U.S. Fish and Wildlife Service

Draft
Revised Recovery Plan
for
Gila trout
(*Oncorhynchus gilae*)

4th Revision
July 2021

Illustration Credit: Joseph R. Tomelleri

Recovery Plan
for
Gila trout (*Oncorhynchus gilae*)
4th Revision

(Original approved 12 January 1979)
(First revision approved 3 January 1984)
(Second revision approved 8 December 1993)
(Third revision approved 15 August 2003)

Prepared by the
Gila Trout Recovery Team
Albuquerque, New Mexico

Approved: ____

Regional Director
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Date: ______________________________

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Executive Summary

Current Species Status

As of August 2019, there were 17 populations of Gila trout (*Oncorhynchus gilae*) inhabiting approximately 137.5 kilometers (km) (85.2 miles (mi)) of stream habitat. All known, remnant genetic lineages (Main Diamond Creek, South Diamond Creek, Whiskey Creek, Iron Creek and Spruce Creek) were represented by at least two wild populations. The five remnant lineages encompass the existing genetic diversity of the species, and each contributes significantly to it. Heterozygosity of all of the remnant lineages of Gila trout, with the exception of Iron Creek, has declined from 2002 to 2013. Loss of genetic diversity has been particularly acute in the Spruce Creek lineage. The Main Diamond and South Diamond lineages were relatively secure, with hatchery broodstock and production having been successfully developed and populations present in 9 of the 17 occupied streams. The current situation of the other three lineages, however, is less secure, and only one mixed-lineage population existed by August 2019. The remnant-lineage populations in Whiskey Creek and Spruce Creek were extirpated following large-scale, high-severity wildfire. At the beginning of 2019, populations of these lineages were present in only three other streams, and these streams supported only small populations. The Iron Creek lineage occurred in only two streams at the beginning of 2019, and those populations contained unique genetic variation. Resiliency of Gila trout is constrained by the patchy distribution and geographic isolation of cold-water streams, many of which are single-stream systems that are relatively small, throughout the species' historical range. Few, if any, extant populations of Gila trout are large enough to survive extremes in environmental conditions without experiencing a severe population bottleneck (drastic reduction in population size). Currently only the Mogollon and Willow creek drainages (where the South Diamond lineage has been established) have a dendritic (branching stream network) population structure, and even the largest single-stream systems where Gila trout have been repatriated (e.g., Black Canyon) have been subject to extirpations associated with environmental stochasticity. Recovery actions implemented to date have greatly improved redundancy by increasing the number of populations of Gila trout. However, spatial distribution of populations is constrained by the geographical distribution of currently suitable habitat for the species.

Habitat Requirements and Limiting Factors

Persistent, viable populations of Gila trout require *perennial* stream flow, which must be adequate to maintain sufficient habitat diversity and volume to support all life stages of Gila trout (eggs, fry, juveniles, adults). Flow regimes required to maintain sufficient habitat diversity and volume vary depending on site-specific characteristics of stream reaches (e.g., stream gradient, seepage, substrate composition, channel dimensions, watershed hydrology). Gila trout require cold-water aquatic habitats with unimpaired water quality. Suitable water temperature was observed up to 26°C by Lee and Rinne (1980). Their observations noted normal activity during temperature fluctuations between 20-26°C; however, as temperature rose to 27°C, abnormal activity and eventual mortality occurred. Suitable water quality for Gila trout is characterized by high dissolved oxygen concentration, low turbidity and conductivity, low levels of total dissolved solids, and near-neutral pH. In addition to perennial stream flow and suitable water temperature and water quality, Gila trout require a diversity of habitats sufficient to sustain all life stages of the species. This includes suitable spawning habitat, habitat where fry can find shelter and food, and areas suitable for occupancy by juvenile and adult Gila trout. The two most important features with respect to population persistence are likely sufficient pool habitat and spawning habitat. The threat of local extinction of native salmonid populations increases with isolation and decreasing population size. It follows that persistence of Gila trout over the long term requires combinations of sufficiently large occupied habitats and, where possible, connectivity in dendritic stream networks, not only with respect to population size but also to maintenance of genetic variation and access to suitable habitat in response to environmental variation and life history requirements. A key biological requirement for sustaining viable populations of Gila trout is the absence of nonnative salmonids (Family Salmonidae), with viable populations defined as those that exhibit annual reproduction, size structure indicating multiple ages, and individuals attaining sufficient sizes to indicate three to seven years of survival (Service 2006). The threats of predation and competition, and human-mediated introgressive hybridization result from the presence of nonnative salmonids. Viable populations of Gila trout cannot persist when either or both of these threats are present. Consequently, the absence of nonnative salmonids is a fundamental requirement for sustaining viable populations of Gila trout.

Recovery Goal

The goal of the recovery program is to improve the conservation status of Gila trout to the extent that the species is viable and no longer requires protection under the Endangered Species Act. To ensure that the Gila trout will no longer meet the definition of threatened or endangered, multiple resilient populations must be well distributed in suitable habitats throughout the species presumed historical range, and threats to its existence must be eliminated or sufficiently abated.

Recovery Strategy

The primary focus of the recovery effort for Gila trout is to evolve from a crisis-management situation focused on preventing extinction to a perspective of sustainable populations established throughout the historical range that contain the breadth of genetic diversity of the species. This will entail incremental replacement of nonnative salmonids with Gila trout in suitable habitat throughout a significant portion of the historical range of the species. This strategy will be implemented by conducting actions to substantially improve redundancy, representation, and resiliency to the point that protections under the Endangered Species Act are no longer necessary.

Recovery Objectives

The recovery goal is expressed by the following objectives:

1. Secure the existing genetic diversity of Gila trout through the establishment of additional populations (both single-lineage stream segments and mixed-lineage metapopulations), the prevention of introgression by nonnative salmonids, the continuation of development of broodstock and hatchery production programs, and the continuation of work on assessment of genetic diversity and detection of introgression.
2. Increase the geographic distribution of the species so that it inhabits a substantial portion of its historical range which represents the spectrum of ecological conditions present in suitable habitats (Carroll *et al.*, 2010).
3. Increase the size, dendritic population structure, and interconnectedness of populations through nonnative salmonid removal and the strategic installation or modification of barriers (to prevent nonnative salmonid invasion but also to improve access to diverse habitats).

These objectives can also be presented in the context of redundancy, representation and resiliency:

- Redundancy: Viable populations of Gila trout are established in watersheds throughout the presumed historical range of Gila trout, as constrained by availability of suitable habitat.
- Representation Genetic diversity of Gila trout is maintained by establishing viable populations that replicate remnant genetic lineages, genetic diversity is augmented through planned lineage mixing, and all recovery streams are free of and protected from invasion by nonnative trout.
- Resiliency: The combination of numbers and sizes of Gila trout populations are sufficient to maintain genetic diversity, allow for persistence, and maintain evolutionary potential.

Recovery Criteria

The following objective, measurable criteria which, when met, would result in a determination that Gila trout be removed from the endangered species list:

Criterion A – Area of Occupancy

Gila trout occupy 280 km. (174 mi.) of stream within the presumed historical range of the species. Occupancy, in the context of this criterion, refers to streams being inhabited by viable populations.

Criterion A explicitly addresses objective 1, redundancy and also contributes to meeting objective 2, representation, and objective 3, resiliency.

Criterion B – Remnant Genetic Lineages

Each remnant genetic lineage of Gila trout is represented by at least three geographically separate, viable populations and requires one replicate population of each lineage to be geographically separated by at least 34.0 km (21.1 miles) from the other two replicate populations of that genetic lineage. These populations and the streams they inhabit would contribute to meeting the area of occupancy threshold in Criterion A. Criterion B explicitly addresses objective 2, representation.

Criterion C – Dendritic Metapopulations

At least four dendritic metapopulations of Gila trout are established. These metapopulations and the streams they inhabit would contribute to meeting the area of occupancy threshold in criterion A. Criterion C explicitly addresses objective 3, resiliency and also contributes to meeting objectives 1, redundancy and 2, representation.

Criterion D – Absence of Nonnative Salmonid Species

Nonnative salmonids are absent from recovery streams and measures are in place to prevent re-invasion by nonnative salmonids. In limited circumstances where non-hybridizing, nonnative salmonids persist in recovery streams, active management and suppression may occur to mitigate effects on the Gila trout recovery populations until complete eradication of nonnative salmonids is achieved. Criterion D explicitly addresses objectives 1, redundancy and 2, representation.

Actions Needed

Recovery actions are the site-specific management actions needed to address threats to the species and achieve recovery criteria. For the Gila trout, implementation of the following recovery actions will involve participation from the Service, Forest Service, Arizona Game and Fish Department, and New Mexico Department of Game and Fish.

1. Repatriate Gila trout to streams within its presumed historical range (Priority 1).
2. Establish and maintain captive propagation methods and conservation hatchery facilities in suitable locations (Priority 1).
3. Manage the presence of nonnative salmonid species in recovery streams in Arizona and New Mexico (Priority 1)
4. Monitor remnant and repatriated Gila trout populations within the Gila River drainage basin (Priority 2)

5. Conduct public education, involvement, and outreach in areas with an interest in Gila trout (Priority 3).
6. Develop and implement regulations to maintain sustainable Gila trout populations in recovery streams opened to sport fishing in Arizona and New Mexico (Priority 3).

Recovery actions are assigned numerical priorities, as defined below, to highlight the relative contribution they may make toward species recovery.

- Priority 1: An action that must be taken to prevent extinction; or to prevent the species from declining irreversibly in the foreseeable future.
- Priority 2: An action that must be taken to prevent a significant decline in species population/habitat quality, or some other negative impact short of extinction.
- Priority 3: All other actions necessary to meet recovery objectives.

Flexibility, which is essential to Gila trout recovery, can be hard to obtain with rigid timelines and schedules. Therefore, we have developed a supplemental Recovery Implementation Strategy (RIS), which provides additional detailed, site-specific activities needed to implement the actions identified in this Recovery Plan.

Estimated Date and Cost of Recovery

The estimated date of recovery of Gila trout is 2030, and the estimated total cost of recovery over this 10-year period is $15,619,030.

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Chapter 1- Introduction

Background

The Endangered Species Act of 1973 (ESA), as amended (16 U.S.C. 1531 *et seq.*) establishes policies and procedures for identifying, listing, and protecting species of wildlife and plants that are endangered or threatened with extinction. Recovery is defined as "the process by which listed species and their ecosystems are restored and their future is safeguarded to the point that protections under the ESA are no longer needed", according to the 2010 updated National Marine Fisheries Service's and U.S. Fish and Wildlife Service's (Service) Interim Recovery Planning Guidelines (2010a).

Recovery plans are strictly advisory documents developed to provide recovery recommendations based on alleviating the threats to the species and ensuring self-sustaining populations in the wild. According to the ESA, recovery plans are to include (1) a description of site-specific management actions necessary to conserve the species or population; (2) objective, measurable criteria that, when met, will allow the species or populations to be removed from the Federal List of Endangered and Threatened Wildlife (List); and (3) estimates of the time and cost required to achieve the plan's goals and intermediate steps.

The original recovery plan for Gila trout (*Oncorhynchus gilae*) was approved on January 12, 1979 (Service, 1979), with subsequent revisions approved on January 3, 1984 (Service, 1984), December 8, 1993 (Service, 1993), and August 19, 2003 (Service, 2003). This draft Revised Recovery Plan for Gila Trout (Recovery Plan) represents the fourth revision and considers updated information on genetics, population status, and threats (principally wildfire effects and introgressive hybridization) in the development of revised recovery objectives, actions, and implementation.

Brief Overview and Status

The Gila trout (*Oncorhynchus gilae*) is endemic to mountain streams in the Gila, San Francisco, Agua Fria and Verde River drainages in New Mexico and Arizona (Miller, 1950; Minckley, 1973; Behnke, 1992). Although Gila trout were known in the upper Gila River basin since at least 1885, the species was not described until 1950, by which time its distribution had been dramatically reduced (Miller, 1950).

The Gila trout was originally recognized as endangered under the Federal Endangered Species Preservation Act of 1966 (Service, 1967). Federally designated status of the fish as endangered was continued under the Endangered Species Act of 1973 (ESA). Gila trout was reclassified, or down-listed, from endangered to threatened in 2006 (Service, 2006). The 2006 reclassification also included a special rule under section 4(d) of the ESA that enabled the New Mexico Department of Game and Fish (NMDGF) and the Arizona Game and Fish Department (AGFD) to promulgate special regulations, in collaboration with the Service, allowing recreational fishing for Gila trout. The Gila trout was listed as endangered by the NMDGF in 1975 under the Wildlife Conservation Act and was down-listed to threatened in 1988. Gila trout is considered a Species of Concern by the AGFD.

The Gila trout is assigned a recovery priority number of 8, meaning that the species has a moderate degree of threat with high potential for recovery. The most recent 5-year status review for the species was completed in 2013.

Chapter 2- Life History, Biology, Distribution, and Resource Needs

Morphological Description

Gila trout are readily identified by their iridescent gold sides that blend to a darker shade of copper on the opercles (bony plates surrounding the gills) (Figure 1). Spots on the body of this trout are small and profuse, generally occurring above the lateral line and extending onto the head, dorsal fin, and caudal fin. Spots are irregularly shaped on the sides and increase in size dorsally. On the dorsal surface of the body, spots may be as large as the pupil of the eye and are rounded. A few scattered spots are sometimes present on the anal fin, and the adipose fin is typically large and well-spotted. Dorsal, pelvic, and anal fins have a white to yellowish tip that may extend along the leading edge of the pelvic fins. A faint, salmon-pink band is present on adults, particularly during spawning season when the normally white belly may be streaked with yellow or reddish orange. A yellow cutthroat mark is present on most mature specimens. Parr marks (markings present when trout are less than a year old) are commonly retained by adults, although they may be faint or absent (Miller, 1950; David, 1976).

Field characteristics that distinguish Gila trout from other co-occurring nonnative trout include the golden coloration of the body, parr marks, and fine, profuse spots above the lateral line (Figure 1). These characters differentiate Gila trout from rainbow (*O. mykiss*), brown (*Salmo trutta*), and cutthroat trout (*O. clarkii*).

See Appendix A for additional information on Gila trout morphology, including differentiation between lineages.

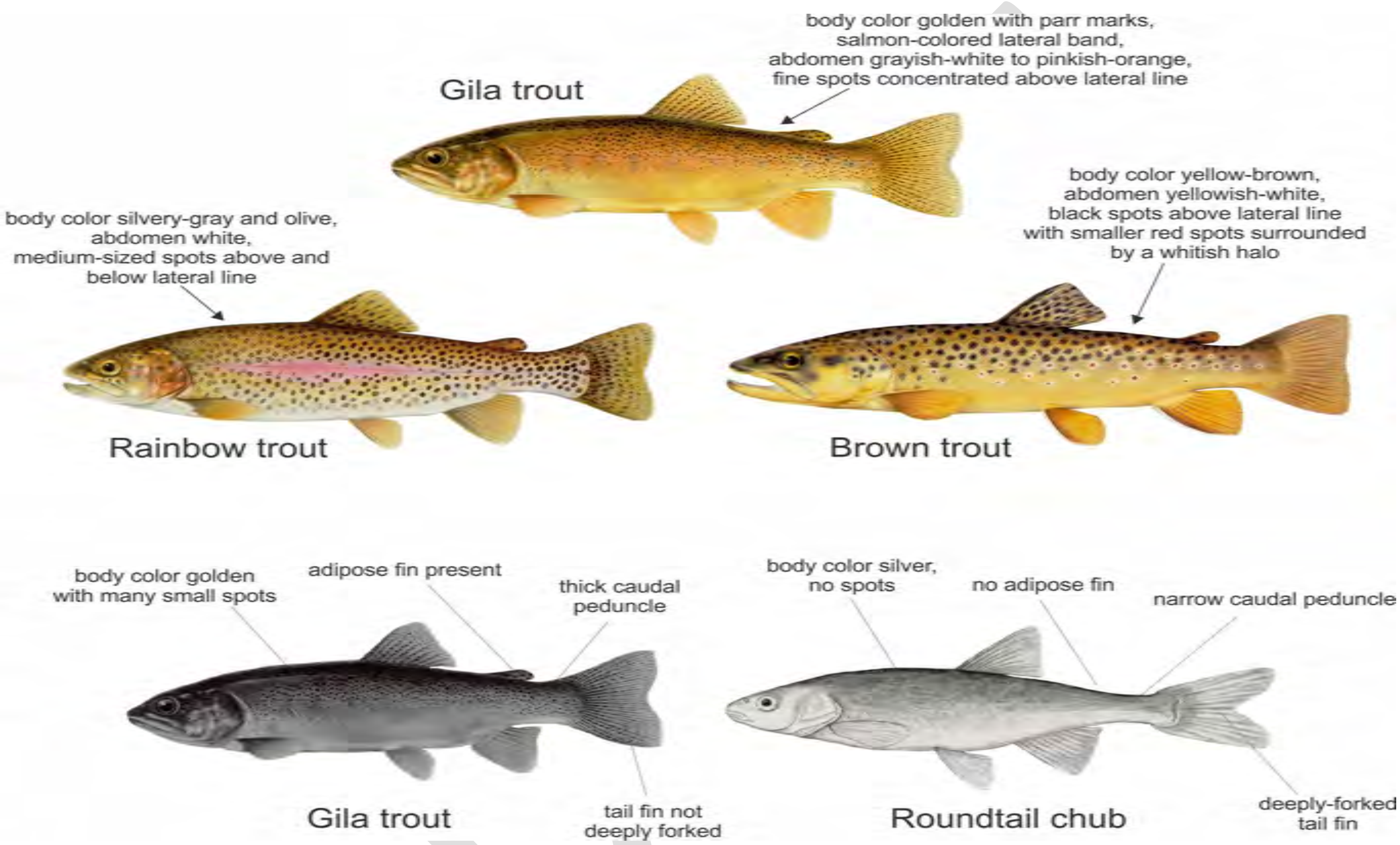

Figure 1. Comparison of field characteristics that distinguish Gila trout from co-occurring, nonnative trout and roundtail chub (Joseph R. Tomelleri).

Systematics

The genus *Oncorhynchus* is monophyletic (Wilson and Turner, 2009) meaning that it consists of a common ancestor and all of its descendants. Gila trout is in the Pacific trout clade (a common ancestor and all lineal descendants) along with Apache trout (*O. apache*), rainbow trout (*O. mykiss*) and cutthroat trout (*O. clarkii*) (Figure 2). The Pacific trout lineage split from the Pacific salmon lineage approximately 6.3 million years ago, the cutthroat trout and rainbow trout lineages diverged approximately 2.3 to 3.8 million years ago, and lineages of the rainbow trout clade diverged sometime in the last 1.4 million years (Wilson and Turner, 2009). The Gila trout and rainbow trout lineages split 0.61 to 2.3 million years ago, and the Gila trout and Apache trout lineages diverged approximately 0.15 to 1.3 million years ago (Wilson and Turner, 2009). Therefore, Gila trout and Apache trout are more closely related to rainbow trout than they are to cutthroat trout. In addition, Gila trout and Apache trout are closely related, and the two taxa compose a monophyletic group. The analysis conducted by Wilson and Turner (2009) confirmed earlier work that indicated Gila and Apache trout were derived from an ancestral form that also gave rise to rainbow trout (Behnke, 1992; Dowling and Childs, 1992; Utter and Allendorf, 1994; Nielsen *et al.*, 1998; Riddle *et al.*, 1998).

Genetics

Since the time of listing, a vast number of genetic studies have been conducted on Gila trout, with most analyses focused on assessing the 'purity' (extent of distinctiveness in terms of lineages, extent of hybridization) and diversity of remnant populations. Early studies analyzing genetic differentiation between Gila trout, Apache trout, rainbow trout, and cutthroat trout confirmed separation of Gila trout from other *Oncorhynchus* species (Figure 2). Genetic similarity is not surprising as these species share a common ancestor. However, examination of allozymes revealed differentiation between Gila trout, rainbow trout, and cutthroat trout (Loudenslager *et al.*, 1986; Leary and Allendorf, 1999; Dowling and Childs, 1992). Analysis of mitochondrial DNA also indicated genetic differentiation of Gila trout, Apache trout, rainbow trout, and cutthroat trout (Dowling and Childs, 1992; Riddle *et al.*, 1998; Wares *et al.*, 2004; Wilson and Turner, 2009).

See Appendix B for an in-depth discussion of Gila trout genetics.

Description of Lineages

Historical collections from streams in the upper Gila River Basin and San Francisco River Basin along with genetic analysis indicated that five lineages of Gila trout persist on the landscape; Main Diamond Creek, South Diamond Creek, Whiskey Creek, Spruce Creek, and Iron Creek. Allozyme data has revealed divergence between Gila trout populations of the San Francisco River Drainage and the Gila River Drainage (Wares *et al.*, 2004). The Spruce Creek population (San Francisco Drainage) contained four unique alleles not found in the Gila River Drainage populations. The common allele found in all the upper Gila River drainage populations was absent in the Spruce Creek population. Further investigations (using microsatellites, mitochondrial DNA, and MHC) into variation among the five remnant populations indicated that the Whiskey Creek lineage was likely an intermediary between the Main Diamond Creek and South Diamond Creek lineages and is highly genetically diverse. Spruce Creek lineage, however, had the least genetic diversity of all lineages. Iron Creek lineage possessed more unique variation than all other lineages of Gila Trout and is evolutionarily important to Gila Trout recovery (Turner, 2013).

There is considerable genetic variation among populations of Gila trout in Main Diamond Creek, South Diamond Creek, Whiskey Creek and Spruce Creek. Introgression of nonnative trout has not been detected in any of these four populations. There is substantial genetic divergence of the Spruce Creek population from the Main Diamond Creek, South Diamond Creek and Whiskey Creek populations (Leary and Allendorf, 1999; Wares *et al.*, 2004; Peters and Turner, 2008). The populations of Gila trout from Main Diamond Creek and South Diamond Creek are in the East Fork Gila River drainage, the Whiskey Creek population is in the West Fork Gila River drainage, and the Spruce Creek population is in the San Francisco River drainage. A fifth population, located in Iron Creek (David, 1976), is in the Middle Fork Gila River drainage. These populations, hereafter referred to as remnant lineages, encompass the breadth of local adaptation and evolutionary potential represented by known genetic variation that presently exists within the species.

See Appendix C for an in-depth discussion of Gila trout lineages.

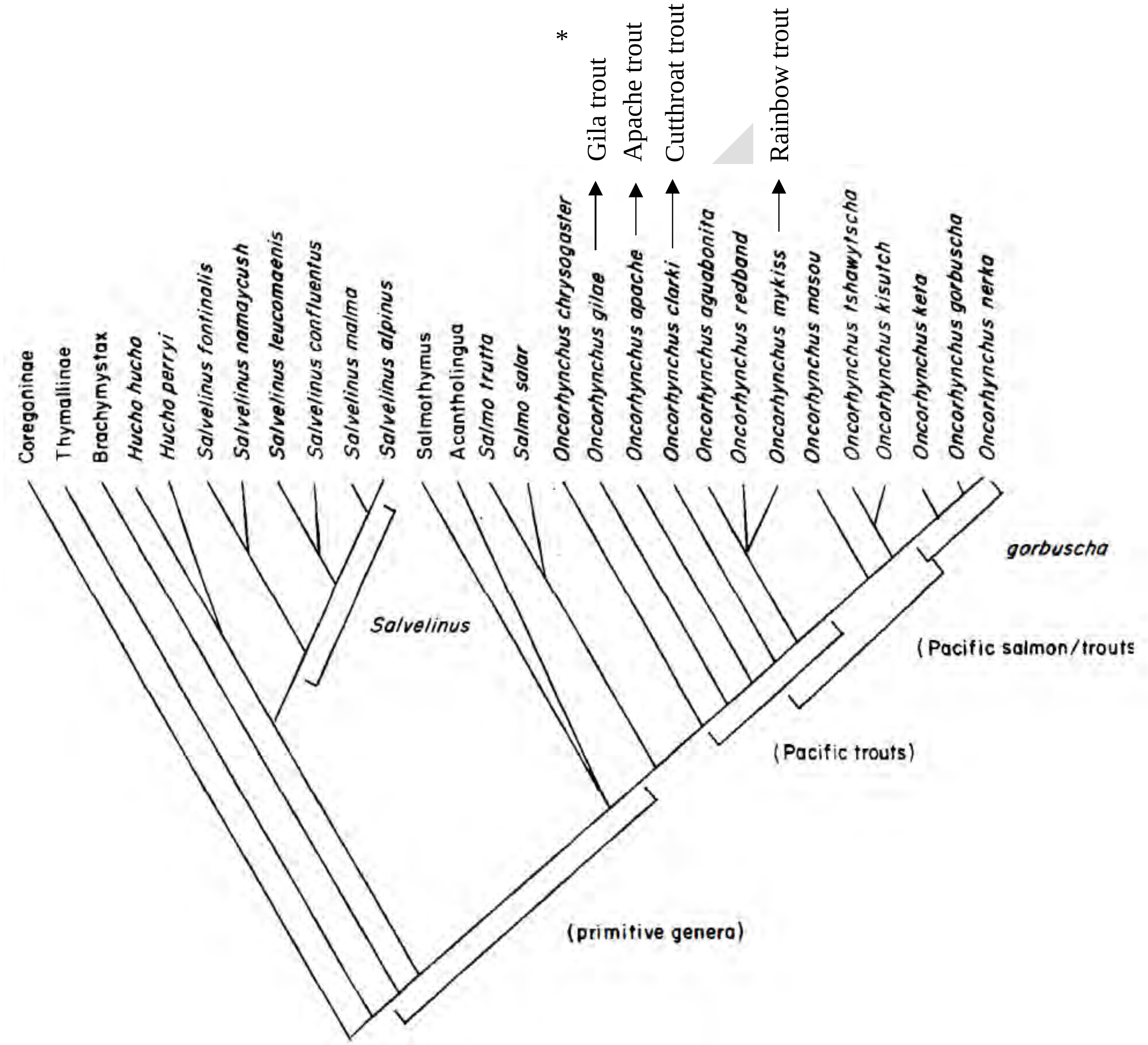

Figure 2. Hypothetical phylogenetic tree of Salmonidae based on morphology and karyotypes, modified from Phillips and Pleyte (1991).

Historical Range and Current Distribution

Historical Range

The historical range of Gila trout is not definitively known and can only be inferred from available evidence, which includes: a few early collection records; reports of native trout from drainages prior to the introduction of nonnative species (with the understanding that confusion of chubs and trout was locally common, *cf*. Appendix A – Morphological Description); current distributions of trout in the Gila River drainage basin; and distributions of historically co-occurring species. Based on these information sources, the historical distribution likely included montane, cold-water stream habitats in Sierra, Grant, and Catron counties in New Mexico and Greenlee, Apache, Graham, Gila, and Yavapai counties in Arizona (Figure 3).

In order to map the potential historical extent of habitat suitable for Gila trout, mapping efforts visualized perennial stream segments over 1,524 m (5,000 ft.) using National Hydrography Dataset (NHD) data from U.S. Geological Survey (2016*b*; Figure 3). The 1,524 m (5,000 ft.) lower elevation limit was defined because it roughly corresponds with contemporary distributional limits for *Oncorhynchus* species. The NHD represent contemporary stream conditions (post-1950), and therefore may not be an entirely accurate depiction of the potential distribution of Gila trout prior to the onset of large-scale Euro-American settlement of the Southwest (*ca*. 1848). An assumption was made that prior to widespread Euro-American settlement largely unaltered watershed and riparian conditions would have sustained stream flows and adequate temperatures suitable for habitation by native trout throughout most stream segments above 1,524 m (5,000 ft.) that are mapped as perennial by the NHD. However, it is likely that not all of this habitat was occupied by native trout due to stream isolation, site-specific conditions that rendered habitat unsuitable, and errors in mapping. With this understanding, it was assumed that NHD mapping of perennial streams over 1,524 m (5,000 ft.) elevation provided a reasonable facsimile of the "potential" extent and distribution of suitable habitat for Gila trout throughout its historical range prior to large-scale settlement by Euro-Americans.

Historically, the Gila River had surface flow from its headwaters to its confluence with the Colorado River (Corle, 1951 cited in Rinne *et al.*, 2005). Miller (1961) described the historical character of the main-stem Gila River as a "large, essentially permanent stream of clear to sea-green water." Consequently, at least some of the watersheds within the historical range of Gila trout (Figure 3) may have been hydrologically connected periodically. Consequently, conditions may have been suitable for at least occasional, seasonal movement of trout through main-stem river habitats in the current climate period (Marine Isotope Stage 1, Holocene epoch) prior to substantial human-caused habitat changes. The potential historical distribution of Gila trout in various sub-basins of the Gila River drainage is described below.

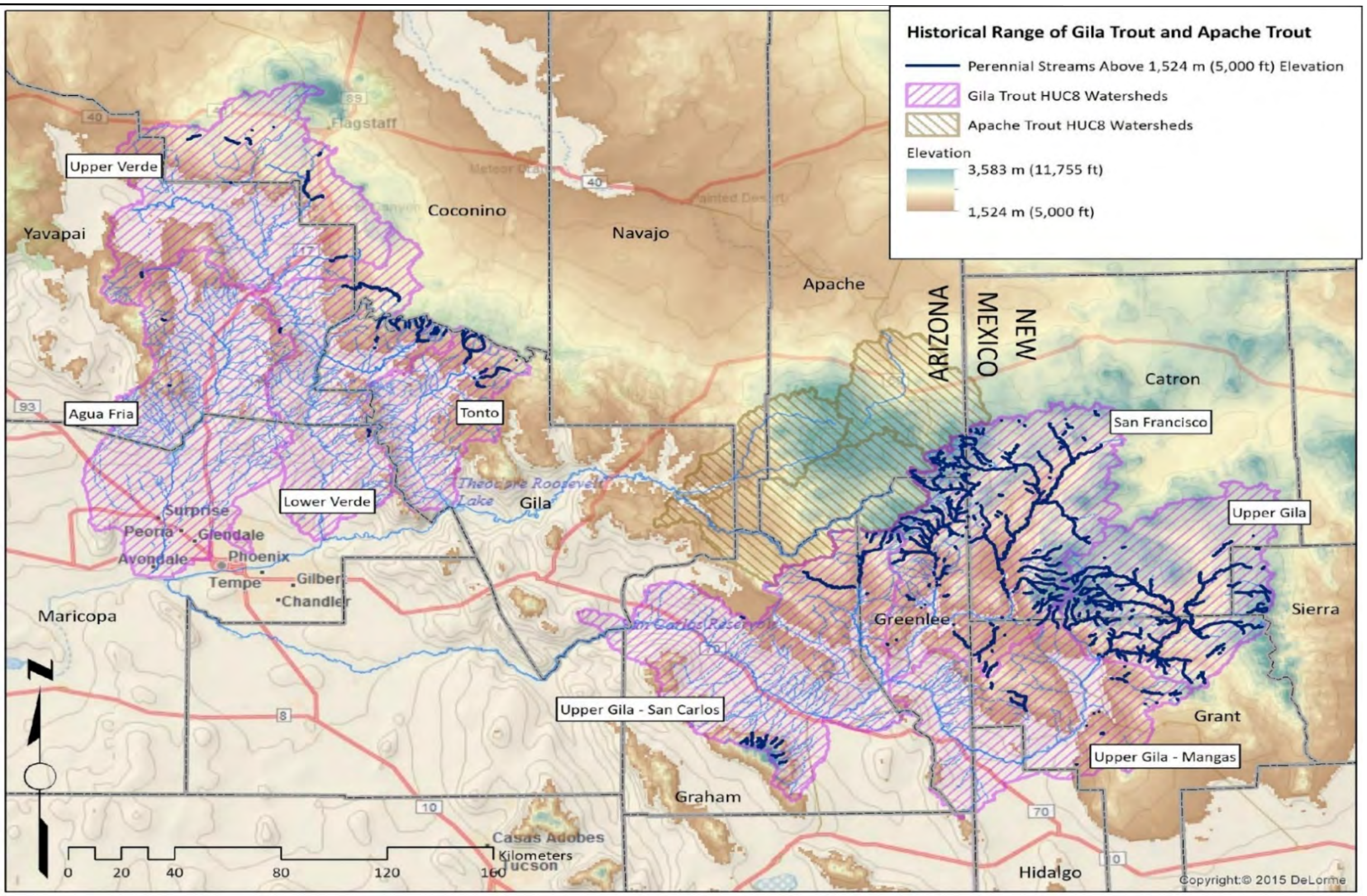

Figure 3. Historical range of Gila trout based on past observations and collections. Highlighted river segments are the potential historical suitable habitats established by mapping the streams and stream segments that lie above 1,524 m (5,000 ft.) elevation.

Upper Gila River, New Mexico

The earliest documented collections of Gila trout in the upper Gila River drainage (Figure 4) were from Main Diamond Creek, made by R.R. Miller in 1939 (UMMZ 137089; museum acronyms follow Leviton *et al.*, 1985). Gila trout was collected from White Creek in 1952 (E. Huntington, MSB 002045) and from Langstroth Canyon and South Diamond Creek in 1953 (J. Sands, MSB 2046 and MSB 2047 & 2050). Huntington (1955) reported Gila trout from 17 streams in the Gila River drainage in New Mexico. These streams included:

- Main Diamond Creek and South Diamond Creek in the East Fork drainage;
- Little Creek, McKenna Creek, Trail Canyon, Langstroth Canyon, White Creek, Cub Creek and the upper West Fork in the West Fork Gila River drainage;
- upper Willow Creek and Iron Creek in the Middle Fork drainage;
- Rain Creek, West Fork Mogollon Creek, Mogollon Creek in the Mogollon Creek drainage and Turkey Creek, a tributary to the Gila river main-stem upstream from Mogollon Creek; and
- Whitewater Creek and Spruce Creek in the San Francisco River drainage.

Dinsmore (1924) reported that the headwaters of the West Fork Mogollon Creek were fishless prior to the stocking of 23 “trout” there in 1914. The source of the stocked “trout” was not specified. In 1975, Gila trout was collected from McKenna Creek (P. Turner, NMSU 3 and 4) and Iron Creek (R. David, NMSU 5). Gila trout was discovered in Whiskey Creek, a tributary to the upper West Fork Gila River, by N. W. Smith in 1992 (Figure 4). Beginning in the late 1970s, hybrids of Gila trout and rainbow trout (Gila x rainbow) were reported from Black Canyon, Sycamore Creek, Langstroth Canyon, Miller Spring Canyon, Trail Canyon, upper Mogollon Creek, upper Turkey Creek, and West Fork Mogollon Creek (David, 1976; Riddle *et al.*, 1998; Figure 4).

Early reports indicate that Gila trout was found throughout tributary streams of the upper Gila River drainage. Rixon (1905) noted that “Snow Creek drains the Mogollon Mountains in this township (Township 10 South, Range 16 West); it is a large stream, well stocked with mountain trout, but is being rapidly depleted owing to lack of proper protection.” Miller (1950) recounted reports from long-time residents of the region that indicated Gila trout occurred in “all of the Gila headwaters” at the turn of the century. Specific streams mentioned included Gilita Creek, Willow Creek, South Diamond Creek, Black Canyon, Mogollon Creek (including West Fork Mogollon Creek; Figure 4). Gila trout was reported as occurring in the Middle and West forks of the Gila River and in the main stem of the Gila River downstream to near the Mogollon Creek confluence, approximately 11 km (7 mi) upstream from Cliff.

Collections of pure Gila trout and Gila x rainbow trout hybrids, reports from around the turn of the century, and the distribution of streams in the upper Gila drainage that currently support trout populations indicate that Gila trout was likely found in many cold-water streams throughout the drainage upstream from the confluence of Mogollon Creek and the Gila River.

