Species Status Assessment Report for the

Big Creek Crayfish
(*Faxonius peruncus*)

and

St. Francis River Crayfish
(*Faxonius quadruncus*)

Big Creek Crayfish (left) and St. Francis River Crayfish (right)
Photos: Chris Lukhaup, Missouri Department of Conservation

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Executive Summary

This report summarizes results of a species status assessment (SSA) conducted for the Big Creek Crayfish (*Faxonius peruncus*) and St. Francis River Crayfish (*Faxonius quadruncus*) to assess their viability. The Big Creek Crayfish and St. Francis River Crayfish are stream-dwelling crayfish endemic to the Upper St. Francis watershed in southeastern Missouri. Due to similarities in threats and because the species share a similar range, we have included both SSA results in one report.

In conducting our status assessment, we first considered what each 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 each species. Lastly, we predicted the future condition of each species based on its current condition and expected future influences on viability.

For survival and reproduction at the individual level, the Big Creek Crayfish and St. Francis River Crayfish require pools, runs, or riffles with relatively low water velocity, shallow water depth, and low turbidity. The species also require rock substrate to use as refuge from predators and to harbor prey resources, likely consisting of invertebrates, periphyton, and plant detritus. The Big Creek Crayfish appears to consist of two populations; whereas the St. Francis River Crayfish appears to consist of only one population. However, to better represent groups of individuals that occupy the same area and are subject to the same ecological pressures, we describe population needs at the subpopulation level. For Big Creek Crayfish and St. Francis River Crayfish subpopulations to be healthy, they require a population size and growth rate sufficient to withstand natural environmental fluctuations, habitat of sufficient quantity and quality to support all life stages, gene flow among subpopulations, and a native community structure free from non-native crayfish species that may outcompete and ultimately displace the two species.

At the species level, the Big Creek Crayfish and St. Francis River Crayfish require resiliency, adaptive capacity (representation), and redundancy. Resiliency is the ability of the species to withstand stochastic events and, in the case of the crayfish, is best measured by the number, distribution, and health of populations across the species' ranges (or subpopulations, in the case of the St. Francis River Crayfish). Representation is an indicator of the ability of a species to adapt to changing environmental conditions; for both species it can be measured by the number and distribution of healthy subpopulations across areas of unique adaptive diversity. For the Big Creek Crayfish we presume this includes the Twelvemile Creek and Main populations; whereas we presume it includes the entire range for the St. Francis River Crayfish. Redundancy is an indicator of the ability of a species to withstand catastrophic events by "spreading the risk." It can be measured for the two species through the duplication and distribution of resilient subpopulations across the species' ranges.

The primary factor influencing viability of the Big Creek Crayfish and St. Francis River Crayfish is invasion by the Woodland Crayfish (*Faxonius hylas*). The Woodland Crayfish was first documented in the Upper St. Francis River watershed in 1984 and is now known to occur in 11 streams in the watershed. The invasion resulted in reduced abundance of the two native species, and in some areas, complete displacement. There are currently no known mechanisms to stop or reverse the Woodland Crayfish invasion. The only other major factor likely impacting the Big Creek Crayfish and St. Francis River Crayfish is contamination by lead mining. Positive influences include research efforts, policies to curtail future introductions of non-native crayfish, a large amount of public land in the watershed (41%), and remediation and habitat restoration efforts. Due to effects of the Woodland Crayfish invasion and presumed impacts from lead mining, we expect that resiliency, representation, and redundancy have already been reduced to some degree for both the Big Creek Crayfish and St. Francis River Crayfish.

To evaluate future conditions of the Big Creek Crayfish and St. Francis River Crayfish, we predicted the expansion of the Woodland Crayfish within the species' ranges and its expected impact. 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 Woodland 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 Big Creek Crayfish abundance may be reduced 50-100% in 49-90% of the Main population and 0-100% in the Twelvemile Creek population (constituting 46-91% of the species' total range) due to the Woodland Crayfish invasion. We expect that these impacts will result in further reduction in the species' resiliency, representation, and redundancy. In particular, if abundance of the Twelvemile Creek population is reduced towards the higher end of these predictions, representation may be appreciably reduced.

The future conditions models predict that St. Francis River Crayfish abundance may be reduced 10-100% in 38-82% of the species' range within 50 years due to the Woodland Crayfish invasion. We expect that these impacts will result in further reduction in the species' resiliency, representation, and redundancy.

The exact number and distribution of populations required to maintain resiliency and representation of the Big Creek Crayfish and St. Francis River Crayfish is unknown, as is the distribution and number of healthy populations (or for the St. Francis River Crayfish subpopulations) required to guard against catastrophic events. Therefore, it is unclear how a reduction in resiliency, representation, and redundancy from the predicted range contractions will affect viability of the species. If the reduction in the 3Rs is within the lower range of predicted impacts (i.e., lower proportion of range invaded with a lesser impact on abundance), we expect a lesser impact on viability and thus a higher probability of persistence. However, if the reduction in the 3Rs is towards the higher end of the predictions (i.e., greater proportion of range invaded with a greater impact on abundance), we expect a greater impact on viability with a lower probability of persistence.

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Chapter 1. Introduction and Analytical Approach

This report summarizes results of a species status assessment (SSA) conducted for the Big Creek Crayfish (*Faxonius peruncus*) and St. Francis River Crayfish (*Faxonius quadruncus*). Due to similarities in life history and threats and because the species share a similar range, we have included both SSA results in one report.

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

1.1 Resiliency, Representation, and Redundancy (3Rs)

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

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

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

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

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

1.2 Analytical Approach

Our analytical approach for assessing viability of the Big Creek Crayfish and St. Francis 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 Big Creek Crayfish and St. Francis 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.

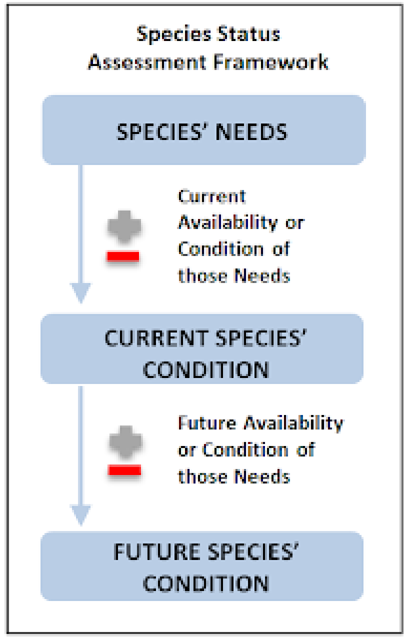

Figure 1-1. Species Status Assessment Framework.

Chapter 2. Species Descriptions, Distribution, and Ecology

2.1 Taxonomy and Species Description

The Big Creek Crayfish (*Faxonius peruncus*) is a small, olive-tan crayfish with blackish blotches and specks over the upper surface of pincers, carapace and abdomen (Fig. 2-1)(Pflieger 1996, p. 114). Length of adult individuals ranges from 2.8 to 5.6 centimeters (cm)(1.1 to 2.2 inches)(in)(Pflieger 1996, p. 114). The species was first described as *Cambarus peruncus* from specimens collected in Little Creek, a tributary to Big Creek in the Upper St. Francis River watershed (Creaser 1931, pp. 7-10).

The St. Francis River Crayfish (*Faxonius quadruncus*) is a rather small, dark brown crayfish with blackish blotches or specks over the upper surfaces of the pincers, carapace, and abdomen (Fig. 2-1)(Pflieger 1996, p. 120). Length of adult individuals also ranges from 2.8 to 5.6 centimeters (cm)(1.1 to 2.2 inches)(in)(Pflieger 1996, p. 120). The species was first described as *Faxonius quadruncus* in 1933 from specimens collected in from the Little St. Francis River and Stout's Creek, a tributary to the St. Francis River (Creaser 1933, pp. 10-12).

In 1942 the genus name for both the Big Creek Crayfish and St. Francis River Crayfish was changed to *Orconectes* based on more accurate knowledge of species' ranges and discovery of a new species (Hobbs 1942, pp. 334, 352-353). Based on phylogenetic analyses, the genus name was changed to *Faxonius* in 2017 (Crandall and De Grave 2017, pp. 619-620, 630).

Figure 2-1. The Big Creek Crayfish (left) and St. Francis River Crayfish (right). Photos by Chris Lukhaup (Missouri Department of Conservation) used with permission.

2.2 Historical Range and Distribution

Both the Big Creek Crayfish and the St. Francis River Crayfish have localized distributions in the St. Francis River basin upstream of Wappapello dam in Iron, Madison, St. Francois, and Wayne counties in southeastern Missouri (Fig. 2-2)(Pflieger 1996, pp. 116, 120; Riggert et al. 1999, p. 352). The Big Creek Crayfish appears most abundant in the Big Creek and other streams on the west side of the basin and primarily Twelvemile Creek subwatersheds on the east side (Pflieger 1996, p. 116; Riggert et al. 1999, p. 352; MDC 2017, unpublished data); while the St. Francis River Crayfish mainly inhabits the upper St. Francis River tributaries on the upper end of the Upper St. Francis River watershed (Riggert et al. 1999, p. 352; MDC 2017, unpublished data). Despite occupying the St. Francis River watershed at a coarse spatial scale, these two species have been observed at the same location only seven times and exhibit mostly discrete distributions (Westhoff 2011, pp. 34-36).

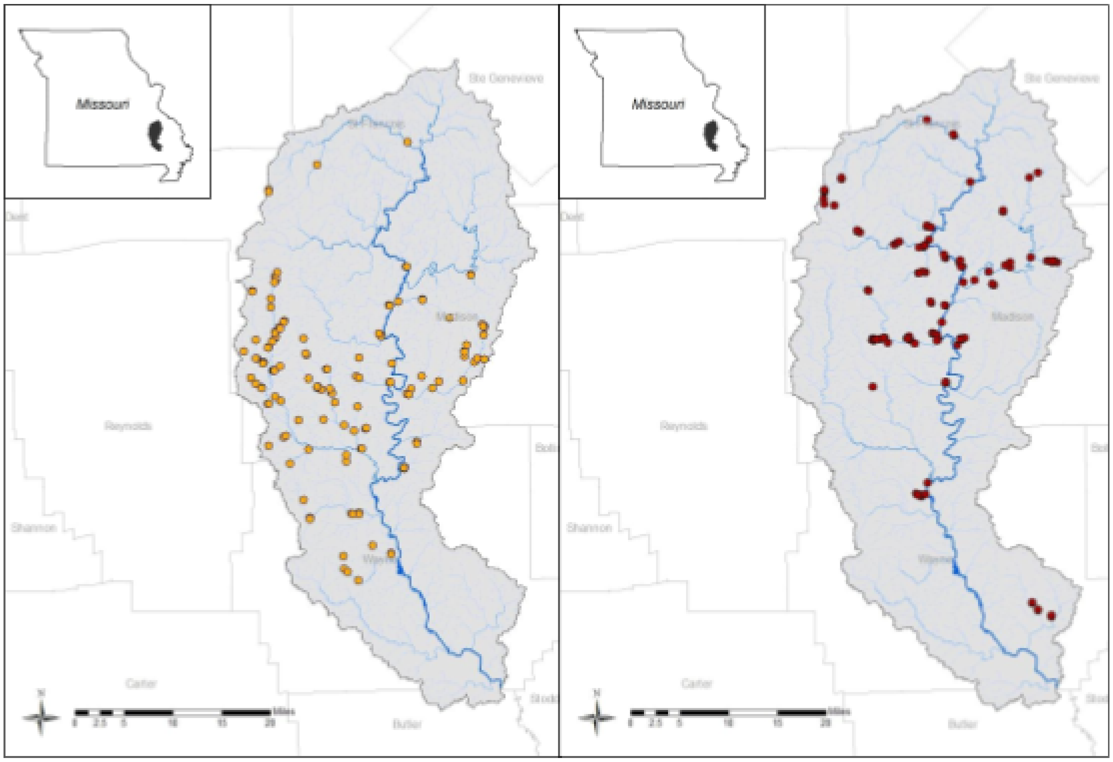

Figure 2-2. Known locations of the Big Creek Crayfish (left) and St. Francis River Crayfish (right).

2.3 Life History and Individual-Level Requirements

<u>Habitat</u>

Early reports of the Big Creek Crayfish suggest the species was found only under small rocks and in shallow burrows in gravel of primary headwater streams (Creaser 1931, p. 9; Williams 1954, p. 847; Pflieger 1996, p. 116), with Pflieger (1996, p. 116) also reporting that the species occurs exclusively in small, high-gradient rocky creeks. Subsequent studies reported that the species was most abundant in smaller streams with widths less than 10 meters (m)(10.9 yards)(yd) and individuals were collected most often from shallow depths (less than 0.5 m), in association with pebble- and cobble-sized rocky substrate, and from habitats with slower current velocities generally ranging from 0.00-0.35 meters per second (m/s)(Riggert et al. 1999, pp. 352-258; Westhoff 2011, p. 95). Daytime water temperatures of sites from which the Big Creek Crayfish were captured ranged from 1.1° Celsius (C)(34.0° Fahrenheit)(F) in December to 28.9° C (84.0° F) in July (Riggert et al. 1999, p. 357).

The St. Francis River Crayfish was originally reported as being found under rocks in small, rocky headwater streams to moderately large rivers (Creaser 1933, p. 12; Williams 1954, p. 845; Pflieger 1996, p. 122). Creaser (1933, p. 12) also reported that the species was confined to swifty-moving streams with water tumbling over boulders and rocks in the stream bed. However, Riggert et al. (1999, p. 357) found lower densities in faster riffles as compared to pool/backwater and run macrohabitats, as did Westhoff (2011, p. 95) at some sampling sites. Riggert et al. (1999, p. 358) generally found the species in current velocities ranging from 0.00-0.39 m/s (although one individual was collected in a current velocity of 1.90 m/s). Westhoff (2011, p. 108) found the St.

Francis River Crayfish in similar velocities ranging from 0.0-0.91 m/s with the average velocity often between 0.05 and 0.15 m/s. Daytime water temperatures of sites from which St. Francis River Crayfish were captured ranged from 1.1° C (34.0° F) in December to 28.9° C (84.0° F) in July (Riggert et al. 1999, p. 357).

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 Big Creek Crayfish and St. Francis River Crayfish, 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.

Reproduction and Growth

Similar to other crayfish occupying Ozark streams, individuals of the Big Creek Crayfish and St. Francis River Crayfish mate in the fall (Fig 2-3)(Pflieger 1996, pp. 116,122). 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). Big Creek Crayfish females generate an average of 61 eggs (Pflieger 1996, pp. 116), ranging from 10 to 90 eggs on each female (DiStefano et al. 2002, p. 449). St. Francis River Crayfish generate an average of 43-81 eggs, with 21-161 eggs on each female (Pflieger 1996, p. 122; Mabery et al. 2017, pp. 16,18). Eggs are fertilized internally, extruded, and then attached to the female's abdomen the following spring (Pflieger 1996, p. 28). 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 normal lifespan for both the Big Creek Crayfish and St. Francis River Crayfish appears to be about 2 years (Pflieger 1996, pp. 116, 122).

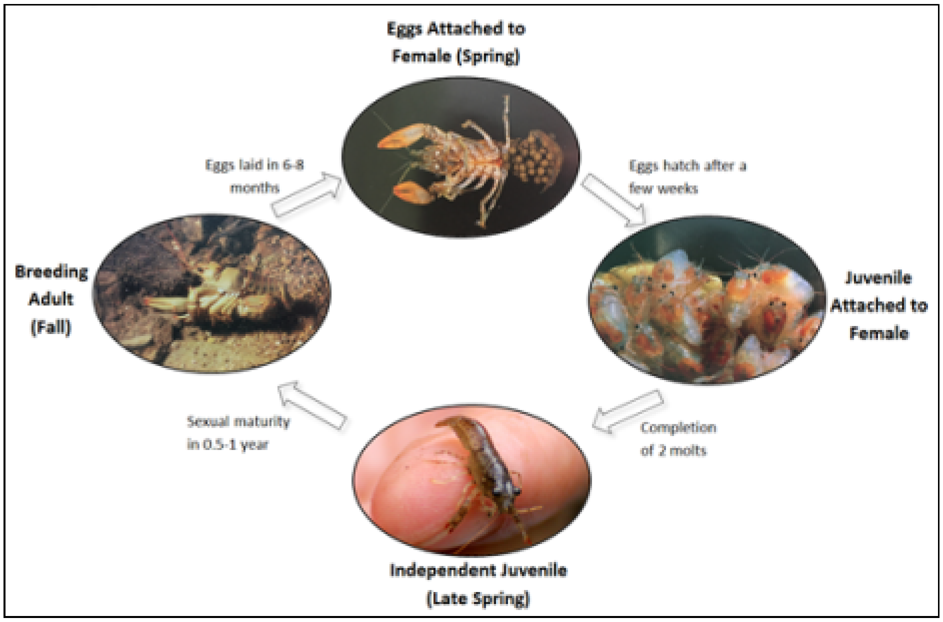

Figure 2-3. Life cycle diagram of most stream-dwelling *Faxonius* species. Photos of breeding adults, eggs, and juveniles attached to females modified from Pflieger 1996 (pp. 28-29).

