Species Status Assessment Report

for the

Ozark pyrg (*Marstonia ozarkensis*)

Ozark pyrg shell, scale bar is 1mm, credit Robert Hershler (1994).

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Executive Summary

The Ozark pyrg (*Marstonia ozarkensis*) is a freshwater snail originally found in the White River near Cotter, Arkansas and North Fork White River near Norfork, Arkansas. The species was petitioned for federal listing under the Endangered Species Act of 1973, as amended (ESA), as part of the 2010 petition to list 404 aquatic, riparian, and wetland species from the southeastern United States by the Center for Biological Diversity (Center for Biological Diversity 2010, pp. 694-695). In September 2011, the U. S. Fish and Wildlife Service (Service) found that the petition presented substantial scientific or commercial information indicating that the listing of 374 species, including Ozark pyrg, may be warranted.

The Species Status Assessment (SSA) framework (USFWS 2016) is intended to be an in-depth review of the species' biology and threats, an evaluation of its biological status, and an assessment of the resources and conditions needed to maintain long-term viability. The intent is for the SSA report to be easily updated as new information becomes available and to support all functions of the Endangered Species Program from candidate assessment to listing to consultations and recovery. As such, the SSA report will be a living document used to inform decisions under the ESA.

The Ozark pyrg SSA is intended to provide the biological support for the decision on whether to propose listing the species as threatened or endangered and, if so, to determine whether it is prudent to designate critical habitat areas essential to its conservation. This report is not a decisional document by the U.S. Fish and Wildlife Service (Service); rather, it provides a review of available information strictly related to the biological status of the Ozark pyrg. A listing decision will be made by the Service after reviewing this document and all relevant laws, regulations, and policies. The results of a proposed decision will be announced in the Federal Register with appropriate opportunities for public input.

Using the SSA framework (Figure 1), we consider what the species needs to maintain viability (the species' ability to sustain populations in the wild over time) by characterizing the status of the species in terms of its redundancy, representation, and resiliency (USFWS 2016; Wolf et al. 2015).

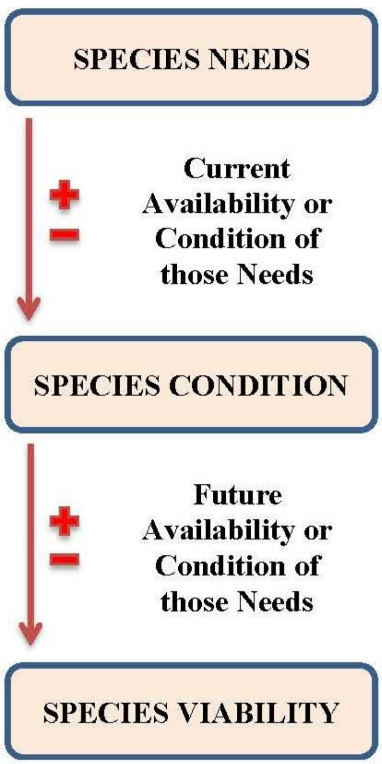

Figure 1. SSA Framework

- Resiliency is assessed at the population level and reflects a species' ability to withstand stochastic events (arising from random factors). Demographic measures that reflect population health, such as fecundity, survival, and population size, are the metrics used to evaluate resiliency. Resilient populations are better able to withstand disturbances such as random fluctuations in birth rates (demographic stochasticity), variations in rainfall (environmental stochasticity), and the effects of anthropogenic activities.

- Representation is assessed at the species' level and characterizes the ability of a species to adapt to changing environmental conditions. Metrics such as a species' adaptive potential and genetic and ecological variability can be used to assess representation. Representation is directly correlated to a species' ability to adapt to changes (natural or human-caused) in its environment.

- Redundancy is also assessed at the species level and reflects a species' ability to withstand catastrophic events (such as a rare destructive natural event or episode involving many populations). Redundancy is about spreading the risk of such an event across multiple, resilient populations. As such, redundancy can be measured by the number and distribution of resilient populations across the range of the species.

To evaluate the current and future viability of Ozark pyrg, we assessed a range of conditions to characterize the species' redundancy, representation, and resiliency (together, the 3Rs). This report provides a thorough account of biology, natural history and assesses the risk of threats and limiting factors affecting the future viability of the species.