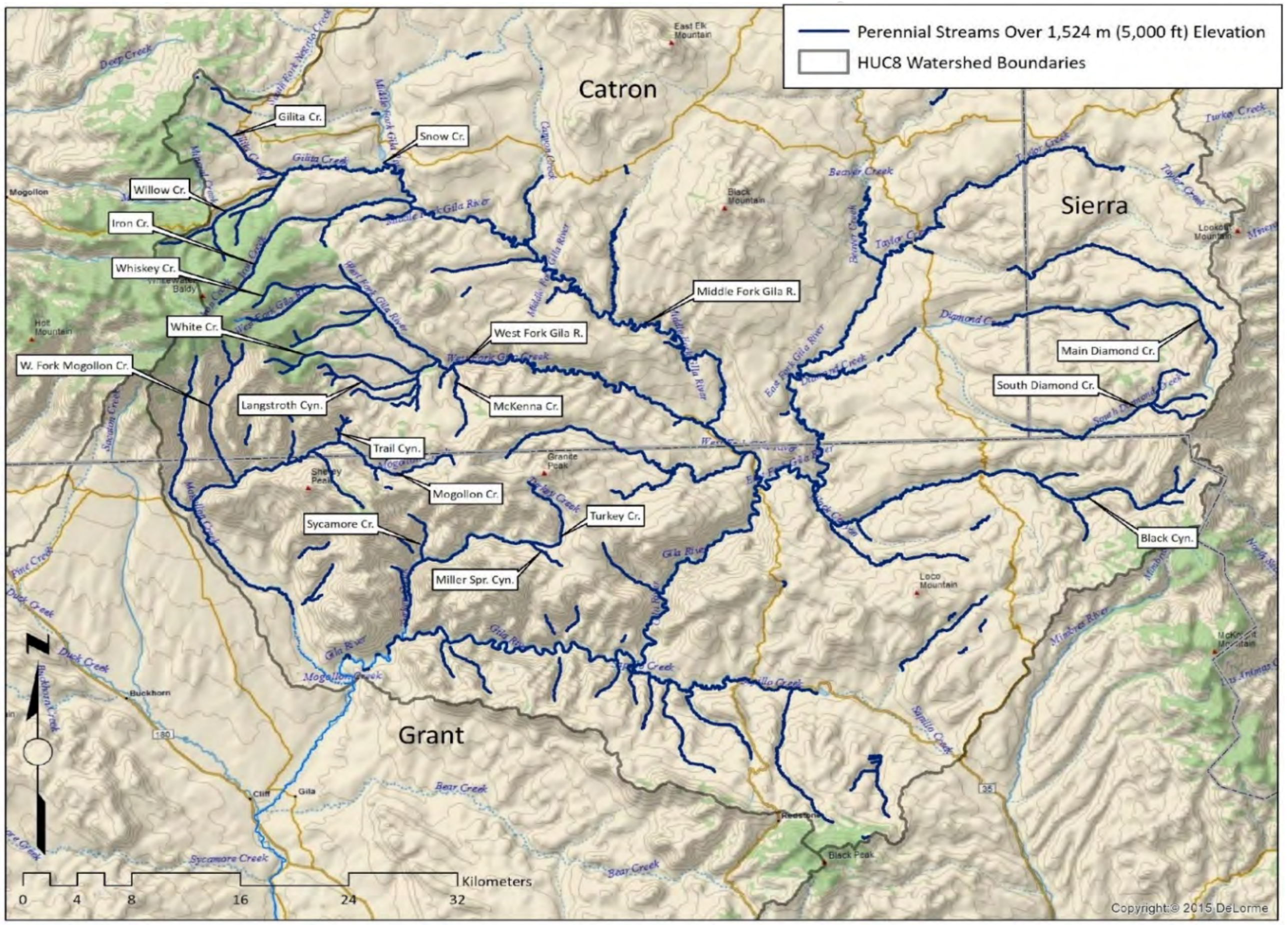

Figure 4. The upper Gila River drainage in New Mexico, showing locations references in discussion of the historical distribution of Gila trout.

San Francisco River, Arizona and New Mexico

Native trout were reported from the San Francisco River drainage (Figure 5) as early as 1885 (Leopold, 1921). Lack of collections prior to introduction of nonnative trout and absence of preserved specimens from many drainages led investigators to consider this native fish variously as Gila trout, Apache trout or an intergrade between the two. Leopold (1921) reported that the valley of the Blue River (Figure 5), a tributary to the San Francisco River, was "at the time of settlement in about 1885, stirrup-high in gramma grass and covered with groves of mixed hardwoods and pine. The banks were lined with willows and the river abounded with trout." Native trout were collected from KP Creek (Figure 5), a tributary to the Blue River, in 1904 by F. Chamberlain (Miller, 1950).

David (1976) collected and described Gila trout (NMSU 6) from above a series of waterfalls in Spruce Creek (Figure 5), a tributary to the San Francisco River in New Mexico. Miller (1950) reported that Spruce Creek contained a population of Gila trout, with the implication that it was native to that stream. This was inconsistent with the report that the San Francisco River was originally devoid of Gila trout and that the species was stocked into Big Dry Creek, Little Dry Creek, Little Whitewater Creek, Whitewater Creek, and Mineral Creek in 1905 (Miller, 1950). However, native trout occurred in the Blue River and there are no physical barriers that would have prevented native trout from migrating up into the San Francisco River drainage (Behnke, 1979; David, 1998). Gila x rainbow trout hybrid populations were found in several tributaries to the San Francisco River including Whitewater Creek, Big Dry Creek, Mineral Creek, and Lipsey Canyon (Figure 5; David, 1976; Riddle *et al.*, 1998).

These early reports and collections of a native trout in the San Francisco River drainage and the occurrence of a population of Gila trout in Spruce Creek above a series of waterfalls suggest that Gila trout likely occurred throughout the drainage in suitable habitats. Historically occupied streams may have included the Blue River and its tributaries and perennial tributaries of the San Francisco River in New Mexico.

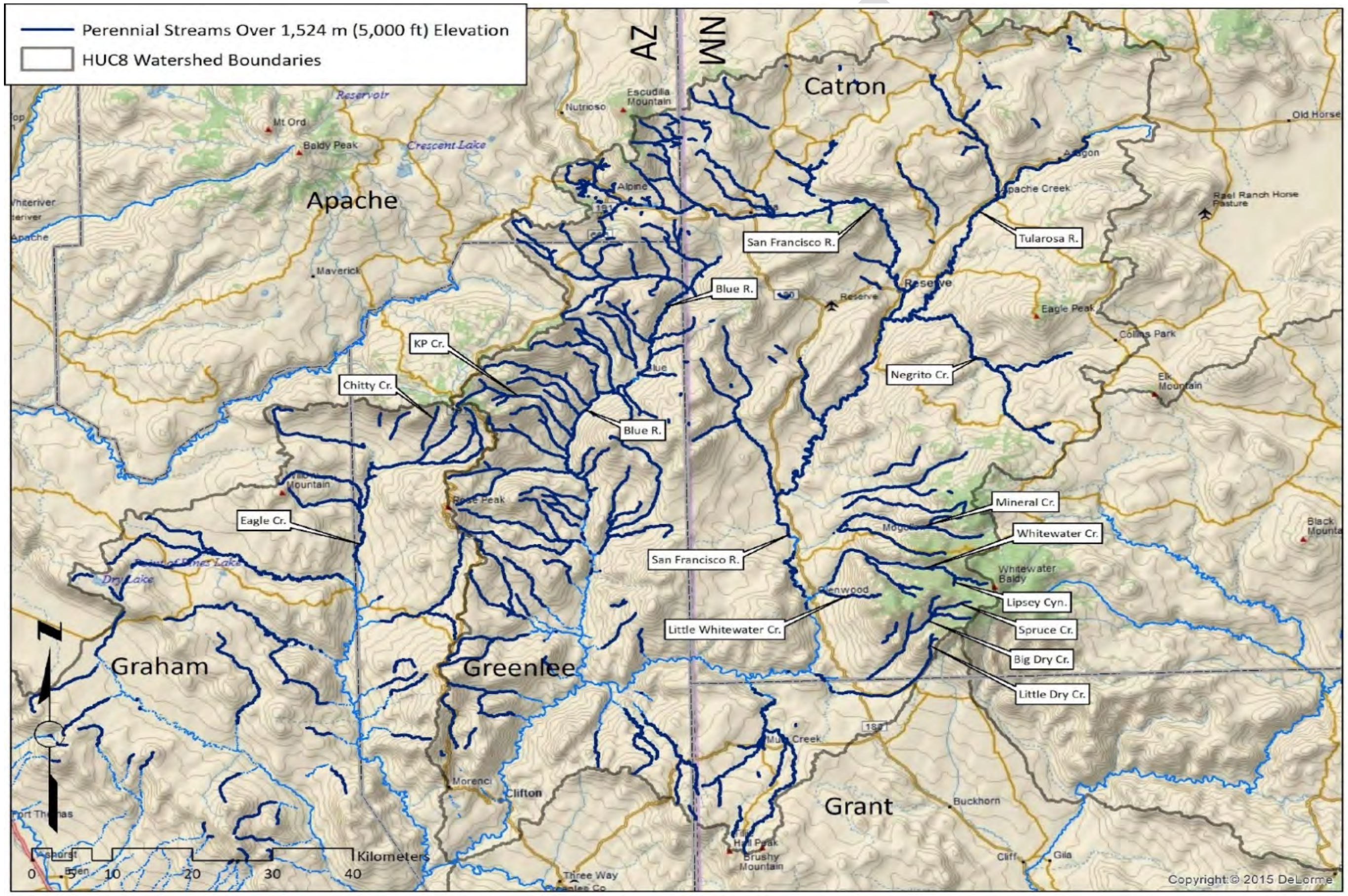

Figure 5. The San Francisco River and Eagle Creek drainages in New Mexico and Arizona, showing locations references in discussion of the historical distribution of Gila trout.

Tributaries to the Gila River, Arizona

Native trout occurred in the Eagle Creek drainage (Figure 6), a tributary of the Gila River in Arizona located west of the San Francisco River drainage (Mulch and Gamble, 1956; Kynard, 1976; Service, 2009). The identity of this native trout, collected in Chitty Creek (Figure 6) and now lost through hybridization with rainbow trout, is uncertain (Marsh *et al.*, 1990). Native trout were reported from Oak Creek (Figure 6), a tributary to the Verde River, before the turn of the century (Miller, 1950). Specimens collected from Oak Creek before 1890 (USNM 39577-79, 41568) were ascribed to Gila trout (Miller, 1950; Minckley, 1973). Native trout were also reported from West Clear Creek (Miller, 1950; Figure 6). Trout collected in 1975 from Sycamore Creek (Figure 6) in the Agua Fria River watershed were reported to be Gila x rainbow trout hybrids. However, this determination was based solely on examination of spotting pattern (Behnke and Zarn, 1976). A note in the archives of Aldo Leopold, dated 1923, contains anecdotal evidence of a native trout in Tonto Creek: “Trout in Tonto Cr. seem to be Eastern Brook. First put in 1920. Now seem to be up to 16”. (Hubert says there are also natives in it).”

Historical occurrence of Gila trout in the Verde and Agua Fria drainages was inferred by Minckley (1973) based on parallel distribution of a morphological form of roundtail chub. At that time Gila trout was the only recognized native trout in the Gila River drainage. Subsequent description of Apache trout demonstrated differentiation of native trout within the Gila River drainage (Miller, 1972). The degree of differentiation of the native trout in the Agua Fria River and Verde River drainages is unknown (Minckley, 1973) and cannot be resolved because specimens are lacking. However, this native trout was likely very closely related to Gila trout based on lack of long-term hydrologic isolation of the Verde and Agua Fria drainages from the main-stem Gila River.

Based on these early reports and collections of native trout within various tributaries of the Gila River within Arizona, historically occupied streams may include the Verde, Agua Fria, Tonto, and Blue River drainages in Arizona

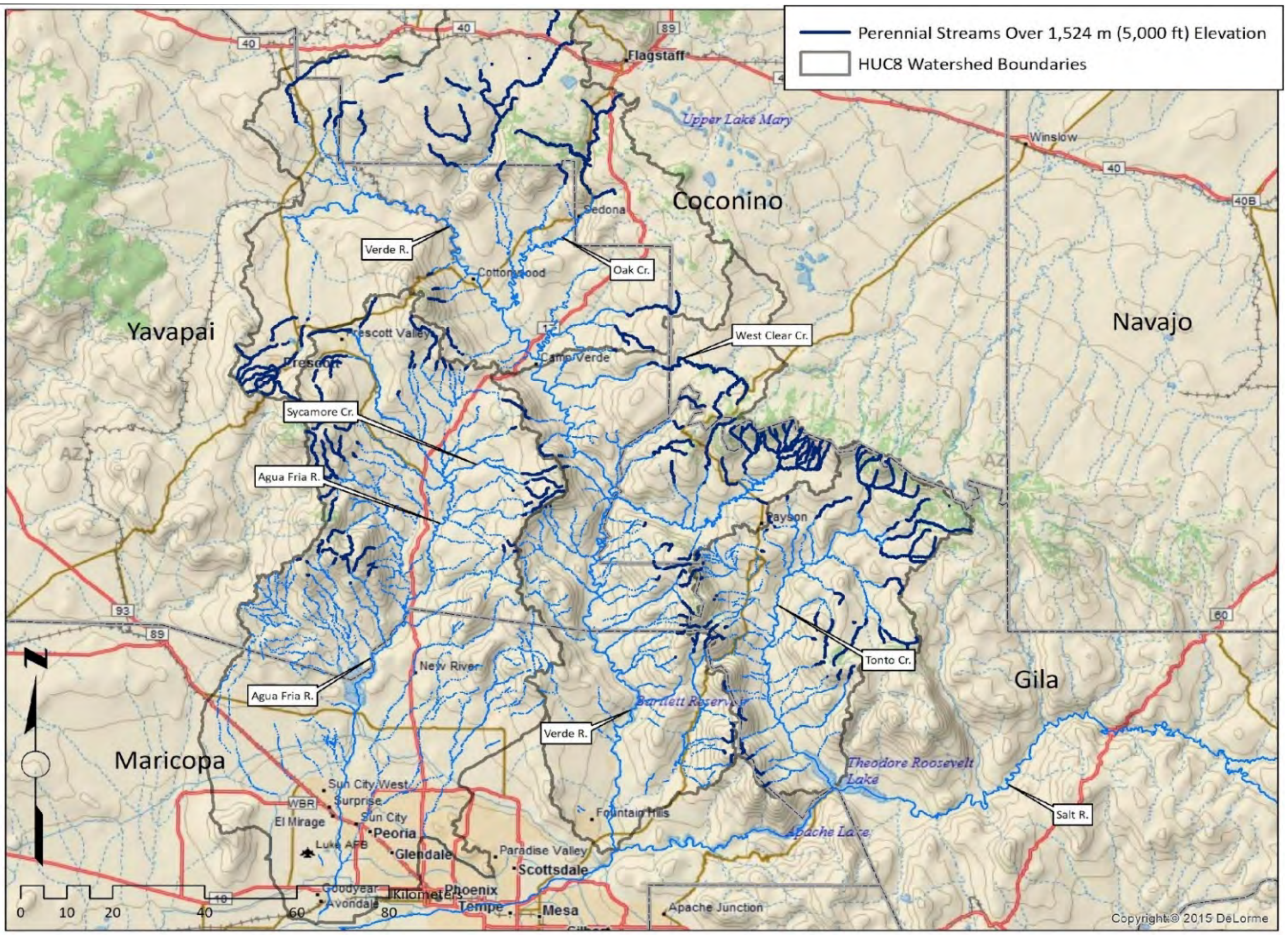

Figure 6. Tributaries of the Gila River in Arizona, showing locations references in the discussion of the historical distribution of Gila trout.

Current Distribution

The five lineages of Gila trout (Main Diamond Creek, South Diamond Creek, Whiskey Creek, Spruce Creek, and Iron Creek) have fluctuated in distribution since 1975; at that time, only five remnant populations were known, with populations being defined as self-sustaining groups of Gila trout which exhibit annual reproduction, size structure indicating multiple ages, and individuals attaining sufficient sizes to indicate three to seven years of survival (Service 2006). As of August 2019, there were 17 populations of Gila trout inhabiting approximately 137.5 km (85.2 mi) of stream habitat (Table 1 and Figure 7). Currently, there are 5 populations of the Main Diamond Creek lineage, 4 populations of the South Diamond Creek lineage, 3 populations of the Whiskey Creek lineage, 2 populations of the Spruce Creek lineage, 2 populations of the Iron Creek lineage, and 1 population (Dude Creek) that is considered a mixed-lineage population (a stream or metapopulation that contains multiple lineages of Gila Trout instead of a single lineage).

Several of these populations may occur in complex drainage systems as a metapopulation, spatially structured populations where: 1) habitat consists of discrete patches or collections of habitats capable of supporting local breeding populations; 2) the dynamics of occupied patches are not perfectly synchronous; and, 3) dispersal among the component populations influences the dynamics and/or the persistence of the metapopulation (Rieman and Dunham, 2000). For example, Trail Canyon, Woodrow Canyon, Mogollon Creek and South Fork Mogollan Creek are all considered single populations that collectively compose a metapopulation.

Table 1. Extant populations of Gila trout as of August 2019. Map No. refers to the notations on Figure 7. Codes for mixed lineages are SC= Spruce Creek, WC= Whiskey Creek, MD= Main Diamond Creek, and SD= South Diamond Creek

Lineage and Stream	Map No.	Occupied Habitat		HUC8 Watershed (Stream Drainage)	County	State
		km	mi			
Main Diamond Creek Lineage						
Main Diamond Creek	1	6.3	3.9	Upper Gila (East Fork Gila River)	Sierra	NM
Black Canyon	2	17.4	10.8	Upper Gila (East Fork Gila River)	Grant	NM
Sheep Corral Canyon	3	1	0.6	Upper Gila (Sapillo Creek)	Grant	NM
Langstroth Canyon (upper)	4	6.8	4.2	Upper Gila (West Fork Gila River)	Catron	NM
Little Creek (lower)	5	4.6	2.9	Upper Gila (West Fork Gila River)	Grant, Catron	NM
Subtotal		**36.1**	**22.4**	**5 Populations**		
South Diamond Creek Lineage						
South Diamond Creek	6	3.2	2.0	Upper Gila (East Fork Gila River)	Sierra	NM
Mogollon Creek (Includes tributaries upstream of West Fork Mogollon Creek)	9	25.3	15.7	Upper Gila (Mogollon Creek)	Grant, Catron	NM
Grapevine Creek	11	1.9	1.2	Agua Fria (Big Bug Creek)	Yavapai	AZ
Willow Creek (Includes tributaries upstream of Gilita Creek)	13	19	11.8	Upper Gila (Middle Fork Gila River)	Catron	NM
Subtotal		**49.4**	**30.7**	**4 Populations**		

Lineage and Stream	Map No.	Occupied Habitat		HUC8 Watershed (Stream Drainage)	County	State
		km	mi			
Whiskey Creek Lineage						
White Creek	15	11.0	6.8	Upper Gila (West Fork Gila River)	Catron	NM
Mineral Creek (Includes South Fork Mineral Creek)		18.8	11.7	San Francisco (San Francisco River)	Catron	NM
Raspberry Creek		4.1	2.5	San Francisco (San Francisco River)	Greenlee	AZ
Subtotal		**33.9**	**21.0**	**3 Populations**		
Iron Creek Lineage						
Iron Creek	16	4.4	2.7	Upper Gila (Middle Fork Gila River)	Catron	NM
Chase Creek		2.0	1.2	Upper Gila (Gila River)		AZ
Subtotal		**6.4**	**3.9**	**2 Populations**		
Spruce Creek Lineage						
Spruce Creek (upper)		5.7	3.5	San Francisco (San Francisco River)	Catron	NM
Big Dry Creek (upper)	17	2.9	1.8	San Francisco (San Francisco River)	Catron	NM
Subtotal		**8.6**	**5.3**	**2 Populations**		
Mixed Lineages						
Dude Creek (MD, SD, WC, SC x WC)	18	3.1	1.9	Lower Verde (East Verde River)	Gila	AZ
Subtotal		**3.1**	**1.9**	**1 Population**	Gila	AZ
Grand Total		**137.5**	**85.2**	**17 Populations**		

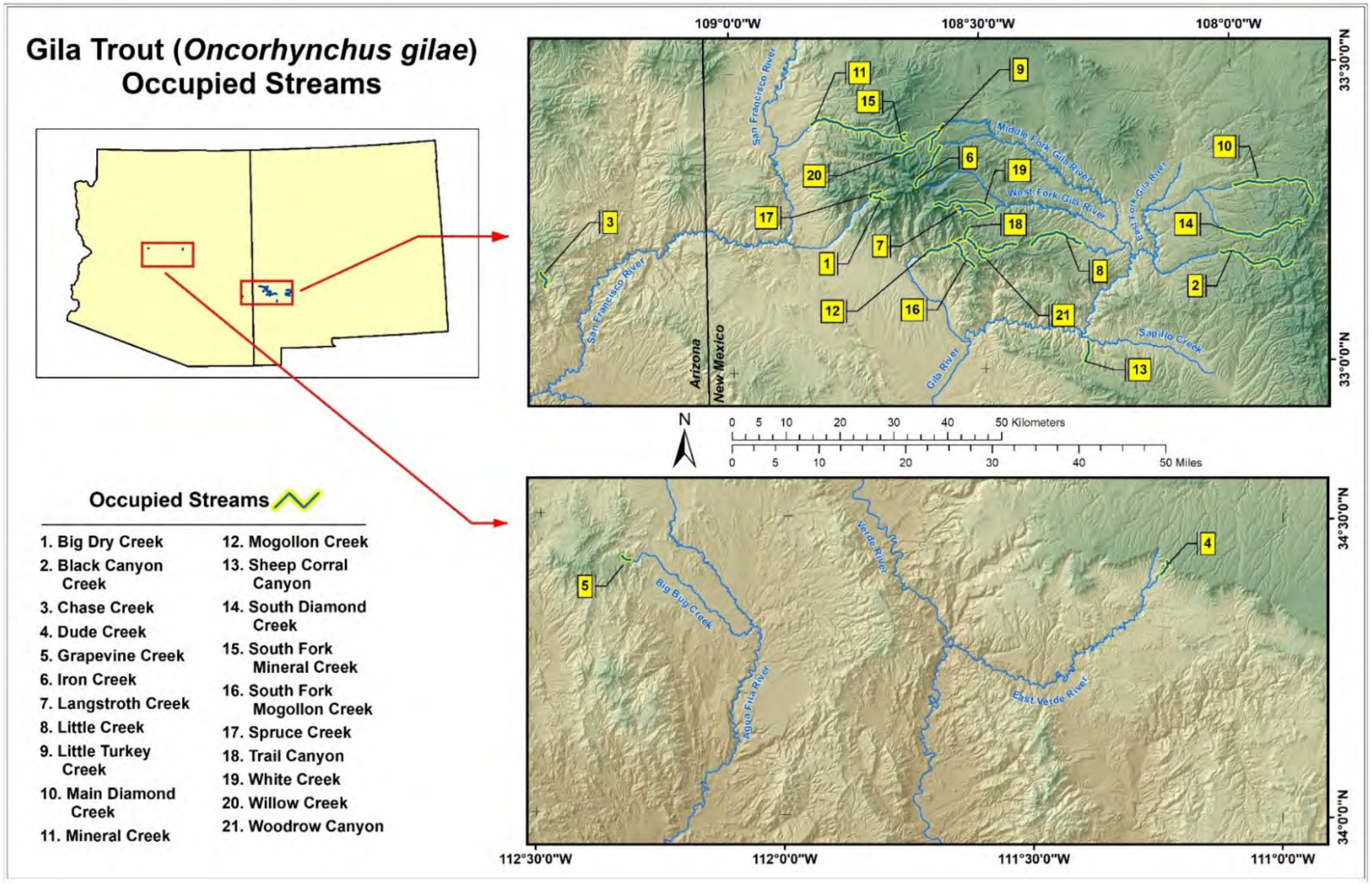

Figure 7. Current distribution of Gila trout as of August 2019.

Ecology and Life History

Reproduction and Growth

Spawning of Gila trout occurs mainly in April (Rinne, 1980). Spawning begins when water temperatures reach about 8°C (46ºF), but day length may also be an important cue. Stream flow is apparently of secondary importance in triggering spawning activity (Rinne, 1980). Female Gila trout typically construct redds in water 6 to 15 cm (2.4 to 6 in) deep within 5 m (16 ft.) of cover. Redds are three to four cm (1.2 to 1.6 in) deep in fine gravel and coarse sand substrate (particle size ranging from 0.2 to 3.8 cm [0.08 to 1.5 in] diameter). Redd size varies from less than 0.1 to 2.0 m^2 (1.1 to 21.5 $ft.^2$). Spawning activity typically occurs between 1300 and 1600 hours. Rinne (1980) noted one pair of Gila trout normally occurred over a redd and spawning behavior was typical of other salmonids (Family Salmonidae).

Females reach maturity at Age II to Age IV (time since hatching) (Nankervis, 1988), with a minimum length of about 130 mm (5 in) reported for mature fish (Nankervis, 1988; Propst and Stefferud, 1997). However, most individuals are mature at a length of 150 mm (6 in) or greater (Propst and Stefferud, 1997). Males typically reach maturity at Age II or Age III. Fecundity is dependent upon body size and condition (Behnke and Zarn, 1976; Behnke, 1979). Behnke and Zarn (1976) reported a general figure of 2.20 ova per gram of body weight (62 ova/oz.) for native trouts. Brown and others (2001) reported individual fecundity (count of mature ova) of approximately 62 for Gila trout 100 to 150 mm (3.9 to 5.9 in) total length and 197 for Gila trout greater than 150 mm (5.9 in) total length. Gila trout had an average of 2.54 ova per gram of body weight (72 ova/oz.) in Main Diamond Creek and 3.33 ova/g of body weight (94 ova/oz.) in McKnight Creek (Nankervis, 1988).

Gila trout fry (20 to 25 mm [0.8 to 1.0 in] total length) emerge from redds in 56 to 70 days (Rinne, 1980). By the end of the first summer, fry attain a total length of 70 to 90 mm (2.7 to 3.5 in) at lower elevation streams and 40 to 50 mm (1.6 to 2.0 in) at higher elevation sites (Rinne, 1980; Turner, 1986). Growth rates are variable, but Gila trout generally reach 180 to 220 mm (7.1 to 8.7 in) total length by the end of the third growing season in all but higher elevation streams (Table 2).

Mean survival rates for life stages of Gila trout range from 0.128 to 0.497 (Table 2; Brown *et al.*, 2001). Survival rate is defined as the proportion of individuals of age x that survive to age x + 1. On the average, for every 100 eggs that hatch about half will survive to the juvenile life stage. Of those 49 or 50 fish, only about six will survive to the subadult stage and of those six subadults, only two will survive to the adult life stage. Most adult Gila trout live to about Age V (Turner, 1986), with a maximum age of IX reported by Nankervis (1988). Thus, the majority of adult female Gila trout only spawn twice before dying and most adult males only spawn three or four times before dying.

Table 2. Life-stage specific survival rates for Gila trout (Brown *et al.*, 2001).

Life Stage	Total Length	Survival Rate (mean ± one standard deviation)
Juvenile	< 100 mm (< 4 in)	0.497 ± 0.445
Subadult	100 to 150 mm (4 to 6 in)	0.128 ± 0.063
Adult	> 150 mm (> 6 in)	0.430 ± 0.068

See Appendix D for additional information on Gila trout ecology and life history, including specific information on each lineage as well as the impacts of disease on the Gila trout.

Diet

Gila trout are generally insectivorous. However, the species coevolved with several other fishes and there is some evidence of piscivory in Gila trout. Regan (1964) reported that adult Diptera (true flies), Trichoptera (caddisfly) larvae, Ephemeroptera (mayfly) nymphs, and aquatic Coleoptera (beetles) were the most abundant food items in stomachs of Gila trout in Main Diamond Creek. There was little variation in food habits over the range of size classes sampled (47 to 168 mm [1.8 to 6.6 in] total length). These taxa were also predominant in stomach contents of other trout species in the Gila River drainage, indicating the potential for interspecific competition. Hanson (1971) noted that Gila trout established a feeding hierarchy in pools during a low flow period in Main Diamond Creek. Larger fish aggressively guarded their feeding stations and chased away smaller fish.

Van Eimeren (1988) compared food habits of Gila trout and speckled dace in Little Creek and found no significant overlap in diet despite the fact that the two species were found in general proximity. Large Gila trout occasionally consumed speckled dace and may also consume smaller Gila trout (Van Eimeren, 1988; Propst and Stefferud, 1997). Gila trout diet shifted on a seasonal basis as the relative abundance of various prey taxa changed. In February, Diptera larvae (primarily blackflies, Family Simuliidae) were very abundant in the stream and were the principal prey of Gila trout. By May, the principal prey shifted to Ephemeroptera nymphs (primarily *Paraleptophlebia*) that were present at very high density. No single prey taxon dominated the diet of Gila trout in June. In October, Gila trout shifted to consuming primarily terrestrial insects and larvae of the caddisfly *Helicopsyche*. Gila trout fed mainly between the hours of 0900 and 1300, while speckled dace fed primarily between the hours of 2100 and 1300 (Van Eimeren, 1988). As in Regan's (1964) study, Van Eimeren (1988) reported a large overlap in food habits throughout all size classes of Gila trout.

Movement

Rinne (1982) considered adult Gila trout to typically be quite sedentary, with movement influenced by population density and territoriality. However, individual fish may move considerable distances (over 1.5 km [0.9 mi]). Gila trout showed a tendency to move upstream in South Diamond Creek, possibly to perennial reaches with suitable pool habitat in response to low summer discharge. Gila trout movement was predominately in a downstream direction in Main Diamond and McKnight creeks. Most of these fish were one or two year-old Gila trout (Rinne, 1982). High density of log structures in Main Diamond Creek appeared to reduce mobility of Gila trout in that stream.

Data collected from White Creek in 1999 and 2000 indicate that dispersal by Gila trout is slow, even when there are no physical barriers to movement. The Lookout Complex fire in 1996 burned much of the White Creek watershed upstream to near Halfmoon Park. During sampling in 1999, Gila trout was found to be absent from all portions of the stream except from the vicinity of Halfmoon Park and upstream from that location. In 2000, the downstream limit of Gila trout was only about 0.5 km (0.3 mi) downstream from Halfmoon Park. Fire-affected reaches of the stream below Halfmoon Park had recovered and were suitable for Gila trout in 2000. In contrast, upstream movement of over three kilometers following stocking of Gila trout was reported in Willow Creek.

Population Dynamics

Population Size

Regulation of population size and dynamics of populations (size and age structure) of Gila trout are not well understood. Inferences about factors that control population size have been made from analysis of time-series data (Turner and McHenry, 1985; Turner, 1989; Propst and Stefferud, 1997). Density-independent factors, namely hydrologic variability, appear to be most important in regulating population size of Gila trout in many of the streams occupied by the species (McHenry, 1986; Turner, 1989; Brown *et al.*, 2001). However, density-dependent regulation in the form of competition for space (territoriality) was suggested as a factor contributing to controlling population size in Main Diamond Creek before that population was extirpated by a stand-replacing forest fire in 1989 (Nankervis, 1988).

The changes in abundance of Gila trout in McKnight Creek from its establishment through 2000 suggest that population was regulated primarily by hydrologic regime. The population was founded in November 1970 when 307 Gila trout were transplanted from Main Diamond Creek to McKnight Creek. The population declined to about 20 fish in 1971, concurrent with a period of low total annual stream discharge. Consequently, the population was augmented with 110 Gila trout translocated from Main Diamond Creek in April 1972, and the population size increased substantially from 1974 to 1976 (Mello and Turner, 1980).

The McKnight Creek population remained relatively stable from 1977 to 1984 (Turner and McHenry, 1985). Flood flows in December 1984 were followed by a marked reduction in abundance of Gila trout (Figure 8; Turner, 1989). The population expanded following the 1984 flood and by June 1985 had recovered to near pre-flood abundance and size structure. The apparent reduced abundance of Gila trout in October 1985 was likely an artifact of reduced sampling efficiency due to high flows, and Gila trout abundance remained relatively stable through June 1988. Flooding in August 1988 was followed by elimination of the 1988 year class and reduced abundance of all other size classes (Figure 8; Turner, 1989). By fall 1990, the McKnight Creek population had recovered from the 1988 flood impacts (Figure 9; Propst and Stefferud, 1997). The population remained relatively stable from 1991 through spring 1994. However, very low flows in summer 1994 followed by winter flooding was associated with reduced abundance of juvenile Gila trout in spring 1995 (Figure 9). After two years of no monitoring, sampling from 1998 through 2000 indicated continued reproduction and relative stability of adult Gila trout abundance.

The role of hydrologic variation in regulation of Gila trout populations may be most relevant in influencing the abundance of Age 0 fish. For example, Cattanéo and others (2002) found that high flows during emergence significantly reduced Age 0+ brown trout densities, and that Age I+ trout densities were linked to Age 0+ densities from the previous year. Similarly, hydrologic variables including peak flows and extreme low flows were found to influence young-of-year abundance in cutthroat (Owens, 2013), rainbow and brook trout (Parker, 2008). Furthermore, Richard and others (2015) reported density-dependent regulation of Age 0+ brown trout abundance during summer low-flow periods. Wood and others (2012) determined that minimum territory size for juvenile rainbow trout (5 cm [2 in] total length) was approximately 0.2 m^2 (2.15 $ft.^2$), which they hypothesized as a threshold for activation of density-dependent regulation. Vincenzi and others (2008) suggested that resilience of marble trout (*Salmo marmoratus*) to irregular, severe flooding was a function of increases in size-dependent fecundity resulting from reduced population size following peak flow events.

Populations of Gila trout may vary in sensitivity and response to removal of adult fish. Populations with high densities and reduced growth rates due to crowding may benefit from limited harvest of adult fish. For example, biomass and condition of Gila trout increased following experimental removal of fish from a section of Main Diamond Creek in 1986 to 1987 (Nankervis, 1988). Brown and others (2001) found that simulated catch-and-release angling mortality of adult Gila trout of 5 to 15 percent per year had no effect on population viability.

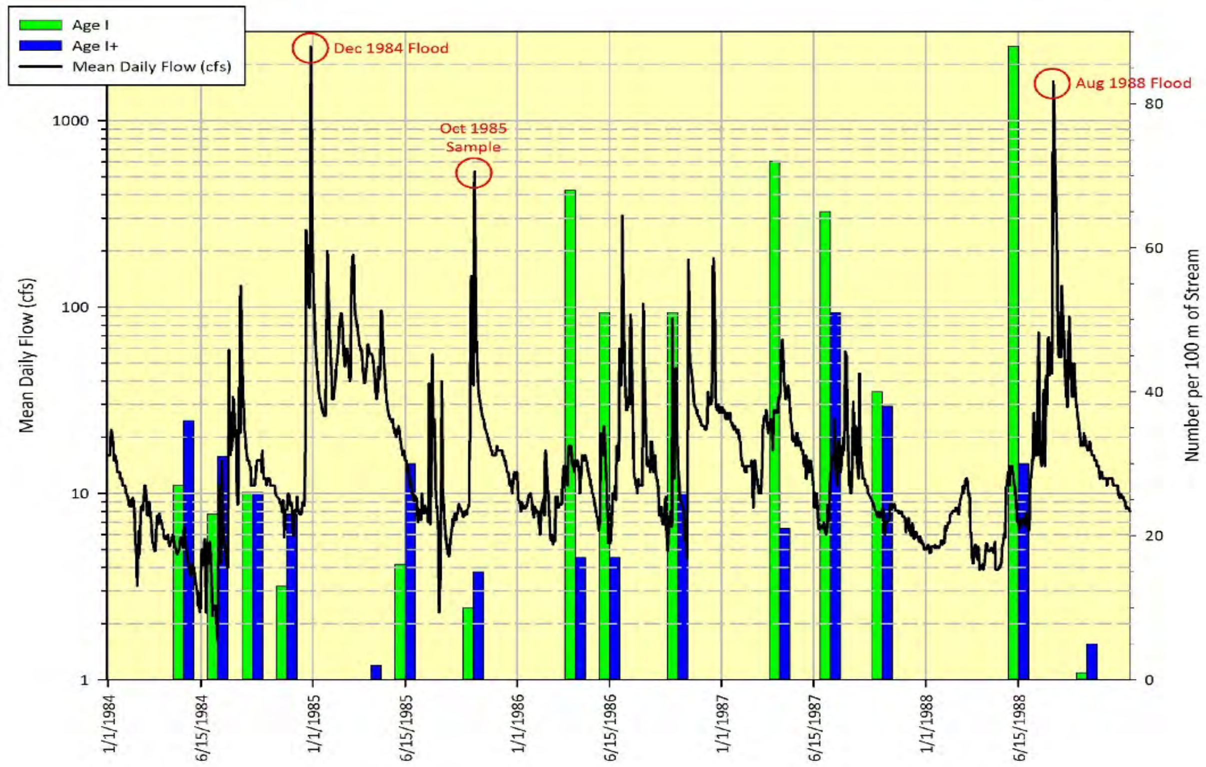

Figure 8. Catch per unit effort of Gila trout in McKnight Creek, 1984 through 1988, along with mean daily discharge data from U.S. Geological Survey gauge no. 08477110 Mimbres River at Mimbres, New Mexico.