Feeding Habits

We are unaware of gut content or stable isotope analyses specific to the Big Creek Crayfish and St. Francis River Crayfish. However, we assume that their diet is similar to other Ozark-endemic crayfishes and consists of plant detritus, with invertebrates and periphyton also consumed.

Individual-Level Requirements

The Big Creek Crayfish and St. Francis 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 Big Creek Crayfish and St. Francis River Crayfish.

Type of Requirement	Description
Macrohabitats	Pools, runs, and riffles
Stream Flow Velocity	Big Creek Crayfish: low water velocity (0.00-0.35 m/s) St. Francis River Crayfish: low water velocity (0.00-0.35 m/s)
Water Depth	Big Creek Crayfish: 0.06-0.49 m St. Francis River Crayfish: 0.06-0.52 m
Water Temperature	1.1° C (34.0° F) to 28.9° C (84.0° F)
Embeddedness	Low so that spaces under rocks and cavities in gravel remain available
Refugia	Under rocks or in shallow burrows in gravel
Diet	Invertebrates, periphyton, plant detritus

2.4 Subpopulation-Level Requirements

Results from genetic analyses indicate that there is gene flow throughout the St. Francis River Crayfish's range (Fetzner and DiStefano 2008, pp. 14-15). Thus, we presume that the species functions as a single population. There also appears to be gene flow throughout most of the Big Creek Crayfish's range, as evidenced by a haplotype[1] contained at high frequencies by most of the sampled individuals (Fetzner and DiStefano 2008, p. 12). However, crayfish in Twelvemile Creek and Dry Creek contained their own unique haplotypes that were not found anywhere else in the watershed (Fetzner and DiStefano 2008, p. 12)(Fig. 2-4). We consider crayfish in these subwatersheds as constituting a separate population from the rest of the species' range (which we will refer to as the Main population).

For the St. Francis River Crayfish population and the two Big Creek Crayfish 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. Subpopulation level requirements are described below and summarized in Table 2-2.

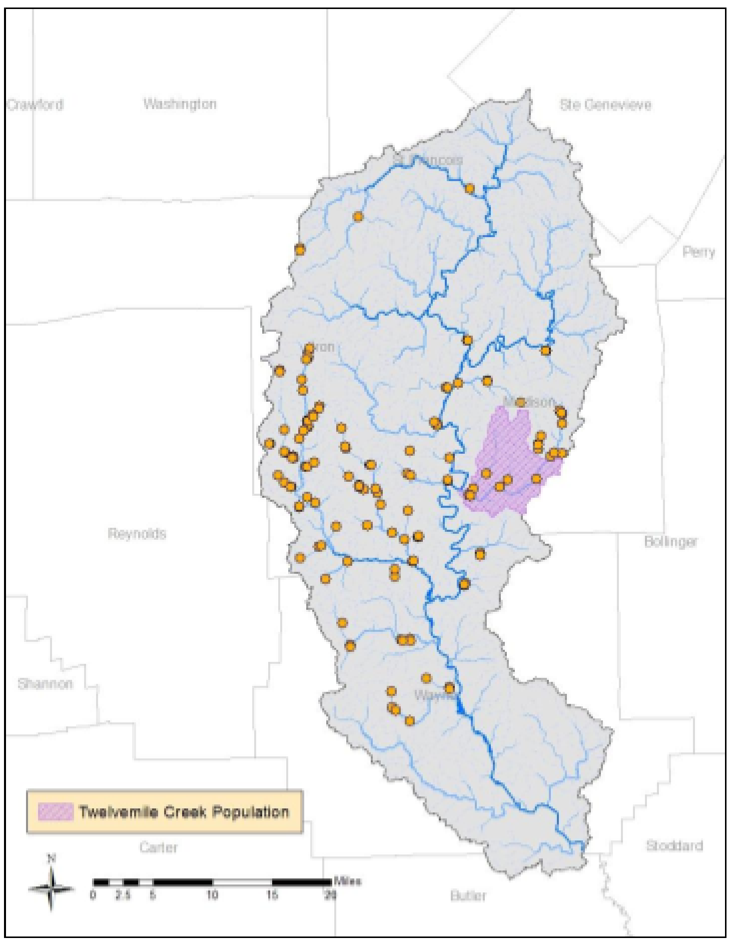

Figure 2-4. Populations of the Big Creek Crayfish. The Twelvemile Creek subwatershed represents one population (purple); while the rest of the range represents the Main population (remainder of the orange dots).

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

Healthy Demography

For subpopulations of the Big Creek Crayfish and St. Francis 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 for each species to maintain a healthy subpopulation is unknown. Based on general ecological principles, however, we know that λ must be at least 1 for a population to remain stable over time. In the absence of population size and growth rate information, vital rates can also be used to represent healthy demography. Though data on survivorship and recruitment rates are currently not available, mean individual fecundity has been reported as 61 eggs for the Big Creek Crayfish and 43-81 eggs for the St. Francis River Crayfish (Pflieger 1996, pp. 116,122; Mabery 2017, p. 16).

Habitat to Support a Healthy Demography

Healthy Big Creek Crayfish and St. Francis 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. Healthy subpopulations must also have connectivity between ovigerous[2] 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 Big Creek Crayfish and St. Francis River Crayfish subpopulations require a community structure free from non-native crayfish species that may outcompete and ultimately displace the two species. We also presume that non-native organisms other than crayfish, such as predatory fish or a benthic competitor (e.g., the round goby)(*Neogobius melanostomus*), could impact the two species.

[2] Bearing or carrying eggs.

Table 2-2. Subpopulation-level requirements for the Big Creek Crayfish and St. Francis 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 61 eggs for the Big Creek Crayfish and at least 43 eggs for the St. Francis River Crayfish
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 Big Creek Crayfish and St. Francis River Crayfish are described below and summarized in Table 2-3.

<u>Resiliency</u>
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 Big Creek Crayfish and St. Francis River Crayfish, we presume environmental stochasticity primarily includes differences in precipitation (wet and dry years) and temperature (hot and cold years) throughout the Upper St. Francis River watershed. Given the narrow range of each species, these and other environmental differences could affect the species throughout their ranges; thus they are inherently vulnerable to environmental stochasticity. Therefore, for the Big Creek Crayfish and St. Francis River Crayfish to be resilient to this stochasticity, the species require subpopulations distributed across their range in the Upper St Francis River watershed. For the Big Creek Crayfish, this includes healthy subpopulations in both the Twelvemile Creek and Main populations. The greater the number of subpopulations and the greater the distribution of those subpopulations relative to the diversity of temperature and precipitation conditions, the greater resiliency the species will possess.

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

Representation

Representation is a function of both genetic and adaptive diversity. As described in Chapter 1, genetic diversity is important because it can delineate evolutionary lineages that may harbor unique genetic variation, including adaptive traits. It can also indicate gene flow, migration, and dispersal. Adaptive diversity is important because it provides the variation in phenotypes[3] and ecological settings on which natural selection acts. As noted under section 2.4, Big Creek Crayfish individuals in the Twelvemile Creek subwatershed contain unique haplotypes not detected elsewhere in the species range. Therefore, we consider Big Creek Crayfish representation as having healthy subpopulations throughout the Twelvemile Creek subwatershed as well as the rest of the range (the Main population). Also required are the processes that drive evolution: gene flow, natural selection, mutations, and genetic drift (Crandall 2000, p. 291).

According to the species experts, the St. Francis River Crayfish exhibits no phenotypic or genetic diversity that might readily represent adaptive diversity (a measure of adaptive capacity)(DiStefano 2017, pers. comm.; Magoulick 2017, pers. comm.; Taylor 2017, pers. comm.; Wagner 2017, pers. comm.; Westhoff 2017, pers. comm.). However, we know that each species requires some form of adaptive diversity to preserve its adaptive capacity. Until more information is available on adaptive diversity of the St. Francis River Crayfish, we will presume that the species require healthy subpopulations distributed throughout its range to preserve adaptive capacity. As with the Big Creek Crayfish, the processes that drive evolution (gene flow, natural selection, mutations, and genetic drift) are also required.

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. Thus, we consider redundancy for the St. Francis River Crayfish as having multiple, healthy subpopulations distributed across the breadth of adaptive diversity relative to the spatial occurrence of catastrophic events (i.e., throughout its range in the Upper St. Francis River watershed). Because the Big Creek Crayfish appears to contain two populations, we presume redundancy for the species requires multiple, healthy subpopulations distributed throughout the Twelvemile Creek subwatershed, as well as the Main population.

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

Table 2-3. Species-level requirements for the Big Creek Crayfish (top) and St. Francis River Crayfish (bottom).

Big Creek 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 (we presume this includes the Twelvemile Creek and Main populations) 2) Evolutionary processes (gene flow, natural selection, genetic drift) are maintained
Redundancy	Sufficient number and distribution of healthy subpopulations across the range to guard against the loss of the species from catastrophic events and to allow for re-population when subpopulations are lost or reduced

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

Chapter 3. Threats and Conservation Actions

In this chapter we describe current and future threats to the Big Creek Crayfish and St. Francis River Crayfish and how these threats affect the species. We also describe conservation efforts and their expected effects.

3.1 Non-native Crayfish

The Woodland Crayfish (*Faxonius hylas*) is native to southeastern Missouri in the Black River drainage and the headwaters of the Meramec and Big rivers (Fig. 3-1)(Pflieger 1996, p. 82). In 1984, the species was discovered outside of its native range in Stouts Creek, a tributary of the St. Francis River (Pflieger 1996, p. 82), presumably from a bait bucket introduction[4] (Westhoff et al. 2011, p. 2416). Subsequent sampling has documented the Woodland Crayfish in multiple reaches of the Upper St. Francis River watershed (Figs. 3-1, 3-2)(Riggert et al. 1999, pp. 360-361; DiStefano 2008a, p. 191; DiStefano 2008b, p. 419; DiStefano and Westhoff 2011, pp. 40-41, MDC 2018a, unpublished data). As of 2011, the Woodland Crayfish was estimated to occupy 166 to 649 stream kilometers (km)(103 to 403 miles)(mi) in 11 streams (DiStefano and Westhoff 2011, p. 40). This constitutes 5-20% of the total stream distance in the Upper St. Francis River watershed (DiStefano and Westhoff 2011, p. 40).

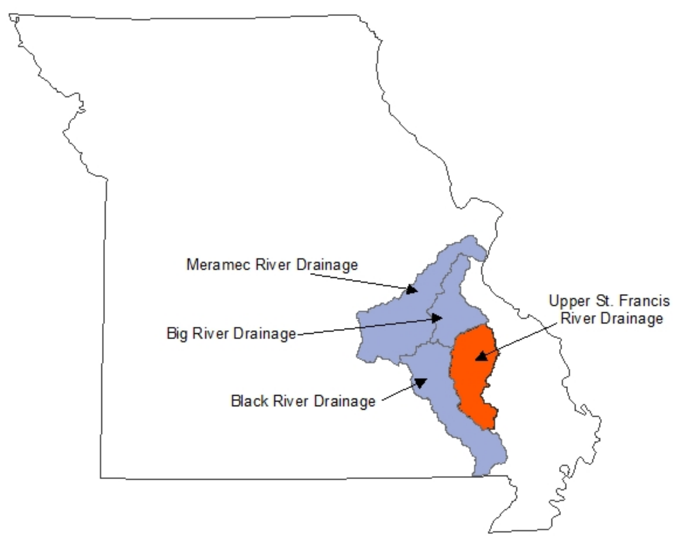

Figure 3-1. Native and introduced range of the of the Woodland Crayfish.

<u>Impact on Distribution of the Big Creek Crayfish and St. Francis River Crayfish</u>
Because not all stream reaches within the ranges of the Big Creek Crayfish and St. Francis River Crayfish have been sampled, we cannot report the actual amount of range contraction that has resulted from the Woodland Crayfish invasion. However, the range of the Big Creek Crayfish contracted 14.7 stream km (9.1 mi) in Carver Creek from 2004-2009 (Fig. 3-2)(DiStefano and Westhoff 2011, p. 41). We presume that this is an extreme underestimate of the actual extent of the range contraction given that this represents conditions in only 1 of the 11 streams known to be invaded by the Woodland Crayfish (DiStefano and Westhoff 2011, p. 42). The range of the St.

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

Francis River Crayfish has also contracted due to the Woodland Crayfish invasion in portions of at least three streams (Stouts Creek, Orr Hollow Creek, and Marble Creek), with St. Francis River Crayfish in two-thirds of the length of Stout's Creek presumably now extirpated (Riggert et al., 1999, p. 1999; DiStefano 2008b, p. 419). The distance from which the St. Francis Crayfish has been displaced from Orr Hollow Creek and Marble Creek was not reported, but the length of Stout's Creek from which the St. Francis River Crayfish has been extirpated is 13.7 stream km (8.5 mi)(Fig. 3-2)(DiStefano 2008b, p. 419). As with the Big Creek Crayfish, we presume this is an extreme underestimate of the actual extent of the St. Francis River Crayfish range contraction given that this represents only 1 of the 11 invaded streams.

<u>Impact on Abundance of the Big Creek Crayfish and St. Francis River Crayfish</u>
Although the Big Creek Crayfish and St. Francis River Crayfish have not been completely displaced in all stream reaches where the Woodland Crayfish has invaded, abundance appears to be substantially impacted. In Orr Hollow Creek, the St. Francis River Crayfish constituted approximately 50% of the crayfish community in uninvaded areas, while constituting only 13% of the community in invaded areas (DiStefano and Westhoff 2011, p. 40). In Marble Creek the St. Francis River Crayfish also appears to have co-occurred with the Woodland Crayfish for over 10 years without being completely displaced, though the Woodland Crayfish appears to now be the dominant species in the crayfish community (Westhoff 2017, unpublished data). Similarly, the Big Creek Crayfish constituted 87% of the crayfish community in areas not invaded by the Woodland Crayfish in Carver Creek, but only 27% of the community in invaded areas (DiStefano and Westhoff 2011, p. 40). However, the reduction of Big Creek Crayfish relative abundance in Carver Creek appeared to be followed by complete displacement (DiStefano and Westhoff 2011, pp. 40-41). Although impacts likely vary among streams, these results suggest that the Woodland Crayfish has the potential to completely displace the Big Creek Crayfish in invaded areas and substantially reduce abundance of the St. Francis River Crayfish (if not fully displace it).

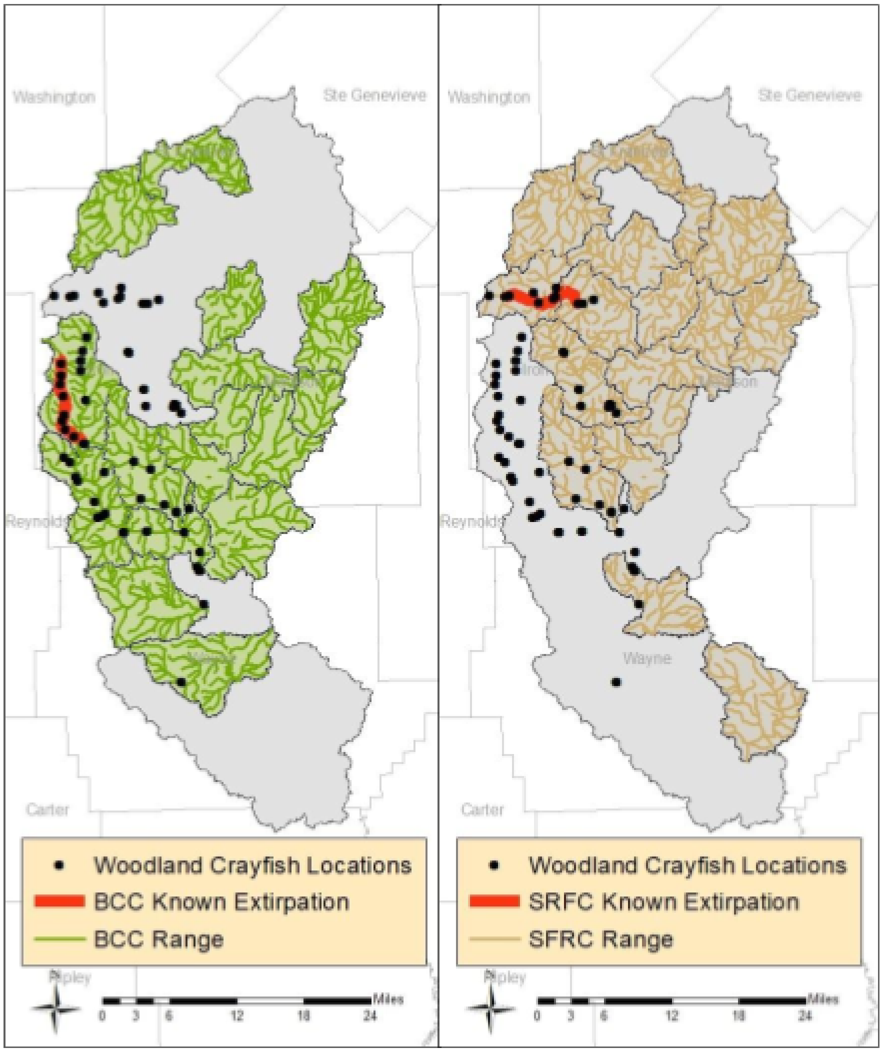

Figure 3-2. Known locations of the Woodland Crayfish and stream segments from which the Big Creek Crayfish (left) and St. Francis River Crayfish (right) have been extirpated due to the Woodland Crayfish invasion. Details on how the species' ranges were delineated are outlined in Chapter 4.

