Species Status Assessment Report for the

Spring River Crayfish
(*Faxonius roberti*)

Spring River Crayfish; Photo: Christopher Taylor, Illinois Natural History Survey

U.S. Fish and Wildlife Service

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Executive Summary

This report summarizes results of a species status assessment (SSA) conducted for the Spring River Crayfish (*Faxonius roberti*) to assess its viability. The Spring River Crayfish is a stream-dwelling crayfish occurring in the Spring River and Strawberry River watersheds in southern Missouri and northern Arkansas.

In conducting our status assessment, we first considered what the species needs 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 its current condition and expected future influences on viability.

For survival and reproduction at the individual level, the Spring River Crayfish requires large, clear permanent streams with fast flowing currents. The species also requires coarse gravel and larger rock substrate to use as refuge from predators and to harbor prey resources, primarily consisting of invertebrates. Though the species consists of three populations (South Fork Spring River, Spring River mainstem, and Strawberry River), 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 Spring 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 Spring River Crayfish.

At the species level, the Spring River Crayfish requires resiliency, adaptive capacity (representation), and redundancy. Resiliency is the ability of the species to withstand stochastic events and, in the case of the crayfish, is best measured by the number, distribution, and health of populations across the species' range. Representation is an indicator of the ability of a species to adapt to changing environmental conditions; for the Spring River Crayfish, it can be measured by the number and distribution of healthy populations across areas of unique adaptive diversity (i.e., the South Fork Spring River, Spring River mainstem, and Strawberry River). Redundancy is an indicator of the ability of a species to withstand catastrophic events by "spreading the risk." It can be measured for the Spring River Crayfish through the duplication and distribution of resilient populations across the species' range.

The primary factor influencing viability of the Spring River Crayfish is invasion by the Gap Ringed Crayfish (*Faxonius neglectus chaenodactylus*). The Gap Ringed Crayfish was first documented in the Spring River watershed in 1998 in the West Fork Spring Creek (part of the South Fork Spring River population) and appears to have spread 29 stream kilometers (18 miles) within 15 years. Where it has become established, it has completely displaced the Spring River Crayfish, extirpating the species from several stream segments. There are currently no known mechanisms to stop or reverse the Gap Ringed Crayfish invasion. Other factors currently impacting the Spring River Crayfish include excessive sedimentation in the Strawberry River and degraded water quality in both the Spring and Strawberry rivers. Sedimentation covers the habitat and reduces the prey base; whereas degraded water quality is presumed to reduce the health of individuals. Positive influences include research efforts, policies to curtail future introductions of non-native crayfish, and efforts to improve stream health in the Spring River and Strawberry River watersheds.

Because sedimentation is reducing the quality of Spring River Crayfish habitat in portions of the species' range, the health of subpopulations in these areas is reduced. In addition, subpopulations in areas invaded by the Gap Ringed Crayfish appear to have been completely extirpated. This has resulted in an estimated 52% range reduction of the South Fork Spring River population, which constitutes a 25% reduction in the species' range (from 243 to 182 stream kilometers)(151 to 113 miles). Consequently, resiliency, representation, and redundancy have been reduced from historical conditions for Spring River Crayfish, a species already inherently vulnerable to stochastic and catastrophic events due to its small range.

To evaluate future conditions of the Spring River Crayfish, we predicted the expansion of the Gap Ringed Crayfish within the species' range and its expected impact on the Spring River Crayfish. 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. From 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 within 50 years the Gap Ringed Crayfish will have invaded 61-100% of the South Fork Spring River population (95% being the most likely amount) and 0-100% of the Spring River mainstem population (with 0% being the most likely amount). This constitutes 29-79% of the total Spring River Crayfish range. In invaded areas, Spring River Crayfish abundance is predicted to be reduced by 10% up to complete displacement (i.e., functional extirpation), with 50-100% being the most likely amount. Though the invasion is currently limited to the Spring River watershed, experts estimated that there is a 0-70% chance that the Strawberry River watershed will also be invaded by one of the Ringed Crayfish subspecies in 50 years.

Based on the future conditions models, we predict that resiliency, representation, and redundancy of the Spring River Crayfish's will continue to be reduced in the future due to the Gap Ringed Crayfish invasion and other threats. The extent to which they will be reduced varies based on the different modeling scenarios. Under the Reasonable Best Scenario, additional impacts to the species' viability will be minimal. Under the Reasonable Worst Scenario, the Spring River Crayfish will be effectively extirpated in the Spring River watershed within 50 years and will be highly susceptible to both stochastic and catastrophic events. Under the Reasonable Worst Scenario, the species also will have a substantially reduced ability to adapt to future changes in environmental conditions. Under the Most Likely Scenario, the species will retain a higher level of viability than under the Reasonable Worst Scenario in that the Spring River mainstem and Strawberry River populations are not predicted to be impacted by the Gap Ringed Crayfish. Thus, the species will retain some level of protection against stochastic and catastrophic events under the Most Likely Scenario.

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Chapter 1. Introduction and Analytical Approach

This report summarizes results of a species status assessment (SSA) conducted for the Spring River Crayfish (*Faxonius roberti*). The intent of the SSA is to assess the ability of the Spring River Crayfish to sustain populations in the wild 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 (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. 2018, 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 Spring 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 Spring 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.

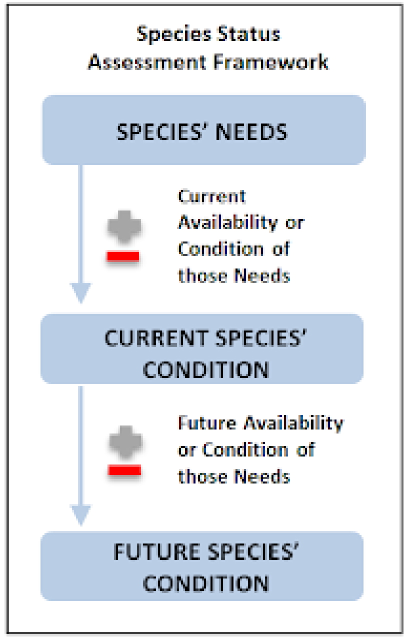

Figure 1-1. Species Status Assessment Framework.

Chapter 2. Species Descriptions, Distribution, and Ecology

2.1 Taxonomy and Species Description

The Spring River Crayfish was originally included in the Coldwater Crayfish species, first described by Williams (1952, pp. 330-334) from the Eleven Point River in Missouri and Arkansas. The Coldwater Crayfish 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). However, recent genetic and morphological investigations indicate that the Coldwater Crayfish 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. 501-512). Henceforth we will refer to the former Coldwater Crayfish species delineation (that is now described as three species) as the Coldwater Crayfish complex.

As noted above, the Spring River Crayfish was first described by Fetzner and Taylor (2018, pp. 501-512). Individuals are dark brown to dark orange (Fig. 2-1) and have a black saddle crossing the juncture of the carapace and abdomen (Fetzner and Taylor 2018, p. 504). Carapace length of females ranged from 16.5 to 36.3 millimeters (mm)(0.7-1.4 in) and carapace length of males ranged from 15.6 to 38.1 mm (0.6-1.5 in)(Fetzner and Taylor 2018, p. 504).

Figure 2-1. The Spring River Crayfish. Photo by Christopher Taylor, used with permission.

2.2 Historical Range and Distribution

Based on the new species description, the Spring River Crayfish is considered limited to the Spring River and Strawberry River watersheds in northern Arkansas and southern Missouri (Fig. 2-2)(Fetzner and Taylor 2018, p. 502). The species is known only from the river mainstems (i.e. generally not found in tributaries), except in the Spring River watershed where it has also been found in the South Fork Spring River and the West Fork Spring Creek (also referred to as the West Fork of the South Fork Spring River)(Fetzner and Taylor 2018, p. 504).

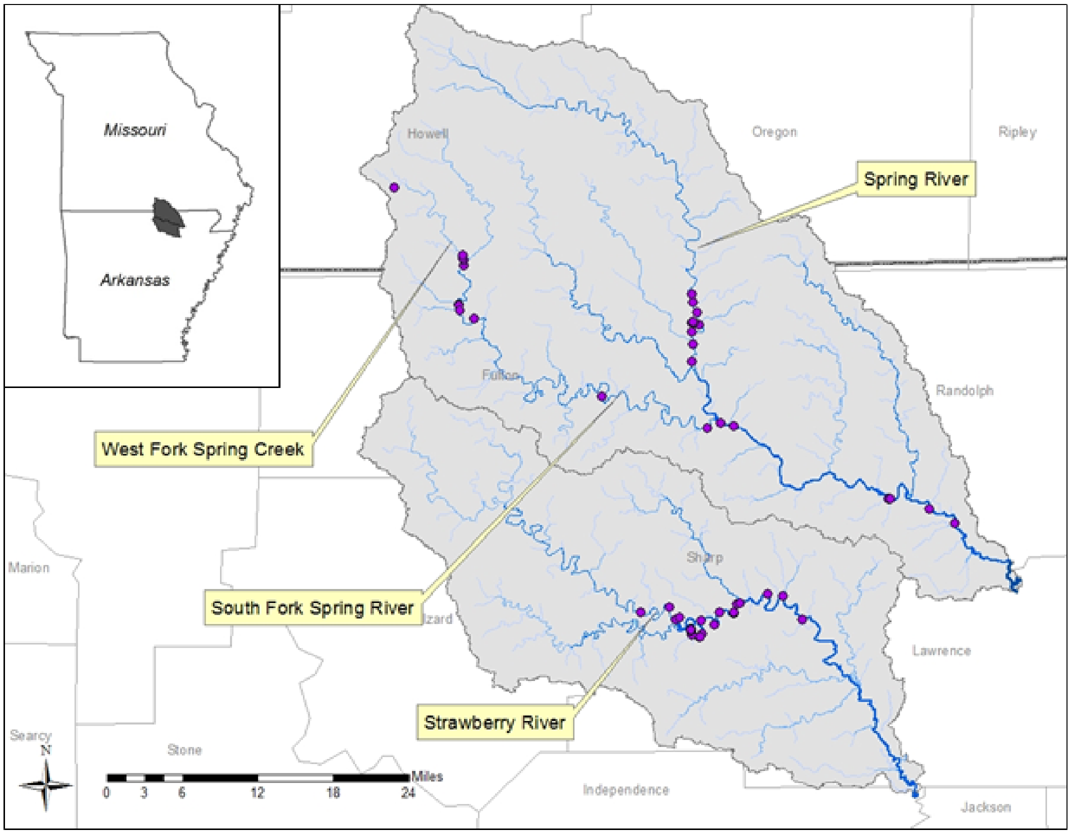

Figure 2-2. Locations from which the Spring River Crayfish has been documented.

2.3 Life History and Individual-Level Requirements

Because the former Coldwater Crayfish taxon (i.e., Coldwater Crayfish complex) was recently revised, life history information specific to the Spring River Crayfish is currently limited. 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 River Crayfish, and Spring River Crayfish. We reference information specific to the Spring River Crayfish where possible.

<u>Habitat</u>

The Spring River Crayfish occurs in the mainstem of large streams (4th order[1] or larger), although it has also been found in the West Fork Spring Creek, a medium stream (3rd order). It is most commonly encountered in riffle areas with substrates of cobble and gravel (Fetzner and Taylor 2018, p. 505). Nolen et al. (2014, p. 2380) found the species primarily in areas with a high current velocity (exceeding 0.54 meters per second)(m/s), although current velocity is lower in deep pools occupied by the species (Rice 2018, pers. comm.).

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[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.

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). 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 (the structure allowing males to mate) 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) 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 to early May (Flinders and Magoulick 2005, p. 367; Larson and Magoulick 2008, p. 331), 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).

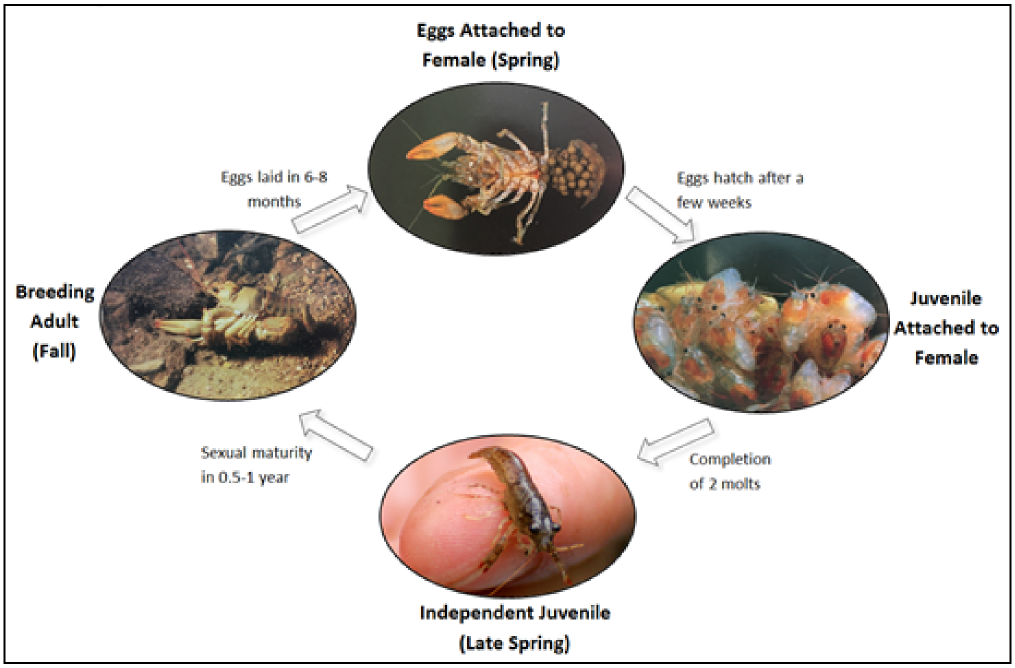

Figure 2-3. Life cycle diagram of most stream-dwelling *Faxonius* species. Photos of breeding adults, eggs, and juveniles attached to females modified from Pflieger 1996 (pp. 28-29).

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 30º Celsius (C)(85° Fahrenheit)(F), with significantly higher respiration at 26º C (79° F) than at 18º C (64° F). Whitledge and Rabeni (2002, p. 1124) also found that the maximum daily consumption rate peaked at 22º 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 22º C (72° F), indicating that the optimal temperature for growth is at that temperature (Whitledge and Rabeni (2002, p. 1127).

Stream drying is another factor strongly influencing physiology of the Spring River Crayfish. Under simulated stream drying in mesocosms[2], Larson et al. (2009, pp. 1903-1904) found that Spring River Crayfish individuals had low survival rates due to simulated drying conditions. In addition, field sampling demonstrated a significant negative relationship between Spring River Crayfish density and low summer flows (Larson et al. 2009, p. 1904). These results are supported by habitat modeling demonstrating that the Coldwater Crayfish complex is often associated with

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

larger-order rivers with high volumes of spring flow, which is likely important in sheltering individuals from drought and stream drying (Nolen et al. 2014, p. 2384).

