Species Status Assessment Report for the

Coldwater Crayfish
(*Faxonius eupunctus*)

and

Eleven Point River Crayfish
(*Faxonius wagneri*)

Coldwater Crayfish (left); Photo: Chris Lukhaup, Missouri Department of Conservation
Eleven Point River Crayfish (right); Photo: Christopher Taylor, Illinois Natural History Survey

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Executive Summary

This report summarizes results of a species status assessment (SSA) conducted for the Coldwater Crayfish (*Faxonius eupunctus*) and Eleven Point River Crayfish (*Faxonius wagneri*) to assess their viability. The Coldwater Crayfish and Eleven Point River Crayfish are stream-dwelling crayfish occurring primarily in the mainstem of the Eleven Point River in Missouri and Arkansas. Due to similarities in life history and threats and because the species share a similar range, we have included both SSA results in one report.

In conducting our status assessment we first considered what the two crayfishes need to ensure viability. We then considered factors that are currently influencing those viability needs or expected to in the future. Based on the species viability needs and current influences on those needs, we evaluated the current condition of the species. Lastly, we predicted the future condition of the species based on their current condition and expected future influences on viability.

For survival and reproduction at the individual level, the Coldwater Crayfish and Eleven Point River Crayfish species require large, cold, clear permanent streams with high spring volume. The species also require coarse gravel and rock substrate to use as refuge from predators and to harbor prey resources, primarily consisting of invertebrates. Because genetic analyses indicate that each of the species consists of only one population, we describe population needs at the subpopulation level to better represent groups of individuals that occupy the same area and are subject to the same ecological pressures. For Coldwater Crayfish and Eleven Point River Crayfish subpopulations to be healthy, they require a population size and growth rate sufficient to withstand natural environmental fluctuations, habitat of sufficient quantity and quality to support all life stages, gene flow among subpopulations, and a native community structure free from non-native crayfish species that may outcompete and ultimately displace the two species.

At the species level, the Coldwater Crayfish and Eleven Point River Crayfish require resiliency, adaptive capacity (representation), and redundancy. Resiliency is the ability of the species to withstand stochastic events and, in the case of the crayfishes, is best measured by the extent of occupied habitat and the health of subpopulations. Representation is the ability of a species to adapt to changing environmental conditions; for both species it can be measured by the breadth of genetic diversity within and among subpopulations and the ecological diversity of subpopulations across the species' ranges. Redundancy is an indicator of the ability of a species to withstand catastrophic events by "spreading the risk". It can be measured for these crayfishes through the duplication and distribution of resilient subpopulations across their ranges.

Factors currently impacting these two crayfishes include excessive sedimentation and degraded water quality. Sedimentation covers the crayfishes habitat and reduces the prey base; while degraded water quality is presumed to reduce the health of individuals. Positive influences include research efforts, policies to help curtail future introductions of non-native crayfish, a large amount of public land in the watershed (22%), and efforts to improve stream health in the Eleven Point River.

Although sedimentation is reducing the amount of habitat available to the crayfishes in both downstream and upstream reaches, the overall condition of the Coldwater Crayfish and Eleven Point River Crayfish appears generally healthy. The species are inherently vulnerable to stochastic and catastrophic events due to their small ranges. The Coldwater Crayfish occupies 124 stream kilometers (77 miles); while the Eleven Point River Crayfish occupies 89 stream kilometers)(55 miles). The specie are also vulnerable to catastrophic events because they exclusively occupy the mainstem of the Eleven Point River (i.e., a high vulnerability to events such as chemical spills that affect downstream sites). However, we are unaware of any changes in the distribution, representation, or redundancy of the species from historical conditions.

Despite the relatively healthy current conditions of the Coldwater Crayfish and Eleven Point River Crayfish, the viability of both species is in question due to invasion of the Eleven Point River watershed by a non-native crayfish. The Gap Ringed Crayfish (*Faxonius neglectus chaenodactylus*) was first discovered in the watershed in 2011 in a small tributary to the Eleven Point River, approximately 15 kilometers (9 miles) from the Coldwater Crayfish range and 50 kilometers (31 miles) from the Eleven Point River Crayfish range. The invading species was found at 4 sites spanning a distance of 3.4 stream kilometers (2.1 miles), and adults and juveniles were present, indicating an established, reproducing population. Invasion of the species is a concern given impacts of the species to the Spring River Crayfish (*Faxonius roberti*)(previously part of the Coldwater Crayfish species). The Gap Ringed Crayfish was first documented in the Spring River watershed in 1998 and appears to have spread 29 stream kilometers (18 miles) within 15 years. Where it has become established, it has completely replaced the Spring River Crayfish, extirpating the species from several stream segments and the portion of the range where it occurred in Missouri. There are currently no known mechanisms to stop or reverse the Gap Ringed Crayfish invasion.

To evaluate future conditions of the Coldwater Crayfish and Eleven Point River Crayfish, we modeled the projected expansion of the Gap Ringed Crayfish within the Eleven Point River watershed and its expected impact on the native species within 10, 25, and 50 years. We used expert-elicited estimates for the rate of expansion and impacts on abundance. As a way to characterize uncertainty in predicting the future conditions, we asked experts to provide estimates for the lowest plausible, highest plausible, and most likely rates of expansion for the Gap Ringed Crayfish and to estimate the likelihood of different levels of impact. Fom these estimates we developed Reasonable Best, Reasonable Worst, and Most Likely scenarios which represent the plausible range of future conditions (the percentage of the species' ranges invaded and the degree of impact in invaded areas).

Results of the future conditions models predict that the Gap Ringed Crayfish may invade 0-100% of the Coldwater Crayfish range in 50 years, with 34% being the most likely amount. In invaded areas, abundance may be reduced by 10% up to complete displacement (i.e., functional extirpation). Results of the Eleven Point River Crayfish models predict that 0-100% of the species' range also may be invaded by the Gap Ringed Crayfish in 50 years, with 7% being the most likely amount. In invaded areas, abundance of the Eleven Point River Crayfish may be reduced by 10-50%.

Based on genetic analyses, the Coldwater Crayfish exists as a single population. We presume the Eleven Point River Crayfish does as well given the species' similar ranges. Therefore, the loss of subpopulations, or the reduction of health of subpopulations, effectively reduces the species' resiliency, representation and redundancy (viability). The impact on viability will be lower if only a small percentage of the species' ranges are impacted and if impacts to abundance are towards the lower end of the range of estimates. However, if a larger percentage of the species' ranges are impacted or if the impacts are greater than the minimum level predicted, viability of the species may be appreciably reduced. Though not incorporated into the models, we expect viability of the species will be further impacted by the presence of other threats, such as sedimentation, which affect the health of subpopulations directly and are anticipated to exacerbate displacement of the native species by the Gap Ringed Crayfish. Extreme events such as drought, extreme flood events, and toxic chemical spills, were also not incorporated into the models. Should these events occur, we expect that subpopulations in affected areas would be extirpated or experience reduced abundance, further reducing viability of the species.

Lastly, we did not incorporate effects from other non-native species, such as the Virile Crayfish (*Faxonius virilis*) which could also invade the Eleven Point River watershed, or additional introductions of the Gap Ringed Crayfish within the watershed.

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Chapter 1. Introduction and Analytical Approach

This report summarizes results of a species status assessment (SSA) conducted for the Coldwater Crayfish (*Faxonius eupunctus*) and Eleven Point River Crayfish (*Faxonius wagneri*). Due to similarities in life history and threats and because the species share a similar range, we have included both SSA results in one report.

The intent of this SSA was to assess the ability of these species to maintain healthy populations over time (i.e., viability). To assess viability, we applied the conservation biology principles of resiliency, representation, and redundancy (Smith et al. 2018, pp. 5-6; henceforth, 3Rs), in conjunction with an assessment of the threats acting on the species. These principles are described more fully below.

1.1 Resiliency, Representation, and Redundancy (the 3Rs)

Resiliency is the ability to sustain populations in the face of environmental variation and transient perturbations. Environmental variation includes normal year-to-year variation in rainfall and temperatures, as well as unseasonal weather events. Perturbations can be stochastic events such as fire, flooding, and storms. Simply stated, resiliency is having the means to recover from "bad years" and disturbances. It means that populations are able to sustain themselves through good and bad years (i.e., having healthy vital rates). The healthier the populations and the greater the number of healthy populations, the more resiliency a species possesses. For many species, resiliency is also affected by the degree of connectivity among populations. Connectivity among populations increases the genetic health of individuals (heterozygosity) within a population and bolsters a population's ability to recover from disturbances via rescue effect (immigration).

Representation refers to the array of different environments in which the species occurs or areas of significant ecological, genetic, or life-history variation, referred to as ecological settings (Shaffer and Stein 2000, p. 308; Wolf et al. 2015, p. 204). We use this diversity as a proxy for adaptive capacity (Smith et al. 2018, p.5), that is the ability of a species to adapt to near and long-term changes in the environment, or the evolutionary capacity or flexibility of a species (Beever et al. 2015, p. 132; Nicotra et al. 2015, p. 2). The source of a species' adaptive capabilities is the range of variation found in the species, called adaptive diversity. Therefore, representation can be measured by the species' breadth of adaptive diversity. The greater the adaptive diversity, the more responsive and adaptable the species will be over time. Maintaining adaptive diversity includes conserving both the phenotypic diversity and genetic diversity of a species. Phenotypic diversity is the ecological, physiological, and behavioral variation exhibited by a species across its range, and it is important because it provides the variation on which natural selection acts. Genetic diversity is the number and frequency of unique alleles within and among populations and is important because it can delineate evolutionary lineages that may harbor unique genetic variation including adaptive traits. Genetic diversity can also indicate gene flow, migration, and dispersal. The species' responsiveness and adaptability over time is preserved by maintaining these two sources of adaptive diversity across a species' range (representation).

In addition to preserving the breadth of adaptive diversity, maintaining evolutionary capacity requires maintaining the evolutionary processes that drive evolution, namely gene flow, genetic drift, and natural selection. Gene flow is the physical transfer of genes or alleles from one population to another through immigration and breeding. Gene flow will generally increase genetic variation *within* populations by bringing in new alleles from elsewhere, but decrease genetic variation *among* populations by mixing their gene pools (Hendry et al. 2011, p. 173). Genetic drift is the change in the frequency of alleles in a population due to random, stochastic events. Genetic drift always occurs, but is more likely to negatively affect populations that have a smaller effective population size and populations that are geographically spread and isolated from one another. Natural selection is the process by which heritable traits can become more (selected for) or less (not selected for) common in a population based on the reproductive success of an individual with those traits. Natural selection influences the gene pool by determining which alleles are perpetuated in particular environments. This selection process generates the unique alleles and allelic frequencies, which reflect specific ecological, physiological, and behavioral adaptations that are optimized for survival in specific environments.

Redundancy is an indicator of the ability of a species to withstand catastrophic events. Redundancy protects species against the unpredictable and highly consequential events for which adaptation is unlikely. In other words, it is about spreading the risk among multiple populations or areas to minimize the risk of losing the entire species (or significant diversity or adaptive capacity within the species), especially from large-scale, high-impact catastrophic events (Smith et al. 2015, p. 5). Generally speaking, redundancy is best achieved by having multiple populations widely distributed across the species' range. This reduces the likelihood that all populations are affected simultaneously; while having widely distributed populations reduces the likelihood of populations possessing similar vulnerabilities to a catastrophic event. Given sufficient redundancy, single or multiple catastrophic events are unlikely to cause the extinction of a species. Furthermore, the more populations and the more diverse or widespread that these populations are, the more likely it is that the adaptive diversity of the species will be preserved. Thus, having multiple populations distributed across the range of the species may also help preserve representation.

In summary, long-term species viability requires having multiple (redundancy), healthy populations (resiliency) distributed across the species' range to maintain the ecological and genetic diversity (representation).

1.2 Analytical Approach

Our analytical approach for assessing viability of the Coldwater Crayfish and Eleven Point River Crayfish involved 3 stages (Fig. 1-1). In Stage 1 (Chapter 2), we described the species' needs in terms of the 3Rs. Specifically, we identified the ecological requirements for survival and reproduction at the individual, subpopulation, and species levels. In Stage 2 (Chapter 4), we determined the baseline condition of the species using the ecological requirements previously identified in Stage 1. That is, we assessed the species' current condition in terms of the 3Rs and past and ongoing factors influencing viability (Chapter 3) that have led to the species' current condition. In Stage 3 (Chapter 5), we projected future conditions of the Coldwater Crayfish and Eleven Point River Crayfish using the baseline conditions established in Stage 2 and the predictions for future risk and beneficial factors. Lastly, we provide a synthesis (Chapter 6) of the species' viability over time, given our analyses of current conditions and projections of future conditions relative to historical conditions.

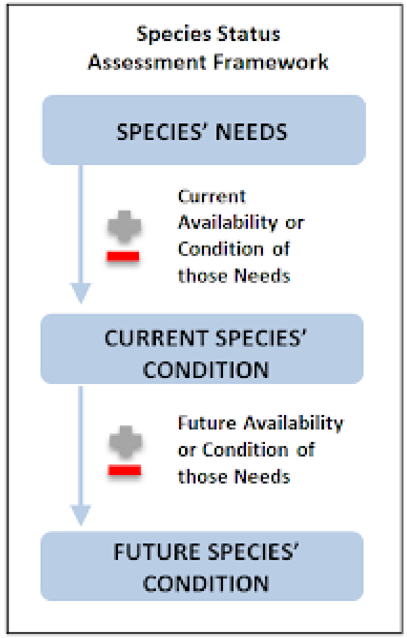

Figure. 1-1. Species Status Assessment Framework.

Chapter 2. Species Descriptions, Distribution, and Ecology

2.1 Taxonomy and Species Description

The Coldwater Crayfish was first described by Williams (1952, pp. 330-334) from the Eleven Point River in Missouri. The species was previously in the genus *Orconectes*, but was moved to the genus *Faxonius* based on phylogenetic information (Crandall and DeGrave 2017, pp. 619-620). In addition, recent genetic and morphological investigations indicate that the species actually consisted of several undescribed species (Fetzner et al. 2013, p. 26; Fetzner 2017, p. 13). Based on this information, two additional species were described: the Eleven Point River Crayfish (*Faxonius wagneri*) and the Spring River Crayfish (*Faxonius roberti*)(Fetzner and Taylor 2018, pp. 500-515). Henceforth we will refer to the former Coldwater Crayfish species delineation (that is now described as three species) as the Coldwater Crayfish complex.

An updated physical description of the Coldwater Crayfish is not available, but individuals of the Coldwater Crayfish complex have been described as small, stout crayfish with a blue-green head and pincers and a reddish-brown thorax and abdomen (Pflieger 1996, p. 76)(Fig. 2-1). Adults of the Coldwater Crayfish complex are 30.5 to 71.1 millimeters (mm)(1.2-2.8 inches)(in) long, with males and females generally similar in size (Pflieger 1996, p. 76).

As noted above, the Eleven Point River Crayfish was first described by Fetzner and Taylor (2018, pp. 500-515). Individuals are brown to dark brown (Fig. 2-1), with some crayfish more reddish or purplish (Fetzner and Taylor 2018, p. 510). Individuals also have a black saddle crossing the juncture of the carapace and abdomen (Fetzner and Taylor 2018, p. 510). Carapace length of females ranged from 18.6 to 30.9 mm (0.7-1.2 in), and carapace length of males ranged from 18.9 to 33.1 mm (0.74-1.3 in)(Fetzner and Taylor 2018, p. 510).

Figure 2-1. The Coldwater Crayfish (left) and the Eleven Point River Crayfish (right). Photos by Christopher Taylor, used with permission.

2.2 Historical Range and Distribution

Based on the new species description, both the Coldwater Crayfish and Eleven Point River Crayfish are now considered limited to the Eleven Point River watershed in Oregon County, Missouri and Randolph County, Arkansas (Fig. 2-2)(Fetzner and Taylor 2018, pp. 518-519). The Eleven Point River is fed primarily by Greer Spring, one of the largest Ozark Springs (Pflieger 1996, p. 76). Both species primarily inhabit the mainstem of the Eleven Point River, though some specimens of the Coldwater Crayfish complex have been found in tributaries close to the confluence of the Eleven Point River (Pflieger 1996, p. 76; Rice 2017, p. 39), as have specimens of the Coldwater Crayfish itself (Fetzner and Taylor 2018, pp. 518-520).

Figure 2-2. The Eleven Point River watershed containing the Coldwater Crayfish and Eleven Point River Crayfish.

2.3 Life History and Individual-Level Requirements

Because the former Coldwater Crayfish taxon (i.e., Coldwater Crayfish complex) has recently been revised, life history information specific to the new Coldwater Crayfish taxon and the Eleven Point River Crayfish are currently not available. Therefore, we will rely on life history information as it has been described for the Coldwater Crayfish complex, which includes the Coldwater Crayfish, Eleven Point Crayfish, and Spring River Crayfish. We reference individual species' differences where possible.

<u>Habitat</u>
The Coldwater Crayfish complex inhabits large, cold, clear permanent streams with strong, fast flowing currents (Williams 1952, p. 332; Williams 1954, p. 841; Flinders and Magoulick 2005, p. 370) and has been characterized as a riffle and run-dwelling crayfish (Bouchard and Robison 1980, p. 25; Larson and Magoulick 2007, p. 59), with the Coldwater Crayfish and Eleven Point Crayfish also known to inhabit pools (Rice 2017, p. 26). The species complex is found primarily in large order[1] (4th-6th order), spring-fed streams that have a high current velocity (exceeding 0.54 meters per second)(m/s)(Nolen et al. 2014, p. 2380), although current velocity is lower in deep pools occupied by the Coldwater Crayfish and Eleven Point River Crayfish (Rice 2018, pers. comm.). Pflieger (1996, p. 76) found the species in greatest abundance in areas with coarse gravel and rock substrate in swift, shallow water. The species are often found beneath rocks or in cavities that they excavate in gravel and sand (Williams 1954, p. 841; Pflieger 1996, p. 78).

The Eleven Point River Crayfish is typically associated with gravel or cobble substrates, and the species was most commonly encountered in areas of the river with lower water flow (for example, side channels and along banks)(Fetzner and Taylor 2018, p. 505). According to Fetzner and Taylor

[1] Stream order is used to define stream size based on a hierarchy of tributaries. Headwaters streams are represented by stream orders 1-3, medium streams are represented by stream orders 4-6, and large rivers are streams of order 7 and above.

(2018, p. 505), the species seems to be more common in the Arkansas portion of its range, being known from only ten specimens from four sites in Missouri.

Molting

Crayfish are encased in a rigid exoskeleton and must periodically discard the old shell and replace it with a new shell when they grow, a process called molting. Once crayfish shed the old shell, the new shell must harden, which can take up to 10 days. During this time crayfish are particularly vulnerable to predation and even cannibalism (Pflieger 1996, pp. 25-29) as well as pollution (Weis et al. 1992, pp. 496-499). Thus, they usually find refuge in a protected place in preparation for molting (Pflieger 1996, pp. 25-29). Molting appears to be stressful, and some crayfish die during the process (Pflieger 1996, pp. 25-29).