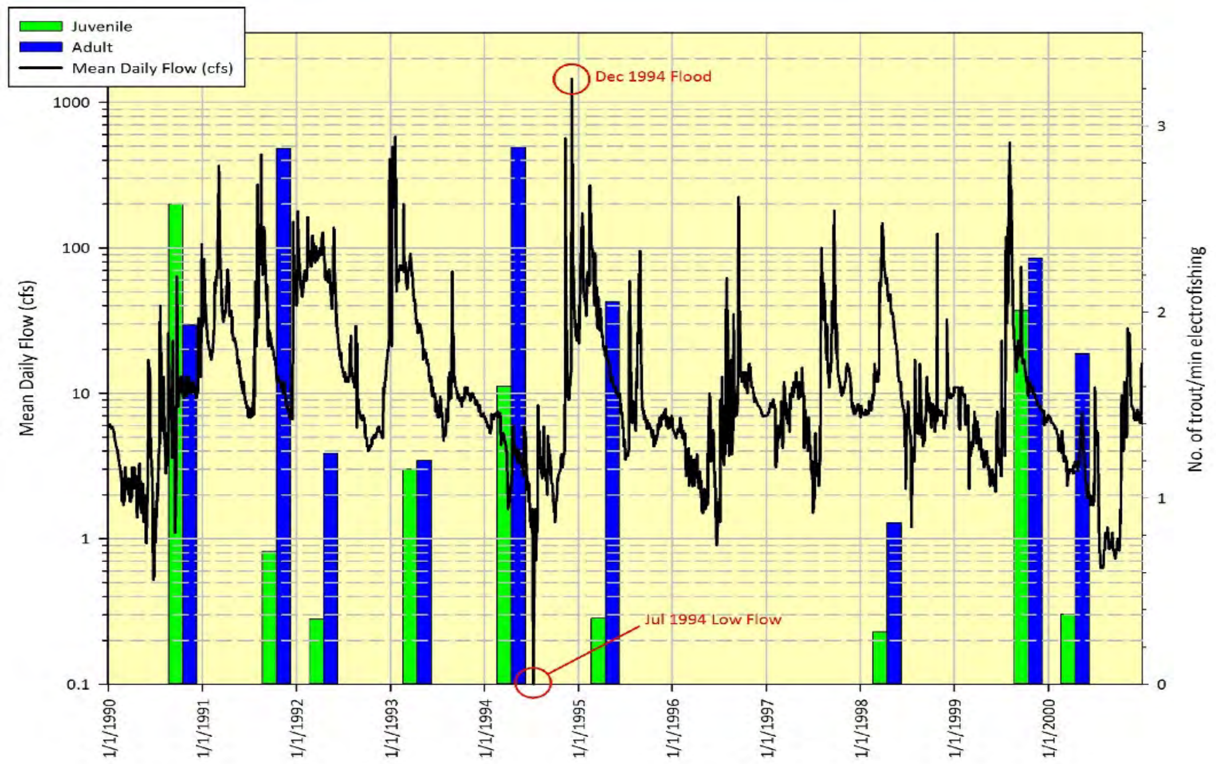

Figure 9. Catch per unit effort of Gila trout in McKnight Creek, 1990 through 2000, along with mean daily discharge data from U.S. Geological Survey guage no. 08477110, Mimbres River at Mimbres, New Mexico.

Population Persistence and Viability

Persistence of a species is generally defined as the ability of populations to remain in a given location over time. Viability of a species is generally defined as the ability to sustain populations over time. Historically, populations of Gila trout existed in multiple streams and tributaries within the Gila River and San Francisco River drainages. Fragmentation of the historical distribution of Gila trout has resulted in several populations confined to smaller, isolated segments of those streams and tributaries. These remnant populations characteristically have high densities during relatively stable flow periods (Platts and McHenry, 1988). The overall importance of environmental factors, specifically quantity and variability of stream discharge, in determining persistence of Gila trout populations is evidenced by the effects of fire, flood, and low flow on population size and density of this species. The elimination or extreme reduction of Gila trout populations following large-scale, high-severity wildfire and subsequent flooding provide a vivid example. Similarly, prolonged low flows or stream drying may also eliminate or markedly reduce populations of Gila trout (see tables 17 and 18). The importance of stream discharge in the

population dynamics of Gila trout has been consistently reported in the literature (Regan, 1964; Mello and Turner, 1980; McHenry, 1986; Turner, 1989; Propst and Stefferud, 1997).
Catastrophic events were found to have a much larger influence on the viability of Gila trout populations than population size, fecundity, or population structure (Brown *et al.*, 2001). The risk of extinction of Gila trout was found to be closely related to the number of extant populations. Brown and others (2001) reported that increasing the number of populations by 11 significantly reduced the probability of extinction from 36 percent to 12 percent. The Spruce Creek lineage of Gila trout was considered at higher risk of extinction than the Gila River lineages due to the small number of populations. Increasing the number of populations in the San Francisco River basin by six was estimated to reduce the risk of extinction from 81 percent to 44 percent. The population viability analysis conducted by Brown and others (2001) was completed prior to recent large-scale, high-severity wildfires that caused numerous population extirpations (see section on Large-Scale, High-Severity Wildfire and tables 4 and 5). These recent events indicate that spatial distribution is also an important component of population viability and persistence. Spatial distribution was not incorporated in the population viability analysis conducted by Brown and others (2001).

Habitat Characteristics

Elevation and Vegetative Community Associations

Habitat of Gila trout currently consists of montane streams ranging from approximately 1,660 m (5,400 ft.) to over 2,800 m (9,200 ft.) elevation (Propst and Stefferud, 1997). Suitable stream habitat within the range of the species is situated between about 33° to near 35° north latitude and 107° 45' to near 112° 15' west longitude. Streams with suitable habitat for Gila trout are found in coniferous and mixed woodland, montane coniferous forest, and subalpine coniferous forest (Dick-Peddie, 1993). Coniferous and mixed woodland vegetation occur at lower elevations and on southern exposures within the range of Gila trout. Dominant tree species in the coniferous and mixed woodland are piñon (*Pinus edulis*), juniper (*Juniperus* spp.), and oak (*Quercus* spp.). Montane coniferous forest occurs up to about 3,048 m (10,000 ft.) elevation. Below 2,591 m (8,500 ft.) elevation, this forest is characteristically dominated by ponderosa pine (*Pinus ponderosa*). Above about 2,438 m (8,000 ft.) elevation Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), blue spruce (*Picea pungens*) and aspen (*Populus tremuloides*) are common. Subalpine coniferous forest is characterized by Engelmann spruce (*Picea engelmannii*) and corkbark fir (*Abies lasiocarpa*) and is generally found from about 2,896 m (9,500 ft.) elevation to timberline (Dick-Peddie, 1993).

Riparian habitats include the montane riparian vegetation type described by Dick-Peddie (1993) and the arctic-boreal and cold-temperate riparian communities of Brown (1982). Thirteen of the 18 series described for the montane riparian vegetation type are found in habitats of Gila trout (Dick-Peddie, 1993). These series are: Willow; Willow-Mountain Alder; Willow-Dogwood; Blue

Spruce; Aspen; Aspen-Maple; Boxelder; Alder; Narrowleaf Cottonwood; Narrowleaf Cottonwood-Mixed Deciduous; Broadleaf Cottonwood; Broadleaf Cottonwood-Mixed Deciduous; and Sycamore.

Hydrologic Conditions

Stream flow in habitat of Gila trout is characterized by a snowmelt-dominated hydrograph (Figure 10). Snowmelt runoff peaks from February to April, and stream flow then gradually decreases through May. Base flow conditions prevail in June and into July. Mean monthly discharge characteristically increases in July through September coincident with runoff from convectional summer thunderstorms. Sporadic periods of runoff from winter rains or mid-season snowmelt often results in flows slightly elevated above base level in December and January. Discharge from springs may provide substantial flow augmentation in some drainages, notably in streams originating along the Mogollon Rim in the Verde River and Tonto Creek (Arizona Department of Water Resources, 2009) watersheds in central Arizona.

There is substantial variation in this general pattern of stream discharge. Although the shape of the annual hydrographs may be similar, actual discharge may vary by an order of magnitude or more between wet and dry years. During low-flow years, marginal habitats may become too warm to support trout or surface flow may cease and stream segments may dry. Pool depth may diminish to the extent that winter mortality of trout is greatly increased. Large magnitude flood events during high flow years may scour stream channels and eliminate year classes of trout. These frequent, recurring extremes in flow conditions are a basic element of the relatively harsh environment that distinguishes habitat of Gila trout from the typical trout streams of more northern latitudes.

Long-term discharge data from streams inhabited by or suitable for Gila trout are lacking. Short-term or single point-in-time measurements of stream discharge have been made by numerous investigators (Regan, 1966; Mello and Turner, 1980; Rinne, 1980; McHenry, 1986; Propst and Stefferud, 1997). Propst and Stefferud (1997) reported summer base flow in habitats of Gila trout in New Mexico ranging from less than five L/sec (0.18 cfs) in the smallest streams (Sheep Corral Canyon and Sacaton Creek), 30 to 50 L/sec (1.0 to 1.8 cfs) in intermediate-sized streams (Spruce and McKnight creeks), and about 60 L/sec (2.1 cfs) in large streams (Mogollon Creek). Minimum discharge measured in Mogollon Creek from 1967 through 1995 (discontinuous measurements, N = 158) was 0.001 m^3/sec (0.03 cfs) while maximum discharge measured during that period was 7.4 m^3/sec (261.3 cfs; Mast and Turk, 1999).

Rinne (1980) reported mean daily flow in McKnight Creek during March and April of 1978, which included a peak snow-melt runoff flow of approximately 53 m^3/sec (1,872 cfs) on 23 March. Snow-melt runoff began to diminish on 1 April 1978, and stream flow declined steadily from approximately 51 m^3/sec (1,801 cfs) on 1 April to approximately 0.15 m^3/sec (5.3 cfs) on 25 April 1978. The McKnight Creek watershed encompassed approximately 2,043 ha (5,048 ac) at the point of Rinne's (1980) stream-flow measurement.

The relationship between watershed area and bankfull flow in streams throughout the historical range of Gila trout was investigated by Moody and others (2003). Bankfull discharge is defined as the stream stage where flooding begins, which is associated with the point where the stream is just about to flow out of its banks and onto the floodplain (Rosgen, 1996). Bankfull flow is also associated with the dominant channel-forming discharge (Dunne and Leopold, 1978), which transports the majority of available sediment (Wolman and Miller, 1960).

The regional curve describing the relationship between watershed area and bankfull discharge for eastern Arizona and New Mexico streams within the historical range of Gila trout is $\mathbf{y = 15.31x^{0.6119}}$ ($R^2 = 0.8591$) while the curve for streams in central Arizona within the historical range is $\mathbf{y = 88.73x^{0.4711}}$ ($R^2 = 0.6649$), where $\mathbf{y}$ = bankfull discharge in cfs and $\mathbf{x}$ = watershed area in mi^2 (Moody *et al.*, 2003). Local calibration (offset) curves were also developed for streams in the Blue River drainage and Prescott, Arizona area. These local calibration surveys indicated no offset from the regional curve for the Prescott area streams but a slight, consistent offset above the eastern Arizona-New Mexico regional curve for the Blue River sites (Moody *et al.*, 2003). Recurrence interval for bankfull flow of streams in the historical range of Gila trout ranges from 1.1 to 1.8 years, with central Arizona streams typically having lower values than streams in eastern Arizona and New Mexico (Moody *et al.*, 2003).

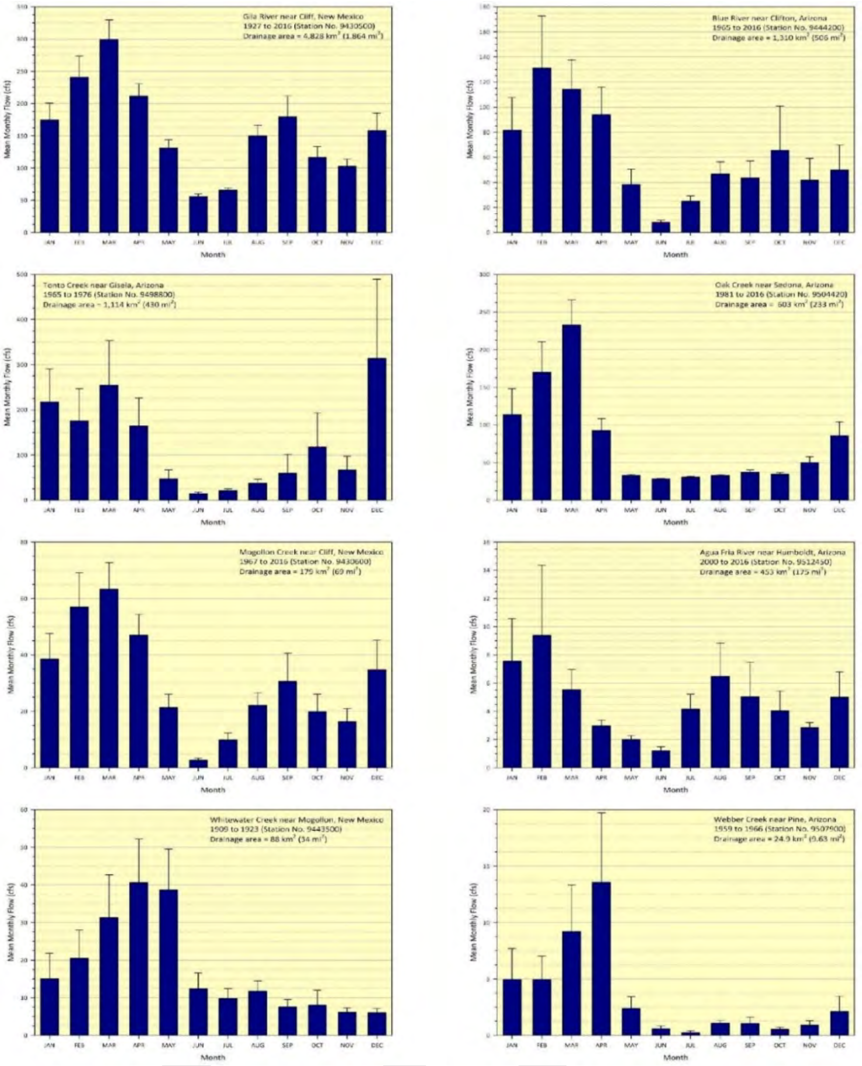

Figure 10. Mean monthly flow at locations throughout the historical range of Gila trout (U.S. Geological Survey 2016b).

Water Quality

Water quality in habitat of Gila trout is generally characterized by high dissolved oxygen concentration, low turbidity and conductivity, low levels of total dissolved solids, near-neutral pH, and low conductivity (Appendix E: Tables 1-3). However, localized and radical changes in water quality may occur with removal of canopy shading and introduction of ash and sediment following forest fires (Baker, 1988; Novak, 1988; Amaranthus *et al.*, 1989; Rinne, 1996; Gresswell, 1999). For example, a maximum suspended sediment concentration of 10,140 mg/L was recorded in Main

Diamond Creek in the year following a high-severity wildfire in that watershed (Wood and Turner, 1992). Similarly, Rinne (1996) reported suspended sediment concentrations of up to 700,000 mg/L during “slurry flows” in headwater streams affected by the 1990 Dude Fire.

Water-quality impairment in cold-water streams within the historical range of Gila trout falls into two main categories: chemical or physical impairment and water temperature impairment (Table 2). Water temperature impairment in cold-water streams in New Mexico results when temperature exceeds 20^{o}C (68^{o}F) for six or more consecutive hours in a 24-hour period on more than three consecutive days, or when maximum temperature exceeds 24^{o}C (77^{o}F; 20.6.4 NMAC). Lee and Rinne (1980) found that Gila trout could tolerate temperatures up to 27°C (81^{o}F) for only up to two hours. There are no water temperature standards for cold-water streams in Arizona. Chemical or physical impairment includes elevated turbidity, excessive sediment deposition, chemical constituents present at chronic or acutely toxic concentrations, and high nutrient levels (eutrophication) in excess of established standards (20.6.4 NMAC; R18-11-1 Arizona Administrative Code).

See Appendix E for more detailed information on water quality, including specific water quality parameters and specific examples of water quality impairment in streams within Gila trout habitat.

Table 3. Impaired cold-water streams in watershed within the historical range of Gila trout in New Mexico (New Mexico Environment Department, 2016). An * indicates streams that contain viable populations of Gila trout.

Stream Segment	**Temperature**	**Nutrients**	**Turbidity**	**Sediment Deposition**	**Depressed Benthos**	**Chemical Pollutant**
Black Canyon (East Fork to headwaters)*	X					
Canyon Creek (Middle Fork to headwaters)		X	X			
East Fork Gila River (West Fork Gila River confluence to headwaters)					X	
Gila River (Mogollon Cr. to confluence of East and West forks of the Gila R.)	X					
Gilita Creek (Middle Fork to Willow Cr.)	X					
Iron Creek (Middle Fork to headwaters)*	X					
Middle Fork Gila River (Canyon Cr. to headwaters)	X					
Middle Fork Gila River (West Fork Gila R. to Canyon Cr.)	X					
Mogollon Creek (perennial potions, USGS gage to headwaters)*						Aluminum
Taylor Creek (perennial portion, Beaver Cr. to headwaters)	X	X				

Stream Segment	Temperature	Nutrients	Turbidity	Sediment Deposition	Depressed Benthos	Chemical Pollutant
Turkey Creek (Gila R. to headwaters)	X					
West Fork Gila River (East Fork to Middle Fork)	X					
West Fork Gila River (Middle Fork to headwaters)	X					
Willow Creek (Gilita Cr. to headwaters)*	X					Aluminum
Centerfire Creek (San Francisco R. to headwaters)	X	X	X	X		
Negrito Creek (Tularosa R. to confluence of North and South forks)	X					
San Francisco River (NM12 crossing to Centerfire Cr.)	X		X			
San Francisco River (Centerfire Cr. to state line)	X				X	
South Fork Negrito Creek (Negrito Creek to headwaters)	X					
Trout Creek (perennial portion, San Francisco R. to headwaters)	X					
Tularosa River (San Francisco R. to Apache Cr.)	X		X			
Total	**18**	**3**	**4**	**1**	**2**	**2**

Stream Morphology

Quantitative data on channel pattern, bankfull channel dimensions, and substrate characteristics of streams within the range of Gila trout are sparse or lacking. Channel gradient varies widely in habitat of Gila trout, from near 1 percent to over 14 percent (McHenry, 1986; Propst and Stefferud, 1997). Average substrate composition in spawning habitat of Gila trout in Main Diamond, South Diamond, and McKnight creeks consisted of 6.6 percent silts, clays, and very fine to coarse sands (less than 1 mm diameter), 14.4 percent very coarse sand (1 to 2 mm), 27.4 percent very fine to medium gravels (2 to 9 mm), 20.1 percent medium to coarse gravels (9 to 18 mm), 17.8 percent coarse gravels (18 to 38 mm), 6.9 percent very coarse gravels (38 to 63 mm), and 6.7 percent cobbles (64 to 256 mm; data summarized from Rinne, 1980; particle diameter class names adapted from Rosgen, 1998).

Stefferud (1995*a*, 1995*b*) reported Rosgen stream types A1, A2, B3, B4 and D4 for several streams within the range of Gila trout (White Creek, Langstroth Canyon, West Fork Gila River, Mogollon Creek, South Fork Mogollon Creek, Trail Canyon, and Corral Canyon). Moody and others (2003) reported stream types B4, B4c, C3, C4b, E3b, and F4 in habitats within the range of Gila trout, based on detailed field measurements. Basin-wide habitat typing conducted on White Creek found step-run habitat to be the dominant type in a reach with a channel slope of 4.6 percent (Stefferud, 1994). Width-to-depth ratio in McKnight Creek ranged from 7.6 to 51.7 (Medina and Martin, 1988).

Pool area relative to riffle area is variable among streams. Stefferud (1994) reported a pool-to-riffle ratio in White Creek of 0.26:1 based on length and 0.30:1 based on area. Nankervis (1988) found pool-to-riffle ratios ranging from 0.23:1 to 0.28:1 in Main Diamond Creek, while values ranging from 0.05:1 to 1.17:1 were reported for numerous streams by Mello and Turner (1980). Rinne (1981*a*) found significantly greater mean and maximum depths in pools created by log structures compared to natural pools. Log structures have been constructed in numerous streams within the range of Gila trout including McKnight Creek, Main Diamond Creek, South Diamond Creek, Sheep Corral Canyon, White Creek, Beaver Creek and others (Regan, 1966; Rinne, 1981*a*; Stefferud, 1994). Mean and maximum water depth has been reported by several investigators but measurements were not recorded relative to bankfull stage or any other consistent elevation (Rinne, 1978; Rinne, 1981*a* and 1981*b*; Stefferud, 1994). Therefore, meaningful comparisons and generalizations about variation in depth are not possible.

McHenry (1986) reported cover values ranging from 10.7 percent to 45.8 percent in seven streams occupied by Gila trout or Gila x rainbow hybrids, while Nankervis (1988) reported cover values ranging from 13.7 percent to 21.3 percent in Main Diamond Creek. Cover was defined as areas providing refuge from current velocity, predators, and light and included undercut banks, woody debris, root wads, deep pools, overhanging vegetation, aquatic macrophytes, rock shelter, and areas of surface turbulence (McHenry, 1986; Nankervis, 1988).

Habitat Types

Spawning Habitat

Spawning habitat is defined as areas suitable for deposition and fertilization of eggs and development of embryos of Gila trout. The egg and embryo life stages are completed in the substrate of the stream. Essential habitat elements for these life stages include adequate dissolved oxygen concentration, circulation of fresh water in the stream substrate, appropriate substrate composition, and the absence of gametes or eggs of rainbow trout or Gila x rainbow trout.

Suitable substrate composition for development of eggs and embryos is characterized by approximately seven percent or less fines (particles less than 1 mm [0.04 in] diameter) by weight (Rinne, 1980). Coarse sands and gravels ranging from 1 mm (0.04 in) to 18 mm (0.7 in) diameter compose approximately 60 percent of the substrate in suitable habitat for eggs and embryos. Intra-gravel water flow and substrate conditions that provide dissolved oxygen concentrations at or near 100 percent saturation are optimal for development of eggs (Piper *et al.*, 1983). This typically translates to dissolved oxygen concentrations of nine to 12 mg/L (ppm) or higher (Behnke, 1992). Minimum intra-gravel water flow for development of eggs has not been quantified for Gila trout. However, stagnant or still water conditions would very likely result in elevated or complete egg mortality. Populations of Gila trout may withstand losses of individual redds and even whole year classes that may result from siltation, low flows, or scouring floods (Nankervis, 1988). However, conditions of excessive siltation, low intra-gravel dissolved oxygen concentrations, or inadequate intra-gravel water circulation that persist over two or more years may result in population decline and eventual extirpation. Absence of rainbow trout or rainbow x Gila hybrid trout is another essential element of spawning habitat. Rainbow trout and Gila trout have concurrent spawning periods. Therefore, rainbow trout may fertilize eggs of Gila trout and vice versa, resulting in hybrid offspring.

Nursery and Rearing Habitat

Nursery and rearing habitats are areas used by larval and fry life stages of Gila trout. Although no studies have been done on habitat use by this life stage of Gila trout, generalizations can be made based on characteristics of related trout species. Suitable nursery habitat for trout includes areas with slow current velocity such as stream margins, seeps, shallow bars, and side channels (Behnke, 1992). Threshold current velocities, water depths, water temperatures, and substrate conditions that define nursery and rearing habitat of Gila trout are not known. Similarly, threshold values for the quantity of nursery and rearing habitat required to maintain populations of Gila trout are not known. Survival rate of Gila trout larvae and fry may be influenced by characteristics of the annual hydrograph as well. Low flows during emergence from the egg and early growth of larval trout may result in strong year classes (Behnke, 1992), as may constant, elevated flows during summer. Absence of predation by nonnative trout, particularly brown trout, is another essential element of nursery and rearing habitat.

As with spawning habitat, populations of Gila trout can withstand impacts to nursery and rearing habitat of short duration and if the population has an existing size structure that will ensure reproduction in subsequent years. Populations of Gila trout may be able to withstand low levels of predation by brown trout. However, predation effects exerted over several consecutive years, coupled with population expansion of brown trout, may result in extirpation of Gila trout from a stream.

Subadult and Adult Habitat

Subadult and adult habitats are defined as areas suitable for survival and growth of these life stages of Gila trout. Subadults are immature individuals generally less than 150 mm (6 in) total length and adults are mature individuals typically greater than or equal to 150 mm (6 in) total length (Propst and Stefferud, 1997). The quantity and quality of adult habitat typically limits population biomass of trout (Behnke, 1992). Essential elements of subadult and adult habitat relate principally to channel dimensions, cover, and hydrologic variability. Absence of competition with brown trout for foraging habitat is also an essential element of subadult and adult habitat.

Populations of Gila trout are particularly sensitive to impacts that cause reductions in cover and pool depth. These elements of subadult and adult habitat are major components that influence biomass and size structure of populations of Gila trout. Cover includes overhanging woody and herbaceous riparian vegetation, undercut banks, woody debris in the stream channel, boulders, and deep water. Populations of the species may also be dramatically affected by variation in stream flow (McHenry, 1986; Turner, 1989; Propst and Stefferud, 1997). Impacts to habitat of Gila trout that increase variability of stream flow, such as changes in watershed condition, can result in population decline and extirpation.

Subadult Gila trout occur primarily in riffles, while adults are found mainly in pools (Rinne, 1978). Cover is an important component in both riffle and pool habitat (Hanson, 1971; McHenry, 1986; Rinne, 1981*a* and 1981*b*). Size of Gila trout is positively correlated with maximum pool depth and individuals larger than 200 mm (8 in) total length are typically found in pools that are 0.5 m (1.6 ft.) deep or deeper (Rinne, 1978; Rinne, 1981*a* and 1981*b*). Pool depth in suitable habitats is generally 0.3 m (1 ft.) or greater. Areas within pools with current velocity ranging from 0 to 0.1 m/sec (0 to 0.3 ft. /sec) adjacent to areas of swifter flow provide locations where trout can rest and obtain food from drift (Behnke, 1992). Large woody debris has been identified as an important component of pool habitat, both in terms of pool formation and providing cover (Stefferud, 1994).

Variation in stream flow has been identified as a major factor affecting subadult and adult population size (McHenry, 1986; Turner, 1989; Propst and Stefferud, 1997). In particular, reduction in abundance is often associated with major flood events. These events result in short-term, radical changes in habitat conditions, primarily in flow velocity. Because most habitats of Gila trout are characterized by relatively narrow floodplains, the forces associated with major floods are concentrated in and immediately adjacent to the bankfull channel. High stream flow velocities and shear stresses cause channel scouring and displacement of fish downstream, often into unsuitable habitats (Rinne, 1982).

Overwintering Habitat

Overwintering habitat is defined as areas used by Gila trout that afford shelter during periods of water temperature minima generally from November through February. Rinne (1981*a* and 1981*b*) and Propst and Stefferud (1997) indicated the importance of pool habitat for overwinter survival of Gila trout. Essential elements of overwintering habitat are deep water with low current velocity and protective cover (Behnke, 1992). Examples include deep pools with cover such as boulders or tree root masses or deep beaver ponds. Access to larger main-stem habitats from headwater streams may be an important function of overwinter survival where a perennial surface water connection between streams exists. Similar to subadult and adult habitat, populations of Gila trout may be quite sensitive to impacts that result in reduced cover and pool depth. Creation of barriers to fish movement that may prevent fish from accessing overwintering habitat may also result in impacts to populations of Gila trout.

Aquatic Macroinvertebrates

Aquatic macroinvertebrate community composition in habitats of Gila trout has been reported by numerous investigators (Regan, 1966; Hanson, 1971; Mello and Turner, 1980; Mangum, 1981, 1984, and 1985; McHenry 1986; Jacobi, 1988; Van Eimeren, 1988). Benthic macroinvertebrate communities are typically dominated by Diptera (true flies), Ephemeroptera (mayflies), and Trichoptera (caddisflies). Plecoptera (stoneflies), Coleoptera (beetles), and other orders typically constitute less than 10 percent of the number of aquatic benthic macroinvertebrates in habitats of Gila trout. Density of benthic macroinvertebrates varies considerably among streams and within streams between years. Aquatic macroinvertebrate densities ranging from 69 to 1,934/m^2 (742 to 20,810/ft.^{2}) have been reported (Regan, 1964; Hanson, 1971; Mello and Turner, 1980; Mangum, 1984; Mangum, 1985; McHenry, 1986; Van Eimeren, 1988).

Trophic Structure and Trout Biomass

Gross primary productivity (comprised of both allochthonous and allochthonous primary production) in streams within the range of Gila trout has not been directly measured. Allochthonous primary production is the input of organic matter into a stream that is derived from an external source, such as leaves falling into the stream from riparian vegetation. Autochthonous production refers to organic matter produced within the stream itself through the process of photosynthesis (Wetzel, 1983). In general, allochthonous primary production exceeds autotrophic production in headwater streams (Vannote *et al.*, 1980). This results in a ratio of gross primary productivity to community respiration of less than one in headwater stream habitats. The relative importance of allochthonous versus autochthonous production is largely a function of the degree of stream shading by riparian vegetation or topography. Also, there may be seasonal shifts in the relative importance of the two forms of production (Minshall, 1978).

Benthic macroinvertebrate communities in headwater stream ecosystems are typically dominated by two functional feeding groups: shredders and collectors (Cummins and Klug, 1979). The shredder feeding group forage on coarse particulate organic material, such as leaves, conifer needles, and scales of conifer cones. Particulate materials that have been colonized by microorganisms are preferentially selected. Foraging action by macroinvertebrates in the shredder feeding group produce fine particulate organic matter. This material, together with fine particulate and dissolved organic matter produced by microbial decomposition and mechanical breakdown, is consumed by the collector feeding group. The collector feeding group consists of macroinvertebrates that gather or filter fine or dissolved particulates. These organisms, together with terrestrial invertebrates that fall into the stream or that metamorphose from aquatic larvae, constitute the primary food source of Gila trout (Van Eimeren, 1988).

Fish community structure in streams within the range of Gila trout is typically characterized by low species richness. In most streams, trout are the only fishes present. However, historically Gila trout coexisted with other native fishes. Native fish species that may occur in habitats of Gila trout include longfin dace (*Agosia chrysogaster*), roundtail chub (*Gila robusta*, formerly headwater chub *G. nigra*), speckled dace (*Rhinichthys osculus*), desert sucker (*Catostomus clarkii*), and Sonora sucker (*Catsotomus insignis*). McHenry (1986) reported Gila trout biomass ranging from 2.6 to 20 grams/m^2 (23.2 to 178.4 lbs./ac) in Main Diamond, South Diamond, McKenna, Iron, Spruce, McKnight, and Big Dry creeks. Biomass (g/m^2) of Gila trout is comparable to and often higher than that of other western trouts (Platts and McHenry, 1988).

Chapter 3- Assessment of Threats

Introduction

Recovery of Gila trout requires that threats to its existence are removed or reduced to a level that the species is no longer at risk of extinction and may be delisted. Consequently, thorough identification and description of threats is the foundation of effective recovery planning (Lawler *et al.*, 2002). Section 4(a) (1) of the Endangered Species Act describes five factors, or categories of threats, that are evaluated in determining whether a species is endangered or threatened. These factors include:

- A) the present or threatened destruction, modification, or curtailment of the habitat or range of the species;
- B) overutilization of the species for commercial, recreational, scientific, or educational purposes;
- C) disease or predation;
- D) the inadequacy of existing regulatory mechanisms; and
- E) other natural or man-made factors affecting the continued existence of the species.

Gila trout were recognized as endangered in 1967 (Service, 1967) prior to passage of the Endangered Species Act of 1973. Consequently, an evaluation of the five listing factors was not developed when the species was originally designated as endangered. However, the five listing factors were subsequently evaluated in the reclassification rule for the Gila trout (Service, 2006). Specifically, the reclassification rule evaluated the following as threats to Gila trout under Factors A, B, C, and E: habitat degradation from livestock grazing, timber harvest, and wildfire (Factor A); sport fishing (Factor B); predation from brown trout (*Salmo trutta*) and disease (Factor C); inadequate regulatory mechanisms to protect and enhance Gila trout populations and their habitat (Factor D); and hybridization and competition with nonnative trout, drought, wildfire, and floods (Factor E).

The following discussion describes historical and contemporary threats to Gila trout as identified in the reclassification rule and new information that has since become available. Threats identified in the reclassification rule were reevaluated and in some instances, re-characterized through consideration of the recent histories of individual populations, newly understood attributes of Gila trout life history and ecology, research conducted on the species, and trends in environmental conditions. Threats were systematically evaluated and described in terms of the specific stressors that affect individuals or populations of Gila trout, the source of each stressor, and the exposure and response of the species to each stressor. The description of specific stressors was then used to subjectively assess the magnitude of its effect. Magnitude was qualitatively described as a function of the geographic extent or scope of the stressor, the timing over which the stressor acts or acted in the past, and the intensity (strength of the effect) of the stressor.

Summary of Current Threats

Seven specific threats to the continued existence of Gila trout have been identified and are evaluated as follows: Two threats are habitat-related and discussed under listing factor A: large-scale, high-severity wildfire; and the effects of climate change. One threat is discussed under listing factor B: unregulated harvest. Two threats are discussed under listing factor C: nonnative trout predation and competition; and disease. Two threats are discussed under listing factor E: human-mediated introgressive hybridization; and small, isolated populations. Consistent with the reclassification rule, no threats are identified under listing factor D. The stressors associated with each threat and the species response are identified in Table 3 and described in detail in the following sections. Also, each stressor was evaluated based on the scope (geographic extent; e.g., range-wide or localized), time frame (e.g., historic, imminent, or future), intensity (strength of the effect of the stressor; e.g., high, medium, or low), and magnitude (overall level of threat to the species which integrates scope, time frame, and intensity; e.g., high, medium, or low).

Table 3. Assessment of threats. Threats are organized by listing factor (**A** through **E**) as described in the text. **Scope** is the geographic extent of the threat, and is coded as range-wide (R) or localized (L). **Time Frame** is coded as historic (H), imminent (I) or future (F). **Intensity**, or the strength of the effect of the stressor, is coded as high (H), medium (M) or low (L). **Magnitude**, coded as high (H), moderate (M) or low (L), is the overall level of threat to the species and is an integration of scope, time frame and intensity.