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 during crayfish sampling, conductivity may be used as a proxy for conditions suitable for the Spring 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 Spring River, ambient conductivity generally ranges from 350-600 microsiemens per centimeter (μS/cm); while the Strawberry River generally ranges from 200-300 μS/cm (ADEQ 2018, unpublished data).

Individual-Level Requirements

The Spring 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 Spring River Crayfish. Requirements are assumed the same as those for the Coldwater Crayfish complex.

Type of Requirement	Description
Stream Permanence	Permanent
Stream Order	Primarily stream orders 4 and above, with some occurrences in a 3rd order stream
Stream Flow Velocity	Swift water (velocity exceeding 0.54 m/s) in riffle habitats; lower water velocity in deep pools
Stream Temperature	Optimal growth rates at 22º 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

Species experts consider the Spring River Crayfish as having three populations: the South Fork Spring River (which contains the West Fork Spring Creek), the mainstem of the Spring River, and the mainstem of the Strawberry River (Figure 2-4)(DiStefano 2017, pers. comm.; Magoulick 2017, pers. comm.; Taylor 2017, pers. comm.; Wagner 2017, pers. comm.; Westhoff 2017, pers. comm.). For each of these populations to be healthy, they must have multiple, interconnected, healthy subpopulations distributed throughout the population. We consider a subpopulation to be those individuals that are able to interbreed and occur within the same stream reach of occupied habitat. Because the Spring River Crayfish occurs 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 Spring 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 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).

Habitat to Support a Healthy Demography

Healthy Spring 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 Requirements. The quantity of habitat likely varies among subpopulations and is unknown. In addition, healthy Spring River Crayfish subpopulations must have connectivity between ovigerous[3] and molting microhabitats 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 Spring River Crayfish subpopulations require a community structure free from non-native crayfish species that may outcompete and ultimately displace them. 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 species.

[3] Bearing or carrying eggs.

Table 2-2. Subpopulation-level requirements for the Spring 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 Crayfish Community	Community structure free from non-native crayfish species that may outcompete and ultimately displace the species

2.5 Species-Level Requirements

Species-level requirements (i.e., what the species needs for viability) of the Spring 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 Spring River Crayfish, we expect that environmental stochasticity primarily includes differences in precipitation (wet and dry years) and temperature (hot and cold years) throughout the Spring River and Strawberry River watersheds. Given the relatively narrow range of the Spring River Crayfish, these and other environmental differences could affect the species throughout its range in any one year. Thus, the species is inherently vulnerable to environmental stochasticity.

Given the above, we consider Spring River Crayfish resiliency as having healthy populations distributed across its range in the Spring River and Strawberry River watersheds. As described under section 2.4 (Subpopulation-level Requirements), a healthy population is comprised of multiple, healthy, interconnected subpopulations. The greater the number of healthy populations and the greater the distribution of those populations relative to the diversity of temperature and precipitation conditions, the greater resiliency the species will possess. Of the three Spring River Crayfish populations (Fig. 2-4), the population in the mainstem of the Spring River is particularly important in maintaining resiliency because its subpopulations are less likely to experience temperature extremes and low stream flow due to the spring influence.

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. Ecological diversity is important because it provides the variation in phenotypes[4] and ecological settings on which natural selection acts. Although Spring River Crayfish in the Spring and Strawberry Rivers have similar morphology (Fetzner 2017, pp. 6-13), they do not share any of the same haplotypes[5] (Fetzner et al. 2013, p. 13), and thus represent areas of genetic diversity. Ecological differences between the watersheds such as greater spring influence in the Spring River watershed, different ranges in ambient conductivity[6], and primary geologic rock types[7] provide further support that the two watersheds represent areas of potential adaptive diversity. There are also geological, physical, and hydrological differences between the South Fork Spring River and Spring River mainstem populations (Magoulick 2017 pers. comm.), which we presume also represent ecological diversity. Thus, we consider Spring River Crayfish representation as having healthy populations in the South Fork Spring River, in the Spring River mainstem, and the Strawberry River. In addition, the processes that drive evolution (gene flow, natural selection, mutations, and genetic drift) are required to maintain species-level representation (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, redundancy is important to protect against losing irreplaceable sources of adaptive diversity. To determine what the Spring River Crayfish requires to guard against catastrophic events, we first considered what catastrophic events to which the species may be subjected. 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.

For the Spring River Crayfish, we considered extreme drought and toxic chemical spills to be the only events potentially resulting in catastrophic impacts to one or more populations (see Appendix A for additional information). Species experts did not believe an extreme drought which occurred in 2012[8] resulted in catastrophic effects to the Spring River Crayfish. While another drought of similar intensity and magnitude may not cause catastrophic impacts to a population, it could reduce the overall viability by extirpating or compromising subpopulations in the impacted area. Another extreme drought could also increase the Spring River Crayfish's susceptibility to the invasion of Gap Ringed Crayfish and to other stressors (see Chapter 3). Repeated or prolonged droughts also could ultimately result in the loss of subpopulations. Thus, while an extreme drought may not be a catastrophic event for an entire population, it could function as a catastrophic event at the subpopulation level and reduce resiliency of the species by potentially extirpating or compromising subpopulations throughout the impacted area. These impacts are discussed in Chapter 3 under Extreme Events. It is possible, however, that a single toxic chemical spill could impact one or more of the Spring River Crayfish populations in their entirety given that multiple pipelines and a railway cross the species' range (see Appendix A for additional information).

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

[5] A group of specific genes that are likely inherited together and conserved as a sequence.

[6] As noted in section 2.3, ambient conductivity in the Spring River generally ranges from 350-600 µS/cm and 200-300 µS/cm in the Strawberry River.

[7] The primary rock type in the Spring River watershed is almost entirely dolostone (dolomite). However, the Strawberry River watershed also contains a substantial portion of sandstone as the primary rock type.

[8] In 2012, all of the Spring River watershed was affected by a D3-D4 drought, and all of the Strawberry River watershed was affected by a D4 drought (USDM 2018b). D3 droughts are characterized as extreme droughts with major crop/pasture losses, widespread water shortages or restrictions, and USGS weekly streamflow percentiles of 3-5 (USDM 2018a). 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).

After concluding that a toxic chemical spill is the only event likely to affect one of the Spring River Crayfish populations in its entirety, we consider Spring River Crayfish redundancy as having multiple, healthy populations distributed across its range. For maximum redundancy, the species would have healthy populations in the South Fork Spring River, Spring River mainstem, and Strawberry River.

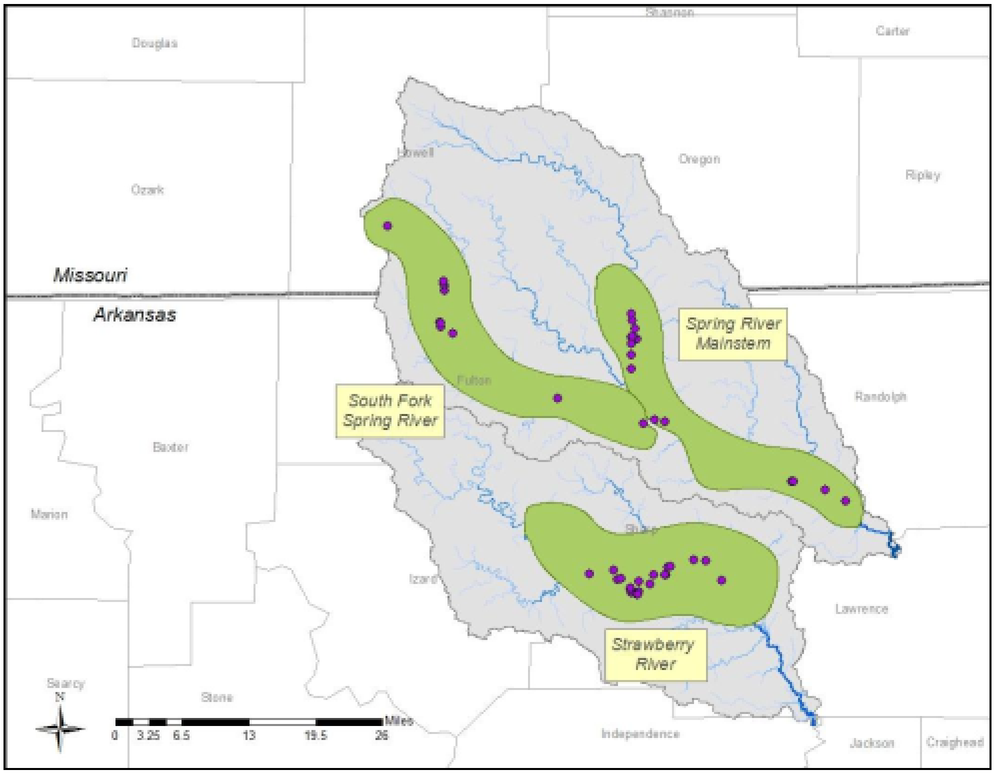

Figure 2-4. Populations of the Spring River Crayfish (green polygons). Dots represent locations from which the species has been captured.

Table 2-3. Species-level requirements for the Spring River Crayfish.

Requirement	Description
Resiliency	Multiple, healthy populations distributed across the range (see section 2.4 for requirements of a healthy population)
Representation	1) Healthy populations distributed across areas of unique adaptive diversity (the South Fork Spring River, Spring River mainstem, and Strawberry River populations) 2) Evolutionary processes (gene flow, natural selection, genetic drift) are maintained
Redundancy	Multiple, healthy populations to guard against the loss of the species from catastrophic events

Chapter 3. Threats and Conservation Actions

In this chapter we describe current and future threats to the Spring 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 1998, however, the Gap Ringed Crayfish was discovered outside of its native range in the Spring River watershed, presumably from a bait bucket introduction[9] (Flinders and Magoulick 2005, pp. 362-363; Magoulick and DiStefano 2007, p. 148). During surveys conducted in 1998-1999, the Gap Ringed Crayfish was collected at five sites in the Spring River watershed: in the main channel of the West Fork Spring Creek, three intermittent headwater streams, and at the confluence of the West Fork Spring Creek and South Fork Spring River (Flinders and Magoulick 2005, pp. 362-364). Subsequent surveys in 2001 documented expansion of the Gap Ringed Crayfish in the South Fork Spring River approximately 3 km (2 mi) and 10 km (6 mi) downstream from the mouth of the West Fork Spring Creek (Magoulick and DiStefano 2007, p. 147). By 2001, the subspecies had invaded 29 stream km (18 mi) within the drainage and was the dominant species in run habitats where it was collected (Fig. 3-1)(Flinders and Magoulick 2005, pp. 362-364; Magoulick and DiStefano 2007, pp. 144-146; DiStefano et al. 2015, pp. 399-401). The entire range expansion evidently occurred between 1984 and 2001 (Magoulick and DiStefano 2007, pp.144-146), suggesting an invasion rate of 1.9 kilometers per year (km/yr)(1.2 miles (mi)/yr)(DiStefano et al. 2017, p. 531). Previously abundant in these systems, the Spring River Crayfish (then considered the Coldwater Crayfish) appears to have been completely displaced where the Gap Ringed Crayfish is now established (Magoulick and DiStefano 2007, pp. 147-148).

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). Though desiccation is likely not a high risk in the Spring River due to high spring flow volume, it may be a risk in the South Fork Spring River and Strawberry River.

Currently, there are no feasible actions expected to be able to curtail the Gap Ringed Crayfish's range expansion or the resulting impacts to the Spring River Crayfish.

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

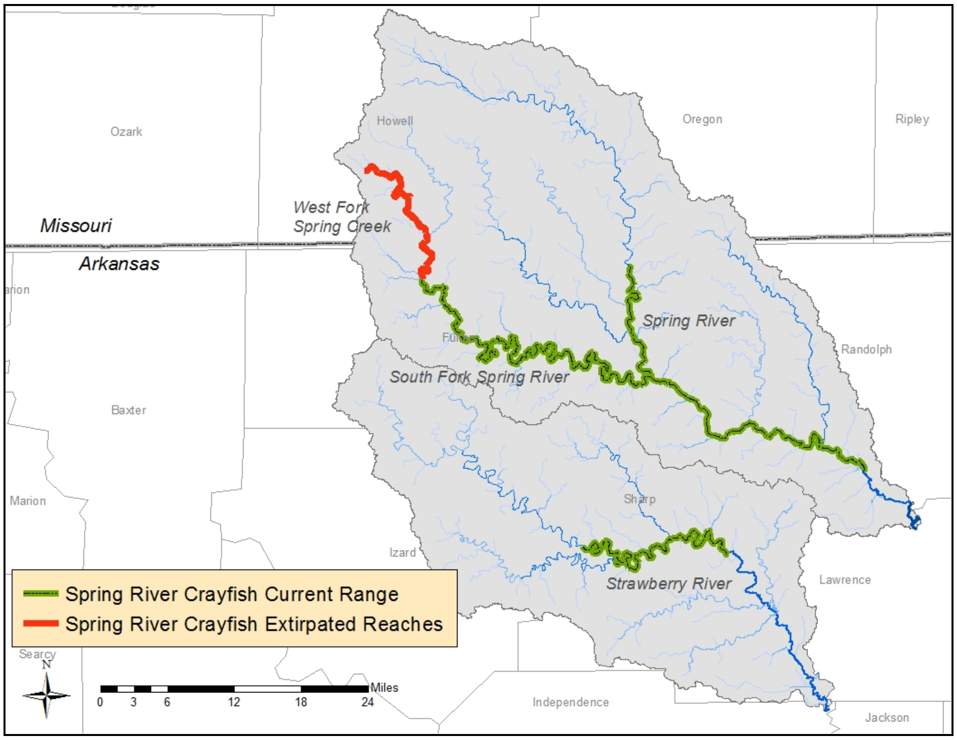

Figure 3-1. Invasion of the Gap Ringed Crayfish in the Spring River watershed (red) and subsequent extirpation of the Spring River Crayfish by 2001 (also in red).

3.2 Degraded Water Quality

The Spring River and South Fork Spring River are designated as Extraordinary Resource Waters in Arkansas, with the Spring River also designated an Ecologically Sensitive Waterbody (APCEC 2017, pp. D-3, D-4). Mammoth Spring is the second largest spring in the Ozarks and produces a coldwater ecosystem with limestone falls and chert (a hard, dark, opaque rock composed of silica) gravel riffles that transition into a warm-water ecosystem downstream, creating a diverse freshwater community (Trauth et al. 2007, pp. 4-5). Waters within the Spring River are also designated for propagation of fish and wildlife; primary and secondary contact recreation; and domestic, agricultural, and industrial water supplies (ADEQ 2016, p. A-241), and waters within the Warm Fork Spring River have been designated for cold-water fishery in Missouri (Missouri Code of State Regulations 2018c, p. 34). Despite these designations, the U.S. Environmental Protection Agency identified the Spring River and South Fork Spring River as water bodies that should potentially be on the list of impaired waterbodies under 303(d) of the Clean Water Act (EPA 2017, p. 8). Temperature was identified as the water quality parameter of concern in the Spring River and dissolved oxygen was the parameter in question for the South Fork Spring River (EPA 2017, p. 8). In addition, there have been numerous chemical spills and train derailments in the Spring River which have affected water quality.