All crayfishes of the family Cambaridae, including the Coldwater Crayfish complex, exhibit a cyclic dimorphism associated with reproduction (Pflieger 1996, p. 27). Males molt prior to the breeding season, with the gonopod (a sperm transfer organ) changing during the molting process. Males in breeding form are referred to as Form I, whereas males in non-breeding form are referred to as Form II. During the winter and early spring most mature males of the Coldwater Crayfish complex are in the Form I condition (Pflieger 1996, p. 78; Larson and Magoulick 2008, p. 329), although some males have been observed in Form I condition as early as September (Larson and Magoulick 2008, p. 329). Most males undergo a molt to Form II in early May, remaining in the Form II condition throughout the summer, and molt back to Form I by September, just before the fall breeding season (Pflieger 1996, p. 78; Larson and Magoulick 2008, p. 329). In females, the spring molt was delayed until after reproduction (Pflieger 1996, p. 78).

Reproduction and Growth

Individuals in the Coldwater Crayfish complex mate in the fall from September to November (Pflieger 1996, p. 78)(Fig 2-3). During mating, males deposit a sperm plug in the sperm receptacle of the female. The plug remains until the eggs are extruded (or released) in the spring, and functions to retain the sperm and perhaps to prevent the female from being inseminated by other males (Pflieger 1996, p. 78). Females of the Coldwater Crayfish complex generate an average of 54 to 79 small (about 2 mm (less than 1 in) in diameter), black eggs (Pflieger 1996, p. 78; Larson and Magoulick 2008, p. 331), although as many as 212 eggs were found on one Eleven Point River Crayfish female (Fetzner and Taylor 2018, p. 505). Eggs are fertilized internally, extruded, and then attached to the female's abdomen the following spring in March through May (Pflieger 1996, p. 78). Once hatched, the young crayfish remain attached to the female's swimmerets (forked swimming limbs) under her abdomen until they complete two molts. They then begin making brief forays from the female, returning to the safety of her abdomen and clamping themselves to her swimmerets with their pincers when they feel threatened (Pflieger 1996, pp. 25-29). The juvenile crayfish become independent around late April (Flinders and Magoulick 2005, p. 367), although they complete several more molts during their first summer (Pfleiger 1996 pp. 25-29). Juveniles are recruited into the population in late spring to early summer (Larson and Magoulick 2008, p. 331). Some individuals of both sexes reached maturity by the end of their first growing season when they were just over 25 mm (1 in) long; however, many did not mature until the second growing season (Pflieger 1996, p. 78; Larson and Magoulick 2008, p. 331). The normal lifespan appears to be about 2.5 years (Pflieger 1996, p. 78).

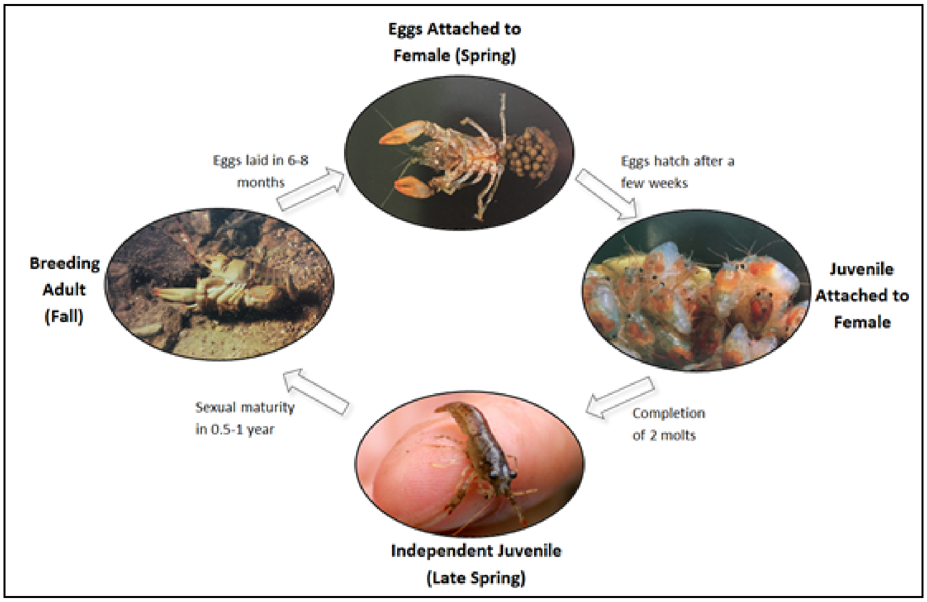

Figure 2-3. Life cycle diagram of most stream-dwelling *Faxonius* species. Photos of breeding adults, eggs, and juveniles attached to females modified from Pflieger 1996 (pp. 28-29).

Feeding Habits

Gut content analysis indicates that individuals of the Coldwater Crayfish complex consume mainly plant detritus, with invertebrates and periphyton also consumed (Magoulick and Piercey 2016, p. 240). However, a stable isotope analysis revealed that most of the nutrients are obtained from invertebrates (Magoulick and Piercey 2016, p. 240). Magoulick and Piercey (2016, p. 240) also found that diets and isotopic signatures of juvenile and adult individuals of the Coldwater Crayfish complex were similar and that both age classes gained most of their energy and nutrients from invertebrates.

Physiological Tolerances

Stream temperature appears to play an important role in the physiology of individuals in the Coldwater Crayfish complex. Whitledge and Rabeni (2002, p. 1124) found that respiration rates of the species were highest at 30°Celsius (C)(85° Fahrenheit)(F), with significantly higher respiration at 26° C (79° F) than at 18° C (64° F). Whitledge and Rabeni (2002, p. 1124) also found that the maximum daily consumption rate peaked at 22° C (72° F). Growth scope, the difference between the maximum daily consumption rate and respiration rate, is the energy potentially available for growth (Warren and Davis 1967, p. 184). For the Coldwater Crayfish complex, growth scope was highest at 22° C (72° F), indicating that the optimal temperature for growth is at that temperature (Whitledge and Rabeni (2002, p. 1127). An investigation of Coldwater Crayfish thermal tolerance and preference is currently underway (Westhoff 2018, pers. comm.).

Stream drying is another factor strongly influencing physiology of the Coldwater Crayfish complex. Under simulated stream drying in mesocosms[2], Larson et al. (2009, pp. 1903-1904) found that individuals of the complex were unable to survive longer than 2 days without water. In addition, field sampling demonstrated a significant negative relationship between Coldwater Crayfish complex density and low summer flows (Larson et al. 2009, p. 1904). These results are supported by habitat modeling and field sampling demonstrating that the Coldwater Crayfish complex is associated with larger-order rivers with high volumes of spring flow, which is likely important in

[2] An outdoor experimental system that examines the natural environment under controlled conditions.

sheltering individuals from drought and stream drying (Nolen et al. 2014, p. 2384; Rice 2017, p. 28).

Water Chemistry

Like other crustaceans, crayfish exoskeletons are composed of calcium carbonate; thus, large amounts of calcium are required for growth and molting (Greenaway 1985, pp. 425-428). Whereas food can be a source of calcium, the major source of calcium for aquatic crayfish is the environment (i.e., water)(Greenaway 1985, p. 426). Because calcium and calcium carbonate are not frequently measured at crayfish sampling, conductivity may be used as a proxy for conditions suitable for the Coldwater Crayfish and Eleven Point River Crayfish. Conductivity, the ability of water to pass an electrical current, is an indirect measure of dissolved salts and the resulting ion concentration in the water (calcium and carbonate are both ions). On the Eleven Point River, ambient conductivity generally ranges from 200-350 microsiemens per centimeter (μS/cm)(MDC 2018, unpublished data).

Individual-Level Requirements

The Coldwater Crayfish and Eleven Point River Crayfish individual-level requirements, based on the life history information outlined above, are summarized in Table 2-1.

Table 2-1. Individual-level requirements of the Coldwater Crayfish and Eleven Point River Crayfish. Except where stated otherwise, requirements are assumed the same as those for the Coldwater Crayfish complex.

Type of Requirement	Description
Stream Permanence	Permanent
Stream Order	Stream orders 4-6
Stream Flow Velocity	Coldwater Crayfish: Swift water in riffle habitats (velocity exceeding 0.54 m/s); lower water velocity in deep pools Eleven Point River Crayfish: Lower water velocity than that documented for the Coldwater Crayfish complex
Stream Temperature	Optimal growth rates at 22° C (72° F)
Embeddedness	Low so that spaces under rocks and cavities in gravel and sand remain available
Refugia	Cavities in gravel or sand under large rocks
Diet	Invertebrates, periphyton, plant detritus

2.4 Subpopulation-Level Requirements

Results from genetic analyses indicate that the Coldwater Crayfish functions as a single population, with gene flow throughout the entire range (Fetzner et al. 2013, pp. 10-11). Because the known range of the Eleven Point River Crayfish is similar to that of the Coldwater Crayfish, we presume that the species also functions as a single population. However, to better represent which individuals are able to interbreed (based on proximity to each other) and are subjected to the same ecological pressures, we describe requirements of each species at the subpopulation level. We consider a subpopulation to be those individuals within a stream reach of occupied habitat. Because the Coldwater Crayfish and Eleven Point River Crayfish occur in riffles and pools, occupied stream reaches may consist of a riffle and pool adjacent to each other or a series of riffles and pools adjacent to each other. Subpopulation level requirements are described below and summarized in Table 2-2.

Healthy Demography
For subpopulations of the Coldwater Crayfish and Eleven Point River Crayfish to be healthy, they must have a healthy demography with population size and growth rate (lambda, or λ) sufficient to withstand natural environmental fluctuations. The exact population size and growth rate necessary for each species to maintain a healthy subpopulation is unknown. Based on general ecological principles, however, we know that λ must be at least 1 for a population to remain stable over time. In the absence of population size and growth rate information, vital rates can also be used to represent healthy demography. Though data on survivorship and recruitment rates are currently not available, individual fecundity has been reported as 13-103 eggs for the Coldwater Crayfish complex (Pflieger 1996, p. 78; Larson and Magoulick 2008, p. 329), and one female Eleven Point River Crayfish was found with 212 eggs (Fetzner and Taylor 2018, p. 505). In addition, mean density of the Coldwater Crayfish at occupied sites has been reported as 0.1-7.9 individuals per m^2 (0.08-6.61 individuals per square yard)(yd)(Rice 2017, p. 25).

Habitat to Support a Healthy Demography
Healthy Coldwater Crayfish and Eleven Point River Crayfish subpopulations require habitat of sufficient quality and quantity to support all life stages. The habitat quality necessary to support healthy subpopulations is described under Life History and Individual-Level Requisites. The quantity of habitat likely varies among subpopulations and is unknown. However, riffles and adjacent pools in the Eleven Point River are often 60-300 m (200-980 feet)(ft) in length (Briggler 2018, pers. comm.). Thus, the stream length for a healthy subpopulation of each species is likely a minimum of 60 m (200 ft). In addition, healthy subpopulations must have connectivity between ovigerous[3] and molting microhabitats (e.g., cavities under rocks and logs)(Pflieger 1996, p. 26) and between adult and juvenile microhabitats.

Gene Flow Among Subpopulations
Movement among subpopulations is needed to maintain genetic diversity and to allow recolonization of subpopulations in the event of local extirpation. For movement to occur, the subpopulations must be in sufficient proximity of each other to allow at least occasional interaction among individuals. In addition, movement among subpopulations must not be restricted. Thus, barriers, such as dams or large stream reaches of unsuitable habitat, must not be present.

Native Community Structure
Environmental tolerances and other abiotic factors can influence the distribution and structure of crayfish communities (Flinders and Magoulick 2005, p. 370; Westhoff et al. 2011, p. 2424). However, resource partitioning (dividing or differentiating use of resources to avoid competition) has been observed in many *Faxonius* species based on substrate availability, macrophyte cover, flow velocity, water depth, and macrohabitats (e.g., riffles, pools, runs)(Flynn and Hobbs 1984, pp. 386-388; Rabeni 1985, pp. 22-28; DiStefano et al. 2003, pp. 351-354). These observations suggest that interspecific competition also influences species distribution. This idea is further supported by observations of species displacement by non-native crayfish species (Riggert et al. 1999, pp. 360-361; Flinders 2000, p. 18; Magoulick and DiStefano 2007, pp. 147-148). Based on these observations, we presume that healthy Coldwater Crayfish and Eleven Point River Crayfish subpopulations require a community structure free from non-native crayfish species that may outcompete and ultimately displace the two species. We also presume that non-native organisms other than crayfish, such as predatory fish or a benthic competitor (e.g., the round goby)(*Neogobius melanostomus*), could impact the two species.

[3] Bearing or carrying eggs.

Table 2-2. Subpopulation-level requirements for the Coldwater Crayfish and Eleven Point River Crayfish.

Requirement	Description
Healthy Demography	Sufficient population growth ($\lambda \geq 1$) and size to withstand natural environmental fluctuations; mean fecundity of females at least 54 eggs
Habitat and Microhabitat to Support a Healthy Demography	Sufficient quality to support healthy individuals of all life stages (see Individual-level Ecology)
	Sufficient quantity to support healthy individuals of all life stages
	Connectivity between ovigerous and molting microhabitats
	Connectivity between juvenile and adult microhabitats
Gene Flow Among Subpopulations	Unrestricted movement of individuals among occupied stream reaches to maintain gene flow among subpopulations
Native Community Structure	Community structure free from non-native species that may outcompete and ultimately displace the two species

2.5 Species-Level Requirements

Species-level requirements (i.e., what the species needs for viability) of the Coldwater Crayfish and Eleven Point River Crayfish are described below and summarized in Table 2-3.

Resiliency
Species-level resiliency is a function of the number of healthy populations and the distribution of these populations relative to the degree and spatial extent of environmental stochasticity. Environmental stochasticity acts at local and regional scales; thus, the health of populations in any one year can vary over geographical areas (Hanski 1999, p. 372). For this reason, having populations distributed across a diversity of environmental conditions reduces the likelihood of concurrent losses of populations at local and regional scales.

For the Coldwater Crayfish and Eleven Point River Crayfish, environmental stochasticity likely primarily includes differences in precipitation (wet and dry years) and temperature (hot and cold years) throughout the Eleven Point River mainstem. Though the water temperature in the Eleven Point River is largely buffered from changes in air temperature due to groundwater influence (Miller and Wilkerson 2000, p. WQ01), extreme air temperatures (either low or high) may affect the species. Given the narrow range of each species, these and other environmental differences could affect the species throughout their ranges. Thus they are inherently vulnerable to environmental stochasticity, especially upstream of the confluence with Greer Spring where spring flow volume is much less. For the Coldwater Crayfish and Eleven Point River Crayfish to be resilient to this stochasticity, therefore, the species require subpopulations distributed across their ranges in the Eleven Point River. The greater the number of subpopulations and the greater the distribution of those subpopulations relative to the diversity of temperature and precipitation conditions, the greater resiliency the species will possess. For the Coldwater Crayfish[4], subpopulations[5] downstream of Greer Spring are particularly important in maintaining resiliency because these

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[4] The Eleven Point River Crayfish only occurs downstream of Greer Spring.
[5] As noted under Subpopulation-Level Requirements, we discuss subpopulations instead of populations to reflect which individuals are capable of interbreeding.

subpopulations are less likely to experience temperature extremes and low stream flow due to the spring influence.

The Coldwater Crayfish and Eleven Point River Crayfish also require connectivity among subpopulations for gene flow and demographic rescue (an influx of individuals that keeps a population from going extinct).

Representation

Representation is a function of both genetic and adaptive diversity. As described in Chapter 1, genetic diversity is important because it can delineate evolutionary lineages that may harbor unique genetic variation, including adaptive traits. It can also indicate gene flow, migration, and dispersal. Adaptive diversity is important because it provides the variation in phenotypes[6] and ecological settings on which natural selection acts. We are currently unaware of specific phenotypic or genetic diversity that might readily represent adaptive diversity in the Coldwater Crayfish and Eleven Point River Crayfish. However, we know that each species requires some form of adaptive diversity to preserve its adaptive capacity. Until more information is available on adaptive diversity of the Coldwater Crayfish and Eleven Point River Crayfish, we will assume that the species require healthy subpopulations distributed throughout their range to preserve adaptive capacity. Also required are the processes that drive evolution: gene flow, natural selection, mutations, and genetic drift (Crandall 2000, p. 291).

Redundancy

Redundancy reflects the ability of a species to withstand catastrophic events and is best achieved by having multiple, widely distributed populations relative to the spatial occurrence of catastrophic events. In addition to guarding against a single or a series of catastrophic events extirpating the entire species (for these species, the species is comprised of one population), redundancy is important to protect against losing irreplaceable sources of adaptive diversity. Although the Coldwater Crayfish and Eleven Point River Crayfish each function as a single population, subpopulations better describe the structure of individuals that can interbreed. Thus, for the Coldwater Crayfish and Eleven Point River Crayfish, redundancy requires subpopulations distributed throughout the species' range in the Eleven Point River.

Table 2-3. Species-level requirements for the Coldwater Crayfish and Eleven Point River Crayfish.

Requirement	Description
Resiliency	Interconnected, healthy subpopulations distributed across the range (see Table 2-2 for requirements of a healthy subpopulation)
Representation	1) Healthy subpopulations distributed across the range to maintain adaptive capacity 2) Evolutionary processes (gene flow, natural selection, genetic drift) are maintained
Redundancy	Sufficient number and distribution of healthy subpopulations across the range to guard against the loss of the species from catastrophic events and to allow for re-population when subpopulations are lost or reduced

[6] The observable characteristics of an organism, as determined by its genetic makeup

Chapter 3. Threats and Conservation Actions

In this chapter we describe current and future threats to the Coldwater Crayfish and Eleven Point River Crayfish and how these threats affect the species. We also describe conservation efforts and their expected effects.

3.1 Non-native Crayfish

The Gap Ringed Crayfish (*Faxonius neglectus chaenodactylus*) is native to the central White River basin of Arkansas and Missouri (Pflieger 1996, pp.105-106; Wagner et al. 2010, pp. 116-120). In 2011, the Gap Ringed Crayfish was discovered outside of its native range in Joliff Spring Branch[7], presumably from a bait bucket introduction[8] (Imhoff et al. 2012, pp. 129-130, 133). This stream is a headwater stream in the Eleven Point River watershed, the watershed adjacent to the eastern edge of the Gap Ringed Crayfish's native range. Following discovery of the introduction, additional sampling was conducted to document the extent of the invasion. The subspecies was found at four sites spanning a distance of 3.4 km (2.1 mi)(Fig. 3-1)(Imhoff et al. 2012, p. 132). Adult and juvenile specimens were present, indicating an established, reproducing population (Imhoff et al. 2012, p. 132). No surveys to determine the extent of the invasion have been conducted in Joliff Spring Branch since 2011, so we are unable to describe the current location of the Gap Ringed Crayfish within Joliff Spring Branch.

Though the range of the Gap Ringed Crayfish does not currently overlap with those of the Coldwater Crayfish and Eleven Point River Crayfish, the invading species is present in the Eleven Point River watershed and the leading edge of the invasion is currently 14.5 km (9.0 mi) from the Coldwater Crayfish range and 49.5 km (30.8 mi) from the Eleven Point River Crayfish range. Expansion of the invasion is expected to continue within the Eleven Point River watershed, based on an invasion by the Gap Ringed Crayfish in the Spring River[9] watershed. Provided below are additional details of the Gap Ringed Crayfish invasion in the Spring River watershed and impacts of the invasion on another species of the Coldwater Crayfish complex.