Threat (Listing Factor-Threat Description)	Stressor(s) Associated with Threat	Response of Species to Threat	Scope	Time Frame	Intensity	Magnitude
A Large-scale, high-severity wildfire	Ash flows, sediment slugs, low dissolved oxygen	Extirpation of Gila trout populations, mortality, reduced abundance	R	I, F	H	H
	Post-fire habitat degradation (sedimentation, increased water temperature, reduced prey base, habitat simplification)	Reduced abundance, mortality, reduced growth and survival, reduced reproduction and recruitment	R	I, F	H	H
	Loss of watershed function (increased peak flows, reduced phreatic[1] groundwater and stream base flows, higher flow variation)	Reduced abundance, mortality, reduced growth and survival, reduced reproduction and recruitment	R	I, F	H	H

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[1] Phreatic groundwater is water that's derived from the catchment aquifer.

A Effects of climate change	Loss of suitable habitat (increased water temperature, reduced flow, increased sediment input), shift in precipitation patterns, earlier snowmelt, shift in storm intensity	Reduced population size, contraction of geographic distribution, population isolation	R	I, F	M	H
B Unregulated harvest	Unsustainable removal of fish, selective harvest of larger fish, introduction of nonnative trout	Extirpation of Gila trout populations, reduced abundance, genetic effects	L	H	M	L
C Nonnative species (predation and competition)	Mortality of early life stages, competition for food and space	Reduced abundance, reduced growth and survival, reduced reproductive output	L	I	M	M
C Disease	Bacterial kidney disease and whirling disease which lead to impaired metabolic function	Mortality, reduced survival, reduced abundance	L	F	L	L

E	Human-mediated introgressive hybridization	Hybridization with rainbow or cutthroat trout and subsequent backcrossing resulting in introgression and development of hybrid swarms	Genetic modification, genomic extinction	R	I	H	H
E	Small population size	Loss of connectivity between populations and increased demographic stochasticity	Reduced genetic diversity, increased vulnerability to extirpation	R	H,I	M	H

Large-Scale, High-Severity Wildfire

In the 2006 reclassification rule, we identified severe wildfire as a relatively recent threat to Gila trout habitat (Service 2006). Although native trout of the western U.S. have evolved with and adapted to natural forest fire regimes (Gresswell, 1999), natural fire regimes have been altered or interrupted throughout the historical range of Gila trout, leading to increased occurrence and probability of uncharacteristic, high-severity, large-scale wildfires (Covington *et al.*, 1994; Allen *et al.*, 2002; Fulé *et al.*, 2013; Dennison *et al.*, 2014; Hunter *et al.*, 2014; O'Connor *et al.*, 2014). This departure from natural fire regimes has created novel disturbance conditions and processes in cold-water stream habitats, often resulting in dramatically reduced abundance or extirpation of local populations of Gila trout. Local extirpation of trout populations caused by high-severity wildfire has been documented throughout the historical range of Gila trout, as indicated in the following select examples:

- The Divide Fire in 1989 (7,408 ha [18,305 ac]; Gila National Forest, 2005) caused extirpation of the remnant population of Gila trout in Main Diamond Creek (Propst *et al.*, 1992).
- The Dude Fire in summer 1990 (*ca.* 12,000 ha [29,652 ac]) extirpated or markedly reduced populations of brook trout or rainbow trout in Dude, Ellison and Bonita creeks in the Lower Verde River watershed, Arizona (Rinne, 1996).
- In 1995 the Bonner Fire (*ca.* 10,157 ha [25,098 ac]; Gila National Forest, 2005) eliminated the remnant population of Gila trout in South Diamond Creek and its headwater tributary, Burnt Canyon (Propst and Stefferud, 1997).
- The Lookout Fire in 1996 (3,873 ha [9,570 ac]; Gila National Forest, 2005) extirpated populations of Gila trout in Trail and Woodrow canyons, both tributaries to Mogollon Creek, and Sacaton Creek (Brown *et al.*, 2001).
- The Chitty Fire in 2007 (2,334 ha [5,767 ac]; Apache-Sitgreaves National Forest, 2016) eliminated rainbow trout from Chitty Creek (Gila trout Recovery Team, 2010).
- The Wallow Fire in 2011 (217,523 ha [537,509 ac]; Apache-Sitgreaves National Forest, 2016) extirpated the Gila trout population in Raspberry Creek (Gila trout Recovery Team, 2011).
- The Whitewater-Baldy Complex Fire in 2012 (120,334 ha [297,351 ac]; Gila National Forest, 2016) eliminated five Gila trout populations and eliminated or markedly reduced populations of nonnative trout in Willow Creek and Mineral Creek (Wick *et al.*, 2014).
- The Silver Fire in 2013 (56,129 ha [138,698 ac]; Gila National Forest, 2013) eliminated Gila trout population in McKnight Creek and markedly reduced the population in Black Canyon.

High-severity, or stand-replacing, wildfire in small- to moderate-sized patches was a component of the natural fire regime in mesic to wet forest types such as mixed conifer and spruce-fir (Margolis *et al.*, 2011; Hunter *et al.*, 2014). Prior to human alteration of forest fuel loads and fire return frequency, such wildfires in the historical range of Gila trout may have extirpated trout from some headwater stream reaches. However, recolonization of accessible reaches in historically unfragmented cold-water stream systems would have enabled natural restoration of trout populations in affected areas (Dunham *et al.*, 2003; Howell, 2006). The isolation of Gila trout populations and increased fragmentation of the distribution of the species has eliminated this natural recovery process, which has heightened the vulnerability of the species to adverse effects of wildfire.

The occurrence of large-scale, high-severity wildfire in a watershed does not necessarily reduce the potential for subsequent high-severity fire and the associated stressors on Gila trout. In fact, Holden and others (2010) found that re-burned areas where initial fire was severe showed a higher probability of re-burning at high severity likely due to large changes in vegetation following the initial, high-severity fire. This pattern of high-severity re-burning was suggested to be a relatively new phenomenon outside of the historical range of variation. In contrast, Holden and others (2010) reported that areas with initial low-severity fire tended to re-burn at low severity.

Stressors

Fire effect is a function of severity and extent of fire and the storms that follow, the distribution and connectivity of adjacent populations, and effects of past land and water management (Howell, 2006). Large-scale, high severity wildfire has both direct, immediate effects on trout populations as well as persistent, longer term indirect effects on physical and ecological attributes of aquatic habitat (Rinne and Jacobi, 2005; Rieman *et al.*, 2012; Bixby *et al.*, 2015). Stressors associated with this particular threat include the direct effects from ash flows, sediment slugs, and low dissolved oxygen, as well as post-fire habitat degradation (e.g., increased sedimentation, increased water temperature, reduced prey base, and habitat simplification) and loss of watershed function (e.g., increased peak flows, reduced groundwater and stream base flows, and higher flow variation).

Direct, immediate effects of fire may occur in the form of direct mortality of trout during fire in situations where the riparian corridor has high fuel loads and experiences high-severity fire (Rinne and Jacobi, 2005; Howell, 2006). While specific cause-and-effect mechanisms have not been studied, trout mortality during high-severity wildfire likely results from rapid increases in water temperature and toxic chemical conditions associated with smoke and ash (i.e., ash flows and sediment slugs), and decreased dissolved oxygen (Minshall and Brock, 1991; Rieman *et al.* 2012; Bixby *et al.*, 2015).

Indirect effects of high-severity wildfire may include post-fire habitat degradation and loss of watershed function. Examples of post-fire habitat degradation include: changes in the hydrologic cycle that affect stream flow as well as changes in physical channel conditions (e.g., habitat simplification), altered water quality (e.g., increased sedimentation, increased water temperature), and reduced aquatic macroinvertebrate abundance (reduced prey base) (Bixby *et al.*, 2015). Examples of loss of watershed function include: increased peak flows, reduced groundwater and stream base flows, and higher flow variation.

Low-severity fire does not typically result in adverse effects on watershed condition. However, large-scale, high-severity fires usually have extensive, adverse effects on watershed condition that result in hydrologic responses well beyond the natural range of variation (Neary *et al.*, 2008). In summary, the characteristic hydrologic response following high-severity wildfire in forest vegetation is a decrease in infiltration, an increase in overland flow, and stream flow patterns that are more immediately responsive and sensitive to precipitation events (e.g., flash floods orders of magnitude higher than pre-fire flows). Altered stream flow patterns following extensive high-severity wildfire in a watershed are typically characterized by reduced base flow, greatly increased flood peak flows (which may be exacerbated by formation and subsequent failure of debris dams), and greater temporal variation in flow magnitude (Neary *et al.*, 2008). Increases in peak flows following high-severity wildfire are greatest in smaller sized watersheds. In extreme situations, perennial streams may become ephemeral following high-severity wildfire that affects a substantial portion of a stream's watershed, such as occurred in upper Little Creek following the Dry Lakes Complex Fire in 2003. It should be noted that severe wildfire in arid shrub vegetation sites characterized by deep soils may result in increased base flow when deep-rooted woody plants are replaced by shallow-rooted herbaceous vegetation (Neary *et al.*, 2008).

When wildfire is severe enough to expose bare soil, the following effects on the hydrologic cycle are likely to occur (Neary *et al.*, 2008):

- The soil surface is exposed to erosion due to loss of interception of precipitation by vegetation and litter, resulting in increased soil loss and sediment transport to the stream.
- Infiltration is reduced due to combustion of organic matter on the soil surface, ash and charcoal residue clogging of soil pores, and collapse of soil structure.
- Soils (particularly in oak shrub vegetation) may also develop a characteristic of water repellency following wildfire (hydrophobic soils), which reduces infiltration.
- Reduced infiltration results in increased overland flow in response to precipitation that in turn causes increases in stream discharge, and often severe flooding.
- Evapotranspiration loss is reduced, resulting in increased overland flow in response to precipitation events.
- Less snow accumulation and faster snow melt, resulting in increased overland flow.

Impacts to water quality following high-severity wildfire include pulses of greatly increased suspended sediment concentration (e.g., ash slurry flows), increased sedimentation caused by accelerated rates of soil erosion, increased water temperature caused by loss of shading and reduced base flow (Dunham *et al.*, 2007), and increases in pH in the first year or two following high-severity wildfire (Neary *et al.*, 2008). Chemical constituents including nitrogen, phosphorus, potassium, and calcium may also increase in the first year or two following high-severity wildfire (Earl and Blinn, 2003). Nutrient loading following high-severity wildfire, coupled with increases in water temperature, characteristically result in reduced dissolved oxygen concentrations in affected streams. Sedimentation and changes in stream flow (primarily peak flow characteristics) following high-severity wildfire often result in stream channel reorganization and degraded trout habitat. Increased stream width, reduced cover, loss of pool habitat, and homogenization of stream depth are typical channel changes following high-severity wildfire (Minshall *et al.*, 1997; Moody and Martin, 2001; Zelt and Wohl, 2004).

Species Response

Responses of Gila trout to the threat of large-scale, high-severity wildfire and its associated stressors may include reduced abundance, reduced growth and survival, reduced reproduction and recruitment, and extirpation of Gila trout populations. Specific examples of these responses have included the following:

- Elimination of populations in 1989 (Main Diamond Creek), 1995 (South Diamond Creek), 1996 (Sacaton Creek), 2003 (upper Little Creek), 2004 (Raspberry Creek), 2011 (Raspberry Creek), 2012 (Spruce Creek, White Creek, Cub Creek, upper West Fork Gila River, Whiskey Creek), and 2013 (McKnight Creek and Black Canyon).
- Post-fire degradation and loss of habitat such as in upper Little Creek following the Dry Lakes Complex Fire in 2003, where a previously perennial stream reach became ephemeral, and in Dude Creek where habitat degradation following the 1989 Dude Fire precluded re-establishment of a trout population until 2015.
- Reduced trout abundance, physical condition and reproductive output due to habitat degradation (i.e., loss of pools, reduced macroinvertebrate prey base, higher water temperatures, lower dissolved oxygen) following high-severity wildfire in South Diamond Creek following the 1989 Divide Fire; in Little Creek following the Bloodgood (2000), Dry Lakes Complex (2003), and Miller (2011) fires; in the upper West Fork Gila River following the Whitewater-Baldy Complex Fire (2012); in Mogollon Creek following the Sprite (1995) and Dry Lakes Complex (2003) fires; and of nonnative trout in Cub Creek following the 2002 Cub Fire (Wick *et al.*, 2014).

Populations of Gila trout persisted in Whiskey Creek following the Cub Fire in 2002 (Gila trout Recovery Team, 2003), in Raspberry Creek following the Raspberry Fire in 2004 (Gila trout Recovery Team, 2005), and in Big Dry Creek, Iron Creek and Mogollon Creek following the

Whitewater-Baldy Complex Fire in 2012. Persistence of Gila trout populations following wildfire appears to be primarily a function of the proportion of the watershed that is subject to high-severity (i.e., stand-replacement) fire. For example, only 4.6 percent of the Cub Creek watershed was subject to 50 percent or greater stand-replacement fire during the 2002 Cub Fire, which the population of Gila trout in the stream withstood. Similarly, although approximately 35 percent of the watershed of Big Dry Creek had moderate- to high-severity burn from the 2012 Whitewater-Baldy Complex Fire (Gila trout Recovery Team, 2012), most of this area was downstream from habitat occupied by Gila trout.

Magnitude of Threat

The overall magnitude of the threat of large-scale, high-severity wildfire (and its associated stressors) to persistence of Gila trout is ranked as high (Table 3). The geographic extent of the threat and its associated stressors is range-wide because cold-water streams throughout the historical range of Gila trout are situated in forest vegetation, and large-scale, high-severity wildfire has occurred throughout the historical range. The time frame over which the stressors may act is both immediate and in the future, which reflects the direct and short-term indirect (imminent with occurrence of wildfire) effects, as well as the longer term indirect (future) effects of wildfire on Gila trout and its habitat. The intensity of the stressors associated with the threat of large-scale, high-severity wildfire is high, as indicated by the history of wildfire impacts on populations of Gila trout.

Effects of Climate Change

In the Gila trout reclassification rule, drought and floods were evaluated as specific threats to Gila trout under listing Factor E (Service 2006). In this Recovery Plan, these threats are more broadly characterized as the effects of climate change on Gila trout habitat and evaluated under Factor A. Usage of the terms "climate" and "climate change" in this Recovery Plan are as defined by the Intergovernmental Panel on Climate Change (IPCC). The term "climate" refers to the mean and variation of different types of weather conditions over time, with 30 years being a typical period for such measurements, although shorter or longer periods also may be used (IPCC 2007*a*). Concordantly, the term "climate change" refers to a change in the mean or variation of one or more measures of climate (e.g., temperature, precipitation) that persists for an extended period, typically decades or longer, whether the change is due to natural variability, human activity, or both (IPCC 2007*a*).

Scientific measurements spanning several decades demonstrate that changes in climate are occurring, and that the rate of change has been faster since the 1950s. Examples include warming of the global climate system, substantial increases in precipitation in some regions of the world, and reduced precipitation in other regions (IPCC 2007*a*; Solomon *et al.*, 2007). Results of scientific analyses presented by the IPCC show that most of the observed increase in global average temperature since the mid-20th century cannot be explained by natural variability in climate, and is “very likely” (defined by the IPCC as 90 percent or higher probability) due to the observed increase in greenhouse gas concentrations in the atmosphere as a result of human activities, particularly carbon dioxide emissions from use of fossil fuels (IPCC 2007*a*: 5-6 and figures SPM.3 and SPM.4; Solomon *et al.*, 2007). Further confirmation of the role of greenhouse gases in climate change comes from analyses by Huber and Knutti (2012), who concluded it is extremely likely that approximately 75 percent of global warming since 1950 has been caused by human activities. The role of increased greenhouse gas emissions in affecting climate change was recognized by the U.S. Supreme Court in *Massachusetts v. EPA* (127 S. Ct. 1438 [2007]), in which the majority opinion begins with the recognition that "[a] well-documented rise in global temperatures has coincided with a significant increase in the concentration of carbon dioxide in the atmosphere" (127 S. Ct. at 1446).

Scientists use a variety of climate models, which include consideration of natural processes and variability, as well as various scenarios of potential levels and timing of greenhouse gas emissions, to evaluate the causes of changes already observed and to project future changes in temperature and other climate conditions (Meehl *et al.*, 2007; Ganguly *et al.*, 2009; Prinn *et al.*, 2011). All combinations of models and emissions scenarios yield very similar projections of increases in the most common measure of climate change, which is average global surface temperature (commonly known as global warming), until about 2030. Although projections of the magnitude and rate of warming differ after about 2030, the overall trajectory of all the projections is one of increased global warming through the end of this century, even for the projections based on scenarios that assume that greenhouse gas emissions will stabilize or decline. Thus, there is strong scientific support for projections that warming will continue through the 21st century, and that the magnitude and rate of change will be influenced substantially by the extent of greenhouse gas emissions (IPCC 2007*a*; Meehl *et al.*, 2007; Ganguly *et al.*, 2009; Prinn *et al.*, 2011). The IPCC also summarized other global projections of climate-related changes, such as frequency of heat waves and changes in precipitation (IPCC, 2007*b*) and observations and projections of extreme climate events (Field *et al.*, 2011).

Climate modeling projections indicate that average winter temperatures may increase up to 1.5°C (2.7°F) in the next 20 years, while summer temperatures may increase up to 2.0°C during the same time span (van Oldenborgh *et al.*, 2013). Average temperature change projected for 2046-2100 during winter months is 1°C to 3°C (1.8°F to 5.4°F) over the baseline, and for summer months the change is projected to be 2°C to 3°C (3.6°F to 5.4°F) (Appendix F). Projections of precipitation changes show no change compared to 1986-2005 conditions except for a -20 percent to +30 percent change for April-September precipitation over the next 20 years in the 25th percentile of model runs (Appendix F). The climate change model projections indicate that although total precipitation amounts may not change substantively compared to 1986-2005 conditions, air temperature is likely to increase both in summer and winter months (Appendix F). The temperature and precipitation projections are more pronounced in scenarios with higher radiative forcing, which correspond to situations with higher greenhouse gas emissions (representative concentration pathway [RCP] scenarios 6.0 and 8.5; Appendix F; van Oldenborgh *et al.*, 2013).

All figures mentioned in this section are located in Appendix F.

Stressors

Stressors associated with climate change include loss of suitable habitat (e.g., increased water temperatures, altered stream flow regimes, and increased sediment input), shift in precipitation (reduced precipitation), earlier snowmelt, and shift in storm intensity (e.g., increased frequency of large-scale, high-severity wildfire) (Williams *et al.*, 2009; Wenger *et al.*, 2011; see section on Large-Scale, High-Severity Wildfire threat). With the exception of habitats with stream flow dominated by spring discharge or hypolimnetic reservoir releases, water temperature in the historical range of Gila trout is closely correlated with air temperature (New Mexico Environment Department, 2010). Increasing air temperatures associated with anthropogenic inputs of greenhouse gases are expected to result in a loss of suitable habitat for Gila trout, with estimates of up to a 70 percent reduction in suitable, summer-time habitat (Kennedy *et al.*, 2008).

Using a regional climate model, Kennedy and others (2008) predicted a 20 percent reduction in summer precipitation, an increase in summer average temperature of approximately 2ºC (3.6ºF), and a pronounced increase in the number of days with temperature above 32ºC (90ºF) and 37ºC (99ºF) by 2040-2059. The modeling indicated that the projected climate changes would result in the lower elevation limit of Gila trout habitat rising 269 m (882 ft.) to 286 m (938 ft.; Kennedy *et al.*, 2008). In addition to changing the geographic extent of suitable habitat, increased water temperatures can result in direct mortality. For example, the largest fish kill in the history of Yellowstone National Park occurred in the Firehole River in 2007 during the hottest July on record. Up to 1,000 trout died due to elevated water temperature and associated low dissolved oxygen concentration (Kinsella *et al.*, 2008). Increased water temperatures may also cause shifts in aquatic macroinvertebrate community structure and abundance, increased microbial metabolism, and reduced dissolved oxygen concentration (Poff *et al.*, 2002). Warmer winter temperatures are likely to result in reduced snowpack, earlier runoff, and reduced summer flows (Poff *et al.*, 2002; Williams *et al.*, 2009; Luce *et al.*, 2012).

Johanson and Fu (2009) reported a poleward widening of the Hadley cell[2] of approximately 2º to 5º of latitude since 1979, likely in response to climate change. They indicated that the coincident

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[2] The Hadley cell is a large-scale atmospheric circulation pattern characterized by the rising of warm, moist air near

poleward displacement of the subtropical dry zone could be accompanied by large-scale drying near 30^{o}N latitude (the historical range of Gila trout extends from approximately latitude 32.5^{o}N to 35^{o}N). Continued poleward widening of the Hadley cell (Seidel *et al.*, 2008) would likely result in increased drying in the historical range of Gila trout, with consequent reduction in annual stream flow and increased flow variability (Luce *et al.*, 2012). Climate change may also result in an increase in the frequency and intensity of extreme short-duration rainfall events (Westra *et al.*, 2014).

While recent large-scale modeling indicated no marked shifts in precipitation (van Oldenborgh *et al.*, 2013), such general circulation models are not particularly good at predicting changes in precipitation (Johnson and Sharma, 2009). Others have reported the likelihood of a drier climate in the region encompassing the historical range of Gila trout. In the near future, the Southwest is likely to become drier and experience more droughts that last longer (12 years or more; Cayan *et al.*, 2010). Seager and others (2007) forecasted an imminent change in climate in the Southwest of increased aridity similar to levels experienced during the Dust Bowl or the extended 1950s drought.

Species Response

The responses of Gila trout to the threat of climate change, which is manifest primarily in a loss of suitable habitat, include reduced population size, contraction of the geographic distribution of the species, and increased isolation of populations. A warmer and drier climate will compound the intensity of stressors associated with the threats of high-severity, large-scale wildfire, habitat loss and fragmentation, long-term changes in suitable habitat, and possibly even disease (Westerling *et al.*, 2006; Williams *et al.*, 2009; Luce *et al.*, 2012).

Magnitude of Threat

The overall magnitude of the threat of climate change is ranked as high based primarily on the small size of streams in suitable habitat, which are sensitive to any environmental changes (Table 3). The geographic extent of the threat is range-wide. The time frame over which the stressors of climate change may act is both immediate and in the future, based on modeling and climate projections for the Southwest. The intensity of the stressors associated with the threat of climate change is moderate due to the uncertainty of the strength of climate effects, the accuracy of climate change projections, and the potential for gradual changes in habitat suitability as opposed to abrupt shifts in habitat characteristics.

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the equator, loss of moisture through precipitation, poleward divergence of resulting upper troposphere air masses, and subsidence or sinking of warm, dry air in subtropical zones of high aridity.

Unregulated Harvest

The deleterious effects of unregulated harvest on fish and wildlife populations were not generally acknowledged until the end of the 19th century, by which time overexploitation had decimated American bison (*Bison bison*) and contributed significantly to the extinction of the passenger pigeon (*Ectopistes migratorius*). In the West, excessive harvest of native trout apparently was not uncommon. For example, Minckley (1973) recounted a report of large groups making annual forays into the headwaters of the Little Colorado River in the mid-1880s to harvest Apache trout, which were salted and stored in barrels for use as food during the winter. Yellowstone cutthroat trout were harvested in increasingly great quantities from Yellowstone Lake from 1870 to the early 1900s, with associated declines in catch rates (Gresswell and Varley, 1988).

Historically, unregulated harvest of Gila trout likely contributed to the reduction in distribution of the species by the 1960s (Rixon, 1905; Propst, 1994). The impact of unregulated harvest of Gila trout is evident from an account of a July 1923 survey of trout streams on the Gila National Forest where it was observed that Gila trout "… are absolutely at the mercy of anyone who wants them. In a similar pool in another creek they took grasshoppers eagerly from Mr. Soule's fingers. If this opinion is correct, it is probably the cleanings of these small streams that has so rapidly exterminated the fish in the river. If the river is to be restocked the first step should be the closing of these streams for all time" (Dinsmore, 1924). At Iron Creek, it was reported that "… sportsmen were seen with their limit – perhaps more – of 50 fish" and that "an aeroplane from El Paso had landed fishermen near here, a new menace to this very limited area of trout waters" (Dinsmore, 1924). In the upper West Fork Mogollon Creek it was reported that two fishermen took 37 trout from a single pool (Dinsmore, 1924). Similarly, the fishless condition of former trout streams near Silver City was noted in 1924, with the implication that the streams (Meadow Creek, Trout Creek, Cow Creek, Sheep Corral Canyon, Snow Creek and Panther Canyon) had been overfished to the point that the populations were extirpated (Sportsmen's Association of Southwestern New Mexico, 1924*a*).

Stressors

Stressors associated with unregulated harvest may include unsustainable removal of fish, selective harvest of larger fish, and the introduction of nonnative trout. By the time regulations were implemented to limit the harvest of fish, the range of Gila trout had been reduced to several isolated headwater streams. Unregulated harvest that results in exploitation of large individuals may result in unnatural selection in the population for traits such as reduced body size, earlier sexual maturity, and slower growth rate (Biro and Post, 2008; Allendorf and Hard, 2009). However, any genetic effects of size-selective harvest may only be temporary (O'Conover *et al.*, 2009). Streams depleted of native trout were stocked with nonnative species, including rainbow trout, brook trout, cutthroat trout and brown trout, to support recreational fishing. In situations where Gila trout co-occur with brown trout, even modest harvest of native trout may result in an increase in brown trout and eventual extirpation of the native trout population (Behnke, 1992). The threat of nonnative trout competition and predation is discussed below in section 1.8.6. Introduction of rainbow trout and, potentially, cutthroat trout into the range of Gila trout resulted in genetic introgression, which is discussed below in the section on human-mediated introgressive hybridization.

Species Response

The response of Gila trout to historical, unregulated harvest is largely documented as extirpation of local populations or substantial reduction of abundance and the genetic effects of small population size. Potential effects of prolonged, selective removal of large fish are unknown because by the time studies of phenotype and genetics of the species were conducted the distribution of Gila trout was so diminished that it occurred only as isolated populations in small, headwater habitats. Harvest-induced changes in life history or size-related traits may occur in fish populations, resulting in permanent loss of adaptive genetic variation (Allendorf and Hard, 2009; Darimont *et al.*, 2009; Kuparinen and Merilä. 2009). The responses of Gila trout to the interconnected effect of nonnative trout introductions following unregulated harvest are discussed in sections 1.8.6 and 1.8.8 below.

Magnitude of Threat

In the reclassification rule, we determined that overutilization of Gila trout would not be a threat to the species because of the remoteness of recovery streams, the special regulations that would be imposed on angling through implementation of a 4(d) rule, and the small amount of Gila trout collected for scientific and educational purposes (Service 2006). The magnitude of this threat remains ranked as low. Currently, angling for Gila trout is allowed only in selected areas, thus has a localized geographic extent, and is regulated to ensure that populations are not adversely affected, making for a moderate intensity of the stressor.

Nonnative Species (Predation and Competition)

Nonnative trout now occur and are naturalized throughout the historical range of Gila trout (Minckley, 1973; Sublette *et al.*, 1990). Brook trout were introduced into New Mexico in the late 1800s and brown trout in the early 1900s (Sublette *et al.*, 1990: 70). Both brook trout and brown trout are piscivorous species, which also compete for food and resources with native trout species. As the species response to predation and competition are similar, we discuss these threats together. However, competition with nonnative trout was evaluated as a threat under Factor E in the reclassification rule.

Stressors

Stressors associated with the threat of nonnative trout include mortality of early life stages from predation and competition for food and space. Piscivory by nonnative trout may have a substantial adverse effect on native trout populations. Wilkinson (1996) found that fish constituted a greater percentage of the diet of brown trout with increasing size, and that brown trout larger than 500 mm (20 in) total length preyed almost exclusively on fish. Among fish prey of brown trout, salmonids composed the greatest percentage. At one of the sites studied, rainbow trout biomass declined 71 percent over a 16-year period while brown trout biomass increased 494 percent over the same interval. Additionally, brown trout may negatively impact Gila trout through competition. For example, McHugh and Budy (2005) reported significantly lower condition of Bonneville cutthroat trout raised in sympatry with brown trout, and Wang and White (1994) documented competitive advantage of brown trout over greenback cutthroat trout for energetically profitable sites in pools and near food sources. Dietary overlap between brown trout and native trout likely leads to competition for available food resources (McHugh *et al.*, 2008).

Species Response

Gila trout likely negatively respond to predation by and competition with brown trout, similar to other native western U.S. trout species, via reduced abundance, reduced growth and survival, and reduced reproductive output. Nonnative trout predation on young Gila trout may reduce year-class strength and result in population decline. Mello and Turner (1980) reported the absence of Gila trout less than 150 mm (6 in) total length in a pool in Iron Creek that was occupied by one large (303 mm [12 in]) brown trout that had a high condition factor ($K_{TL} = 1.02$), suggesting that small Gila trout were eliminated from the pool by brown trout predation. Competitive interactions may result in reduced condition of Gila trout with cascading effects on survival and reproductive output.

Magnitude of Threat

At the time the Gila trout was reclassified, the threat of nonnative trout predation and competition had been reduced through nonnative trout removal efforts and the construction of barriers to prevent nonnative reinvasions (Service 2006). Currently, the geographic extent of brown trout and Gila trout sympatry has been localized and has been limited to instances where brown trout were found subsequent to Gila trout repatriation. In these cases brown trout populations have been suppressed using electrofishing. Therefore, the overall magnitude of the threat of nonnative trout predation and competition is ranked as moderate (Table 3). While the threat is considered imminent, the intensity of the threat is ranked as moderate because in cases where non-hybridizing nonnative trout are found subsequent to Gila trout repatriation, predation and competition can be alleviated through removal of nonnative trout before a population of Gila trout is lost.

Disease

Pathogen introduction may result in loss of aquatic biodiversity or negative impacts on wild fish populations (Gozlan *et al.*, 2006). For example, the causative bacterium (*Renibacterium salmoninarum*) of bacterial kidney disease (BKD) occurs in very low amounts in brown trout populations in the upper West Fork Gila River drainage and in the Whiskey Creek population of Gila trout. The bacterium was also detected in the Main Diamond Creek, South Diamond Creek and Iron Creek populations and rainbow x Gila trout hybrid populations in McKenna Creek and White Creek. Trout populations in the Mogollon Creek drainage, McKnight Creek, Sheep Corral Canyon, and Spruce Creek have all tested negative for BKD. In the wild, BKD is not likely a threat to Gila trout populations because of limited distribution, low occurrence within populations, and lack of any clinical evidence of the disease in Gila trout (N. Wiese, U.S. Fish and Wildlife Service, Mora National Fish Hatchery, pers. comm., 24 August 2017).

In the western U.S., whirling disease (*Myxobolus cerebralis*) has had devastating effects on some wild trout populations (Hedrick *et al.*, 1998). Whirling disease is caused by the metazoan parasite *Myxobolus cerebralis*. The disease is a serious problem in hatchery and wild populations of rainbow trout throughout the western United States. Annual fish health inspections (which include testing for whirling disease) of selected wild and hatchery stocks of Gila trout have been conducted since 2011 and all wild and hatchery populations of Gila trout have tested negative for whirling disease. There have been no documented cases of whirling disease in Arizona or New Mexico (N. Wiese, U.S. Fish and Wildlife Service, Mora National Fish Hatchery, pers. comm., 24 August 2017).

For more information on disease and pathogens related to Gila trout, see Appendix G

Stressors

Potential diseases that may affect Gila trout include whirling disease and bacterial kidney disease. Other diseases may affect populations of Gila trout. For example, there is an anecdotal report from 1924 of a fungal infection in the trout population in Big Dry Creek (Sportsmen’s Association of Southwestern New Mexico, 1924*b*). Whirling disease and bacterial kidney disease both lead to stressors on Gila trout that include impaired metabolic function.

Species Response

Responses to stressors associated with disease may include mortality, reduced survival, and reduced abundance within Gila trout populations. Whirling disease can cause year-class losses and marked reductions in trout abundance (Nearing and Walker, 1996; Vincent, 1996). Elevated water temperature may increase mortality of fingerling trout infected with whirling disease (Schisler *et al.*, 2000). Prolonged crowding, such as may occur in pool habitats during severe drought, can result in elevated plasma cortisol levels, leading to increased mortality due to fungal and bacterial diseases (Pickering and Pottinger, 1989). Loss of variation in genes of the Major Histocompatibility Complex may increase susceptibility of Gila trout populations to disease (Radwan *et al.*, 2010).

Magnitude of Threat

Bacterial kidney disease and Whirling disease were determined to be unlikely threats to Gila trout in the reclassification rule (Service 2006). Currently, the overall magnitude of the threat of disease is ranked as low. There are no indications that diseases are currently affecting any population of Gila trout. However, considering an increase in water temperature and lower dissolved oxygen due to climate change, Gila trout may experience increases in rates of disease threatening populations or contributing to the vulnerability of Gila trout in the future. The geographic extent of the threat of disease is considered localized, as it may impact some populations and not others and the intensity of this threat is considered low based on the low prevalence of disease within populations of Gila trout.

Human-mediated Introgressive Hybridization

Hybridization is the mating of two different species (or two genetically distinct populations) that produces offspring, regardless of the fertility of the offspring. Introgression is the incorporation of genes from one population or species into another through hybridization that results in fertile offspring, which further hybridize with parental populations or species (backcross). Over several generations introgression can result in a complex mixture of parental genes, while in simple hybridization 50 percent of genes will come from each of the two parental species. Without introgression, the parental species or populations are not genetically altered by hybridization.

Natural hybridization and introgression are creative evolutionary processes that may give rise to new species or increase genetic diversity of existing populations (Dowling and Secor, 1997). However, human-mediated introgressive hybridization between geographically isolated taxa (previously allopatric species brought into contact by human introductions) may result in genomic extinction and loss of the evolutionary legacy of a native species (Rhymer and Simberloff, 1996; Allendorf *et al.*, 2001; Ellstrand *et al.*, 2010; Todesco *et al.*, 2016). External fertilization of eggs and the lack of strong pre-zygotic reproductive barriers make many fish taxa, including trout, very susceptible to introgressive hybridization (Hubbs, 1955; Scribner *et al.*, 2001).

Widespread human-mediated introgressive hybridization of native trout in the southwestern U.S. has resulted from extensive stocking of rainbow trout, which is not native to the region (Dowling and Childs, 1992; Propst *et al.*, 1992; Carmichael *et al.*, 1993). Rainbow trout was first introduced into New Mexico in 1896 (Sublette *et al.*, 1990) and into Arizona in 1897 (Arizona Department of Game and Fish, 2011). Stocking of rainbow trout within the historical range of Gila trout began in 1907 (Miller, 1950). By the early 1970s, reproducing populations of rainbow trout were well established throughout the historical range of Gila trout (Minckley, 1973; Sublette *et al.*, 1990).

Introgressive hybridization with cutthroat trout has not been observed in Gila trout but has been documented in Apache trout (Carmichael *et al.*, 1993). Carmichael and others (1993) identified four allozyme loci with allele's diagnostic for cutthroat trout: *ADA-2**, *LDH-C**, *PEPB-1** and *PGM**. Some or all of these loci were examined by Loudenslager and others (1986), Dowling and Childs (1992) and Leary and Allendorf (1999), but no cutthroat trout alleles were reported in any of the populations of Gila trout examined. Similarly, Riddle and others (1998) found no evidence of cutthroat trout influence in their analysis of mtDNA variation in Gila trout.

Nonnative cutthroat trout were first stocked in Arizona around the turn of the 20th century but most populations did not persist due to introduction of rainbow trout (Minckley, 1973). Yellowstone cutthroat trout were widely stocked throughout New Mexico beginning in 1902 (Sublette *et al.*, 1990). Cutthroat trout were introduced into streams in the upper Gila River drainage in the early 1920s via planting of fertilized eggs. In 1923, 25,000 fertilized cutthroat trout eggs from Yellowstone (described as "blackspotted trout eggs … from the Yellowstone") were planted in streams on the Gila National Forest, as follows: 2,000 each in Little Turkey Creek, Willow Creek, Iron Creek and Langstroth Canyon,; 4,000 in Little Creek; 1,000 in Cub Creek; and 12,000 in the West Fork Gila River at White Creek confluence (Dinsmore, 1924). The planted eggs were monitored and apparently there was successful hatching and fry production in the streams (Dinsmore, 1924). Populations of introduced cutthroat trout in the upper Gila River drainage in New Mexico were apparently extirpated by the early 1950s (Sublette *et al.*, 1990).