This report includes: (1) a description of Ozark pyrg resource needs at both individual and population levels (Chapter 1); (2) a characterization of the historical and current distribution of populations across the species' range (Chapter 2); (3) an assessment of factors that contributed to the current and future status of the species and degree to which various factors influenced viability (Chapter 3); and (4) a synopsis of factors characterized in earlier chapters as a means of examining future biological status of the species (Chapter 4). This document is a compilation of the best available scientific information (and associated uncertainties regarding that information) used to assess Ozark pyrg viability.

Chapter 1 – Individual Needs: Life History and Biology

In this section, we provide basic biological information about the Ozark pyrg (*Marstonia ozarkensis*). As little is known about the species, we use data from other, better studied species within the genera *Marstonia* and *Pyrgulopsis* and family Hydrobiidae. We then outline the resource needs of individuals and populations.

1.1 Taxonomy

The family Hydrobiidae is found within the subclass Caenogastropoda of class Gastropoda (superfamily Rissoidea). Hydrobiidae are the most diverse freshwater gastropods, with over 1000 species (Delicado et al. 2013). Hydrobiids are classified as prosobranch snails; characteristics of prosobranchs include gills located near the front of their body, a spirally coiled shell, and a mantle cavity near the head that contains sensory and excretory organs, as well as the anus (Kabat and Hershler 1993, p. 5).

Hydrobiidae are generally found in freshwater habitats. Many species within the family appear to have restricted distributions, often associated with springs, and even more are known only from their respective type locality (Hershler 1994, p. 1; Watson 2000, p. 233). Information on hydrobiids is lacking in comparison to other mollusks, due to their small size and the need to differentiate between species morphologically, primarily by the male genitalia.

This species was first described as *Pyrgulopsis ozarkensis* from the North Fork White River near Norfork, Arkansas. It was recently shifted from the genus Pyrgulopsis to the resurrected genus Marstonia along with all eastern North American species previously placed in Pyrgulopsis (Thompson and Hershler 2002). This shift was based on genetic data from a majority of the species involved, which supports Marstonia as a separate monophyletic genus. However, no Marstonia ozarkensis genetic data was available for analysis (Hershler et al. 2003a).

The currently accepted taxonomy for this species is:

Phylum: Mollusca
Class: Gastropoda
Order: Neotaenioglossa
Family: Hydrobiidae
Genus: *Marstonia*
Species: *ozarkensis*

1.2 Description

Hydrobiid species are primarily identified by male genitalia (Thompson 1977, p. 114; Thompson and Hershler 2002, p. 269). Male *Marstonia ozarkensis* have a single ducted verge (penis) with elaborate patterns of glands on an apical crest. This snail has a narrowly conic, smooth, olive-tan shell with five whorls (Hinkley 1915, p 588; Hershler 1994, p. 78). The shell averages between 2.5 and 3 mm in height, and seldom exceeds 5 mm (Hinkley 1915, p. 588; Thompson 1977 p. 115; Hershler 1994, p. 78).

1.3 Reproduction

No specific life history data exists for this species. North American hydrobiids are sexually dimorphic, with the females larger than males (Hershler and Davis 1980, p. 209; Hershler and Landye 1988). Hydrobiid females are oviparous and are thought to deposit single eggs on hard substrates (Hershler 1998). After the eggs hatch, the small snails disperse throughout the habitat. Breeding is seasonal in cooler systems, as it is temperature dependent (Hershler 1984; Wells et al. 2012); in one spring species, breeding occurs between July and November (Wells et al. 2012).

1.4 Diet

No specific life history data exists for this species. Hydrobiids in general are nonspecific grazers, feeding primarily on periphyton and detritus (Dillon 2000; Wells et al. 2012, p. 70). *Pyrgulopsis* species feed primarily on algae, with detritus forming a lesser portion of their diet (Wells et al. 2012).

