Wilkerson 2001, Wilkerson 2003). Poor land use practices that contribute to sedimentation include indiscriminate land clearing and allowing livestock in riparian areas for long periods of time (Miller and Wilkerson 2000, Miller and Wilkerson 2001, Wilkerson 2003). Unrestricted cattle access to streams increases sedimentation because cattle can defoliate vegetation that protects streambanks from eroding and because the cattle trample the banks into sloping profiles, changing the morphology of the stream channel (Clary and Kinney 2002). Unrestricted cattle access to streams is particularly a concern for the Eleven Point River in Arkansas, where it contributes significant sedimentation (Irwin 2008b, pers. comm.). Indiscriminate land clearing includes timber harvest and associated activities (construction and increased use of unpaved roads, skid trails, and fire breaks) that do not implement Best Management Practices (BMPs). Timber harvest is prominent in many areas within the range of the Ozark hellbender, and peak stream flows can rise in watersheds where timber harvesting is occurring without appropriate implementation of BMPs. The rise in stream flows is due in part to vegetation removal and also to compacted soils resulting from construction of roads and landings[1] (Box and Mossa 1999, Allan and Castillo 2007). However, implementation of BMPs is required for forest landowners and mills that are certified under forest certification standards (NCASI 2019), and when implemented, greatly reduce effects of forest management on water quality (Anderson and Lockaby 2011, Cristan et al. 2016). The extent of certification, and thus BMP implementation, within the range of the Ozark hellbender, however, is unknown. In addition to those constructed for timber harvest, other roads that are improperly designed and maintained can cause marginally stable slopes to fail and also capture surface runoff and channel it directly into streams (Allan and Castillo 2007).

As noted above, when BMPs are implemented, erosion and sedimentation is reduced. However, the cumulative effects of timber harvest and other sources of disturbance on sedimentation rates may last for a couple of decades, even after harvest practices have ceased in the area (Frissell 1997). Time lags on the order of years to decades exist between disturbance to headwater areas and impacts to riverine habitat downstream (Coats and Miller 1981, Hagans et al. 1986). This means that even once sources of disturbance have been removed, the stored sediment in the system can result in persistent sediment problems and cumulative effects long after the initial erosion (Jacobson 2004).

Excessive sediment can fill interstitial spaces between substrate particles (i.e., sand, gravel, and cobble), reducing suitable habitat for hellbender larvae and subadults (FISRWG 1998) as well as hellbender prey. Excessive sediment also can cover the stream bottom, degrading suitable habitat for adults and suffocating eggs. In severe cases, sedimentation can even cause stream bottoms[2] to become embedded,and when habitat patches are completely lost due to sedimentation, the movement of individuals and colonization of new habitat can be impeded (Routman 1993). Increased sediment can also increase suspended particle loads, which can cause water temperatures to increase, and cause more particles to absorb heat, thereby reducing dissolved oxygen levels (Allan and Castillo 2007). In addition, various chemicals, such as pesticides, bind to silt particles and become suspended in the water

[1] The landings are locations where products are sorted and loaded for transportation.
[2] The stream bottoms consist of large substrate features such as cobble, rocks, and boulders.

column when flushed into a stream (Widenfalk 2002). The hellbender's permeable skin can allow direct exposure to these chemicals, which can be toxic (Wheeler et al. 1999). The extent of sedimentation in each Ozark hellbender stream is discussed in Chapter 3 under **Habitat Quantity and Quality**.

Additional information is needed on the extent of sedimentation in Ozark hellbender streams and the extent of the impact it may have on the species survival and reproduction.

Gravel Mining

Gravel mining, which continues to occur in a number of streams within the range of the Ozark hellbender, has directly contributed to Ozark hellbender habitat alteration and loss. Gravel mining, also referred to as dredging, can result in stream instability, both up and downstream of the dredged portion when done improperly (Box and Mossa 1999). Head cutting, in which the increase in transport capacity of a dredged stream causes severe erosion and degradation upstream, results in extensive bank erosion and increased turbidity (Allan and Castillo 2007). Reaches downstream of the dredged stream reach often experience aggradation (raised stream bed from sediment build up) as the sediment transport capacity of the stream is reduced (Box and Mossa 1999). Gravel mining can physically disturb hellbender habitat in dredged areas, and associated silt plumes can impact various aspects of the hellbender's life requisites (nesting habitat, prey, dissolved oxygen for egg development). In addition, these effects reduce crayfish populations, which are the primary prey species for Ozark hellbenders. Because noncommercial gravel mining is not regulated by the States or by the U.S. Army Corps of Engineers, it is difficult to determine the extent of gravel mining within southern Missouri and northern Arkansas. However, an aerial survey conducted in 2001 reported an estimated 12 and 41 active mining sites in the North Fork White River and Current River watersheds, respectively (no data were reported for watersheds of the Eleven Point or Spring rivers)(Noell 2003).

Lead and Zinc Mining

Portions of the Ozark Plateau have a history of being major producers of lead and zinc, and some mining activity still occurs in the southeastern Ozarks, although at levels that are lower than those recorded historically. Results of a U.S. Geological Survey water quality study conducted from 1992 to 1995 in the Ozark Plateau (Peterson et al. 1998) revealed that concentrations of lead and zinc in bed sediment and fish tissue were substantially higher at sites with historical or active mining activity. These concentrations were high enough to suggest adverse biological effects, such as reduced enzyme activity or death of aquatic organisms. Because hellbenders have highly permeable skin and obtain most of their oxygen through subcutaneous respiration, they are particularly susceptible to absorbing contaminants such as lead and zinc. Furthermore, because Ozark hellbenders are long lived, they may be at higher risk of bioaccumulation of harmful chemicals (Peterson et al. 1998). Although mining for lead and zinc no longer occurs within the range of the Ozark hellbender, Petersen et al. (1998) determined that elevated concentrations of lead and zinc were still present in the streams where mining occurred historically. Although it is possible for these metals to be transported and diluted, they will not degrade over time; therefore, it is likely that lead and zinc concentrations found more than 10 years ago in these rivers would remain at similar concentrations today (Mosby 2008, pers. comm.). In addition, there are historical lead and zinc mining sites that are near Ozark hellbender populations on the North Fork in Ozark County, Missouri (Mosby 2008, pers. comm.).

Contamination input to the Current River by way of the active Sweetwater Mine on Adair Creek in Reynolds County, Missouri, is a potential future risk. Adair Creek is a tributary of Logan Creek, a losing stream (loses water as it flows downhill) connected to Blue Spring, which discharges to the Current River. Although lead and zinc contaminants have been found in Logan Creek, there is no evidence that

contaminants from Sweetwater Mine have migrated to Blue Spring. However, if the Sweetwater Mine's current tailings dam on Adair Creek were to fail, large concentrations of lead and zinc would be added to Blue Spring and the Current River (Mosby 2008, pers. comm.). Although not common, failures of tailings mines have occurred on 6 occasions in Missouri since 1940, with several releasing tailings into nearby drainages or creeks (USCOLD 1994).

Huang et al. (2010) evaluated the presence of select heavy metals in blood samples from Ozark and eastern hellbenders (Table 4-1). Concentrations of cadmium and chromium did not differ between subspecies or among rivers, and concentrations of cadmium were low and near the limit of detection (0.002 µg/g)(Table 4-1)(Huang et al. 2010). However, concentrations of lead and mercury appear to accumulate in both hellbender subspecies, with the source of the accumulated heavy metals likely from their diet of crayfish (Huang et al. 2010). Of the rivers tested, blood mercury was highest in the Current River hellbenders, with a concentration 3 times as high as that of hellbenders from the North Fork White River)(Huang et al. 2010). It is currently unclear how these blood concentrations may affect survival and reproduction of Ozark hellbenders.

Table 4-1. Whole blood weight in µg/g of heavy metal concentration in blood samples of Ozark hellbenders from the North Fork White, Eleven Point, and Current rivers (Huang et al. 2010).

Metal	North Fork White River	Eleven Point River	Current River
Mercury	0.11 ± 0.02 (0.08-0.16)	0.35 ± 0.17 (0.2-0.61)	0.38 ± 0.08 (0.24-0.48)
Lead	0.044 ± 0.013 (0.031-0.057)	0.046 ± 0.01 (0.026-0.056)	0.055 ± 0.049 (0.013-0.180)
Cobalt	0.95 ± 0.31 (0.84-1.41)	0.74 ± 0.23 (0.53-1.15)	0.85 ± 0.29 (0.53-1.32)
Chromium	0.92 ± 0.46 (0.58-1.69)	0.66 ± 0.27 (0.47-1.04)	1.18 ± 0.58 (0.34-1.91)
Cadmium	0.022 ± 0.007 (0.011-0.032)	0.016 ± 0.007 (0.007-0.028)	0.020 ± 0.016 (0.007-0.057)

Water Quality

Despite the claim by some that many Ozark streams outwardly appear pristine, Harvey (1980) clearly demonstrated that various sources of pollution exist in the ground water in the Springfield and Salem plateaus of southern Missouri.

Water in the Ozark Plateaus is contaminated by nutrients from increased human waste (in part due to rapid urbanization and increased numbers of septic systems), fertilizers (including land application of chicken litter (poultry manure, bedding material, and wasted feed)), logging, and expanded industrial agricultural practices such as concentrated animal feeding operations (Petersen et al. 1998). This contamination was evidenced when water samples from the North Fork White and Eleven Point rivers in 2003-2004 contained concentrations of total phosphorus and total nitrogen exceeding the U.S. Environmental Protection Agency (EPA) recommended criteria two-thirds of the time (Solis et al. 2007). Agricultural land and livestock production comprises a large percentage of the land use within the Ozark hellbender range and is a continuing source of contamination (Wheeler et al. 2003). Missouri is the

second largest beef cattle-producing State in the nation, with the majority of animal units produced in the Ozarks. Both Arkansas and Missouri are leading States in poultry production. The National Water Quality Assessment data collected in the Ozarks in 1992-1995 from wells and springs indicated that nitrate concentrations were strongly associated with the percentage of mostly agricultural land near the wells or springs (Petersen et al. 1998). Nitrogen and phosphorus contamination also occurred in the Spring River in the late 1980s when the wastewater treatment plant in West Plains, Missouri failed, depositing all stored waste into the recharge area for the Spring River. Although nitrogen and phosphorus are essential plant nutrients that are found naturally in streams, elevated concentrations of these nutrients can cause increased growth of algae and aquatic plants in many streams and are detrimental to aquatic biota (Petersen et al. 1998). Increased levels of nitrates (nitrate is a compound of nitrogen and oxygen and usually the most abundant form of nitrogen in the water) can also affect amphibians by inhibiting growth, decreasing survivability, and impairing their immune systems (Marco et al. 1999, Rouse et al. 1999, Ortiz et al. 2004, Earl and Whiteman 2009).