For information on ways to measure the degree of hybridization in Gila trout populations, see Appendix H.

Stressors

The principle stressors associated with human-mediated introgressive hybridization include hybridization with rainbow trout which is a major cause of decline and continued imperilment of Gila trout (Miller, 1950; Behnke and Zarn, 1976; David, 1976). Introduced rainbow trout hybridize extensively with Gila trout, resulting in formation of hybrid swarms and eventual replacement of the native species (Rinne and Minckley, 1985; Loudenslager *et al.*, 1986). This has occurred throughout the historical range of Gila trout. Hybrid Gila x rainbow trout populations have been removed from White Creek, the upper West Fork Gila River, McKenna Creek, Black Canyon, Little Creek, Mogollon Creek, and other streams (see section on Conservation Efforts for detailed accounts).

Species Response

Responses to stressors associated with human-mediated introgressive hybridization include genetic modification and genomic extinction (Allendorf *et al.*, 2013). Hybridization may also affect fitness-related traits (Drinan *et al.*, 2015). For example, Brown and others (2004) reported faster hatching time in developmental crosses of rainbow x Apache trout compared to pure Apache trout crosses, which could potentially infer a competitive advantage to hybrids and accelerate introgression. Boyer and others (2008) reported long-distance and stepping-stone dispersal of rainbow x cutthroat hybrid trout that promoted the spread of rainbow trout introgression in a drainage network. Hybridization may also result in reduced fitness due to outbreeding depression. For example, Muhlfeld and others (2009) reported a 50-percent decline in reproductive success in a population of westslope cutthroat x rainbow trout with 20-percent admixture. However, hybridization spread rapidly despite this fitness cost. Repeated genetic modification may lead to genomic extinction, which would constitute the loss of the evolutionary legacy of remnant, pure Gila trout lineages.

Magnitude of Threat

When the Gila trout was listed as endangered, the most important reason for the species' decline was hybridization and competition with and/or predation by nonnative trout (Service 1987). At the time the Gila trout was reclassified, some of the threats from nonnative trout, such as predation and competition with brown trout, had been reduced. (Service 2006). However, rainbow trout and Gila x rainbow hybrid trout are naturalized throughout the historical range of Gila trout. Hatchery-raised rainbow trout continue to be stocked in ponds, lakes and some streams within the historical range of Gila trout in Arizona (Arizona Department of Game and Fish, 2011; Arizona Department of Game and Fish, 2015). Fertile rainbow trout are no longer stocked within the historical range of Gila trout in New Mexico. Because rainbow trout are present, either as naturalized populations or as stocked fish, throughout the historical range of Gila trout, the geographic scope of the threat of human-mediated introgressive hybridization was considered to be range-wide. The time-frame of the threat is immediate. Intensity of the threat is high due to the unidirectional and persistent nature of introgressive hybridization. Therefore the overall magnitude of the threat of human-mediated introgressive hybridization is high.

Small Population Size

Historical changes in the extent, quality and connectivity of cold-water stream habitat within the presumed historical range of Gila trout has resulted in the establishment of small, isolated populations. These changes can only be qualitatively assessed due to the lack of quantitative baseline data on habitat conditions prior to the mid-1800s and the onset of widespread Euro-American settlement of the region. Historical reports provide evidence of major habitat changes occurring around the turn of the 20th century that were brought about by a suite of coinciding, intensive human factors including fuel-wood cutting, timber harvest, water diversion, and open-range grazing by sheep, goats and cattle. These factors acted in concert with severe drought around the turn of the 20th century, followed by destructive flooding, to cause major alterations of many stream systems within the presumed historical range of Gila trout. Select examples of these impacts are described below.

The Blue River in Arizona was highly affected by grazing and logging. Browsing of vegetation by large herds of goats apparently was particularly destructive in the Blue River watershed, as reported by W. W. R. Hunt of the Forest Service following the massive floods of 1904 and 1905. Historical logging and clearing of streams for log drives also caused destabilization of streams and "tremendous damage to stream channel and banks" (National Riparian Service Team unpublished report, as cited in Stauder, 2009). Leopold reported that timber harvest in the watershed in the early 1900s was approximately 15 million board feet a year, and that logs were delivered via stream channels and the Blue River. The combined effect of unchecked logging, fuel-wood cutting, and grazing throughout the watershed undoubtedly had a major impact on the extent and quality of cold-water stream habitat. Additionally, watershed function was apparently altered throughout the drainage to the point that stream flows were visibly affected. These reports point to not only physical impacts to stream habitat, but also marked reduction in base flows resulting from reduced infiltration. Consequently, increased fragmentation of cold-water habitats that were formerly connected, at least on a periodic basis (e.g., during wet years or seasonally), in the Blue River drainage was a likely result.

Miller (1950) also described changes in suitability of habitat for trout in the upper Gila River drainage in New Mexico. In 1898, Gila trout was reported to be found in the upper Gila River drainage from the headwaters downstream to the Mogollon Creek confluence. By 1915, the downstream limit in the Gila River had receded upstream to the confluence of Sapillo Creek. By 1950, water temperature in the Gila River at Sapillo Creek was considered too warm to support any trout species. The causes of habitat degradation that led to this range contraction were not reported. However, the effects of unregulated, open-range grazing of domestic livestock in the late 1800s throughout the upper Gila River drainage (Baker *et al.*, 1988) along with localized, indiscriminate logging in stream bottoms (Rixon, 1905) likely resulted in changes in habitat characteristics such as reduced riparian shading, timing and duration of peak flows, extent of perennial flow, base flow discharge, increased water temperature, and increased sediment loading (Rich, 1911; Duce, 1918).

Contemporary habitat fragmentation may continue to persist on the landscape as a result of historic land management practices. For example, effects of unregulated, open-range livestock grazing in the late 1880s persist to varying degrees throughout the upper Gila River watershed in New Mexico via alterations to watershed form and function which may take millennia to fully recover (Stauder, 2009). However, the threats to Gila trout habitat from livestock grazing and timber harvest have been greatly reduced over time, contributing to the reclassification of the species from endangered to threatened (Service 2006). Contemporary habitat loss now occurs primarily as the result of large-scale, high-severity wildfire and effects of climate change (discussed above), however, the persistence of fragmented habitat on the landscape continues to impact the long term persistence of Gila trout populations.

Additional information and personal accounts can be found in Appendix H

Stressors

The effects of historical habitat loss and fragmentation may include the establishment of small, isolated populations and increased demographic stochasticity within those populations. The risk of population extinction increases with decreasing population size (Hanski (1999) due to the heightened susceptibility of small populations to the effects of genetic, demographic and environmental variability (Caughley and Gunn, 1996: 163; Kruse *et al.*, 2001; Fausch *et al.*, 2006; Letcher *et al.*, 2007). Genetic drift (the random change in allele frequencies from generation to generation) and inbreeding in small populations reduce genetic variation (Allendorf *et al.*, 2013). Loss of genetic variation can reduce the capability of a population to persist and evolve. This reduced capability occurs through changes in allele frequencies that may cause an increase in deleterious alleles or a loss of allelic diversity (e.g., in the major histocompatibility complex which influences immune response) that increases vulnerability.

Demographic stochasticity arises from the unpredictable variation in individual reproduction and survival. In large populations, the effect of variation in reproduction and survival among individuals is dampened by large numbers. However, in small populations the coincidence of poor reproduction or survival among its members during a single, unfortunate year may have profound effects on population size and thus the probability of population persistence. The variation in population growth rate in a constant environment depends upon population size; a halving of population size causes a doubling of the variation in growth rate. Consequently, small populations are subject to erratic swings in size due to demographic stochasticity alone, and have little buffer against spiraling declines that end in population extinction (Caughley and Gunn, 1996). Small populations may be subject to depressed per capita growth rate due to reduced mating success (Allee effect) and increased emigration.

Environmental variation such as prolonged drought, scouring floods, or extended periods of favorable, stable flow conditions, may have a strong influence on population growth rate, with cascading effects on demographic stochasticity. However, the effect of environmental variation is reduced with increased size of area occupied because environmental conditions have a spatial component and are typically scale-dependent (e.g., a wildfire that affects one watershed within a contiguous, six-watershed area occupied by the species). Large, occupied areas have higher habitat heterogeneity than small areas, which provides a better chance of maintaining some favorable habitat at all times. In contrast, suitable habitat may temporarily disappear entirely from small areas resulting in population extinction (Hanski, 1999).

Fragmentation of distribution disrupts the dynamics of migration and colonization. For example, natural recolonization of stream reaches in which habitat has recovered following elimination of populations by flood, fire effects, or drought is not possible when populations are isolated from one another. Lack of immigration also may result in increased inbreeding and reduced genetic variation (Wofford *et al.*, 2005; Neville *et al.*, 2006; Morrissey and de Kerckhove, 2009).

Species Response

Responses of Gila trout to the threat of small population size include increased vulnerability of populations to extirpation and reduced genetic variation. Isolated populations have been extirpated by the effects of wildfire (see section on Large-Scale, High-Severity Wildfire), drought, suspected demographic stochasticity, or a combination of factors. For example, remnant populations of Gila trout were extirpated in a variety of locations as a result of wildfire in 1989, 1990, 1995, 1996, 2007, 2011, 2012, and 2012. Heterozygosity of all of the remnant lineages of Gila trout, with the exception of Iron Creek, has declined from 2002 to 2013 (Gila trout Recovery Team, 2014). Loss of genetic diversity has been particularly acute in the Spruce Creek lineage. The erosion of genetic diversity in the remnant lineages is likely due to the consequence of bottlenecks and small genetically effective population size in many of the occupied streams.

Magnitude of Threat

The overall magnitude of the threat of small population size is ranked as high (Table 3). As of 2017, only the Mogollon Creek and Willow Creek drainages had dendritically structured populations of Gila trout with some potential for colonization and movement dynamics. In relation to geographic extent, population isolation and small population size are a range-wide concern for Gila trout. In relation to timeframe, these stressors constitute an imminent, ongoing historic threat to the species. Intensity of the threat is ranked as moderate because even relatively small populations may persist for a decade or more. The potential negative effects of genetic drift and inbreeding depression in such small populations suggest that they may best be considered as natural refuge sites that require periodic introductions of fish to maintain genetic diversity.

Chapter 4- Conservation Efforts

Introduction

The history of actions from the early 20th century through 2015 to conserve Gila trout have been documented by Turner (1986), Propst and others (1992), Propst (1994), Turner (1996), notes from recovery team meetings, and other sources. The following discussion of conservation measures to date was adapted from those sources.

See Appendix I for an account of conservation efforts prior to 2011.

2011 through Present

The 2011 Wallow Fire affected Gila trout recovery streams in the Blue River drainage. The Gila trout population in Raspberry Creek (Spruce Creek lineage) was eliminated by the fire. Several other potential recovery streams were also affected by the fire including Coleman, KP and Grant creeks. After removal of hybrid trout, KP Creek was subsequently found to be fishless. AZGFD will collect eDNA samples in 2019 or 2020 to confirm the fishless state of KP Creek. Manual removal of nonnative trout (using electrofishing) was conducted in Black Canyon and McKenna Creek in 2011. The entire length of perennial stream in McKenna Creek (*ca*. 1.6 km [1 mi]) was intensively electrofished five times, resulting in removal of 495 Gila x rainbow hybrid trout. In August 2011, electrofishing in Black Canyon resulted in removal of 164 brown trout from the stream above the fish barrier. Construction of a new fish barrier on Black Canyon was completed in July 2011. The new barrier, located adjacent to the existing gabion structure, was constructed of concrete and included a splash pad on the downstream side of the barrier. The existing gabion structure had been compromised and likely was not effective in preventing upstream movement of nonnative trout into the Gila trout restoration area. Monitoring in May 2011 found no nonnative trout in the upper West Fork Gila River restoration area. In October 2011, 199 Gila trout (Main Diamond lineage) were collected from upper White Creek and were stocked in the West Fork Gila River below Packsaddle Canyon. The population of South Diamond lineage Gila trout in Frye Creek, which was established in 2009, was supplemented by stocking in February (N = 650) and November (N = 150) 2011. Ash Creek was stocked with five Spruce Creek lineage Gila trout from Mora National Fish Hatchery in November 2011.

The naturalized rearing system at Mora National Fish Hatchery was improved in 2011 to address gas super-saturation issues, and other refinements to the system were made in water quality monitoring and maintenance, provision of live and natural feed, and regulation of photoperiod and temperature. The result was the highest hatch rate of Gila trout eggs in five years and higher survival rates of wild fish brought into the station. A program of marking members of each broodstock family was implemented using passive integrated transponder tags. Stocking of the recreational Gila trout fisheries in the West Fork Gila River near the Heart Bar Wildlife Area and Sapillo Creek was conducted in January and November 2011. A recreational fishery was also established at Frye Mesa Reservoir with stocking of 1,446 South Diamond lineage Gila trout in 2011.

Monitoring in spring of 2012 discovered brown and rainbow trout in the upper West Fork Gila River above the waterfall near White Creek Cabin, indicating that the waterfall did not constitute an effective barrier to upstream movement of nonnative trout. A large boulder lodged in a narrow space below the waterfall was causing a marked increase in water surface elevation during high flows and a consequent decrease in the height of the waterfall to the point that upstream fish movement was possible.

The Whitewater-Baldy Complex Fire burned through portions of the upper Gila River and San Francisco River watersheds from May through July 2012. The wildfire burned more than 120,534 ha (465 mi^2) and was the largest wildfire in New Mexico state history. Aerial reconnaissance was conducted to assess the condition of Gila trout recovery streams in June 2012. Numerous streams were observed to have been severely affected by the fire, with the most extreme impacts occurring at Whiskey Creek, West Fork Mogollon Creek, Rain Creek, Whitewater Creek and East Fork Whitewater Creek (Figure 11; Brooks, 2012*a*).

Figure 11. Whitewater-Baldy Fire effects in the West Fork Mogollon Creek watershed, looking upstream (James Brooks, June 2012)

The fire also severely affected many other existing or potential Gila trout recovery streams including the upper West Fork Gila River, Cub Creek, White Creek, Langstroth Canyon, Spruce Creek, Big Dry Creek and Mogollon Creek, Iron Creek, Willow Creek, South Fork Whitewater Creek, and Mineral Creek (Brooks, 2012*a*). Gila trout were evacuated from Spruce Creek in June 2012, with 100 taken to Mora National Fish Hatchery and another 210 translocated to Ash Creek in Arizona (Brooks, 2012*b*) because approximately 22 percent of the watershed burned had with high to moderate severity and severe post-fire impacts were anticipated (Brooks, 2012*a*). The population in Spruce Creek was subsequently extirpated in the aftermath of the Whitewater-Baldy Complex Fire, but the Spruce Creek lineage population in Big Dry Creek persisted. Similarly, Gila trout were evacuated from Whiskey Creek in June prior to the onset of major post-fire impacts (Figure 12). Over 80 percent of the Whiskey Creek watershed had burned with high to moderate severity. Eighty-one Gila trout were captured and were transported to a naturalized rearing facility at the New Mexico Fish and Wildlife Conservation Office in Albuquerque (Brooks, 2012*c*). Approximately 60 Gila trout (Whiskey Creek lineage) were also evacuated from Langstroth Canyon in June 2012 and transported to Mora National Fish Hatchery (Brooks, 2012*c*). In July 2012, another 67 Gila trout were captured in Langstroth Canyon and translocated to McKenna Creek. Post-fire impacts subsequently caused the extirpation of the Gila trout population in Whiskey Creek.

Figure 12. Gila trout being collected for evacuation from Whiskey Creek (James Brooks, June 2012)

By the end of 2012, Mora National Fish Hatchery had 232 Whiskey Creek lineage and 96 Spruce Creek lineage Gila trout. The naturalized rearing facility at the New Mexico Fish and Wildlife Conservation Office housed 68 Whiskey Creek lineage Gila trout. KP Creek was electrofished to remove Apache x rainbow trout hybrids. Two hybrid trout were found and removed. Following electrofishing the stream was considered likely to be fishless. Electrofishing was also conducted in upper Turkey Creek, which was affected by the Whitewater-Baldy Complex Fire. Two Gila x rainbow hybrid trout and 13 rainbow trout were removed during electrofishing. Electrofishing removal of nonnative trout was continued in Black Canyon and McKenna Creek in 2012. Six electrofishing passes were made through the entire perennial reach of McKenna Creek in June 2012, and no fish were collected during the fifth and sixth passes. Consequently, hybrid trout were determined to have been eliminated from the stream. As noted above, Gila trout of Whiskey Creek lineage were subsequently translocated from Langstroth Canyon to McKenna Creek. Willow Creek was stocked with South Diamond lineage Gila trout in 2012.

Monitoring conducted in April 2013 found trout populations had been eliminated in the upper West Fork Gila River (above the waterfall near White Creek Cabin), Whiskey Creek, White Creek and Langstroth Canyon. Whiskey Creek lineage Gila trout evacuated from the stream in 2012 were stocked in McKenna Creek in May 2013. In November 2013, lower White Creek was stocked with Main Diamond lineage Gila trout and Cub Creek was stocked with South Diamond lineage fish. The Silver Fire, which started in June 2013, brought about the extirpation of Gila trout populations in McKnight Creek and Black Canyon. Black Canyon was stocked in October and November 2013 with Main Diamond lineage Gila trout. Main Diamond lineage fish were also stocked in Little Creek (N = 2,750) and Sheep Corral Canyon in September and October 2013. Gila trout were evacuated from South Diamond Creek in June as a precaution against potential impacts from the Silver Fire. The fire did not reach the South Diamond Creek watershed, so the fish were returned to the stream in October.

The Iron Creek population survived the Whitewater-Baldy Complex Fire. In May 2013, 51 fish were collected from Iron Creek and taken to Mora National Fish Hatchery. The South Diamond lineage broodstock at Mora National Fish Hatchery was augmented with 200 Gila trout collected from Mogollon Creek in May 2013. A temporary fish barrier, constructed of gabion baskets, was installed on Willow Creek in 2013, and the stream above the barrier was stocked with South Diamond lineage Gila trout.

Genetic analysis of trout from above the barrier in Iron Creek found a greater than 95 percent probability that the fish were not recently hybridized with rainbow trout (Turner, 2013), in contrast to earlier work that concluded the population was introgressed (Leary and Allendorf, 1999). It was suggested that the contradiction may have arisen from: 1) retention of ancestral polymorphism at allozyme loci; 2) retention of allozyme loci through the effect of purifying selection; or 3) past introgression and subsequent loss of rainbow trout alleles through backcrossing with pure Gila trout. Turner (2013) concluded that the Iron Creek population was essentially pure and that it represented a unique evolutionary lineage. The Iron Creek population also was found to have unique alleles at relatively high frequencies at the MHC class II β gene, and that this population had the highest diversity among Gila trout populations at the MHC locus (Turner, 2013). Subsequent analysis of single nucleotide polymorphisms found no evidence of recent hybridization in the Iron Creek population (Turner and Camack, 2017).

An analysis of natural and man-made barriers on seven recovery streams was conducted in 2014 (Gila trout Recovery Team, 2014). The analysis concluded that the man-made barriers on Little Creek, Iron Creek and Black Canyon were effective at preventing upstream movement of fish. The man-made barrier on McKnight Creek was found to be compromised but it was determined that the structure could be repaired. A permanent fish barrier was constructed in Willow Creek immediately upstream of the confluence with Gilita Creek in 2016, replacing the gabion structure that served as a temporary barrier since 2014. The temporary barrier on Willow Creek was assessed to be a functional barrier to upstream movement of fish during low to moderate flows, but not during high flows. The natural waterfall barrier on White Creek was determined to be a barrier to upstream movement of fish at all flows. The waterfall on the West Fork Gila River, consisting of three drops, was determined to allow upstream movement of fish during high flows due to boulders that reduced drop height.

Genetic analysis of trout samples collected in April and July 2014 from the upper West Fork Gila River found the Gila trout populations in the West Fork Gila River and Cub Creek to be introgressed with rainbow trout. Apparently, rainbow trout or Gila x rainbow trout hybrids either survived the 2010 rotenone treatments or subsequently gained access to the restoration area either by human-assisted fish movement or by upstream movement of rainbow trout or Gila x rainbow hybrid trout past the waterfall on the West Fork Gila River located below the confluence of White Creek.

Little Creek was found to continue to support only low numbers of Gila trout likely due to the lack of pool habitat (a lingering effect of sediment input following the 2011 Miller Fire). Main Diamond lineage Gila trout were stocked in Little Creek (N = 2,050) again in 2014. Sheep Corral Canyon was also stocked with Main Diamond lineage Gila trout (N = 165) in 2014. South Diamond lineage fish were stocked in Grapevine Creek (N = 290) and Frye Creek (N = 290). None of the Gila trout stocked in Black Canyon in 2013 survived, and the stream was stocked again in 2014 with Main Diamond lineage fish (N = 3,200). Monitoring in October 2014 found the stream above the barrier to be fishless. Upper White Creek was stocked with Whiskey Creek lineage Gila trout (N = 5,300). Spruce Creek lineage Gila trout (N = 200) were stocked in Ash Creek post-Whitewater Baldy Fire in 2012. However, Gila trout were evacuated from the stream in November 2014 and moved to MNFH due to lack of reproduction, lack of genetic diversity, high relatedness, and overall vulnerable status of the lineage. South Diamond lineage Gila trout were stocked above the gabion structure in Willow Creek in 2014 to maintain a popular recreational fishery not considered a recovery stream due to the impermanence and possible ineffectiveness of the temporary barrier. After construction of the permanent fish barrier was completed on Willow Creek, the population was augmented with South Diamond lineage Gila trout. No nonnative salmonids were recorded in Willow Creek above the permanent barrier. Willow Creek is now considered a recovery stream and regulated harvest is allowed under the special 4(d) rule for Gila trout (Service 2006). Recreational fisheries in the West Fork Gila River, Snow Lake, and Frye Mesa Reservoir were also stocked with Gila trout in 2014.

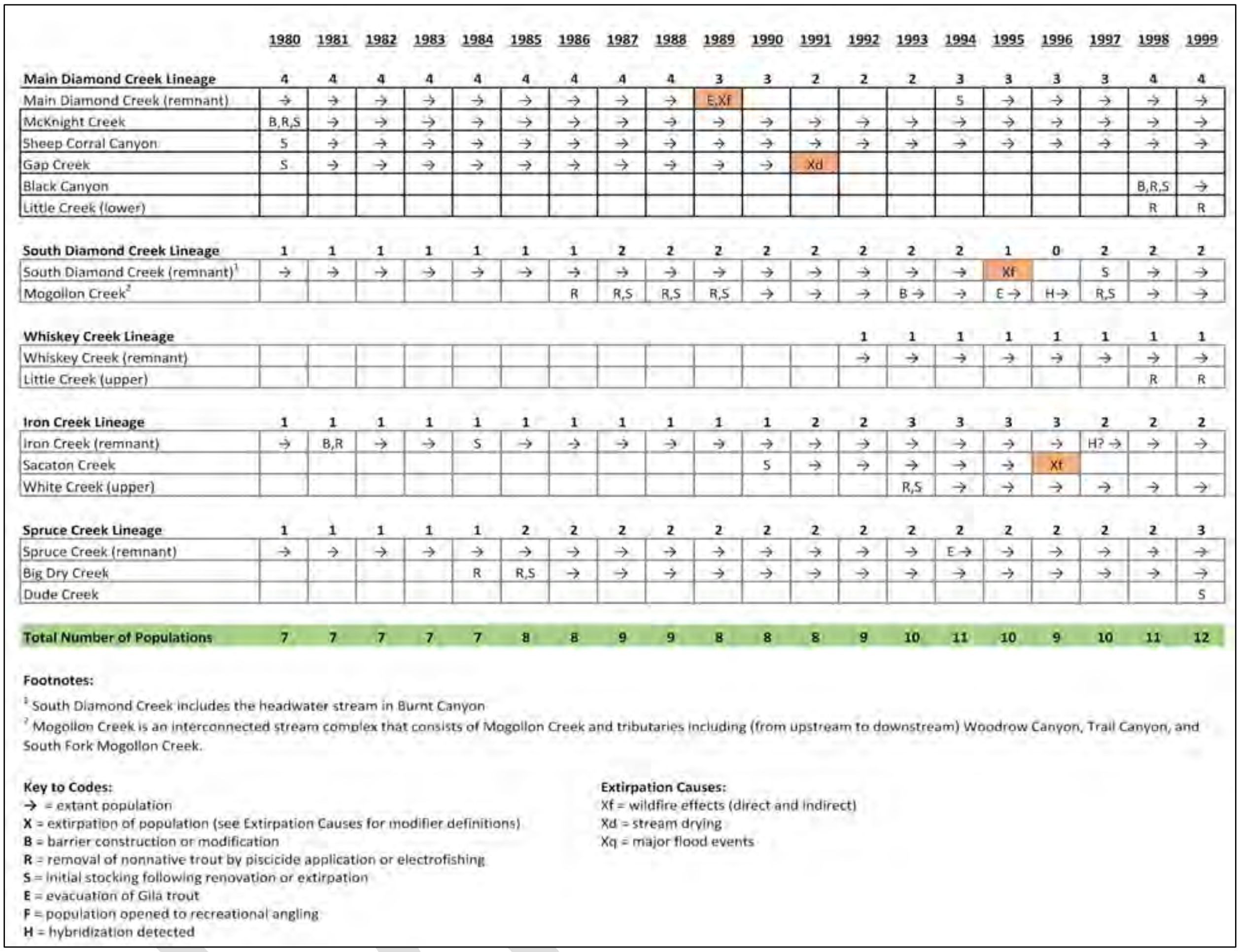
Monitoring in 2014 indicated substantial reproduction of nonnative trout in upper Turkey Creek, indicating that mechanical removal would not suffice to renovate the stream from Gila trout. Assessment of West Fork Mogollon Creek and Rain Creek found that nonnative trout populations survived the Whitewater-Baldy Complex Fire. Assessment of Whitewater Creek found nonnative brook trout in very low numbers in the South and East forks and rainbow trout in the upper reaches of the stream. Mineral Creek was confirmed in 2014 to be fishless. However, post-fire habitat degradation rendered the stream unsuitable for restoration of Gila trout. Iron Creek was closed to angling in 2014.

Monitoring in July 2015 found that the Spruce Creek lineage Gila trout population in Big Dry

Creek survived the Whitewater-Baldy Complex Fire. Main Diamond Creek lineage Gila trout were stocked into upper Langstroth Canyon in 2015. Dude Creek was stocked with 500 Main Diamond and 500 South Diamond lineage Gila trout, and Ash Creek was stocked with 500 Whiskey Creek lineage Gila trout in 2015. The McKenna Creek population (Whiskey Creek lineage) was monitored in May 2015 and found to consist of multiple age classes, indicating successful reproduction and recruitment. Monitoring in 2015 also confirmed persistence of Gila trout populations in Sheep Corral Canyon and Little Creek. Removal of boulders and sediment limiting the effectiveness of the waterfall barrier on the West Fork Gila River near White Creek Cabin was conducted in May 2015. The boulders were removed using explosives. The result was an increase in vertical drop to more than 2.4 m (8.0 ft.). Trail cameras were installed to record conditions at various flows. Despite efforts to increase the height of the waterfall, spring runoff and monsoonal floods compromised its effectiveness as a barrier. Also, water-temperature dataloggers were installed at six locations in the upper West Fork Gila River drainage. Electrofishing removal of nonnative trout from upper Marijilda Creek was conducted in 2015 in an effort to make the stream suitable for restoration of Gila trout. Frye Creek was opened to angling in January 2015.

Conservation efforts currently concentrate on repatriating both streams affected by fire and streams devoid of nonnative salmonids. Unexpected benefits arose from the large-scale wildfires. For example, effects from fires extirpated Gila trout from streams within the fire perimeter, however post-fire effects also eliminated nonnative trout from a number of streams opening the possibility for Gila trout repatriations. Mineral Creek was one stream that benefitted from post-fire extirpation of nonnative trout. Mineral Creek was subsequently stocked with Whiskey Creek lineage Gila trout from 2016-2018 with natural reproduction reported in 2018. The Whitewater Creek drainage also lost most of the Rainbow and Brook trout that previously inhabited the drainage. In response, the recovery team recommended a renovation of Whitewater Creek to remove the remaining nonnative trout. NMDGF headed the renovation project in 2017 and 2018 and is currently ongoing with a goal to begin Gila trout repatriations by 2019. In Arizona, effects from fires eliminated populations of Gila trout from Ash Creek, Frye Creek, and Grapevine Creek in 2017. Experimental egg-outplanting occurred in Frye and Grapevine creeks. Surveys in 2018 indicated survival of outplanted eggs in Grapevine Creek. Coleman and Chase creeks were determined to be void of nonnative salmonids. Chase Creek was stocked with Iron Creek lineage Gila trout in 2017 and 2018. Coleman Creek will also be stocked with Iron Creek lineage Gila trout when fish become available. The history of each lineage and its fate (survival each year, extirpated by fire or flood, or loss from introgression) within streams from 1980 through 2016 can be found in Tables 4 and 5.

Table 4. Status of Gila trout populations, pre-1980 through 1999, showing numbers of extant populations of each lineage.



	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Main Diamond Creek Lineage	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**3**	**3**	**2**	**2**	**2**	**3**	**3**	**3**	**3**	**4**	**4**
Main Diamond Creek (remnant)	→	→	→	→	→	→	→	→	→	E,Xf					S	→	→	→	→	→
McKnight Creek	B,R,S	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→
Sheep Corral Canyon	S	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→
Gap Creek	S	→	→	→	→	→	→	→	→	→	→	Xd								
Black Canyon																			B,R,S	→
Little Creek (lower)																			R	R
South Diamond Creek Lineage	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**1**	**0**	**2**	**2**	**2**
South Diamond Creek (remnant)[1]	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	Xf		S	→	→
Mogollon Creek[2]							R	R,S	R,S	R,S	→	→	→	B →	→	E →	H →	R,S	→	→
Whiskey Creek Lineage													**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Whiskey Creek (remnant)													→	→	→	→	→	→	→	→
Little Creek (upper)																			R	R
Iron Creek Lineage	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**2**	**2**	**3**	**3**	**3**	**3**	**2**	**2**	**2**
Iron Creek (remnant)	→	B,R	→	→	S	→	→	→	→	→	→	→	→	→	→	→	→	H? →	→	→
Sacaton Creek											S	→	→	→	→	→	Xf			
White Creek (upper)														R,S	→	→	→	→	→	→
Spruce Creek Lineage	**1**	**1**	**1**	**1**	**1**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**3**
Spruce Creek (remnant)	→	→	→	→	→	→	→	→	→	→	→	→	→	→	E →	→	→	→	→	→
Big Dry Creek					R	R,S	→	→	→	→	→	→	→	→	→	→	→	→	→	→
Dude Creek																				S
Total Number of Populations	**7**	**7**	**7**	**7**	**7**	**8**	**8**	**9**	**9**	**8**	**8**	**8**	**9**	**10**	**11**	**10**	**9**	**10**	**11**	**12**

Footnotes:

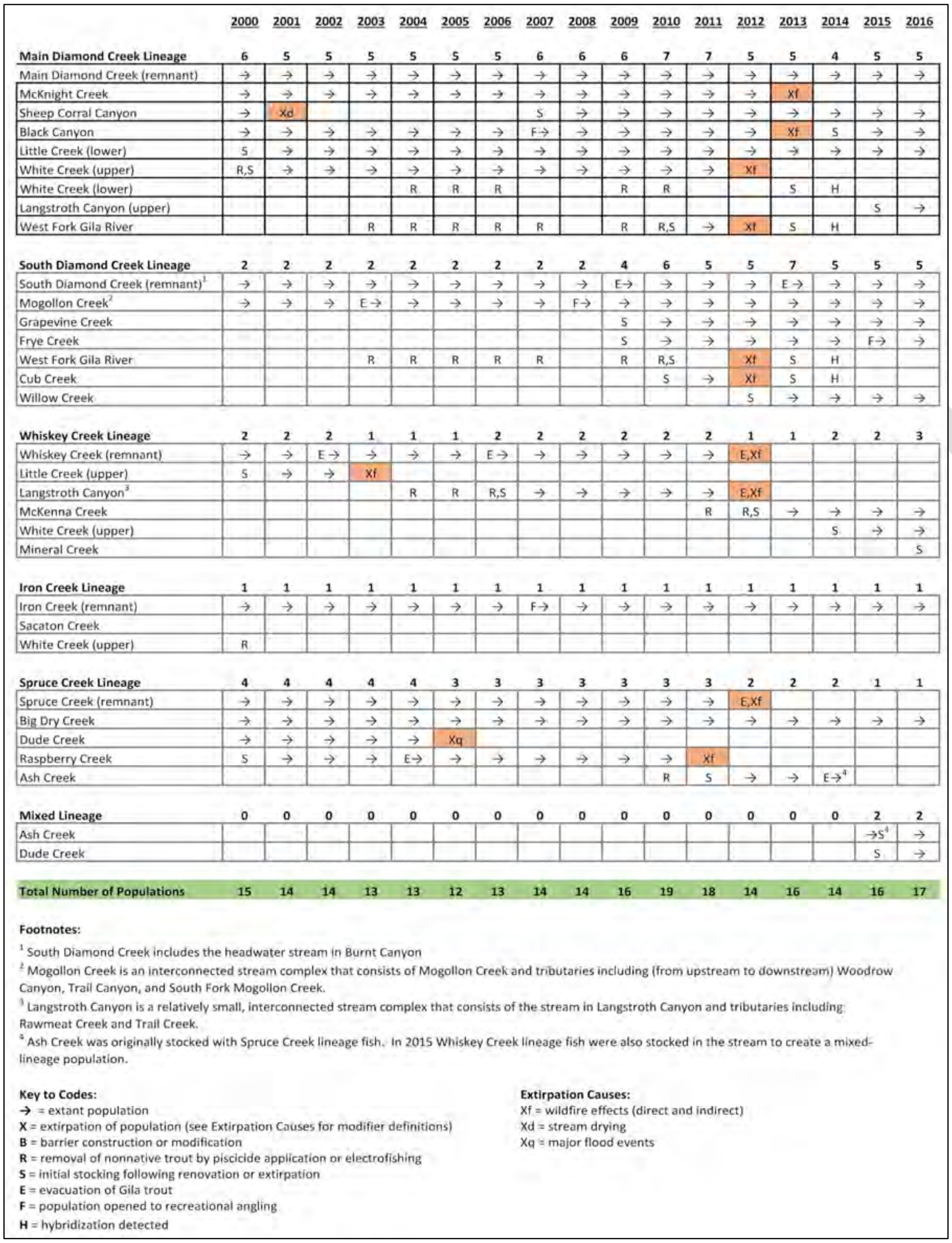
[1] South Diamond Creek includes the headwater stream in Burnt Canyon

[2] Mogollon Creek is an interconnected stream complex that consists of Mogollon Creek and tributaries including (from upstream to downstream) Woodrow Canyon, Trail Canyon, and South Fork Mogollon Creek.

Key to Codes:
→ = extant population
X = extirpation of population (see Extirpation Causes for modifier definitions)
B = barrier construction or modification
R = removal of nonnative trout by piscicide application or electrofishing
S = initial stocking following renovation or extirpation
E = evacuation of Gila trout
F = population opened to recreational angling
H = hybridization detected

Extirpation Causes:
Xf = wildfire effects (direct and indirect)
Xd = stream drying
Xq = major flood events

Table 5. Status of Gila trout populations, 2000 through 2006, showing number of extant populations of each lineage.