1.5 Age, Growth, Population Size Structure, and Fecundity

No specific life history, population demographic, and abundance data exists for this species. The average lifespan of hydrobiids is generally 9 to 15 months (Brown et al 2008; Wells et al. 2012). Sex ratios in hydrobiids are commonly skewed towards females. It is difficult to apply life-history information from other *Marstonia* and *Pyrgulopsis* species because many of the better-studied species are found in small, isolated springs in arid areas (Wells et al 2012).

1.6 Habitat

The holotype specimen was found in shallow water over bedrock (Hinkley 1915). Hydrobiids generally need highly oxygenated conditions (Wells et al. 2011, p. 69). Many species within the genus are adapted to springs, ponds, and other sensitive aquatic habitats (Hershler 1994). Some species show a preference for gravel and pebble substrates and shallower water depths (Martinez and Thome 2006; Mladenka 1992; Wells et al. 2011).

Chapter 2 – Population and Species Needs and Current Condition

In this chapter, we consider the historical distribution of the Ozark pyrg, its current distribution, and the factors that contributed to the species current condition. We first review the historical distribution of the species. Next, we evaluate species' requisites to consider their relative influence on Ozark pyrg representation and redundancy. We then analyze the threats to the watershed and how they may affect this species.

2.1 Species Needs and Population Needs

No studies have been completed on the life history or population dynamics of *Marstonia ozarkensis*. Factors that influence the abundance of hydrobiids in general include substrate size, stream shading, water velocity, and flood frequency. Females attach single eggs to solid substrates (Hershler 1994). Given the type locality and needs of other hydrobiid species discussed in Section 2, we assume this species needs shallow water over coarse substrate to survive and reproduce. Coarse substrates provide stable surfaces for egg deposition in flowing water, protect snails from high velocity water flow, and provide a suitable surface for periphyton growth (Stewart and Garcia 2002; Wells et al. 2012, p. 70).

Periphyton productivity has been associated with growth rates, fecundity, and secondary production (see review in Russell-Hunter 1983). Periphyton is easier to remove by scraping from a hard substrate, and contains higher concentrations of limiting nutrients such as nitrogen than other food sources (Russell-Hunter 1978, Aldridge 1983, Brown 2001).

2.2. Historical Distribution and Current Condition of Historical Habitat

The Ozark pyrg was historically found in a shoal of the White River near Cotter, AR and in the North Fork White River near the confluence (Hinkley 1915). There is one positive record for Ozark pyrg between discovery in 1915 and 2000. In 1997, a population in North Fork White River in Missouri was thought to be the last surviving population (Wu et al. 1997); however, the museum records cited for this population are not present in the museum database; we have no information about this collection or population. A "very limited" unpublished survey in the vicinity of the type locality in 1991 and 1992 found no individuals (Hershler, pers. comm.; Hershler 1994).

In the early 1940s, the Army Corp of Engineers (ACOE) built Norfork Dam approximately 7 kilometers north of Norfork, Arkansas, and impounded approximately 52 kilometers of the lower North Fork White River. This greatly changed the habitat at the type locality; dam releases create areas of cold water and low dissolved oxygen below the dams called tailwaters (Bayless and Vitello 2001). The drastically lowered temperature, lower dissolved oxygen, and presence of predatory trout in tailwaters makes it unlikely that *M. ozarkensis* could survive and reproduce.

The Norfork Dam tailwater extends the 8 kilometers between the dam and the confluence with the White River, including the type locality.

The White River is approximately 1,210 km long with a drainage basin of approximately 72, 520 square kilometers. There are eight dams along the length of the White River, built between 1913 and 1966. In total, over 241 kilometers of the main stem White River is classified at tailwater and is no longer suitable habitat for *M. ozarkensis*. The approximately 148 kilometers long Bull Shoals Dam tailwater greatly changed the habitat in the main stem White River, including at the 1915 Cotter Shoals collection site.

The North Fork White River above the lake in Missouri has been less affected by habitat degradation and may still support a *M. ozarkensis* population. However, no recent surveys have been completed in the area since Wu et al.'s (1997) record. Interestingly, one riverine species, *Marstonia arga*, has recently adapted to the impounded reaches of large rivers in Tennessee. No known survey efforts have sampled White River watershed impoundments for *M. ozarkensis*.