During surveys conducted in 1998-1999, the Gap Ringed Crayfish was found at five sites in the Spring River watershed: the main channel of the West Fork River, 3 intermittent headwater streams, and at the confluence of the West Fork and South Fork Rivers (Flinders and Magoulick 2005, p. 362-364). The range expansion evidently occurred between 1984 and 2001 (Magoulick and DiStefano 2007, pp.144-146), suggesting an invasion rate of 1.9 km/yr (1.2 mi/yr)(DiStefano et al. 2017, p. 4). By 2001, the subspecies had invaded 29 stream km (18 mi) within the drainage and was the dominant species in run habitats from where it was collected (Flinders and Magoulick 2005, pp. 362-364; Magoulick and DiStefano 2007, pp. 144-146; DiStefano 2015, p. 399-401). Previously abundant in these systems (Flinders and Magoulick 2005, pp. 153-154), the Spring River Crayfish (formerly part of the Coldwater Crayfish complex), appears to have been completely displaced where the Gap Ringed Crayfish is now established (Flinders and Magoulick 2005, p.154; Magoulick and DiStefano 2007, pp. 147-148).

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[7] Initially the subspecies in Joliff Spring Branch was identified as the Ringed Crayfish (*Faxonius neglectus neglectus*). Subsequent genetic analyses, however, indicate that it is the Gap Ringed Crayfish subspecies which has invaded the drainage (Taylor 2018, unpublished data).

[8] An introduction due to release of live bait used by anglers.

[9] The Spring River in the central Ozarks (instead of the Spring River in the western Ozarks).

Figure 3-1. Invasion of the Gap Ringed Crayfish in the Eleven Point River watershed, relative to the range of the Coldwater Crayfish (top) and the Eleven Point River Crayfish (bottom).

Displacements of crayfish species are generally attributed to one, or a combination, of four mechanisms: competition, differential predation, reproductive interference or hybridization, and disease transmission (Lodge et al. 2000, pp. 9, 12). Though the Spring River Crayfish and Gap Ringed Crayfish occur in similar habitats (Magoulick and DiStefano 2007, pp. 144-146) and feed on similar resources (Magoulick and Piercey 2016, pp. 240-241), some studies suggest that interspecific competition with the Gap Ringed Crayfish is not the primary mechanism responsible for the displacement of the Spring River Crayfish (Rabalais and Magoulick 2006a, pp. 299-302; Rabalais and Magoulick 2006b, pp. 1042-1044; Larson and Magoulick 2009, pp. 729-730). Other biotic factors, such as reproductive interference, also could play a role, or a combination of biotic and abiotic factors may be the basis for the displacement. For example, the Gap Ringed Crayfish is more tolerant of desiccation than the Spring River Crayfish and is able to withstand drying conditions for much longer (2 weeks compared to 2 days)(Larson et al. 2009, pp. 1903-1904).

Because the Gap Ringed Crayfish has not yet reached the Coldwater Crayfish and Eleven Point River Crayfish ranges, it is unclear exactly how the species may be affected. However, there is concern among species experts given effects observed to the Spring River Crayfish in the Spring River watershed and the impacts of non-native crayfishes on native species in other regions of the United States (Lodge et al. 2000, pp. 7-14). It is also possible that other non-native crayfish species may be introduced into the watershed and invade the two species' ranges.

3.2 Degraded Water Quality

Water quality in the Eleven Point River is generally good (Miller and Wilkerson 2000, p. CO02), although high levels of fecal bacteria are periodically recorded (Miller and Wilkerson 2000, p. WQ01). According to MODNR (as cited in Miller and Wilkerson 2000, p. CO02), livestock waste is a large source of nonpoint pollution and constitutes a major percentage of the Eleven Point watershed's total organic waste, contributing to the biochemical oxygen demand, suspended solids, fecal coliform, and fecal streptococci loads. Negative impacts to aquatic ecosystems also occur when "no discharge" lagoons associated with confined animal feeding operations discharge to streams after a flood event. A large poultry processing plant also has been recently built east of the Eleven Point River watershed in Pocahontas, Arkansas. An increase in poultry farms in the surrounding area may occur to supply poultry to the facility. As a result, additional organic wastes may be introduced to the Eleven Point River via direct input from farms immediately adjacent to the river or from tributaries. Another source of nonpoint pollution is the failure of private septic systems, which can occur when septic systems are not constructed properly or are not properly maintained (Miller and Wilkerson 2000, p. WQ05). Whereas the exact impact of private septic systems on water quality within the Eleven Point Watershed is unclear, there is an increased potential for contamination in areas of soluble bedrock (such as the Eleven Point River watershed)(Aley 1972 and Aley 1974, as cited in Miller and Wilkerson 2000, p. WQ05).

Though the effects of degraded water quality on the two species of crayfish is unclear, we presume that degraded water quality reduces reproduction and survivorship of crayfish. Additional information is needed to better understand potential impacts.

3.3 Sedimentation

According to Pflieger (1996, p. 17), the thin, stony soils of the Ozarks natgurally contribute little fine sediment to surface runoff, which makes Ozark streams clear and cool. However, Jacobson and Primm (1994, pp. 80-81) determined that Ozark streams have been disturbed from their natural condition and characterized the disturbance as accelerated erosion, gravel accumulation, and channel migration. While historical timber clearing contributed to the large quantity of gravel currently in Ozark streams (Jacobson and Primm 1994, pp. 80-81), gravel dredging and poor land use practices (e.g., indiscriminate land clearing, allowing livestock in riparian areas for long periods of time) continue to cause soil erosion, sediment deposition, and resulting degradation of in-stream habitat within the Eleven Point River watershed (Miller and Wilkerson 2000, p. WQ05).

In Missouri, sedimentation is currently considered the second biggest threat to crayfishes (second to displacement by non-native crayfishes)(DiStefano 2017, pers. comm.). In Arkansas, the Eleven Point River was included on the Environmental Protection Agency's 303(d) list of impaired waters not meeting water quality standards for dissolved oxygen. Though the river was removed from the list in 2016, the Arkansas Game and Fish Commission and U.S. Fish and Wildlife Service recommended against removal due to continued changes in the quality and quantity of aquatic habitat in the Eleven Point River due to excessive sedimentation (AGFC 2016, pp. 1-2; USFWS 2016, pp. 1-3). In particular, the downstream end of the Eleven Point River has experienced increased sedimentation in recent years, presumably due to surrounding land use practices (Briggler 2015, pers. comm.; Irwin 2015, pers. comm.).

Excessive deposition of fine and coarse sediment can cover rocks and cavities used by Coldwater Crayfish and Eleven Point River Crayfish. We presume that the loss of substrate diversity results in reduced foraging habitat, thereby reducing carrying capacity and the density of subpopulations. The loss of refugia may also increase competition with the Gap Ringed Crayfish and potentially facilitate displacement of the Coldwater Crayfish and Eleven Point River Crayfish. Dukat and Magoulick (1999, p. 47) documented lower predation rates on two Ozark-endemic crayfishes in stream reaches with greater substrate diversity. Thus, the loss of refugia from predators by sedimentation likely also increases predation risk. These presumptions correspond with studies on other crayfish species demonstrating that crayfish presence was dependent on rocks embedded in little or no sediment and open interstitial spaces (Loughman 2016, p. 645; Loughman 2017, p. 5).

Furthermore, excessive sediment deposition negatively impacts macroinvertebrates (Jones et al. 2012, pp. 1056-1062), a primary food source of the Coldwater Crayfish complex (Magoulick and Piercey 2016, p. 240).

3.4 Disease

Crayfishes are subject to a wide range of infectious and non-infectious agents that can cause mortalities in individuals and affect populations. Described below are the primary pathogens that have been documented in North American crayfish populations and could affect the Coldwater Crayfish and Eleven Point River Crayfish.

The Crayfish Plague is a water mold caused by *Aphanomyces astaci* (OIE 2009, p. 2). The fungus has led to widespread mortality of crayfish populations in Europe (Longshaw 2011, p. 55). Most crayfishes of the genus *Faxonius* are suspected to be carriers of *A. astaci*; however, infected individuals appear to succumb to *A. astaci* only under stress (Cerenius and Söderhäll 1992 as cited in Holdich et al. 2009, p. 3). Therefore, the Crayfish Plague is unlikely to affect subpopulations of the Coldwater Crayfish and Eleven Point River Crayfish unless resiliency of the subpopulations is already reduced.

White Spot Syndrome Virus (WSSV) is another infectious pathogen that has been documented in North American crayfish populations. The virus can infect a wide range of crustaceans, most notably shrimp and crayfish. The virus has been documented in the United States at multiple sites in Louisiana in freshwater-farmed crayfishes, including a *Faxonius* species (Baumgartner et al. 2009, pp. 15-16). Infected crayfish exhibit white spots on the abdomen, and mortality has reached 90% in some farmed crayfish populations (Baumgartner et al. 2009, pp. 15-16). Introduction of WSSV has previously been through shrimp aquaculture (from water, feed, infected females to young, untreated pond effluent, untreated processing effluent, flooding, escape of farmed species)(APHIS Veterinary Services 2007, p. 2; Baumgartner et al. 2009, p. 21), but other potential pathways of transmission include birds moving from infected to uninfected wetlands, imported frozen shrimp used for bait, and ballast water exchange (APHIS Veterinary Services 2007, p. 2). Currently the virus is not known to occur in Arkansas or Missouri, and we are currently unaware of any shrimp or crayfish farms within or near the Eleven Point River watershed. If introduced into the range of the Spring River Crayfish, however, the WSSV has the potential to impact subpopulations, although the extent of the impact is unclear.

Porcelain Disease, caused by the microsporidian *Thelohania contejeani*, is a third infectious pathogen documented in North American crayfish populations. The pathogen causes whitening of the skeletal muscle and reduced locomotor activity (Quilter 1976, pp. 226, 228), eventually resulting in the death of infected individuals (Pretto et al. 2018, p. 60). There are putative observations of the disease across the eastern United States and in the Ozarks (Fetzner 2018, pers. comm.). However, additional information on the disease's prevalence and its impacts on North American crayfish is currently not available.

3.5 Narrow Distribution

Because species with small ranges are inherently more vulnerable to extirpation (Gilpin and Soulé 1986, p. 27), having a restricted range is one of the primary criteria used by the American Fisheries Society Endangered Species Committee to assign conservation status to crayfishes (Taylor et al. 1996, p. 27; Taylor et al. 2007, p. 376). Although having a narrow range increases a species' vulnerability to other threats, it is not a threat itself (Westhoff 2011, p. 3). For this reason, we consider the size of the Coldwater Crayfish and Eleven Point River Crayfish ranges in evaluating the 3Rs, rather than discussing it further in this chapter.

3.6 Climate Change

Results from Whitledge and Rabeni (2002, p. 1127) indicate that the optimal temperature for growth for the Coldwater Crayfish complex is 22° C (72° F), and they postulated that temperatures above 26° C (79° F) are likely suboptimal for most Missouri crayfishes, including the Coldwater Crayfish complex (p. 1129). This postulation is supported by observations of latent mortality[10] when placing individuals of the Coldwater Crayfish complex in 25° C (77° F) water (Allert et al. 2014, unpublished data). These findings suggest that an increase in stream temperature beyond 22° C (72° F) will result in reduced fitness of individuals if the response of Coldwater Crayfish and Eleven Point River Crayfish is similar to that of the Coldwater Crayfish complex.

Whitledge and Rabeni (2002, p. 1129) also postulated that under warmer stream conditions in the future, native crayfish species could be displaced by non-native crayfishes with higher thermal optima. Thus, increased stream temperatures could facilitate displacement of the Coldwater Crayfish and Eleven Point River Crayfish should the Gap Ringed Crayfish reach their range and have a higher thermal optima. Though results are preliminary, it appears that the Gap Ringed Crayfish has a thermal tolerance similar to that of the Coldwater Crayfish (another species of the Coldwater Crayfish complex)(Westhoff 2018, pers. comm.). However, the temperature preference of the Gap Ringed Crayfish is significantly higher than that of the Coldwater Crayfish (by 1.5° C)(Westhoff 2018, pers. comm.). Thus, increased stream temperatures due to climate change could facilitate displacement of the Coldwater Crayfish by the Gap Ringed Crayfish. Increased stream temperatures could also facilitate displacement of the Eleven Point River Crayfish if the species has a thermal preference similar to that of the Coldwater Crayfish. Displacement could be further facilitated if climate change results in increased stream drying (Larson et al. 2009, p. 1906). Though the range of the Coldwater Crayfish and Eleven Point River Crayfish in the mainstem of the Eleven Point River is unlikely to dry completely, lower water levels could reduce the amount of

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[10]Mortality that does not occur immediately after an event (i.e., delayed).

available habitat (e.g., stream edges and areas around gravel bars), thereby reducing the number of individuals.

3.7 Extreme Events

Based on considerations outlined in Chapter 4, we do not consider extreme drought a catastrophic event likely to impact the Coldwater Crayfish and Eleven Point River Crayfish at the population level (i.e., the entire species becomes irreversibly headed towards extinction). However, an extreme drought would act as an extreme stressor to one or more subpopulations of each species. We discuss this and other extreme events separate from water quality and climate change because they act as acute, rather than chronic, stressors.

A severe drought could affect Coldwater Crayfish and Eleven Point River Crayfish subpopulations by reducing the amount of available habitat and by increasing water temperatures (see Climate Change section above). In addition, drought could exacerbate effects of the Gap Ringed Crayfish invasion. Larson et al. (2009, p. 1903) found that survival rates of the Coldwater Crayfish complex were significantly lower than those of the Gap Ringed Crayfish during stream drying experiments, indicating that the Gap Ringed Crayfish is better able to withstand drought events. Based on these results, Larson et al. (2009, p. 1905) postulated that persistence of the Gap Ringed Crayfish during drying events could inhibit the Coldwater Crayfish complex from reestablishing extirpated sites after the drying events recede. Thus, if similar differences in drying tolerance are exhibited by the Gap Ringed Crayfish and Coldwater Crayfish and Eleven Point River Crayfish (i.e., the Gap Ringed Crayfish can better withstand drying), extreme drought events could facilitate displacement of both native crayfishes.

Extreme flood events may also affect Coldwater Crayfish and Eleven Point River Crayfish individuals and subpopulations. During severe flooding, the stream substrate, including large rocks, can be mobilized. When this happens, crayfish individuals using the mobilized substrate as refugia would be dislodged and potentially injured or killed during the flood event. Though it seems unlikely that an extreme flood event would extirpate an entire subpopulation, such an event could substantially reduce the health of affected subpopulations, increasing their vulnerability to other stressors. In addition, flood events create higher stream flow and flow velocity, which can increase erosion of unstable stream banks and degrade habitat due to sedimentation. The higher stream flow and flow velocity can also accelerate the downstream expansion of invading crayfish, particularly of juveniles (DiStefano 2017, pers. comm.). Thus, flooding may also facilitate displacement of the Coldwater Crayfish and Eleven Point River Crayfish by the Gap Ringed Crayfish.

A toxic chemical spill could also impact Coldwater Crayfish and Eleven Point River Crayfish individuals and subpopulations and could even function as a catastrophic event. Though no hazardous material routes cross the Eleven Point River watershed (see Appendix A), several highways do cross the Eleven Point River. Thus, an overturned truck could result in a chemical spill impacting Coldwater Crayfish and Eleven Point River Crayfish downstream of the spill. In addition to spills that could occur near transportation routes, there is a facility at the upper end of the Eleven Point River in Willow Springs that has a storage capacity of 2.8 million gallons of liquid asphalt, denatured ethanol, and diesel fuel (Fig. 3-2)(USEPA 2015, p. 5). In the event of a spill, this facility has the potential to release a large volume of chemicals into the Eleven Point River. Impacts to aquatic species from a chemical spill depend on the volume and substance being spilled or released, hydrological conditions of the river, and dilution water available for flushing (Poulton et al. 1997, p. 274). In addition, responses of benthic communities to petroleum spills vary widely (Poulton et al. 1997, p. 268). For example, a ruptured pipeline in the northern Ozarks released 3.3 million liters (900,000 gallons) of crude oil into the Gasconade River in 1988.

Although water quality was severely affected[11] for more than 75 km (47 mi) downstream, minimal effects were observed on macroinvertebrates in riffles (Poulton et al. 1997, pp. 269, 271). Others studies, however, report elimination of or significant effects to aquatic invertebrates, including crustaceans, in areas impacted by a spill (McCauley 1966, pp. 483-485; Meynell 1973, pp. 512-517; St Lawrence et al. 2014, pp. 558-559).

Whereas the exact effects of a chemical spill on the Coldwater Crayfish and Eleven Point River Crayfish remains unclear, we expect that some subpopulations could be extirpated or severely impacted in the instance of a major spill (see Appendix A).

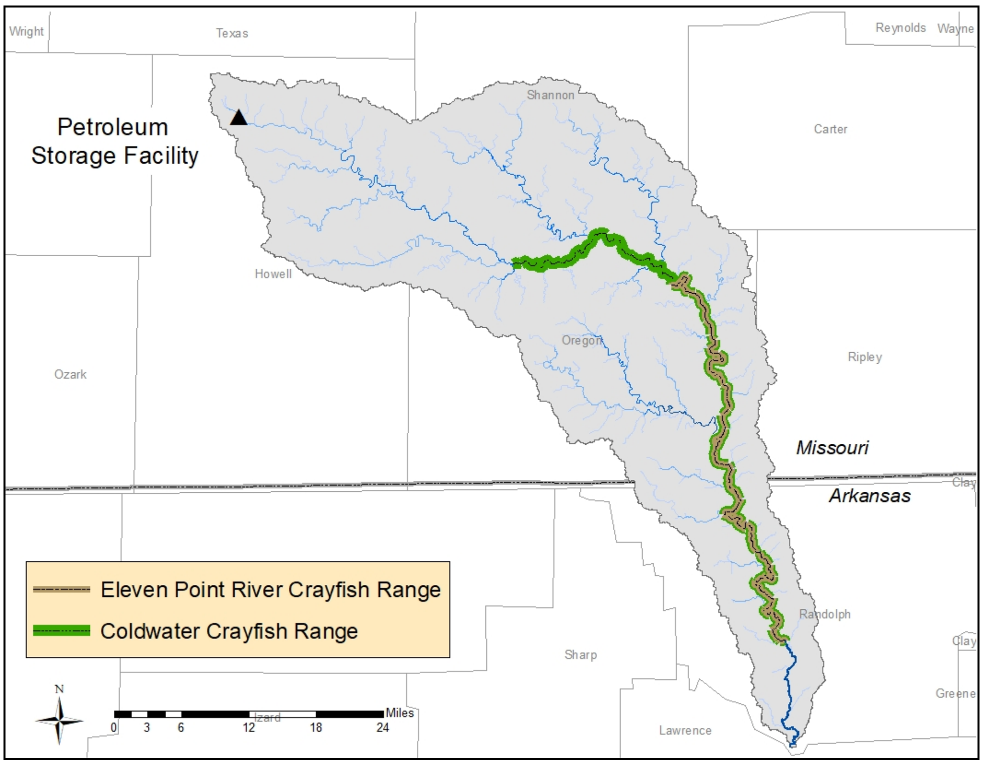

Figure 3-2. Petroleum storage facility at the upper end of the Eleven Point River.