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Main Diamond Creek Lineage	**6**	**5**	**5**	**5**	**5**	**5**	**5**	**6**	**6**	**6**	**7**	**7**	**5**	**5**	**4**	**5**	**5**
Main Diamond Creek (remnant)	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→
McKnight Creek	→	→	→	→	→	→	→	→	→	→	→	→	→	Xf			
Sheep Corral Canyon	→	Xd						S	→	→	→	→	→	→	→	→	→
Black Canyon	→	→	→	→	→	→	→	F→	→	→	→	→	→	Xf	S	→	→
Little Creek (lower)	S	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→
White Creek (upper)	R,S	→	→	→	→	→	→	→	→	→	→	→	Xf				
White Creek (lower)					R	R	R			R	R			S	H		
Langstroth Canyon (upper)																S	→
West Fork Gila River				R	R	R	R	R		R	R,S	→	Xf	S	H		
South Diamond Creek Lineage	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**4**	**6**	**5**	**5**	**7**	**5**	**5**	**5**
South Diamond Creek (remnant)[1]	→	→	→	→	→	→	→	→	→	E→	→	→	→	E→	→	→	→
Mogollon Creek[2]	→	→	→	E→	→	→	→	→	F→	→	→	→	→	→	→	→	→
Grapevine Creek										S	→	→	→	→	→	→	→
Frye Creek										S	→	→	→	→	→	F→	→
West Fork Gila River				R	R	R	R	R		R	R,S		Xf	S	H		
Cub Creek											S	→	Xf	S	H		
Willow Creek													S	→	→	→	→
Whiskey Creek Lineage	**2**	**2**	**2**	**1**	**1**	**1**	**2**	**2**	**2**	**2**	**2**	**2**	**1**	**1**	**2**	**2**	**3**
Whiskey Creek (remnant)	→	→	E→	→	→	→	E→	→	→	→	→	→	E,Xf				
Little Creek (upper)	S	→	→	Xf													
Langstroth Canyon[3]					R	R	R,S	→	→	→	→	→	E,Xf				
McKenna Creek												R	R,S	→	→	→	→
White Creek (upper)															S	→	→
Mineral Creek																	S
Iron Creek Lineage	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Iron Creek (remnant)	→	→	→	→	→	→	→	F→	→	→	→	→	→	→	→	→	→
Sacaton Creek																	
White Creek (upper)	R																
Spruce Creek Lineage	**4**	**4**	**4**	**4**	**4**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**2**	**2**	**2**	**1**	**1**
Spruce Creek (remnant)	→	→	→	→	→	→	→	→	→	→	→	→	E,Xf				
Big Dry Creek	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→
Dude Creek	→	→	→	→	→	Xq											
Raspberry Creek	S	→	→	→	E→	→	→	→	→	→	→	Xf					
Ash Creek											R	S	→	→	E→[4]		
Mixed Lineage	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**2**	**2**
Ash Creek																→S[4]	→
Dude Creek																S	→
Total Number of Populations	**15**	**14**	**14**	**13**	**13**	**12**	**13**	**14**	**14**	**16**	**19**	**18**	**14**	**16**	**14**	**16**	**17**

Footnotes:

[1] South Diamond Creek includes the headwater stream in Burnt Canyon

[2] Mogollon Creek is an interconnected stream complex that consists of Mogollon Creek and tributaries including (from upstream to downstream) Woodrow Canyon, Trail Canyon, and South Fork Mogollon Creek.

[3] Langstroth Canyon is a relatively small, interconnected stream complex that consists of the stream in Langstroth Canyon and tributaries including Rawmeat Creek and Trail Creek.

[4] Ash Creek was originally stocked with Spruce Creek lineage fish. In 2015 Whiskey Creek lineage fish were also stocked in the stream to create a mixed-lineage population.

Key to Codes:
→ = extant population
X = extirpation of population (see Extirpation Causes for modifier definitions)
B = barrier construction or modification
R = removal of nonnative trout by piscicide application or electrofishing
S = initial stocking following renovation or extirpation
E = evacuation of Gila trout
F = population opened to recreational angling
H = hybridization detected

Extirpation Causes:
Xf = wildfire effects (direct and indirect)
Xd = stream drying
Xq = major flood events

Chapter 5- Current Condition and Species Needs

Introduction

This section describes the biological needs and situational background of the Gila trout, and is intended to give a clear sense of the species' current status and inform the recommended approach to its recovery.

Current Condition and Species Needs

What the Gila trout needs to maintain viability is presented here by characterizing the status of the species in terms of its resiliency, redundancy, and representation (Wolf *et al.* 2015). For the purpose of this document, we define **viability** as the ability of a species to persist over the long term and, conversely, avoid extinction. We use the conservation principles of **redundancy**, **representation**, and **resiliency** (Shaffer and Stein 2000) (together, the 3Rs) to better inform our view of what contributes to species' probability of persistence, how best to conserve them, and how to achieve recovery.

Redundancy describes the ability of a species to withstand catastrophic events. Measured by the number of populations, their resiliency, and their distribution (and connectivity), redundancy gauges the probability that the species has a margin of safety to withstand or can bounce back from catastrophic events (such as a rare destructive natural event or episode involving many populations.

Representation describes the ability of a species to adapt to changing environmental conditions. Representation can be measured by the breadth of genetic or environmental diversity within and among population and gauges the probability that a species is capable of adapting to environmental changes. The more representation, or diversity, a species has, the more it is capable of adapting to changes (natural or human-caused) in its environment. In the absence of species-specific genetic and ecological diversity information, we evaluate representation based on the extent and variability of habitat characteristics across the geographical range.

Resiliency describes the ability of a population to withstand stochastic events (arising from random factors). We can measure resiliency based on metrics on population health; for example, birth versus death rates, and population size. Highly resilient populations are better able to withstand disturbances such as random fluctuations in birth rates (demographic stochasticity), variations in rainfall (environmental stochasticity), or the effects of anthropogenic activities.

Summary of the Current Status of Gila trout

Redundancy

Redundancy is a function not only of the number of populations (Brown *et al.*, 2001) but also their spatial distribution across the landscape (Wolf *et al.*, 2015). Recovery actions implemented to date have greatly improved redundancy by increasing the number of populations of Gila trout to 19. However, spatial distribution of populations is constrained by the geographical distribution of currently suitable habitat for the species.

Representation

With respect to representation, the genetic diversity of Gila trout is encompassed in the remnant lineages of Main Diamond Creek, South Diamond Creek, Whiskey Creek, Spruce Creek, and Iron Creek (see section on Genetics). The Main Diamond and South Diamond lineages are relatively secure, with hatchery broodstock and production having been successfully developed and populations present in numerous streams by the end of 2016 (Table 6). The current situation of the other three lineages, however, is less secure, and only two mixed-lineage populations existed by the end of 2016. The remnant-lineage populations in Whiskey Creek and Spruce Creek were extirpated following large-scale, high-severity wildfire. At the end of 2016, populations of these lineages were present in only five other streams, and some of these streams supported only small populations. The Iron Creek lineage occurred in only one stream at the end of 2016, and that population contains unique genetic variation. Finally, only two mixed-lineage populations existed at the end of 2016 (Table 6). Genetic introgression with introduced rainbow trout or rainbow x Gila trout hybrids remains a threat to at least some of the populations due to illicit stocking or failure of fish barriers to prevent upstream movement of nonnative salmonids.

Resiliency

Resiliency of Gila trout is constrained by the patchy distribution and geographic isolation of cold-water streams, many of which are single-stream systems that are relatively small, throughout its historical range (see section on Historical Range and Current Distribution). Few, if any, extant populations of Gila trout are large enough to survive extremes in environmental conditions without experiencing a severe population bottleneck (drastic reduction in population size) (Gilpin and Soulé, 1986; see section on Habitat Loss and Fragmentation). Currently, only the Mogollon and Willow creek drainages (where the South Diamond lineage has been established) have a dendritic population structure, and even the largest single-stream systems where Gila trout have been repatriated (e.g., Black Canyon) have been subject to local extinctions associated with environmental stochasticity (see section on Conservation Efforts).

Biological Constraints and Needs

The biological constraints and needs of Gila trout comprise inherent limiting factors, and therefore must be incorporated into the recovery and conservation program for the species. The threats described in the Assessment of Threats section above exert stressors on particular limiting factors, such as the potential effect of a future warmer, drier climate on water temperature. Furthermore, limiting factors place constraints on recovery planning and implementation. For example, Gila trout cannot be successfully repatriated to formerly suitable habitats within its historical range that no longer have perennial flow. Consequently, recognition of biological constraints and needs in this Recovery Plan will ensure that ecologically relevant and valid goals, strategies, and recovery actions are developed, given the current state of knowledge and understanding of the species and its habitat.

Perennial Stream Flow

Persistent, viable populations of Gila trout require perennial stream flow. Ephemeral stream reaches may support Gila trout temporarily but not over the long term. Continuous occupation of a stream reach is possible only when flow is perennial. Additionally, stream flow must be adequate to maintain sufficient habitat diversity (see section on Diversity of Habitats below) and volume to support all life stages of Gila trout (eggs, fry, juveniles, adults). Flow regimes required to maintain sufficient habitat diversity and volume vary depending on site-specific characteristics of stream reaches (e.g., stream gradient, seepage, substrate composition, channel dimensions, watershed hydrology).

Suitable Water Temperature Regime and Water Quality

Gila trout require cold-water aquatic habitats with unimpaired water quality. Suitable water temperature regimes are characterized by maximum water temperatures that do not exceed 26^{o}C (78^{o}F). Suitable water quality for Gila trout is characterized by high dissolved oxygen concentration, low turbidity and conductivity, low levels of total dissolved solids, near-neutral pH, and low conductivity.

Diversity of Habitats

In addition to perennial stream flow and suitable water temperature and water quality, Gila trout require a diversity of habitats sufficient to sustain all life stages of the species. This includes suitable spawning habitat, habitat where fry can find shelter and food, and areas suitable for occupancy by juvenile and adult Gila trout. Specific habitat attributes required by Gila trout are described in the section on Habitat Characteristics The two most important features with respect to population persistence are likely sufficient pool habitat (Harig and Fausch, 2002) and spawning habitat (Magee *et al.*, 1996; Suttle *et al.*, 2004).

Population Size and Habitat Connectivity

The threat of local extinction of native salmonid populations increases with isolation and decreasing population size (see review in Fausch *et al.*, 2006; also Caughley and Gunn, 1996; Hanski, 1999; Fausch *et al.*, 2009; Roberts *et al.*, 2013). It follows that persistence of Gila trout over the long term requires combinations of sufficiently large occupied habitats and, where possible, connectivity in dendritic stream networks, not only with respect to population size but also to maintenance of genetic variation (Morrisey and de Kerckhove, 2009; Wofford *et al.*, 2005) and access to suitable habitat in response to environmental variation and life history requirements (Young, 2011). Many streams within the presumed historical habitat of Gila trout in Arizona may not fully meet the requirements listed here. However, smaller stream segments in Arizona and New Mexico have been shown to support viable populations in the past (Sheep Corral Canyon, Main Diamond, South Diamond, Frye Creek, and Grapevine Creek). Considering the limited amount of available habitat, small streams, although not ideal, may be useful in meeting recovery requirements for Gila trout.

Absence of Nonnative Salmonids

A key biological need for sustaining viable populations of Gila trout is the absence of nonnative salmonids (Family Salmonidae, Figure 2). The threats of brown trout (*Salmo trutta*) predation and competition (see section on Nonnative Trout Predation and Competition) and human-mediated introgressive hybridization with nonnative *Oncorhynchus* species (see section on Human-mediated Introgressive Hybridization) result from the presence of nonnative salmonids. Viable populations of Gila trout cannot persist when nonnative *Oncorhynchus* species are present. Consequently, the absence of nonnative salmonids is a fundamental requirement for sustaining viable populations of Gila trout.

Chapter 6- Recovery Program

Introduction

This section describes the goal, strategy, objectives, and criteria for the Gila trout recovery program, and identifies the specific actions that, when implemented, would alleviate known threats to the species and restore Gila trout to long-term sustainability.

Recovery Goal

The goal of the recovery program is to improve the conservation status of Gila trout to the extent that the species is viable and no longer requires protection under the Endangered Species Act. To ensure that the Gila trout will no longer meet the definition of threatened or endangered, multiple resilient populations need to be well-distributed in suitable habitats throughout the species presumed historical range, and threats to its existence must be eliminated or sufficiently abated.

Recovery Strategy

The primary focus of the recovery effort for Gila trout is to evolve from a crisis-management situation focused on preventing extinction to a perspective of sustainable populations established throughout the historical range that contain the breadth of genetic diversity of the species (Redford *et al.*, 2011). This will entail incremental replacement of nonnative salmonids with Gila trout in suitable habitat throughout a significant portion of the historical range (*cf.* Service, 2014) of the species. This strategy will be implemented by conducting actions to substantially improve redundancy, representation, and resiliency (*cf.* Haak and Williams, 2013; Wolf *et al.*, 2015), as noted in Table 6, to the point that protections under the Endangered Species Act are no longer necessary.

Table 6. Summary of the recovery strategy to address aspects of redundancy, representation, and resiliency for Gila trout.

	Current Situation	Recovery Strategy
Redundancy	Spatial distribution somewhat geographically clustered due largely to availability of suitable habitat.	Increase spatial distribution, where possible, and number of populations.
Representation	Main Diamond and South Diamond lineages are relatively secure. Status of the other three lineages is less secure. Few mixed lineage populations exist.	Maintain and conserve the genetic diversity and integrity of the species. Increase number of replicates of each genetic lineage. Increase number of mixed-lineage metapopulations.

Resiliency	Few populations have dendritic structure; most populations are relatively small and isolated.	Increase the number of large populations with dendritic structure. Increase population size and interconnectedness.

Key Assumptions

Two important assumptions are inherent in the recovery strategy. First, it is assumed that sufficient suitable habitat will be available in the future and that the effects of climate change will not be so severe as to preclude recovery of the species. Current information indicates that consequences of climate change are likely to be substantial for cold-water habitats within the presumed historical range of Gila trout. However, actual changes in habitat conditions that may occur are unknown, as are actions that society may or may not take to address climate change. Emerging issues, such as greenhouse gas release from thawing permafrost (Schuur *et al.*, 2015) and improved quantification of methane emissions (Turner *et al.*, 2016), may result in a significant increase in the challenge of dealing with climate change in recovery of Gila trout. A second key assumption is that public and agency support for Gila trout will be maintained. Prevention of replacing populations of nonnative salmonids with Gila trout within the historical range of the species would foreclose the possibility of recovery.

Recovery Units

The previous version of the recovery plan defined two recovery units as a context for delisting criteria (Service, 2003). These were the Gila River Recovery Unit, consisting of three remnant lineages in the upper Gila River drainage (Main Diamond, South Diamond, and Whiskey creeks) and the San Francisco River Recovery Unit, which consisted of the Spruce Creek lineage. A recovery unit is defined as "a special unit of the listed entity that is geographically or otherwise identifiable and is essential to the recovery of the entire listed entity, i.e., recovery units are *individually necessary* to conserve genetic robustness, demographic robustness, important life history stages, or some other feature necessary for long-term sustainability of the *entire listed entity*" (National Marine Fisheries Service and U.S. Fish and Wildlife Service, 2010). Identification of recovery units is optional in recovery plans (National Marine Fisheries Service and U.S. Fish and Wildlife Service, 2010).

The use of recovery units is discontinued in this plan for several reasons. First, it imposed unnecessary constraints on recovery of the species. For example, recovery would not be achievable if the Spruce Creek lineage were lost. While such an event would certainly be unfortunate, it would not necessarily preclude recovery and long-term sustainability of Gila trout as a biological entity. Secondly, information and knowledge of the genetics of Gila trout gained since the last recovery plan revision highlight the conservation importance of genetic exchange between lineages in mixed populations. While the recovery unit approach did acknowledge mixed-lineage populations, it only specified San Francisco River-Gila River unit combinations as contributing to recovery (Service, 2003). The benefit of other lineage combinations in developing mixed-lineage populations is now recognized. Consequently, it was determined that identification of recovery units is not necessary for recovery of Gila trout.

Recovery Objectives

The recovery goal is expressed by the following objectives:

1. Secure the existing genetic diversity of Gila trout through the establishment of additional populations (both single lineage stream segments and mixed-lineage metapopulations), the prevention of introgression by nonnative salmonids, the continuation of development of broodstock and hatchery production programs, and the continuation of work on assessment of genetic diversity and detection of introgression.
2. Increase the geographic distribution of the species so that it inhabits a substantial portion of its historical range which represents the spectrum of ecological conditions present in suitable habitats (Carroll *et al.*, 2010).
3. Increase the size, dendritic population structure, and interconnectedness of populations through nonnative salmonid removal and the strategic installation or modification of barriers (to prevent nonnative salmonid invasion but also to improve access to diverse habitats).

These objectives can also be presented in the context of redundancy, representation and resiliency:

- <u>Redundancy:</u> Viable populations of Gila trout are established in watersheds throughout the presumed historical range of Gila trout, as constrained by availability of suitable habitat.
- <u>Representation</u> Genetic diversity of Gila trout is maintained by establishing viable populations that replicate remnant genetic lineages, genetic diversity is augmented through planned lineage mixing, and all recovery streams are free of and protected from invasion by nonnative trout.
- <u>Resiliency:</u> The combination of numbers and sizes of Gila trout populations are sufficient to maintain genetic diversity, allow for persistence, and maintain evolutionary potential.

Recovery Criteria

The following are objective, measurable criteria which, when met, would result in a determination that Gila trout be removed from the endangered species list:

Criterion A – Area of Occupancy

Gila trout occupy 280 km. (174 mi.) of stream within the presumed historical range of the species. Occupancy, in the context of this criterion, refers to streams being inhabited by viable populations. Criterion A explicitly addresses objective 1, redundancy and also contributes to meeting objective 2, representation, and objective 3, resiliency.

Justification

Viable populations are defined as those populations that exhibit annual reproduction, size structure indicating multiple ages, and individuals attaining sufficient sizes to indicate three to seven years of survival (Service 2006). An analysis of extinction probability based on results of a PVA by Brown and others (2001) indicated that 280 km. (174 mi.) of occupied stream resulted in approximately 3% probability of extinction. Brown and others (2001) focused on risk associated with catastrophic wildfire; however, the PVA did not account for the large-scale wildfires that have recently burned in the Gila River Basin, NM. Population viability defined as a less than ten percent extinction probability has been used in other recovery plans (Service, 2010) and by the International Union for Conservation of Nature as a threshold in assessing a species' vulnerability of extinction. In recognition of the severity of recent wildfires that were not evaluated by Brown and others (2001), using stream occupancy associated with a more conservative extinction probability is prudent. Additionally, better, more precise mapping of suitable stream habitat resulted in a slight increase from 273 km. in the 2006 plan to 280 km. required in this plan, which will provide sufficient redundancy and resiliency for Gila trout recovery.

The threat of climate change and factors associated with climate change (wildfire, drought, and stream temperature) are highly variable throughout Gila trout habitat (Dennison *et al.* 2014, Kennedy *et al.* 2014, and Isaak *et al.* 2016). Although climate change is a threat to Gila trout, a recent analysis of vulnerability of Gila trout to future wildfire and stream temperature projections indicates that the vast majority of currently occupied and unoccupied, available streams will maintain suitable temperatures into the 2080s (Dauwalter *et al.* 2017). The occupied length requirement (280 km.) should encompass a variety of habitats within and among streams to provide refuge for Gila trout when faced with the effects of climate change.

The previous revision of the recovery plan also included a minimum number of populations in the recovery criteria (Service, 2003). However, a population can be defined in a number of arbitrary ways. For the purposes of Gila trout recovery and conservation a population typically has been defined as the fish inhabiting a particular stream segment, or a short section of stream with no perennial tributaries that may be fragmented from the rest of the same stream and contains a type of barrier to fish migration (dry reach or waterfall) at the downstream end. This perspective is problematic when fragmented stream systems or "complex" dendritic systems[4] are considered (e.g., upper and lower Little Creek, Mogollon Creek and its tributaries Woodrow and Trail canyons and South Fork Mogollon Creek). For example, Brown and others (2001) considered Mogollon Creek, Woodrow Canyon, Trail Canyon, and South Fork Mogollon Creek individual populations as opposed to others who consider dendritic systems a single population unless impassable barriers are present (Service *et al.* 2015). Therefore, no minimum number of populations is required within this plan. Criteria B and C include additional representation, redundancy, and resiliency safeguards rather than including a minimum number of populations.

Criterion B – Remnant Genetic Lineages

Each remnant genetic lineage of Gila trout is represented by at least three geographically separate, viable populations and requires one replicate population of each lineage to be geographically separated by at least 34.0 km (21.1 miles) from the other two replicate populations of that genetic lineage. These populations and the streams they inhabit would contribute to meeting the area of occupancy threshold in Criterion A. Criterion B explicitly addresses objective 2, representation.

Justification

Conservation of genetically distinct lineages is an important component of maintaining the genetic integrity of Gila trout (Wares *et al.*, 2004; Allendorf *et al.*, 2013). Individual populations of each remnant genetic lineage should preferably be established in larger stream systems to maximize effective population size, thereby minimizing the loss of genetic variation through drift and inbreeding depression (Franklin and Frankham, 1998; Lynch and Lande, 1998; Rieman and Allendorf, 2001; Traill *et al.*, 2010; Allendorf *et al.*, 2013; Frankham *et al.*, 2014). As described above, viable populations are defined as those populations that exhibit annual reproduction, size structure indicating multiple ages, and individuals attaining sufficient sizes to indicate three to seven years of survival. Persistent, viable populations may exist on the landscape at highly varying population sizes; therefore, specifying a number of individuals to define a viable population is not prudent as population dynamics are a more appropriate predictor of population viability than population size. Maintenance of genetic diversity within Gila trout lineages will be accomplished by replication of individual lineages to new streams, geographic separation between those replicated populations, and planned mixing of lineages in the remaining streams necessary to meet Criteria A and C. Planned mixing of lineages in the remaining recovery streams will ensure remnant genetic diversity is present across the range of Gila trout. Requiring a minimum distance between populations of individual lineages reduces the risk that one catastrophic event will affect all populations of that lineage. The distance of separation is based on the Whitewater Baldy Fire in 2012, which burned approximately 297,845 acres and had a maximum burn diameter of approximately 34.0 km wide (U.S. Forest Service, 2011), the largest fire in New Mexico history.

Criterion C – Dendritic Metapopulations

At least four dendritic metapopulations of Gila trout are established. These metapopulations and the streams they inhabit would contribute to meeting the area of occupancy threshold in criterion A. Criterion C explicitly addresses objective 3, resiliency and also contributes to meeting objectives 1, redundancy and 2, representation.

Justification

Ideally, the dendritic metapopulations should support effective population sizes of at least 500 (Franklin and Frankham, 1998) and preferably over 1,000 individuals (Lynch and Lande, 1998; Traill *et al.*, 2010; Frankham *et al.*, 2014). Habitat fragmentation and isolation of local populations exerts a strong influence on loss of genetic diversity (Carim *et al.*, 2016) and risk of extinction (Dunham *et al.*, 1997). Much of the divergence among remnant genetic lineages of Gila trout likely does not reflect local adaptation but rather is the effect of drift (Wares *et al.*, 2004). The isolation of remnant populations since widespread Euro-American settlement of the region has resulted in loss of genetic diversity and it is likely that, historically, there was genetic transfer within drainage systems (Turner *et al.*, 2009).

As a result of the Whitewater-Baldy Fire many isolated trout populations were eliminated; however, trout populations survived in all dendritic systems within the fire footprint, including Whitewater Creek, Willow Creek, West Fork Gila River, and Mogollon Creek. Larger dendritic systems may provide more refuge habitat during stressful environmental disturbances such as fires or floods (Nakamura *et al.*, 2000). This demonstrates the value of dendritic systems for providing resiliency from catastrophic wildfire, floods, and drought.

The metapopulation concept is important in Gila trout recovery. As mentioned above, populations within the complex dendritic systems provided the resiliency against large catastrophic wildfire. We may not be able to produce a classical metapopulation with distinct populations, patches, or groups of individuals that experience local extinctions and recolonizations (Hanski 1999, Rieman and Dunham 2000). However, metapopulations can vary from the conventional definition depending upon spatial and temporal scales (Harrison and Taylor 1997). In that regard we are able to apply the metapopulation concept to complex dendritic systems within the suitable habitat of Gila trout. In the metapopulation concept here, any potential loss of a group of individuals (within a tributary, adjacent tributaries, or section of the mainstem) due to fire, flood, or disease may be reestablished by individuals from another portion of the metapopulation.

Additionally, increasing the genetic diversity will aid in achieving the desired representation of genetic information across lineages and resiliency of the metapopulation over time. When a dendritic system becomes available for Gila trout recovery efforts, the stocking strategy will be evaluated on a case by case basis in order to achieve the best representation of the available genetics given the limitations at that time (hatchery availability, habitat availability and quality, and existing genetic representation on the landscape). This strategy will contribute to attaining representation as well as realizing greater resiliency for Gila trout.

Criterion D – Absence of Nonnative Salmonid Species

Nonnative salmonids are absent from recovery streams and measures such as barriers and eradication programs are in place to prevent re-invasion by nonnative salmonids. If non-hybridizing, nonnative salmonids persist in recovery streams, active management and suppression will occur to mitigate effects on the Gila trout recovery populations until complete eradication of nonnative salmonids is achieved. Criterion D explicitly addresses objectives 1, redundancy and 2, representation.

Justification

A key biological need for sustaining viable populations of Gila trout is the absence of nonnative salmonids. The threats of brown trout predation and competition (see section on Nonnative Trout Predation and Competition) and human-mediated introgressive hybridization with nonnative *Oncorhynchus* species (see section on Human-mediated Introgressive Hybridization) result from the presence of nonnative salmonids. Reducing and eliminating nonnative trout from streams occupied by or potentially occupied by Gila trout is crucial to maintaining viable populations of Gila trout.

Recovery Actions and Implementation

Actions Needed

Recovery actions are the site-specific management actions needed to address threats to the species and achieve recovery criteria. For the Gila trout, implementation of the following recovery actions will involve participation from the Service, Forest Service, Arizona Game and Fish Department, and New Mexico Department of Game and Fish.

1. Repatriate Gila trout to streams within its presumed historical range (Priority 1). Reintroduction of fish to extirpated habitats and stocking of fish to unoccupied streams will increase the number of Gila trout populations (species redundancy) across its range, thus increasing the species' ability to withstand catastrophic events such as large-scale, high intensity wildfires. Supplementing fish to increase the abundance in existing Gila trout populations will also increase the resiliency of those populations, making them better able to withstand the demographic stochasticity associated with small, isolated populations and environmental stochasticity associated with climate change.

2. Establish and maintain captive propagation methods and conservation hatchery facilities in suitable locations (Priority 1). Establishing and maintaining conservation hatcheries is directly related to recovery action 1. The hatchery stock will be used for the reintroduction

to historical habitat that creates species redundancy by establishing new wild populations. It also mitigates the threat of extirpation of a genetic lineage due to catastrophic events in the remaining populations due to wildfire, climate change or introduction of a nonnative salmonid species that may hybridize with a wild population; maintaining a hatchery stock will allow for reestablishment of the genetic lineage due to these events.

3. Manage the presence of nonnative salmonids in recovery streams in Arizona and New Mexico (Priority 1). Managing and monitoring for nonnative salmonids allows the Service and its partners to try and prevent their establishment in streams that are home to wild Gila trout populations. Nonnative salmonids may outcompete the Gila trout and this may be exacerbated by the increased effects of climate change. Preventing the establishment of nonnative salmonids reduces the risk of predation on Gila trout and hybridization, which can lead to a decrease in natural genetic lineage and population abundance.

4. Monitor remnant and repatriated Gila trout populations within the Gila River drainage basin (Priority 2). Monitoring Gila trout populations provides increased data on how species are responding to environmental changes such as climate change, invasive species and wildfire. The increase in knowledge and understanding allows the Service to make more informed decisions regarding the recovery of Gila trout and adapt to changes in population sizes or habitat.

5. Conduct public education, involvement, and outreach in areas with an interest in Gila trout (Priority 3). Increasing public awareness and interest in restoring the Gila trout populations provides an additional resource to the Service for monitoring and responding to populations and changes to the environment on the local scale. An informed public can better understand how their decisions can affect the population of Gila trout, including fire safety near native habitat and reducing the risk of introduction of invasive species. Education on best logging and grazing practices can decrease the associated habitat fragmentation that leads to smaller populations. Maintaining healthy population sizes increases the resiliency of the Gila trout to adapt to environmental stochasticity.

6. Develop and implement regulations to maintain sustainable Gila trout populations in recovery streams opened to sport fishing in Arizona and New Mexico (Priority 3). Implementing regulations in recovery streams open to sport fishing will minimize the amount of unregulated harvest by the public of the Gila trout. Regulated sport fishing will create additional enthusiasm for the recovery of Gila trout, while ensuring that the size and number of fish removed will not create an additional burden on population growth.

Estimates of the cost and time required to implement these recovery actions and achieve the plan’s goal of recovering the Gila trout are outlined in Table 7 below.

Flexibility, which is essential to Gila trout recovery, can be hard to obtain with rigid timelines and schedules. Therefore, we have developed a Gila trout supplemental Recovery Implementation Strategy (RIS), which provides additional detailed, site-specific activities needed to implement the actions identified in this Recovery Plan. We intend to update the RIS as frequently as needed by incorporating new information, including the findings of future 5-year status reviews. The activities, schedules, and estimated costs identified in the RIS will be continually updated as recovery implementation progresses. Therefore, we anticipate being able to provide a greater degree of specificity in the RIS than the recovery actions in the Recovery Plan.

Estimated Timing and Cost of Recovery

We expect the status of the Gila trout to improve such that we can achieve the delisting criteria in approximately 10 years. In other words, 2030 is the approximate date to reach the goal of recovery for the Gila trout. The time to recovery is based on the expectation of full funding, implementation of recovery actions as provided for in this Recovery Plan, implementation of activities as provided for in the RIS, and full cooperation of partners.

The total estimated cost of recovery is $15,619,030. This cost includes those borne by Federal and State governmental agencies, as well as other institutions, universities, and organizations with an interest in recovering the Gila trout.

Annual cost estimates to implement recovery actions for the first 5 years are as follows:
Year 1 = $1,494,900
Year 2 = $1,381,800
Year 3 = $1,552,300
Year 4 = $1,895,600
Year 5 = $1,725,500

The estimated cost to implement the first 5 years of recovery actions (intermediate steps toward the goal of recovery) is $8,050,100. The calculation of the total estimated cost to recovery is included in the Recovery Action Table below. The cost of implementing the first 5 years of recovery, as well as a description of the costs for these years, is detailed in the Implementation Schedule Table of the RIS.

Implementation

The Recovery Action Table below (Table 7) lists actions and estimated costs for meeting the recovery objectives for Gila trout, as set forth in this Recovery Plan. Recovery actions are assigned numerical priorities, as defined below, to highlight the relative contribution they may make toward species recovery.

Priority 1 - An action that must be taken to prevent extinction; or to prevent the species from declining irreversibly in the foreseeable future.

Priority 2 - An action that must be taken to prevent a significant decline in species population/habitat quality, or some other negative impact short of extinction.

Priority 3 - All other actions necessary to meet recovery objectives.

Parties with authority, responsibility, or expressed interest to implement a specific recovery action are identified in the Recovery Action Table. When more than one party has been identified, the proposed lead party is indicated by a superscript plus symbol. As stated in the Disclaimer, recovery plans are advisory documents, not regulatory documents. A recovery plan does not commit any entity to implement the recommended strategies or actions contained within it for a particular species, but rather provides guidance for ameliorating threats and implementing proactive conservation measures, as well as providing context for implementation of other sections of the ESA, such as section 7(a) (2) consultations on Federal agency activities, development of Habitat Conservation Plans, or the creation of experimental populations under section 10(j).

Table 7. Recovery Action Table detailing the site-specific management actions needed for Gila trout recovery. Abbreviations are: **USFWS** = U.S. Fish and Wildlife Service; **FS** = U.S. Forest Service; **AGFD** = Arizona Game and Fish Department; **NMDGF** = New Mexico Department of Game and Fish. Increases in annual costs are meant to reflect annual inflation rates of 2.0%.

Priority #	Action #	Action Description	Action Duration	Responsible Parties	Total Estimated Cost ($)	Threat(s) Addressed (ESA Listing Factor)
1	1	Repatriate Gila trout to streams within its presumed historical range	10 years	USFWS, FS, AGFD, NMDGF	1,281,000	Large-scale, high-severity wildfire; Effects of climate change (Factor A) Small population size (Factor E)
1	2	Establish and maintain captive propagation methods and conservation hatchery facilities in suitable locations	Continuous until recovery is achieved	USFWS, FS, AGFD, NMDGF	8,839,000	Large-scale, high-severity wildfire; Effects of climate change (Factor A) Disease (Factor C) Human-mediated introgressive hybridization; Small population size (Factor E)

Priority #	Action #	Action Description	Action Duration	Responsible Parties	Total Estimated Cost ($)	Threat(s) Addressed (ESA Listing Factor)
1	3	Manage the presence of nonnative species in recovery streams in Arizona and New Mexico	8	USFWS, FS, AGFD, NMDGF	3,437,000	Effects of climate change (Factor A) Nonnative species predation and competition (Factor C) Human-mediated introgressive hybridization; (Factor E)
2	4	Monitor remnant and repatriated Gila trout populations within the Gila River drainage basin	Continuous (minimum of 10 years)	USFWS, FS, AGFD, NMDGF	1,391,000	Large-scale, high-severity wildfire; Effects of climate change (Factor A) Human-mediated introgressive hybridization; Small population size (Factor E)
3	5	Conduct public education, involvement, and outreach in areas with an interest in Gila trout	Continuous (minimum of 10 years)	USFWS, FS, AGFD, NMDGF	320,000	Large-scale, high-severity wildfire, Effects of climate change (Factor A) Small population size (Factor E)
3	6	Develop and implement regulations to maintain sustainable Gila trout populations in recovery streams opened to sport fishing in Arizona and New Mexico	Continuous (minimum of 10 years)	USFWS, AGFD, NMDGF	351,000	Unregulated harvest (Factor B)
Total Cost					**15,619,000**	

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Appendix A – Morphological Description of Gila Trout

As described by David (1976, 1998) Gila trout has 135 to 165 scales in the lateral line series, 59 to 63 vertebrae, and 25 to 45 pyloric caecae in all populations except Spruce Creek, which has a mean of 48 pyloric caecae. Gila trout from Spruce Creek (a tributary to Big Dry Creek in the San Francisco River watershed) and Oak Creek (an extinct population from the Verde River drainage) have basibranchial teeth (David, 1976). The Spruce Creek population is morphologically similar to Apache trout (*O. apache*) (David, 1976), but biochemical systematics indicate it is more closely related to Gila trout (see section 1.3; Loudenslager *et al.*, 1986; Riddle *et al.*, 1998). Thus, the Spruce Creek population likely represents an evolutionary unit native to the San Francisco River drainage, which includes the Blue River (David, 1998).

In addition to confusions among co-occurring nonnative trout, chubs (*Gila* spp.) have been and may continue to be locally confused with Gila trout (*cf.* allusion to "Gila trout" versus "true trout" in Dinsmore, 1924; reference to "Verde trout" and "Gila trout" as local common names for chubs in Minckley, 1973). The two fish share a similar distribution, although chubs typically occur at lower elevations than Gila trout currently occupies. The two taxa may be confused partly because chubs may be caught by anglers fishing in trout waters. Chubs (family Cyprinidae) differ from Gila trout (family Salmonidae) in both body shape and coloration. Chubs lack an adipose fin and have a narrow caudal peduncle (the segment of the body to which the tail fin is attached). Also, chubs lack parr marks, golden coloration, yellow cutthroat marks, and the salmon-pink band found on Gila trout. Chubs are typically a mottled olive or dark silver color above the lateral line. Body coloration lightens to a light silvery hue below the lateral line (Sublette *et al.*, 1990).

Appendix B – Gila Trout Genetics

Beamish and Miller (1977) reported karyotypes for Gila trout ranging from 2n = 55 to 2n = 58, with the majority of samples having a diploid chromosome number of 2n = 56. When 2n = 56, there were 49 metacentric or submetacentric chromosomes (diploid chromosomes in which the centromere occurs approximately in the middle) and seven acrocentric or telocentric chromosomes (diploid chromosomes in which the centromere is near or at, respectively, the end of the chromosome; Beamish and Miller, 1977). The number of chromosome arms in Gila trout is 105 (Beamish and Miller, 1977).