2.3 Current Condition of Population

Because so few studies or surveys for this species have been completed, the potential for Ozark pyrg populations to occupy habitats differing from the type locality warrants further sampling to determine the most suitable habitat features, or if the species even remains extant on the landscape. A 2006 survey for mollusks at randomly selected sites throughout the presumed range in Arkansas found a single hydrobiid snail that was identified as *M. ozarkensis* (Hayes 2010). The collection site (Mud Creek, Randolph County, Arkansas; Figure 2) is over 365 river kilometers from the type locality and is within the upper portion of the Lower Black River (a White River tributary) watershed, 184 kilometers upstream from the confluence of the White and Lower Black Rivers.

Speciation and high levels of genetic drift in hydrobiids have been exhibited both within and between watersheds (Hershler et al. 2003b; Liu and Hershler 2005; Hershler and Liu 2008; Liu et al. 2013). For example, *Marstonia halcyon* is endemic to a 100 km stretch of river in Georgia (Hershler 1994), and many other species are restricted to single springs or streams. Alternatively, *Marstonia comalensis* has been found at only 12 localities across four river basins in south-central Texas over a 20 year period. However, the authors recognize that the geographic range of *M. comalensis* is broadly disjunct relative to other species in the genus (Hershler and Liu 2011). Given that no historical or current records of *M. ozarkensis* exist between the two watersheds, the individual found in 2010 may be a morphologically similar undescribed species (D. Hayes, pers. comm.).

Hayes (2010, p. 91) surveyed 271 sites across all major drainages within the Interior Highlands of Arkansas, including 34 sites across the White River and North Fork White River watersheds, and found only three hydrobiid species, with fewer than three individuals per species and two or fewer sites per species. Hayes acknowledges that hydrobiid populations are easily overlooked, but “special effort” was put into the search for hydrobiids (Hayes 2010, p. 91). It is unknown if the Missouri population is still extant. If it is extant, we have no data about the current condition of the population.

Habitat fragmentation and drying have been related to diversification and speciation in other families of hydrobiid snails (Delicado et al. 2013). It is unlikely that the Mud Creek site is *M. ozarkensis* (D. Hayes, pers. comm.), but if it is, it is likely a small, isolated population. Only one individual was found, and hydrobiids generally occur in large numbers (greater than 100/site; Hayes 2010, p. 91).

2.5 3 R’s Analysis

Because of our lack of even basic information about the species and its current range or population, the degree of uncertainty is so high on current conditions that making reasonable projections of current or future conditions is impossible. Based on known collection data and the single extant potential site, redundancy and representation is currently very low or absent. Resiliency cannot be determined.