The Strawberry River is a high quality water resource that also is designated as an Extraordinary Resource Waters as well as a Natural and Scenic Waterway (APCEC 2017, pp. D-1, D-2). Most of the Strawberry River and the Little Strawberry River are also designated as Ecologically Sensitive Waterbodies (APCEC 2017, pp. D-4, D-5). Approximately 60% of the watershed is forested and the river supports over 100 species of fish and over 30 species of mussels (FTN 2016, pp i, 2-10). However, both the Strawberry and Little Strawberry rivers are currently on Arkansas' Impaired Waterbodies List (303(d) list) for not supporting fisheries use and not attaining standards for turbidity and bacteria (ADEQ 2016, pp. IV-11, IV-18)(see section 3.3 for additional information on sedimentation). Nonpoint sources have been identified as the primary sources of the bacteria and sediment affecting water quality, with these sources including runoff from animal feeding operations, livestock access to streams, and erosion from pasture, unpaved roads, and forest harvest operations (FTN 2016, p. 4-1). Figure 3-2 depicts rankings of areas in the watershed with the potential for water quality impacts from animal manure.

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. More information is needed to better understand potential impacts.

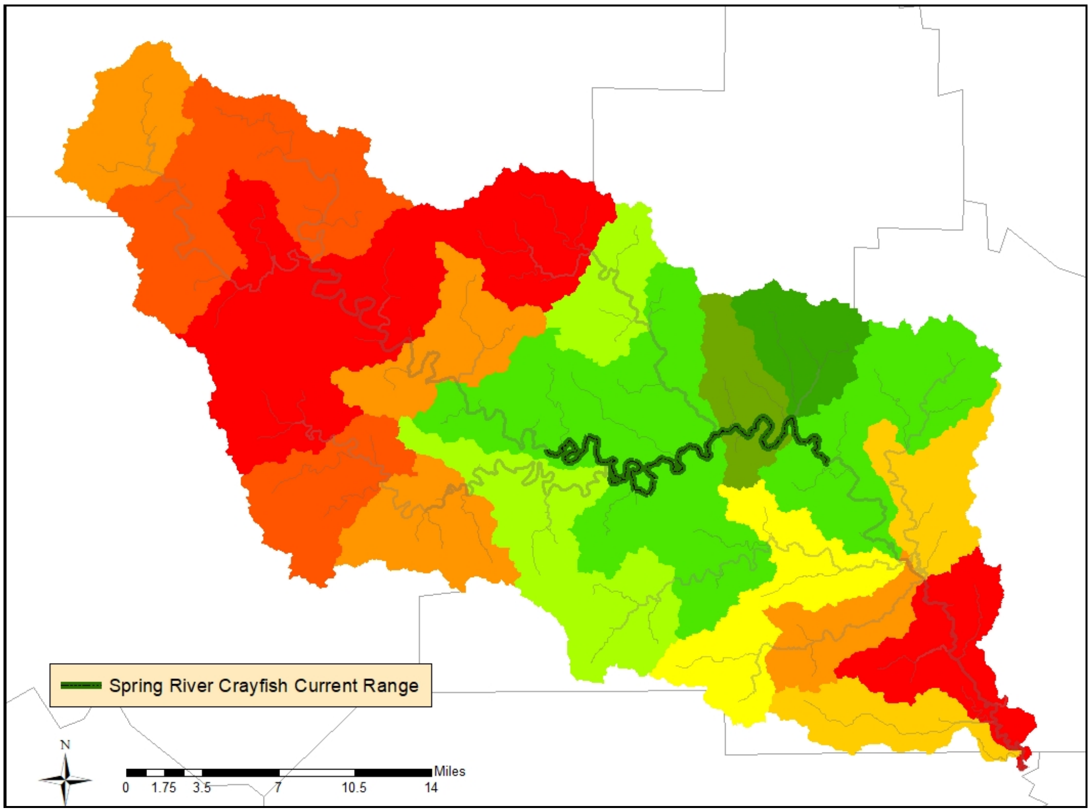

Figure 3-2. Rankings of 12-digit hydrologic unit watersheds of the Strawberry River based on the potential for water quality impacts from animal manure. Red areas represent areas with the highest mean value of water quality degradation; green areas represent those with the lowest mean value. Figure taken from FTN 2016 (p. 4-5).

3.3 Sedimentation

According to Pflieger (1996, p. 17), the thin, stony soils of the Ozarks naturally 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 due to historical timber harvest and land use changes throughout their watersheds. The disturbance was characterized by accelerated aggradation of gravel (especially in formerly deep pools), accelerated channel migration and avulsion, and growth of gravel point bars (Jacobson and Primm 1994, p. 80).

As with other Ozark streams, sedimentation in the Spring River watershed has increased, causing part of the river to be designated as impaired under section 303(d) of the Clean Water Act due to sedimentation (ADEQ 2008, p. 5). Sedimentation has been identified as one of the stresses most impacting the aquatic community in the watershed (Fig. 3-3)(Melnechuk et al. 2009, p. 35). The primary sources of sedimentation in the Spring River watershed include road crossings, unstable streambanks, unpaved roads, incompatible development, gravel mining, and dams (Melnechuk et al. 2009, pp. 35-36).

Excessive sedimentation is also an issue in the Strawberry River, as noted under section 3.2, with 150.0 km (93.2 mi) included in Arkansas' Impaired Waterbodies List (303(d) list) for not attaining turbidity standards due to sedimentation (ADEQ 2016, pp. IV-11, IV-18). Sources of sedimentation in the watershed include unpaved roads and erosion from silviculture activities, animal agriculture construction sites, stream bank erosion, and stream channel erosion (FTN 2016, pp. 4-1 to 4-17). In addition, at least two sand and gravel mines are operating within the Strawberry River watershed (FTN 2016, pp. 2-15, 2-16), which can contribute to stream instability, and thus sedimentation, if operated in a non-compatible manner.

Deposition of fine and coarse sediment can cover rocks and fill cavities that the Spring River Crayfish uses as refugia. The loss of refugia likely 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 Spring 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 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 et al. 2016, p. 645; Loughman 2017, p. 5). Further support is provided by anecdotal observations during surveys which indicate that the Spring River Crayfish is absent in riffles with significant embeddedness of rock substrate due to fine sediment (Wagner 2018, pers. comm.).

Furthermore, excessive sediment deposition negatively impacts macroinvertebrates (Jones et al. 2011, pp. 1056-1062), an important food source of the Coldwater Crayfish complex (Magoulick and Piercey 2016, p. 240). Excessive sedimentation also can increase stream temperature, which could make reduce fitness of the Spring River Crayfish in affected stream reaches.

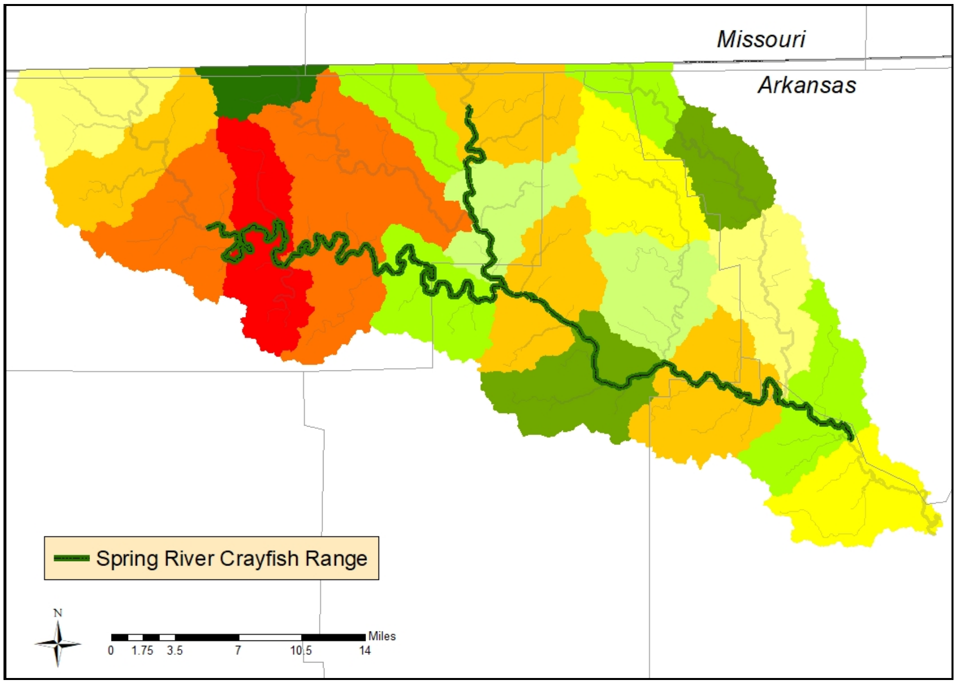

Figure 3-3. Map of sediment index values by 12-digit hydrologic unit in the Spring River watershed in Arkansas. Red areas represent areas with higher sediment impacts; green areas represent areas with the lowest sediment impacts. Map taken from Melnechuk et al. 2009 (p. 25).

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 Spring 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). While 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 Spring 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 in freshwater-farmed crayfishes at multiple sites in Louisiana, 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 the nearest shrimp farm is located approximately 72 km (45 mi) from the Spring 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 observed 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 Spring River Crayfish range 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. 2018, 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 the Spring River Crayfish is similar to that of the Coldwater Crayfish complex.

Whitledge and Rabeni (2002, p. 1129) also postulated that native crayfish species could be displaced in the future under warmer stream conditions by non-native crayfishes with 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 was 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 Spring River Crayfish by the Gap Ringed Crayfish if the Spring River Crayfish has a thermal preference similar to that of the Coldwater Crayfish. Displacement could be further facilitated if climate change results in increased stream drying. In addition, lower water levels could reduce the amount of available habitat (e.g., stream edges and areas around gravel bars), thereby reducing the number of Spring River Crayfish individuals, and also reduce connectivity between occupied sites.

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

3.7 Extreme Events

Based on considerations outlined in Chapter 4, we do not consider extreme drought or chemical spills as catastrophic events likely to impact the Spring River Crayfish at the population level. However, both events would act as extreme stressors to one or more subpopulations. We discuss these 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 Spring 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 in extirpated sites after the drying events recede. Thus, extreme drought events could facilitate displacement of native crayfishes.

Extreme flood events may also affect Spring 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 Spring River Crayfish by the Gap Ringed Crayfish.

A toxic chemical spill could also impact Spring River Crayfish individuals and subpopulations. 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).

While the exact effects of a chemical spill on the Spring River Crayfish remains unclear, we expect that some subpopulations could be extirpated or severely impacted in the instance of a major spill, even if the spill doesn’t result in catastrophic effects to one or more populations.

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,

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

U.S. Geological Survey, and various universities. Monitoring efforts benefit the Spring River Crayfish by providing information on population health and trends and the magnitude and extent of threats; research efforts provide information on mechanisms by which threats may impact the species. 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).

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 Crawfish and Red Swamp Crawfish (*Procambarus acutu*s and *P. clarkii*) unless a permit is obtained or unless the crayfish naturally colonized their ponds (AGFC 2018, §35.06, Addendum J1.01)[12].

In both states, it also is unlawful to import, transport, or possess the Rusty Crayfish (*Faxonius rusticus*)(AGFC 2018, §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 Spring River and Strawberry River watersheds. However, as the Gap Ringed Crayfish has already been introduced into the Spring River watershed, the policies will not affect the inevitable spread of that species within the Spring River watershed (and thus throughout the range of the Spring River Crayfish within the watershed). 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

Very little land is in public ownership in the Spring River Crayfish range - approximately 2% of the Spring River watershed and less than 1% of the Strawberry River watershed. As noted under section 3.2, the Spring River, South Fork Spring River, and Strawberry River are all designated Extraordinary Resource Waters in Arkansas, with the Spring and Strawberry rivers also designated as Ecologically Sensitive Water Bodies (APCEC 2017, pp. D-3, D-4). In addition, 69 km (43 mi) of the Strawberry River is designated an Arkansas Natural and Scenic Waterway (APCEC 2017, p. D-3), although the designated area occurs upstream of the presumed range of the Spring River Crayfish. All of these designations represent high quality waters, and the uses and water quality for which the water bodies were designated are protected by 1) water quality controls, 2)

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

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). However, as noted above, reaches of the South Fork Spring River, Spring River, and Strawberry River either have been or are currently listed as impaired waterbodies under 303(d) of the Clean Water Act (ADEQ 2016, pp. IV-11, IV-18; EPA 2017, p. 8).

Restoration Efforts

Due to its diverse assemblage of aquatic species and historically high water quality, the Spring River watershed has been identified by The Nature Conservancy (TNC) as a priority area for conservation efforts in the Ozark Ecoregion (TNC 2003, p. 34). It is also listed by TNC as the number 12 priority watershed for conservation of freshwater biota in North America (Masters et al. 1998, p. 57). This prioritization has resulted in identification of threats and development of a conservation action plan to reduce aquatic impacts in the watershed (Melnechuk et al. 2009, p. 2). Within the conservation plan, conservation strategies were identified to reduce threats in the watershed (Melnechuk et al. 2009, pp. 36-37). The strategies included: 1) maintain or increase forested riparian areas in key stream reaches of the Spring River, 2) work with county officials to investigate feasibility and potential funding sources for alternative road surfaces, facilitate training to county road departments through technical workshops, and develop road Environmentally Sustainable Management Practices (ESMP), 3) reduce or eliminate instream gravel mining in the Spring River and its tributaries, 4) re-establish stable streambanks and riparian forests on priority private lands through federal, state, and TNC or other private cost-share/grant programs, and 5) prevent the establishment of new dams on the mainstem or tributaries of the Spring River.

The Strawberry River watershed has also been identified by TNC as a priority area for conservation efforts in the Ozark Ecoregion (TNC 2003, p. 34) and is listed as the number 28 priority watershed for the conservation of freshwater biota in North America (Masters et al. 1998, p. 57). In addition, the watershed was identified as a priority area for water quality protection and restoration in the 1998 Arkansas Unified Watershed Assessment (EPA 1998, p. 4) and as a priority for the 2011-2016 Arkansas Nonpoint Source Pollution Management Plan (ANRC 2011, p. 15). As an action item for the Arkansas Nonpoint Source Pollution Management Plan, the Strawberry River Watershed-Based Management Plan was developed in 2016 for the Arkansas Natural Resources Commission. In addition to summarizing current and historical water quality in the watershed, the plan identifies areas with reduced water quality and provides recommendations to manage nonpoint source pollution and associated costs (FTN 2016, pp. 3-3 to 3-46, 8-1 to 8-20).