Additional pollutants have been detected in parts of Ozark hellbender range. Outlined in Table 4-2 and depicted in Figure 4-2 are portions of Ozark hellbender streams which have been included on EPA's 303(d) list of impaired waterbodies (MDNR 1998-2018; ADEQ 2008-2018). Portions of the Eleven Point and Current rivers have been listed as impaired due to unacceptable levels of chlorine and atmospheric deposition of mercury (Table 4-2)(Fig. 4-2). Increased mercury levels have been implicated as a potential cause in the decline of other aquatic amphibians, such as the northern dusky salamander (*Desmognathus fuscus fuscus*; Bank et al. 2006). The Eleven Point River in Arkansas also was listed from 2008-2010 due to low dissolved oxygen (ADEQ 2008-2010). As described under in Chapter 2, Ozark hellbenders require high levels of dissolved oxygen for respiration, so these conditions may have affected Ozark hellbender health during the time of impairment. The Spring River has suffered from many water quality perturbations over recent decades and has had a total of 14.5 mi (23.3 km) included on the 303(d) list for high temperature, with 5.2 mi (8.4 km) currently listed (Table 4-2, Fig. 4-2)(ADEQ 2008-2018). The source of increased temperature is unknown (ADEQ 2008-2018), as is the effects on hellbenders. An additional 9.5 mi (15.3 km) in the Spring River were listed from 2008-2010 for siltation (due to surface erosion) and low dissolved oxygen (Table 4-2, Fig. 4-2) (ADEQ 2008-2018).

In addition to the pollutants described above, estrogenic compounds have been detected during water quality monitoring on both the North Fork White and Eleven Point rivers in Missouri (Solis et al. 2007). Although concentrations were lower than those shown to adversely affect aquatic organisms, evidence indicates that hellbenders in the North Fork White and Eleven Point rivers in Missouri are exposed to a variety of organic chemicals with potential estrogenic activity, and the total effect of these chemicals remains unknown (Solis et al. 2007).

Heavy recreational use of Ozark hellbender rivers, such as canoeing, kayaking, rafting, and inner tube floating) also may impact water quality. Ultraviolet (UV) filters, ingredients in sunscreen which absorb and reflect harmful UV radiation, can disrupt endocrine activity in freshwater fish (Kunz et al. 2006; Brausch and Rand 2011). When recreationists urinate in the rivers, pharmaceuticals such as antibiotics, antihistamines, antidepressants, and other medicines are introduced into the water. Effects vary by type of pharmaceutical and include a range of behavioral and physical effects which can affect the health and reproduction of aquatic species (Corcoran et al. 2010; Brodin et al. 2014).

The effects to Ozark hellbenders from the pollutants described above remains unknown. Although various endocrine disruptors have been documented in Ozark hellbender streams, results from Crabill and Briggler (2016 unpublished data) indicate that sperm health is high. Numerous nests containing fertilized

eggs are found in the wild each year, further indicating that hellbenders are producing healthy, viable sperm (Briggler 2018, pers. comm.). However, there are other mechanisms by which endocrine disruptors and other pollutants could impact health and/or reproduction of Ozark hellbenders. Additional work is needed to compile and summarize existing water quality information to better determine if degraded water quality could be contributing to Ozark hellbender population declines.

Table 4-2. Portions of Ozark hellbender rivers included on EPA's 303(d) list of impaired waters (MDNR 1998-2018; ADEQ 2008-2019). Data for Arkansas were only available from 2008-2019.

River (Location)	Impaired Size (mi)	Years Listed	Pollutant (Source)
Eleven Point River in MO (Upper)	22.3	2008-Present	Mercury in Fish Tissue (Atmospheric Deposition of Mercury)
Eleven Point River in MO (Middle)	11.4	2006-Present	Mercury in Fish Tissue (Atmospheric Deposition of Mercury)
Eleven Point River in MO (Lower)	22.7	2002-Present	Mercury in Fish Tissue (Atmospheric Deposition of Mercury)
Eleven Point River in AR	33.1	2008-2010	Low Dissolved Oxygen (Unknown)
Jacks Fork	7.5	1998-2004	Fecal Coliform (Organic Wastes)
Current River (Far Upper)	18.8	2018-Present	Mercury in Fish Tissue (Atmospheric Deposition of Mercury)
Current River	124.0	2006-Present	Mercury in Fish Tissue (Atmospheric Deposition of Mercury)
Spring River	5.20	2018-Present	Temperature (Unknown)
Spring River	9.5	2008-2010	Siltation (Surface Erosion) and Dissolved Oxygen (Unknown)
Spring River	4.0	2008-2011	Temperature (Unknown)
Spring River	5.3	2008-2011	Temperature (Unknown)

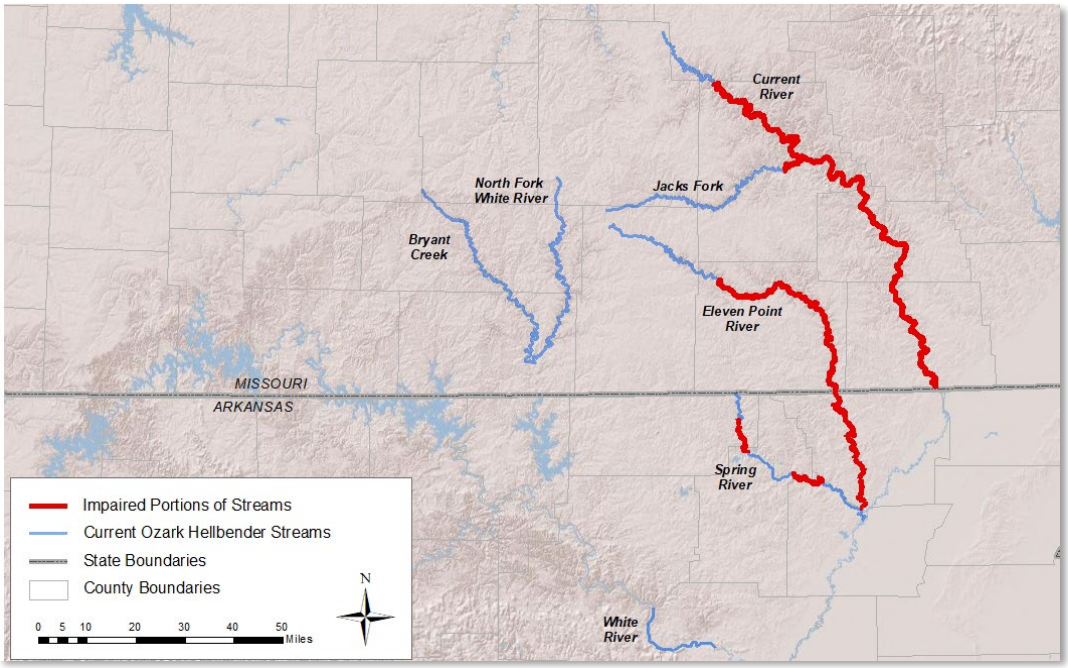

Figure 4-2. Map depicting portions of Ozark hellbender streams included on EPA 303(d) list of impaired waters between 1998-2019. Data for Arkansas were only available from 2008-2019.

Habitat Disturbance

Habitat disturbance affects hellbender survival in multiple rivers. Most rivers and streams inhabited by hellbenders are extremely popular with canoeists, kayakers, rafters, inner tube floaters, or operators of low-horsepower motorboats. Canoe, kayak, and motor and jet boat traffic continues to increase on the Jacks Fork River, Current, Eleven Point, and North Fork rivers. On the North Fork River, an average of 5 canoes per weekday were observed in 1998, and in 2004, that figure increased to 21 canoes per weekday (Pitt and Nickerson 2012.). Hellbenders encountered with gashes in their heads suggest that watercraft traffic likely impacts these animals. New roads, boat ramps, and other river access points have been constructed, which lead to increased river access and increased disturbance to hellbenders (Briggler et al. 2007). Off-road vehicle (ORV) recreation is also widespread throughout the Ozarks region. ORVs frequently cross rivers inhabited by hellbenders and are driven in riverbeds where the water is shallow enough to enable this form of recreation. The force delivered by a boat or ORV hitting a rock could easily injure or kill a hellbender, in addition to displacing or disrupting cover rocks. ORV activity also increases erosion and sedimentation by exposing bare erodible soils in areas with frequent activity.

The practice of removing large rocks and boulders (by hand, machinery, or dynamite) to reduce damage to canoes is common on many hellbender streams (Nickerson and Mays 1973a, Wheeler et al. 1999). It has been reported that rocks are possibly removed from streams for home landscaping projects (Briggler et al. 2007), although data to support this assertion is lacking. Rock turning and flipping is also done by crayfish hunters, herpetofauna enthusiasts, and researchers (Briggler et al. 2007). The areas under these large rocks are important habitat for cover and nest sites; therefore, overturning or removing these rocks can diminish available cover and nest sites for hellbenders.

Illegal and Legal Collection

Large numbers of Ozark hellbenders have been collected for commercial and scientific purposes (Trauth et al. 1992, Nickerson and Briggler 2007). Although commercial collecting of Ozark hellbenders has never been permitted by the Arkansas Game and Fish Commission (Irwin 2011, pers. comm.) nor by the Missouri Department of Conservation (Briggler 2011a, pers. comm.), Nickerson and Briggler (2007) determined that large numbers of Ozark hellbenders have been sold for the pet trade. Because of their protected status in Missouri and Arkansas, any actions involving interstate or foreign commerce of Ozark hellbenders collected from these States would also be prohibited by the Federal Lacey Act (16 U.S.C. 3371-3378).

In Arkansas, hellbenders may be collected with a scientific collecting permit from the Arkansas Game and Fish Commission (Arkansas Game and Fish Commission); however, no permits are being issued currently or are anticipated to be issued in the future because the State acknowledges the severely imperiled status of the subspecies (Irwin 2008b, pers. comm.). Missouri imposed a moratorium on hellbender scientific collecting from 1991 to 1996 and has since issued only limited numbers of scientific collecting permits for research (Horner 2008, pers. comm.). Despite these restrictions, unauthorized collecting for the pet trade remains a threat throughout the range because of the willingness of individuals to collect hellbenders illegally (Briggler 2011a, pers. comm.).

The illegal and legal collection of hellbenders for research purposes, museum collections, zoological exhibits, and the pet trade has undoubtedly been a contributing factor to hellbender declines. Nickerson and Briggler (2007) documented the removal of 558 hellbenders (approximately 300 animals illegally) from the North Fork White River from 1969 to 1989. At least 100 of these were collected in the mid-1980s by individuals from Alabama (Figg 1992, pers. comm.). One of these collectors contacted the Missouri Department of Conservation in 1992 out of remorse and provided details about collecting the hellbenders (Figg 1992, pers. comm.). According to the individual, animals were exported to Japan and labeled as eastern hellbenders because Ozark hellbenders were protected. The individual also relayed that he knew where to search for hellbenders by reading the published literature. In 1985, Missouri Department of Conservation agents apprehended 2 other individuals illegally collecting Ozark hellbenders, among other protected species, from Bryant Creek and North Fork White River (McNair 2011, pers. comm.). The 2 individuals were cited and fined for ‘‘possession of a protected species.’’