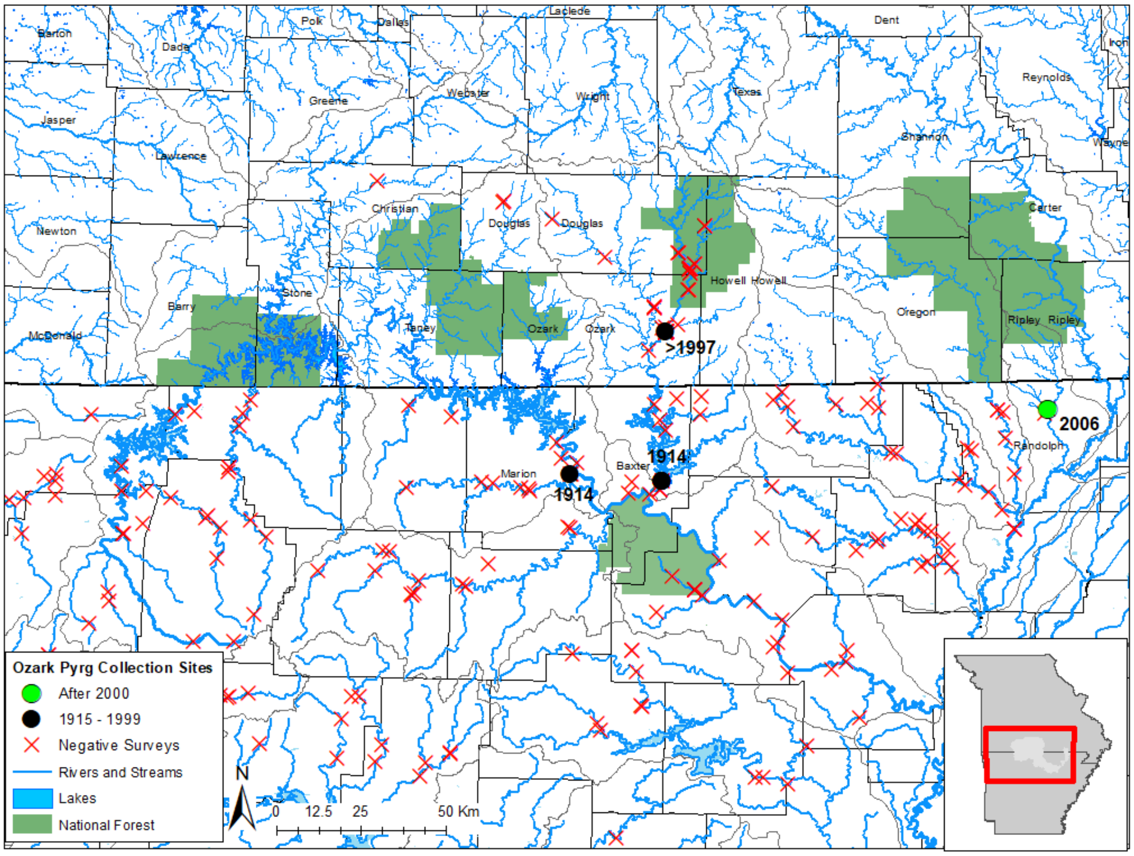

Figure 2. Range map of *Marstonia ozarkensis* including historical and current collection records in Arkansas and Missouri, USA.

Chapter 3 - Future Conditions

The intent of this analysis is to predict the persistence of Ozark pyrg populations in the future and to inform us of the species viability. Our ability to predict is limited due to a lack of any life history, range, or population data and our uncertainty about how Ozark pyrg populations respond to stressors. Thus, our analysis will be limited to a discussion of future changes in assumed stressors to the species, both the addition of new stressors and changes in the existing stressors.

3.1 Habitat Loss

The construction of Norfork Dam and Bull Shoals Dam in the mid-20th century likely inundated a large portion of the original habitat for the species and drastically changed the habitat downstream of both dams. Dam releases have shifted the downstream water temperature to cooler temperatures, spurred the introduction of a cold water fishery that includes predatory rainbow and brown trout, inundated shallow riffle habitat, and lowered dissolved oxygen concentrations (Berger and Kaster 1978, p. 511; Bayless and Vitello 2001; Brown 2001, p. 315). Impoundments also reduce the availability of periphyton food (Lodge and Kelly 1985, p. 111; Brown and Lydeard 2009, p. 291) and dramatically reduced overall mollusk diversity downstream of the dams (Gordon 1982). Mollusk surveys after the construction of the dams found no *M. ozarkensis* in the White River downstream of Bull Shoals Dam (Gordon 1982).

There are no current plans for additional large scale water control projects in either watershed, and it is unlikely that any will be developed in the future. Stressors associated with impoundments have already reduced the presumed historical range and isolated remaining populations. It is unlikely that additional stressors will be associated with the existing dams in the future, and given the economic benefit to the region it is unlikely that existing dams will be altered or removed to recreate suitable habitat.

3.2 Habitat Degradation

Degradation of water quality is likely the most significant threat to the species' continued survival. Because we are fairly certain that *M. ozarkensis* has a one year life cycle (Brown et al 2008), if the habitat or water quality deteriorates to the point where a single year's reproduction fails or is significantly reduced, the species is subject to drastic population decline or extirpation from the area. Habitat degradation can also cause habitat fragmentation, which can make gene flow and recolonization of extirpated sites difficult.

Threats include habitat modification from certain types of logging, agriculture (primarily livestock), mining, and various other point and nonpoint pollution discharges (Miller and Wilkerson 2001). Activities can have varying effects on water quality depending on the type of practice, and conservation practices exist that can reduce the negative effects of many of these stressors.