Chapter 4. Species Current Conditions

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

4.1 Current Distribution, Abundance, and Habitat

The historical range of the Spring River Crayfish is depicted in Figure 4-1. For the purpose of this SSA, we assume that the species occurred between the farthest known upstream and downstream locations in each occupied stream. Therefore, we presume the total historical range of the species spanned a distance of 242.9 stream km (150.9 mi) with 117 km (73 mi) in the South Fork Spring River population, 76 km (47 mi) in the Spring River mainstem population, and 50 km (31 mi) in the Strawberry River population. By 2001 the range in the Spring River watershed appeared to have been restricted by 29 stream km (18 mi) due to the Gap Ringed Crayfish invasion (Magoulick and DiStefano 2007, p. 144), extirpating the species from Missouri. Because the Gap Ringed Crayfish appears to have expanded at an average rate of 1.9 km/yr (1.2 mi/yr) between 1984 and 2001 (DiStefano et al. 2017, p. 532), we presume that the invasion may have expanded by an additional 32.3 km (20.1 mi) by 2018. Thus, the current range is presumed to span a distance of 181.6 stream km (112.8 mi)(Fig. 4-2). The change from historical condition in the total stream distance occupied represents a 25% reduction in the species' range. The Gap Ringed Crayfish is expected to continue to expand throughout the Spring River watershed, as no feasible efforts are known to effectively curtail the expansion or the resulting impacts.

As noted above, the distribution and abundance of the Spring River Crayfish in the South Fork Spring River population has been impacted by invasion of the Gap Ringed Crayfish. Abundance in the Spring River mainstem population, to our knowledge, has not changed from historical conditions. A lack of historical data on Spring River Crayfish abundance in the Strawberry River makes it is difficult to determine if abundance has changed in this population from historical conditions. However, the species no longer occurs at two locations where it was documented in the 1970s, and anecdotal observations during surveys indicates it is absent in riffles with significant embeddedness of rock substrate due to fine sediment (Wagner 2018, pers. comm.). Thus, abundance in both the South Fork Spring River and Strawberry River populations appears to be reduced from historical conditions.

Habitat degradation in both the Spring River and Strawberry River watersheds has been documented due to sedimentation (see section 3.3). 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 Spring 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 gravel already in the system (i.e., upstream and in the headwaters)(Jacobson and Primm 1994 p. 81). Whereas these observations pertain to Ozark streams in general, they are consistent with documented increased sedimentation in both the Spring River and Strawberry River watersheds (ADEQ 2008, p. 5; ADEQ 2016, pp. IV-11, IV-18). In the Strawberry River watershed, water quality is also periodically impacted by high fecal bacteria levels, which have exceeded state standards for fisheries designated use (protection and propagation of fish, shellfish, and other forms of aquatic life)(ADEQ 2016, pp. II-6, IV-11, IV-18). As noted above, the Spring River Crayfish appears to be absent in riffles where rock substrate is embedded in fine sediment (Wagner 2018, pers. comm.).

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

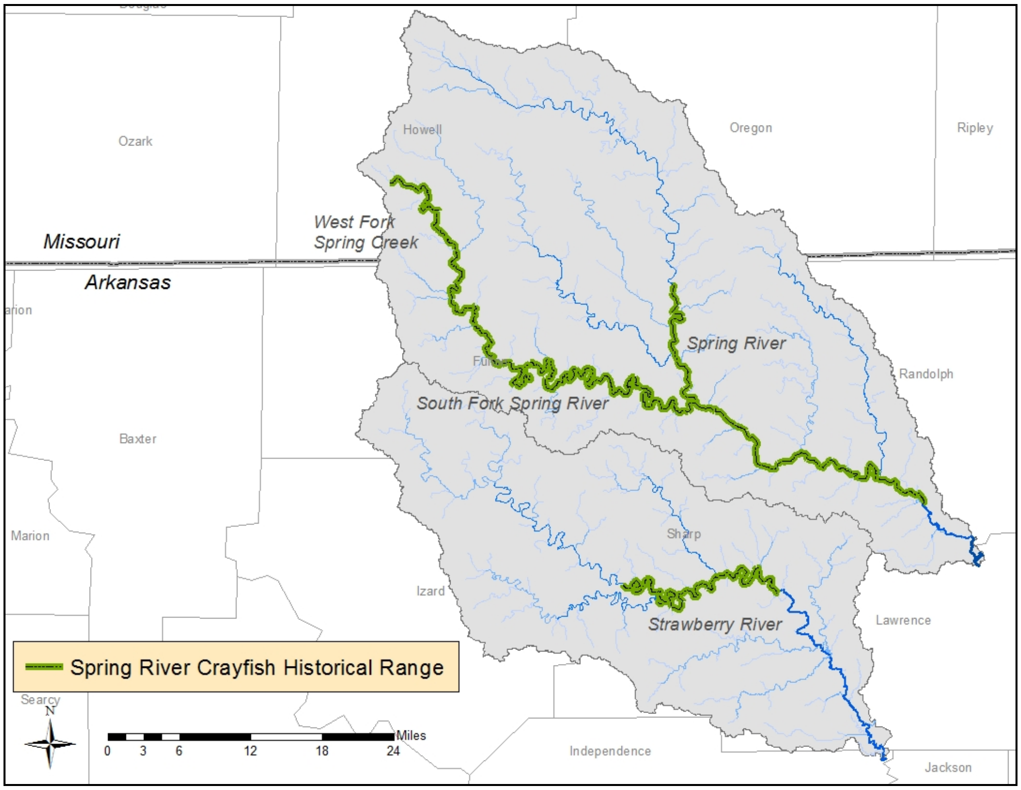

Figure 4-1. Presumed historical range of the Spring River Crayfish.

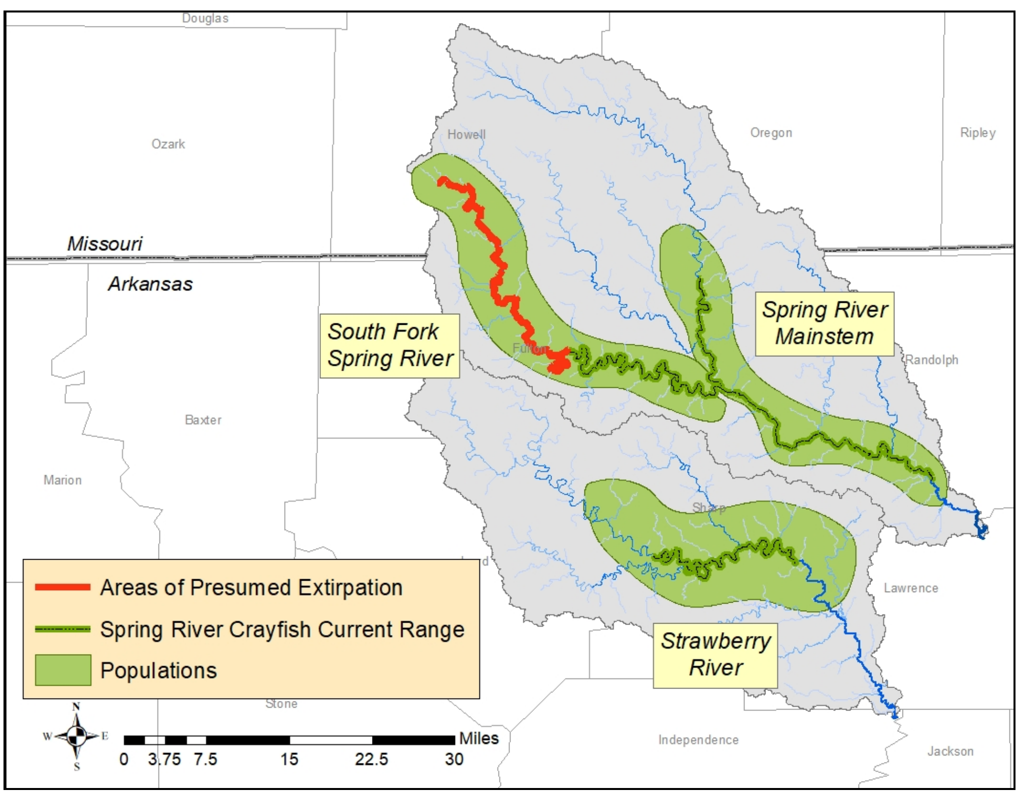

Figure 4-2. Presumed current range of the Spring River Crayfish and areas of extirpation with population delineations.

4.2 Resiliency, Representation, and Redundancy

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

<u>Resiliency</u>

Given its small range, the Spring River Crayfish is inherently vulnerable to environmental variation and stochastic events that could impact individual subpopulations or entire populations (e.g., extreme drought or flooding), depending on the severity of the event. In addition, the range of the species has been reduced from historical conditions by an estimated 61 stream km (38 mi) in the Spring River watershed due to replacement by the Gap Ringed Crayfish, with the species now extirpated from Missouri. This reduction constitutes 25% of the total range of the Spring River Crayfish and 52% of the South Fork Spring River population. Sedimentation appears to also be reducing the quality and quantity of habitat in some areas of both watersheds and particularly in the Strawberry River (see sections 3.3-3.3). Though the health of the Spring River mainstem population appears to be unchanged from historical conditions, the reduced health of the two other Spring River Crayfish populations reduces the species' ability to persist if range-wide environmental or stochastic events occur.

<u>Representation</u>

To maintain the full breadth of adaptive diversity (and thus, adaptive capacity and representation), the Spring River Crayfish requires healthy populations in the South Fork Spring River, Spring River mainstem, and the Strawberry River. The Spring River mainstem population appears healthy with no evidence of a change in abundance or distribution from historical conditions. Thus it appears the adaptive diversity provided by this population remains unchanged and it will continue to contribute to the species' adaptive capacity. Because there is no evidence of genetic differences between the South Fork Spring River and Spring River mainstem populations, the reduction in range of the South Fork Spring River population may not indicate a loss of genetic diversity. However, the South Fork Spring River population does provide ecological diversity not already provided by the two other populations (see Chapter 2). Therefore, the estimated 41% range reduction of the South Fork Spring River population represents a reduction in Spring River Crayfish adaptive diversity and thus, adaptive capacity and representation.

Adaptive capacity and representation have also been affected by the reduced health of the Strawberry River population. There are no shared haplotypes between the Strawberry River population and the two populations in the Spring River watershed (see Chapter 2), indicating that the Strawberry River population provides unique genetic diversity. The apparent absence of the species in areas with excessive sedimentation (see section 4.1) impedes the movement of individuals among sites and reduces breeding opportunities (in that the habitat is no longer available). Both impact gene flow and the perpetuation of haplotypes unique to the Strawberry River population. As a result, the population's contribution to the Spring River Crayfish's adaptive capacity is compromised.

None of the processes that drive evolution (gene flow, natural selection, mutations, and genetic drift)(Crandall 2000, p. 291) to our knowledge, are currently impacted.

<u>Redundancy</u>

For maximum protection against catastrophic events and the loss of irreplaceable sources of adaptive diversity, the Spring River Crayfish requires healthy populations in the the South Fork Spring River, Spring River mainstem, and Strawberry River. Although all three populations of the species are still present, the range of the South Fork Spring River population has been reduced by an estimated 52% (from 117 to 56 stream km)(73 to 35 mi). The reduction in the population's spatial extent increases the vulnerability of the population to a catastrophic loss by a toxic chemical spill. The reduced spatial extent of the population could also result in an extreme drought or other extreme event functioning as a catastrophic event (whereas it would otherwise function as a stressor and not cause extirpation of the entire population). The Strawberry River population also is more vulnerable to catastrophic events than historically given its reduced health due to habitat degradation. Similar to the South Fork Spring River population, the threshold for a stressor (e.g., disease, climate change) or an extreme event to result in catastrophic losses to the Strawberry River population is lower than what it was historically. Because vulnerability to catastrophic events has increased for both the South Fork Spring River and Strawberry River populations, contribution of the populations to the species' redundancy has been compromised. As a result, redundancy of the Spring River Crayfish is reduced.

Table 4-1. Summary of current condition of the Spring River Crayfish.

	Assessment of Current Condition
Occupied Stream Distance	The Spring River Crayfish currently occupies 182 stream km (113 mi) of the 243 stream km (151 mi) it occupied historically (a 25% reduction).
Health of Populations	The Spring River mainstem population appears to be healthy. However, the South Fork Spring River population is no longer considered healthy due to the loss of xx% of the population's range. The health of the Strawberry River population has also been reduced due to habitat degradation from sedimentation.
Resiliency	The species is inherently vulnerable to stochastic events due to its small range. In addition, resiliency has been reduced due to the presumed loss of 52% of the South Fork Spring River population range, reducing the total range of the species by 25% from historical conditions. The reduced health of the Strawberry River population (due to degraded habitat) also reduces resiliency of the species.
Representation	Reduced from historical conditions due to the presumed 52% reduction in range of the South Fork Spring River population range, which provides unique ecological diversity. Also compromised by the reduced health of the Strawberry River population, which provides unique genetic diversity.
Redundancy	Reduced from historical conditions due to the increased vulnerability of the South Fork Spring River and Strawberry River populations to catastrophic events and the the lowered threshold for stressors or extreme events to result in catastrophic losses to one or both populations.

Chapter 5. Species Future Conditions

5.1 Methods for Evaluating Future Conditions

To evaluate future conditions of the Spring River Crayfish, we modeled the predicted expansion of the non-native, invasive Gap Ringed Crayfish within the range of the Spring River Crayfish. We asked biologists with expertise on crayfishes to estimate the future rate of expansion in the Spring River watershed, the impact on Spring River Crayfish abundance from the invasion, the length of time for those impacts to be fully realized, and the likelihood of a Gap Ringed Crayfish invasion in the Strawberry River watershed. Additional details on the expert elicitation and a summary of results can be found in Appendix B.

In estimating the rate of expansion of the Gap Ringed Crayfish, experts provided different rates for upstream and downstream movement because streamflow facilitates downstream expansion. Other factors experts believed could influence the expansion rate include barriers (dams, culverts, waterfalls), biotic interactions (predation, competition), water depth, environmental conditions (flooding, drought, temperature) and substrate types. For the Gap Ringed Crayfish in the Spring River Crayfish range, upstream movement pertains to the mainstem of the Spring River above the confluence with the South Fork Spring River (Figure 5-1).

Because the Spring River Crayfish is a habitat specialist, experts predicted that it would experience greater impacts in areas with less suitable (marginal) habitat than in areas with ideal habitat because in marginal habitat the species is 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 Spring River; while marginal habitat was defined as the West Fork Spring Creek and South Fork Spring River. Ideal and marginal habitat in the Strawberry River watershed was not delineated because the Gap Ringed Crayfish has not invaded that watershed.

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 Spring River Crayfish future conditions (Table 5-1). The Reasonable Best Scenario represents the smallest plausible proportion of the Spring River Crayfish range 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' range that may be invaded with the highest plausible level of impact. The Most Likely Scenario represents the most likely proportion of the range 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, time for impacts to be fully realized, and likelihood of a Ringed Crayfish[14] invasion in the Strawberry River watershed.

[14] Because both subspecies of the Ringed Crayfish occur in adjacent drainages, we elicited the likelihood of an introduction in the Strawberry River watershed for both subspecies.