3.8 Conservation Actions

<u>Research and Monitoring</u>
Monitoring and research on the Gap Ringed Crayfish and Coldwater Crayfish complex has been conducted by the Arkansas Game and Fish Commission, Missouri Department of Conservation, U.S. Geological Survey and various universities. Monitoring efforts benefit the Coldwater Crayfish and Eleven Point River Crayfish by providing information on population health and trends and the magnitude and extent of threats; whereas research efforts provide information on mechanisms by which threats may impact the native crayfishes. In addition, sampling methods using environmental DNA have recently been developed and implemented for the Coldwater Crayfish complex, which aids in documenting distribution of the species (Rice et al. 2018, entire).

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[11] Hydrocarbon concentrations in sediment were 119 times those of background levels (Poulton et al. 1997, p. 271).

Policies

To help curtail the spread of non-native crayfish in Missouri, the MDC amended the Missouri Wildlife Code in 2011-2012 to increase regulations pertaining to the sale, purchase, and import of live crayfishes. While the Virile Crayfish (*Faxonius virilis*) may still be commercially sold in the State for live bait, all other live crayfishes can be imported, sold, or purchased in Missouri only for the purposes of human consumption or as food for captive animals kept by authorized entities (e.g., research institutions/agencies, publicly owned zoos)(Missouri Code of State Regulations 2018b, pp. 6-7). With the exception of the Virile Crayfish, this effectively bans the sale and purchase of live crayfish for bait, the import and sale of live crayfishes in pet stores, and the purchase and import of live crayfishes by schools for classroom study, all of which are vectors for crayfish invasions. It is also illegal in Missouri to release any baitfish or crayfish into public waters, except as specifically permitted by the MDC (Missouri Code of State Regulations 2018a, p. 3).

In Arkansas, it is illegal to release any baitfish or crayfish into public waters without written permission from the AGFC, unless the species is released into waters where it was originally taken (AGFC 2018, §26.12). It is also unlawful for fish farmers to possess, rear, propagate, or sell any crayfish except the White River Crayfish and Red Swamp Crayfish (*Procambarus acutus* and *P. clarkii*) unless a permit is obtained (AGFC 2018, §35.06, Addendum J1.01)[12]. In addition, it is unlawful to import, transport, or possess the Rusty Crayfish (*Faxonius rusticus*)(AGFC 2018, §26.13), a species that has invaded lakes and streams throughout the northeastern United States and Canada (USGS 2008).

In both states, it also is unlawful to import, transport, or possess the Rusty Crayfish (*Faxonius rusticus*)(AGFC 2017, §26.13; Missouri State Code of Regulations 2018a, p. 6), a species that has invaded lakes and streams throughout the northeastern United States and Canada (USGS 2008).

Though their effectiveness remains unclear, these policies may help reduce the likelihood of future invasions of non-native crayfishes within the Eleven Point River and other watersheds. However, as the Gap Ringed Crayfish has already been introduced into the Eleven Point River watershed, the policies will not affect the inevitable spread of that species within the Eleven Point River (and thus the ranges of the Coldwater Crayfish and Eleven Point River Crayfish). In addition, the current policies in Missouri only address the commercial sale of crayfish and do not address the release of crayfish captured by anglers to use as bait (currently anglers may collect 150 crayfish per day to use as live bait)(Missouri Code of State Regulations 2018b, p. 12). Thus, non-native crayfish may still be inadvertently released in watersheds other than those from which they were collected.

Public Land and Other Protective Designations

Approximately 22% of the Eleven Point River watershed is in public ownership, with the majority of this land managed as part of the Mark Twain National Forest (Fig. 3-3). In addition to maintaining over 570 km^2 (140,000 acres) of forested habitat within the watershed, Forest Service management efforts benefit stream health by focusing on riparian protection and control and reduction of sediment entering streams. In addition, 71 km (48 mi) of the total 222 km (138 mi) of the Eleven Point River are protected under the Wild and Scenic River Act, with the adjacent land protected by scenic easements (Fig. 3-3). These protections help maintain water quality and minimize additional sedimentation, which reduce the quantity and quality of habitat of the Coldwater Crayfish and Eleven Point River Crayfish. The majority of the Eleven Point River in Missouri is also designated an "Outstanding National Resource Waters", which are waters that have outstanding national recreational and ecological significance and receive special protection against degradation in quality (Fig. 3-3)(Missouri Code of State Regulations 2018c, p. 6, 14, 16, 20, 21, 39). In Arkansas, the Eleven Point River is designated an Extraordinary Resource Water (Fig. 3-3)(APCEC 2017, p. D-2). Streams with this designation are protected by 1) water quality

[12] Though it is legal to sell native crayfish that naturally colonize aquaculture facilities unless otherwise prohibited (35.09).

controls, 2) maintenance of natural flow regime, 3) protection of instream habitat, and 4) encouragement of land management practices protective of the watershed (APCEC 2017, p. 2-1).

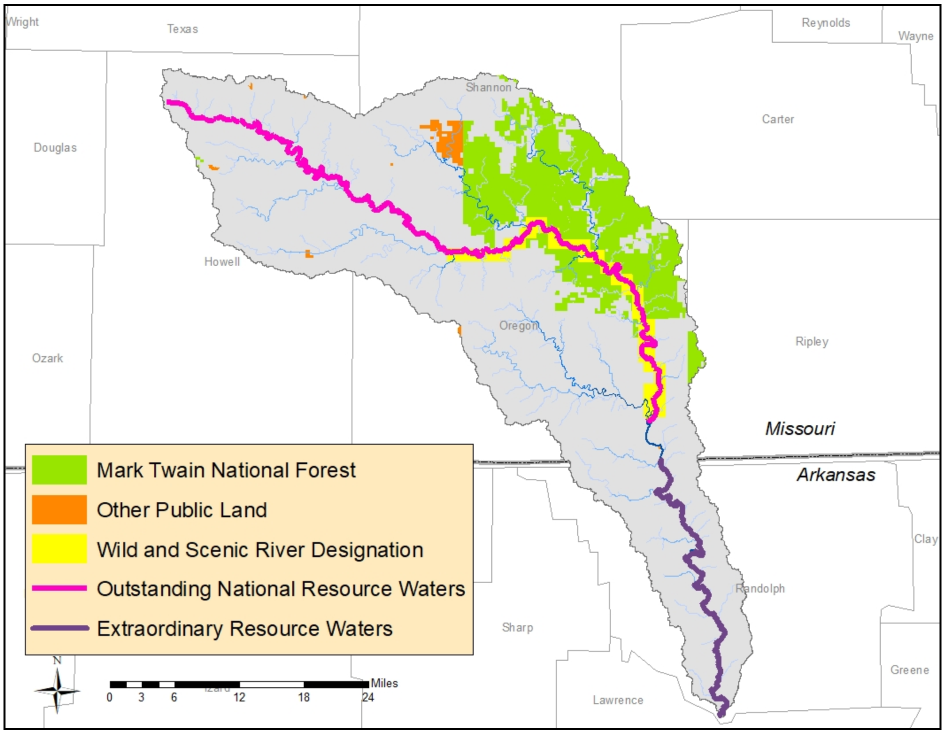

Figure 3-3. Public land and protective designations within the Eleven Point River watershed.

<u>Restoration Efforts</u>

From 2015 to 2017 the Joint Chiefs' Landscape Restoration Partnership, a collaboration between the Forest Service and the Natural Resources Conservation Service, provided over $2.2 million for landowner incentives under the Farm Bill to support forest and stream health in the Ozark Highlands in Missouri (NRCS 2018). Relevant conservation practices for which landowners received incentives included tree/shrub establishment, development of forest management plans, and upland wildlife habitat management (the latter two practices include best management practices that protect stream health). These practices help reduce sedimentation and improve water quality within the Ozarks, including the Eleven Point River watershed.

Chapter 4. Species Current Conditions

In this chapter we describe the current condition of the Coldwater Crayfish and Eleven Point River Crayfish given the threats and conservation actions described in Chapter 3.

4.1 Current Distribution, Abundance, and Habitat

Because the Coldwater Crayfish complex was only recently divided into multiple species (Fetzner and Taylor 2018, pp. 500-514), the exact distributions of the Coldwater Crayfish and Eleven Point River Crayfish are not clearly defined. Figure 4-1 depicts locations from which specimens have been identified specifically as each species (Fetzner and Taylor 2018, pp. 518-520) as well as locations from which specimens of the Coldwater Crayfish complex have been identified. For the purposes of this SSA, we assume that the Coldwater Crayfish occurs throughout the Eleven Point River between the furthest upstream and downstream locations depicted in Figure 4-1, a distance of 123.7 stream kilometers (km)(76.9 miles)(mi). Similarly, we assume that the Eleven Point River Crayfish occurs in the Eleven Point River between the furthest upstream and downstream locations depicted in Figure 4-2, a distance of 89.0 stream km (55.3 mi).

With the recent taxonomic division, we have no information on changes in Coldwater Crayfish and Eleven Point River Crayfish population trends or abundance. Thus, we assume that subpopulations of both species are currently healthy (see Chapter 2 for requirements of a healthy subpopulation).

No changes in Coldwater Crayfish or Eleven Point River Crayfish abundance have been documented, and water quality is generally good within the Eleven Point River (Miller and Wilkerson 2000, p. CO02). Some habitat degradation in the Eleven Point River has been documented, however. Based on stratigraphic observations[13], pre-settlement period historical descriptions, and oral-history accounts, Jacobson and Primm (1994, p. 80) determined that Ozark streams have been disturbed from their natural condition. The disturbance is characterized by accelerated erosion, gravel accumulation, and channel migration (Jacobson and Primm 1994 pp. 80-81), all of which cause increased sedimentation and reduce the availability of Coldwater Crayfish and Eleven Point River Crayfish habitat. Although land use practices have improved in recent decades and some riparian areas have recovered, Ozark streams continue to experience high sedimentation rates due to large quantities of silt, sand, and gravel already in the system (i.e., upstream and in the headwaters)(Jacobson and Primm 1994, p. 81). While these observations pertain to Ozark streams in general, they are consistent with observations of increased sedimentation in the Eleven Point River (Briggler 2015, pers. comm.; Irwin 2015, pers. comm.). Water quality is also impacted periodically from high fecal bacteria levels, which have often exceeded state standards for drinking water and whole-body-contact recreation (Miller and Wilkerson 2000, p. WQ01).

As described in Chapter 3, the Gap Ringed Crayfish is the primary threat to the Coldwater Crayfish and Eleven Point River Crayfish. The range of the Gap Ringed Crayfish currently does not overlap with those of the Coldwater Crayfish and Eleven Point River Crayfish. However, the invasive species is present in the Eleven Point River watershed, and the leading edge of the invasion is currently 14.5 km (9.0 mi) from the Coldwater Crayfish range and 49.5 km (30.8 mi) from the Eleven Point River Crayfish range (Fig. 3-1). Expansion of the invasion is expected to continue within the Eleven Point River watershed based on the Gap Ringed Crayfish invasion in the Spring River watershed.

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[13] Stratigraphic observations are made by studying rock layers and stratification (layering).

Figure 4-1. Known locations of the Coldwater Crayfish (top) and the Eleven point River Crayfish (bottom). Large green or pink circles depict locations of each species; small circles represent locations of the Coldwater Crayfish complex.

4.2 Resiliency, Representation, and Redundancy

To evaluate the current condition of the Coldwater Crayfish and Eleven Point River Crayfish in terms of the 3Rs, we reviewed available information on health of the subpopulations and queried species experts on the species' representation and redundancy[14]. Results are described below and summarized in Table 4-1.

Resiliency

Information is currently not available on Coldwater Crayfish and Eleven Point River Crayfish changes in abundance from their historical condition. Thus, it is unclear if any subpopulations have declined or if they all currently remain healthy. Given their small range, however, the Coldwater Crayfish and Eleven Point River Crayfish are inherently more vulnerable to environmental variation and stochastic events that could impact a large area (e.g., extreme drought or flooding). Although the specific rate of changes in environmental variation and stochastic events are uncertain, we anticipate that the magnitude of changes will be greater than these species have experienced in the past as a result of climate change.

Representation

According to the species experts, the Coldwater Crayfish and Eleven Point River Crayfish exhibit no phenotypic or genetic diversity that might readily represent adaptive diversity (a measure of adaptive capacity)(DiStefano 2017, pers. comm.; Magoulick 2017, pers. comm.; Taylor 2017, pers. comm.; Wagner 2017, pers. comm.; Westhoff 2017, pers. comm.). In addition, both species occupy a narrow range of ecological settings, occurring almost exclusively in the mainstem of the Eleven Point River with little difference throughout the range in habitat features, such as substrate and water velocity. Though there is a difference in stream temperature and spring flow between sites upstream and downstream of Greer Spring, species experts did not believe the difference represented adaptive diversity. Instead, they considered the difference in stream temperature and flow as differences in habitat suitability.

Because there appears to be no change in the range or distribution of the species from historical conditions (they appear to currently occupy the same ecological settings they historically occupied), we presume that adaptive diversity is the same as or comparable to historical conditions. Adaptive capacity is also maintained through evolutionary processes, with key evolutionary drivers being natural selection, gene flow, mutations, and genetic drift (Crandall 2000, p. 291). To our knowledge, none of these evolutionary drivers are currently impacted. Based on these considerations, we assume that current adaptive capacity of the species is the same as it was historically.

Redundancy

We are unaware of any changes in the distribution of subpopulations throughout the range of the Coldwater Crayfish and Eleven Point River Crayfish. Thus, we presume that both species' redundancy is unchanged from historical conditions. The narrow range of the species, however, inherently makes them more vulnerable to catastrophic events that could impact the species' entire range within the Eleven Point River.

For the purposes of this SSA, we define a catastrophic event as a biotic or abiotic event that causes significant impacts at the population level such that the population cannot rebound from the effects or the population becomes highly vulnerable to normal population fluctuations or stochastic events. At the Coldwater Crayfish and Eleven Point River Crayfish population level (i.e., the entire ranges of the species, rather than at the subpopulation level), we considered whether extreme drought and toxic chemical spills may be potential catastrophic events (Appendix A).

[14] We did not query experts on resiliency as any available information on abundance, fecundity, and other indicators of health is already published.

Species experts did not believe an extreme drought in 2012[15] resulted in catastrophic effects to the Coldwater Crayfish and Eleven Point River Crayfish. While another drought of similar intensity and magnitude may not cause catastrophic impacts to either species, it could reduce the overall viability by extirpating or compromising[16] subpopulations in the impacted area. Another extreme drought could also increase susceptibility of each species to other stressors (see Chapter 3), and repeated or prolonged droughts could ultimately result in the loss of subpopulations. Thus, whereas an extreme drought may not be a catastrophic event for the entire species, it could function as a catastrophic event at the subpopulation level.

Though unlikely, it is possible that a single toxic chemical spill could impact the entire range of the Coldwater Crayfish and Eleven Point River Crayfish. There is only one major pipeline which crosses the Eleven Point River watershed (Appendix A). The pipeline carries anhydrous ammonia and crosses the Eleven Point River near the upstream end approximately 27 km (17 mi) above the Coldwater Crayfish range and 62 km (39 mi) above the Eleven Point River Crayfish range. Although the Eleven Point River is an intermittent stream at the crossing, it could transport large volumes of the pipeline's contents downstream during high water flow or if there is a losing reach of the stream[17] that is part of the Greer Spring recharge area. At the upper reaches of the watershed where the Eleven Point River is an intermittent stream, there is also a railway carrying crude oil that crosses the river and a large petroleum storage facility located near the river (Appendix A). Similar to the pipeline, it is unlikely that a spill from either the railway or the storage facility would reach the Coldwater Crayfish and Eleven Point River Crayfish ranges unless the river in that section is at high flow. No hazardous routes currently cross the Eleven Point River watershed (Appendix A).

Based on the considerations outlined above, we do not consider extreme drought as a catastrophic events to the Coldwater Crayfish and Eleven Point River Crayfish. While a drought events may not cause a devastating impact to the entire Coldwater Crayfish or Eleven Point River Crayfish populations, its occurrence would reduce resiliency of the species by potentially extirpating or compromising subpopulations throughout the impacted area (see Extreme Events in Chapter 3). We do, however, consider chemical spills as a potential catastrophic event for both species.

[15] In 2012, the entire Eleven Point River watershed was affected by a D4 drought (USDM 2018b). D4 droughts are characterized as exceptional droughts with exceptional and widespread crop/pasture damage, shortages of water in reservoirs, streams, and wells creating water emergencies, and USGS weekly streamflow percentiles of 0-2 (USDM 2018a).

[16] In addition to compromised the health, affected subpopulations could also experience reduced genetic diversity, potentially leading to bottlenecks and impacts to allelic frequencies.

[17] Losing stream reaches are those that lose a significant part of their flow to the groundwater system. Water from losing stream reaches may flow into recharge systems for springs (such as Greer Spring).

Table 4-1. Summary of current condition of the Coldwater Crayfish and Eleven Point River Crayfish.

	Assessment of Current Condition
Occupied Stream Distance	The Coldwater Crayfish currently occupies 124 stream km (77 mi); the Eleven Point River Crayfish occupies 89 stream km (55 mi).
Health of Subpopulations	Subpopulations appear healthy within occupied stream reaches.
Resiliency	Both species are inherently vulnerable to stochastic events due to their small ranges. We are uncertain as to whether abundance has changed from historical conditions.
Representation	For both species there appears to be no change in adaptive capacity from historical conditions. In addition, no significant difference in representation has been identified across their ranges (genetic, phenotypic, or diversity in ecological settings).
Redundancy	Although there is no apparent change in redundancy from historical conditions, both species are inherently vulnerable to catastrophic events due to their narrow ranges, primarily in the main stem of the Eleven Point River.

Chapter 5. Species Future Conditions

5.1 Methods for Evaluating Future Conditions

To evaluate future conditions of the Coldwater Crayfish and Eleven Point River Crayfish, we modeled the predicted expansion of the non-native, invasive Gap Ringed Crayfish. Because the actual future expansion rate of the Gap Ringed Crayfish is unknown, we asked biologists with expertise on crayfishes to estimate the anticipated expansion rate. We also queried experts on how Coldwater Crayfish and Eleven Point River Crayfish abundance may be impacted and the length of time for those impacts to be fully realized. Additional details on the expert elicitation and a summary of results can be found in Appendix B.

Because the Coldwater Crayfish and Eleven Point River Crayfish are habitat specialists, experts predicted that they would experience greater impacts in areas with less suitable (marginal) habitat than in areas with ideal habitat because in marginal habitat the species are less biotically fit and cannot compete as well with the Gap Ringed Crayfish, which is a habitat generalist. Experts thought that the length of time for impacts to be fully realized would also differ between habitats. Therefore, they provided different estimates for the impact on abundance from the Gap Ringed Crayfish invasion and time for impacts to be fully realized in marginal versus ideal habitat. Ideal habitat was defined as the mainstem of the Eleven Point River downstream of Greer Spring; whereas stream reaches upstream of the spring were defined as marginal habitat[18] (marginal habitat was not relevant to the Eleven Point River Crayfish since it occurs only downstream of Greer Spring).

As a way to characterize uncertainty in predicting future conditions, we developed Reasonable Best, Reasonable Worst, and Most Likely scenarios that represent the plausible range of the Coldwater Crayfish and Eleven Point River Crayfish future conditions (Table 5-1). The Reasonable Best Scenario represents the smallest plausible proportion of the Coldwater Crayfish and Eleven Point River Crayfish ranges that the Gap Ringed Crayfish may invade with the lowest plausible level of impact. The Reasonable Worst Scenario represents the highest plausible proportion of the species' ranges that may be invaded with the highest plausible level of impact. The Most Likely Scenario represents the most likely proportion of the ranges impacted with the most likely level of impact. Each of the scenarios is based on the expert-elicited estimates of the Gap Ringed Crayfish expansion rates, impacts of the invasion, and time for impacts to be fully realized.