Mud Creek, the location of the most recent collection, converges with Fourche River, a tributary to the Black River, approximately 1.4 kilometers from the collection site. The entire length of Fourche River in Arkansas has been listed as a 303(d) impaired waterway for high turbidity loads and sediment levels. The majority of the sediment most likely comes from land surrounding the Fourche River, which is cleared for agriculture with little to no riparian vegetation. While it is probable that small amounts of sediment are mobilized through Mud Creek, forest makes up a higher proportion of the land cover surrounding the creek (Google Earth 2017).

Logging has long been associated with degraded water quality, primarily through increased in-stream sedimentation and turbidity, changes in nutrient cycling, and increased water temperature during and after a logging operation (Swank et al. 2001; Peterman and Semlitsch 2009 p. 12). Disruption of the ground surface by tree removal, skid trails or roads allows for soil erosion at greater than normal rates; this is often the primary producer of off-site sedimentation (Corbett et al. 1997, Grace III 2002). Most states with a commercial timber industry, including Arkansas and Missouri, have created Best Management Practices (BMPs) specific to timber harvest activities to protect water quality; the primary focus of forestry BMPs is to minimize timber harvest effects on water quality and aquatic habitat (Koirala 2009). These BMPs often include a streamside management zone (SMZ): an undisturbed buffer around all waterways that acts as a filter to sediment and slows surface runoff (Koirala 2009). Studies across the eastern United States have demonstrated that timber harvest causes an increase in sediment, discharge, and nutrients, but the implementation of BMPs with SMZs seems to be effective in reducing the effect of the harvest on water quality (Koirala 2009 p. 188, Peterman and Semlitsch 2009 p. 11, reviewed in Boggs et al. 2016 p. 12).

The North Fork White River watershed is primarily rural; pastures and rangeland comprise the second largest percentage of land use in the watershed. This watershed contains some of the primary cattle-producing areas for Missouri, and the density of cattle in this area is predicted to increase (Miller and Wilkerson 2001). Certain cattle practices, primarily unrestricted cattle access to streams and riparian areas, have been identified as a source of nonpoint source pollution; unrestricted cattle cause soil compaction, reduced riparian vegetation, increased in-stream disturbance through increased suspended sediment and associated contaminants, and actively contribute to bank erosion (Owens et al. 1996, Vidon et al. 2008). BMPs to restrict cattle access to streams and riparian areas, including exclusion fencing, off–stream water sources, and seasonal or rotational grazing, have been shown to greatly reduce sedimentation, soil loss, and sediment-bound pollutants such as nitrogen and phosphorus, and allow for revegetation of riparian buffers (Miner et al. 1992, Owens et al. 1996, Sheffield et al. 1997, Clary 1999). However, large scale implementation of fencing can be costly and difficult (Wilson and Clark 2007), and many landowners are unwilling to follow BMPs and maintain associated structures.

As of 1998, there were 22 permitted gravel mines in the North Fork White River watershed, with three active gravel mines near the 1997 record for the species. Limestone quarries, almost all of which are surface mines, can act as a direct link to the groundwater system. Gravel and sand is generally taken from streamside sites, and can have an even greater effect on the surrounding and downstream habitats. The negative effects of gravel mining have been shown to include channel deepening, sedimentation of downstream habitats, accelerated bank erosion, the formation of a wider and shallower channel, the lowering of the floodplain water table, and channel shift (Roell 1999). Mining is not a large stressor in the Fourche River watershed.

3.3 Reduced Gene Flow

Species with low vagility (ability of an organism to move throughout its environment) are restricted to migration between populations that are near neighbors (Colgan and Ponder 1997). Individuals in subfamily Nymphophilinae, of which *Marstonia* is a part, have limited dispersal abilities and most species are narrowly distributed in local drainage systems (Hershler et al. 2003). Studies of the Hydrobiidae family and *Marstonia* and *Pyrgulopsis* genera have documented multiple species that show genetic divergence between and within watersheds (Hershler et al. 2010; Delicado et al. 2012; Liu et al. 2013); many of these species are restricted to springs and small streams (Hershler 1998; Ponder and Walker 2003). Speciation is directly related to reductions in gene flow (genetically-effective transmission of alleles between extant populations and various parts of the range within species, from Colgan and Ponder 1994).