Table 5-1. Scenarios representing the plausible range of future conditions for the Spring 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 Spring River Crayfish abundance Highest number of years for impacts to be fully realized Lowest likelihood of a Ringed Crayfish invasion in the Strawberry River watershed
Reasonable Worst	Highest plausible expansion rate of the Gap Ringed Crayfish Highest level of predicted impact on Spring River Crayfish abundance Lowest number of years for impacts to be fully realized Highest likelihood of a Ringed Crayfish invasion in the Strawberry River watershed
Most Likely	Most likely expansion rate of the Gap Ringed Crayfish Most likely level of predicted impact on Spring River Crayfish abundance Most likely number of years for impacts to be fully realized Most likely likelihood of a Ringed Crayfish invasion in the Strawberry River watershed

For each of the scenarios, we predicted the extent of future expansion of the Gap Ringed Crayfish at 10, 25, and 50 years into the future. We then calculated how much of the Spring River Crayfish's range would be impacted and described effects to abundance based on the experts' projections. We also calculated the time it would take for the Gap Ringed Crayfish to invade the entire range of the Spring River Crayfish within the Spring River watershed.

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

5.2 Spring River Crayfish Future Conditions

Reasonable Best Scenario

Under the Reasonable Best Scenario, experts estimated that the Gap Ringed Crayfish invasion is predicted to expand downstream at a rate of 200 m (219 yard)(yd) per year and upstream at a rate of 50 m (55 yd) per year. Based on this expansion rate, an additional 2.0 km (1.2 mi) of the South Fork Spring River is predicted to be invaded by the Gap Ringed Crayfish in 10 years (Fig. 5-1, Table 5-2). The total amount of the South Fork Spring River population invaded will then be 54.1%, which constitutes 26.1% of the entire Spring River Crayfish range. Abundance is predicted to be reduced in the newly-invaded[15] area by 10-50% within 20-30 years.

In 25 years, 66.3 km (41.2 mi) (56.7%) of the South Fork Spring River population is predicted to have been invaded, constituting 27.3% of the Spring River Crayfish range (Fig. 5-2, Table 5-3). Abundance in newly-invaded areas is predicted to be reduced 10-50% within 20-30 years of the invasion. Under this scenario, there is a 0% chance that the Ringed Crayfish will invade the Strawberry River watershed within 25 years (Table 5-3).

[15] At the date of development of this SSA, subpopulations in already-invaded areas are presumed to be extirpated.

In 50 years, 71.3 km (44.3 mi) (61.0%) of the South Fork Spring River population is predicted to have been invaded, constituting 29.4% of the species' entire range (Fig. 5-3, Table 5-4). Abundance is predicted to be reduced 10-50% in invaded areas within 20-30 years. Under this scenario, there also is a 0% chance that the Ringed Crayfish will invade the Strawberry River watershed within 50 years (Table 5-4).

The length of time for the entire South Fork Spring River population to be invaded under this scenario is beyond reliable prediction (over 275 years), as is the length of time for the entire range of the species in the Spring River watershed to be invaded (over 725 years)(Table 5-5).

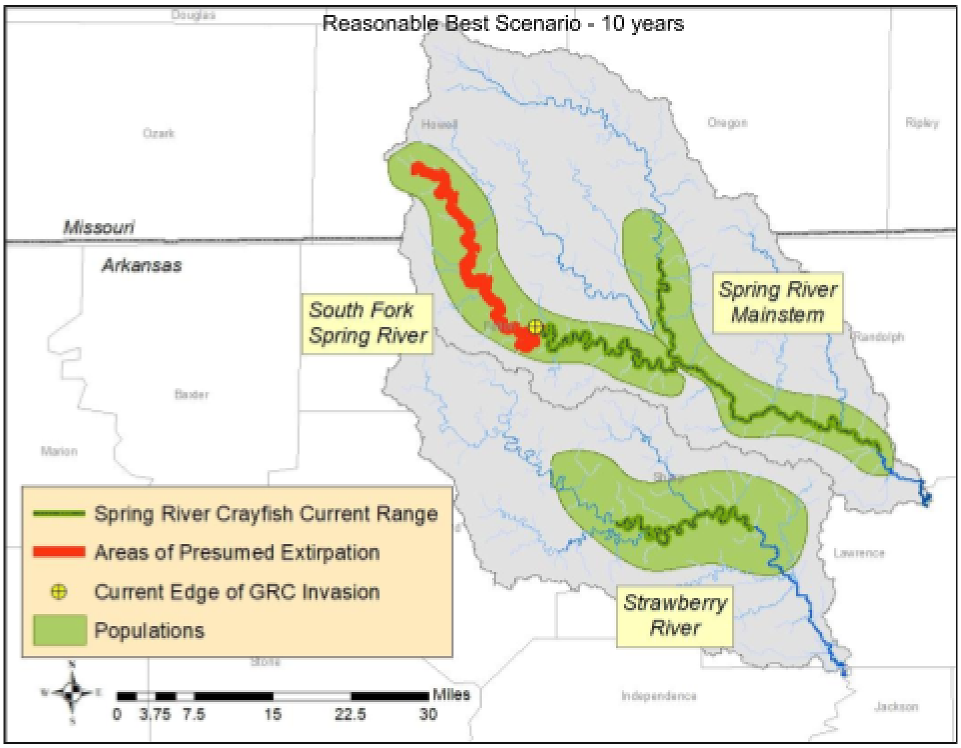

Fig. 5-1. Predicted expansion of the Gap Ringed Crayfish in the Spring River watershed at 10 years under the Reasonable Best Scenario.

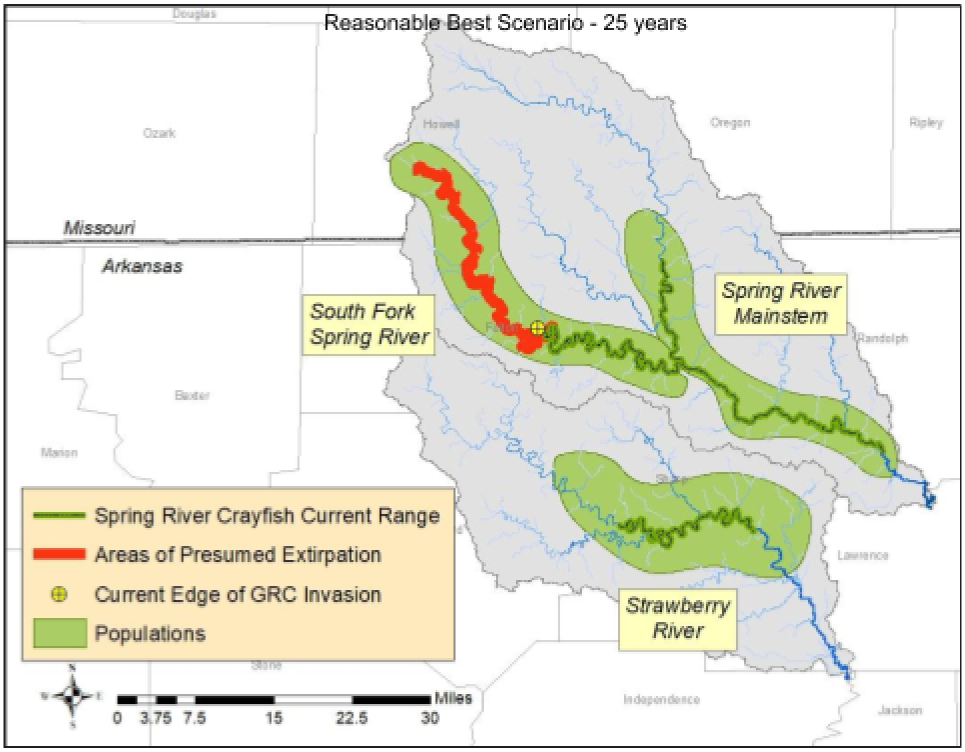

Fig. 5-2. Predicted expansion of the Gap Ringed Crayfish in the Spring River watershed at 25 years under the Reasonable Best Scenario.

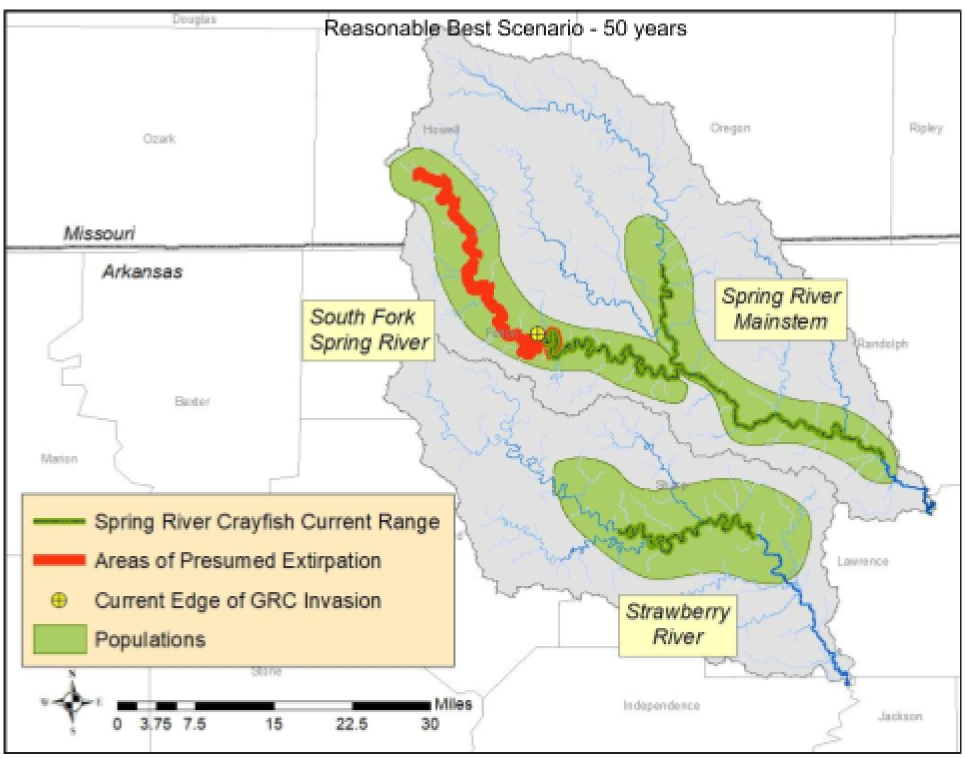

Fig. 5-3. Predicted expansion of the Gap Ringed Crayfish in the Spring River watershed at 50 years under the Reasonable Best Scenario.

Reasonable Worst Scenario

Under the Reasonable Worst Scenario, experts estimated that the Gap Ringed Crayfish invasion will expand downstream at a rate of 3,000 m (3,280 yd) per year and upstream at a rate of 1,000 m (1,094 yd) per year. Based on this expansion rate, an additional 30.0 km (18.6 mi) of the South Fork Spring River is predicted to be invaded by the Gap Ringed Crayfish in 10 years (Fig. 5-4, Table 5-2). The total amount of the South Fork Spring River population invaded will then be 78.0%, which constitutes 37.6% of the entire Spring River Crayfish range. Abundance is predicted to be reduced in the newly-invaded[16] area by 100% (i.e., functional extirpation) within 10 years.

In 25 years, all of the South Fork Spring River and 28.2 km (17.5 mi)(37.4%) of the mainstem Spring River is predicted to have been invaded, constituting 59.8% of the species' entire range (Fig. 5-5, Table 5-3). Abundance in newly-invaded areas is predicted to be reduced 100% (i.e., functional extirpation) within 10 years. Under this scenario, there is also a 50% chance that one of the Ringed Crayfish subspecies will invade the Strawberry River watershed within 25 years (Table 5-3). If this occurs, abundance in invaded areas is predicted to be reduced 100% within 10 years of the invasion.

In 50 years, all of the South Fork Spring River and all of the mainstem Spring River is predicted to have been invaded, constituting 79.2% of the Spring River Crayfish range (Fig. 5-6, Table 5-4). Abundance in newly-invaded areas is predicted to be reduced 100% (i.e., functional extirpation) within 10 years. Under this scenario, there is also a 70% chance that one of the Ringed Crayfish subspecies will invade the Strawberry River watershed within 50 years (Table 5-4). If this occurs, abundance in invaded areas is predicted tol be reduced 100% within 10 years of the invasion.

The length of time for the entire South Fork Spring River population to be invaded by the Gap Ringed Crayfish is predicted to be 19 years; while the length of time for the range of the species in the Spring River watershed to be invaded is 42 years (Table 5-5). Abundance in both the South Fork Spring River population (marginal habitat) and mainstem Spring River population (ideal habitat) will be reduced 100% (i.e., functionally extirpated). Because the Strawberry River has yet to be invaded and we cannot predict where the invasion might occur, we are unable to predict the length of time for the entire watershed to be invaded.

[16] At the date of development of this SSA, subpopulations in already-invaded areas are presumed to be extirpated.

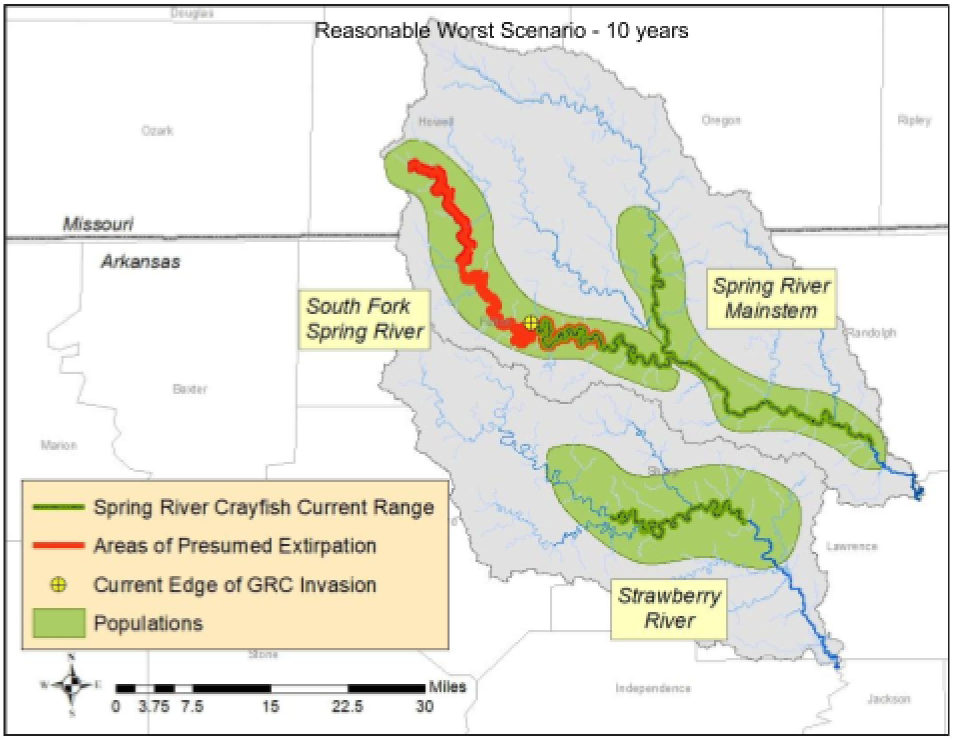

Fig. 5-4. Predicted expansion of the Gap Ringed Crayfish Spring River watershed at 10 years under the Reasonable Worst Scenario.