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[18] Though the Eleven Point River upstream of Greer Spring was the only portion of the range defined as marginal habitat, Rice (2017, p. 31) postulated that the lower portion of the species' ranges also functioned as marginal habitat due to degradation from sedimentation. Thus, marginal habitat may be underrepresented in our analyses.

Table 5-1. Scenarios representing the plausible range of future conditions for the Coldwater Crayfish and Eleven Point River Crayfish due to the Gap Ringed Crayfish invasion.

Scenario	Estimates Used
Reasonable Best	Lowest plausible expansion rate of the Gap Ringed Crayfish Lowest level of predicted impact on Coldwater Crayfish and Eleven Point River Crayfish abundance Highest number of years for impacts to be fully realized
Reasonable Worst	Highest plausible expansion rate of the Gap Ringed Crayfish Highest level of predicted impact on Coldwater Crayfish and Eleven Point River Crayfish abundance Lowest number of years for impacts to be fully realized
Most Likely	Most likely expansion rate of the Gap Ringed Crayfish Most likely level of predicted impact on Coldwater Crayfish and Eleven Point River Crayfish abundance Most likely number of years for impacts to be fully realized

For each of the scenarios, we predicted the extent of future expansion of the Gap Ringed Crayfish at 10 and 25 years into the future. We then calculated how much of the Coldwater Crayfish and Eleven Point River Crayfish ranges would be impacted and described effects to abundance based on the experts' projections.

Based on results of these scenarios, the plausible range of predicted viability (in terms of the 3Rs) and the impact of other threats, is discussed in Chapter 6.

5.2 Coldwater Crayfish Future Conditions

<u>Reasonable Best Scenario</u>
Under the Reasonable Best Scenario, experts estimated that the Gap Ringed Crayfish invasion will expand at a rate of 200 (219 yd) per year. Based on this expansion rate, none of the Coldwater Crayfish range will be invaded by the Gap Ringed Crayfish in either 10 years or 25 years (Figs. 5-1, 5-2)(Tables 5-2, 5-3). Because the Coldwater Crayfish range will not be invaded within either time interval, we predict no effect within 25 years on resiliency, representation, or redundancy from the Gap Ringed Crayfish invasion.

In 50 years, 1.4 km (0.9 mi) (1%) of the species' range is predicted to be invaded, with the invasion limited to above Greer Spring (Fig. 5-3; Table 5-4). Within the invaded area, abundance will be reduced by 10-50% and impacts will be fully realized within 20-30 years.

The length of time for the Gap Ringed Crayfish to invade the entire Coldwater Crayfish range is beyond reliable prediction (over 600 years)(Table 5-5).

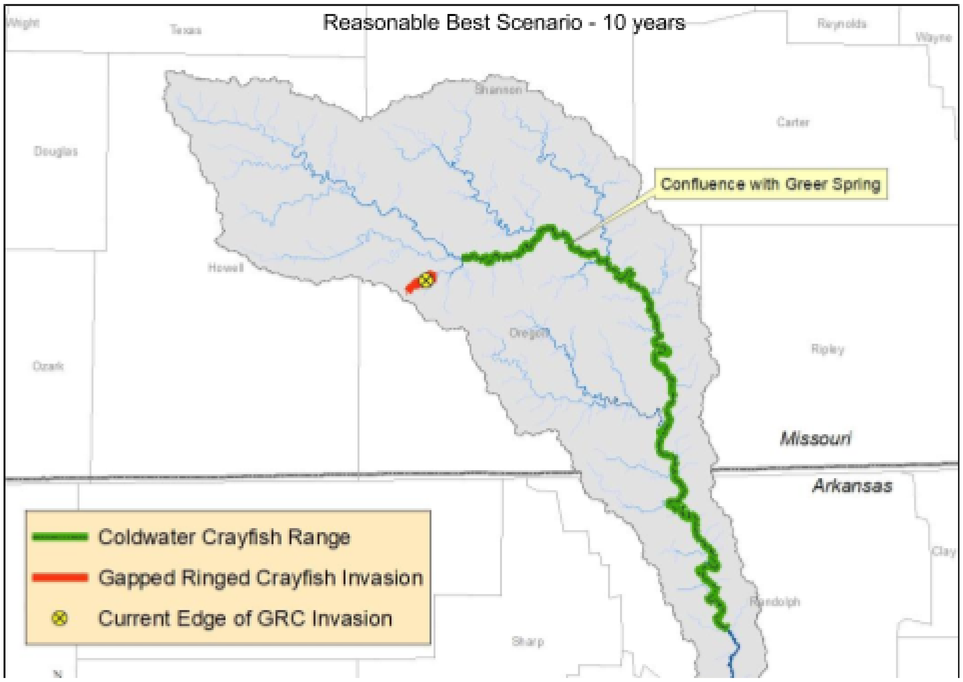

Fig. 5-1. Predicted expansion of the Gap Ringed Crayfish in the Eleven Point River watershed at 10 years under the Reasonable Best Scenario.

Fig. 5-2. Predicted expansion of the Gap Ringed Crayfish in the Eleven Point River watershed at 25 years under the Reasonable Best Scenario.

Fig. 5-3. Predicted expansion of the Gap Ringed Crayfish in the Eleven Point River watershed at 50 years under the Reasonable Best Scenario.

Reasonable Worst Scenario

Under the Reasonable Worst Scenario, experts estimated that the Gap Ringed Crayfish invasion will expand at a rate of 3,000 m (3,300 yd) per year. Based on this expansion rate, 21.5 km (13.4 mi)(17%) of the Coldwater Crayfish range will be invaded in 10 years, with all of the invasion occurring upstream of Greer Spring (i.e., in marginal habitat)(Fig. 5-4, Table 5-2). Within the area invaded, the Coldwater Crayfish will experience virtually complete displacement (i.e., functionally extirpated[19]) within 10 years. Thus, the species' range will effectively be reduced by 17% within 10 years.

In 25 years, 66 km (41.0 mi)(53%) of the species' range is predicted to be invaded, with all of the range above Greer Spring invaded (24 km)(15 mi)(19% of total range) and 42 km (26 mi) of the range downstream of Greer Spring invaded (34% of total range)(Fig. 5-5, Table 5-3). Impacts to abundance will be realized within 10 years and subpopulations above Greer Spring (marginal habitat) will be functionally extirpated. Abundance of subpopulations below Greer Spring (ideal habitat) will be reduced by at least 50%. Thus, the species' range will effectively be reduced by 19% and abundance of subpopulations in an additional 34% of its range will be greatly reduced.

In 46 years, the Gap Ringed Crayfish is predicted to have invaded the entire range of the Coldwater Crayfish (Table 5-5). Thus in 50 years, all of the Coldwater Crayfish's range will be invaded. Impacts to abundance will be realized within 10 years and subpopulations above Greer Spring (19% of range) will be functionally extirpated (Fig. 5-6, Table 5-4). Abundance of subpopulations downstream of Greer Spring (the remaining 81% of the range) will be reduced by at least 50%.

[19] We consider virtual complete displacement to mean that the subpopulation is functionally extirpated.

Fig. 5-4. Predicted expansion of the Gap Ringed Crayfish in the Eleven Point River watershed at 10 years under the Reasonable Worst Scenario.

Fig. 5-5. Predicted expansion of the Gap Ringed Crayfish in the Eleven Point River watershed at 25 years under the Reasonable Worst Scenario.

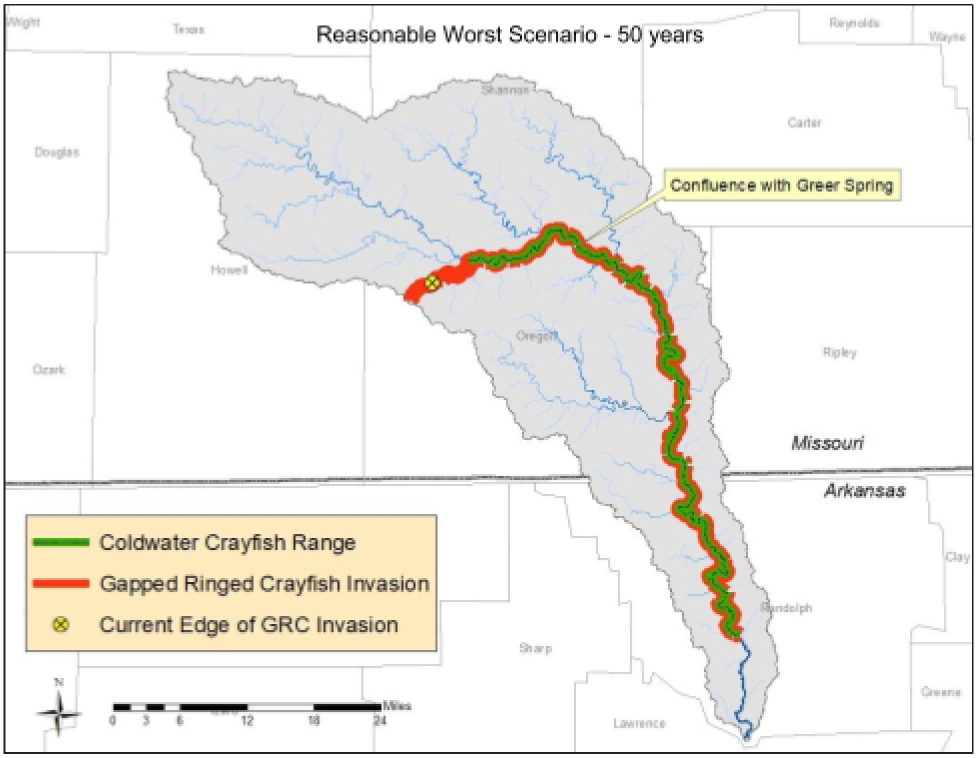

Fig. 5-6. Predicted expansion of the Gap Ringed Crayfish in the Eleven Point River watershed at 50 years under the Reasonable Worst Scenario.

<u>Most Likely Scenario</u>
Under the Most Likely Scenario, experts estimated that the Gap Ringed Crayfish invasion will expand at a rate of 1,000 m (1,100 yd) per year. Based on this expansion rate, 1.5 km (0.9 mi)(1%) of the Coldwater Crayfish range will be invaded in 10 years, with all of the invasion occurring above Greer Spring (Fig. 5-7, Table 5-2). Within the invaded area, abundance will be reduced by at least 50% within 10 years.

In 25 years, 16.0 km (9.9 mi)(13%) of the species' range is predicted to be invaded with all of the invasion still occurring above Greer Spring (marginal habitat)(Fig. 5-8, Table 5-3). Within the invaded area, abundance will be reduced by at least 50% and impacts will be fully realized within 10 years.

In 50 years, 41.5 km (25.8 mi) (34%) of the species' range is predicted to be invaded, with all of the range above Greer Spring invaded (24 km)(15 mi)(19% of total range) and 1.8 km (1.1 mi) of the range downstream of Greer Spring invaded (1% of total range)(Fig. 5-9, Table 5-4). Abundance of subpopulations above Greer Spring will be reduced by over 50% within 10 years, and abundance of subpopulations in invaded areas downstream of Greer Spring will be reduced 10-50% within 20 years.

In 138 years, the Gap Ringed Crayfish is predicted to have invaded the entire range of the Coldwater Crayfish (Table 5-5). Abundance above Greer Spring (19% of range) will be reduced by at least 50% within 10 years, and abundance below Greer Spring (89% of range) will be reduced by 10-50% within 20 years.

Fig. 5-7. Predicted expansion of the Gap Ringed Crayfish in the Eleven Point River watershed at 10 years under the Most Likely Scenario.

Fig. 5-8. Predicted expansion of the Gap Ringed Crayfish in the Eleven Point River watershed at 25 years under the Most Likely Scenario.

Fig. 5-9. Predicted expansion of the Gap Ringed Crayfish in the Eleven Point River watershed at 50 years under the Most Likely Scenario.

Table 5-2. Predicted impacts to the Coldwater Crayfish from the Gap Ringed Crayfish invasion at 10 years for each future scenario.

10 Years			
	Reasonable Best	Most Likely	Reasonable Worst
% of range invaded	0%	1%	17%
% Reduction in abundance in invaded areas	10-50%[20]	> 50%	100%
Time for impacts to be fully realized	20-30 years	<10 years[21]	<10 years

[20] Though the Gap Ringed Crayfish invasion is not expected to reach the Coldwater Crayfish Range within 10 years under the Reasonable Best Scenario, we report the predicted impact to abundance to describe conditions if the invasion does actually reach the range.
[21] If the Gap Ringed Crayfish does expand beyond the confluence with Greer Spring (i.e., into marginal habitat), time for impacts to be fully realized is predicted to be within 20 years.

Table 5-3. Predicted impacts to the Coldwater Crayfish from the Gap Ringed Crayfish invasion at 25 years for each future scenario.

25 Years			
	Reasonable Best	Most Likely	Reasonable Worst
% of range invaded	0%	13%	53%
% Reduction in abundance in invaded areas	10-50%[22]	>50%	~100% in marginal habitat (19% of range) >50% in ideal habitat (34% of range)
Time for impacts to be fully realized	20-30 years	<10 years[23]	<10 years

Table 5-4. Predicted impacts to the Coldwater Crayfish from the Gap Ringed Crayfish invasion at 50 years for each future scenario.

50 Years			
	Reasonable Best	Most Likely	Reasonable Worst
% of range invaded	1%	34%	100%
% Reduction in abundance in invaded areas	10-50%	>50%	~100% in marginal habitat (19% of range) >50% in ideal habitat (81% of range)
Time for impacts to be fully realized	20-30 years	< 10 years in marginal habitat (19% of range) <20 years in ideal habitat (1% of range)	<10 years

[22] Though the Gap Ringed Crayfish invasion is not expected to reach the Coldwater Crayfish Range within 10 years under the Reasonable Best Scenario, we report the predicted impact to abundance to describe conditions if the invasion does actually reach the range.
[23] If the Gap Ringed Crayfish does expand beyond the confluence with Greer Spring (i.e., into marginal habitat), time for impacts to be fully realized is predicted to be within 20 years.

Table 5-5. Length of time for the Gap Ringed Crayfish to invade the entire Coldwater Crayfish range for each future scenario and estimated impact.

Time for Entire Range to be Invaded			
	Reasonable Best	Most Likely	Reasonable Worst
Time	Beyond reliable prediction (>600 yrs)	138 years	46 years
% Reduction in abundance in invaded areas	10-50%	>50% (19% of range) 10-50% (81% of range)	100% in marginal habitat (19% of range) >50% in ideal habitat (81% of range)

<u>Resiliency, Representation, and Redundancy</u>

Based on results of the modeling, 1 to 100% of the Coldwater Crayfish range may be invaded by the Gap Ringed Crayfish within 50 years (with invasion of the entire range taking from 46 to over 600 years). Within invaded areas, the impact on abundance ranges from a 10% reduction in abundance to virtually complete displacement (i.e., functional extirpation). For all but the Reasonable Best Scenario, **resiliency** of the species will be reduced from the current condition due to the loss of subpopulations (where the impact is virtual complete displacement) or the compromised health of subpopulations in invaded areas from reduced abundance. If subpopulations are extirpated or if abundance is reduced such that subpopulations are no longer healthy, **representation** and **redundancy** will also be reduced from the current condition given that we assume that Coldwater Crayfish representation and redundancy requires subpopulations distributed across the range (see Chapter 2).

Threats other than the Gap Ringed Crayfish invasion may further impact resiliency, representation, and redundancy of the Coldwater Crayfish within 50 years if those threats remain the same or increase. In particular, excessive sedimentation continues to degrade Coldwater Crayfish habitat towards the upstream and downstream end of the Eleven Point River (Briggler 2015, pers. comm.; Irwin 2015, pers. comm.) and may exacerbate displacement of the Coldwater Crayfish in areas invaded by the Gap Ringed Crayfish. Thus, the estimated impact due to the Gap Ringed Crayfish is a minimum estimate of the extent of impacts. In addition, if extreme events (drought, severe flooding, or toxic chemical spills) occur, affected subpopulations may be extirpated or have their abundance reduced. These events are expected to exacerbate impacts on the Coldwater Crayfish from the Gap Ringed Crayfish in invaded areas.

5.3 Eleven Point River Crayfish Future Conditions

<u>Reasonable Best Scenario</u>
Under the Reasonable Best Scenario, experts estimated that the Gap Ringed Crayfish invasion will expand at a rate of 200 m (219 yd) per year. Based on this expansion rate, none of the Eleven Point River Crayfish range will be invaded by the Gap Ringed Crayfish in 10, 25, or 50 years (Figs. 5-10, 5-11, 5-12; Tables 5-6, 5-7, 5-8). Because the range will not be invaded within any of these

time intervals, we predict no effect on resiliency, representation, or redundancy from the Gap Ringed Crayfish invasion within 50 years.

In approximately 220 years, the Gap Ringed Crayfish is expected to reach the Eleven Point River Crayfish range, and abundance will be functionally reduced[24] by 10-50% in invaded areas within 20-30 years. The length of time for the Gap Ringed Crayfish to invade the entire Eleven Point River Crayfish range is beyond reliable prediction (over 600 years)(Table 5-9).

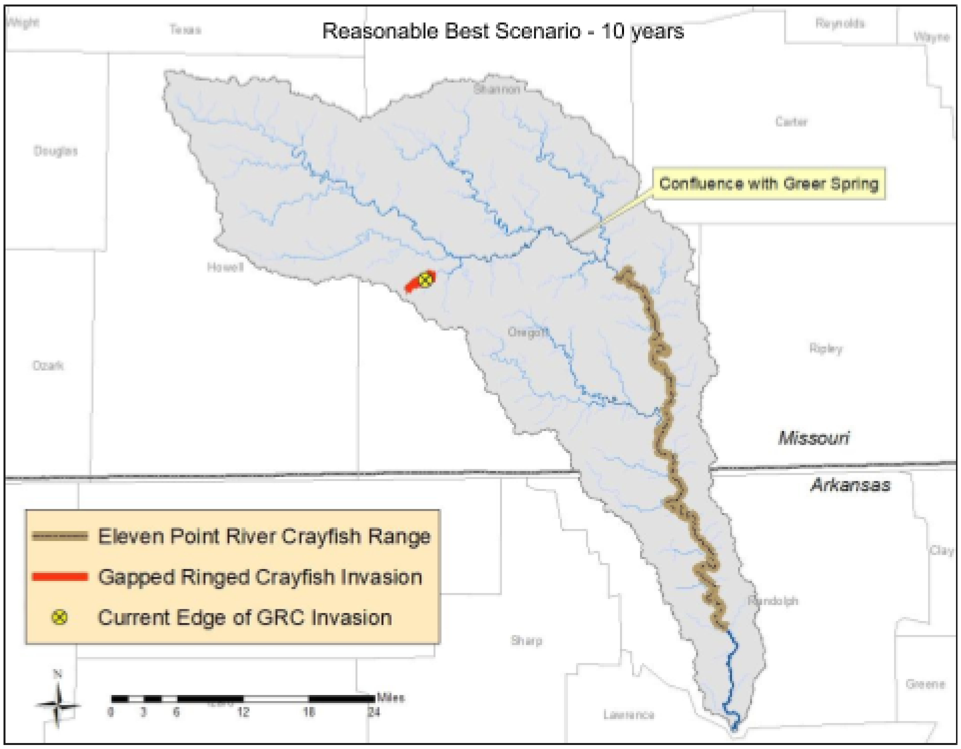

Figure 5-10. Predicted expansion of the Gap Ringed Crayfish in the Eleven Point River watershed at 10 years under the Reasonable Best Scenario.