Anecdotal information suggests unauthorized collection of Ozark hellbenders on the Spring River in Arkansas contributed to the population crash, as reaches of the Spring River that formerly contained 35 to 40 hellbenders have had no individuals present for more than 10 years (Irwin 2008b, pers. comm.). The decline is linked to unauthorized collecting because Ozark hellbenders were located in one small, easily accessible area of the Spring River, and no other event (such as a storm or chemical spill) had occurred in that area that would explain such a rapid decline (Irwin 2008b, pers. comm.). At another Spring River site, personnel from a local canoe rental reported that commercial collectors took more than 100 Ozark hellbenders in 2 days (Trauth et al. 1992), which also likely impacted the population. Amphibians such as the hellbender, a relatively slow-moving, aquatic species, may be collected with little effort, making them even more susceptible to this threat.

While large collecting events appear to have occurred primarily in the 1980s, the unauthorized collection of hellbenders for the pet trade remains a major concern. During monitoring surveys, the Missouri Department of Conservation documented in 2011 and 2014 numerous, large rocks overturned at Ozark hellbender sites, indicating that someone had searched the sites for hellbenders (Briggler 2011, Briggler 2014). In 2001, an advertisement in a Buffalo, New York, newspaper was selling hellbenders for $50 each

(Mayasich et al. 2003). In 2003, a pet dealer in Florida posted an Internet ad that offered ‘‘top dollar’’ for large numbers of hellbenders, wanted in groups of at least 100 (Briggler 2007, pers. comm.). Also in 2003, a person in Pennsylvania had an Internet posting stating specifically that an Ozark hellbender was wanted, no matter the price or regulatory consequence (Briggler 2007, pers. comm.); while in 2010 a person posted an Internet ad looking for wholesale lots of hellbenders (Briggler 2010a, pers. comm.). At the 2005 Hellbender Symposium, it was announced that U.S. hellbenders were found for sale in Japanese pet stores, which is likely the largest market for this species (Briggler 2005, pers. comm.). Further evidence of the current demand for hellbenders overseas includes an eastern hellbender declared for export to Europe in 2010 (Tabor 2010, pers. comm.) and a hellbender (subspecies not specified) declared in 2005 for export to Japan (LEMIS 2008). The Law Enforcement Management Information System (LEMIS) is the Service’s law enforcement data system and includes information on imported and exported wildlife. Numbers provided by LEMIS declarations reports, however, can differ greatly from actual export numbers when animals are collected illegally and not declared. As Ozark hellbenders become rarer, their market value is likely to increase. In fact, listing the subspecies as endangered may also enhance the subspecies potential commercial value as the rarity of the subspecies is made public.

Unlike many U.S. species listed under the Act, the Ozark hellbender has commercial trade value. Due to the market demand and the apparent willingness of individuals to collect hellbenders illegally, we believe that any action that publicly discloses the location of hellbenders (such as publication of specific critical habitat maps or locations) puts the species in further peril. For example, due to the threat of unauthorized collection and trade, the Missouri Department of Conservation and Arkansas Game and Fish Commission have implemented extraordinary measures to control information on the locations of Ozark hellbenders.

Disease

Emerging infectious diseases, especially those that are fungal, are on the rise and salamanders are especially susceptible given the high magnitude of legal and illegal trade in herpetofauna. Given the long-lived environmental stages of fungi, a novel fungal pathogen could cause mass mortality in Ozark hellbenders if it is introduced and spread rapidly through the stream environment (as demonstrated by *Batrachochytrium dendrobatidis* (*Bd*))(see below). Thus, in addition to acting as a stressor, an emerging infectious disease could cause catastrophic loss of one or more populations. Based on current information, the diseases that could impact hellbenders are described below.

<u>Amphibian Chytrid Fungus</u>

Amphibian chytrid fungus, or *Batrachochytrium dendrobatidis* (*Bd*), is a fungal pathogen which can cause chytridiomycosis, a highly infectious amphibian disease associated with mass die-offs, population declines and extirpations, and potentially species extinctions on multiple continents (Berger et al. 1998, Bosch et al. 2001, Lips et al. 2006). *Bd* attacks the keratinized tissue of amphibian skin and can lead to thickened epidermis, lesions, body swelling, lethargy, loss of righting reflex, and death in all life stages (Berger et al. 1998, Bosch et al. 2001, Carey et al. 2003). Chytridiomycosis infection rates among amphibians exposed to *Bd* vary by species (Woodhams et al. 2007), and resistance to *Bd* infection in some amphibians is likely related to levels of antimicrobial peptides found in skin secretions (Woodhams et al. 2007), beneficial skin bacteria (Harris et al. 2006), and possibly frequent skin shedding (Woodhams et al. 2007).

Based on U.S. Geological Survey water data from 1996-2006, the maximum temperature of Ozark hellbender streams is 77.0 to 80.6 °F (25 to 27 °C)(Barr 2007, pers. comm., as cited in USFWS 2011a).

These temperatures make the streams ideal for the spread and persistence of *Bd*, which has optimal growth at temperatures around 73 °F (23 °C)(Daszak et al. 1999). In 2006 *Bd* was detected in captive hellbenders at the Saint Louis Zoo following a power outage in the zoo's herpetarium (Briggler et al. 2007). It is presumed that hellbenders were stressed during the outage since cooling systems were not working. Several captive hellbenders were observed ''with substrate (rocks) sticking to the skin and many were floating'' (Duncan 2007, pers. comm.). From March 2006 through April 2007, 59 hellbenders died, with over 75% of the deaths attributed either directly or indirectly to *Bd* (Duncan 2007, pers. comm.).

As a result of the mortalities in the Saint Louis Zoo hellbender population, the Missouri Department of Conservation and Arkansas Game and Fish Commission began testing wild hellbenders in Missouri in 2006 for infection by the pathogen. The only Ozark hellbender river not surveyed for the pathogen was the Spring River, where the subspecies is considered functionally extirpated (Irwin 2008a, pers. comm.). All Ozark hellbender streams surveyed had individual hellbenders that tested positive for the pathogen (Briggler 2008b, pers. comm.). *Bd* infection on Ozark hellbenders has since been confirmed in all streams in which they still occur (North Fork White River, Eleven Point River, and Current River)(Briggler et al. 2007, Briggler et al. 2008). For individuals sampled from 2006 to 20016, the prevalence of *Bd* varied from 15-23% among rivers (Briggler 2016). These results indicate the minimum number of infected individuals because polymerase chain reaction (PCR) tests for *Bd* may produce false negative results if the infection is localized in different tissues than were analyzed (Beard and O'Neill 2005).

In 2008 -2009, a study was conducted to determine if *Bd* occurred historically in Ozark hellbender populations or if the pathogen was a relatively novel occurrence (Bodinof et al. 2011). Bodinof et al. (2011) used histological techniques and a immunoperoxidase stain[1] to evaluate the occurrence of the fungus in tissue samples from Ozark hellbender museum specimens collected from Missouri in 1896-1994. *Bd* was confirmed in 6.9% of the 102 specimens evaluated and in specimens collected as early as 1969 (Bodinof et al. 2011). With both Ozark and eastern hellbenders, *Bd*-positive individuals were collected and deposited in collections prior to or during the period when hellbender populations in Missouri declined (Bodinof et al. 2011).

The specific effects of *Bd* infection in wild Ozark hellbenders are not clear. While *Bd* currently does not appear to be causing large-scale mortality events in wild Ozark hellbender populations, there is concern that these could occur in the future if other stressors weaken hellbenders' immune systems, such as environmental contaminants or rising water temperatures (Briggler et al. 2007, Regester et al. 2012). It also has been hypothesized that *Bd* increases the vulnerability of hellbenders to secondary bacterial and fungal infections and thus is associated with the severe physical abnormalities observed on many animals (see **Physical Abnormalities** in Chapter 2)(Irwin 2010, pers. comm.). Because Bd can cause an increase in some pathogens (Jani and Briggs 2014; Federici et al. 2015; Walke et al. 2015), it is postulated that Bd may play a role in development of the severe abnormalities observed on many Ozark hellbenders (Hernández-Gómez et al. 2018b).

Batrachochytrium salamandrivorans

Another fungal pathogen, *Batrachochytrium salamandrivorans* (*Bsal*), invaded Europe from Asia around 2010 and is responsible for causing mass die-offs of fire salamanders (*Salamandra salamandra*) in northern Europe (Martel et al. 2014, Fisher 2017). Given extensive unregulated trade and the recent discovery of *Bsal* in amphibians, there is concern about the introduction of a novel pathogen causing

[1] An immunoperoxidase stain is a stain used to detect specific antigens or antibodies in tissue sections. An antigen is a toxin or other foreign substance which induces an immune response in the body; an antibody is the blood protein produced in response to and counteracting the antigen.

extirpations of naive salamander populations in North America (Yap et al. 2017). While we still do not have a clear understanding of all of the salamander species that will be susceptible to *Bsal*, there is concern that Ozark hellbenders could be impacted. The Ozark Highlands are within an area identified as having a medium risk of introduction of *Bsal* based on proximity to areas with a high volume of amphibian trade (Richgels et al. 2016)(Fig. 4-3). Since *Bsal* can be transmitted via environmentally-resistant zoospores and encysted spores that can float at the water-air interface (Stegen et al. 2017) in addition to direct contact, it is expected to spread readily in stream environments.

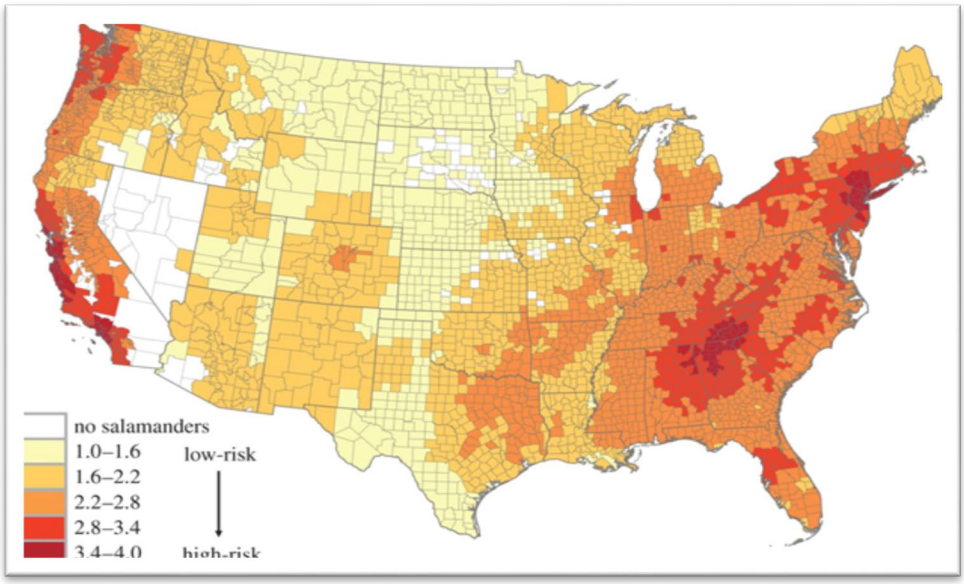

Figure 4-3. Heat map of the USA showing the total relative risk of *Bsal* to native US salamanders based on an introduction assessment (a combination of areas with high numbers of pet trade establishments and high levels of imports) and consequence assessment (a combination of species richness and environmental suitability). Taken from Richgels et al. (2016).