The karyotype of Gila trout is similar to that of Apache trout except that Gila trout has one more acrocentric and one less meta- or submetacentric chromosome (Beamish and Miller, 1977; Table B1). Beamish and Miller (1977) suggested that this may have resulted from a pericentric inversion in only one meta- or submetacentric chromosome in Gila trout. An inversion results when a chromosome breaks at two points producing a fragment, the fragment is inverted and then reattaches. A pericentric inversion is when the two breaks in the chromosome are on opposite sides of the centromere.

Table B 1. Karyotypes of Gila, Apache, rainbow and cutthroat trout (Beamish and Miller, 1977; Gold, 1977)**.**

Species	**Chromosome Number**	**Number of Acrocentric or Subtelocentric Chromosomes**	**Number of Chromosome Arms**
Gila trout	56-58	7	105
Apache Trout	56-58	6-10	106
Rainbow Trout	60	16	104
Cutthroat Trout	64-70	22-34	104-106

Although chromosome arm numbers are unequal in rainbow trout and Gila or Apache trout, alignment of haploid chromosome arms does occur as evidenced by fertile hybrids of Gila x rainbow and Apache x rainbow trout (Brown *et al.*, 2004).

Structural genes code for RNA or non-regulatory protein products, such as enzymes. Allozymes are the various forms of an enzyme that are coded for by the different alleles at a given gene locus. Allozymes provide a means for assessing genetic variation because they are a product of the DNA base-pair sequences that compose genes. The variation in allozymes is analyzed using protein electrophoresis.

Loudenslager and others (1986) reported five diagnostic gene loci for differentiating Gila and rainbow trout (Table B2). However, Dowling and Childs (1992) could not confirm one of these loci, dipeptidase (*PEPA**), for discrimination of Gila and Apache trout. Dowling and Childs (1992) found three diagnostic loci for differentiation of Gila trout from nonnative trout (rainbow and cutthroat trout). These three loci were alcohol dehydrogenase (*ADH**), lactate dehydrogenase (*LDH**) and tripeptidase (*PEPB**).

Leary and Allendorf (1999) analyzed allozymes translated by 48 structural genes and found fixed to nearly fixed frequency differences at eight gene loci. These eight loci were considered diagnostic for Gila trout. The eight diagnostic loci reported by Leary and Allendorf (1999) were alcohol dehydrogenase (*ADH**), creatine kinase (*CK-C2**), fumarate hydratase (*FH-1**), glyceraldehyde-3-phosphate dehydrogenase (*GAPDH-4**), L-lactate dehydrogenase (*LDH-C**), tripeptide aminopeptidase (*PEPB**), phosphoglycerate kinase (*PGK-2**) and phosphoglucomutase (PGM-1*).

Table B 2. Allele frequencies for diagnostic gene loci in Gila and rainbow trout, from Loudenslager and others (1986). Loci are: ADH* = alcohol dehydrogenase; PEPA* = dipeptidase; PEPB* = tripeptide aminopeptidase; MDH* = malate dehydrogenase; and mMEP* = malic enzyme. Loci nomenclature follows Shaklee and others (1990).

Gene Locus	**Allele**	**Allele Frequency**	
		Gila trout	**Rainbow Trout**
*ADH**	-120	0.025	
	-100		1.000
	-80	0.975	
*PEPA**	110	1.000	
	1400		
*PEPB**	150	1.000	
	100		1.000
*MDH-3,4**	100	0.659	0.950
	75	0.341	
*mMEP-3**	100	---	0.956
	50	---	0.043

Mitochondrial DNA (mtDNA) exists as thousands of copies of small (*ca*. 17,000 base pairs), circular molecules in mitochondria. Mitochondrial DNA is maternally inherited and therefore typically does not undergo recombination during meiosis (pairing of homologous chromosomes from both parents). Mitochondrial DNA is haploid and progeny generally inherit a single genotype from the mother. Therefore, the mtDNA of a species represents a single, non-recombining genealogical unit with multiple alleles or haplotypes (Allendorf *et al*., 2013).

Dowling and Childs (1992) reported diagnostic characteristics of mtDNA from the products of two restriction endonucleases: *Nhe*I (a six-base recognizing enzyme) and *Mbo*I (a four-base recognizing enzyme). Gila and Apache trout had the same restriction fragment pattern for *Nhe*I, which differed from the restriction fragment pattern of rainbow trout by at least one site change. All three species had distinct fragment patterns for *Mbo*I, with Gila and Apache trout distinguished by differences at one site. Cutthroat trout had numerous fragment differences from Gila, Apache and rainbow trout in both enzymes (Dowling and Childs, 1992).

Riddle and others (1998) analyzed variable sites in the 3' and 5' ends of the control region of mtDNA (a region of the mtDNA that is non-coding) from samples of Gila, Apache, cutthroat, rainbow and Gila x rainbow trout. They reported eight haplotypes at the 5' end (377 base-pair sites) and 16 haplotypes at the 3' end (195 base-pair sites) of the mtDNA control region. Restriction-site analysis of whole-genome mtDNA revealed eight different composite mtDNA haplotypes (R.1 through R.8) that varied from one another by two to 26 restriction-site changes. The control-region and whole-genome mtDNA haplotypes differentiated Gila, Apache, cutthroat, rainbow and Gila x rainbow trout (Table 3). Gila and Apache trout are differentiated by whole mtDNA restriction-site composite haplotypes: R.5 in Gila trout and R.3 in Apache trout (Table B3). The two native trout are distinguished from rainbow trout by 5' end haplotypes (C5.6 and C5.7 in Gila and Apache trout and C5.1 in rainbow trout) and whole mtDNA restriction-site composite haplotype (R.5 in Gila trout, R.3 in Apache trout, and R.1 or R.2 in rainbow trout). Cutthroat trout is distinguished by unique control-region and whole mtDNA restriction-site composite haplotypes (Table B3). Both rainbow trout and Gila trout mtDNA haplotypes were found in the trout population in McKenna Creek. No populations were found with both Gila and cutthroat trout mtDNA haplotypes (Riddle *et al*., 1998).

Wares and others (2004) reported a single diagnostic mtDNA control-region haplotype (AF517763) from Gila trout populations in the Gila River drainage (Table B3), as in the R.5 whole-genome mtDNA haplotype reported by Riddle and others (1998). However, Wares and others (2004) also reported four other mtDNA control-region haplotypes (AY490781 through AY490784) found only in the Spruce Creek population (Table B3). Seven mtDNA control-region haplotypes (AF517756 through AF517762) were recovered from rainbow trout (Table B3).

Table B 3. Mitochondrial DNA haplotypes for Gila, Apache, cutthroat and rainbow trout. The asterisk (*) denotes haplotypes specific to the Spruce Creek population of Gila trout. Haplotypes from Riddle and others (1998) are noted for the 3' end of the mtDNA control region (C3 prefix), the 5' end (C5 prefix), and whole-genome mtDNA (R prefix). The R.5 haplotype in the Spruce Creek population of Gila trout had an increase of approximately 300 base pairs at the 3' end of the control region (Riddle *et al.*, 1998).

Taxa	**mtDNA Haplotypes**	**No. of Unique mtDNA Haplotypes**	**Source**
Gila trout	C3.14, C3.15*, C5.6, C5.7*, R.5	3	Riddle *et al.* (1998)
	AF517763, AY490781 – AY490784*	4	Wares *et al.* (2004)
Apache Trout	C3.14, C5.6, R.3	1	Riddle *et al.* (1998)
	AF517764 – AF517767, AY490785, AY490786	6	Wares *et al.* (2004)
Rainbow Trout	C3.01 to C.3.14, C5.1, R.1, R.2	16	Riddle *et al.* (1998)
	AF517756 – AF517762	7	Wares *et al.* (2004)
Cutthroat Trout	C3.16, C5.8, R.6	3	Riddle *et al.* (1998)

A 768 base-pair fragment of the nicotinamide adenine dinucleotide dehydrogenase subunit 4 region of mtDNA (MT-ND4) was sequenced by Wilson and Turner (2009) in an investigation of the phylogeny of freshwater *Oncorhynchus* species. Sixteen different MT-ND4 haplotypes were found (Table B4). Gila trout had two unique MT-ND4 haplotypes, as did Apache trout (Table B4). Eleven MT-ND4 haplotypes were found in cutthroat trout with six of these occurring in the Rio Grande subspecies (*O. clarkii virginalis*; Table B4). Five MT-ND4 haplotypes were reported for rainbow trout (Table B4).

Several studies have directly examined nuclear DNA markers including microsatellites and nucleotide sequences at various loci. Microsatellites are tandemly repeated nucleotide sequences, where the repeating unit is one to four nucleotides long. The variability in the number of times the unit is repeated in a given microsatellite is analyzed. The majority of microsatellites occur in non-coding regions of the genome.

Wares and others (2004) found that the 499 base-pair sequence at exon 13 of the transferrin gene distinguished Gila and Apache trout from rainbow, cutthroat and other trout species. The distinctiveness of the exon 13 base-pair sequence in Gila trout and Apache trout consisted of two fixed nucleotide substitutions. No diagnostic microsatellite loci were found.

Turner (2013) examined variation at 13 microsatellite loci in Gila trout and rainbow trout. Multi-locus genotype analysis indicated a high probability ($p > 0.95$) that the Main Diamond Creek, South Diamond Creek, and Iron Creek populations had genetic backgrounds consistent with Gila trout, and that these three populations were more similar to each other than to rainbow trout. However, no unique alleles for Gila trout were identified for the 13 microsatellite loci that were examined.

Table B 4. MT-ND4 haplotypes for Oncorhynchus species from Wilson and Turner (2009). Common names of trout species are: O. gilae = Gila trout; O. apache = Apache trout; O. mykiss = rainbow trout' O. clarkii = coastal cutthroat trout; O. c. virginalis = Rio Grande cutthroat trout; O. c. stomias = greenback cutthroat trout; O. c. pleuriticus = Colorado River cutthroat trout; O. c. utah = Bonneville cutthroat trout; O. c. bouvieri = Yellowstone cutthroat trout; O. c. lewisii = westslope cutthroat trout; and O. chrysogaster = golden trout.

Taxa	**MT-ND4 haplotype**																							
	FJ813495	FJ813496	FJ813497	FJ813498	FJ813499	FJ813500	FJ813501	FJ813502	FJ813503	FJ813504	FJ813505	FJ813506	FJ813507	FJ813508	FJ813509	FJ813510	FJ813511	FJ824664	FJ824665	DQ288268	DQ288269	DQ288270	DQ288271	ONHMTCG
O. gilae															X	X								
O. apache													X	X										
O. mykiss																				X	X	X	X	X
O. clarkii												X												
O. c. virginalis	X	X	X	X	X	X																		
O. c. stomias							X																	
O. c. pleuriticus								X																
O. c. utah									X															
O. c. bouvieri										X														
O. c. lewisii											X													
O. chrysogaster																			X					

Appendix C – Gila trout Lineages

Loudenslager and others (1986) reported genetic variation at six loci among four populations of Gila trout. Gila trout from the South Diamond Creek, Main Diamond Creek and Spruce Creek populations were homozygous at the *ADH** and *PGM** loci for alleles *-80* and *100*, respectively (Table C1). In contrast, the Iron Creek population was heterozygous at these two loci, with low frequencies of two unique alleles: *ADH*-120* and *PGM*85* (Table C1). The Spruce Creek population was fixed (homozygous) at four of the six loci examined, the Main Diamond Creek was fixed at three of the analyzed loci, and the South Diamond Creek population was homozygous at two of the six analyzed loci. Only the Iron Creek population was heterozygous at all six of the loci examined by Loudenslager and others (1986).

Table C 1. Allele frequencies at six allozyme loci in four populations of Gila trout (data from Loudenslager *et al.*, 1986). Allozyme loci are: ADH* = alcohol dehydrogenase; sIDDH* = L-iditol dehydrogenase (sorbital dehydrogenase); MDH = malate dehydrogenase; mMEP* = malic enzyme; PA* = para albumin; PGM* = phosphoglucomutase.

Locus	**Allele**	**South Diamond Creek**	**Main Diamond Creek**	**Spruce Creek**	**Iron Creek**
*ADH**	-120				0.100
	-80	1.000	1.000	1.000	0.900
*sIDDH-3**	170	0.367	0.062		0.200
	140	0.333	0.938	1.000	0.733
	100	0.300			0.067
*MDH-3,4**	100	0.450	0.719	1.000	0.467
	75	0.550	0.281		0.533
*mMEP-3**	100	0.900	1.000	0.750	0.933
	80	0.100		0.250	0.067
*PA-1,2**	105	0.500	0.167	0.417	0.500
	100	0.500	0.833	0.583	0.500
*PGM**	100	1.000	1.000	1.000	0.867
	85				0.133

Leary and Allendorf (1999) found substantial genetic divergence between Gila trout populations in the Gila River and the San Francisco River drainages. The two groups were fixed for different alleles at the *PGM-1** locus, as well as having marked differences in allele frequencies at other loci (Table C2).

Unique alleles were found in Gila trout from Main Diamond Creek (*sAAT-1*null* and *sIDHP-1, 2*80*) and South Diamond Creek (*sMEP-2*115* and *sMEP-2*85*; Table C2). Two other alleles (*sMDH-B1, 2*74* and *sMEP-1*100*) were found at variable frequencies in the three remnant populations in the upper Gila River drainage (Leary and Allendorf, 1999). The Whiskey Creek population did not contain any unique alleles and was either homozygous or has allelic frequencies intermediate between the Main Diamond Creek and South Diamond Creek populations at seven loci (Leary and Allendorf, 1999; Table 2).

Riddle and others (1998) identified an mtDNA haplotype unique to the Spruce Creek population of Gila trout. The unique Spruce Creek mtDNA haplotype had a 300 base-pair length increase at the 3' end of the mtDNA control region. In subsequent analysis of the mtDNA control region, Wares and others (2004) found four unique haplotypes (SPR1 through SPR4) in the Spruce Creek population. The upper Gila River drainage populations all shared a single haplotype, which was absent from the Spruce Creek population.

Peters and Turner (2008) reported substantial genetic variation among remnant populations of Gila trout through analysis of exon[1] 2 of the major histocompatibility complex (MHC) class II β gene and six microsatellite loci. No MCH alleles were unique to any remnant population (Table C3). The *Ongi-DAB*0101* and *Ongi-DAB*0102* alleles were most common in the Main Diamond Creek and South Diamond Creek populations, while the *Ongi-DAB*0201* allele was most common in the Spruce Creek population (Table 3). The populations in Whiskey Creek and McKnight Creek (a replicate of the Main Diamond Creek population) contained all five MHC alleles (Table 3).

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[1] An exon is a nucleotide sequence within a gene that becomes part of the final ribonucleic acid (RNA) produced by that gene after intronsintron (non-protein coding nucleotide sequences) have been removed by RNA splicing.

Table C 2. Allele frequencies at seven allozyme loci in five populations of Gila trout (from Leary and Allendorf, 1999). The McKnight Creek population was established with fish from Main Diamond Creek, the Mogollon Creek population was established with fish from South Diamond Creek and the Big Dry Creek population was established with fish from Spruce Creek. Allozyme loci are: sAAT-1* = aspartate aminotransferase; sIDHP-1, 2* = isocitrate dehydrogenase; sMDH-B1, 2* = malate dehydrogenase; sMEP-1* and sMEP-2* = malic enzyme; PGM-1* = phosphoglucomutase; and sSOD-1* = superoxide dismutase.

Locus	**Allele**	**McKnight Creek (Main Diamond)**	**Mogollon Creek (South Diamond)**	**Whiskey Creek**	**Spruce Creek**	**Big Dry Creek (Spruce)**
*sAAT-1**	100	0.368	1.000	1.000	1.000	1.000
	null	0.632				
*sIDHP-1,2**	100	0.925	0.804	1.000	1.000	1.000
	125	0.067	0.196			
	80	0.008				
*sMDH-B1,2**	100	0.833	0.510	0.643	1.000	1.000
	74	0.167	0.490	0.357		
*sMEP-1**	100	0.350	0.315	0.071		
	90	0.650	0.685	0.929	1.000	1.000
*sMEP-2**	100	1.000	0.442	1.000	1.000	1.000
	115		0.135			
	85		0.423			
*PGM-1**	133	1.000	1.000	1.000		
	Null				1.000	1.000
*sSOD-1**	100	1.000	1.000	1.000	0.957	1.000
	152				0.043	

Table C 3. Allele frequencies at exon 2 of the MHC class II β gene in four remnant populations of Gila trout (from Peters and Turner, 2008). Frequencies are shown as ranges for remnant populations with samples also taken from replicated, wild populations (number of populations sampled is shown in parentheses). Single values are the frequency of an allele that was found in only one population. A blank cell indicates that the allele was absent from the population(s).

MHC Allele	**Main Diamond (4)**	**South Diamond (2)**	**Whiskey (1)**	**Spruce (3)**
*Ongi-DAB**0101	0.500 - 0.867	0.567 - 0.600	0.250	0.281 – 0.313
*Ongi-DAB**0102	0.033		0.036	
*Ongi-DAB**0201	0.031 – 0.067	0.033 – 0.167	0.357	0.500 – 0.700
*Ongi-DAB**0202	0.033 – 0.094	0.067	0.286	
*Ongi-DAB**0301	0.067 – 0.367	0.167 – 0.400	0.071	0.188 – 0.219

Variation at the MHC gene indicated modest reduction in heterozygosity due to genetic drift, with an overall fixation index (F_{ST}) value of 0.214 among populations of Gila trout. The fixation index, which ranges from 0 (no genetic divergence, panmixis[2]) to 1 (maximum genetic divergence, complete isolation), is a measure of the proportional increase in homozygosity attributable to population subdivision. An F_{ST} value greater than 0.25 indicates substantial genetic divergence among population subdivisions. A significant excess of homozygotes (compared to that expected under Hardy-Weinberg proportions) in MHC alleles was detected in the Spruce Creek population and one of its replicates, while a significant excess of heterozygotes in MHC alleles was detected in the Whiskey Creek population (Peters and Turner, 2008). Variation at the six microsatellite loci examined by Peters and Turner (2008) showed a pattern similar to that found at the MHC class II β gene. The Whiskey Creek population had the highest average gene diversity across all six microsatellite loci while a replicate of the Spruce Creek population (Raspberry Creek) had the lowest.

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[2] Panmixis is random mating within a population (all individuals in the population have an equal probability of paired mating).

Status of the Iron Creek Population

Based on analysis of allozymes coded by eight gene loci, Leary and Allendorf, (1999) indicated that the Iron Creek population "appeared to contain a few individuals recently descended from rainbow trout." Samples taken in May 1997 from four sites in Iron Creek found seven fish out of a sample of 12 from the uppermost site with genotypes that included alleles characteristic of both Gila trout and rainbow trout (Table C4). The average frequency of alleles characteristic of rainbow trout in the upper Iron Creek sample was 0.021 (Leary and Allendorf, 1999). Leary and Allendorf (1999) did not identify potential rainbow trout introgression in trout collected from any of the other three downstream sample sites in Iron Creek.

In contrast to the findings of Leary and Allendorf (1999), multi-locus genotype analysis using 13 microsatellite loci concluded with assignment of the Iron Creek population to Gila trout, not rainbow trout, and that there was a low probability ($p < 0.05$) of rainbow trout introgression in the population (Turner, 2013). Further, Riddle and others (1998), and more recent analysis by Wade Wilson (Regional Geneticist, Southwestern Native Aquatic Resources and Recovery Center, U.S. Fish and Wildlife Service) found no evidence of rainbow trout introgression in analysis of mtDNA in samples from Iron Creek.

Turner (2013) suggested that the contradiction with Leary and Allendorf (1999) could have arisen from: 1) retention of ancestral polymorphism at allozyme loci; 2) retention of allozyme loci through the effect of purifying selection; or 3) past introgression and subsequent loss of rainbow trout alleles through backcrossing with pure Gila trout. Turner (2013) also reported that the Iron Creek population represents a unique evolutionary lineage. It was found to have unique alleles at relatively high frequencies at the MHC class II β gene, and that this population had the highest diversity among Gila trout populations at the MHC locus (Turner, 2013).

Analysis of single nucleotide polymorphisms (SNPs) at 28,127 loci using nextRAD sequencing methodology concluded that "there is no evidence of recent hybridization among species in any (Gila trout) individual surveyed," which included 31 specimens from Iron Creek (Turner and Camack, 2017). The analysis also found that the Iron Creek population is at least as "pure," genetically, as any of the other remnant populations, none of which have any indication of rainbow trout introgression (Wares *et al.*, 2004). The SNP analysis indicated that the level of alleles similar to those found in rainbow trout (genetic similarities related to common ancestry) was the same in the Main Diamond, South Diamond, and Iron Creek populations (Turner and Camack, 2017).

Table C 4. Allele frequencies in 12 trout from upper Iron Creek collected in May 1997. Alleles identified by Leary and Allendorf (1999) as characteristic of Gila trout are shown first (e.g., ADH*25) and those identified as characteristic of rainbow trout are shown second (e.g., ADH*-100). Data are from Leary and Allendorf (1999).

Locus	**Allele**	**Frequency**
*ADH**	25	0.984
	-100	0.016
*CK-C2**	110	0.969
	100	0.031
*FH-1**	70	0.938
	100	0.062
*GAPDH-4**	70	0.969
	100	0.031
*LDH-C**	110	1.000
	100	
*PEPB**	135	0.984
	100	0.016
*PGK-2**	90	0.984
	100	0.016
*PGM-1**	-133	1.000
	-100	
Ave. Frequency of Alleles Characteristic of Gila trout		0.979
Ave. Frequency of Alleles Characteristic of Rainbow Trout		0.021

In light of the current understanding of conservation genetics the data reported by Leary and Allendorf in 1999 may not be indicative of introgression at all. As later noted by Allendorf and others (2013), low levels of introgression (e.g., less than five percent, as in Table B4) may be difficult to distinguish from natural polymorphisms. Seemingly diagnostic alleles identified from limited reference samples may appear to become non-diagnostic as the number of individuals tested increases (Pritchard *et al.*, 2007) or as the level of divergence between the hybridizing groups decreases (Sovic *et al.*, 2014). In such cases, determining whether a shared allele represents recent hybridization or ancestral polymorphism may be largely subjective (Pritchard *et al.*, 2007). An in-depth, locus-level analysis of introgression designed to distinguish whether SNPs shared between rainbow trout and Gila trout are due to common ancestry versus more recent introgression is underway (Turner and Camack, 2017).

Appendix D – Gila Trout Ecology and Life History

Reproduction and Fecundity

Fecundity is dependent upon body size and condition (Behnke and Zarn, 1976; Behnke, 1979). Nankervis (1988) described the relationship between total length (TL in mm) and ova number (F) as:

$\log_{10}F = (-3.0738) + (2.3305 \times (\log_{10}TL))$ for Main Diamond Creek, $r^2 = 0.92$; and

$\log_{10}F = (-3.5443) + (2.6078 \times (\log_{10}TL))$ for McKnight Creek, $r^2 = 0.92$.

Growth, Somatic Statistics, Survivorship and Longevity

Condition factor of Gila trout was found to vary from 0.4235 to 1.2149 in a data set that included samples from 11 streams and that spanned seven years (Propst and Stefferud, 1997). Propst and Stefferud (1997) also reported length-weight relationships for this data set using the function $W = ((aL^b) \times 10^{-6})$ where W = mass in grams, a = ordinate intercept, L = total length in mm, and b = slope of the regression line. Changes in physical habitat that affect Gila trout density and aquatic macroinvertebrate populations may be causes of variation in condition factor (Turner, 1989).

Diseases and Pathogens

The causative bacterium (*Renibacterium salmoninarum*) of bacterial kidney disease (BKD) occurs in very low amounts in brown trout populations in the upper West Fork Gila River drainage and in the Whiskey Creek population of Gila trout. The bacterium was also detected in the Main Diamond Creek, South Diamond Creek and Iron Creek populations and rainbow x Gila trout hybrid populations in McKenna Creek and White Creek. Trout populations in the Mogollon Creek drainage, McKnight Creek, Sheep Corral Canyon, and Spruce Creek have all tested negative for BKD. In the wild, BKD is not likely a threat to Gila trout populations because of limited distribution, low occurrence within populations, and lack of any clinical evidence of the disease in Gila trout (N. Wiese, U.S. Fish and Wildlife Service, Mora National Fish Hatchery, pers. comm., 24 August 2017).

The causative bacterium of BKD was confirmed in the Brood Year 2016 lot of Gila trout at Mora National Fish Hatchery in August 2016. The presence of BKD antibodies in the hatchery Gila trout was considered a sub-clinical exposure because survival rates were at all-time highs and all tested fish appeared healthy. Origin of BKD in the hatchery was suspected to be vertical transmission from 2013 Main Diamond broodstock spawned in the spring of 2016. Mora National Fish Hatchery routinely imports wild Gila trout and *Catostomus* species for broodstock management and polyculture purposes. These imported fish are kept in isolation facilities and quarantined prior to fish culture use. During spawning operations ovarian fluid samples are taken and tested for BKD infection to identify vertical transmission to offspring. Since ovarian fluid testing is not fail-safe, there is always some risk of BKD exposure. As a result of the positive BKD finding, all Brood Year 2016 Main Diamond Gila trout and the 2013 year class of Main Diamond broodstock were destroyed. This action was necessary to reduce the risk of horizontal transmission of the disease at Mora National Fish Hatchery. In 2017, Mora National Fish Hatchery reduced the number of fish on site to reduce stress and potential BKD outbreaks. The hatchery has since tested negative for BKD and is now classified as "BKD suspect." If testing in 2018 is again negative, the hatchery will regain its "Class A" disease status.

Whirling disease is caused by the metazoan parasite *Myxobolus cerebralis*. The disease is a serious problem in hatchery and wild populations of rainbow trout throughout the western United States. Annual fish health inspections (which include testing for whirling disease) of selected wild and hatchery stocks of Gila trout have been conducted since 2011 and all wild and hatchery populations of Gila trout have tested negative for whirling disease. There have been no documented cases of whirling disease in Arizona or New Mexico.

In April 2010, cutthroat trout virus was detected in ovarian fluid of Gila trout broodstock from Main Diamond Creek and South Diamond Creek held at Mora National Fish Hatchery (Gila trout Recovery Team, 2010). This virus of the family Hepeviridae was described in 1988 and is not known to be associated with any disease (Batts *et al.*, 2011). Spread of the virus to wild trout populations in the western U.S. is likely associated with shipments of infected eggs from hatcheries (Batts *et al.*, 2011). It may be intentionally introduced to captive stocks to increase their resistance to more severe viruses, such as infectious hematopoietic necrosis virus. The impact, if any, of cutthroat trout virus on native fish species and its persistence in aquatic habitats is unknown.

Table D 1. Mean total length (mm) at age for Gila trout from selected populations.

Population	Year	Age								
		I	II	III	IV	V	VI	VII	VIII	IX
Sheep Corral Canyon	1983[2]	77[1]	138	204	243	---	---	---	---	---
South Diamond Creek	1975[2]	85	143	219	303	337	---	---	---	---
“ “	1983[2]	69	124	182	223	256	---	---	---	---
Spruce Creek	1983[2]	77	135	180	250	---	---	---	---	---
McKnight Creek	1976[2]	102	179	235	290	---	---	---	---	---
“ “	1983[2]	73	131	182	223	267	---	---	---	---
“ “	1987[3]	63	128	158	190	206	248	274	---	---
“ “	1988[3]	69	119	162	185	204	---	---	---	---
Main Diamond Creek	1969[4]	45	86	120	157	163	---	---	---	---
“ “	1986[5]	51	81	97	126	142	---	---	---	186
“ “	1987[5]	53	88	113	137	146	167	214	148	---
“ “	1987[3]	44	84	107	125	142	152	170	---	---

[1] Back-calculated mean total length at annulus (mm); [2] Turner (1986); [3] Turner (1989); [4] Hanson (1971); [5] Nankervis (1988)

Appendix E – Water Quality in the Gila River Drainage Basin

In 2016, the cold-water or high quality cold-water aquatic life designated use was determined to be impaired in 21 stream segments within the historical range of Gila trout in New Mexico (Table 2 of main document). Water temperature was the cause of impairment in 18 of these 21 stream segments. Water temperature is influenced by the interaction of external factors (drivers) and internal factors (structure; Poole and Berman, 2001). External temperature drivers determine heat loading and water delivery to the stream, while internal stream structure determines the resistance of the aquatic habitat to warming or cooling through insulating and buffering processes. The primary drivers, or external factors, that influence temperature are climatic variables (e.g., solar radiation, precipitation, air temperature, wind speed) while the principle structural features, or internal factors, that insulate or buffer aquatic habitat include stream morphology, groundwater influences, and riparian canopy condition (Burkholder *et al.*, 2008; Li *et al.*, 1994; Poole *et al.*, 2001). Aside from anthropogenic alteration of climatic conditions, the most immediate effect of human activities on temperature arise from impacts to characteristics of the watershed and alluvial aquifers, stream morphology and riparian canopy condition (Poole and Berman, 2001).

In small streams, riparian shading and phreatic groundwater inputs have the highest influence on water temperature, while hyporheic[3] groundwater and tributary input have a moderate influence (Poole and Berman, 2001). Riparian shading and phreatic groundwater inputs provide thermal stability in small stream systems, while coarse sediment storage (such as that provided by large woody debris) drives hyporheic flow. Tributary input can have a major effect on overall stream temperature due to relatively low discharge characteristic of small stream systems during base-flow periods (Poole and Berman, 2001). Consequently, factors that influence infiltration in uplands, such as decreased vegetation cover, can reduce phreatic groundwater discharge and result in increased water temperature. Similarly, reduced riparian shading and channel widening increase heat loading to the stream system (Amaranthus *et al.*, 1989). Simplification of channel morphology and increased fine sediment loading reduce hyporheic flow, resulting in loss of heat-exchange buffering capacity. Potential pathways of human-caused increases in water temperature are shown in Figure E1. Riparian and upland management pathways have the highest importance in small stream systems, while the channel engineering (modification) pathway is of moderate importance with respect to influences on water temperature. Channel modifications in habitats of Gila trout most frequently result from large flood events, particularly following high-severity wildfire in cold-water stream watersheds.

Chemical or physical impairment of cold-water streams within the historical range of Gila trout in New Mexico results primarily from sediment inputs or nutrients (Table 3 of main document). Sediment-related causes, including turbidity, were implicated in 5 of the 21 impaired cold-water streams while high nutrient levels were a cause of impairment in 3 of the listed streams.

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[3] Hyporheic groundwater is water that travels along localized subsurface flow pathways for relatively short periods of time and then reemerges into the stream channel downstream.

Numerous probable source of sediment input were identified for these stream segments, ranging from road and bridge runoff to grazing (New Mexico Environment Department, 2016). The presence and concentration of organic and inorganic nitrogen in surface water may be indicative of water quality degradation resulting from livestock grazing (Nash *et al.*, 2009). Concentrations of organic nitrogen in excess of 1.0 mg/L have been recorded in streams with watersheds subject to domestic livestock grazing, such as Canyon Creek (Table E1), Mineral Creek (Table E2), and Negrito Creek (Table E2). High aluminum concentrations resulting in impairment of the cold-water aquatic life designated use were reported in Mogollon Creek and Willow Creek (Table 3 of main document).

Table E 1. Selected water quality parameters in four cold-water streams in the Upper Gila watershed. All units are mg/L except for specific conductance (umhos/cm) and turbidity (nephelometric turbidity units [NTU]). Source: U.S. Environmental Protection Agency (2016).

Parameter	Black Canyon	Iron Creek	Turkey Creek	Canyon Creek
Total Alkalinity	41.6-58.8	37.2-49.0	45.4-72.0	46.8
Bicarbonate	50.8-71.7	45.4-59.8	55.4-87.8	57.1
Calcium	11.0-16.6	7.7-10.9	7.3-12.3	13.2-14.6
Total Organic Carbon	<5-17.0	<5	<5-9.7	8.16-8.88
Hardness	43.7-60.4	30.9-41.9	28.7-33.7	59.1-59.5
Inorganic Nitrogen	<0.1-0.15	<0.1	<0.1	<0.1-0.95
Organic (Kjeldahl) Nitrogen	<0.1-0.55	<0.1-0.23	0.14-0.30	1.15-1.20
Magnesium	3.97-4.64	<1-3.58	2.51-2.83	5.58-6.32
pH	6.45-8.09	6.90-8.02	7.10-8.90	7.28-9.16
Phosphorus	0.05-0.12	<0.05-0.09	<0.05	0.19-0.25
Potassium	<1	<1	<1	5.73
Sodium	5.47-7.59	<1-5.43	17.8-40.5	7.16
Total Dissolved Solids	146-198	92-326	136-248	180-220
Total Suspended Solids	<3-157	<3	<3	6-11
Specific Conductance	107.4-143.6	80.4-95.3	140.3-256.8	112.3-146.3
Sulfate	10.4-15.7	<10	14.8-28.5	23.5
Turbidity	1.35-61.5	0.67-5.42	0.46-5.79	5.94-14.50

Table E 2. Selected water quality parameters in four cold-water streams in the San Francisco watershed. All units are mg/L except for specific conductance (umhos/cm) and turbidity (nephelometric turbidity units [NTU]). Source: U.S. Environmental Protection Agency (2016).

Parameter	**Mineral Creek**	**Negrito Creek**	**Whitewater Creek**	**Trout Creek**
Total Alkalinity	60.4-98.8	59.6-152.0	99.8-228.0	161-181
Bicarbonate	73.7-118.0	72.7-182.0	122-270	195-219
Calcium	9.9-22.5	14.5-36.2	6.0-77.4	27.8-43.4
Total Organic Carbon	<5-5.7	<5	<5-6.48	<5
Hardness	33.9-87.8	55.3-138.0	15.2-99.5	103-149
Inorganic Nitrogen	<0.1-0.13	<0.1	<0.1-0.12	<0.1-0.19
Organic (Kjeldahl) Nitrogen	<0.1-4.77	<0.1-2.72	<0.1-0.50	<0.1-0.60
Magnesium	1.83-7.66	4.61-11.50	<1-7.82	8.03-11.8
pH	7.00-8.37	6.80-8.45	6.40-8.47	6.80-8.23
Phosphorus	<0.05-0.11	0.07-0.11	<0.05-0.16	<0.05-0.19
Potassium	<1	<1-3.47	<1-3.11	<1-2.63
Sodium	7.98-14.50	7.9-27.8	10.1-20.2	20.7-24.2
Total Dissolved Solids	118-198	134-256	111-334	218-268
Total Suspended Solids	<3	<3-40	<3	<3-59
Specific Conductance	88.4-291.4	142.3-330.7	2.18-501.0	239.3-357.0
Sulfate	<10-10.4	<10-10.4	14.1-22.0	10.1-11.7
Turbidity	1.0-6.3	1.0-6.6	0.9-12.4	0.7-48.3

Table E 3. Selected water quality parameters in three cold-water streams in the Tonto watershed. All units are mg/L except for specific conductance (umhos/cm) and turbidity (nephelometric turbidity units [NTU]). Source: U.S. Environmental Protection Agency (2016). The symbol "---" indicates that the parameter was not assessed.