[24] Even though impacts of an invasion may not be fully realized, we consider abundance to be functionally reduced because the trajectory cannot be reversed and the impacts will inevitably occur.

Figure 5-11. Predicted expansion of the Gap Ringed Crayfish in the Eleven Point River watershed at 25 years under the Reasonable Best Scenario.

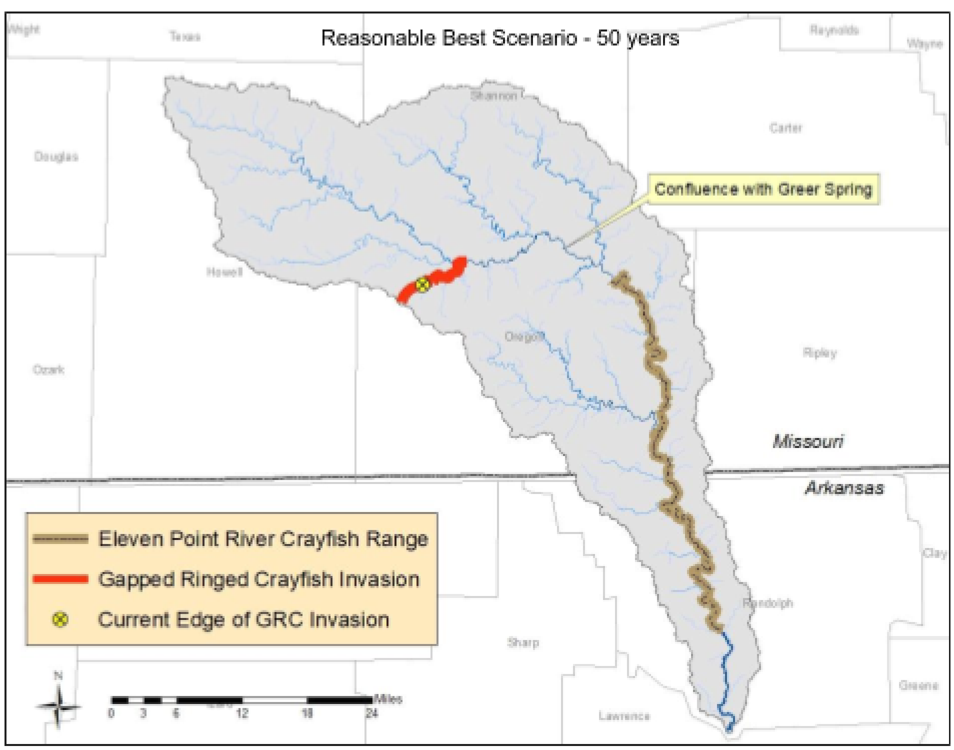

Figure 5-12. Predicted expansion of the Gap Ringed Crayfish in the Eleven Point River watershed at 50 years under the Reasonable Best Scenario.

Reasonable Worst Scenario

Under the Reasonable Worst Scenario, experts estimated that the Gap Ringed Crayfish invasion will expand at a rate of 3,000 m (3,300 yd) per year. Based on this expansion rate, none of the Eleven Point River Crayfish range will be invaded in 10 years (Fig. 5-13; Table 5-6). In 25 years, however, 31.8 km (19.8 mi)(36%) of the species' range will be invaded (Fig. 5-14; Table 5-7). Impacts will be realized within 10 years and abundance will be reduced by at least 50%.

In 46 years, the Gap Ringed Crayfish will have invaded the entire range of the Eleven Point River Crayfish (Table 5-9). Thus in 50 years, all of the Eleven Point River Crayfish's range will be invaded. Impacts to abundance will be realized within 10 years and abundance will be reduced by at least 50%.

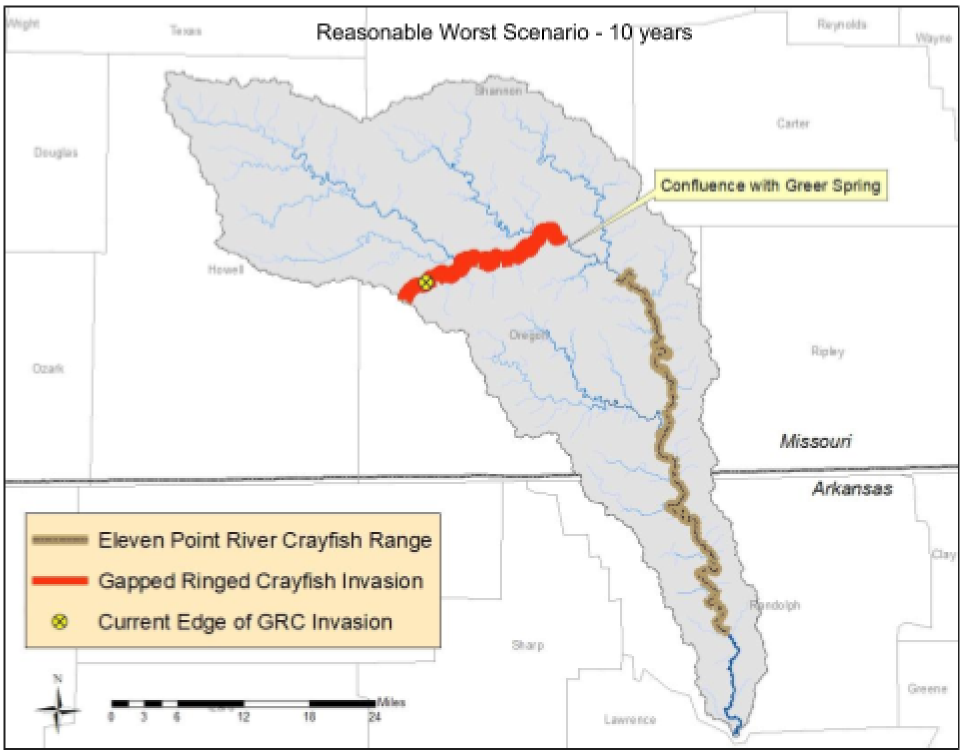

Figure 5-13. Predicted expansion of the Gap Ringed Crayfish in the Eleven Point River watershed at 10 years under the Reasonable Worst Scenario.

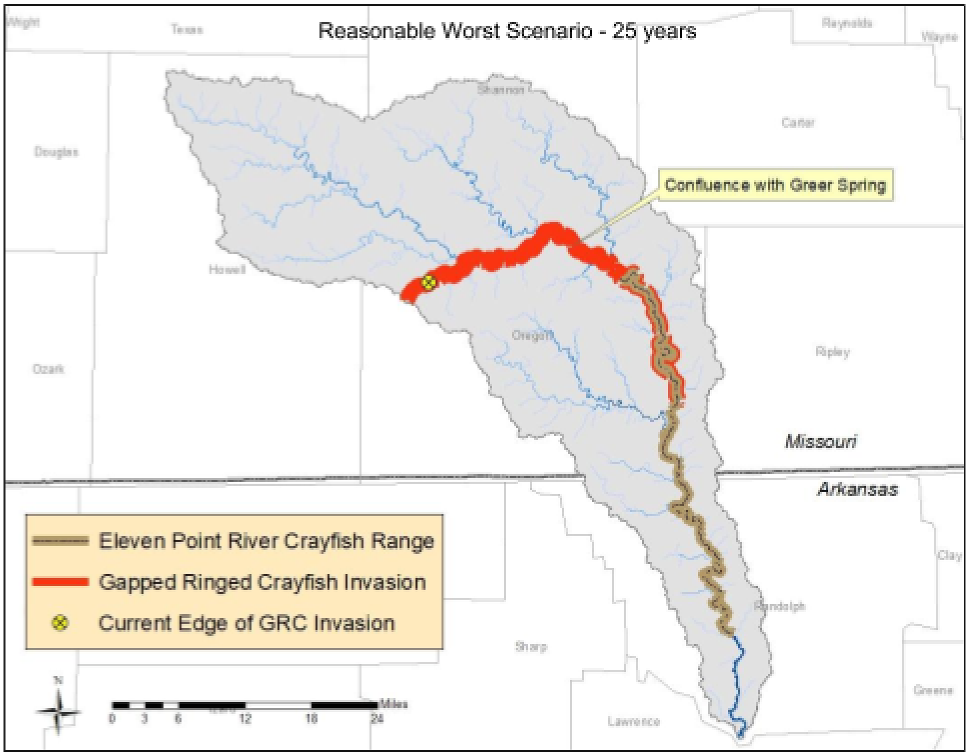

Figure 5-14. Predicted expansion of the Gap Ringed Crayfish in the Eleven Point River watershed at 25 years under the Reasonable Worst Scenario.

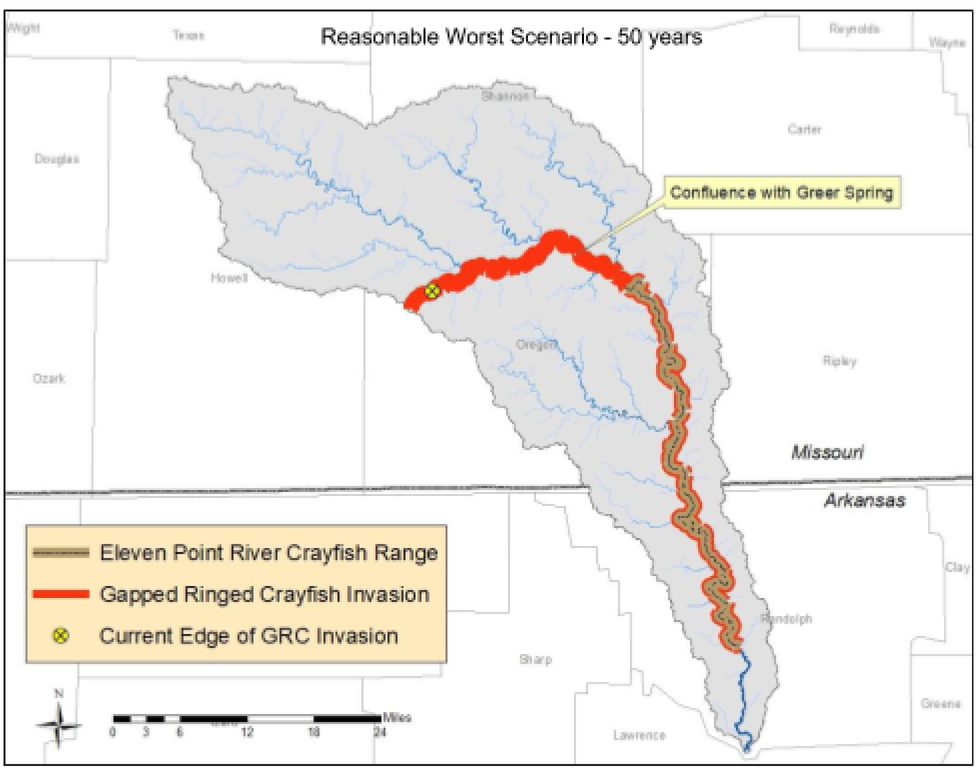

Figure 5-15. Predicted expansion of the Gap Ringed Crayfish in the Eleven Point River watershed at 50 years under the Reasonable Worst Scenario.

Most Likely Scenario

Under the Most Likely scenario, experts estimated that the Gap Ringed Crayfish invasion will expand at a rate of 1,000 m (1,100 yd) per year. Based on this expansion rate, none of the Eleven Point River Crayfish range will be invaded in 10 years or in 25 years (Figs. 5-16, 5-17; Tables 5-6, 5-7).

In 50 years 6.5 km (4.0 mi)(7%) of the species' range will be invaded (Fig. 5-18; Table 5-8). Within invaded areas, abundance will be reduced by 10-50% and impacts will be fully realized within 20 years.

In 138 years, the Gap Ringed Crayfish will have invaded the entire range of the Eleven Point River Crayfish and abundance will be reduced by 10-50% (Table 5-9).

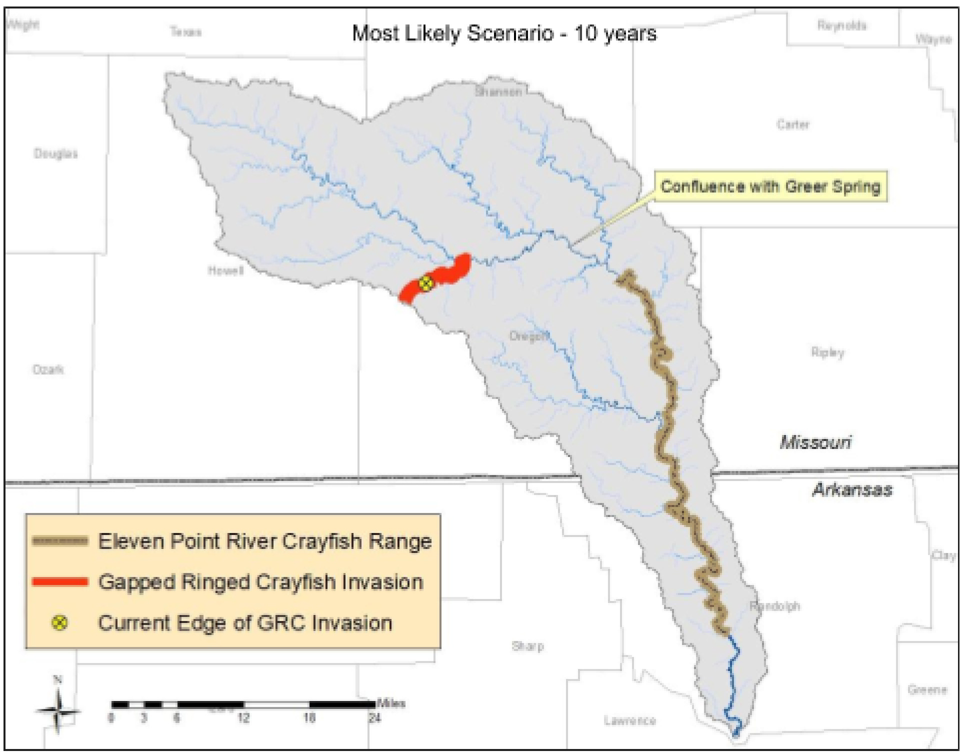

Figure 5-16. Predicted expansion of the Gap Ringed Crayfish in the Eleven Point River watershed at 10 years under the Most Likely Scenario.

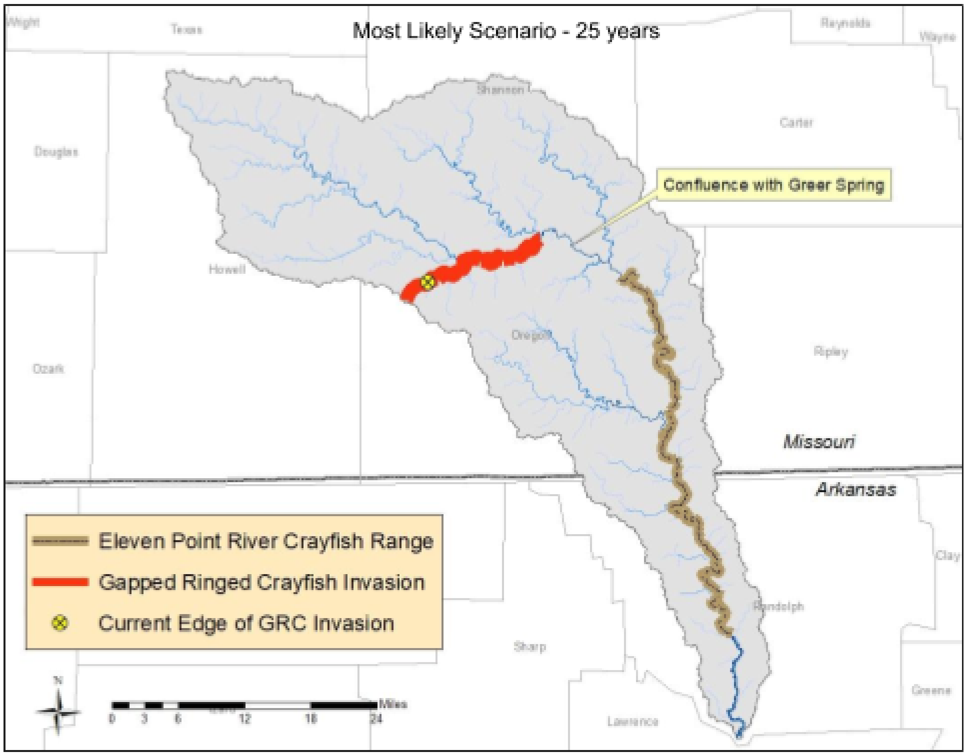

Figure 5-17. Predicted expansion of the Gap Ringed Crayfish in the Eleven Point River watershed at 25 years under the Most Likely Scenario.

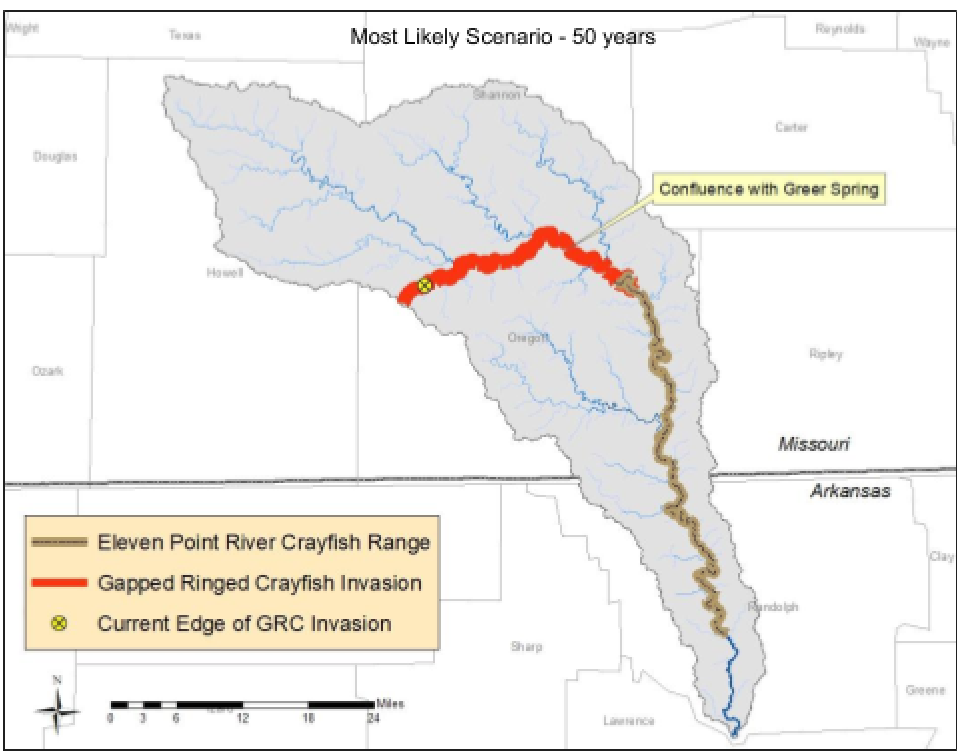

Figure 5-18. Predicted expansion of the Gap Ringed Crayfish in the Eleven Point River watershed at 50 years under the Most Likely Scenario.