<u>Mechanisms of Displacement</u>

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). DiStefano et al. 2002 (pp. 452-452) compared life history patterns, morphometrics, and early life history data among the Woodland Crayfish, Big Creek Crayfish, and St. Francis River Crayfish and found that the Woodland Crayfish may have a competitive advantage in that individuals grew faster as juveniles, achieved larger size at maturity, were more fecund[5], and released young earlier than the native species. However, Rahm et al. (2005, pp. 442-446) examined agonistic interactions of adults and juveniles between the Woodland Crayfish and the two native species, but found no dominance by the invasive Woodland Crayfish in interaction trials. Rahm et al. (2005, pp. 446-447) documented similar results when adult Woodland Crayfish were paired with Big Creek Crayfish and St. Francis River Crayfish of smaller size. In addition, Mabery et al. (2017, p. 18) found no statistically significant differences in fecundity between the Woodland Crayfish and St. Francis River Crayfish. These findings suggest

[5] Producing or capable of producing an abundance of offspring.

that interspecific competition may not be the mechanism causing displacement, as do those of Westhoff et al. (2011, pp. 46-47) in which Woodland Crayfish and Big Creek Crayfish male juveniles were contained together in enclosures. Furthermore, Westhoff and Rabeni (2013, pp. 1389-1392) found no significant shifts in habitat use by the St. Francis River Crayfish when paired with the Woodland Crayfish, providing additional evidence that interspecific competition may not be the mechanism responsible for the displacement. An examination of the influence of abiotic (anthropogenic and natural) factors on the distributions of Woodland Crayfish and Big Creek Crayfish suggests that anthropogenic factors also are not causing the displacement of at least the Big Creek Crayfish species (Westhoff et al. 2011, pp. 2425-2426).

The leading hypothesis is that the mechanism causing the displacement is reproductive interference in the form of hybridization. Fetzner and DiStefano first hypothesized that this may be the cause of the displacement (Fetzner and DiStefano 2008, p. 1), and in 2009 Westhoff (2011, p. 117) observed a Woodland Crayfish male engaging in mating behavior with a St. Francis River Crayfish female. Additional work by Fetzner et al. (2016, pp. 19-26) provides genetic evidence of hybridization between the Woodland Crayfish and the Big Creek Crayfish, as well as between the Woodland Crayfish and the St. Francis River Crayfish. Alleles[6] from both parental species detected in individuals in areas invaded by the Woodland Crayfish, suggests that both native species readily hybridize with the Woodland Crayfish (Fetzner et al. 2016, p. 28).

Invasion by the Belted Crayfish
It should also be noted that the Belted Crayfish (*Faxonius harrisoni*) was discovered in 1987 in the St. Francis River and has since been documented at multiple other locations in the Upper St. Francis River watershed (Fig. 3-3)(MDC 2018b, unpublished data). The native range of this species is the Big River and Meramec River watersheds, which are located north and west of the Upper St. Francis River watershed. Impacts to the Big Creek Crayfish and St. Francis River Crayfish from the Belted Crayfish are currently unknown (DiStefano 2017 pers. comm.).

[6] One of two or more alternative forms of a gene that arise by mutation and are found at the same place on a chromosome.

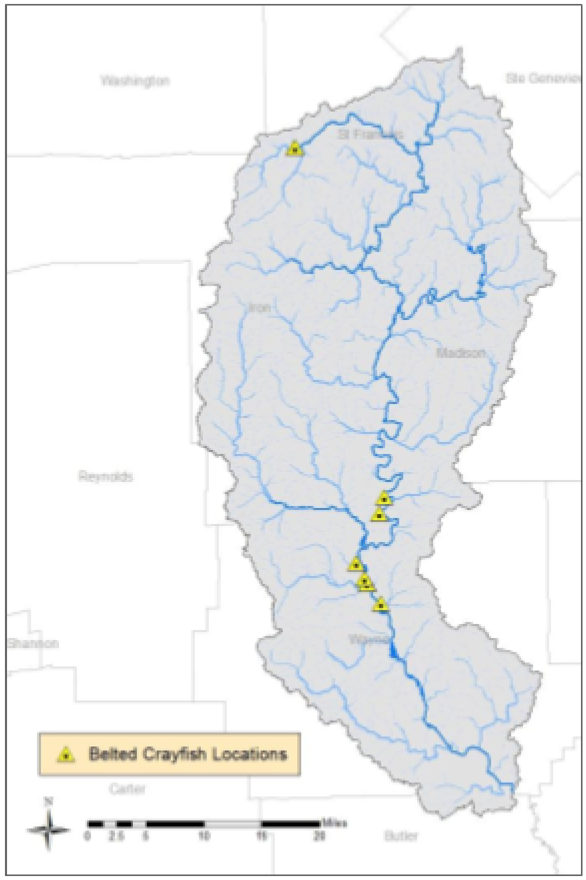

Figure 3-3. Known locations of the Belted Crayfish (*Faxonius harrisoni*).

3.2 Lead Mining Contamination

Southeastern Missouri has been a primary producer of lead since the early 1700s in an area referred to as the Old Lead Mining Belt (Fig. 3-4). Though mining ceased in the 1970s, waste from mining operations is still present in the landscape (Missouri Natural Resource Trustee Council, p. 14), resulting in contamination of fish and other aquatic biota, alteration of fish and invertebrate communities, and public health advisories against human consumption of lead-contaminated fish (Czarneski 1985; pp. 17-23; Schmitt et al. 1993, pp. 468-471). The relocation of mine waste (chat) throughout the area as topsoil, fill material, and aggregate for roads, railroads, concrete, and asphalt has further expanded the area of contamination, as has the use of lead mining tailings[7] for agricultural purposes due to its lime content. All of these uses have contributed to contamination of streams in portions of the St. Francis River watershed (Fig. 3-4). As a result, 32.4 miles of Little St. Francis River have been added to the Environmental Protection Agency's (EPA) 303(d) list of impaired waters for not meeting water quality standards for lead; while 34.1 miles of Big Creek have been added for not meeting water quality standards for lead and cadmium (EPA 2016, pp. 1,5 of attachment 2).

[7] A type of mining waste made of sand and fine gravel-sized particles of crushed rock and ore that contain high concentrations of residual metals (Voss 2017, p. 20).

Several studies investigating effects from heavy metal contamination in Southeastern Missouri and the Tri-State Mining District[8] indicate that heavy metals and mining-related tailings adversely affect riffle-dwelling crayfish. Metal concentrations in crayfish at sites downstream of mining activities were significantly higher than those at reference sites (Allert et al. 2008, pp. 100-101). Allert et al. (2008, p. 100) also found significantly lower crayfish densities at sites downstream of mining activities than those at reference sites, indicating that metals associated with mining activities have negative impacts on crayfish populations in Ozark streams. Similar results were observed in another area impacted by mining wastes (including sites in the Upper St. Francis River watershed), with sites downstream of mining activities having reduced densities of crayfish (from 80 to 100%) and significantly higher metal concentrations in crayfish (Allert et al. 2013, p. 512; Allert et al. 2016, unpublished data). Allert et al. (2013, p, 512) also found significantly lower survival rates of crayfish caged at the downstream sites. These results support those of laboratory and in situ toxicity tests documenting the sensitivity of crayfish to mining-related metals (Allert 2013, p. 518).

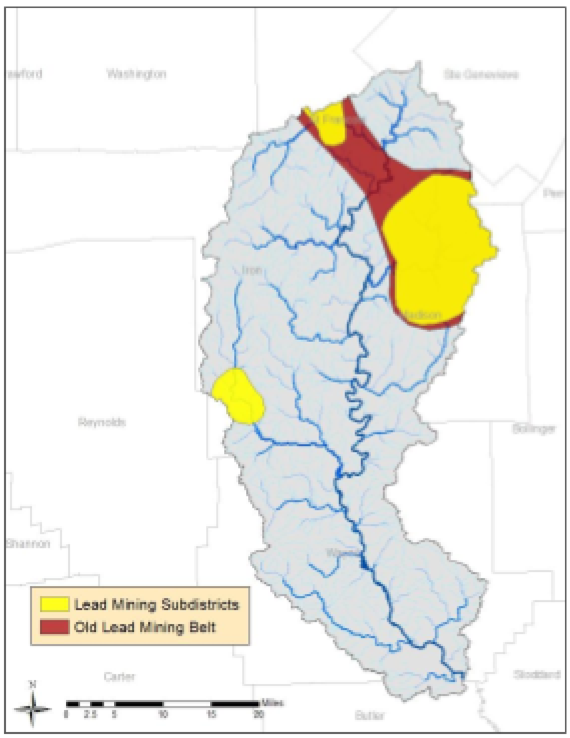

Figure 3-4. Portions of the Old Lead Mining Belt and lead mining sub-districts located in the Upper St. Francis River watershed. Sub-districts represent areas where significant historical mining activities occurred and heavy metal contamination is likely.

3.3 Degraded Water Quality from Other Sources

Streams in the Upper St. Francis River watershed generally exhibit good water quality and most streams are classified as full use attainment, meaning that they can be used for fishing, swimming, public water supply, and agriculture, among other uses (Boone 2001, p. WQ1) . The basin also

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[8] The Tri-State Mining District is located in southwest Missouri, northeast Oklahoma, and southeast Kansas

has good aquatic biodiversity,and most streams support a diverse benthic invertebrate fauna (Boone 2001, p. CO2). However, as noted in section 3.2, there have been some problems with lead contamination due to mining and smelting activities. There have also been impacts to water quality from inadequate wastewater treatment facilities in the watershed (Boone 2001, p. WQ3). These impacts have resulted in the addition of 93.1 miles of the St. Francis River to the EPA's 303(d) list of impaired waters for not meeting water quality standards for temperature and 1.5 miles of a tributary to Wolf Creek for not meeting water quality standards for dissolved oxygen (EPA 2016, pp. 8-9 of attachment 2).

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.

3.4 Sedimentation

Many Ozark streams have been disturbed from their natural condition and have accelerated erosion and gravel accumulation (Jacobson and Primm 1994, pp. 80-81). However, in the Upper St. Francis River basin, the absence of a deep cherty (a hard, dark, opaque rock composed of silica) residuum in the igneous Ozark uplift, combined with the formation of erosion-resistant upland soils, results in little gravel accumulation in alluvial floodplain soils (Boone 2001, p. LO3). Streambank soils also are more cohesive than in most Ozark streams because of lower densities of gravel, with channel substrates containing a significant proportion of stable cobble, stone, and boulders (Boone 2001, p. LO3). There are some localized areas within the watershed, however, that do have excessive sedimentation due to eroding or breached mine tailings (Boone 2001, p. WQ4, DiStefano 2008a, p. 191). For example, in 1992 a breached tailings barrier spilled 1,150 cubic meters (1,500 yd) of non-toxic powdered rhyolite rock into Big Creek near Annapolis, Missouri (Boone 2001, p. WQ4). The breach resulted in deposition of fine sediments, two feet deep, for a distance of one mile and temporarily caused extreme turbidity for 24 (km)(15 mi)(Boone 2001, p. WQ4). According to Boone (2001, p. WQ4), macroinvertebrate communities did not fully recover until most of the sediment had been flushed out of the system (over 1.5 yrs later).

Excessive deposition of fine sediment can cover rocks and cavities used by the Big Creek Crayfish and St. Francis River Crayfish as refugia. We presume that the loss of refugia results in reduced foraging habitat, thereby reducing carrying capacity and the density of subpopulations. The loss of refugia may also increase competition with the Woodland Crayfish and potentially facilitate displacement of the Big Creek Crayfish and St. Francis 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 et al. 2017, p. 5).

Furthermore, excessive sediment deposition negatively impacts macroinvertebrates (Jones et al. 2011, pp. 1056-1062), a primary food source of many stream-dwelling crayfishes.

3.5 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 Big Creek Crayfish and St. Francis 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 Big Creek Crayfish and St. Francis 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 Missouri, and the nearest shrimp farm is located approximately 160 km (100 mi) from the Upper St. Francis River watershed. If introduced into the Upper St. Francis, however, the WSSV has the potential to impact Big Creek Crayfish and St. Francis River Crayfish 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.

3.6 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 Big Creek Crayfish and St. Francis River Crayfish ranges in evaluating the 3Rs, rather than discussing it further in this chapter.

3.7 Climate Change

We are unaware of data on the thermal preferences and tolerances of the Big Creek Crayfish, St. Francis River Crayfish, and Woodland Crayfish. Therefore, we cannot predict with certainty how the species will respond if stream temperatures increase. However, climate change could facilitate displacement of the native crayfishes by the Woodland Crayfish if the latter species has a higher tolerance to stream drying. Lower water levels could also reduce the amount of available habitat (e.g., stream edges and areas around gravel bars), thereby reducing abundance in areas occupied by the Big Creek Crayfish or St. Francis River Crayfish.

3.8 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 Big Creek Crayfish and St. Francis River Crayfish at the population level (i.e., the entire species becomes irreversibly headed towards extinction). However, both events would act as extreme stressors to one or more subpopulations of each species. 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 Big Creek Crayfish and St. Francis 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 Woodland Crayfish invasion if the native species are less tolerant of drying conditions than the Woodland Crayfish.

Extreme flood events may also affect Big Creek Crayfish and St. Francis 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 Big Creek Crayfish and St. Francis River Crayfish by the Woodland Crayfish.

A toxic chemical spill could also impact Big Creek Crayfish and St. Francis 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[9] 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 Big Creek Crayfish and St. Francis River Crayfish remains unclear, we expect that some subpopulations could be extirpated or severely impacted in the instance of a major spill.

3.9 Conservation Actions

<u>Research and Monitoring</u>

Monitoring and research on the Big Creek Crayfish and St. Francis River Crayfish has been conducted by the Missouri Department of Conservation and various other organizations. Multiple evaluations of effects from lead mining contamination on crayfish, including the St. Francis River Crayfish, have been conducted by the U.S. Geological Survey. Monitoring efforts benefit conservation of the Big Creek Crayfish and St. Francis River Crayfish by providing information on population health and trends and the magnitude and extent of threats; while research efforts

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

provide information on mechanisms by which threats may impact the native crayfishes.

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 addition, it is unlawful to import, transport, or possess the Rusty Crayfish (*Faxonius rusticus*)(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).

These policies may help reduce the likelihood of future invasions of non-native crayfishes within the Upper St. Francis River watershed. However, as the Woodland Crayfish has already been introduced at several locations in the watershed, the policies will not affect the inevitable spread of that species within the Upper St. Francis River watershed (and thus the ranges of the Big Creek Crayfish and St. Francis River Crayfish).

Public Land and Other Protective Designations

Approximately 41% of the Upper St. Francis River watershed is in public ownership, with the majority of land managed as part of the Mark Twain National Forest (Fig. 3-5). In addition to maintaining over 1376 km^2 (340,000 acres) of forested habitat within the watershed, Forest Service management efforts benefit stream health by focusing on riparian protection and control and reduction of sediment entering streams. Other major public landowners in the watershed include the MDC, the U.S. Army Corps of Engineers, and the Missouri Department of Natural Resources. In addition, 8.5 km (5.3 mi) of Big Creek, a tributary to the St. Francis River, is designated an “Outstanding State Resource Waters” (Missouri Code of State Regulations 2018c, p. 35). Missouri Outstanding State Resource Waters are high quality waters with significant aesthetic, recreational, or scientific value and receive special protection against degradation in quality (Missouri Code of State Regulations 2018c, pp. 14, 16). These protections help maintain water quality and minimize additional sedimentation, which reduce the quantity and quality of habitat of the Big Creek Crayfish and St. Francis River Crayfish.