Given the high risk of invasion, the Service recently listed 20 salamander genera[1] known to carry *Bsal* as injurious under the Lacey Act to limit importation into the United States (USFWS 2016). Despite this protection, it is possible that an unknown carrier or illegal import could introduce this pathogen into Ozark hellbender populations. The likelihood of introduction of *Bsal* or another emerging infectious disease remains high for the following reasons: 1) incoming amphibians are not monitored or tested for amphibian diseases, 2) wildlife trade is prevalent and increasing with the number of declared shipments doubling since 2000)(Smith et al. 2017), 3) some of the species that carry *Bsal* could still be entering the country illegally, 4) international wildlife trade is commonly plagued by misidentification of animals and their origins (Gerson 2012), and 5) there are other ways that diseases and especially fungal diseases could enter the United States (e.g., some species of toads could be carriers)(Stegen et al. 2017).

The Missouri Department of Conservation has been testing Ozark and eastern hellbenders for *Bsal* and so far, all samples have been negative (95 individuals were tested).

[1] The listing included all salamander species within the 20 genera known to carry *Bsal*. This resulted in 201 salamander species being listed as injurious, although not all of the 201 species are known to carry *Bsal*.

Ranaviruses

Ranaviruses are another emerging group of pathogens affecting amphibian populations worldwide. *Ranavirus* is one of 5 genera in the family Iridoviridae, a family of viruses known to infect a diversity of invertebrate and ectothermic (cold-blooded) vertebrate hosts. Ranaviruses were originally detected in frogs (Granoff et al. 1965, Rafferty 1965) but are now known to infect and cause disease in fish, reptiles, and other amphibians (Marschang and Miller 2012). Ranaviruses are often virulent and can cause systemic infections in amphibians (Daszak et al. 1999). Mortality caused by ranaviruses has been reported from 5 continents and in most of the major families of frogs and salamanders (Gray et al. 2009).

Amphibian larvae seem to be the developmental stage most susceptible to ranaviruses (Daszak et al. 1999), with physical characteristics of infections in larval stages including skin hemorrhages, ulcers, and bloating (Marschang and Miller 2012. Overt signs of infection may not be exhibited in juvenile and adult stages (Daszak et al. 1999), but when present typically include skin abnormalities (e.g., sloughing, hemorrhaging) and sometimes necrosis (tissue death) of digits and limbs (Cunningham et al. 1996, Jancovich et al. 1997). The exact mechanism by which *Ranavirus* infections cause amphibian mortalities remains unclear, but hemorrhaging in skeletal tissue (Daszak et al. 1999) and extensive necrosis in the liver, spleen, kidneys, and digestive tract have been observed in infected individuals (Gray et al. 2009). It is also postulated that viral infections may suppress the immune system, resulting in secondary invasion by opportunistic pathogens (Miller et al. 2008).

Though broad-scale *Ranavirus* outbreaks have not been documented among Ozark or eastern hellbenders, *Ranavirus* has been detected in several eastern hellbender populations. Since 2010, 84 Ozark hellbenders in Missouri have been tested for *Ranavirus* using internal cloacal and buccal swabs and external swabs of skin hemorrhages and ulcers (Briggler 2020a, pers. comm.). The testing yielded no positive results, as did results of the 47 eastern hellbenders tested in Missouri (Briggler 2020a, pers. comm.). Testing in Arkansas indicates that the pathogen may be present (Miller et al. 2016), however, there is some uncertainty regarding the results given the number of times samples needed to be amplified before *Ranavirus* DNA could be detected (Crabill 2017, pers. comm.). The role that *Ranavirus* may play in declines of Ozark hellbenders, and the threat it poses to this species, is unclear.

Increased Predation Rates

Trout stocking has increased in recent years both in Missouri and Arkansas. While no trout are native to Missouri, both nonnative brown trout (*Salmo trutta*) and nonnative rainbow trout (*Oncorhynchus mykiss*) have been sporadically introduced into Ozark area waters for recreational fishing purposes since the 1800s. The 2003 Missouri Department of Conservation Trout Management Plan calls for increased levels of stocking as well as increasing the length of cold-water-stream stretches that will be stocked with brown and rainbow trout (MDC 2003). Nonnative trout are stocked in all rivers that historically and currently contain Ozark hellbenders (MDC 2003, AGFC 2004). In Arkansas, the Arkansas Game and Fish Commission is currently working with the U.S. Army Corps of Engineers to improve cold water releases from mainstem dams along the White River, to improve conditions for trout below the reservoirs (USACE 2008). In addition, highly predacious tiger muskies (hybrids between Northern pike and muskellunge (*Esox masquinogy x E.lucius*) were introduced into the Spring River in Arkansas in 1989.

Introduced fishes have had dramatic negative effects on populations of amphibians throughout North America (Bradford 1989, Funk and Dunlap 1999, Gillespie 2001, Pilliod and Peterson 2001, Vredenburg 2004). Rainbow trout and brown trout are considered opportunists in diet, varying their diet with what is available, including larval amphibians (Smith 1985, Pflieger 1997). Brown trout grow bigger and tolerate a

wider range of habitats than do rainbow trout and, therefore, may be a more serious threat to hellbenders, particularly at the larval stage. Dunham et al. (2004) assessed the impacts of nonnative trout in headwater ecosystems in western North America. The authors documented at least 8 amphibian species that exhibited negative associations with nonnative trout in mountain lakes, specifically regarding the occurrence or abundance of larval life stages of native amphibians. Also, salamander species, such as the long-toed salamander (*Ambystoma macrodactylum*), have been extirpated from waterbodies in high-elevation lakes in western North America due to stocked nonnative trout (Pilliod and Peterson 2001).

Preliminary data suggest that larval hellbenders from declining populations in Missouri do not recognize brown trout as dangerous predators. In contrast, larvae from more stable southeastern (U.S.) populations that co- occur with native trout show ‘‘fright’’ responses to brown trout (Mathis 2008a, pers. comm.). The failure of hellbender larvae to recognize trout as a threat is likely a non-adaptive response the makes this amphibian more susceptible to predation. A recent study conducted by Gall (2008) confirmed results found with this preliminary data on Missouri hellbender populations.

Gall and Mathis (2010a, 2010b) examined Ozark and eastern hellbender predator-prey interactions by 1) studying the foraging behavior of predatory fish species (native and nonnative (trout)) in response to the presence of hellbender secretion (a potentially noxious chemical cue produced by stressed hellbenders), 2) comparing the number of secretion-soaked food pellets consumed by rainbow and brown trout, and 3) comparing the response of larval hellbenders to chemical stimuli between native predatory fishes and nonnative trout. Gall and Mathis (2010b) determined that brown trout were attracted to the secretion emitted by hellbenders, and hellbender secretions were more palatable to brown trout than to rainbow trout. Also, although hellbenders in Missouri exhibited only weak fright responses when exposed to trout stimuli, they responded with strong fright responses to other native predatory fish (Gall and Mathis 2010a).

Gall and Mathis (2010a) suggested that the limited evolutionary history between salmonids (brown and rainbow trout) and hellbenders in Missouri is likely responsible for the weak fright behavior exhibited by hellbenders in response to trout stimuli. Although brown and rainbow trout are a threat to hellbenders, results from this study indicate that rainbow trout are less of an immediate concern than brown trout (Gall and Mathis 201a). This may be due to the difference in diet of the two species: rainbow trout maintain a predominately invertebrate diet throughout their lives and brown trout switch from predominately invertebrate prey to predominately vertebrate prey (including salamanders) at about 8.7 in (22 cm) in length (Gall and Mathis 2010a). Gall and Mathis (2010a) provided evidence that predation by introduced trout cannot be ruled out as a factor affecting the Ozark hellbender and possibly contributes to their decline.

In addition to brown trout and 4 other native predatory fish, walleye (*Stizostedion vitreum*) have been stimulated to approach prey more often and faster in the presence of hellbender secretions (Gall and Mathis 2010b). Although walleye are native, stocking the species at greater densities than those occurring naturally may increase predation pressures on hellbender larvae stocked in hellbender streams, because walleye share similar activity periods with hellbenders (Mathis 2008b, pers. comm.).

Electrofishing

Electrofishing is a common method of freshwater fish sampling and is conducted in many streams throughout the Ozarks, including streams occupied by Ozark hellbenders. Until recently, experts believed that cover rocks largely buffer hellbenders from the electrical field produced from electrofishing. However, hellbenders have been “coaxed” out of rocks using electrofishing (N. Burkhead, pers. comm., as cited in

Nickerson and Krysko 2003), and Williams et al. (1981) concluded that electrofishing was the most effective technique for sampling hellbenders in a northwestern Pennsylvania stream. Both Ozark and eastern hellbenders also have been inadvertently sampled during diurnal fish surveys in Missouri (D. Campbell pers. comm. as cited in Nickerson and Krysko 2003; Briggler 2016, pers. comm.). For this reason, in 2011 the Missouri Department of Conservation placed restrictions on electrofishing over Ozark hellbender sites containing a large number of animals or where reproduction is known to occur (electrofishing was already restricted on hellbender sites in Arkansas)(Irwin 2016, pers. comm.).

Because electrofishing was still conducted on other Ozark hellbender sites and because electrofishing in an important tool used in fish sampling, a study was initiated in 2015 to determine exposure of hellbenders to the electrical field and potential effects. Using a voltage probe developed specifically for the project, it was determined that the electrical field does extend under rocks and in gravel when applying the recommended target power setting identified in Bonar et al. (2009) and mimicking typical electrofishing operations (Briggler 2016, pers. comm.). Based on the data collected in the field, various hellbender life stages were exposed in a laboratory setting to a range of voltage gradients (0.5 V/in to 5.1 V/in)(0.2 V/cm to 2.0 V/cm)(Morrison 2019). Results of the study indicate that there are behavior effects when hellbenders are exposed to electrofishing, including embryo twitching and twitching of other life stages, latency to move to cover, reduced activity immediately after exposure, mouth gaping, time to individuals to right themselves, and full immobilization (Morrison 2019). There was also a greater percentage of abnormalities upon hatching for eggs exposed to electrofishing, and there was one subadult exposed to the medium-low voltage gradient (2.0 V/in) (0.8 V/cm) that experienced a broken vertebra (Morrison 2019). However, there was no significant effect on the number of eggs that successfully hatched, the mass of larvae upon hatching, or survivorship of individuals (Morrison 2019).

Due to the spinal injury that occurred with one of the subadults, electrofishing is currently avoided on any known Ozark hellbender sites (Crabill 2019a, pers. comm.). Electrofishing is now also avoided within core areas of Ozark hellbender streams during the breeding season, defined as September 15 to November 1 (Crabill 2019a, pers. comm.). Core areas are defined as the portion of the stream occurring between the furthest upstream occupied location and the furthest downstream occupied location. The second measure is intended to avoid disruption to breeding or impacts to individuals moving among sites. Additional studies will be conducted to better understand the effects to Ozark hellbenders from electrofishing and if the current conservation measures are appropriate for the level of impacts expected.