With the low mobility of freshwater hydrobiid snails, it is likely that there is little, if any, gene flow between remaining populations of *M. ozarkensis*. Loss of genetic variability can negatively affect disease resistance, adaptive capacity, and genotypes in the affected species.

There is some evidence of snail dispersal among hydrologically separate areas, which has been attributed to passive transport on migratory waterfowl (reviewed in Green and Figuerola 2005; Wesselingh et al. 1999). However, this is generally more successful in species that have internal brood care, are capable of self-fertilization, and/or occur abundantly in areas where birds rest and forage (Wesselingh et al. 1999). While some Hydrobiidae show evidence of passive transport on waterfowl (Colgan and Ponder 1994), it has not been documented in the *Marstonia* genus, and, based on other *Marstonia* species, *M. ozarkensis* is unlikely to have the traits mentioned above.

3.4 Disease and Predation

There is no record of diseases affecting hydrobiids. Hydrobiid snails serve as first intermediate hosts for a variety of trematodes worldwide (Pung et al. 2008 p. 718; Sargent et al. 2014), but the effect of this parasitism on hydrobiid individuals and populations is little studied. Coastal hydrobiids infected by trematodes have demonstrated lower resistance to desiccation (Jensen et al. 1996). In general, trematode-infected snails commonly develop morphological differences such as shell size and shape and sometimes exhibit shifts in behavior (Krist 2000; Lagrue et al. 2007).

Predators on hydrobiid snails include sunfish (Osenberg et al 1992). More generally; fish and crayfish have been shown to prey on snails (Covich 1977; Brown 2001 p. 311; Greenwood and Thorp 2001; Krist 2002; Haag and Warren 2006), but given the small size of hydrobiids, it is unlikely they will be a primary prey item for most predators.

3.5 Collection

This species has not been the focus of any known large collection activities (scientific, commercial, or otherwise). It is highly unlikely that any new collection pressure will develop in the foreseeable future that may affect remaining populations.

3.6 Catastrophe

A catastrophic event is generally defined as a temporally and spatially discrete devastating event, such as a rare natural disaster or an incident covering multiple populations. As of 2017, no large-scale catastrophic events have been recorded affecting waterways in the assumed range of the Ozark pyrg. The Missouri Department of Conservation (MDC) tracks and investigates fish kill and water pollution events throughout the state. Overall, the number of fish kill/pollution incidents recorded by the MDC peaked in the mid to late 1990s and has declined since (O'Hearn and Martin 2012). Generally, the investigation includes water chemistry screening and a record of the number and species of fish killed; they do not track other aquatic organisms. In the seven years between 2006 and 2013, only two pollution events of any size were recorded within the North Fork White River watershed (Zweig 2008; O'Hearn and Martin 2012; O'Hearn and Martin 2014). In 2011, a fish kill from low dissolved oxygen was recorded in Bull Shoals Lake; however, Ozark pyrg is not expected to be found in lotic environments such as Bull Shoals Lake. In 2010, there is a record of an event in Bryant Creek, Douglas County, Missouri; the cause of the event and the number of animals killed was not determined by MDC investigators. There are no records of Ozark pyrg in Bryant Creek, although it may be historical habitat. There are no records of pollution or fish kill events in Mud Creek, the stream in which Ozark pyrg was last collected.

3.7 Climate Change and Shifts in Water Regime

The terms "climate" and "climate change" are defined by the Intergovernmental Panel on Climate Change (IPCC). The term "climate" refers to the mean and variability of different types of weather conditions over time, with 30 years being a typical period for such measurements (IPCC 2013a, p. 1,450). Thus, the term "climate change" [or changing climate conditions] refers to a change in the mean or variability of one or more measures of climate (for example, temperature or precipitation) that persists for an extended period, whether the change is due to natural variability or human activity (IPCC 2013a, p. 1,450).

All freshwater systems are considered vulnerable to climate change because of the combination of climate-dependent water temperature and habitat availability and existing anthropogenic stressors combined with the limited dispersal ability of many aquatic species (Woodward et al. 2010, p 2093). The specific effect of climate change on aquatic species is difficult to predict because of the potential synergies between components of climate change and other stressors (Woodward et al. 2010, p. 2102).