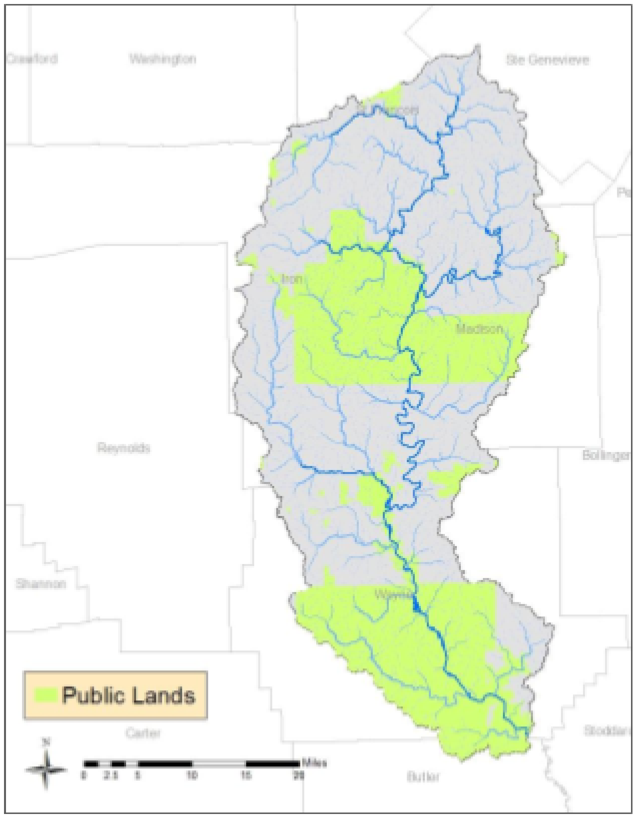

Figure 3-5. Public lands in the Upper St. Francis River watershed.

<u>Restoration Efforts</u>
The EPA has conducted and is currently conducting extensive remediation efforts in areas of Southeast Missouri impacted by lead mining, including the Upper St. Francis River watershed. These efforts include sediment, soil, and mine waste removal. The EPA also has funded the development of a watershed master plan for the Little St. Francis River, located in the upper end of the watershed. This plan will identify sources of pollution (related to lead mining) and measures to reduce the pollution.

The Upper St. Francis River watershed is also part of the Southeast Missouri Ozarks Regional Restoration Plan developed by the Missouri Natural Resource Trustee Council (2014, entire). The plan identifies the types and scope of restoration projects which may use settlement funds to help return natural resources and the services they provide to their baseline condition (i.e., the level of services that would have existed but for the release). Potential projects may also include compensation for impacts to fish and wildlife resource injuries that may have occurred during the response process and may persist into the future. Restoration projects have not yet been completed in the watershed, but will be initiated once EPA remediation efforts are completed.

Chapter 4. Species Current Conditions

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

4.1 Historical Distribution and Abundance

Known historical and current locations of the Big Creek Crayfish and St. Francis River Crayfish are depicted in Figure 4-1. However, given that both species are habitat generalists (Westhoff 2017 pers. comm.) and not all reaches of streams within the watershed have been sampled, it is likely that the species occur at more locations in the watershed. Therefore, we have depicted the species' ranges as the streams within subwatersheds (12-digit hydrologic units[10]) known to be occupied by each species (Fig. 4-1). Within these subwatersheds, we excluded the mainstem of the St. Francis River where it is a 5th order[11] stream given that few individuals of any crayfish species have been collected in these reaches (Westhoff 2018 pers. comm.). We consider these presumed ranges to be a more accurate depiction of the actual ranges of the Big Creek Crayfish and St. Francis River Crayfish than using only known locations. Based on this method and for the purposes of this SSA, we assume that the Big Creek Crayfish has the potential to occupy 1,596 stream km (992 mi) in the Upper St. Francis watershed, with 81.3 km (50.5 mi) in the Twelvemile Creek population and 1514 km (941 mi) in the Main population. The St. Francis River Crayfish has the potential to occupy 1,653 km (1,027 mi). It should be noted, however, that these ranges likely over represent the actual ranges given the two species are rarely sympatric (existing in the same geographic area). Because these ranges do not consider impacts from the Woodland Crayfish invasion, we consider these stream reaches to represent the species' historical distributions.

[10] Hydrologic units represent watershed boundaries. The number of digits in the hydrologic code represents the size of the geographic area represented by the watershed (smaller numbers represent larger watershed regions; while larger numbers represent smaller watersheds.

[11] Stream order is a measure of the relative size of streams. Headwater streams are represented by stream orders 0-3, medium streams are represented by stream orders 4-6, and large rivers are represented by stream orders 7 and greater (Strahler 1952, entire).

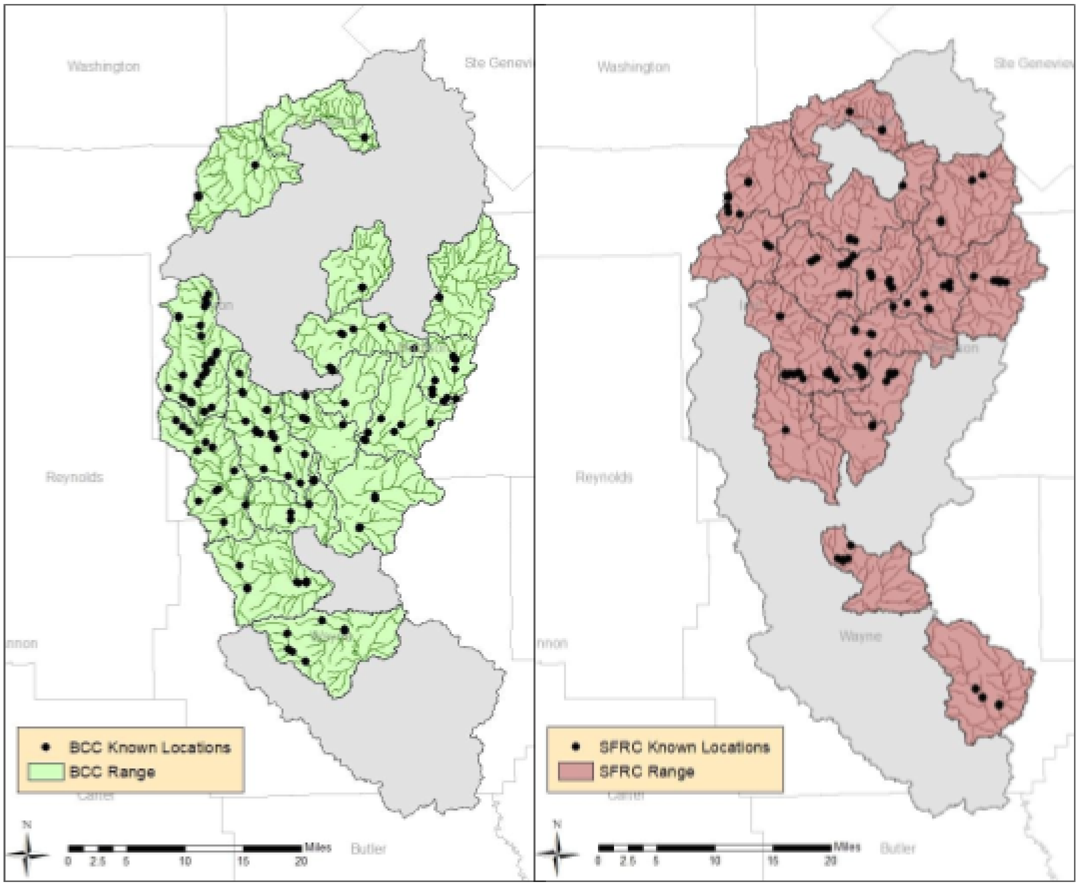

Figure 4-1. Presumed historical distribution of the Big Creek Crayfish (left) and St. Francis River Crayfish (right).

Historically, the Big Creek Crayfish was common in streams in which it occurred (DiStefano 2008a, p. 189), with reported relative densities of 0.9-7.0 individuals per m^2 (Riggert et al. 1999, p. 358). At some sites considered "high density", abundance was reported as high as 21 individuals per m^2 (DiStefano et al. 2002, p. 452). High densities have also been reported for the St. Francis River Crayfish, ranging from 0.9-4 individuals per m^2 (Riggert et al. 1999, p. 358; DiStefano et al. 2002, p. 452). Historical densities of the St. Francis River Crayfish were such that they were described as "almost unbelievable" by Creaser (1933, p. 12). Creaser (1933, p. 12) also relayed that 300 crayfish were obtained in only a few seine hauls in Stout's Creek and that almost all of them were St. Francis River Crayfish.

4.2 Current Distribution, Abundance, and Habitat Conditions

As described in Chapter 3, the Woodland Crayfish has invaded the Upper St. Francis River watershed and as of 2008, was estimated to occupy 166 to 649 stream kilometers (km)(103 to 403 miles)(mi) in the watershed (DiStefano and Westhoff 2011, p. 40). At a minimum, the invasion has resulted in extirpation of the Big Creek Crayfish in 14.7 stream km (9.1 mi) and of the St. Francis River Crayfish in 13.7 stream km (8.5 mi)(Fig. 4-2)(Table 4-1). We presume that this is an extreme underestimate of the actual extent of both range contractions given that this represents conditions in only 2 of the 11 streams known to be invaded by the Woodland Crayfish (DiStefano and Westhoff 2011, p. 42).

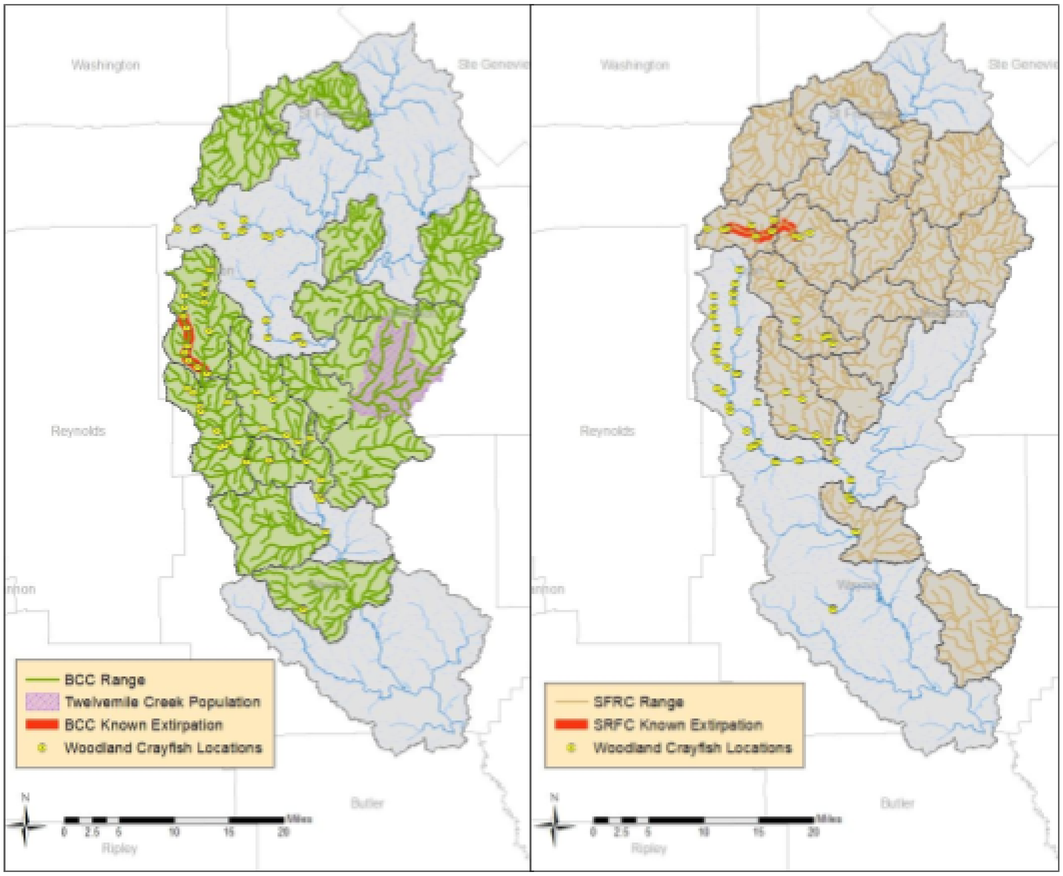

Figure 4-2. Presumed current distribution of the Big Creek Crayfish (left) and St. Francis River Crayfish (right). Red areas represent a portion of the known extirpated stream reaches.

Although the Big Creek Crayfish and St. Francis River Crayfish have not been completely displaced in all stream reaches where the Woodland Crayfish has invaded, abundance appears to be substantially impacted. In Orr Hollow Creek, the St. Francis River Crayfish constituted approximately 50% of the crayfish community in uninvaded areas, while constituting only 13% of the community in invaded areas (DiStefano and Westhoff 2011, p. 40). In Marble Creek the St. Francis River Crayfish appears to have co-occurred with the Woodland Crayfish for over 10 years without being completely displaced, though the Woodland Crayfish appears to now be the dominant species in the crayfish community (Westhoff 2017, unpublished data). Similarly, the Big Creek Crayfish constituted 87% of the crayfish community in areas not invaded by the Woodland Crayfish in Carver Creek, but only 27% of the community in invaded areas (DiStefano and Westhoff 2011, p. 40). However, the reduction of Big Creek Crayfish relative abundance in Carver Creek appeared to be followed by complete displacement (DiStefano and Westhoff 2011, pp. 40-41). Although impacts are likely to vary among streams, these results suggest that the Woodland Crayfish has the potential to completely displace the Big Creek Crayfish in invaded areas and substantially reduce abundance of the St. Francis River Crayfish.

Water quality is generally good within the St. Francis River watershed, except for in areas impacted by lead mining (see section 3.2). Based on impacts to crayfish in other affected watersheds, we expect that Big Creek Crayfish and St. Francis River Crayfish abundance has been reduced in areas downstream of mining activities.

4.3 Resiliency, Representation, and Redundancy

To evaluate the current condition of the Big Creek Crayfish and St. Francis River Crayfish in terms of the 3Rs, we reviewed available information on health of the subpopulations and queried species experts on the species' representation and redundancy. Results are described below and summarized in Tables 4-1 and 4-2.

Resiliency

Though the Twelvemile Creek population of the Big Creek Crayfish has not been invaded by the Woodland Crayfish, the Main population has been reduced by a minimum of 14.7 stream km (9.1 mi) in Carver Creek due to the invasion. We also presume that portions of the Main population have been impacted by lead mining contamination. Given these impacts to the Main population, resiliency of the Big Creek Crayfish has been reduced. Resiliency of the St. Francis River Crayfish has also been reduced due the extirpation of individuals in 13.7 stream km (8.5 mi) in Orr Hollow Creek and presumed impacts in areas impacted by lead mining contamination. As noted above, we consider the amount of the range reduction for both species to be an extreme underestimate of the amount of the range actually impacted given that it represents impacts in only 1 of the 11 streams which the Woodland Crayfish has invaded. Thus, the actual reduction in resiliency of both species is likely higher than what we have described. In addition, the narrow range of the Big Creek Crayfish and St. Francis River Crayfish make them inherently vulnerable to environmental variation and stochastic events that could impact their entire range (e.g., extreme drought or flooding).

Representation

We consider Big Creek Crayfish representation (section 2.5) as having healthy subpopulations throughout the Twelvemile Creek subwatershed as well as the rest of the range (the Main population) to maintain the full breadth of adaptive diversity (and thus, adaptive capacity). Though the Twelvemile Creek population is currently not impacted by the Woodland Crayfish, the range of the Main population has been reduced due to the Woodland Crayfish invasion. Therefore, the species has lost some level of representation. For the St. Francis River Crayfish, we consider representation as having multiple, healthy subpopulations distributed across the breadth of adaptive diversity relative (i.e., throughout its range in the Upper St. Francis River watershed). Similar to the Big Creek Crayfish, some level of representation has been lost due to the extirpation of individuals in Orr Hollow Creek.

To maintain adaptive capacity, the species also requires the processes that drive evolution (gene flow, natural selection, mutations, and genetic drift)(Crandall 2000, p. 291). To our knowledge, none of these evolutionary drivers are currently impacted.

Redundancy

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.

Species experts did not believe an extreme drought, that occurred in 2012[12], resulted in catastrophic effects to the Big Creek Crayfish or St. Francis River Crayfish. While another drought of similar intensity and magnitude may not cause catastrophic impacts to either species, it could reduce the overall viability by extirpating or compromising subpopulations in the impacted area.

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[12] In 2012, all of the Upper St. Francis River watershed was affected by a D3-D4 drought, and 13% of the watershed was affected by a D4 drought. 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; whereas 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 (U.S. Drought Monitor 2018).