Gigging and Recreational Fishing

Recreational fishing may also negatively impact Ozark hellbender populations due to animosity towards hellbenders, which some anglers believe to be poisonous and to interfere with fish production (Gates et al. 1985). In addition, there are unpublished reports of hellbenders accidentally killed by frog or fish gigging (spearing), when a hellbender may get speared inadvertently (Nickerson and Briggler 2007). The Missouri Department of Conservation reports that gigging popularity and pressure have increased, which may increase the threat to hellbenders during the breeding season when they tend to move greater distances and congregate in small groups where they are an easy target for giggers (Nickerson and Briggler 2007). The gigging season for various species of suckers spans the reproductive season of the Ozark hellbender throughout its range. The sucker gigging season opens September 15, during the peak breeding period when hellbenders are most active and, therefore, most exposed.

Gigging is popular in hellbender streams to such a degree that marks are often noticed on the bedrock and the river bottom from giggers' spears (Briggler 2007, pers. comm.). Although the chance of finding a gigged hellbender is small (due to the presence of scavengers, the fast decomposition rate of

amphibians, and the possibility of giggers removing the specimen), 2 gigged hellbenders were found along the stream bank on the North Fork White River in 2004 (Huang 2007, pers. comm.). In their studies of Missouri hellbenders, Nickerson and Mays (1973a) found dead gigged specimens, and they reference data showing how susceptible the species is to this threat. Ozark hellbenders are sometimes unintentionally caught by anglers. However, catching hellbenders while fishing is not a frequent occurrence and is not believed to be a significant threat to the species, especially if anglers follow instructions posted by the Missouri Department of Conservation to remove the hook or cut the fishing line and return the hellbender to the stream (Briggler 2009, pers. comm.).

Climate Change

According to the National Oceanic and Atmospheric Administration's global climate models, increased flooding along rivers and streams is predicted to continue in Missouri, and extreme precipitation events are predicted to increase in Arkansas over the next 80 years (NOAA NCEI 2016a, NOAA NCEI 2016b). If these events result in extreme flooding, they will likely cause substantial disturbance to and mobilization of the substrate, similar to the effects observed on the North Fork White River following the extreme flooding in 2017 (see Chapter 3). This disturbance can directly injure or kill individuals if they are dislodged from their cover rocks and swept downstream in the current. The mobilization of substrate can also impact hellbenders if their cover rocks are buried in gravel or transferred downstream, as were boulders during the 2017 flood on the North Fork White River (Briggler 2018). The flood events are expected to be even greater if substantial forest clearing occurs watersheds due to a synergistic effect between land cover and climate change on stream discharge (Hu et al. 2005).

In both Arkansas and Missouri, the global climate models predict that higher temperatures in the future will result in a greater intensity of droughts (NOAA NCEI 2016a, NOAA NCEI 2016b). A greater intensity of droughts will decrease groundwater levels (Schindler 2001) and significantly reduce annual stream flows (Moore et al. 1997, Hu et al. 2005). The drought conditions and prolonged low flows associated with climate change may favor the establishment and spread of nonnative species (Rahel and Olden 2008). Invasion by nonnative plant species could impact the quality of hellbender habitat; whereas invasion by nonnative animals could create competition for resources. If the higher temperatures predicted by the global climate models are high enough to result in interrupted stream flows, it could cause direct mortality to hellbenders from desiccation and reduced fitness and reproduction due to stress, decreased prey availability, and lower dissolved oxygen. Reduced stream flow may also increase impacts to the stream substrate during flooding because woody debris carried in the stream flow will be lower in the stream channel and more likely to disturb the substrate (Briggler 2020b, pers. comm.).

Because Ozark hellbender streams are spring-fed, their temperatures are influenced by subsurface groundwater temperature. Though groundwater temperature exhibits less seasonal variability than surface water temperature (Constantz 1998, O'Driscoll and DeWalle 2006, Tague et al., 2007), groundwater temperature is still influenced by atmospheric temperatures and is expected to increase with increasing atmospheric temperatures (Menberg et al. 2014; Kurylyk et al. 2014). Changes to stream temperature of spring-fed streams are difficult to predict due to the complex interactions that influence groundwater temperate. However, if the predicted increase in atmospheric temperature substantially increases temperatures of Ozark hellbender streams, the fitness of individuals will be affected. If the health of hellbenders is already compromised by other environmental stressors, elevated water temperatures could increase susceptibility to bacterial and fungal infections (Wanner 2011, pers. comm.). Conversely, an increase in stream temperature may reduce the prevalence of Bd since the fungus thrives at cooler temperatures such as those in Ozark streams (Briggler 2020b, pers. comm.).

Threats Summary

Impoundments reduced the size of the North Fork White River/Bryant Creek population and likely extirpated any populations occurring in the upper portion of the White River. While some individuals have been found in the White River mainstem, species experts do not consider them to represent a viable population due to the hypolimnetic releases from the reservoirs that release lower temperature water, lower dissolved oxygen levels, and create extreme water fluctuations. The lakes continue to impact the North Fork White River/Bryant Creek population by causing backflow and sedimentation during flood events. Collection for scientific research and for the pet trade also had a significant effect on Ozark hellbender populations with records of over 650 individuals removed from the wild from 1969 to 1989[1]. However, despite the continued market for Ozark hellbenders in the illegal pet trade and evidence of recent illegal searches for hellbenders, we do not consider illegal collection as a primary threat that continues to substantially impact populations as long as the exact locations of occupied sites remain restricted.

Degraded water quality from chemical spills and overflow from a waste water treatment plant likely impacted the Ozark hellbenders in the Spring River. However, it is unclear if degraded water quality was the primary factor causing the population to decline. Various pollutants such as estrogenic compounds and elevated levels of nitrogen and phosphorus have been documented in other Ozark hellbender streams. Similarly, it is unclear if degraded water quality or chemical pollutants have contributed to population declines in these streams. Given that hellbenders are long-lived and thus exposed to contaminants for a longer period of time than some other species, and because they are more likely to absorb contaminants due to their permeable skin, additional work is needed to evaluate whether water quality may be a factor contributing to ongoing population declines.

The two factors that species experts believe are most contributing to ongoing population declines are sedimentation and amphibian chytrid fungus (*Bd*). Sedimentation in the form of both fine and coarse sediment (gravel) has many sources and degrades habitat of all life stages by covering rocks and filling in interstitial spaces. Excessive sedimentation can also cover and suffocate eggs, increase stream temperatures, and increase exposure to chemicals in the water column. *Bd* has been confirmed in all Ozark hellbender populations that have been sampled[2] and documented in specimens collected as early as 1969, which is prior to the period Ozark hellbender population declines were observed. While the specific effects of *Bd* infection in wild Ozark hellbenders is not clear, species experts believe the fungus may increase the vulnerability of hellbenders to secondary bacterial and fungal infections and thus be associated with the severe physical abnormalities observed on many animals (see Chapter 3).

As noted in Chapter 3, most Ozark hellbenders captured are large adults, and little recruitment is observed in the wild. Whatever factor(s) may be responsible for the population declines, it appears that it is affecting Ozark hellbenders sometime after the larvae leave the nest[3] but before they reach adulthood.

[1] This includes the 100 individuals that Trauth (1992) reported as having been removed from the Spring River.

[2] The only population that has not been sampled is the Spring River population. Because no hellbenders have been captured since 2006, we cannot say whether or not the fungus was present in the population.

[3] As noted in Chapter 3, successful fertilization and hatching of eggs appear to be occurring based on observations during monitoring of nests (Briggler 2018, pers. comm.)

CHAPTER 5. CONSERVATION MEASURES

The following conservation efforts have either been or are currently being conducted to help recovery the Ozark hellbender.

Ozark Hellbender Working Group

Formed in 2001, the Ozark hellbender Working Group is comprised of individuals from Federal and State agencies, academia, zoos, nonprofit organizations, and others interested in the conservation of the subspecies. The Ozark hellbender Working Group has played a significant role in identifying information needs and guiding conservation efforts for Ozark hellbenders, which includes development of a comprehensive conservation strategy (Briggler et al. 2010).

Population Monitoring

The severe decline in Ozark hellbender populations was first recognized in the late 1990s (Trauth et al. 1992, Wheeler et al. 2003). Subsequently, the Arkansas Game and Fish Commission and Missouri Department of Conservation have been conducting regular surveys to monitor populations and assess the overall health of animals. The survey protocol implemented by Missouri Department of Conservation allows for calculating detection rates, estimating population sizes, and projecting population trends (Calfee et al. 2009). Population monitoring by both State agencies also includes checking nest boxes for individuals and eggs and in some instances, monitoring larvae when nests are found. Additional partners include the National Park Service's Ozark National Scenic Riverways, the U.S.D.A. Forest Service's Mark Twain National Forest, and the Service.

Captive Propagation and Augmentation

The captive propagation program was initiated in 2002, and in 2011, adults successfully bred in captivity at the Saint Louis Zoo (Ettling et al. 2013). Since then, adults from the North Fork White River, Eleven Point River, and Current River have all bred at the Saint Louis Zoo, resulting in successfully fertilized eggs. As of result of captive breeding, collecting eggs from the wild, and head-starting efforts, approximately 7,038 Ozark hellbender larvae and juveniles have been released back into the wild, with 2,357 individuals released into the North Fork White River, 1,451 in Bryant Creek, 1,820 in the Eleven Point River (in both states), and 1,410 in the Current River (Briggler 2019c, pers. comm.).

The captive propagation program has been guided by an interagency propagation, augmentation, and reintroduction plan (Briggler et al. 2012). The plan provides standardized protocols for captive propagation, including collection of brood stock, eggs, and head-starting of young, and standardized protocols to facilitate augmentation and reintroduction. The plan also provides guidelines for using captive-reared individuals for applied research activities to address the causes for decline and helps ensure effective communication and coordination among partners.

Though the long-term success of the propagation efforts has yet to be determined, propagated individuals have successfully bred at the Saint Louis Zoo (Briggler 2019c, pers. comm.), indicating that propagated individuals in the wild have the ability to also successfully reproduce. Some captive-reared individuals have also been captured in in the wild during monitoring surveys. Augmenting the populations will allow the continued persistence of the Ozark hellbender, at least in the near term. Bolstering the populations also will provide additional time as well as individuals to use for research to better understand and address the factor(s) contributing to population declines. In addition, collecting eggs from the wild and

rearing the larvae results in higher survivorship rates than in the wild, which will help to maintain genetic diversity while identifying and addressing population declines. Propagation efforts for the Ozark hellbender have been a collaborative effort led by the Saint Louis Zoo and Missouri Department of Conservation with assistance from the Arkansas Game and Fish Commission, Ozark National Scenic Riverways, Mark Twain National Forest, and the Service.

Augmentation of Nesting Habitat

Artificial nest boxes were developed by Briggler and Ackerson (2012) to provide nesting habitat for hellbenders and to also provide an efficient way to collect eggs for captive rearing. For the same reasons, the nest boxes are used in the captive breeding program. The nest boxes have substantially increased the number of egg clutches found in the wild and have also reduced the amount of habitat disturbance to find and collect them. To date, 9 nest boxes have been augmented into the North Fork River, 98 have been placed in the Eleven Point River in Missouri and Arkansas, and 34 have been placed into the Current River (Briggler 2019c, pers. comm.; Irwin 2020, pers. comm.).