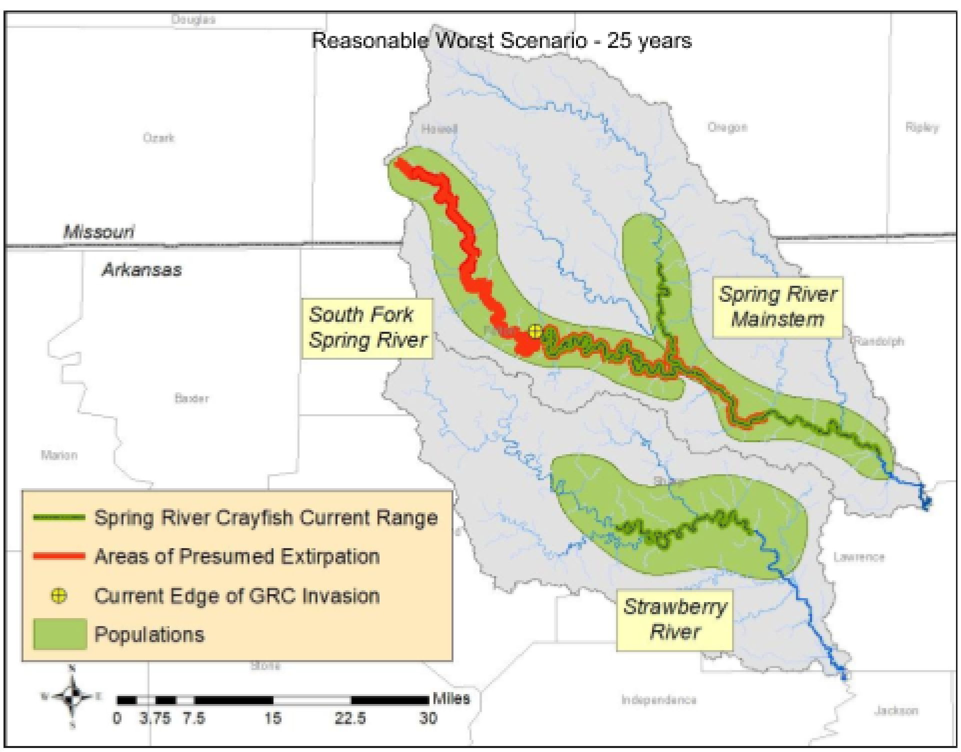

Fig. 5-5. Predicted expansion of the Gap Ringed Crayfish in the Spring River watershed at 25 years under the Reasonable Worst Scenario.

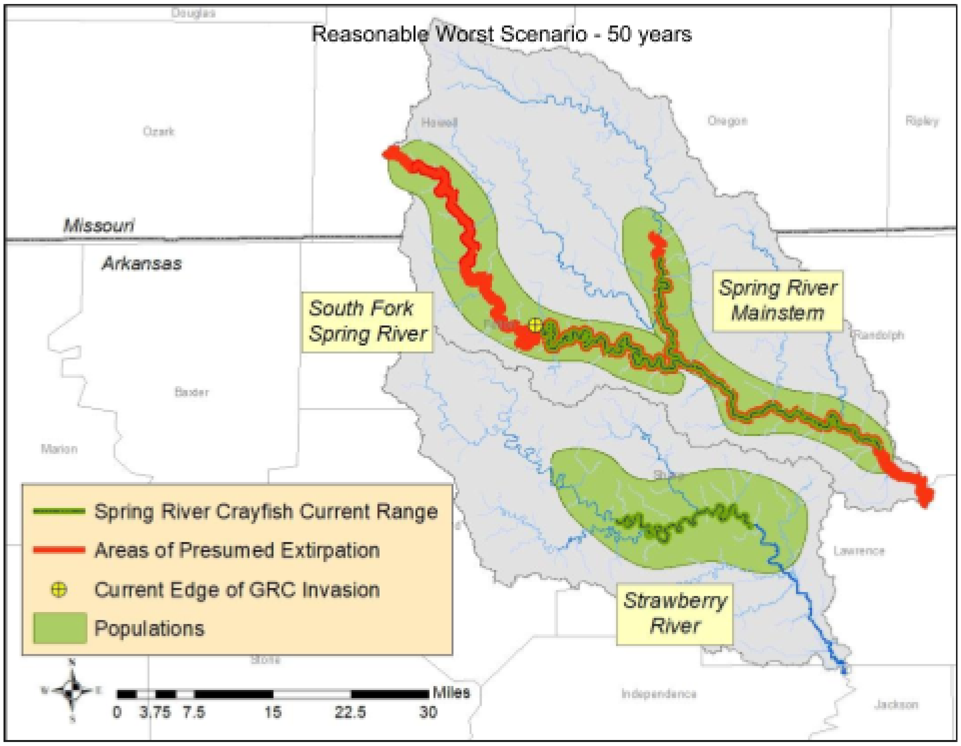

Fig. 5-6. Predicted expansion of the Gap Ringed Crayfish in the Spring River watershed at 50 years under the Reasonable Worst Scenario.

Most Likely Scenario

Under the Most Likely Scenario, experts estimated that the Gap Ringed Crayfish invasion will expand downstream at a rate of 1,000 m (1,094 yd) per year and upstream at a rate of 300 m (328 yd) per year. Based on this expansion rate, an additional 10.0 km (6.2 mi) of the South Fork Spring River is predicted to be invaded by the Gap Ringed Crayfish in 10 years (Fig. 5-7, Table 5-2). The total amount of the South Fork Spring River population invaded will then be 61.0%, which constitutes 29.4% of the entire Spring River Crayfish range. Abundance is predicted to be reduced in the newly-invaded[17] area by over 50% within 10 years.

In 25 years, 86.4 km (53.7 mi) (73.8%) of the South Fork Spring River population is predicted to have been invaded, constituting 35.6% of the Spring River Crayfish range (Fig. 5-8, Table 5-3). Abundance in newly-invaded areas is predicted to be reduced by over 50% within 10 years of the invasion. Under this scenario, there is a 20% chance that the Ringed Crayfish will invade the Strawberry River watershed within 25 years (Table 5-3).

In 50 years, 111.3 km (69.2 mi) (95.1%) of the South Fork Spring River population is predicted to have been invaded, constituting 45.8% of the species' entire range (Fig. 5-9, Table 5-4). Abundance in newly-invaded areas is predicted to be reduced by over 50% within 10 years of the invasion. Under this scenario, there is a 30% chance that the Ringed Crayfish will invade the Strawberry River watershed within 50 years (Table 5-4).

The length of time for the entire South Fork Spring River population to be invaded by the Gap Ringed Crayfish under this scenario is 55 years; while the length of time for the entire range of the species in the Spring River watershed to be invaded is beyond reliable prediction (over 132 years)(Table 5-5). If it does occur, however, abundance in the South Fork Spring River (marginal

[17] At the date of development of this SSA, subpopulations in invaded areas have already been extirpated.

habitat) will be reduced by over 50%; while abundance in the mainstem of the Spring River (ideal habitat) will be reduced 10-50%. We cannot predict the length of time for the entire Strawberry River to be invaded since it has not yet been invaded and we cannot predict where the invasion will occur.

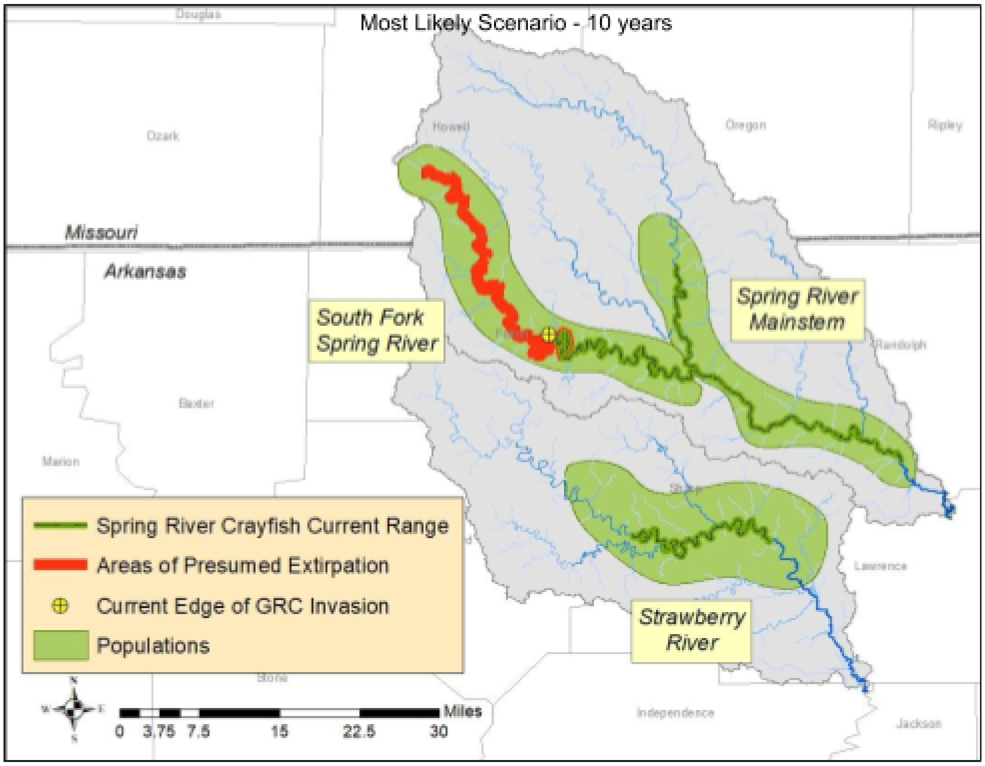

Fig. 5-7. Predicted expansion of the Gap Ringed Crayfish in the Spring River watershed at 10 years under the Most Likely Scenario.

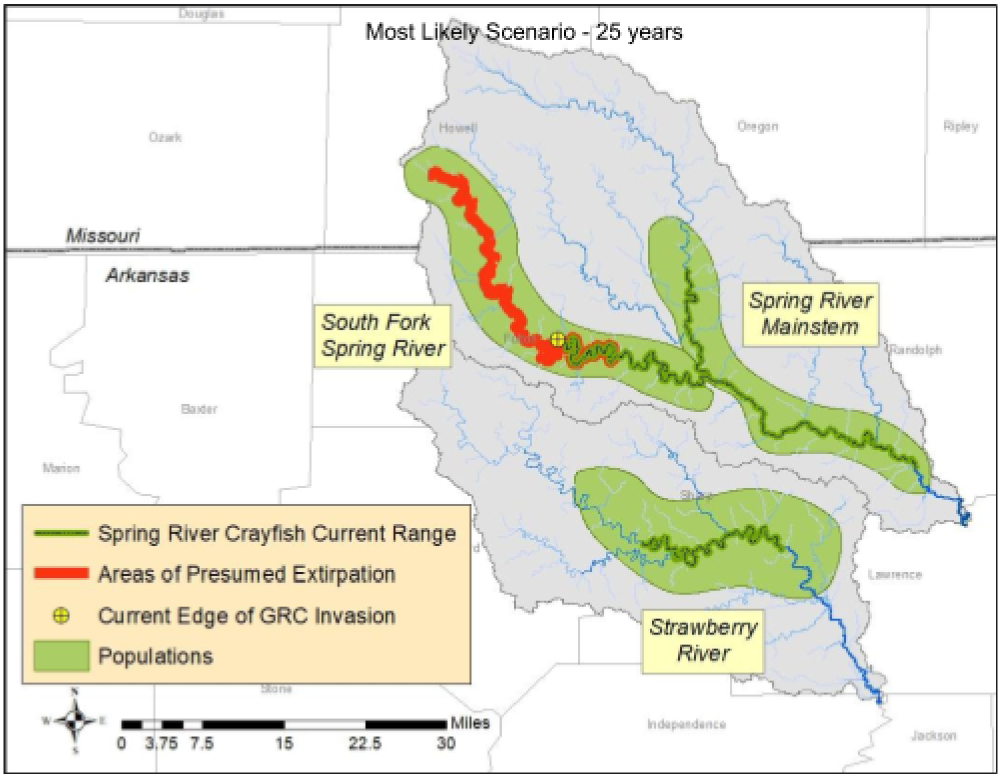

Fig. 5-8. Predicted expansion of the Gap Ringed Crayfish in the Spring River watershed at 25 years under the Most Likely Scenario.

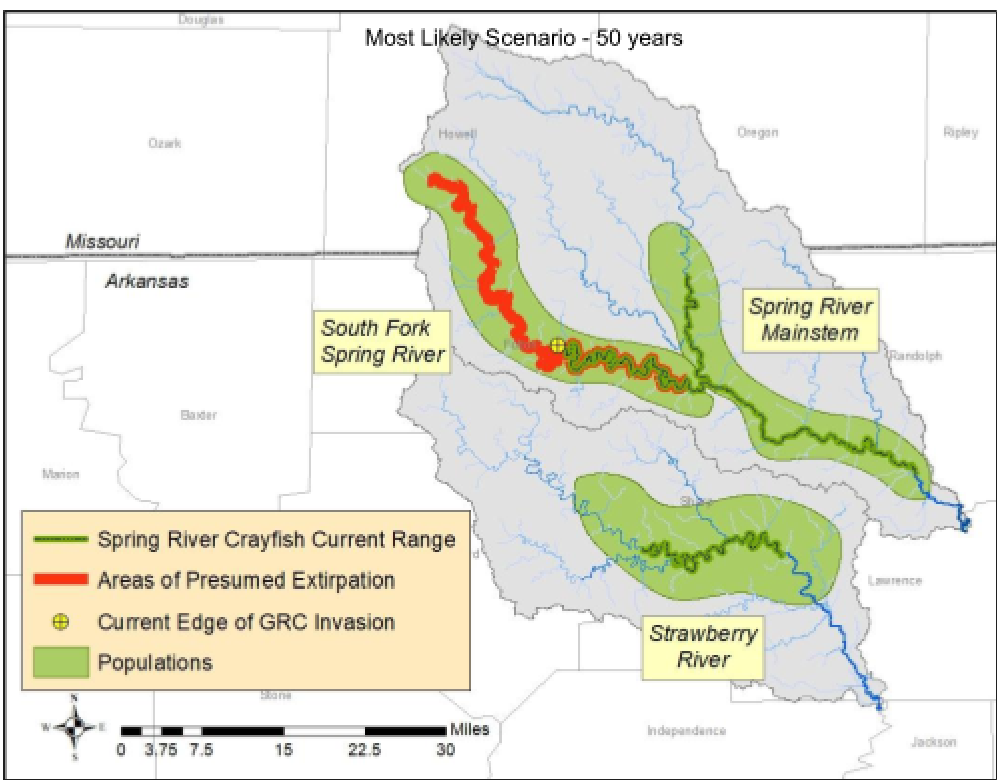

Fig. 5-9. Predicted expansion of the Gap Ringed Crayfish in the Spring River watershed at 50 years under the Most Likely Scenario.