Another extreme drought could also increase susceptibility of each species to other stressors (see Chapter 3), and repeated or prolonged droughts could ultimately result in the loss of subpopulations. Thus, whereas an extreme drought may not be a catastrophic event for the entire species, it could function as a catastrophic event at the subpopulation level.

It is also unlikely that a single toxic chemical spill will impact the entire range of either the Big Creek Crayfish or the St. Francis River Crayfish. There are no hazardous routes or railways carrying crude oil that currently cross the Upper St. Francis River watershed (Appendix A). However, there are four major pipelines which cross the watershed (Appendix A). One pipeline carries crude oil and crosses the lower end of the watershed. Though a spill or release would impact downstream subpopulations, it would not result in a catastrophic loss to either of the two Big Creek Crayfish populations or the St. Francis River Crayfish population given that the line crosses the lower portion of the watershed and upstream sites would not be impacted. The remaining pipelines crossing the watershed are natural gas lines. We do not consider natural gas lines as posing a severe threat because the gas is vaporized and thus, would not be transported downstream. In addition, we consider both the Big Creek Crayfish and St. Francis River Crayfish as having high redundancy pertaining to catastrophic events impacting downstream reaches of the impact source, such as chemical spills, due to the numerous tributaries that each species occupies.

Based on the considerations outlined above, we do not consider extreme drought or chemical spills as likely catastrophic events to the Big Creek Crayfish and St. Francis River Crayfish. While these events may not cause a devastating impact to the entire Big Creek Crayfish and St. Francis River Crayfish populations, their occurrence would reduce resiliency of the species by potentially extirpating or compromising subpopulations throughout the impacted area (see Extreme Events in Chapter 3). However, both species are inherently vulnerable to catastrophic events given their small range, and there has been some reduction in redundancy due to the extirpation of individuals in some areas because of the Woodland Crayfish invasion.

Table 4-1. Summary of Big Creek Crayfish current conditions.

	Assessment of Current Condition
Historically Occupied Stream Distance	Presumed to be approximately 1,596 stream km (992 mi).
Currently Occupied Stream Distance	Presumed to be approximately 1,581 stream km (983 mi)(likely an overestimate given the reported range reduction of 14.7 km (9.1 mi) represents impacts in only 2 of the 11 invaded streams).
Health of Subpopulations	In areas invaded by the Woodland Crayfish, relative abundance appears to be been substantially reduced, with the species completely extirpated in some invaded areas. In areas impacted by lead mining contamination, we presume abundance is also reduced. In areas not invaded by the Woodland Crayfish or impacted by lead mining contamination, we presume subpopulations are healthy.
Health of Populations	We presume the Twelvemile Creek population is currently healthy because it does not appear that the Woodland Crayfish has invaded the population and the population is outside of the area of lead mining contamination. However, a minimum of 14.7 stream km (9.1 mi) of the Main population has been extirpated due to the Woodland Crayfish invasion.
Resiliency	Reduced due to extirpation of the species in at least 14.7 stream km (9.1 mi) of the Main population.
Representation	Reduced due to extirpation of the species in at least 14.7 stream km (9.1 mi) of the Main population.
Redundancy	Inherently vulnerable to some catastrophic events given the species' small range, and there has been some reduction in redundancy due to reduction of the Main population. However, both populations of the species have a high level of redundancy pertaining to catastrophic events that impact areas downstream of the source of event (e.g., chemical spills) because of the number of tributaries they occupy.

Table 4-2. Summary of St. Francis River Crayfish current conditions.

	Assessment of Current Condition
Historically Occupied Stream Distance	Presumed to be approximately 1,653 stream km (1,027 mi) based on probability of presence models.
Currently Occupied Stream Distance	Presumed to be approximately 1,639 stream km (1,018 mi)(likely an overestimate given the reported range reduction of 13.7 km (8.5 mi) represents impacts in only 2 of the 11 invaded streams).
Health of Subpopulations	In areas invaded by the Woodland Crayfish, relative abundance appears to be been substantially reduced, with the species completely extirpated in some invaded areas. In areas impacted by lead mining contamination, we presume abundance is also reduced. In areas not invaded by the Woodland Crayfish or impacted by lead mining contamination, we presume subpopulations are healthy.
Resiliency	Reduced due to extirpation of the species in at least 13.7 stream km (8.5 mi).
Representation	Reduced due to extirpation of the species in at least 13.7 stream km (8.5 mi).
Redundancy	Inherently vulnerable to some catastrophic events given the species' small range, and there has been some reduction in redundancy due to reduction of the range. However, the species has a high level of redundancy pertaining to catastrophic events that impact areas downstream of the source of event (e.g., chemical spills) because of the number of tributaries it occupies.

Chapter 5. Species Future Conditions

5.1 Methods for Evaluating Future Conditions

To evaluate future conditions of the Big Creek Crayfish and St. Francis River Crayfish, we predicted the expansion of the non-native, invasive Woodland Crayfish within the range of the native crayfishes. We asked biologists with expertise on crayfishes to estimate the future expansion rate in the Upper St. Francis River watershed, the impact on Big Creek Crayfish and St. Francis River Crayfish abundance, and the length of time for those impacts to be fully realized. Additional details on the expert elicitation and a summary of results can be found in Appendix B.

In estimating the rate of expansion of the Woodland Crayfish, experts provided different estimated rates for upstream and downstream movement because streamflow facilitates downstream expansion. Experts also provided different estimated expansion rates for movement in intermittent streams, as opposed to perennial streams. 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. In addition, experts provided different estimated rates for Woodland Crayfish in the St. Francis River mainstem (both upstream and downstream movement), based on data collected in 2017 (Westhoff 2017, unpublished data).

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

Table 5-1. Scenarios representing the plausible range of future conditions for the Big Creek Crayfish and St. Francis River Crayfish due to the Woodland Crayfish invasion.

Scenario	Estimates Used
Reasonable Best	Lowest plausible expansion rate of the Woodland Crayfish Lowest level of predicted impact on Big Creek Crayfish and St. Francis River Crayfish abundance Highest number of years for impacts to be fully realized
Reasonable Worst	Highest plausible expansion rate of the Woodland Crayfish Highest level of predicted impact on Big Creek Crayfish and St. Francis River Crayfish abundance Lowest number of years for impacts to be fully realized
Most Likely	Most likely expansion rate of the Woodland Crayfish Most likely level of predicted impact on Big Creek Crayfish and St. Francis River Crayfish abundance Most likely number of years for impacts to be fully realized

For each of the scenarios, we predicted the extent of future expansion of the Woodland Crayfish at 10, 25, and 50 years into the future. We then calculated how much of the Big Creek Crayfish and St. Francis River Crayfish ranges would be impacted and described effects to abundance based on the experts' projections.

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

5.2 Big Creek Crayfish Future Conditions

Reasonable Best Scenario

Under the Reasonable Best Scenario, the Woodland Crayfish invasion will expand at a rate of 150 m (164 yd) per year in intermittent streams in both the upstream and downstream direction, 50 m (55 yd) per year when moving upstream in perennial streams, and 200 m (219 yd) per year when moving downstream in perennial streams. In the St. Francis River mainstem, the invasion is estimated to expand upstream at a rate of 25 m (27 yd) per year and downstream at a rate of 100 m (110 yd) per year. Based on this expansion rate, 25.4% of the Big Creek Crayfish Main population will be invaded by the Woodland Crayfish in 10 years, constituting 24.0% of the species' range (Fig. 5-1, Table 5-2). Abundance will be reduced in invaded areas by over 50% in 10-20 years. The Twelvemile Creek population is not predicted to be invaded in 10 years under this scenario.

In 25 years, 34.7% of the Big Creek Crayfish Main population will have been invaded, constituting 32.9% of the species' range (Fig. 5-1, Table 5-3). In 50 years, 48.7% of the Main population will be invaded, constituting 46.2% of the species' range (Fig. 5-1, Table 5-4). Abundance will be reduced in invaded areas by over 50% in 10-20 years. The Twelvemile Creek population is not predicted to be invaded in 25 or 50 years under this scenario.

The length of time for the entire Twelvemile Creek population to be invaded under this scenario is beyond reliable prediction (>100 years), as is the entire Big Creek Crayfish range (>250 years)(Table 5-5).

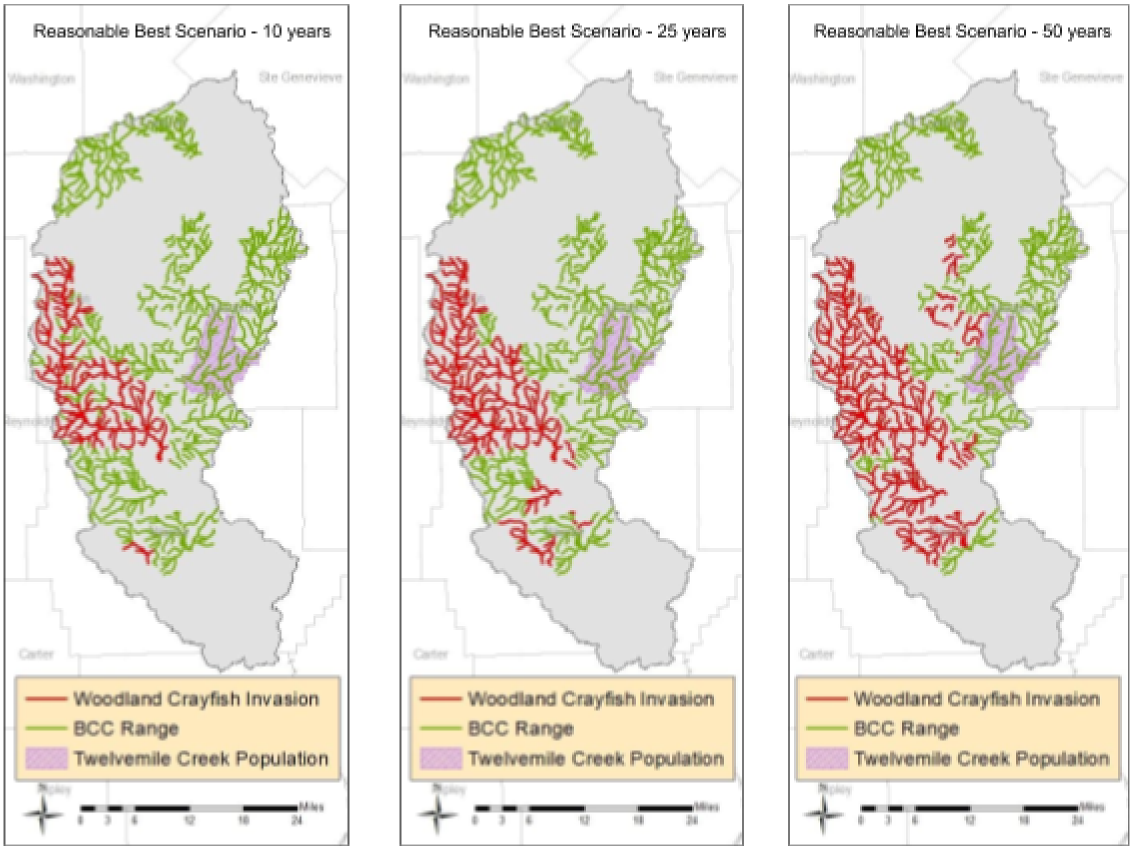

Fig. 5-1. Predicted expansion of the Woodland Crayfish within the Big Creek Crayfish range at 10, 25, and 50 years under the Reasonable Best Scenario[13].

<u>Reasonable Worst Scenario</u>
Under the Reasonable Worst Scenario, the Woodland Crayfish invasion will expand at a rate of 350 m (383 yd) per year in intermittent streams in both the upstream and downstream direction, 1,000 m (1,094 yd) per year when moving upstream in perennial streams, and 3,000 m (3,281 yd) per year when moving downstream in perennial streams. In the St. Francis River mainstem, the invasion is also estimated to expand upstream at a rate of 1,000 m (1,094 yd) per year and downstream at a rate of 3,000 m (3,281 yd) per year. Based on this expansion rate, 44.1% of the Main population and 0.2% of the Twelvemile Creek population will be invaded by the Woodland Crayfish in 10 years, constituting 41.9% of the Big Creek Crayfish's total range (Fig. 5-2, Table 5-2). Abundance will be reduced in invaded areas by approximately 100% (i.e., virtual displacement) in less than 10 years.

In 25 years, 69.9% of the Main population and 80.7% of the Twelvemile Creek population will be invaded by the Woodland Crayfish, constituting 70.4% of the Big Creek Crayfish's total range (Fig. 5-2, Table 5-3). In 50 years, 90.4% of the Main population and 100% of the Twelvemile Creek population will be invaded, constituting 90.9% of the species' range (Fig. 5-2, Table 5-4). Abundance will be reduced in invaded areas by approximately 100% (i.e., virtual displacement) in less than 10 years.

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[13] The entire network of streams within the Upper St. Francis River watershed was used to map the predicted expansion. However, invaded streams outside of the Big Creek Crayfish range are not included in the maps to more clearly depict the predicted portion of the species' range invaded by the Woodland Crayfish.

The length of time for the entire Twelvemile Creek population to be invaded under this scenario is 34 years, and time for the entire Big Creek Crayfish range to be invaded is 70 years (Table 5-5).

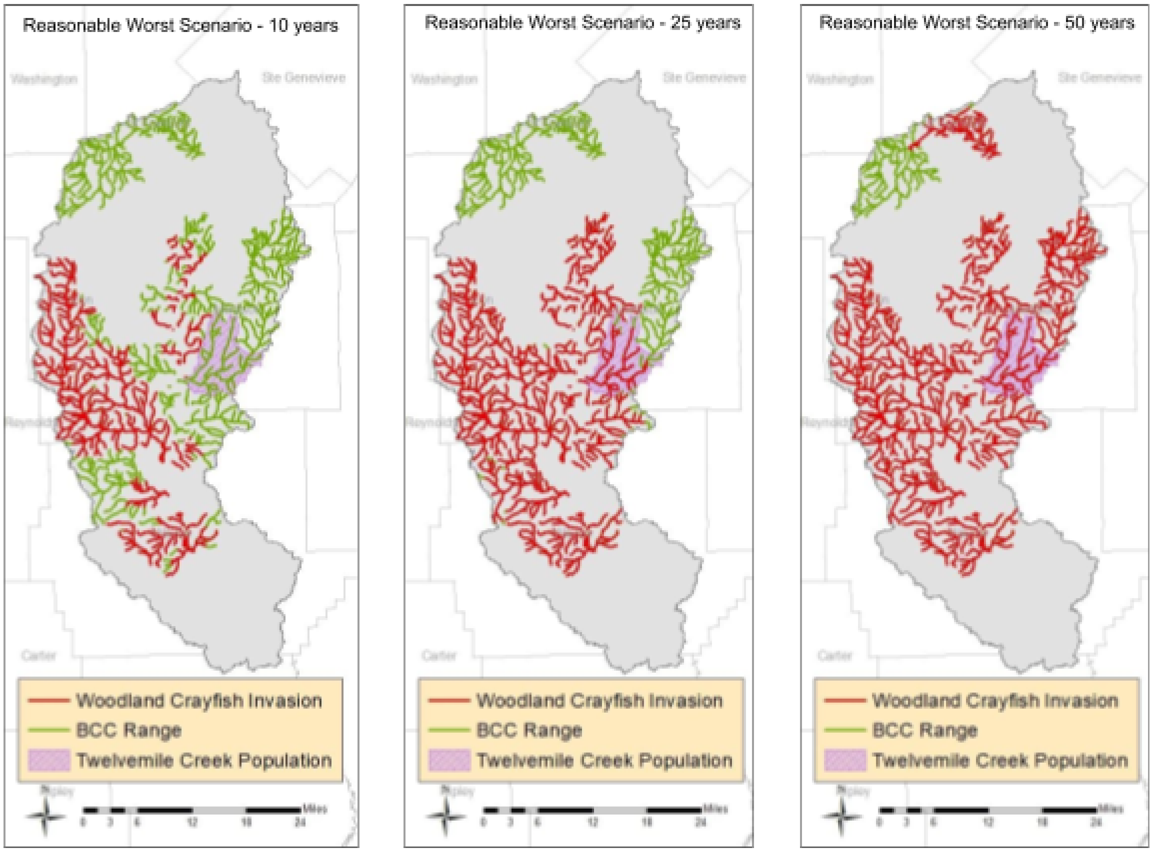

Fig. 5-2. Predicted expansion of the Woodland Crayfish within the Big Creek Crayfish range at 10, 25, and 50 years under the Reasonable Worst Scenario[14].