Protecting Populations and Habitat

The Missouri Department of Conservation, Arkansas Game and Fish Commission, and the Service review projects potentially affecting Ozark hellbenders and make recommendations to minimize or mitigate for adverse effects. The Service reviews proposed projects having a Federal nexus (i.e., authorized, funded, or carried out by a Federal agency) under section 7 of the Endangered Species Act; whereas the state agencies often review projects with no Federal nexus. BMPs were developed by Missouri Department of Conservation and include specific recommendations for activities occurring in or near Ozark hellbender streams. To protect populations from illegal collection, disclosure of specific locations of Ozark hellbender sites is limited and law enforcement and private landowners monitor sites for suspicious activity. Involved partners include the Missouri Department of Conservation, Arkansas Game and Fish Commission, Ozark National Scenic Riverways, Mark Twain National Forest, the Service, and U.S. Army Corps of Engineers.

Disease Assessment and Treatment

Due to the prevalence and severity of physical abnormalities found in Ozark hellbender populations [1], considerable effort has been focused on understanding the cause of these abnormalities as well as other diseases that may be compromising animal health. External microorganisms associated with injured or necrotic tissue have been identified (Nickerson et al. 2011, Hernández-Gómez et al. 2017), and extensive necropsies and screenings have been performed on affected individuals. The microbial communities of captive and wild hellbenders have been compared (Hernández-Gómez et al. 2018a), and the influence of immunogenetics[2] has been evaluated (Hernández-Gómez et al. 2018b). Recent and ongoing monitoring surveys also incorporate sampling protocols for testing of fungal, bacterial, and viral pathogens; whereas museum specimens have been histologically examined to determine when the fungus first occurred in the populations (Bodinof et al. 2011). Additionally, methods to treat captive individuals infected with amphibian chytrid fungus have been explored, with heat treatment methods proving most successful (though adults that are physically compromised typically did not survive). Mitraconazole is also used to suppress *Bd* in Bd-positive animals maintained in outdoor habitat (Junge 2012). Involved partners include the Missouri Department of Conservation, Arkansas Game and Fish Commission, Saint Louis Zoo, the Service, and University of Tennessee.

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[1] With the exception of Bryant Creek, which has a low sample size.

[2] The relationship between a host's immune system and members of the microbiome.

Public Land and Other Protective Designations

Approximately 19% of the Ozark hellbender range is in public ownership, with the primary public landowners being the U.S.D.A. Forest Service, National Park Service, Missouri Department of Conservation, and Arkansas Game and Fish Commission (Fig 4-2). Another 3% of the species' range is owned by conservation organizations (The Nature Conservancy, L-A-D Foundation, and Ozark Regional Land Trust), which we refer to as "Conservation Lands"(Fig. 5-1). The percentage of public and conservation lands within each watershed is provided in Table 5-1. Public and conservation lands benefit stream health, and thus Ozark hellbenders, because their management typically results in less sedimentation and other contaminants into streams, especially when the lands are immediately adjacent to streams.

The Ozark National Scenic Riverways, managed by the National Park Service, protects 134 mi (216 km) of the Current and Jacks Fork rivers. In addition, 48 mi (71 km) of the total 138 mi (222 km) of the Eleven Point River is protected under the Wild and Scenic River Act, with the adjacent land protected by scenic easements. These protections help maintain water quality and minimize additional sedimentation, which reduce the quantity and quality of Ozark hellbender habitat.

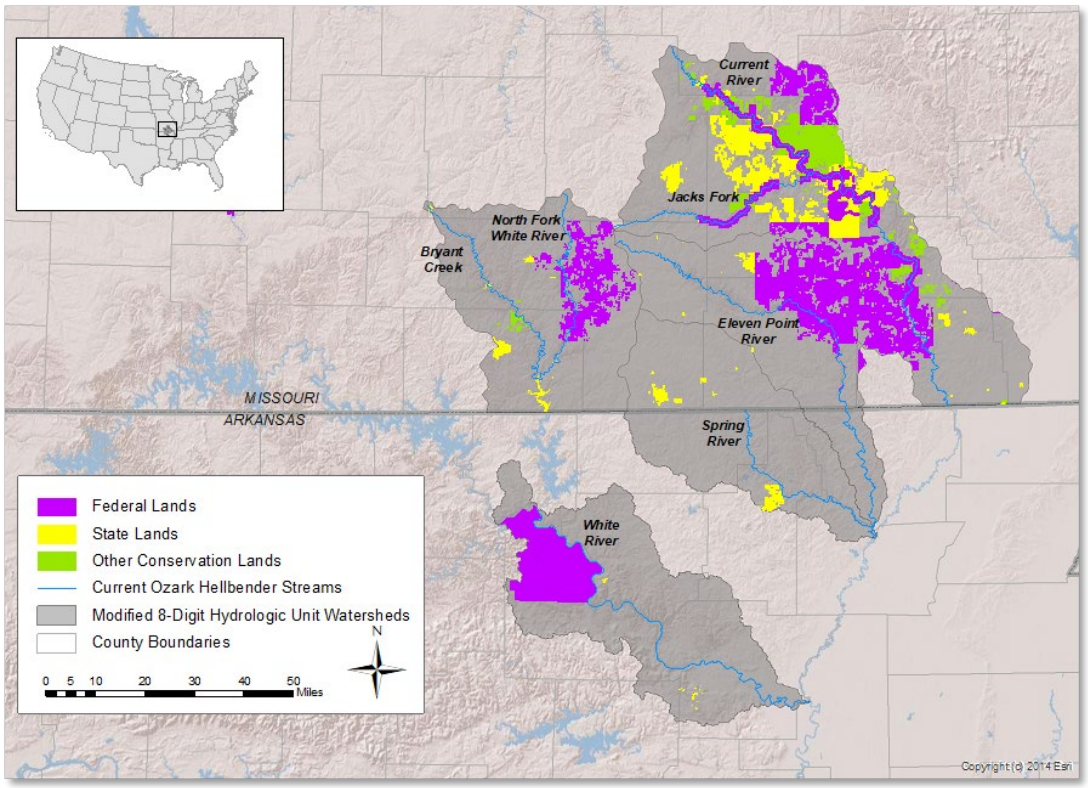

Figure 5-1. Public and other conservation lands within watersheds of presumed Ozark hellbender streams.

Table 5-1. Percentage of public or conservation land within each Ozark hellbender watershed.

Watershed	Percentage of Public or Conservation Lands in Watershed
North Fork White River (in Missouri)	14%
White River (Middle Fork)	15%
Spring River	2%
Eleven Point River	19%
Current River	39%

Other Efforts

Numerous other measures have focused on understanding the causes underlying Ozark hellbender declines or addressing potential threats. These measures include: investigating predation by non-native fish (Gall and Mathis 2010a, Gall and Mathis 2010b), assessing the sperm quality of wild and captive individuals (Unger et al. 2013; Crabill and Briggler 2016, unpublished data), monitoring survivorship of captive-reared individuals (Bodinof et al. 2012b), assessing hematology (Huang et al. 2010), evaluating the effects of electrofishing on various hellbender life stages (Morrison 2019), evaluating movement patterns of released captive-reared individuals (Bodinof et al. 2012a), examining reproductive hormones and heavy metal levels (Huang et al. 2010), evaluating the microbiome of hellbenders (Hernández-Gómez et al. 2017, Hernández-Gómez et al. 2018a, Hernández-Gómez et al. 2018b), adding both Ozark and Eastern subspecies of hellbenders to the Appendix III list for the Convention on International Trade in Endangered Species of Wild Fauna and Flora (USFWS 2011b), preparing outreach materials, developing a Population and Habitat Viability Analysis (Briggler et al. 2007), and multiple genetic studies (Sabatino and Routman 2009, Crowhust et al. 2011, Tonione et al. 2011, Feist et al. 2014, Hime 2017).

CHAPTER 6. OZARK HELLBENDER VIABILITY

For the purpose of this Biological Report, we generally define viability as the ability of the Ozark hellbender to sustain populations in the wild over time. “Over time” means beyond specified time periods that are as long as possible given our ability to predict future conditions and that are biologically meaningful considering the life history of the species.

Population and Habitat Viability Analysis (2007)

At the request of the Saint Louis Zoo’s Wildcare Institute, the Conservation Breeding Specialist Group (CBSG) facilitated a Population and Habitat Viability Analysis (PHVA) for the Ozark and eastern hellbender in August 2006. Thirty workshop participants explored threats to hellbender populations and developed management actions aimed at understanding and halting their decline. Using the software program Vortex (v9.61), the CBSG team prepared and presented a baseline model for hellbender populations and worked through input parameters with participants to optimize the model and determine current and projected mean population sizes for all current populations in 75 years (Briggler et al. 2007).

Based on the model, hellbender experts concluded that the Ozark hellbender subspecies (referred to as “metapopulations” in the PHVA) and each population are expected to decline by more than 50% in 12 to 16 years (Fig. 6-1). Viability of all individual populations will be significantly reduced within 20 to 25 years with estimates of fewer than 100 individuals, and a reduction in genetic diversity by as much as 90% will occur. Additionally, the risk of population extinction is predicted to be high and occur within 40 to 50 years (Fig. 6-2). Without additional management, these models projected the Ozark hellbender subspecies to be functionally extinct within 20 years (Briggler et al. 2007).

The PHVA projections may be optimistic because they are based on best-case density estimates and assume that hellbender populations within each river system are continuous. Hellbenders do not travel great distances, however, and subpopulations within each river system are often separated by miles/kilometers of unsuitable habitat resulting in fragmented populations. Also, the effect of amphibian chytrid fungus on hellbenders was not taken into consideration. However, the model may be pessimistic in that population sizes appear to be larger than what was estimated for the model. A more recent population viability analysis using updated population estimates and considering effects from an increase in threats is needed.

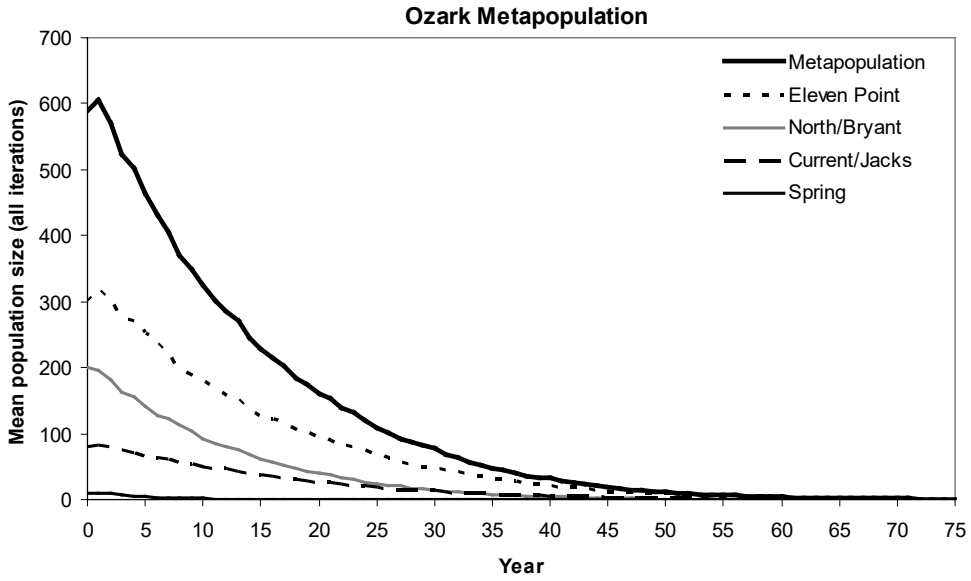

Figure 6-1. Projected mean population size for the Ozark hellbender subspecies (referred to as the "metapopulation") and for each Ozark hellbender population over the next 75 years (taken from Briggler et al. 2007). Estimates of population sizes from 2014 are larger than those used for the PHVA. Thus, the time for population size to reach zero is likely longer, assuming the trajectory still ultimately reaches zero.