Air and surface water temperatures are correlated. Average air temperatures are predicted to increase in the future and surface water will follow this trend; groundwater temperatures will increase after a lag time, depending on aquifer dimensions (Meisner et al. 1988; Stefan and Preud'homme 1993; Karl et al. 2009; Kurylyk et al. 2014; Menberg 2014). As the North Fork White River watershed geography is primarily dolomite and sandstone, karst features such as losing streams are common (285 kilometers of losing streams) and many of the streams are spring fed (Miller and Wilkerson 2001, p. 11). Groundwater discharge, primarily through springs, helps create cooler microhabitats in streams that can provide refugia for species when water temperatures rise (Davis et al. 2013, p. 1975, 1977). Cold-water inputs like those from springs may help moderate the influence of air temperature on surface water temperature in near future scenarios (Davis et al. 2013, p 1978; Luce et al. 2014, p. 9).

Increased water temperatures will alter distributions of aquatic organisms; species' thermal limits will cause shifts or reductions in suitable habitat (Eaton and Scheller 1996; Rieman et al. 2007 p. 1559). Higher water temperatures generally result in lower dissolved oxygen in surface waters which could also restrict available *L. arkansensis* habitat (Covich et al. 1997). Environmental temperature also influences morphological and physiological traits in ectothermic animals (e.g. aquatic invertebrates) including metabolic rate, reproduction, growth, and fecundity (Ficke et al. 2007; Rypel 2009; Whelan et al. 2015). Above an upper thermal limit (approximately 28°C for *L. arkansensis*), physiological function breaks down and death can occur (Magnuson 1979; Gordon 1987, Ficke et al. 2007).

Climate change is also expected to change the timing and quantity of stream flows, and anthropogenic use is likely to exacerbate these effects. Increases in the frequency of severe droughts and storm events are predicted (Karl et al. 2009). During droughts, surface waters will have less surface input, and groundwater recharge of surface streams will decline due to the reduced rainfall. Water withdrawals for human use will put additional strain on ground and surface waters (Covich et al. 1997). Drying and hypoxia associated with high temperature and low dissolved oxygen lower diversity and cause die offs of gastropod populations (Lodge and Kelly 1985; Lodge et al. 1987). Low stream flows are also associated with faster water warming in response to high air temperatures (Poole and Berman 2001). Storm events can cause habitat destruction and shifting in waterways through scouring and debris, and high flow events can wash aquatic invertebrates downstream. Human response to unpredictable rainfall is often to build water control structures, which radically alter natural hydrologic variability and destroy and modify habitat (Poff and Allan 1995; Olden et al. 2006)

Because of their annual life span, hydrobiid snails are greatly affected by sporadic shifts in natural phenomena, including shifts in climate and stream drainage patterns (Goudreau et al. 1993; Neves et al. 1997; Angelo et al. 2002; Lydeard et al. 2004). As discussed in Section 3.2, any change to a population's habitat that causes a lowered recruitment or recruitment failure could extirpate that population. Small or isolated patches of habitat are more vulnerable to local extinction (Rieman et al. 2007); as a species with low vagility, natural reestablishment of extirpated populations is unlikely unless surviving populations are in close proximity.

Table 1. Museum and published records for *Marstonia ozarkensis* since discovery. Numbers correspond to the location on the map. Cat # is the museum catalog number for the specimen, when available (USNM: Smithsonian Department of Invertebrate Zoology, Malacology: Harvard Museum of Comparative Zoology, UCM: University of Colorado Museum). * denotes that catalog numbers were referenced in a publication, but were not found in the museum database.

Collector	Stream	Year	Latitude	Longitude	Cat #	# collected
A. Hinkley	North Fork White River; AR	1915	32.24621	-92.24353	USNM 860581	20
A. Hinkley	White River; AR	1915	36.26639	-92.54406	Malacology 68496	1
S. Wu	North Fork White River; MO	Pre - 1997	36.64311	-92.22571	UCM 40135-8*	4
D. Hayes	Mud Creek; Randolph Co, AR	2010	36.42260	-90.97510		1

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