<u>Most Likely Scenario</u>

Under the Most Likely Scenario, the Woodland Crayfish invasion will expand at a rate of 150 m (164 yd) per year in intermittent streams in both the upstream and downstream direction, 300 m (328 yd) per year when moving upstream in perennial streams, and 1,000 m (1,094 yd) per year when moving downstream in perennial streams. In the St. Francis River mainstem, the invasion is estimated to expand upstream at a rate of 200 m (219 yd) per year and downstream at a rate of 900 m (984 yd) per year. Based on this expansion rate, 27.9% of the Big Creek Crayfish Main population will be invaded by the Woodland Crayfish in 10 years, constituting 26.5% of the species' range (Fig. 5-3, Table 5-2). Abundance will be reduced in invaded areas by approximately 100% (i.e., virtual displacement) in less than 10 years. The Twelvemile Creek population is not predicted to be invaded in 10 years under this scenario.

In 25 years, 43.9% of the Main population and 6.2% of the Twelvemile Creek population will be invaded by the Woodland Crayfish in 10 years, constituting 42.0% of the Big Creek Crayfish's total range (Fig. 5-3, Table 5-3). In 50 years, 64.1% of the Main population and 55.6% of the Twelvemile Creek population will be invaded, constituting 63.7% of the species' range (Fig. 5-3, Table 5-4).

[14] The entire network of streams within the Upper St. Francis River watershed was used to map the predicted expansion. However, invaded streams outside of the Big Creek Crayfish range are not included in the maps to more clearly depict the predicted portion of the species' range invaded by the Woodland Crayfish.

Abundance will be reduced in invaded areas by approximately 100% (i.e., virtual displacement) in less than 10 years.

The length of time for the entire Twelvemile Creek population to be invaded under this scenario is 67 years, and time for the entire Big Creek Crayfish range to be invaded is beyond reliable prediction (>200 years)(Table 5-5).

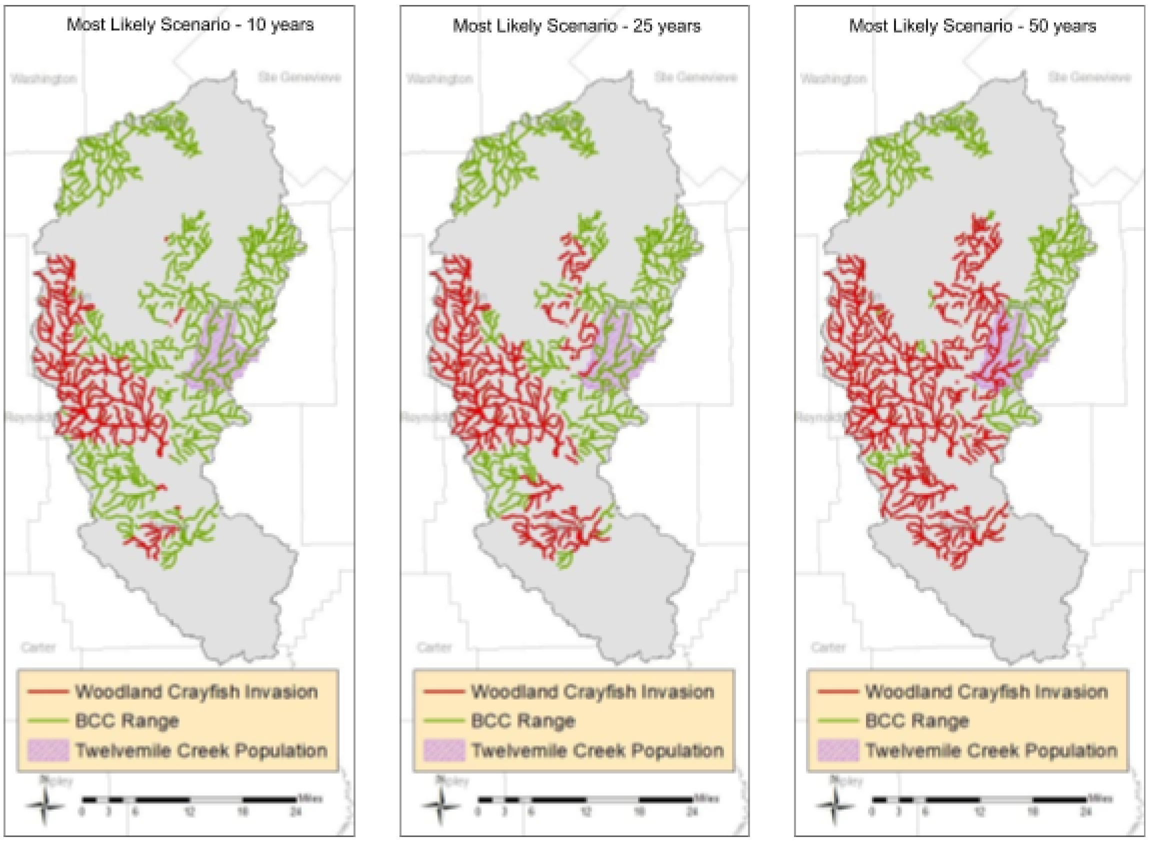

Fig. 5-3. Predicted expansion of the Woodland Crayfish within the Big Creek Crayfish range at 10, 25, and 50 years under the Most Likely Scenario[15].

[15] The entire network of streams within the Upper St. Francis River watershed was used to map the predicted expansion. However, invaded streams outside of the Big Creek Crayfish range are not included in the maps to more clearly depict the predicted portion of the species' range invaded by the Woodland Crayfish.

Table 5-2. Predicted impacts to the Big Creek Crayfish from the Woodland Crayfish invasion at 10 years for each future scenario.

10 Years			
	Reasonable Best	Most Likely	Reasonable Worst
% of Twelvemile Creek population invaded	0%	0%	0.2%
% of Main population invaded	25.4%	27.9%	44.1%
% of total range invaded	24.0%	26.5%	41.9%
% Reduction in abundance in invaded areas	>50%	~100%	~100%
Time for impacts to be fully realized	10-20 yrs	<10 years	<10 years

Table 5-3. Predicted impacts to the Big Creek Crayfish from the Woodland Crayfish invasion at 25 years for each future scenario.

25 Years			
	Reasonable Best	Most Likely	Reasonable Worst
% of Twelvemile Creek population invaded	0%	6.2%	80.7%
% of Main population invaded	34.7%	43.9%	69.9%
% of total range invaded	32.9%	42.0%	70.4%
% Reduction in abundance in invaded areas	>50%	~100%	~100%
Time for impacts to be fully realized	10-20 yrs	<10 years	<10 years

Table 5-4. Predicted impacts to the Big Creek Crayfish from the Woodland Crayfish invasion at 50 years for each future scenario.

50 Years			
	Reasonable Best	Most Likely	Reasonable Worst
% of Twelvemile Creek population invaded	0%	55.6%	100%
% of Main population invaded	48.7%	64.1%	90.4%
% of total range invaded	46.2%	63.7%	90.9%
% Reduction in abundance in invaded areas	>50%	~100%	~100%
Time for impacts to be fully realized	10-20 yrs	<10 years	<10 years

Table 5-5. Length of time for the Woodland Crayfish to invade the entire Big Creek Crayfish range for each future scenario and estimated impact.

Time to be Fully Invaded			
	Reasonable Best	Most Likely	Reasonable Worst
Twelvemile Creek Population	Beyond reliable prediction (>100 yrs)	67 yrs	34 yrs
Entire Range	Beyond reliable prediction (>250 yrs)	Beyond reliable prediction (>200 yrs)	70 yrs
% Reduction in abundance in invaded areas	>50%	~100%	~100%

5.3 St. Francis River Crayfish Future Conditions

<u>Reasonable Best Scenario</u>

Under the Reasonable Best Scenario, the Woodland Crayfish invasion will expand at a rate of 150 m (164 yd) per year in intermittent streams in both the upstream and downstream direction, 50 m (55 yd) per year when moving upstream in perennial streams, and 200 m (219 yd) per year when moving downstream in perennial streams. In the St. Francis River mainstem, the invasion is estimated to expand upstream at a rate of 25 m (27 yd) per year and downstream at a rate of 100 m (110 yd) per year.

Based on this expansion rate, 15.0% of the St. Francis River Crayfish range will be invaded by the Woodland Crayfish in 10 years (Fig. 5-4, Table 5-6). In 25 years, 25.2% of the range will have been invaded (Fig. 5-4, Table 5-7), and 38.0% of the range will have been invaded in 50 years (Fig. 5-4, Table 5-8). Abundance will be reduced in invaded areas by over 10-50% in 30-40 years.

The length of time for the entire St. Francis River Crayfish range to be invaded under this scenario is beyond reliable prediction (>250 years)(Table 5-9).

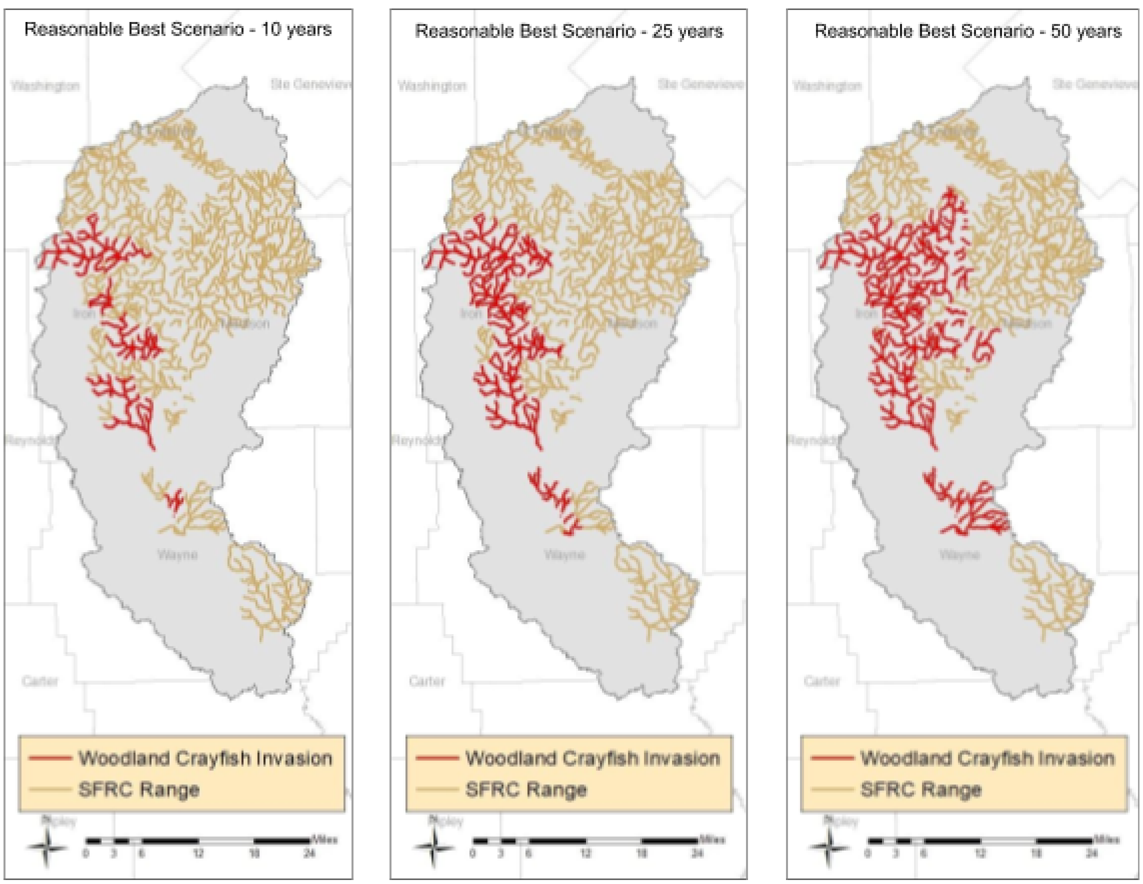

Fig. 5-4. Predicted expansion of the Woodland Crayfish within the St. Francis River Crayfish range at 10, 25, and 50 years under the Reasonable Best Scenario[16].

[16] The entire network of streams within the Upper St. Francis River watershed was used to map the predicted expansion. However, invaded streams outside of the St. Francis River Crayfish range are not included in the maps to more clearly depict the predicted portion of the species' range invaded by the Woodland Crayfish.

Reasonable Worst Scenario

Under the Reasonable Worst Scenario, the Woodland Crayfish invasion will expand at a rate of 350 m (383 yd) per year in intermittent streams in both the upstream and downstream direction, 1,000 m (1,094 yd) per year when moving upstream in perennial streams, and 3,000 m (3,281 yd) per year when moving downstream in perennial streams. In the St. Francis River mainstem, the invasion is also estimated to expand upstream at a rate of 1,000 m (1,094 yd) per year and downstream at a rate of 3,000 m (3,281 yd) per year.

Based on this expansion rate, 32.9% of the St. Francis River Crayfish range will be invaded by the Woodland Crayfish in 10 years (Fig. 5-5, Table 5-6). In 25 years, 59.0% of the range will have been invaded (Fig. 5-5, Table 5-7), and 82.4% of the range will have been invaded in 50 years (Fig. 5-5, Table 5-8). Abundance will be reduced in invaded areas by approximately 100% (i.e., virtual displacement) in less than 10 years.

The length of time for the entire St. Francis River Crayfish range to be invaded under this scenario is 72 years (Table 5-9).

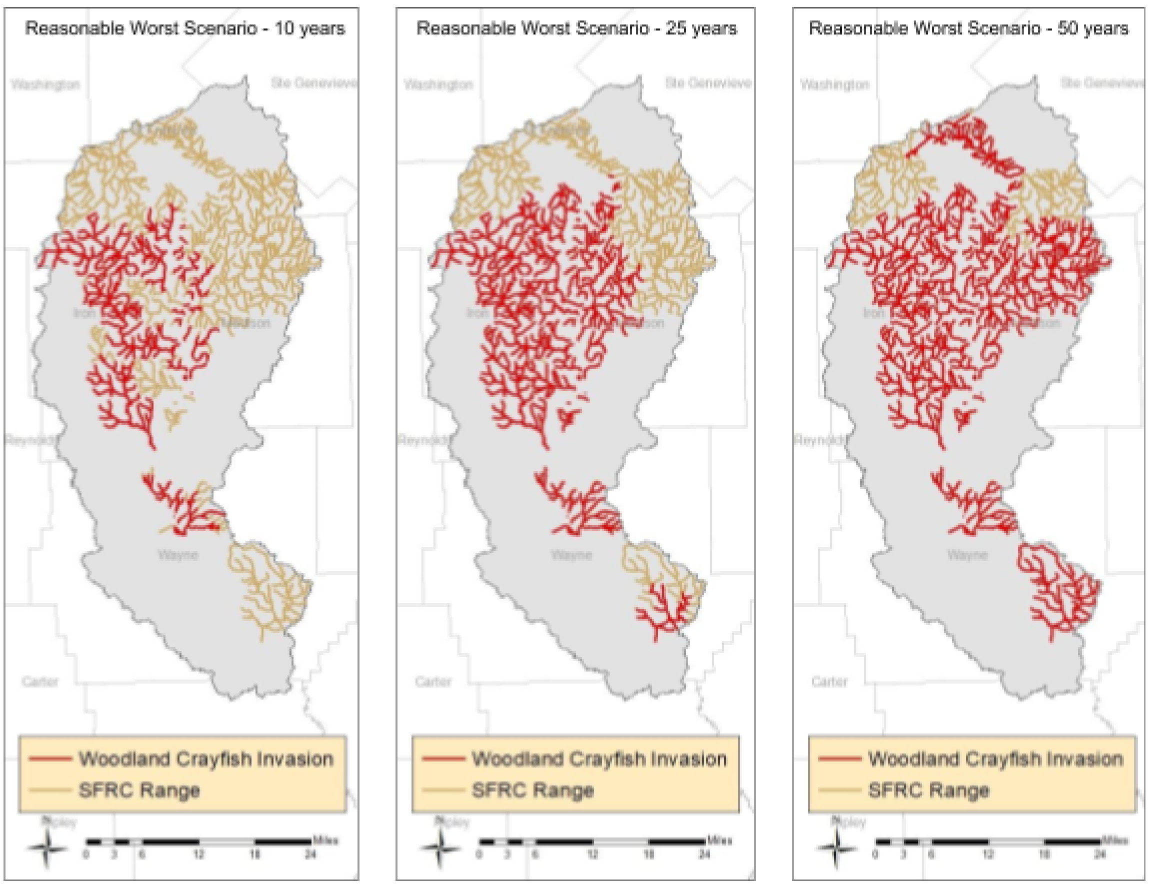

Figure 5-5. Predicted expansion of the Woodland Crayfish within the St. Francis River Crayfish range at 10, 25, and 50 years under the Reasonable Worst Scenario[17].

[17] The entire network of streams within the Upper St. Francis River watershed was used to map the predicted expansion. However, invaded streams outside of the St. Francis River Crayfish range are not included in the maps to more clearly depict the predicted portion of the species' range invaded by the Woodland Crayfish.