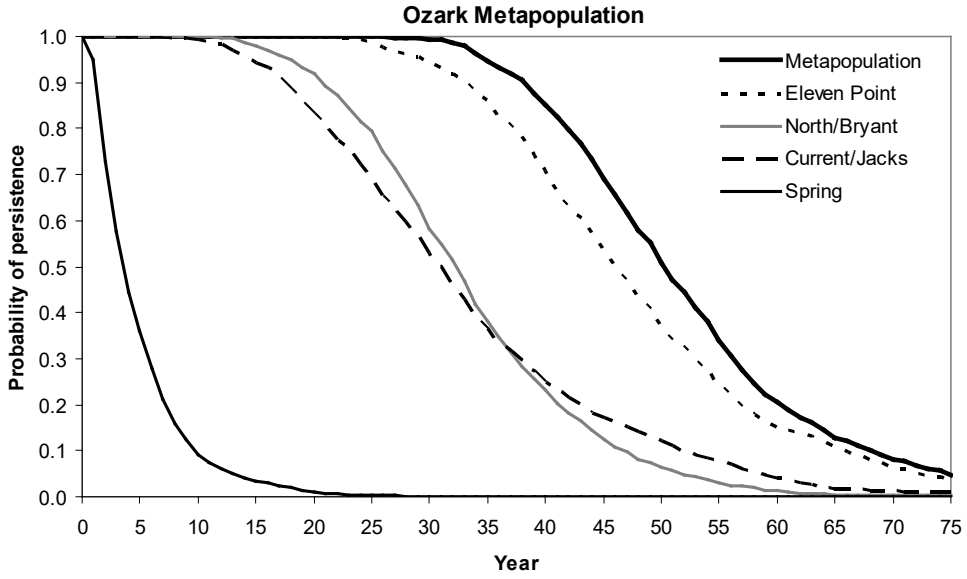

Figure 6-2. Probability of persistence for the Ozark hellbender subspecies (referred to as the "metapopulation") and for each Ozark hellbender population over the next 75 years (taken from Briggler et al. 2007). Current estimates of population sizes from 2014 are larger than those used for the PHVA, so the probability of persistence trajectory may be overly pessimistic.

Resiliency, Redundancy, and Representation

As an additional way to assess the Ozark hellbender's viability, we applied the conservation biology principles of resiliency, representation, and redundancy (Shaffer and Stein 2000), in conjunction with an assessment of the threats acting on the species. A discussion of the Ozark hellbender's requirements and the species' current condition for each of these measures is provided below and summarized in Table 6-1.

Resiliency

Resiliency is having healthy populations that can withstand stochastic events due to environmental stochasticity (normal variations in environmental conditions such as temperature and rainfall), demographic stochasticity (random fluctuations in birth rates), periodic disturbances (fire, floods, storms), and anthropogenic stressors. At the species level, Ozark hellbender resiliency is a function of the number of healthy populations and the distribution of the populations (requirements for a healthy population are described below). For many species, resiliency also requires connectivity among populations for gene flow and demographic rescue. Though Ozark hellbender populations all occur within tributaries of the Black River, we presume there is no movement among the tributaries based on a lack of suitable habitat in the Black River. The North Fork White River/Bryant Creek population is also separated from the White River mainstem and the other populations by the North Fork Reservoir. However, it appears that gene flow among major river drainages was limited historically (Sabatino and Routman 2009). Thus, connectivity among Ozark hellbender populations may not influence species-level resiliency.

For populations to be healthy, they require a healthy demography that has a positive population growth rate (influenced by recruitment and survivorship rates) and healthy population size. Though rates likely vary among populations, the following rates have been used to represent annual survivorship in modelling a stable hellbender population (including eastern hellbenders): 70-85% for adults, 67-75% for subadults, and 10% for early life stages (eggs and larvae)(Briggler et al. 2007, Unger et al. 2013)(estimates recruitment rates for a healthy population are not available). Healthy Ozark hellbender populations also require habitat that supports a healthy demography. This consists of a sufficient amount of suitable habitat (see **Life History** in Chapter 2) as well as connectivity among occupied sites to allow for movement, gene flow, and recolonization of sites following local extirpations.

The Ozark hellbender has already lost some resiliency because the Spring River population is considered functionally extinct and 2 of the 3 remaining populations (Bryant Creek/North Fork[1] and Eleven Point River populations[2]) have each experienced drastic population declines of around 70%[3] (Wheeler et al. 2003). Health of each population is further compromised because many animals test positive for amphibian chytrid fungus (which we presume reduces their immune capacity) and a large percentage of individuals captured also exhibit severe physical abnormalities such as lesions and necrotic limbs (see **Abnormalities** in Chapter 4). Little recruitment is observed in the wild, indicating some stressor is also affecting survivorship of larvae or subadults. In addition, Ozark hellbender habitat has been degraded, primarily due to sedimentation. Thus, less habitat is available within sites as well as among sites, reducing the ability of individuals to move among sites. Though propagated Ozark hellbenders are being

[1] Bryant Creek is considered part of the North Fork White River population due to the historical and possibly current connection between the population.

[2] Though Ozark hellbender individuals have been captured in the White River mainstem and the Black River, we do not consider these rivers to contain populations of the species.

[3] Though no information is available on the historical abundance of Ozark hellbenders in the Current River, we presume that there also has been a decline in this population based on the low abundance currently, especially related to the amount of available habitat.

augmented into each of the 3 remaining populations, the success of these efforts remains unclear as few propagated individuals are captured during monitoring surveys (in part because small individuals are less likely to be captured and because monitoring surveys are conducted less frequently now to minimize disturbance to habitat). Given these considerations, we consider the health of each of these populations to be low and the Ozark hellbender to have low resiliency to withstand stochastic events.

Redundancy

Redundancy is having a sufficient number of populations for the species to withstand catastrophic events such as a rare destructive natural event or episode involving many populations (such as disease). For the Ozark hellbender, redundancy involves having multiple, healthy populations to withstand catastrophic events. Events that could result in catastrophic losses to one or more Ozark hellbender populations include chemical spills, disease, and extreme environmental events (such as flooding or drought).

For chemical spills, having at least 2 populations is likely sufficient to guard against extinction because only one population is likely to be affected by a chemical spill. However, for extreme environmental events, a greater number of healthy populations will ensure more protection against extinction because all of the populations occur in a relatively small geographic area and could be affected by the same environmental events. For example, excessive rainfall in the Ozarks resulted in a historic flood event during the spring of 2017. All 3 of the rivers containing Ozark hellbender populations experienced record flooding (Heimann et al. 2018). The North Fork River, which has been considered the stronghold of the species, was the most severely affected. Large swaths of riparian habitat were removed due to velocity of the floodwater, and substantial damage to hellbender habitat occurred. The population size for the entire North Fork White River was estimated to be reduced by at least 50% (Briggler 2018).

Multiple populations are also needed to protect against extinction due to disease. Though there is no natural movement of Ozark hellbender individuals among populations, there are a number of routes that could transmit pathogens among populations such as the release of unused live bait, the use of boats and other equipment among multiple rivers, and natural transmission due to the movement of other amphibians and wildlife.

Ozark hellbender redundancy has already been reduced by the loss of the Spring River population. Though 3 populations remain, none of the populations are considered healthy due to the reduction in population sizes, limited recruitment observed, and poor health of many individuals (as described above). These factors further reduce the Ozark hellbender's ability to withstand catastrophic events.

Representation

Representation is having the breadth of genetic makeup of the species to adapt to changing environmental conditions, also referred to as adaptive capacity. Representation can be measured through the genetic diversity within and among populations or the ecological (also called environmental variation or diversity) or behavioral diversity of populations across the species' range.

Results from mitochondrial and microsatellite analyses indicate a relatively low level of diversity within Ozark hellbender populations, but significant differentiation is present among populations (Sabatino and Routman 2009, Crowhurst et al. 2011, Tonione et al. 2011). Based on these analyses, 3 distinct genetic lineages have been identified: 1) the North Fork White River and Bryant Creek, 2) the Spring River, and 3) the Eleven Point and Current rivers. Though Ozark hellbender populations in the Eleven Point and

Current rivers cluster together genetically (Sabatino and Routman 2009, Crowhurst et al. 2011, Tonione et al. 2011), populations in these 2 rivers exhibit substantial genetic differentiation (Crowhurst et al. 2011).

Based on the genetic differentiation among the 3 populations, we consider each of the populations as contributing to the species' adaptive capacity. Because changing environmental conditions are difficult to predict and because it is unclear what genetic (or ecological) diversity will be necessary, it is unclear how much genetic and ecological diversity is required for the Ozark hellbender to be able to adapt to changing environmental conditions. However, we can assume that the greater the number of populations and the greater the health of populations, the greater the adaptive capacity of the Ozark hellbender. As with other species, maintaining Ozark hellbender adaptive capacity also requires preserving the processes that allow for evolution to occur: gene flow, genetic drift, and natural selection. Because Ozark hellbender populations are not connected, and perhaps never were historically (Sabatino and Routman 2009), we do not consider gene flow among populations to influence the species adaptive capacity.

Representation, or adaptive capacity of the Ozark hellbender has already been reduced due to the loss of the Spring River population. The Spring River population exhibited different ecology in that animals were much larger than those in other rivers (Peterson et al. 1988) and the breeding season was primarily January instead of mid-September through October (Peterson et al. 1989, Johnson 2000, Briggler 2014, pers. comm.). Thus, the Spring River population would have likely provided valuable adaptive capacity for the species. As with resiliency and redundancy of the species, adaptive capacity has been further reduced due to the poor health of the populations. However, each of the 3 remaining populations exhibits genetic substantial differentiation, which contributes to the Ozark hellbender's adaptive capacity. As noted above, changing environmental conditions are difficult to predict and it is unclear what genetic (or ecological) diversity will be necessary. Thus, it is unclear if the Ozark hellbender has sufficient representation to adapt to changing environmental conditions. Because populations of the Ozark hellbender are currently smaller and occupied habitat patches are more isolated, the processes of genetic drift and natural selection have likely been hindered.

Table 6-1. Summary of the Ozark hellbender's viability needs and the current condition of these measures.