Table 5-2. Predicted impacts to the Spring River Crayfish from the Gap Ringed Crayfish invasion at 10 years for each future scenario[18].

	Reasonable Best	Most Likely	Reasonable Worst
% of South Fork Spring River population invaded	54.1%	61.0%	78.0%
% of mainstem Spring River invaded	0%	0%	0%
% of range invaded	26.1%	29.4%	37.6%
% Reduction in abundance in invaded areas	10-50%	>50%	100%
Time for impacts to be fully realized	20-30 yrs	<10 yrs	<10 yrs

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

	Reasonable Best	Most Likely	Reasonable Worst
% of South Fork Spring River population invaded	56.7%	73.8%	100%
% of mainstem Spring River invaded	0%	0%	37.4%
% of range invaded	27.3%	35.6%	59.8%
% Reduction in abundance in invaded areas	10-50%	>50%	100%
Time for impacts to be fully realized	20-30 yrs	<10 yrs	<10 yrs
Likelihood of a Ringed Crayfish invasion in the Strawberry River watershed	0%	20%	50%

[18] We did not elicit likelihood estimates of a Gap Ringed Crayfish invasion in the Strawberry River within 10 years.

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

	Reasonable Best	Most Likely	Reasonable Worst
% of South Fork Spring River population invaded	61.0%	95.1%	100%
% of mainstem Spring River invaded	0%	0%	100%
% of range invaded	29.4%	45.8%	79.2%
% Reduction in abundance in invaded areas	10-50%	>50%	100%
Time for impacts to be fully realized	20-30 yrs	<10 yrs	<10 yrs
Likelihood of a Ringed Crayfish invasion in the Strawberry River watershed	0%	30%	70%

Table 5-5. Length of time for the Gap Ringed Crayfish to invade the entire South Fork Spring River population and the Spring River watershed for each future scenario and estimated impact.

	Reasonable Best	Most Likely	Reasonable Worst
Time for the entire South Fork Spring River population to be invaded	Beyond reliable prediction (~275 yrs)	55 yrs	19 yrs
Time for entire Spring River watershed to be invaded	Beyond reliable prediction (>725 yrs)	>132 yrs	42 yrs
% Reduction in abundance in invaded areas	10-50% in the South Fork Spring River (the mainstem Spring River is not predicted to be invaded)	>50% in South Fork Spring River 10-50% in mainstem Spring River	100%

Chapter 6. Synthesis

Based on the best available information, we presume that the Spring River Crayfish has been displaced by the Gap Ringed Crayfish in approximately 61 stream km (38 mi) of the Spring River watershed and the Gap Ringed Crayfish expansion is expected to continue. To evaluate future conditions of the Spring River Crayfish due to the Gap Ringed Crayfish invasion, we predicted the expansion of the Gap Ringed Crayfish within the Spring River watershed. We used expert-elicited estimates for 1) the plausible range of Gap Ringed Crayfish expansion rates, 2) resulting impacts on Spring River Crayfish abundance, 3) length of time for effects to be fully realized, and 4) the likelihood of an invasion in the Strawberry River watershed. Using these estimates we created Reasonable Best, Reasonable Worst, and Most Likely scenarios to characterize the range of Spring River Crayfish future conditions in 10, 25, and 50 years. Results are summarized in Tables 6-1 to 6-3.

Table 6-1. The range of predicted impacts to the Spring River Crayfish from the Gap Ringed Crayfish invasion at 10 years based on expert opinion.

	Reasonable Best	Most Likely	Reasonable Worst
% of South Fork Spring River population invaded	54.1%	61.0%	78.0%
% of mainstem Spring River invaded	0%	0%	0%
% of total range invaded	26.1%	29.4%	37.6%
% Reduction in abundance in invaded areas	10-50%	>50%	100%
Time for impacts to be fully realized	20-30 yrs	<10 yrs	<10 yrs

Table 6-2. The range of predicted impacts to the Spring River Crayfish from the Gap Ringed Crayfish invasion at 25 years based on expert opinion.

	Reasonable Best	Most Likely	Reasonable Worst
% of South Fork Spring River population invaded	56.7%	73.8%	100%
% of mainstem Spring River invaded	0%	0%	37.4%
% of total range invaded	27.3%	35.6%	59.8%
% Reduction in abundance in invaded areas	10-50%	>50%	100%
Time for impacts to be fully realized	20-30 yrs	<10 yrs	<10 yrs
Likelihood of a Gap Ringed Crayfish invasion in the Strawberry River watershed	0%	20%	50%

Table 6-3. The range of predicted impacts to the Spring River Crayfish from the Gap Ringed Crayfish invasion at 50 years based on expert opinion.

	Reasonable Best	Most Likely	Reasonable Worst
% of South Fork Spring River population invaded	61.0%	95.1%	100%
% of mainstem Spring River invaded	0%	0%	100%
% of total range invaded	29.4%	45.8%	79.2%
% Reduction in abundance in invaded areas	10-50%	>50%	100%
Time for impacts to be fully realized	20-30 yrs	<10 yrs	<10 yrs
Likelihood of a Gap Ringed Crayfish invasion in the Strawberry River watershed	0%	30%	70%

6.1 Predicted Viability

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 Spring 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 on predicted viability within 50 years. Though the impacts of the invasion may not be fully realized within 50 years, we also 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.

Resiliency

Given its small range, the Spring River Crayfish is inherently vulnerable to environmental variation and stochastic events that could impact individual subpopulations or entire populations (e.g., extreme drought or flooding), depending on the severity of the event. Resiliency of the South Fork Spring River population has already declined since historical conditions due to the Gap Ringed Crayfish invasion, with over half of the population estimated to be extirpated. Sedimentation appears to also be reducing the quality and quantity of habitat in some areas of both the Spring River and Strawberry River watersheds, particularly in the Strawberry River, further reducing resiliency of the species. Resiliency of the species will be continue to be reduced if additional subpopulations are extirpated in the South Fork Spring River population and especially if subpopulations are extirpated in the Spring River mainstem population due to the Gap Ringed Crayfish invasion. Experts also predicted that there is up to a 70% chance that one of the Ringed Crayfish subspecies could be introduced into the Strawberry River drainage within 50 years. Should that occur, resiliency of that population will be reduced, thereby reducing resiliency of the species. In addition, if threats other than the Gap Ringed Crayfish (drought, flood events, disease, degraded water quality) increase, resiliency will be further reduced, especially if those threats exacerbate impacts of the Gap Ringed Crayfish.

Representation
We consider Spring River Crayfish representation as having multiple, healthy populations in the South Fork Spring River, the Spring River mainstem, and the Strawberry River since each population contributes unique genetic or ecological diversity. Therefore, the loss of any healthy populations is considered a reduction in representation. Under the Most Likely and Reasonable Worst scenarios, the South Fork Spring River will be invaded in almost its entirety within 50 years with 50-100% reduction in abundance. We consider this a meaningful reduction in the health of the population. Though there is no evidence of genetic differences between the South Fork Spring River and Spring River mainstem populations, the South Fork Spring River population does provide unique ecological diversity. Thus, a reduction in health of the population would decrease the adaptive diversity of the species representation of the species. If the Gap Ringed Crayfish invades and substantially impacts the Spring River mainstem population, or if one of the Ringed Crayfish subspecies also invades the Strawberry River watershed, adaptive capacity of the Spring River Crayfish will be substantially compromised since each watershed provides unique genetic diversity.

Redundancy
For redundancy, the Spring River Crayfish requires a sufficient number and distribution of healthy populations across the range to guard against the loss of adaptive diversity from catastrophic events. Similar to representation, we consider the expected reduction in abundance of the South Fork Spring River population a meaningful reduction in redundancy that will increase the species' vulnerability to catastrophic events. Because the Spring River Crayfish occurs in the other two populations in the mainstems, each of these populations is vulnerable to toxic chemical spills. Should a spill occur towards the upstream end of the range of occupied habitat, each of these populations could be extirpated or their range reduced. Such an event would further increase the species' vulnerability to additional catastrophic events. An invasion in the Strawberry River watershed by one of the Ringed Crayfish subspecies, or an invasion in a large portion of the Spring River mainstem population (as is predicted under the Reasonable Worst Scenario), would further reduce redundancy of the species.

Interpreting Impacts to the Resiliency, Representation, and Redundancy
Given the Spring River Crayfish's requirements for resiliency, representation, and redundancy, we expect that the 3Rs will continue to be reduced in the future due to the Gap Ringed Crayfish invasion and other threats. The extent to which they will be reduced varies based on the different modeling scenarios. Under the Reasonable Best Scenario, roughly half of the South Fork Spring River population will be invaded in 50 years and additional impacts to the 3Rs (and thus viability) will be minimal. However, under the Reasonable Worst Scenario, the Spring River Crayfish will be effectively extirpated in the Spring River watershed in 50 years and will be highly susceptible to both stochastic and catastrophic events. Under the Reasonable Worst Scenario, the species also will have a substantially reduced ability to adapt to future changes in environmental conditions. Thus, under the Reasonable Worst Scenario, viability of the Spring River Crayfish is predicted to be substantially impacted. Under the Most Likely Scenario, the species will retain a higher level of viability than under the Reasonable Worst Scenario in that the Spring River mainstem and Strawberry River populations are not predicted to be impacted by the Gap Ringed Crayfish. Thus, the Spring River Crayfish will be less vulnerable to stochastic and catastrophic events.

6.2 Uncertainties

Predicting the future condition of the Spring River Crayfish inherently requires us to make plausible assumptions. Our analyses are predicated on multiple assumptions, which could lead to over- and underestimates of viability. In Table 6-2 we identify the key sources of uncertainty and indicate the likely effect of our assumptions on the viability assessment.

Table 6-2. Key assumptions made in evaluating the future condition of the Spring 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 Spring River Crayfish historically occurred between the farthest upstream and downstream locations throughout each occupied stream depicted in Figure 4.1, a distance of 243 stream km (151 mi).	Overestimated
The Spring River Crayfish never occurred outside of the range depicted in Figure 4-1.	Overestimated
The Gap Ringed Crayfish has continued to expand at a rate of 1.9 stream km/year (1.2 mi/yr) so that the current range of the Spring River Crayfish now spans a distance of 182 stream km (113 mi).	*Underestimated/* Overestimated
Response of the Spring River Crayfish to the Gap Ringed Crayfish invasion in the Spring River mainstem and Strawberry River populations will be similar to that of the South Fork Spring River population.	*Underestimated*/ Overestimated
There will be no new introductions of either subspecies of the Ringed Crayfish in the Spring River watershed.	Overestimated
The expansion of the Gap Ringed Crayfish will continue unabated, as there are no known feasible 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 Spring 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 Spring River Crayfish population level, 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 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 Spring River Crayfish. USDM categories of drought and associated conditions are provided in Table A-1.

According to the USDM data, 100% of the Spring River and Strawberry River watersheds were affected by a D3-D4 drought in 2012 (Figs. A-1, A-2)(USDM 2018b). During July and August in 2012, the drought intensified to a D4 drought that affected 58% of the Spring River watershed and 100% of the Strawberry River watershed (Figs. A-1, A-2)(USDM 2018b). We queried species experts on whether they recalled impacts to the Spring 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

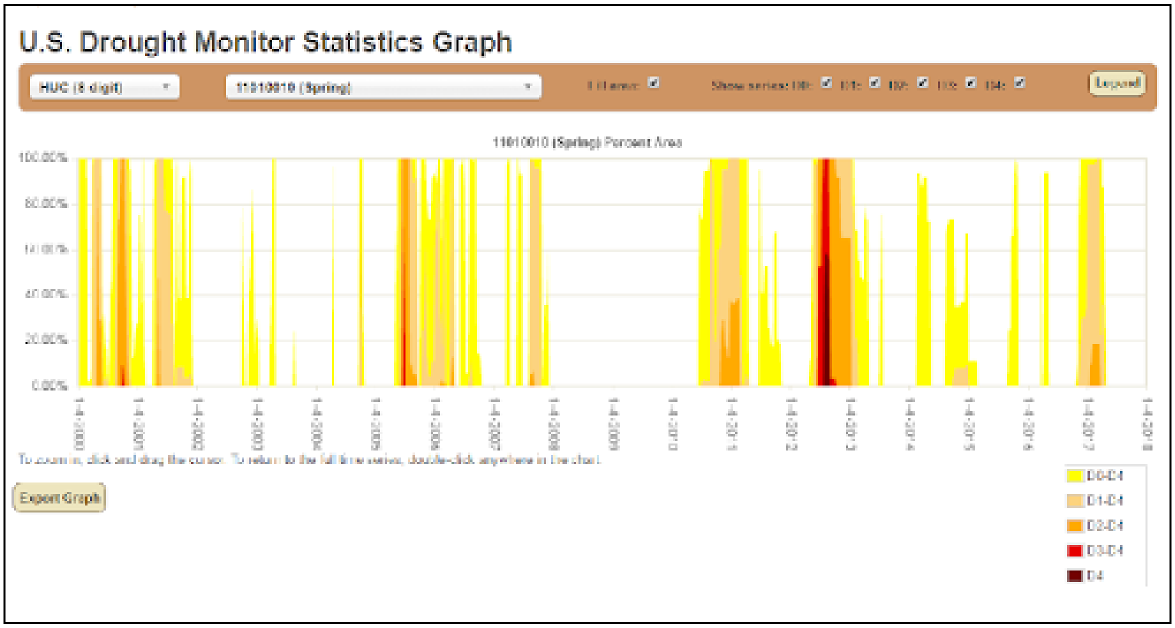

Figure A-1. Drought conditions in the Spring River watershed from January 2000 to January 2018. The entire watershed (100%) was affected by a D3-D4 drought in 2012 (USDM 2018b).