Most Likely Scenario
Under the Most Likely Scenario, the Woodland Crayfish invasion will expand at a rate of 150 m (164 yd) per year in intermittent streams in both the upstream and downstream direction, 300 m (328 yd) per year when moving upstream in perennial streams, and 1,000 m (1,094 yd) per year when moving downstream in perennial streams. In the St. Francis River mainstem, the invasion is estimated to expand upstream at a rate of 200 m (219 yd) per year and downstream at a rate of 900 m (984 yd) per year.

Based on this expansion rate, 20.9% of the St. Francis River Crayfish range will be invaded by the Woodland Crayfish in 10 years (Fig. 5-6, Table 5-6). In 25 years, 35.3% of the range will have been invaded (Fig. 5-6, Table 5-7), and 53.0% of the range will have been invaded in 50 years (Fig. 5-6, Table 5-8). Abundance will be reduced in invaded areas by 50-100% in 10-30 years.

The length of time for the entire St. Francis River Crayfish range to be invaded under this scenario is beyond reliable prediction (>200 years)(Table 5-9).

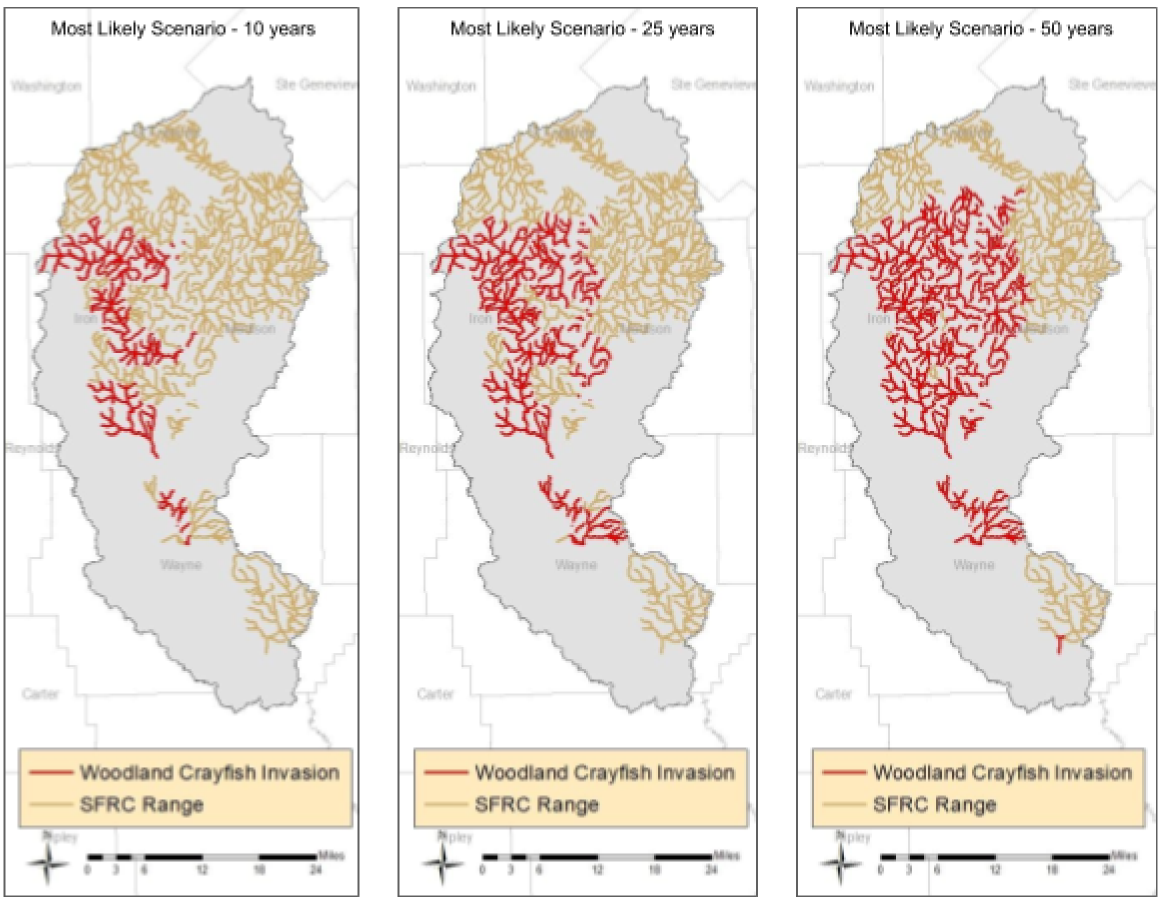

Figure 5-6. Predicted expansion of the Woodland Crayfish within the St. Francis River Crayfish range at 10 and 25 years under the Most Likely Scenario[18].

[18] The entire network of streams within the Upper St. Francis River watershed was used to map the predicted expansion. However, invaded streams outside of the St. Francis River Crayfish range are not included in the maps to more clearly depict the predicted portion of the species' range invaded by the Woodland Crayfish.

Table 5-6. Predicted impacts to the St. Francis River Crayfish from the Woodland Crayfish invasion at 10 years for each future scenario.

10 Years			
	Reasonable Best	Most Likely	Reasonable Worst
% of range invaded	15.0%	20.9%	32.9%
% Reduction in abundance in invaded areas	10-50%	50-100%	~100%
Time for impacts to be fully realized	30-40 yrs	10-30 yrs	<10 yrs

Table 5-7. Predicted impacts to the St. Francis River Crayfish from the Woodland Crayfish invasion at 25 years for each future scenario.

25 Years			
	Reasonable Best	Most Likely	Reasonable Worst
% of range invaded	25.2%	35.3%	59.0%
% Reduction in abundance in invaded areas	10-50%	50-100%	~100%
Time for impacts to be fully realized	30-40 yrs	10-30 yrs	<10 yrs

Table 5-8. Predicted impacts to the St. Francis River Crayfish from the Woodland Crayfish invasion at 50 years for each future scenario.

50 Years			
	Reasonable Best	Most Likely	Reasonable Worst
% of range invaded	38.0%	53.0%	82.4%
% Reduction in abundance in invaded areas	10-50%	50-100%	~100%
Time for impacts to be fully realized	30-40 yrs	10-30 yrs	<10 yrs

Table 5-9. Length of time for the Woodland Crayfish to invade the entire St. Francis River Crayfish range for each future scenario and estimated impact.

Time for Entire Range to be Invaded			
	Reasonable Best	Most Likely	Reasonable Worst
Time	Beyond reliable prediction (>250 yrs)	Beyond reliable prediction (>200 yrs)	72 yrs
% Reduction in abundance in invaded areas	10-50%	50-100%	~100%

Chapter 6. Synthesis

The Woodland Crayfish invasion has resulted in the extirpation of the Big Creek Crayfish in 14.7 stream km (9.1 mi) and of the St. Francis River Crayfish in 13.7 stream km (8.5 mi). Both of these distances are likely an extreme under-representation of the amount of the range impacted given that they represent impacts in only 2 of the 11 streams invaded by the Woodland Crayfish. In invaded areas in which the species have not been completely replaced, relative abundance in the crayfish community is substantially reduced. Based on impacts to crayfish in other watersheds, we presume abundance of both species is also reduced in areas impacted by lead mining contamination.

To evaluate future conditions of the Big Creek Crayfish and St. Francis River Crayfish due to the Woodland Crayfish invasion, we predicted the expansion of the Woodland Crayfish within the Upper St. Francis River watershed. We used expert-elicited estimates for 1) the plausible range of Woodland Crayfish expansion rates, 2) resulting impacts on Big Creek Crayfish and St. Francis River Crayfish abundance, and 3) the length of time for effects to be fully realized. Using these estimates we created Reasonable Best, Reasonable Worst, and Most Likely scenarios to characterize future conditions of the Big Creek Crayfish and St. Francis River Crayfish in 10, 25, and 50 years.

Given that there are currently no known feasible measures to curtail the Woodland Crayfish invasion for the long term, 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 Big Creek Crayfish and St. Francis River Crayfish, we are also reasonably certain that we can predict the plausible range of future conditions within 50 years. For this reason, we have focused our discussion below primarily on predicted viability within 50 years. Though the impacts of the invasion may not be fully realized within 25 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.

6.1 Big Creek Crayfish Predicted Viability

Results of the plausible range of the Big Creek Crayfish's future conditions due to the Woodland Crayfish invasion are summarized in Tables 6-1 to 6-3.

Table 6-1. The range of predicted impacts to the Big Creek Crayfish from the Woodland Crayfish invasion at 10 years based on expert opinion.

10 Years			
	Reasonable Best	Most Likely	Reasonable Worst
% of Twelvemile Creek population invaded	0%	0%	0.2%
% of Main population invaded	25.4%	27.9%	44.1%
% of total range invaded	24.0%	33.1%	41.9%
% Reduction in abundance in invaded areas	>50%	~100%	~100%
Time for impacts to be fully realized	10-20 yrs	<10 years	<10 years

Table 6-2. The range of predicted impacts to the Big Creek Crayfish from the Woodland Crayfish invasion at 25 years based on expert opinion.

25 Years			
	Reasonable Best	Most Likely	Reasonable Worst
% of Twelvemile Creek population invaded	0%	6.2%	80.7%
% of Main population invaded	34.7%	43.9%	69.9%
% of total range invaded	32.9%	54.4%	70.4%
% Reduction in abundance in invaded areas	>50%	~100%	~100%
Time for impacts to be fully realized	10-20 yrs	<10 years	<10 years

Table 6-3. The range of predicted impacts to the Big Creek Crayfish from the Woodland Crayfish invasion at 50 years based on expert opinion.

50 Years			
	Reasonable Best	Most Likely	Reasonable Worst
% of Twelvemile Creek population invaded	0%	55.6%	100%
% of Main population invaded	48.7%	64.1%	90.4%
% of total range invaded	46.2%	63.7%	90.9%
% Reduction in abundance in invaded areas	>50%	~100%	~100%
Time for impacts to be fully realized	10-20 yrs	<10 years	<10 years

Resiliency

As noted above, resiliency of the Big Creek Crayfish has already been reduced from historical conditions due to effects of the Woodland Crayfish invasion and impacts from lead mining contamination. Based on modeling results, we predict that resiliency of the species will be further reduced within 50 years due to the Woodland Crayfish invasion in an estimated 49-90% of the Main population and 0-100% of the Twelvemile Creek population, constituting 46-91% of the species' total range. Abundance is expected to be reduced in invaded areas by 50-100% with approximately 100% being the most likely amount. If threats other than the Woodland Crayfish and lead mining contamination (drought, flood events, disease, degraded water quality) remain the same or increase, resiliency will be further reduced. Thus, 46-91% is the minimum amount of the species' range that is expected to be impacted within 50 years.

Representation

There has already been some loss in Big Creek Crayfish representation due to the reduced health of the Main population resulting from the Woodland Crayfish invasion and impacts of lead mining contamination. The reduction in representation is expected to continue given the predicted 50-100% reduction in abundance in 49-90% of the Main population within 50 years. The Twelvemile Creek population is also expected to experience 50-100% reduction in abundance in invaded areas, with 0-100% of the population expected to be invaded within 50 years. Given the unique haplotypes contained in this population, the reduced abundance (and thus health) of subpopulations in the majority of the population may represent an appreciable reduction in the species' representation if the invasion is toward the higher end of predictions.

Redundancy

The Big Creek Crayfish is inherently vulnerable to catastrophic events given the species' small range, and there has been some reduction in redundancy due to reduction in size and health of the Main population due the Woodland Crayfish invasion and effects of lead mining contamination. However, both populations of the species have a high level of redundancy pertaining to catastrophic events that impact areas downstream of the source of event (e.g., chemical spills) because of the number of tributaries it occupies. Similar to representation, we expect that redundancy of the Big Creek Crayfish will be further reduced by the predicted 50-100% reduction in abundance in 49-90% of the Main population and 0-100% of the Twelvemile Creek population within 50 years. Because the Twelvemile Creek population consists of only one subwatershed, it will be much more vulnerable to catastrophic events if multiple sub-tributaries are impacted by the Woodland Crayfish invasion.

Interpreting Impacts to the 3 Resiliency, Representation, and Redundancy

The exact number and distribution of subpopulations (within the two populations) required to maintain resiliency and adaptive capacity of the Big Creek Crayfish is unknown, as is the distribution and number of healthy populations required to guard against catastrophic events. Therefore, it is unclear if the species will retain sufficient resiliency, representation, and redundancy to maintain viability if abundance is reduced 50-100% in 49-90% of the Main population and 0-100% of the Twelvemile Creek population. If the reduction in the 3 Rs is within the lower range of predicted impacts (i.e., lower proportion of range invaded with a lesser impact on abundance), we expect a lesser impact on viability and thus a high probability of persistence. However, if the reduction in the 3 Rs is towards the higher end of the predictions (i.e., greater proportion of range invaded with a greater impact on abundance), we expect a greater impact on viability with a lower probability of persistence.

6.2 St. Francis River Crayfish Predicted Viability

Results of the plausible range of the St. Francis River Crayfish's future conditions due to the Woodland Crayfish invasion are summarized in Tables 6-4 to 6-6.

Table 6-4. The range of predicted impacts to the St. Francis River Crayfish from the Woodland Crayfish at 10 years based on expert opinion.

10 Years			
	Reasonable Best	Most Likely	Reasonable Worst
% of range invaded	15.0%	20.9%	32.9%
% Reduction in abundance in invaded areas	10-50%	50-100%	~100%
Time for impacts to be fully realized	30-40 yrs	10-30 yrs	<10 yrs

Table 6-5. The range of predicted impacts to the St. Francis River Crayfish from the Woodland Crayfish at 25 years based on expert opinion.

25 Years			
	Reasonable Best	Most Likely	Reasonable Worst
% of range invaded	25.2%	35.3%	59.0%
% Reduction in abundance in invaded areas	10-50%	50-100%	~100%
Time for impacts to be fully realized	30-40 yrs	10-30 yrs	<10 yrs

Table 6-5. The range of predicted impacts to the St. Francis River Crayfish from the Woodland Crayfish at 50 years based on expert opinion.

50 Years			
	Reasonable Best	Most Likely	Reasonable Worst
% of range invaded	38.0%	53.0%	82.4%
% Reduction in abundance in invaded areas	10-50%	50-100%	~100%
Time for impacts to be fully realized	30-40 yrs	10-30 yrs	<10 yrs

Resiliency

Resiliency of the St. Francis River Crayfish has already been reduced from historical conditions due to effects of the Woodland Crayfish invasion and impacts from lead mining contamination. Based on modeling results, we predict that resiliency of the species will be further reduced within 50 years due to the Woodland Crayfish invasion in an estimated 38-82% of the range. Abundance is expected to be reduced in invaded areas by 10-100% with approximately 50-100% being the most likely amount. If threats other than the Woodland Crayfish and lead mining contamination (drought, flood events, disease, degraded water quality) remain the same or increase, resiliency will be further reduced. Thus, 38-82% is the minimum amount of the species' range that is expected to be impacted within 50 years.

Representation

There has already been some loss in St. Francis River Crayfish representation due to the reduced health of the sub populations impacted by the Woodland Crayfish invasion and impacts of lead mining contamination. The reduction in representation is expected to continue given the predicted 10-100% reduction in abundance in 38-82% of the species' range.

Redundancy

The St. Francis River Crayfish is inherently vulnerable to catastrophic events given the species' small range, and there has been some reduction in redundancy due to range reduction and reduced abundance of subpopulations due to the Woodland Crayfish invasion and lead mining contamination. However, the species has a high level of redundancy pertaining to catastrophic events that impact areas downstream of the source of event (e.g., chemical spills) because of the number of tributaries it occupies. Similar to representation, we expect that redundancy of the St. Francis River Crayfish will be further reduced by the predicted 10-100% reduction in abundance in 38-82% of the range within 50 years.

Interpreting Impacts to the 3 Resiliency, Representation, and Redundancy
The exact number and distribution of subpopulations required to maintain resiliency and adaptive capacity of the St. Francis River Crayfish is unknown, as is the distribution and number of healthy populations required to guard against catastrophic events. Therefore, it is unclear if the species will retain sufficient resiliency, representation, and redundancy to maintain viability if abundance is reduced by 10-100% in 38-82% of the range. If the reduction in the 3 Rs is within the lower range of predicted impacts (i.e., lower proportion of range invaded with a lesser impact on abundance), we expect a lesser impact on viability and thus a high probability of persistence. However, if the reduction in the 3 Rs is towards the higher end of the predictions (i.e., greater proportion of range invaded with a greater impact on abundance), we expect a greater impact on viability with a lower probability of persistence.

6.3 Uncertainties

Predicting the future condition of the Big Creek and St. Francis River crayfishes 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 6-7 we identify the key sources of uncertainty and indicate the likely effect of our assumptions on the viability assessment.

Table 6-7. Key assumptions made in evaluating the future condition of the Big Creek Crayfish and St. Francis 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.