Table 5-6. Predicted impacts to the Eleven Point River Crayfish from the Gap Ringed Crayfish invasion at 10 years for each future scenario.

10 Years			
	Reasonable Best	Most Likely	Reasonable Worst
% of range invaded	0%	0%	0%
% Reduction in abundance in invaded areas[25]	10-50%	10-50%	>50%
Time for impacts to be fully realized	20-30 years	<20 years	<10 years

Table 5-7. Predicted impacts to the Eleven Point River Crayfish from the Gap Ringed Crayfish invasion at 25 years for each future scenario.

25 Years			
	Reasonable Best	Most Likely	Reasonable Worst
% of range invaded	0%	0%	36%
% Reduction in abundance in invaded areas[26]	10-50%	10-50%	>50%
Time for impacts to be fully realized	20-30 years	<20 years	<10 years

[25] Though the Gap Ringed Crayfish invasion is not expected to reach the Eleven Point River Crayfish range within 10 years under any of the scenarios, we report the predicted impact to abundance to describe conditions if the invasion does actually reach the range.

[26] Though the Gap Ringed Crayfish invasion is not expected to reach the Eleven Point River Crayfish range within 25 years under the Reasonable Best and Most Likely scenarios, we report the predicted impact to abundance to describe conditions if the invasion does actually reach the range.

Table 5-8. Predicted impacts to the Eleven Point River Crayfish from the Gap Ringed Crayfish invasion at 50 years for each future scenario.

50 Years			
	Reasonable Best	Most Likely	Reasonable Worst
% of range invaded	0%	7%	100%
% Reduction in abundance in invaded areas[27]	10-50%	10-50%	>50%
Time for impacts to be fully realized	20-30 years	<20 years	<10 years

Table 5-9. Length of time for the Gap Ringed Crayfish to invade the entire Eleven Point River Crayfish range for each future scenario and estimated impact.

Time for Entire Range to be Invaded			
	Reasonable Best	Most Likely	Reasonable Worst
Time	Beyond reliable prediction (>600 yrs)	138 years	46 years
% Reduction in abundance in invaded areas	10-50%	10-50%	>50%

Resiliency, Representation, and Redundancy

Based on results of the modeling, 0 to 100% of the Eleven Point River Crayfish range may be invaded by the Gap Ringed Crayfish within 50 years. Within invaded areas, abundance is expected to be reduced by at least 10% and up to greater than 50% (but not virtually complete displacement). If the Gap Ringed Crayfish does reach the Eleven Point River Crayfish range, **resiliency** of the species will be reduced from the current condition due to the compromised health of subpopulations in invaded areas (due to reduction in abundance). If abundance of subpopulations is reduced such that subpopulations are no longer healthy, **representation** and **redundancy** will also be reduced from the current condition given that we assume that Eleven Point River Crayfish representation and redundancy requires subpopulations distributed across the range (see Chapter 2).

Threats other than the Gap Ringed Crayfish invasion may further impact resiliency, representation, and redundancy of the Eleven Point River Crayfish within 50 years if those threats remain the same or increase. In particular, excessive sedimentation continues to degrade Eleven Point River

[27] Though the Gap Ringed Crayfish invasion is not expected to reach the Eleven Point River Crayfish range within 50 years under the Reasonable Best scenario, we report the predicted impact to abundance to describe conditions if the invasion does actually reach the range.

Crayfish habitat towards the upstream and downstream end of the Eleven Point River (Briggler 2015, pers. comm.; Irwin 2015, pers. comm.) and may exacerbate displacement of the Eleven Point River Crayfish in areas invaded by the Gap Ringed Crayfish. Thus, the estimated impact due to the Gap Ringed Crayfish is a minimum estimate of the extent of impacts. In addition, if extreme events (drought, severe flooding, or toxic chemical spills) occur, affected subpopulations may be extirpated or have their abundance reduced. These events are expected to exacerbate impacts on the Eleven Point River Crayfish from the Gap Ringed Crayfish in invaded areas.

Chapter 6. Synthesis

Based on the best available information, the current condition of the Coldwater Crayfish and Eleven Point River Crayfish appears unchanged from the historical condition. However, the watershed occupied by these species has been invaded by the Gap Ringed Crayfish, a species native to the western Ozarks but not the Eleven Point River watershed. The Gap Ringed Crayfish has displaced the Spring River Crayfish (another species in the Coldwater Crayfish complex) in 29 stream km of the Spring River watershed, and abundance of the Coldwater Crayfish and Eleven Point River Crayfish is expected to also be reduced when the Gap Ringed Crayfish reaches their ranges[28].

To evaluate future conditions of the Coldwater Crayfish and Eleven Point River Crayfish due to the Gap Ringed Crayfish invasion, we predicted the expansion of the Gap Ringed Crayfish within the Eleven Point River watershed. We elicited estimates from species experts for 1) the plausible range of Gap Ringed Crayfish expansion rates and 2) resulting impacts on Coldwater Crayfish and Eleven Point River Crayfish abundance. Using these estimates we created Reasonable Best, Reasonable Worst, and Most Likely scenarios to characterize the range of Coldwater Crayfish and Eleven Point River Crayfish future conditions in 10, 25, and 50 years.

Given that there are currently no known feasible measures to curtail the Gap Ringed Crayfish invasion, we consider it extremely likely that the invasion will continue. Based on our use of expert-elicited estimates of the rate of expansion and the resulting impacts on the Coldwater Crayfish and Eleven Point River Crayfish, we are also reasonably certain that we can predict the plausible range of future conditions within 50 years. For this reason, we have focused our discussion below primarily on predicted viability within 50 years. Though the impacts of the invasion may not be fully realized within 50 years, we discuss the functional impacts on abundance (i.e., as if they have already occurred) given that the trajectory cannot be reversed and the impacts will inevitably occur.

6.1 Coldwater Crayfish Predicted Viability

Based on results of the modeling, 1 to 100% of the Coldwater Crayfish range may be invaded by the Gap Ringed Crayfish within 50 years, with 34% being the mostly likely extent (Table 6-1). Under each of the future scenarios, abundance will be reduced if the Gap Ringed Crayfish reaches the Coldwater Crayfish range, with the lowest expected impact being a 10% reduction in abundance (Table 6-1). Coldwater Crayfish abundance is expected to be further reduced due the presence of other threats, with sedimentation being the primary concern. In addition to directly impacting the health of Coldwater Crayfish subpopulations, these threats are anticipated to exacerbate displacement by the Gap Ringed Crayfish, resulting in a synergistic effect. In addition, the occurrence of extreme events (drought, severe flooding, or toxic chemical spills) would extirpate or reduce abundance of subpopulations and also exacerbate impacts on the Coldwater Crayfish from the Gap Ringed Crayfish in invaded areas. For these reasons, results of the scenarios likely reflect the minimum level of impacts.

[28] Though abundance is expected to be reduced, experts predicted that the species may not be completely displaced (as the Spring River Crayfish was) given that habitat in the Eleven Point River is more suitable than in areas where the Spring River Crayfish has been extirpated.

Table 6-1. Based on expert opinion, the range of predicted impacts to the Coldwater Crayfish from the Gap Ringed Crayfish invasion within 50 years.

50 Years			
	Reasonable Best	Most Likely	Reasonable Worst
% of range invaded	1%	34%	100%
% Reduction in abundance in invaded areas	10-50%	>50%	~100% (19% of range) >50% (81% of range)

The loss of healthy subpopulations, whether through extirpation or by reduced abundance (such that they are no longer healthy), reduces Coldwater Crayfish resiliency, representation, and redundancy. As described in Chapter 2, the Coldwater Crayfish requires interconnected, healthy subpopulations distributed across its range to be resilient. To have representation the species must also have healthy subpopulations distributed across the range, as well as intact evolutionary processes. Lastly, to have redundancy the Coldwater Crayfish must have a sufficient number and distribution of healthy subpopulations across its range to guard against the loss of adaptive diversity from catastrophic events.

Interpreting Impacts to Resiliency, Representation, and Redundancy (the 3Rs)

Given the Coldwater Crayfish's requirements for resiliency, representation, and redundancy, we expect that the 3Rs will be reduced in the future due to the Gap Ringed Crayfish invasion and other threats. It is difficult to quantify the extent to which the 3Rs will be affected. However, if we consider that the Coldwater Crayfish consists of only one population, we might assume that a reduction in the number of healthy subpopulations would be proportional to a reduction in resiliency, representation, and redundancy. If we then consider it likely that subpopulations in invaded areas will no longer be healthy[29], we might use the proportion of the Coldwater Crayfish range invaded as a proxy for the extent of reduction in resiliency, representation, and redundancy.

The exact distribution of Coldwater Crayfish subpopulations required to maintain resiliency and adaptive capacity is unknown, as is the number of healthy subpopulations required to guard against catastrophic events. Therefore, it is unclear whether a 10-100% reduction in abundance in 0-53% of the range still provides sufficient resiliency, representation, and redundancy for the Coldwater Crayfish to maintain viability. If the reduction is within the lower range of predictions (closer to 0), we might expect little impact on viability and thus a high probability of persistence. However, if the reduction is towards the higher end of the predictions, we would expect a greater impact on viability with a lower probability of persistence.

Lastly, though we modeled future conditions for 10, 25, and 50 years, we have a high level of confidence that the Gap Ringed Crayfish invasion will continue into the future (beyond 50 years), as there are currently no known mechanisms to stop or reverse the invasion.

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[29] The estimated range of impacts is a 10-100% reduction in abundance, with a most likely estimate of at least 50%.

6.2 Eleven Point River Crayfish Predicted Viability

Based on results of the modeling, 0 to 100% of the Eleven Point River Crayfish range may be invaded by the Gap Ringed Crayfish within 50 years, with 7% being the most likely extent (Table 6-2). Under each of the future scenarios, abundance will be reduced if the Gap Ringed Crayfish reaches the Eleven Point River Crayfish range, with the lowest expected impact being a 10% reduction in abundance (Table 6-2). Similar to the Coldwater Crayfish, Eleven Point River Crayfish abundance is expected to be further reduced due the presence of other threats, with sedimentation being the primary concern. In addition to directly impacting the health of Eleven Point River Crayfish subpopulations, these threats are anticipated to exacerbate displacement by the Gap Ringed Crayfish, resulting in a synergistic effect. In addition, the occurrence of extreme events (drought, severe flooding, or toxic chemical spills) would extirpate or reduce abundance of subpopulations and also exacerbate impacts on the Eleven Point River Crayfish from the Gap Ringed Crayfish in invaded areas. For these reasons, results of the scenarios likely reflect the minimum level of impacts.

The loss of healthy subpopulations, whether through extirpation or by reduced abundance (such that they are no longer healthy), reduces Eleven Point River Crayfish resiliency, representation, and redundancy. As described in Chapter 2, the Eleven Point River Crayfish requires interconnected, healthy subpopulations distributed across its range to be resilient. To have representation the species must also have healthy subpopulations distributed across the range, as well as intact evolutionary processes. Lastly, to have redundancy the Eleven Point River Crayfish must have a sufficient number and distribution of healthy subpopulations across its range to guard against the loss of adaptive diversity from catastrophic events.

Table 6-2. The range of predicted impacts to the Eleven Point River Crayfish from the Gap Ringed Crayfish invasion at 50 years based on expert opinion.

50 Years			
	Reasonable Best	Most Likely	Reasonable Worst
% of range invaded	0%	7%	100%
% Reduction in abundance in invaded areas	10-50%[18]	>50%	>50%

<u>Interpreting Impacts to Resiliency, Representation, and Redundancy (the 3Rs)</u>
Given the Eleven Point River Crayfish's requirements for resiliency, representation, and redundancy, we expect that the 3Rs will be reduced in the future if the Gap Ringed Crayfish reaches the species' range. In the absence of the Gap Ringed Crayfish, the 3Rs may still be reduced in the future due to other threats, particularly excessive sedimentation. As with the Coldwater Crayfish, it is difficult to quantify the extent to which the 3Rs will be affected. However, if we consider that the Eleven Point River Crayfish consists of only one population, we might assume that a reduction in the number of healthy subpopulations would be proportional to a reduction in resiliency, representation, and redundancy. If we then consider it likely that subpopulations in invaded areas will no longer be healthy[30], we might use the proportion of the Eleven Point River Crayfish range invaded as a proxy for the extent of reduction in resiliency, representation, and redundancy.

[30] The estimated range of impacts is a 10-100% reduction in abundance, with a most likely estimate of at least 50%.

The exact distribution of Eleven Point River Crayfish subpopulations required to maintain resiliency and adaptive capacity is unknown, as is the number of healthy subpopulations required to guard against catastrophic events. Therefore, it is unclear if a 10-50% (and possibly greater) reduction in abundance in 0-100% of the range still provides sufficient resiliency, representation, and redundancy for the Eleven Point River Crayfish to maintain viability. If the reduction is within the lower range of predictions (closer to 0), we might expect little impact on viability and thus a high probability of persistence. However, if the reduction is towards the higher end of the predictions (100%), we would expect a greater impact on viability with a lower probability of persistence.

Lastly, though we modeled future conditions for 10, 25, and 50 years, we have a high level of confidence that the Gap Ringed Crayfish invasion will continue into the future (beyond 50 years), as there are currently no known mechanisms to stop or reverse the invasion.

6.3 Uncertainties

Predicting the future condition of the Coldwater Crayfish and Eleven Point River Crayfish inherently requires us to make plausible assumptions. Our analyses are predicated on multiple assumptions, which could lead to overestimates and underestimates of viability. In Table 6-3 we identify the key sources of uncertainty and indicate the likely effect of our assumptions on the viability assessment.

Table 6-3. Key assumptions made in evaluating the future condition of the Coldwater Crayfish and Eleven Point River Crayfish and the impact on our viability assessment if such assumptions are incorrect. "Overestimated" means the viability of the species is optimistic; "Underestimated" means the viability of the species is pessimistic. Text in italics is the more likely result of the two outcomes.

Assumptions	Influence on Viability Assessment if Incorrect
The Coldwater Crayfish and Eleven Point River Crayfish occur throughout the Eleven Point River between the furthest upstream and downstream locations depicted in Figure 3.1, a distance of 124 stream kilometers (km)(77 miles (mi).	Overestimated
Coldwater Crayfish and Eleven Point River Crayfish subpopulations are currently healthy. With the recent taxonomic division, we have no information on population trends. However, no changes in abundance have been documented for the Coldwater Crayfish complex in the Eleven Point River.	Overestimated
Response of the Coldwater Crayfish and Eleven Point River Crayfish to the Gap Ringed Crayfish invasion will be similar to that of the Spring River Crayfish (all 3 species were previously part of the Coldwater Crayfish complex).	*Underestimated*/ Overestimated
There will be no new introductions of the Gap Ringed Crayfish or other non-native crayfish in the Eleven Point River watershed.	Overestimated
The expansion of the Gap Ringed Crayfish will continue unabated, as there are no known mechanisms to halt or reverse it.	Underestimated

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Appendix A. Evaluating Catastrophic Events

For the purposes of the Species Status Assessment (SSA) for the Coldwater Crayfish and Eleven Point River Crayfish, we define a catastrophic event as a biotic or abiotic event that causes significant impacts at the population level such that the population cannot rebound from the effects or the population becomes highly vulnerable to normal population fluctuations or stochastic events. At the Coldwater Crayfish and Eleven Point River Crayfish population level (or species level[31]), we considered whether extreme drought and toxic chemical spills may be potential catastrophic events.

Drought

We evaluated the frequency of drought in previous years using data from the U.S. Drought Monitor (USDM). The USDM is a weekly map of drought conditions produced by the National Oceanic and Atmospheric Administration, the U.S. Department of Agriculture, and the National Drought Mitigation Center at the University of Nebraska-Lincoln. Though data are only available from 1999 to the present, they do provide some information on the likelihood and severity of droughts when predicting future conditions of the Coldwater Crayfish and Eleven Point River Crayfish. USDM categories of drought and associated conditions are provided in Table A-1.

According to the USDM data, 100% of the Eleven Point River watershed was affected by a D3-D4 drought in 2012 (Fig. A-1)(USDM 2018b). During July and August in 2012, the drought intensified to a D4 drought in 18% of the watershed (Fig. A-1)(USDM 2018b). We queried species experts on whether they recalled impacts to the Coldwater Crayfish and Eleven Point River Crayfish during the 2012 drought. Experts did not recall catastrophic impacts to the species. However, they noted that D4 droughts could be catastrophic if they occurred with greater frequency, were of longer duration, or occurred in conjunction with other stressors. In addition, droughts could reduce the overall viability of the species by potentially extirpating or compromising subpopulations in the impacted area.

Table A-1. Drought severity classification (USDM 2018a).

Category	Description	Possible Impacts	USGS Weekly Streamflow (percentiles)
D0	Abnormally Dry	Going into drought: • short-term dryness slowing planting, growth of crops or pastures Coming out of drought: • some lingering water deficits • pastures or crops not fully recovered	21 to 30
D1	Moderate Drought	• Some damage to crops, pastures • Streams, reservoirs, or wells low, some water shortages developing or imminent • Voluntary water-use restrictions requested	11 to 20
D2	Severe Drought	• Crop or pasture losses likely • Water shortages common • Water restrictions imposed	6 to 10
D3	Extreme Drought	• Major crop/pasture losses • Widespread water shortages or restrictions	3 to 5
D4	Exceptional Drought	• Exceptional and widespread crop/pasture losses • Shortages of water in reservoirs, streams, and wells creating water emergencies	0 to 2

[31] Results from genetic analyses indicate that the Coldwater Crayfish functions as a single population, with gene flow throughout the entire range (Fetzner et al. 2013, pp. 10-11).