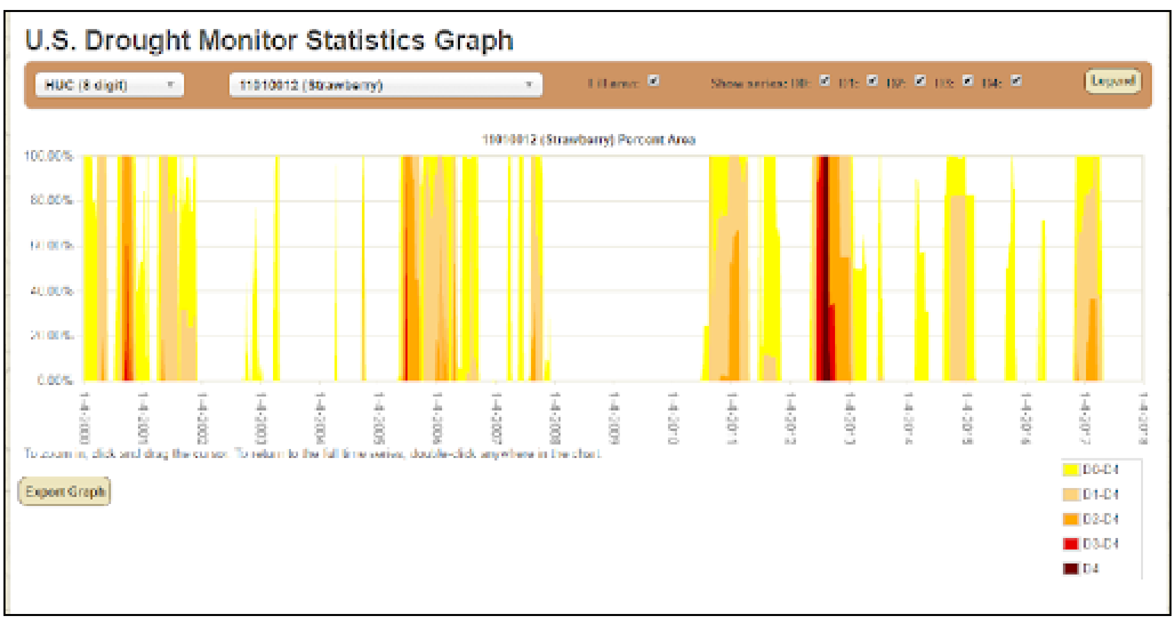

Figure A-2. Drought conditions in the Strawberry River watershed from January 2000 to January 2018. The entire watershed (100%) was affected by a D4 drought in 2012 (USDM 2018b).

Chemical Spills

To evaluate the risk of chemical spills catastrophic to the Spring River Crayfish, we identified 1) major pipelines crossing the Spring River and Strawberry River watersheds, 2) railways that cross the watersheds and could spill large quantities of oil or other chemical substances, 3) hazardous material routes that cross the watersheds, 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 Spring River Crayfish at the population level (i.e., the extirpation of the West Fork Spring Creek, the mainstem of the Spring River, or the mainstem of the Strawberry River). At the subpopulation level, a spill could also be catastrophic, resulting in extirpation or reduction in abundance of multiple subpopulations.

Major Pipelines

According to the Pipeline and Hazardous Materials Safety Administration (2016), three major pipelines cross the Spring River and Strawberry River watersheds (Fig. A-3). One is an 11-inch pipeline carrying anhydrous ammonia and running north to south across the watersheds. The pipeline crosses the mainstem of the Spring River, the West Fork Spring Creek, and the mainstem of the Strawberry River. The second pipeline is a 20-inch line carrying crude oil and it crosses both the Spring River and Strawberry River watersheds at the lower end of the watersheds. In the Spring River watershed, the line crosses the mainstem of the Spring River approximately 4 miles upstream of the downstream end of the range. In the Strawberry River watershed, the line crosses the Strawberry River below the known range of the Spring River Crayfish. The third pipeline is a 16-inch natural gas line crossing the Strawberry River watershed below the known range of the Spring River Crayfish. We do not consider that a spill or release from the crude oil line would result in a catastrophic event given it crosses the watersheds at the far downstream end and at most would only impact 6.4 km (4.0 mi) of the Spring River mainstem population. However, a spill or release from the anhydrous ammonia line could impact substantial portions of any of the three Spring River Crayfish populations given the line's location in the watershed.

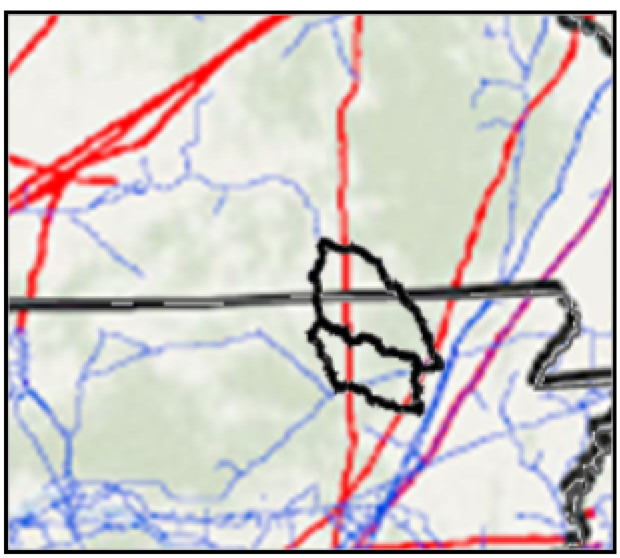

Figure A-2. Gas Transmission and Hazardous Liquid Pipelines[19] (PHMSA 2016). Blue lines represent gas transmission pipelines; red lines represent hazardous liquid pipelines.

[19] 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 range of the Spring River Crayfish (Fig. A-3)(OCI 2017). The railway enters the Spring River watershed near the upper reaches of the watershed and runs diagonally through the watershed from northwest to southeast. The railway crosses the mainstem of the Spring River near the Arkansas-Missouri state line and generally follows the mainstem of the Spring River to the end of the known Spring River Crayfish range. Thus, should a spill occur, it could impact various reaches of the Spring River mainstem.

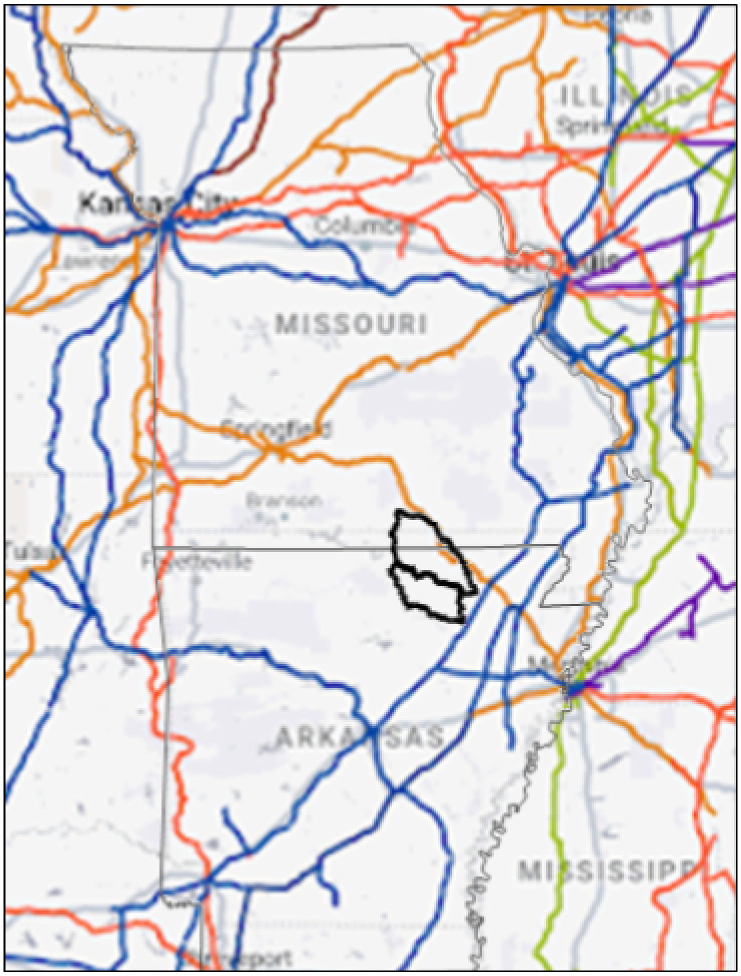

Figure A-3. Major railway routes of transport for crude oil (OCI 2017).

Hazardous Materials Routes
According to data from the Federal Motor Carrier Safety Administration (FMCSA), no hazardous material routes cross the Spring or Strawberry River watersheds (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.

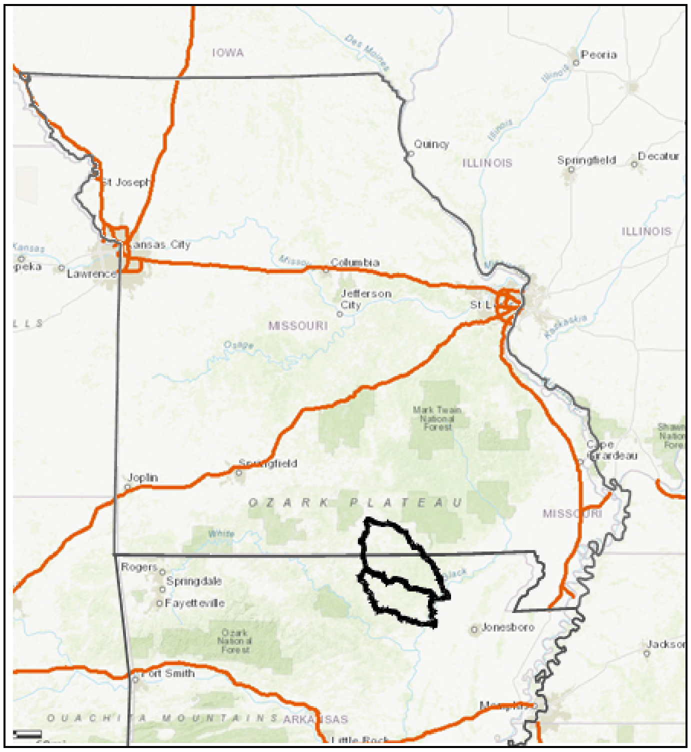

Figure A-4. Hazardous material routes (Federal Motor Carrier Safety Administration 2017)

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[FMCSA] Federal Motor Carrier Safety Administration. 2017. Map of hazardous material routes in the United States. Accessed July 31, 2017 at https://www.arcgis.com/home/item.html?id=8c665f66734e4933a02c9157ea9d6e61.

[OCI] Oil Change International. 2017. Interactive map of North American Crude by Rail. Accessed July 31, 2017 at http://priceofoil.org/rail-map/.

[PHMSA] Pipeline and Hazardous Materials Safety Administration. 2016. Gas Transmission and Hazardous Liquid Pipelines. Accessed July 31, 2017 at https://www.npms.phmsa.dot.gov/Documents/NPMS_Pipelines_Map.pdf.

[USDM] U.S. Drought Monitor. 2018a. Drought classification. Accessed on February 26, 2018 at http://droughtmonitor.unl.edu/AboutUSDM/DroughtClassification.aspx.

[USDM] U.S. Drought Monitor. 2018b. Time series of drought data. Accessed on February 26, 2018 at http://droughtmonitor.unl.edu/Data/Timeseries.aspx.

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 Spring River Crayfish (*Faxonius roberti*), which range has 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 Spring River Crayfish range, 2) impacts of the invasion on the Spring River Crayfish, and 3) the length of time for impacts to be fully realized[20].

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 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.

[20] 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

Likelihood of a Ringed Crayfish Introduction in the Strawberry River Watershed

Neither of the subspecies of the Ringed Crayfish[21] is known to currently occur within the Strawberry River watershed. To evaluate the future conditions of the Spring River Crayfish, we queried species experts on the likelihood of introduction of either Ringed Crayfish subspecies in the Strawberry River watershed within 25 and 50 years. We used the 4-step elicitation technique and elicited each expert's lowest plausible, highest plausible, and most likely estimates for likelihood of an introduction. Results are summarized in Table B-2.

Table B-2. Expert-elicited estimates of the likelihood of an invasion of either Ringed Crayfish subspecies in the Strawberry River watershed within 25 and 50 years.

Categories of Likelihood Estimates	Estimated Likelihood in 25 years		Estimated Likelihood in 50 Years	
	Median	Range	Median	Range
Lowest Plausible	0%	0-10%	0%	0-20%
Highest Plausible	50%	50-80%	70%	60-100%
Most Likely	20%	10-20%	30%	20-30%

[21] The other species of Ringed Crayfish is also named the Ringed Crayfish (*Faxonius neglectus neglectus*).

Impact of the Gap Ringed Crayfish

The Spring River Crayfish is a habitat specialist that require cold, permanent streams with high current velocity[22]. For this reason, experts thought that this species would experience greater impacts in areas of less suitable (marginal) habitat than in areas with ideal habitat because it would not be able to compete well with the invading crayfish. In addition, these impacts would be fully realized more quickly in marginal habitat.

Ideal habitat for the Spring River Crayfish was defined as stream reaches with cold temperature, a stable temperature regime, and a stable groundwater flow regime[23]. For the Spring River watershed, the West Fork Spring Creek and South Fork Spring River were considered marginal habitat, while the mainstem of the Spring River was considered ideal habitat. Ideal and marginal habitat in the Strawberry River watershed was not delineated because neither subspecies of the Ringed Crayfish has invaded that watershed.

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 Table B-3 and Table B-4.

Table B-3. Expert-elicited estimated impact on abundance of the 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 (0-15)	1 (0-5)
Abundance reduced 10-50%	60 (10-65)	10 (10-40)
Abundance reduced > 50% (but not fully displaced)	25 (20-90)	59 (25-90)
Virtual complete displacement (~100% reduction)	10 (0-10)	25 (0-60)

[22] However, the Spring River Crayfish also occupies deep pools with lower flow velocity (Rice 2018, pers. comm.).
[23] 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-4. Expert-elicited estimated length of time for impacts on the Spring 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	35 (10-65)	60 (25-70)
10-20 years	40 (25-55)	35 (20-50)
20-30 years	10 (5-30)	10 (0-25)
30-40 years	0 (0-15)	0 (0-3)
More than 40 years	0 (0-5)	0 (0-2)

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-5).

The Reasonable Best Scenario represents the smallest plausible proportion of the Spring River Crayfish range 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 (Tables B-2) and the greatest number of years for impacts to be realized (Tables 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 Spring River Crayfish range 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 Gap Ringed Crayfish (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 Spring River Crayfish range that may be 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 Gap Ringed Crayfish (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 Spring River Crayfish are provided in Table B-5.

Table B-4. Scenarios representing the plausible range of the Spring River 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 Spring River Crayfish abundance Highest number of years for impacts to be fully realized Lowest likelihood of a Ringed Crayfish invasion in the Strawberry River watershed
Reasonable Worst	Highest plausible expansion rate of the Gap Ringed Crayfish Highest level of predicted impact on Spring River Crayfish abundance Lowest number of years for impacts to be fully realized Highest likelihood of a Ringed Crayfish invasion in the Strawberry River watershed
Most Likely	Most likely expansion rate of the Gap Ringed Crayfish Most likely level of predicted impact on Spring River Crayfish abundance Most likely number of years for impacts to be fully realized Most likely likelihood of a Ringed Crayfish invasion in the Strawberry River watershed

Table B-5. Expert-elicited estimates used for the Spring River Crayfish future scenarios.

Future Scenario	Downstream Expansion Rate (m/year)	Upstream Expansion Rate (m/year)	Level of Impact (reduction in abundance)		Time for Impacts to be Fully Realized (years)		Likelihood of an Introduction in the Strawberry River in 25 years	Likelihood of an Introduction in the Strawberry River in 50 years
			Ideal Habitat	Marginal Habitat	Ideal Habitat	Marginal Habitat		
Reasonable Best	200	50	10-50%	10-50%	20-30 years	20-30 years	0%	0%
Reasonable Worst	3,000	1,000	100%	100%	<10 years	<10 years	50%	70%
Most Likely	1,000	300	10-50%	>50%	10-20 years	<10 years	20%	30%

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