Assumptions	Influence on Viability Assessment if Incorrect
The presumed ranges based on occupied subwatersheds depicts the actual ranges of the Big Creek Crayfish and St. Francis River Crayfish.	Overestimated/ Underestimated
In areas not invaded by the Woodland Crayfish, Big Creek Crayfish and St. Francis River Crayfish subpopulations are currently healthy.	Overestimated
There will be no new introductions of the Woodland Crayfish in the Upper St. Francis River watershed.	Overestimated
The expansion of the Woodland Crayfish will continue unabated, as there are no known mechanisms to halt or reverse it.	Underestimated

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Appendix A. Evaluating Catastrophic Events

For the purposes of the Species Status Assessment (SSA) for the Big Creek Crayfish and St. Francis 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 Big Creek Crayfish and St. Francis 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 2018b). 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 Big Creek Crayfish and St. Francis River Crayfish. USDM categories of drought and associated conditions are provided in Table A-1.

According to the USDM data, 100% of the Upper St. Francis River watershed was affected by a D3-D4 drought in 2012 (Fig. A-1)(USDM 2018b). During July and August in 2012, the drought intensified to a D4 drought in 13% of the watershed (Fig. A-1)(USDM 2018b). We queried species experts on whether they recalled impacts to the Big Creek Crayfish and St. Francis 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

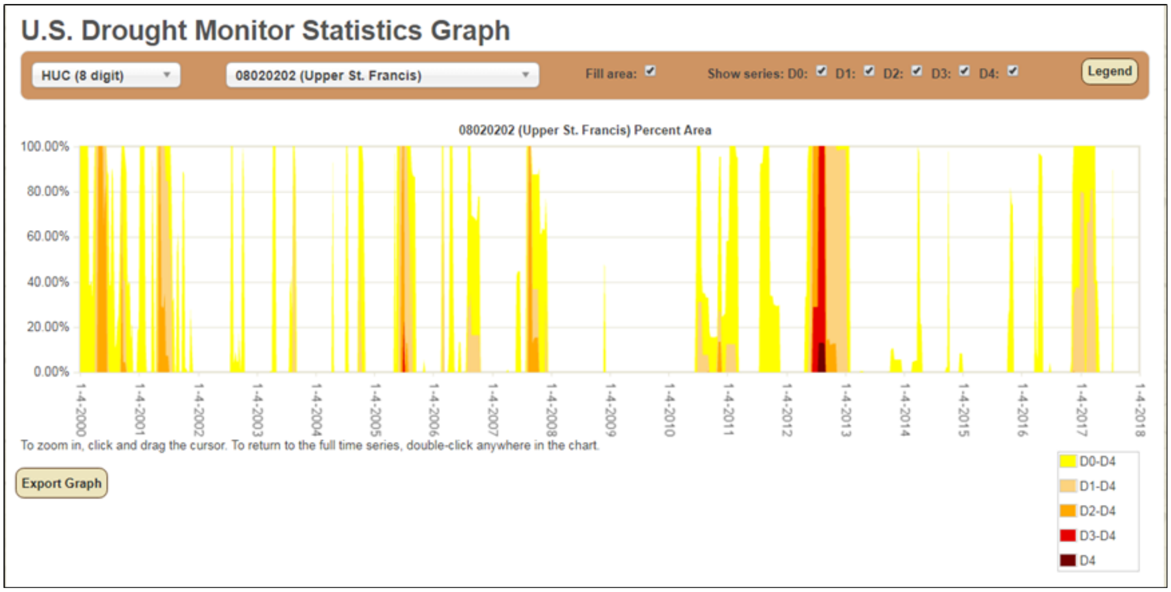

Figure A-1. Drought conditions in the Upper St. Francis River watershed from January 2000 to January 2018. The entire watershed (100%) was affected by a D3-D4 drought in 2012 (USDM 2018b).

Chemical Spills

To evaluate the risk of chemical spills catastrophic to the Big Creek Crayfish and St. Francis River Crayfish, we identified 1) major pipelines crossing the Upper St. Francis River watershed, 2) railways that cross the watershed and could spill large quantities of oil or other chemical substances, 3) hazardous material routes that cross the watershed, and 4) any other sources of large volumes of chemical substances. Based on the information outlined above, we do not think that chemical spills would result in a catastrophic loss to the Big Creek Crayfish and St. Francis River Crayfish at the population level. At the subpopulation level, however, a spill could be catastrophic, resulting in extirpation or reduction in abundance.

Major Pipelines

According to the Pipeline and Hazardous Materials Safety Administration (2016), four major pipelines cross the Upper St. Francis River watershed (Fig. A-2). One is a 20-inch pipeline carrying crude oil and running diagonally through the lower portion of the Upper St. Francis River watershed (Fig. A-2). Though a spill or release would impact downstream subpopulations, it would not result in a catastrophic loss to either of the two Big Creek Crayfish populations or the St. Francis River Crayfish population given that the line crosses the lower portion of the watershed. The remaining pipelines crossing the watershed are natural gas lines. We do not consider natural gas lines as posing a severe threat because the gas is vaporized and thus, would not be transported downstream.

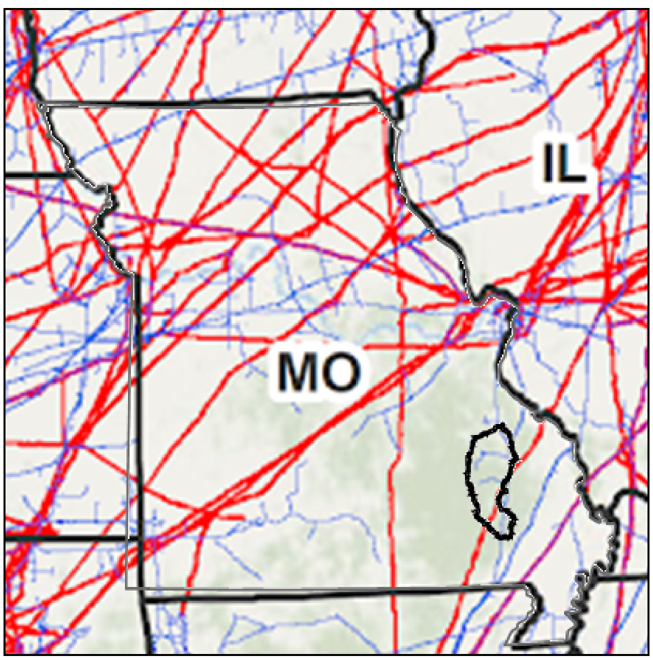

Figure A-2. Gas Transmission and Hazardous Liquid Pipelines[19] (PHMSA 2016). Blue lines represent gas transmission pipelines; red lines represent hazardous liquid pipelines.

[19] A higher resolution map was used to evaluate the exact location of major pipelines relative to the Upper St Francis 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
No major railways carrying crude oil cross the Upper St. Francis River watershed (Fig. A-3)(OCI 2017). Thus, we do not expect a railway spill to result in catastrophic losses to the Big Creek Crayfish or St. Francis River Crayfish from a railway spill.

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 Upper St. Francis River watershed (Fig. A-4)(FMCSA 2017). Hazardous material routes include roads, highways, and interstates by which hazardous materials are transported by commercial motor vehicles. The classes of hazardous materials, as defined by the FMCSA are 1) explosives, 2) gases, 3) flammable liquid and combustible liquids, 4) flammable solids, spontaneously combustible and dangerous when wet, 5) oxidizer and organic peroxide, 6) poison and poison inhalation hazard, 7) radioactive, 8) corrosive, and 9) miscellaneous.

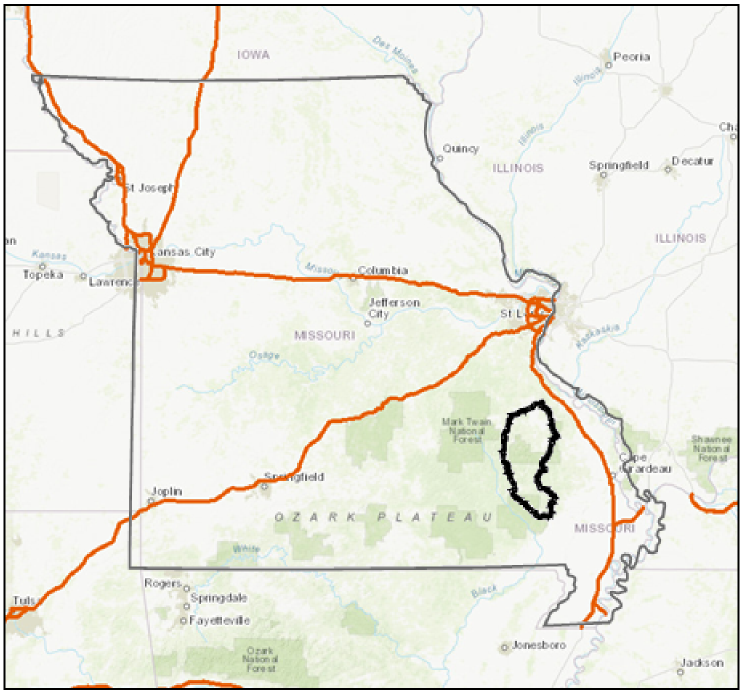

Figure A-4. Hazardous material routes (Federal Motor Carrier Safety Administration 2017)

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Appendix B. Predicting Future Conditions Using Expert Elicitation

On May 10-11, 2017, we convened a group of biologists with expertise on Ozark-endemic crayfishes to provide input on the anticipated future condition of six crayfish species for which we are conducting species status assessments. The species included the Big Creek Crayfish (*Faxonius peruncus*) and St. Francis River Crayfish (*Faxonius quadruncus*). The ranges of both species have been invaded by the Woodland Crayfish (*Faxonius hylas*). We sought the experts' knowledge on 1) the anticipated rate at which the invading crayfishes will expand their range within the watersheds of the six native species, 2) impacts of the invasion on the native species, and 3) the length of time for impacts to be fully realized[20].

Expansion Rate of the Woodland 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 Woodland Crayfish downstream movement in perennial streams, upstream movement in intermittent streams, and upstream movement in perennial streams[21]. We did not elicit rates of expansion for downstream movement in intermittent streams because the Woodland 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 Woodland 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, p. 2259; Magoulick and DiStefano 2007, pp. 146-147; DiStefano and Westhoff 2011, p. 40) 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.

Additional data were collected during field surveys in 2017 that indicated the Woodland Crayfish may expand more slowly in the mainstem of the St. Francis River (in the Upper St. Francis River watershed where the Big Creek Crayfish and St. Francis River Crayfish occur)(Westhoff 2017, unpublished data). Given this information, we asked experts if they would like to revise their estimated expansion rates for this stream. Results are summarized in Table B-2.

[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.
[21] In selecting expansion rates to apply to stream reaches, we used streams with a Strahler stream order (Strahler 1952, entire) of 0 or 1 to represent intermittent streams.

Table B-1. Expert-elicited estimated average annual rates of expansion for the Woodland Crayfish (rates not applicable to the mainstem of the St. Francis River; see below).

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

Table B-2. Expert-elicited estimated average annual rates of expansion for the Woodland Crayfish in the St. Francis River Mainstem.

Categories of Likelihood Estimates	Estimated Expansion Rate (meters per year)			
	St. Francis River Mainstem (Upstream)		St. Francis River Mainstem (Downstream)	
	Median	Range	Median	Range
Lowest Plausible	25	0-100	100	100-200
Highest Plausible	1,000	400-2,000	3,000	2,500-10,000
Most Likely	200	200-500	900	900-2,500

Impact of the Woodland Crayfish

To elicit estimates on the level of impact on abundance from the Woodland Crayfish and the time for impacts to be fully realized, we used the likelihood point method. This method involves experts distributing 100 points across the different categories of effects, with the distribution of points based on each expert's strength of belief that the actual impact will be encompassed in that category (the more points assigned to a category, the more strongly the experts felt that the category captured the actual level of impact). We again used a modified Delphi process, as described above. Results are summarized in Tables B-3 and B-4.

Table B-3. Expert-elicited estimated impact on abundance of the Big Creek Crayfish and St. Francis River Crayfish from invasion of the Woodland 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)	
	Big Creek Crayfish	St. Francis River Crayfish [22]
No observable effect on abundance (~0% reduction)	0 (0-0)	0 (0-0)
Abundance reduced 10-50%	5 (0-50)	15 (5-50)
Abundance reduced > 50% (but not fully displaced)	20 (10-50)	40 (35-50)
Virtual complete displacement (~100% reduction)	75 (0-90)	40 (0-55)

Table B-4. Expert-elicited estimated length of time for impacts to be fully realized on the Big Creek Crayfish and St. Francis River Crayfish from the Woodland Crayfish invasion. Values represent the median of the points experts assigned to each category; values in parentheses represent the range of points experts assigned.

Time for Impacts to be Fully Realized	Points Assigned to Each Category Median (Range)	
	Big Creek Crayfish	St. Francis River Crayfish
Less than 10 years	80 (25-90)	25 (10-55)
10-20 years	10 (5-25)	25 (20-50)
20-30 years	5 (0-10)	25 (15-50)
30-40 years	0 (0-5)	10 (0-15)
More than 40 years	0 (0-5)	5 (0-15)

[22] Values reflect revised estimates based on the additional data collected during field surveys in 2017 indicating that the St. Francis River Crayfish has co-existed with the Woodland Crayfish in Marble Creek for at least 10 years (Westhoff 2017, unpublished data).

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 native species' ranges that the Woodland 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 Woodland Crayfish (Tables B-1 and B-2). We selected the lowest category of impact on abundance of the native species (Table B-3) and the greatest number of years for impacts to be realized (Table B-4). For impact on abundance and time for impacts to be realized, we included only those categories having a median score greater than 5 to exclude those categories that experts felt were highly implausible.

The Reasonable Worst Scenario represents the highest plausible proportion of the native species' ranges that may be invaded with the highest plausible level of impact. For the Reasonable Worst Scenario, we selected the median of the values experts provided for the highest plausible expansion rate for the Woodland Crayfish (Tables B-1 and B-2). We selected the highest category of impact on abundance of the native species (Table B-3) and the lowest number of years for impacts to be realized (Table B-4). For impact on abundance and time for impacts to be fully realized, we again included only categories having a median score greater than 5.

The Most Likely Scenario represents the most likely proportion of the species' ranges impacted with the most likely level of impact. For the Most Likely Scenario, we selected the median of the values experts provided for the most likely expansion rate for the Woodland Crayfish (Tables A-1 and A-2). We selected the category of impact with the highest median value (Tables A-3 and A-4) and the category having the highest median value for the number of years for impacts to be realized (Tables A-5 and A-6). 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 Big Creek Crayfish and St. Francis River Crayfish are provided in Tables B-6 to B-8.

Table B-5. Scenarios representing the plausible range of the Big Creek Crayfish and St. Francis River Crayfish 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 Woodland Crayfish Lowest level of predicted impact on Big Creek Crayfish or St. Francis River Crayfish abundance Highest number of years for impacts to be fully realized
Reasonable Worst	Highest plausible expansion rate of the Woodland Crayfish Highest level of predicted impact on Big Creek Crayfish or St. Francis River Crayfish abundance Lowest number of years for impacts to be fully realized
Most Likely	Most likely expansion rate of the Woodland Crayfish Most likely level of predicted impact on Big Creek Crayfish or St. Francis River Crayfish abundance Most likely number of years for impacts to be fully realized

Table B-6. Expert-elicited estimates used for Woodland Crayfish expansion rates for the Big Creek Crayfish and St. Francis River Crayfish future scenarios.

Future Scenario	Expansion Rate (meters/year)					
	Intermittent Streams		Perennial Streams		St. Francis River Mainstem	
	Upstream	Downstream[23]	Upstream	Downstream	Upstream	Downstream
Reasonable Best	150	150	50	200	25	100
Reasonable Worst	350	350	1,000	3,000	1,000	3,000
Most Likely	150	150	300	1,000	200	900

Table B-7. Expert-elicited estimates of impacts on abundance used for the Big Creek Crayfish future scenarios.

Future Scenario	Level of Impact (reduction in abundance)	Time for Impacts to be Fully Realized (years)
Reasonable Best	>50%	10-20 years
Reasonable Worst	~100%	<10 years
Most Likely	~100%	<10 years

[23] We did not elicit values for downstream movement in intermittent streams. For the purposes of this SSA, we assumed expert-elicited values for upstream movement in intermittent streams.

Table B-8. Expert-elicited estimates of impacts on abundance used for the St. Francis River Crayfish future scenarios.

Future Scenario	Level of Impact (reduction in abundance)	Time for Impacts to be Fully Realized (years)
Reasonable Best	10-50%	30-40 years
Reasonable Worst	~100%	<10 years
Most Likely	50-100%	10-30 years

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