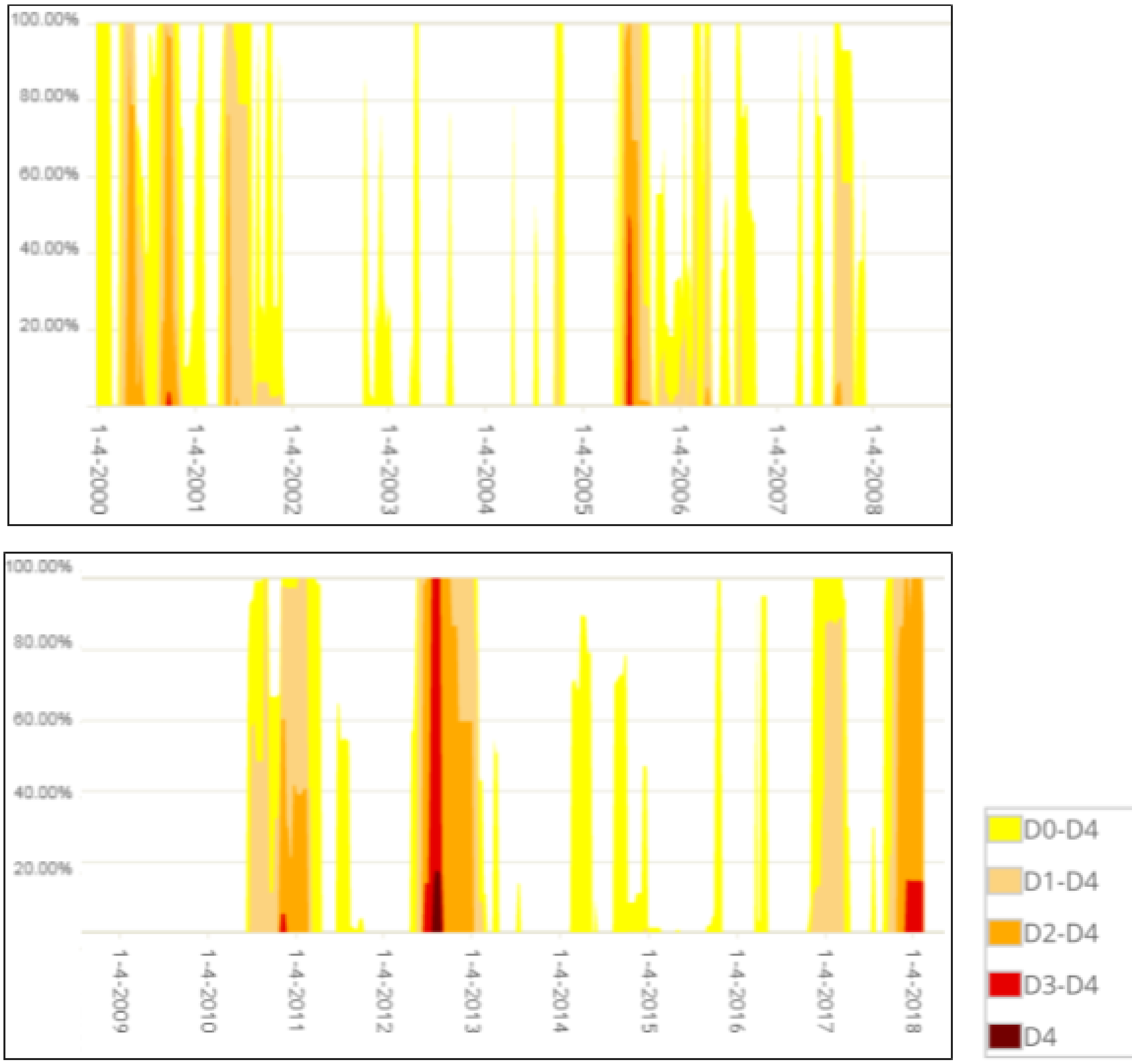

Figure A-1. Drought conditions in the Eleven Point River watershed from January 2000 to January 2018. The entire watershed (100%) was affected by a D3-D4 drought in 2012 (USDM 2018b).

Chemical Spills

To evaluate the risk of chemical spills catastrophic to the Coldwater Crayfish and Eleven Point River Crayfish, we identified 1) major pipelines crossing the Eleven Point River watershed, 2) railways that cross the watershed and could spill large quantities of oil or other chemical substances, 3) hazardous material routes that cross the watershed, and 4) any other sources of large volumes of chemical substances. Based on the information outlined below, we think that chemical spills could result in a catastrophic loss to the Coldwater Crayfish and Eleven Point River Crayfish at the population level.

Major Pipelines

According to the Pipeline and Hazardous Materials Safety Administration (2016), only one major pipeline crosses the Eleven Point River (Fig. A-2). The 11-inch pipeline carries anhydrous ammonia and crosses the Eleven Point River near the upper end of the Coldwater Crayfish and Eleven Point River Crayfish ranges where the Eleven Point River is an intermittent stream. Although the Eleven Point River is an intermittent stream at the crossing, it could transport large volumes of the pipeline's contents downstream during high water flow or if there is a losing reach of the stream[32] that is part of the Greer Spring recharge area.

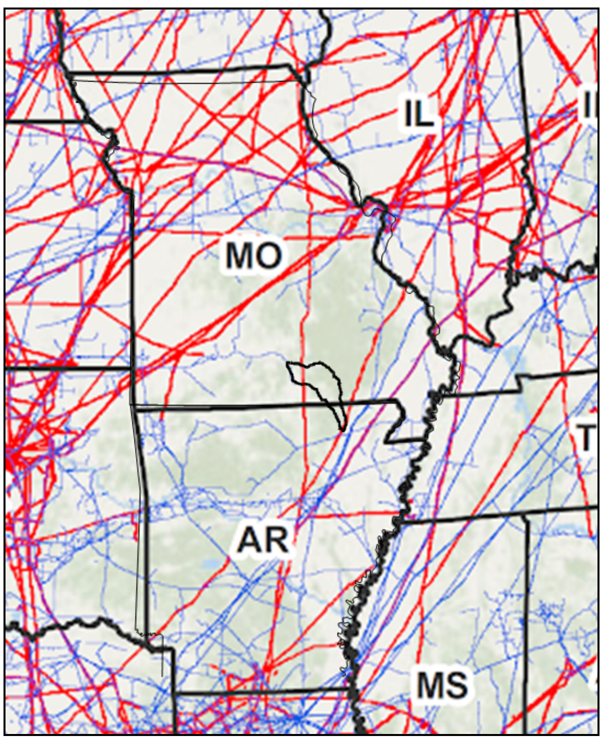

Figure A-2. Gas Transmission and Hazardous Liquid Pipelines[33] (PHMSA 2016). Blue lines represent gas transmission pipelines; red lines represent hazardous liquid pipelines.

[32] Losing stream reaches are those that lose a significant part of their flow to the groundwater system. Water from losing stream reaches may flow into recharge systems for springs (such as Greer Spring).

[33] A higher resolution map was used to evaluate the exact location of major pipelines relative to the Eleven Point River watershed. However, the Pipeline Information Management Mapping Application, developed by PHMSA, contains sensitive pipeline critical infrastructure. Per PHMSA security policy, the scale at which the public may view NPMS data is restricted to 1:24,000.

Railways
Only one railway carrying crude oil crosses the Eleven Point River watershed (Fig. A-3)(OCI 2017). The railway crosses the at the upper reaches of the watershed where the Eleven Point River is an intermittent stream. Similar to a major pipeline rupture, a railway spill could transport large volumes of crude oil downstream during high water flow or if there is a losing reach of the Eleven Point River[34] that is part of the Greer Spring recharge area.

Figure A-3. Major railway routes of transport for crude oil (OCI 2017).

Other Sources of Large Volumes of Chemical Substances
In addition to spills that could occur near transportation routes, there is a facility at the upper end of the Eleven Point River in Willow Springs that has a storage capacity of 2.8 million gallons of liquid asphalt, denatured ethanol, and diesel fuel (Fig. A-4)(USEPA 2015, p. 5). In the event of a spill, this facility has the potential to release a large volume of chemicals into the Eleven Point River. The facility is located approximately 69 km (43 mi) from the Coldwater Crayfish range and 104 km (65 mi) from the Eleven Point River Crayfish range.

[34] Losing stream reaches are those that lose a significant part of their flow to the groundwater system. Water from losing stream reaches may flow into recharge systems for springs (such as Greer Spring).

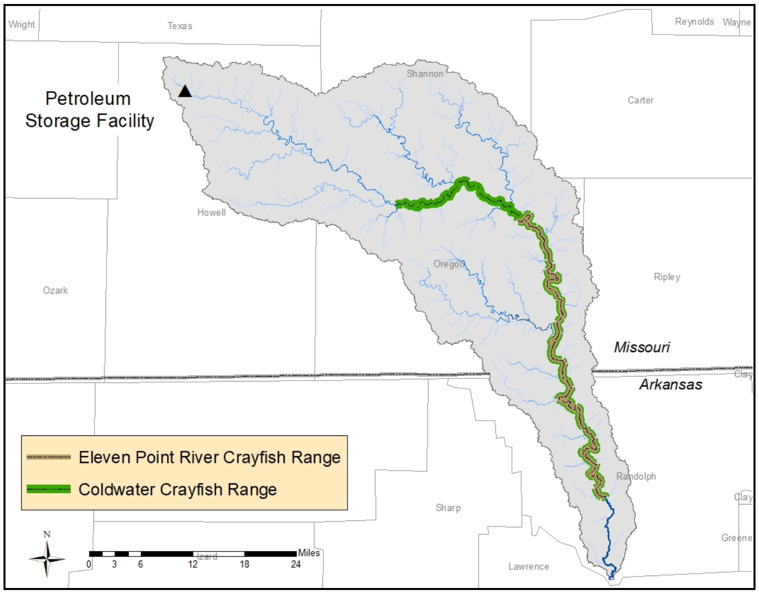

Figure A-4. Petroleum storage facility at the upper end of the Eleven Point River.

Hazardous Materials Routes

According to data from the Federal Motor Carrier Safety Administration (FMCSA), no hazardous material routes cross the Eleven Point River watershed (Fig. A-4)(FMCSA 2017). Hazardous material routes include roads, highways, and interstates by which hazardous materials are transported by commercial motor vehicles. The classes of hazardous materials, as defined by the FMCSA are 1) explosives, 2) gases, 3) flammable liquid and combustible liquids, 4) flammable solids, spontaneously combustible and dangerous when wet, 5) oxidizer and organic peroxide, 6) poison and poison inhalation hazard, 7) radioactive, 8) corrosive, and 9) miscellaneous.

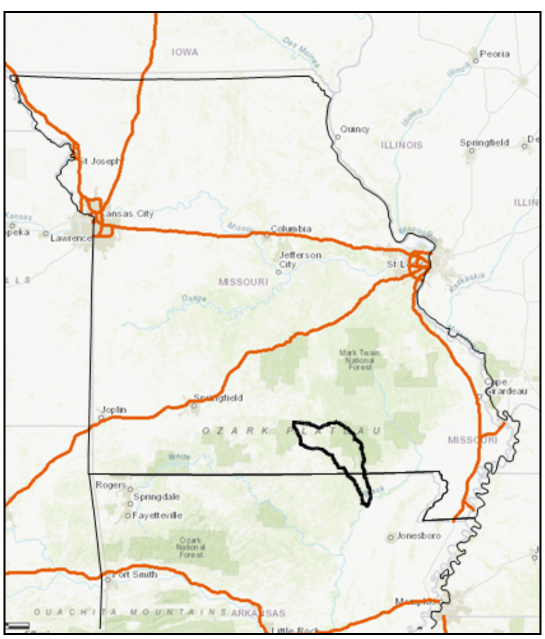

Figure A-4. Hazardous material routes (Federal Motor Carrier Safety Administration 2017).

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Appendix B. Predicting Future Conditions Using Expert Elicitation

On May 10-11, 2017, we convened a group of biologists with expertise on Ozark-endemic crayfishes to provide input on the anticipated future condition of six crayfish species for which we are conducting species status assessments. The species included the Coldwater Crayfish (*Faxonius eupunctus*) and Eleven Point River Crayfish (*Faxonius wagneri*). The ranges of both species have been invaded by the Gap Ringed Crayfish (*Faxonius neglectus chaenodactylus*). We sought the experts' knowledge on 1) the anticipated rate at which the Gap Ringed Crayfish will expand its range within the watersheds of the two native species, 2) impacts of the invasion on the native species, and 3) the length of time for impacts to be fully realized[35].

Expansion Rate of the Gap Ringed Crayfish

Experts relayed that expansion of invading crayfishes is facilitated by streamflow in the downstream direction and that expansion rates differ between upstream and downstream movement. Experts also thought that stream permanence (i.e., intermittent vs. perennial streams) influences the expansion rate. Therefore, we elicited values for Gap Ringed Crayfish downstream movement in perennial streams, upstream movement in intermittent streams, and upstream movement in perennial streams. We did not elicit rates of expansion for downstream movement in intermittent streams because the Gap Ringed Crayfish has already expanded into perennial streams in the Eleven Point Rivershed and any movement into intermittent streams will be in the upstream direction.

To account for annual variation in environmental conditions that could influence the Gap Ringed Crayfish expansion rates (e.g., flooding, drought, etc.), we asked experts to provide an average annual expansion rate over a ten-year period. In estimating the rates of expansion, experts considered results from existing literature (Wilson et al. 2004, Magoulick and DiStefano 2007, Westhoff et al. 2011) and factors that could influence the rates such as barriers (dams, culverts, waterfalls), biotic interactions (predation, competition), water depth, and substrate types.

We used the 4-step elicitation technique and elicited each expert's lowest plausible, highest plausible, and most likely estimates for expansion rates. We also used a modified Delphi process in which experts provided their initial individual response to each question, discussed (as a group) the rationales for their estimates, and then provided their revised individual response based on the rationales discussed. Results are summarized in Table B-1.

[35] The process of an introduced species invading a new area consists of four stages: introduction, establishment, spread, and impact (Lockwood et al. 2013, p. 13-14). That is, once the invading species is introduced, it takes some time for it to establish itself in the new area, spread, and for the impacts to occur.

Table B-1. Expert-elicited estimated average annual rates of expansion for the Gap Ringed Crayfish.

Categories of Likelihood Estimates	Estimated Expansion Rate (meters per year)					
	Perennial Streams (Downstream)		Perennial Streams (Upstream)		Intermittent Streams (Upstream)	
	Median	Range	Median	Range	Median	Range
Lowest Plausible	200	100-200	50	0-100	0	0-25
Highest Plausible	3,000	2,500-10,000	1,000	400-2,000	350	100-1,000
Most Likely	1,000	900-2,500	300	200-500	150	50-300

Impact of the Gap Ringed Crayfish

The Coldwater Crayfish and Eleven Point River Crayfish are habitat specialists that require cold, permanent streams with high current velocity[36]. For this reason, experts thought that these species would experience greater impacts in areas of less suitable (marginal) habitat than in areas with ideal habitat because they would not be able to compete well with the invading crayfish. In addition, these impacts would be fully realized more quickly in marginal habitat[37].

Ideal habitat for these species was defined as stream reaches with cold temperature, a stable temperature regime, and a stable groundwater flow regime[38]. For the Eleven Point River watershed, ideal habitat was identified as the mainstem of the Eleven Point River downstream of Greer Spring, with stream reaches upstream of the spring identified as marginal habitat.

To elicit estimates on the level of impact on abundance from the invading crayfishes and the time for impacts to be fully realized, we used the likelihood point method. This method involves experts distributing 100 points across the different categories of effects, with the distribution of points based on each expert's strength of belief that the actual impact will be encompassed in that category (the more points assigned to a category, the more strongly the experts felt that the category captured the actual level of impact). We again used a modified Delphi process, as described above. Results are summarized in Tables B-2 and B-3.

[36] However, recent surveys have revealed that Coldwater Crayfish and Eleven Point River Crayfish also occupy deep pools with lower flow velocity (Rice 2018, pers. comm.).
[37] Experts did not think a time lag was relevant to the Mammoth Spring Crayfish.
[38] Ozarks rivers with stable groundwater flow regimes are typically large rivers with significant groundwater recharge, large base flows, and extremely low variability in stream flow (Leasure et al. 2016, p. 32).

Table B-2. Expert-elicited estimated impact on abundance of the Coldwater Crayfish, Eleven Point Crayfish, and Spring River Crayfish from invasion of the Gap Ringed Crayfish. Values represent the median of the points experts assigned to each category; values in parentheses represent the range of points experts assigned.

Category of Impact	Points Assigned to Each Category Median (Range)	
	Ideal Habitat	Marginal Habitat
No observable effect on abundance (~0% reduction)	5 (0-10)	5 (0-5)
Abundance reduced 10-50%	60 (10-70)	15 (10-40)
Abundance reduced > 50% (but not fully displaced)	20 (20-90)	54 (25-90)
Virtual complete displacement (~100% reduction)	5 (0-10)	25 (0-55)

Table B-3. Expert-elicited estimated length of time for impacts on the Coldwater Crayfish and Eleven Point River Crayfish from the Gap Ringed Crayfish invasion to be fully realized. Values represent the median of the points experts assigned to each category; values in parentheses represent the range of points experts assigned.

Time for Impact to be Fully Realized	Points Assigned to Each Category Median (Range)	
	Ideal Habitat	Marginal Habitat
Less than 10 years	30 (0-55)	55 (25-65)
10-20 years	30 (0-50)	25 (25-35)
20-30 years	20 (10-50)	20 0-50)
30-40 years	3 (0-50)	0 (0-10)
More than 40 years	0 (0-10)	0 (0-10)

Development of Scenarios to Characterize Uncertainty

As a way to characterize uncertainty in predicting future conditions, we developed Reasonable Best, Reasonable Worst, and Most Likely scenarios that represent the plausible range of each species' future conditions (Table B-4).

The Reasonable Best Scenario represents the smallest plausible proportion of the native species' ranges that the Gap Ringed Crayfish may invade with the lowest plausible level of impact. For the Reasonable Best Scenario, we selected the median of the values experts provided for the lowest plausible expansion rate for the Gap Ringed Crayfish (Table B-1). We selected the lowest category of impact (Table B-2) and the greatest number of years for impacts to be realized (Table B-3). For impact on abundance and time for impacts to be realized, we included only those categories having a median score greater than 5 to exclude those categories that experts felt were highly implausible.

The Reasonable Worst Scenario represents the highest plausible proportion of the native species' ranges that may be invaded with the highest plausible level of impact. For the Reasonable Worst Scenario, we selected the median of the values experts provided for the highest plausible expansion rate for the invading crayfish species (Table B-1). We selected the highest category of impact (Table B-2) and the lowest number of years for impacts to be realized (Table B-3). For impact on abundance and time for impacts to be fully realized, we again included only categories having a median score greater than 5.

The Most Likely Scenario represents the most likely proportion of the species' ranges impacted with the most likely level of impact. For the Most Likely Scenario, we selected the median of the values experts provided for the most likely expansion rate for the invading crayfish species (Table B-1). We selected the category of impact with the highest median value (Table B-2) and the category having the highest median value for the number of years for impacts to be realized (Table B-3). For impact on abundance and time for impacts to be fully realized, we again included only categories having a median score greater than 5.

Expert-elicited estimates used for the three future scenarios for the Coldwater Crayfish and Eleven Point River Crayfish are provided in Table B-5.

Table B-4. Scenarios representing the plausible range of the Coldwater Crayfish's future conditions with the expert-elicited estimates and assumptions used to develop each scenario.

Future Scenario	Estimates Used
Reasonable Best	Lowest plausible expansion rate of the Gap Ringed Crayfish Lowest level of predicted impact on Coldwater Crayfish and Eleven Point River Crayfish abundance Highest number of years for impacts to be fully realized
Reasonable Worst	Highest plausible expansion rate of the Gap Ringed Crayfish Highest level of predicted impact on Coldwater Crayfish and Eleven Point River Crayfish abundance Lowest number of years for impacts to be fully realized
Most Likely	Most likely expansion rate of the Gap Ringed Crayfish Most likely level of predicted impact on Coldwater Crayfish and Eleven Point River Crayfish abundance Most likely number of years for impacts to be fully realized

Table B-5. Expert-elicited estimates used for the Coldwater Crayfish and Eleven Point River Crayfish future scenarios.

Future Scenario	Expansion Rate (meters/year)	Level of Impact (reduction in abundance)		Time for Impacts to be Fully Realized (years)	
		Ideal Habitat	Marginal Habitat	Ideal Habitat	Marginal Habitat
Reasonable Best	200	10-50%	10-50%	20-30	20-30
Reasonable Worst	3,000	>50%	~100%	<10	<10
Most Likely	1,000	10-50%	>50%	<20	<10

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