Viability Metric	Viability Need	Current Condition
Resiliency	A function of the number of healthy populations and the distribution of the populations. Healthy populations require a healthy demography, habitat that supports a healthy demography, and connectivity among occupied sites.	Resiliency is considered to be low based on the loss of the Spring River population and reduced health of the remaining 3 populations (extreme population declines, degraded habitat, limited recruitment observed, and poor health of individuals).
Redundancy	Multiple, healthy populations to withstand catastrophic events.	Redundancy has been reduced due to the loss of the Spring River population. Redundancy is further reduced because none of the 3 remaining populations are considered healthy.
Representation	1) Multiple, healthy populations to be able to adapt to changing environmental conditions 2) Preservation of the processes that allow for evolution to occur (primarily genetic drift and natural selection).	Representation has been reduced due to the loss of the Spring River population and because none of the 3 remaining populations are considered healthy. However, there are genetic differences among the existing populations, indicating the species may have some capacity to adapt to changing environmental conditions. Because populations of the Ozark hellbender are currently smaller and occupied habitat patches are more isolated, the processes of genetic drift and natural selection have likely been hindered.

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APPENDIX A. SURVIVORSHIP ESTIMATES FOR DIFFERENT HELLBENDER LIFE STAGES

Stage	Annual Survivorship Estimate (%)[1]	Subspecies	Source	Comments
Larval: Egg[2] to Year 1	10	Ozark & Eastern	Briggler et al. 2007[3]	Rates based on general amphibian demography
Larval: Egg[2] to Year 1	10	Eastern	Unger et al. 2013	Baseline survivorship based on other larval amphibian survivorship estimates
Larval: Year 1 to 2	40	Ozark & Eastern	Briggler et al. 2007	Rates based on general amphibian demography
Larval: Year 1 to 2	10	Eastern	Unger et al. 2013	Baseline survivorship based on other larval amphibian survivorship estimates
Subadult: Year 2 to 3	50	Ozark & Eastern	Briggler et al. 2007	Rates based on general amphibian demography
Subadult: Year 2 to 3	75	Eastern	Unger et al. 2013	Based on subadult survivorship (6-year olds) from Bodinof et al. 2012 and adjusted to reflect survivorship of non-translocated individuals (i.e., potential increased mortality from surgery complications or unfamiliarity with release sites)
Subadult: Year 3 to 6	67	Ozark & Eastern	Briggler et al. 2007	For year 3 to 5, rates based on general amphibian demography. For year 5, rate based in part on Peterson et al. (1983, 1985, 1988)
Subadult: Year 3 to 6	50-70	Ozark	Bodinof et al. 2012	Results from radio-telemetry
Subadult: Year 3 to 6	75	Eastern	Unger et al. 2013	Values from Bodinof et al. 2012 adjusted to reflect survivorship of non-translocated individuals (i.e., potential increased mortality from surgery complications or unfamiliarity with release sites)
Subadult: Year 3 to 6	53	Eastern	Kraus et al. 2017	Results from radio-telemetry; rates reflect cumulative estimated survival and ranged from (26-100%)
Adult: Year 6+	85-88	Ozark & Eastern	Briggler et al. 2007	Based in part on Peterson et al. (1983, 1985, 1988); range of values reflects the difference between genders after year 8
Adult: Year 6+	87	Ozark	Wheeler 2007	Based on mark-recapture studies
Adult: Year 6+	81	Ozark	Peterson et al. 1983[4]	Based on survivorship curves from length-age relationships and age (size) distributions
Adult: Year 6+	80	Eastern	Olson et al. 2013/ Unger et al. 2013	Results from radio-telemetry

Stage	Annual Survivorship Estimate (%)[1]	Subspecies	Source	Comments
Adult: Year 6+	97	Eastern	Kraus et al. 2017	Results from radio-telemetry; rates reflect cumulative estimated survival and ranged from (91-100%)

[1] Values represent annual survivorship during the defined time period.
[2] Only includes fertilized eggs.
[3] Values from Briggler et al. 2007 represent expected survivorship rates for a stable population.
[4] Estimated rates are likely substantially lower than actual survivorship rates given that the equal catchability assumption, an important assumption of the model used to generate survivorship estimates, was violated.

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APPENDIX B. THREAT ASSESSMENT FOR THE OZARK HELLBENDER

The following threats assessment for the Ozark hellbender was developed by the Ozark hellbender Recovery Planning Team[38] to better understand the relative impacts of various threats affecting the species. Threats are categorized under each of the factors used to evaluate species for listing under the Endangered Species Act, as defined below, and were characterized according to the process or event by which it causes a negative impact (the stressor) and the geographic extent to which it occurs (geographic scope). In some instances, the expected impact is also included with the stressor description. Using these characterizations, the team assigned each threat an overall threat level and also identified the potential for management actions to alleviate each threat. This information, combined with the overall threat level, was used to guide prioritization of recovery actions.

Listing Factors:
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
E = Other natural or manmade factors affecting its continued existence

Scope:
Localized = One watershed
Widespread, but scattered = Multiple watersheds, but not present at all sites
Pervasive /Omnipresent = All rivers, all sites
Uncertain = Scope unknown

[38] The team was an officially-designated Fedreal Recovery Team and consisted of Dr. Jeffrey Briggler (Missouri Department of Conservation)(team co-lead), Kelly Irwin (Arkansas Game and Fish Commission), Dr. Jeffery Ettling (Sedgwick County Zoo; previously Saint Louis Zoo), Mark Wanner (Saint Louis Zoo), Chris Davidson (U.S. Fish and Wildlife Service), Theresa Davidson (Mark Twain National Forest), and Victoria Grant (Ozark National Scenic Riverways), and Trisha Crabill (U.S. Fish and Wildlife Service)(team co-lead).

Listing Factor	Threat	Stressor	Geographic Scope	Overall Threat Level	Management Potential	Comments
A	Impoundments	Loss of habitat upstream of dams (specifically for the North Fork White River) for all life stages due to sediment deposition	Localized	High	Medium	This pertains mainly to the North Fork White River
A	Impoundments	Increased predation by native and non-native fish due to pooling of water above the impoundments	Localized	Moderate	Medium	This pertains mainly to the North Fork White River
A	Impoundments	Possible changes in temperature and dissolved oxygen	Localized	Low	Medium	This pertains mainly to the North Fork White River
A	Gravel Mining	Sedimentation - Loss of habitat for all life stages through sedimentation from streambed destabilization	Widespread, but scattered	Moderate	Medium (due to activities that don't require permits)	Not occurring at hellbender sites, but effects are observed via sedimentation when the gravel mining destabilizes steams; also leads to increased water temperature
A	Sedimentation	Loss of habitat for all life stages	Omnipresent	High	High	Addressing sedimentation will be a long-term effort and require a large amount of funding; reducing sedimentation may also take a long time to occur given the large quantities of gravel already in transport within the river systems
A	Agricultural Practices	Sedimentation from riparian conversion; also reduced water quality from nutrients and other pollutants, such as pharmaceuticals	Widespread but scattered	Medium	Medium	Particularly an issue in the Eleven Point River in Arkansas; medium management potential because not all landowners may be interested in participating in landowner incentive programs

Listing Factor	Threat	Stressor	Geographic Scope	Overall Threat Level	Management Potential	Comments
A	Unpaved Roads	Sedimentation	Pervasive	Moderate	High	Overall threat level could be medium or high, depending on the amount that unpaved roads are contributing to the sediment issues
A	Development adjacent to streams (houses, boat ramps, and other recreational development)	Increased sedimentation, hardening of stream banks, construction of septic tanks, and increased temperatures due to loss of riparian habitat,	Widespread but scattered	Low	Medium	High management potential on public lands, not as much potential on private lands
A	Water quality	Nutrients	Omnipresent	Moderate	Uncertain	There doesn't appear to be an issue with dissolved oxygen
A	Water quality	Chemical contaminants (heavy metals, **pharmaceuticals**, spill, de-icing materials)	Omnipresent	Uncertain	Uncertain	
A	Excessive Recreational Disturbance (motorized and non-motorized boating, ATVs),	Sedimentation from (motorized boats, horse use, ATVs)	Omnipresent	Low	Medium	High management potential on public lands, not as much potential on private lands
A	Excessive Recreational Disturbance (motorized and non-motorized boating, ATVs),	Nutrients	Pervasive	Uncertain	Unknown	
A	Excessive	Chemical contaminants	Pervasive	Uncertain	Unknown	

Listing Factor	Threat	Stressor	Geographic Scope	Overall Threat Level	Management Potential	Comments
	Recreational Disturbance (motorized and non-motorized boating, ATVs),					
B	Illegal Collection	Removal of individuals from the population	Localized	High	Medium	The threat may increase as more animals are released
B	Illegal searching at hellbenders	Habitat disturbance	Localized	High	Medium	The threat may increase as more animals are released
B	Gigging	Injury or mortality	Omnipresent	Uncertain	Medium	Regulations could be changed, but enforcement is difficult. Outreach could increase management potential
B	Other incidental take (catching hellbenders on trotlines)	Mortality or Injury	Omnipresent	Uncertain	Medium	Outreach would increase management potential
B	Electrofishing	Injury, mortality, or reduced reproduction, reduced fitness, etc.	Widespread, but scattered	Uncertain	High	
C	Disease (*Bd*, Ranavirus, etc.)	Reduced fitness, Direct mortality	Omnipresent	High	Unknown	Management potential is unknown because certain aspects cannot be managed. However, if certain size classes are more vulnerable, the effects could be managed by propagation efforts (e.g., rearing young to life stages not as vulnerable).
C	Predation (non-native, and possibly native, predators)	Direct mortality, Injury, Reduced fitness	Pervasive	Uncertain	High	
C	Unknown source causing physical abnormalities	Reduced fitness, Potential mortality	Pervasive/ Range wide	High	Unknown	Further investigations will help us better understand causes; causes most likely disease or compromised immune capacity

Listing Factor	Threat	Stressor	Geographic Scope	Overall Threat Level	Management Potential	Comments
D	Inadequacy of Existing Regulatory Mechanisms	Degradation of water quality from factors not regulated under the Clean Water Act	Omnipresent	Uncertain	High	The overall threat level and thus management potential is uncertain because it is unclear how reduced water quality may have affected Ozark hellbender health in the past or how it may currently be affecting their health
D		Illegal collection (and thus removal of animals from the population) because low fine amounts are not an effective deterrent	Omnipresent	Uncertain	Medium	Fines for illegal collection of Ozark hellbenders could be increased through legislation. However, management potential is considered medium because higher fines are unlikely to be a complete deterrent for all offenders.
E	Unknown/multiple sources	Small, isolated populations resulting in reduced genetic diversity, increased vulnerability to stochastic events	Omnipresent	High	High	Augmenting populations and habitat may be used to create more connectivity among sites; propagation may also be used to maintain genetic diversity
E	Unknown/multiple sources	Reduced recruitment resulting in reduced genetic diversity and Increased vulnerability to stochastic events	Omnipresent	High	Medium	Captive propagation could be used to augment smaller size classes; habitat also may be augmented to create additional nesting and juvenile habitat; addressing threats that affect smaller size classes also may address this threat/stressor; however, depending on the source of the stressor/threat, management may not be able to address the threat (e.g., propagation can maintain the population in the wild but may not be able to allow for recovery)
E	Climate Change	Reduced water levels, increased water	Omnipresent	Uncertain	Low	Could restore riparian corridors to help prevent reduction of water temperatures

Listing Factor	Threat	Stressor	Geographic Scope	Overall Threat Level	Management Potential	Comments
		temperature, reduced dissolved oxygen, increased variability in the hydrologic regime				