Parameter	Tonto Creek	Christopher Creek	Haigler Creek
Total Alkalinity	25.9-74.8	69-99	199-243
Bicarbonate	31-91	69-112	234-296
Calcium	20.2-21.4	30-36	49.8-72
Total Organic Carbon	---	---	---
Hardness	73	103-122	209-255
Inorganic Nitrogen	<0.10-0.21	<0.10-0.14	<0.10-0.11
Organic (Kjeldahl) Nitrogen	<0.10-0.32	<0.10-0.61	<0.10-0.37
Magnesium	5.1	6.9-8.3	16-24
pH	7.40-8.38	7.10-8.19	7.19-8.61
Phosphorus	<0.10	<0.10-0.12	<0.10
Potassium	0.70-1.01	---	0.90-1.88
Sodium	<5.0	---	4.3-6.7
Total Dissolved Solids	51-112	113-166	216-297
Total Suspended Solids	<4-8	<1-12	<4-14
Specific Conductance	56-143	189-299	380-468
Sulfate	<10	17-31	<10-29.4
Turbidity	0.43-7.81	0.25-0.75	0.18-6.10

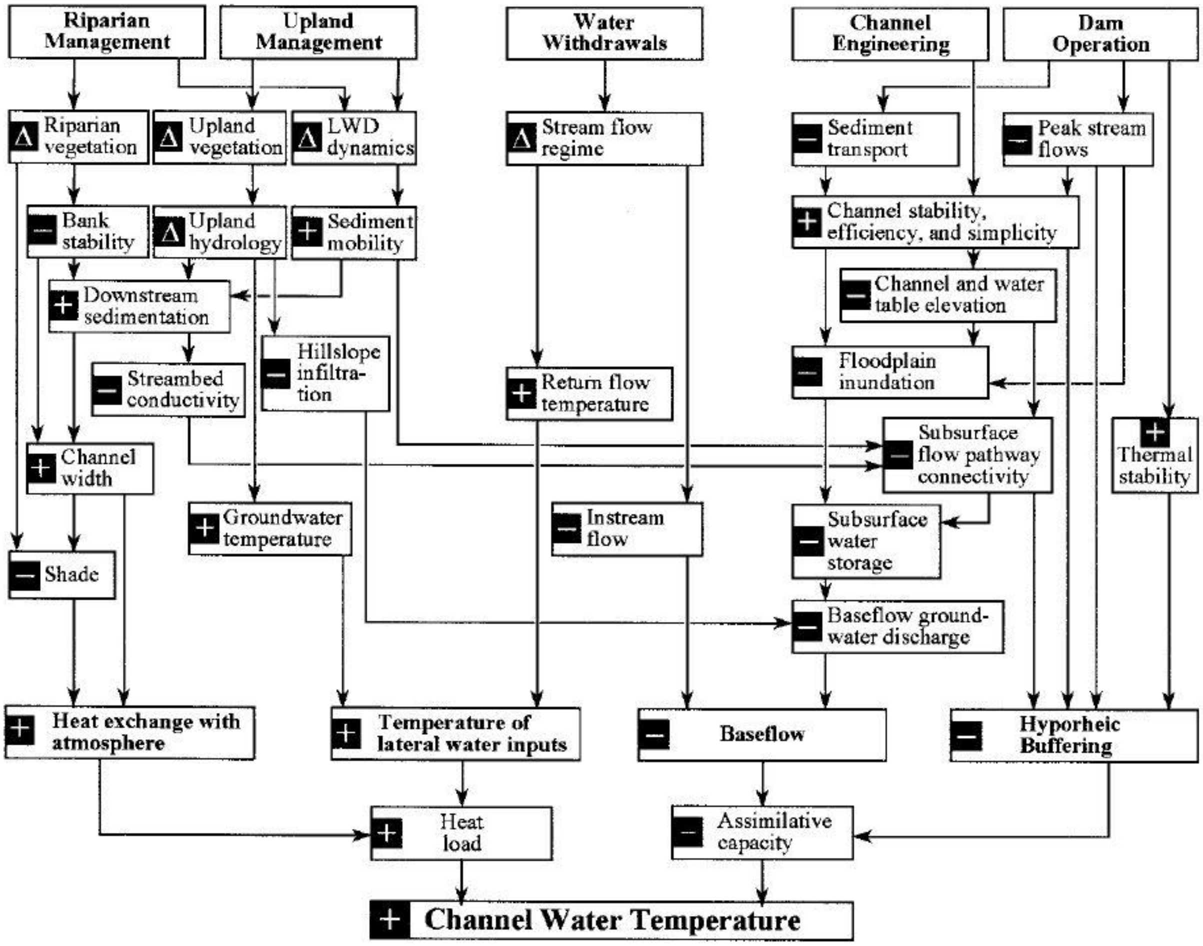


Figure E 1. Pathways of human-caused water temperature increases in stream systems. Symbols are defined as: Δ is a change in the state of the parameter or process (direction of change may vary); + denotes an increase in the parameter; and – denotes a decrease in the parameter. Excerpted from Poole and Berman (2001). LWD = large woody debris. The 'Riparian Management' and "Upland Management' pathways are most relevant to conservation of Gila trout.

Appendix F – Climate Change

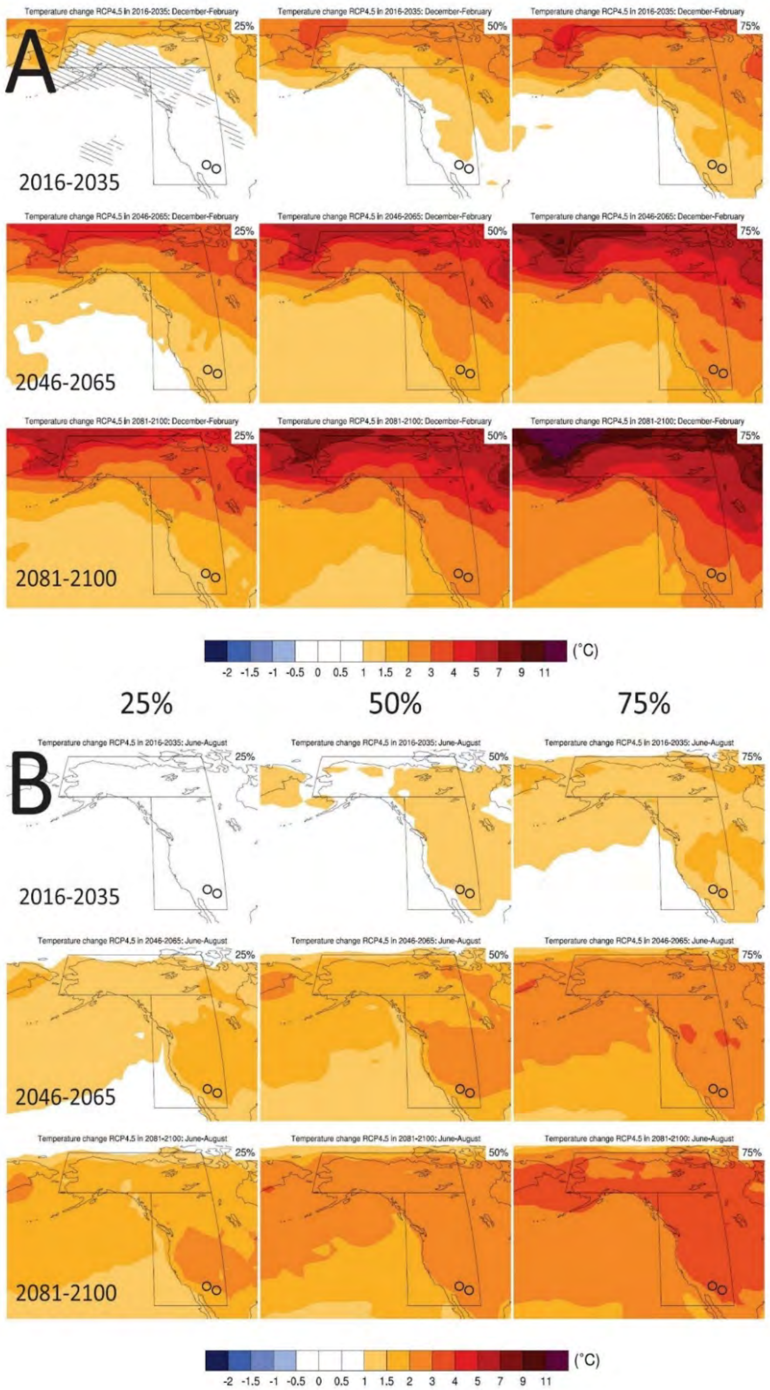


Figure F 1. Modeled temperature change during winter (A) and summer (B) months in 2016-2035, 2046-2065 and 2081-2100 (rows of figures) relative to 1986-2005. Results from the 25th, 50th and 75th percentile distribution of model runs are shown in the columns of figures. The small circles in each figure show the approximate location of the Gila R. and Verde R. headwaters for reference. Figures excerpted from van Oldenborgh *et al.* (2013).

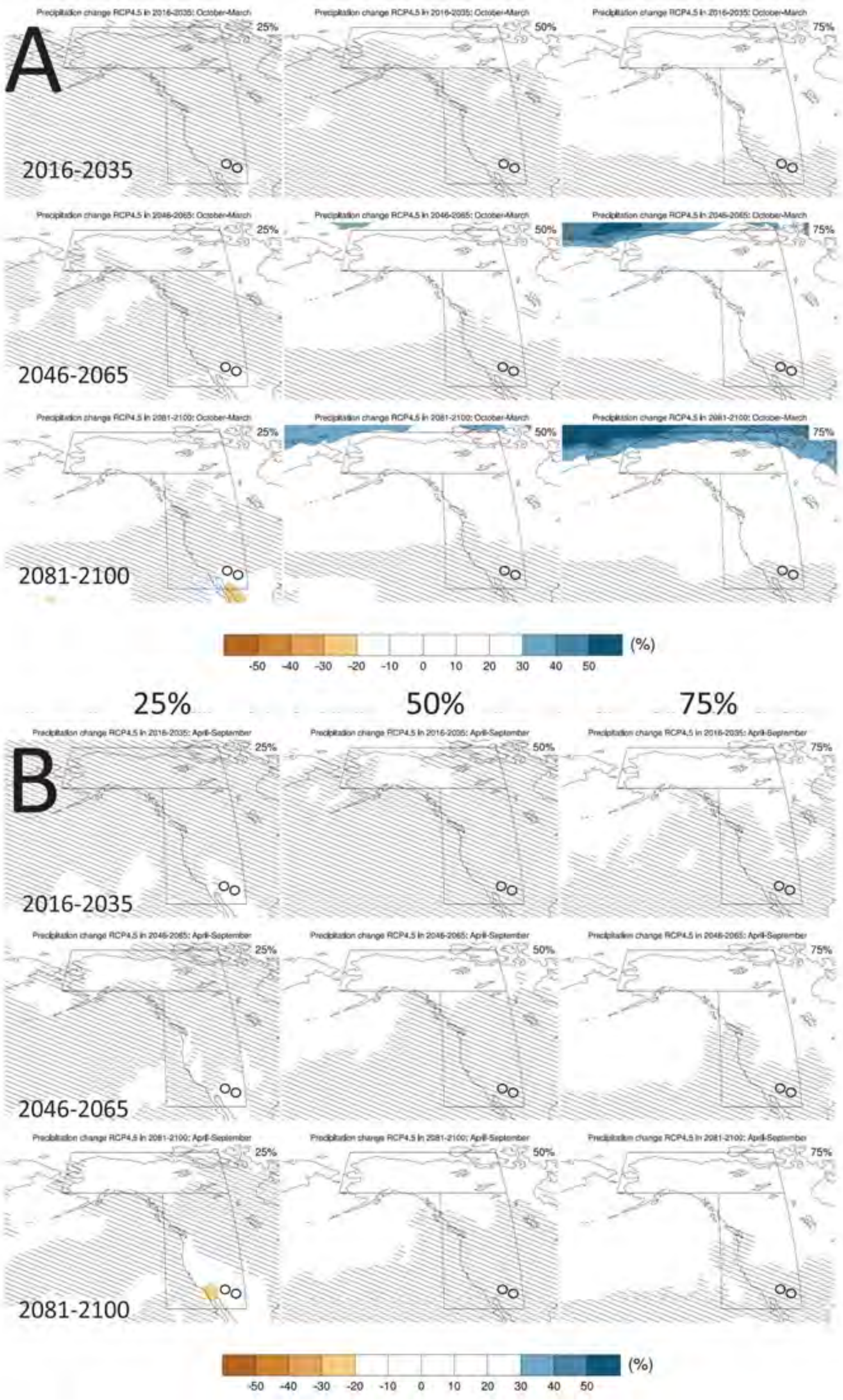


Figure F 2. Modeled precipitation change during winter (A) and summer (B) months in 2016-2035, 2046-2065 and 2081-2100 (rows of figures) relative to 1986-2005. Results from the 25th, 50th and 75th percentile distribution of model runs are shown in the columns of figures. The small circles in each figure show the approximate location of the Gila R. and Verde R. headwaters for reference. Hatching indicates conditions similar to present-day natural variation. Figures excerpted from van Oldenborgh *et al.* (2013).

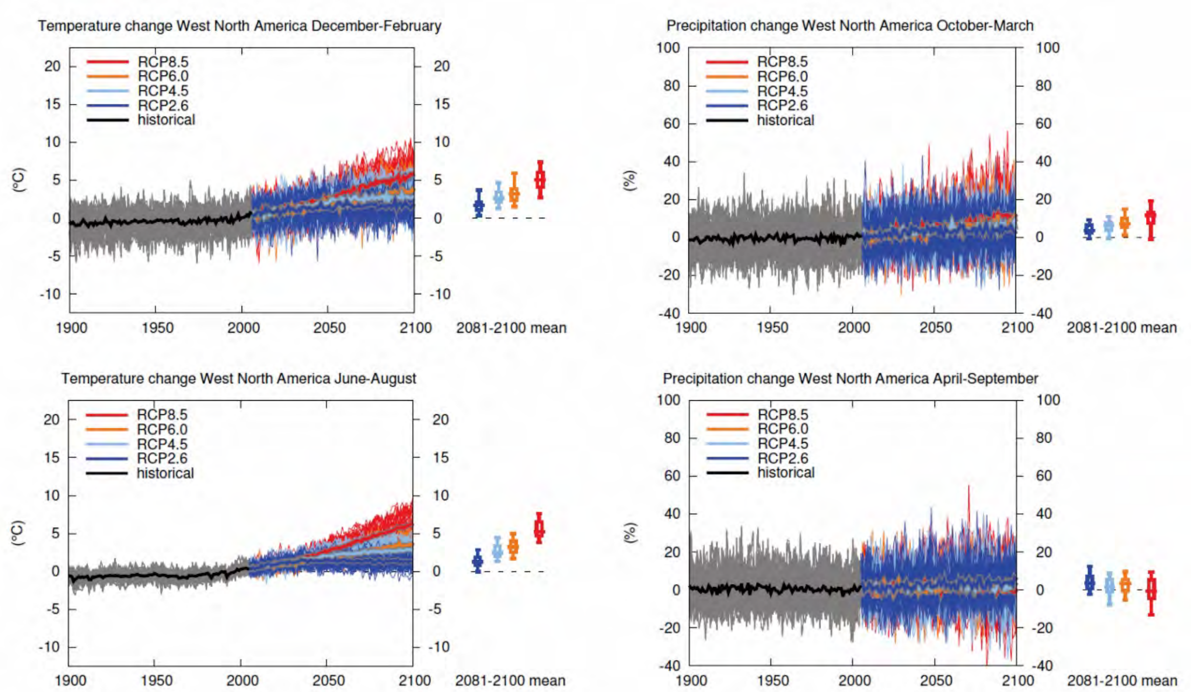


Figure F 3. Time series of temperature (left) and precipitation (right) projections relative to 1985-2005 for representative concentration pathway (RCP) scenarios (from van Oldenborgh *et al.*, 2013). The four RCP scenarios represent radiative forcing values associated with different greenhouse gas emission rates and atmospheric concentrations. For example, RCP 8.5 is consistent with a future with no policy changes to reduce emissions, continued heavy reliance on fossil fuels, and an increasing global population growth rate whereas RCP 2.6 is based on declining use of oil, ambitious greenhouse gas emissions reductions, low energy intensity, and a slower global population growth rate.

Appendix G – Measures of Hybridization in Gila trout

Hybridization is typically detected by analysis using molecular genetic markers (Scribner *et al.*, 2001; Pritchard *et al.*, 2007; Allendorf *et al.*, 2013). Diagnostic loci that are fixed for different alleles in the two hybridizing species are identified and samples from individuals are analyzed to determine allele frequencies at the diagnostic loci. Individuals that are heterozygous for alleles at diagnostic loci from both parent species are first-generation (F_1) hybrids. Subsequent mating between hybrids or backcrosses between hybrids and parental stock produces individuals with variable genotypes composed of alleles from both parental stocks in homozygous and heterozygous combinations (Allendorf *et al.*, 2013). The result is genetic admixture, which is defined as the "formation of novel genetic combinations through hybridization of genetically distinct groups" (Allendorf *et al.*, 2013). A common outcome of continued crossing and backcrossing of fertile hybrids with parental stock is the production of a hybrid swarm, which is a population composed entirely of hybrid individuals (Allendorf *et al.*., 2013). This result of introgressive hybridization is referred to as genomic extinction because the combination of genotypes over the entire genome of the parent species is irretrievably lost (Allendorf *et al.*, 2013).

Low levels of admixture (e.g., less than five percent) may be difficult to distinguish from natural polymorphisms (Allendorf *et al.*, 2013). Seemingly diagnostic alleles identified from limited reference samples may appear to become non-diagnostic as the number of individuals tested increases (Pritchard *et al.*, 2007) or the level of divergence between the hybridizing groups decreases (Sovic *et al.*, 2014). In such cases, determining whether a shared allele represents recent hybridization or ancestral polymorphism may be largely subjective (Pritchard *et al.*, 2007). Recent advances have improved techniques for quantifying admixture and distinguishing between recent introgression and shared ancestral variation (Durand *et al.*, 2011; Hohenlohe *et al.*, 2013; but see Martin *et al.*, 2013 for qualifications).

Populations with low levels of presumed admixture may harbor unique native alleles or genetic diversity not found in other pure populations. Consequently, the presumed admixed populations may be considered to have conservation value (Campton and Kaeding, 2005). On the other hand, if a detected low level of admixture is actually the result of recent introgression, preservation of the population would perpetuate hybridization (Epifanio and Philipp, 2001). All progeny of a hybrid mating will be hybrid individuals, and the process is unidirectional. The frequency of hybrids in a local population may increase even if hybrids suffer high mortality, and parental taxa will trend toward extinction as introgression proceeds (Epifanio and Philipp, 2001). The increase in the proportion of hybridized individuals in the population may occur even when the proportion of admixture in the population is constant (Allendorf *et al.*, 2013). From this perspective, introgressed populations may pose more of a risk than a benefit to conservation of imperiled species (Allendorf *et al.*, 2004; Rubidge and Taylor, 2004).

Appendix H – Small Population Size

Accounts of threats to Gila trout and habitat were recorded by USFS employees, naturalists, and residents before the mid-1800s. Those first hand accounts described listed grazing, logging, and hydrologic alterations that shifted fish community structure and water availability. Some of those accounts are found below.

When Aldo Leopold began working in the Blue River drainage in 1908, the watershed had already been highly altered by 20 years of human use unrestrained by comprehension of the limits of productivity and ecological thresholds of the land. The historical conditions of the Blue River were described as follows (Leopold, 1921):

“All the old settlers agree that the bottoms of Blue River were, at the time of settlement in about 1885, stirrup-high in gramma grass and covered with groves of mixed hardwoods and pine. The banks were lined with willows and the river abounded with trout.”

By 1900, only 15 years later, the Blue River “valley and its tributary valleys were eaten out” (Leopold, 1921). Fred Fritz, Jr., the son of one of the first settlers on the Blue River, recounted the excessive stocking of cattle and goats that occurred with settlement in the watershed, and the resulting effects on the landscape:

“During the severe drought which began in about 1899 and lasted until about 1903 . . . water dried up and cattle died in great numbers . . . and all ranchers took a great loss. . . . [There] was no way to protect your range from over grazing by others, consequently there was no effort made on the part of the rancher to reduce numbers . . . We all had too many cattle on the range back in those days. There was no incentive to try and save forage, you couldn't, other cattle moved in on you, consequently the range, especially around permanent waters, was abused. . . . In addition to the large number of cattle on the range at the turn of the century there were also thousands of goats and large numbers of horses and wild burros. On our particular range there were nine different goat outfits. Most of the goats were gone by 1910 but the scars they made are still here [1964]. It was in those early years that the country was hurt” (Stauder, 2009).

An investigation of watershed and hydrologic conditions in the Blue River drainage was conducted by the National Riparian Service Team in 2000 (Stauder, 2009), with the conclusion that “vegetation and site characteristics, along the entire length of the Blue River, appear to have been severely altered by a number of major impacts" and that “recovery to pre-disturbance conditions will necessarily take centuries if not millennia.” The influence of historical overgrazing was summarized as follows:

“Continuous year long grazing was the historical norm in this area, as was common throughout most of the Southwest. Continuous year long grazing would have limited recruitment of bank stabilizing vegetation and future supplies of large wood. Overgrazing to the point of severely reducing upland vegetative cover further aggravates this by radically altering the hydrograph. The ability of the watershed to store and slowly release precipitation which falls on it is greatly reduced” (as cited in Stauder, 2009).

As recounted by Grace Johnson, who settled in the watershed in 1913:

"There used to be a lot more water in the Blue than there is now. There was enough water that at one time the miners in Clifton floated their logs down the river to Clifton from the Blue. They cut the logs up above the Box and floated them clear to Clifton" (Stauder, 2009).

Excessive grazing by domestic livestock (primarily cattle and sheep and, to a lesser extent, goats and hogs), which peaked around the turn of the 20th century, was reported to have led to severe degradation of streams on the Tonto National Forest in Arizona, as indicated in these excerpts from a 1926 paper entitled "History of Grazing on the Tonto" by Fred Croxen, a Forest Ranger on the Tonto (Tucker, 1989*a*):

"There were perennial grasses on the mesas along Tonto Creek where only brush grows at the present time. Mr. [Florence C.] Packard [who settled in the watershed in 1875] says that Tonto Creek was timbered with the local creek bottom type of timber from bluff to bluff, the water seeped rather than flowed down through a series of sloughs, and fish over a foot in length could be caught with little trouble. Today, this same creek bottom is little more than a gravel bar from bluff to bluff. Most of the old trees are gone, some have been cut for fuel, many others cut down for the cattle during droughts and the winters when the feed was scarce on the range, and many have washed away during the floods that have rushed down this stream nearly every year since the range started to deplete. The same condition applies to practically every stream of any size on the Tonto. The first real flood to come down Tonto Creek was in 1891 after it had rained steadily for 12 days and nights. At this time the country was fully stocked, the ground had been trampled hard, much of the grass was short, or gone, gullies had started and the water came rushing down."

The general condition of uplands within the watershed were described by another early settler, E. M. Watkins, who recounted that "There were no washes at all in those days [before extensive cattle stocking], where at present arroyos many feet deep are found and at places cannot be crossed." Furthermore, Fred Croxen reported that "All the men interviewed [by him] state that there was little brush in the country at the time stock was first brought in, and it was possible to drive a wagon nearly anywhere one desired." The loss of beaver in the region was reported by Mr. Vi Fuller, an early settler on the East Verde River, who stated that ". . . there were beaver in the streams in Tonto Basin in the early days but they were not trapped [out] by white men. The floods caused by the denuding of the ranges finally washed them out." Croxen concludes his report as follows (Tucker 1989*a*):

"The range was not only grazed out, but was trampled out as well. Moisture did not go down to the remaining grass roots and the cow trails were fast becoming gullies which drained the country like a tin roof. Sheet erosion started in many places, especially on the steep slopes and the thin soil was soon washed away and only rocks were left."

An example of how severe erosion and stream sedimentation could be at that time was provided by Leopold (1924), who reported a situation ". . . on the GOS cattle range in the Gila Forest, where earth-scars due to concentration of cattle along the water-courses have caused an entire trout stream to be buried by detritus."

By the time Henry Woodrow began working in 1909 as a forest ranger in the upper West Fork

Gila River watershed, there were at least 13 homesteads in the "McKenna Park District" and cattle and sheep grazing was prevalent throughout the area (Tucker, 1989*b*). By that time, he noted that "The grass here was a bunch-grass type and did not have strength to keep a horse stout, so a great many of those [ranger patrol] trips were made on foot" and that "the main trails [were] . . . made by stock." Woodrow was stationed at White Creek, from where he patrolled "the fish streams and sheep camps on my way to Mogollon-Baldy and Lilly Mountain." The widespread use of the upper West Fork Gila River drainage by sheep is attested to by Woodrow's reports that much of his time was spent enumerating sheep on the district. He reported fighting fires, often alone or with a small group of men, which suggests that most fires at the time were quite small and easily contained, and that fuel loads were very limited. Historical coincidence of fire decline and heavy grazing, particularly by sheep, has been noted elsewhere in the Southwest (Savage and Swetnam, 1990).

Degradation of stream habitat in the upper Gila River watershed from past open-range, unregulated livestock grazing is indicated by early restoration efforts. During an inspection in August 1932, Assistant Regional Forester Hugh G. Calkins "mentioned the great improvement in grass, herbs, alders, and willows along stream courses in four areas of the Gila because of programs that reduced stocking and removed cattle from the sheep range" (Barker *et al.*, 1988: 149). Henry Woodrow reported working with crews in the early 1930s to construct fish "habitat improvements," "fish dams" and fenced exclosures on streams, further suggesting that degradation of stream habitat from excessive livestock grazing was beginning to be recognized.

Appendix I – Gila Trout– Conservation Efforts Prior to 2011

Early 20th Century through 1960

Initial efforts to conserve Gila trout consisted of attempts by the New Mexico Department of Game and Fish to propagate the species in the early 1920s, when Gila trout was locally recognized as ‘mountain trout’ or ‘speckled trout.’ Propagation activities took place at Jenks Cabin Fish Hatchery starting in 1923 and at the Glenwood State Fish Hatchery beginning in 1937. These Gila trout culture programs were discontinued at the Jenks Cabin and Glenwood hatcheries in 1935 and 1947, respectively, due to low production. After the hatchery programs were abandoned, the New Mexico Department of Game and Fish implemented a policy of not stocking nonnative trout into the streams that were known to be inhabited by Gila trout. In the 1930s, the Civilian Conservation Corps constructed log stream improvement structures and fenced exclosures on streams in the Gila National Forest including Turkey Creek, Little Creek, Mogollon Creek, West Fork Gila River, Iron, Creek, White Creek, Willow Creek, and the Middle Fork Gila River (Tucker, 1989*a*). Scientific investigation of Gila trout originally came at the request of Elliot S. Barker, State Game Warden of New Mexico, and led to the description of the species from specimens taken at Glenwood Hatchery and Main Diamond Creek in 1939 (Miller, 1950). The New Mexico Department of Game and Fish closed Main Diamond Creek to fishing in 1958 (Hanson, 1971).

1960 through 1979

Gila trout was listed as endangered in the U.S. Fish and Wildlife Service “Red Book” in 1966. The species was listed as endangered in 1967 under the federal Endangered Species Preservation Act of 1966 (Service, 1967). A study of the ecology of Gila trout in Main Diamond Creek was sponsored by the New Mexico Department of Game and Fish in the early 1960s (Regan, 1966). A study conducted during 1969 and 1970 resulted in selection of McKnight Creek in the Mimbres River drainage as a replication site for the Main Diamond Creek population of Gila trout, and also identified populations in South Diamond, Spruce, and McKenna creeks (Table H1; Hanson, 1971). After construction of a barrier and elimination of the native Rio Grande sucker (*Catostomus plebeius*) with rotenone, 307 Gila trout were transplanted from Main Diamond Creek into McKnight Creek in November 1970.

A management plan for Gila trout was developed by the Gila National Forest and New Mexico Department of Game and Fish in 1972 (Bickle, 1973). On 27 April 1972, 110 Gila trout from Main Diamond Creek were translocated into McKnight Creek to supplement the population. Also in 1972, 89 Gila trout from Main Diamond Creek were transplanted into Sheep Corral Canyon in an attempt to establish a new population in that stream (Table H1; Turner, l989). Sheep Corral Canyon above a waterfall (presumed to be a barrier to upstream fish passage) was devoid of fish prior to the transplant. The Endangered Species Act of 1973 provided protection to all species of wildlife that had been designated under the Endangered Species Preservation Act of 1966, which included Gila trout. In 1974, 65 Gila trout from Main Diamond Creek were translocated into Gap Creek, a tributary of the Verde River on the Prescott National Forest in Arizona (Minckley and Brooks, 1985; Warnecke, 1987). Stream surveys were conducted in 1974 and 1976 that established the distribution and status of Gila trout (David, 1976; Mello and Turner, 1980).

The first comprehensive taxonomic analysis of Gila trout was completed in 1970s (David, 1976), as was a cytotaxonomic study (Beamish and Miller, 1977). Methods for population estimation and habitat evaluation were tested in the late 1970s (Rinne, 1978). The first comprehensive assessment of the distribution of Gila trout was completed in the late 1970s (Mello and Turner, 1980). Replicate populations of the Main Diamond Creek lineage were established in McKnight Creek, Sheep Corral Canyon, and Gap Creek by direct transfer of fish from wild populations (Table H1).

In 1979, the Gila trout Recovery Plan was approved by the U.S. Fish and Wildlife Service with the main objective being “To improve the status of Gila trout to the point that its survival is secured and viable populations of all morphotypes are maintained in the wild” (Service, 1979). An environmental assessment for Gila trout recovery projects on the Gila National Forest was approved in 1979 that authorized the stabilization and replication of indigenous populations of Gila trout involving both artificial barrier construction and piscicide application in streams within the Gila National Forest.

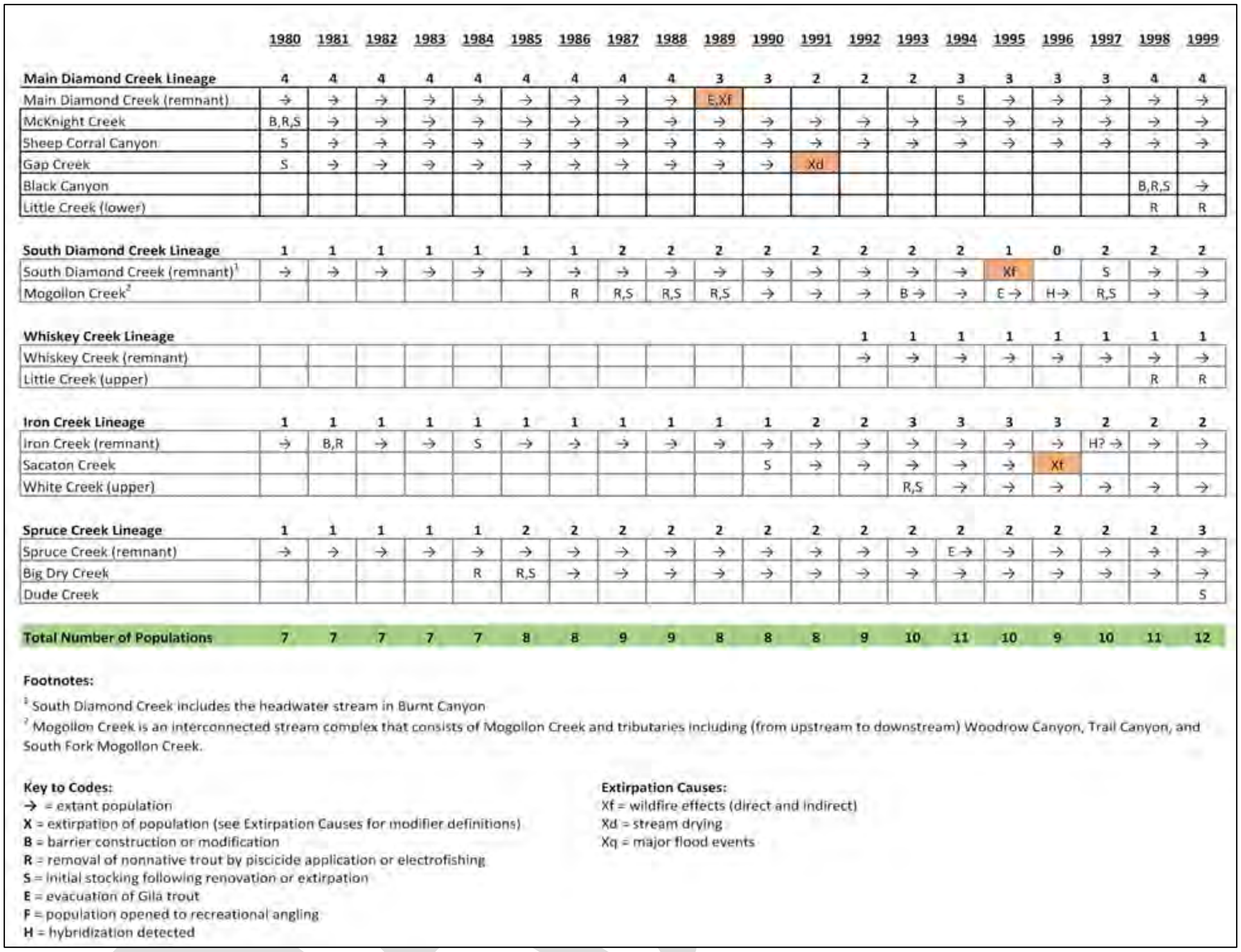
<u>1980 through 1989</u>

In 1981, a concrete and rock barrier was constructed on Iron Creek about 2.9 km (1.8 mi) downstream from an intermittent reach of the stream (Table H1). Brown trout density was reduced with Antimycin A between the barrier and the intermittent reach after Gila trout had been removed from the area by electrofishing and placed in holding pens isolated from the toxicant. Gila trout were prematurely released into the renovated area and suffered high mortality (Coman, 1981). In 1984, 105 Gila trout were moved from the upper reach of Iron Creek downstream to the renovated area (Turner, 1989). Brown trout were removed from the renovated reach in 1985 and 12 Age II brown trout were removed in 1988.
Little Creek was selected as a site to replicate the population of Gila trout in McKenna Creek, which at the time was thought to be a genetically intact, remnant population of Gila trout. In 1982, a concrete and rock barrier was constructed on Little Creek and approximately 9 km (5.6 mi) of stream above the barrier were treated to remove nonnative trout (Table H1). Desert sucker (*Catostomus clarki*) was also eliminated; however, speckled dace (*Rhinichthys osculus*) survived the treatment. In December 1982, 100 Gila trout were successfully transported from McKenna Creek to Little Creek.

The Gila trout Recovery Plan was revised in 1984 with the same objective as the original plan. Down-listing criteria in the plan stated that “The species could be considered for down-listing from its present endangered status to a threatened status when survival of the five original ancestral populations is secured and when all morphotypes are successfully replicated or their status otherwise appreciably improved” (Service, 1984).

The Spruce Creek population was replicated in Big Dry Creek in 1985 (Table H1). A 1.9 km (1.2 mi) reach of Big Dry Creek above a 20 m (66 ft.) high waterfall was treated with Antimycin A in 1984. The first treatment did not remove all nonnative trout so another treatment was applied in 1985. In October 1985, 97 Gila trout were translocated from Spruce Creek to the renovated reach of Big Dry Creek.

Table I 1. Status of Gila trout populations, pre-1980 through 1999. Numbers in each lineage indicate the number of extant populations of that lineage.



	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Main Diamond Creek Lineage	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**3**	**3**	**2**	**2**	**2**	**3**	**3**	**3**	**3**	**4**	**4**
Main Diamond Creek (remnant)	→	→	→	→	→	→	→	→	→	E,Xf					S	→	→	→	→	→
McKnight Creek	B,R,S	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→
Sheep Corral Canyon	S	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→
Gap Creek	S	→	→	→	→	→	→	→	→	→	→	Xd								
Black Canyon																			B,R,S	→
Little Creek (lower)																			R	R
South Diamond Creek Lineage	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**1**	**0**	**2**	**2**	**2**
South Diamond Creek (remnant)[1]	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	Xf		S	→	→
Mogollon Creek[2]							R	R,S	R,S	R,S	→	→	→	B →	→	E →	H→	R,S	→	→
Whiskey Creek Lineage													**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Whiskey Creek (remnant)													→	→	→	→	→	→	→	→
Little Creek (upper)																			R	R
Iron Creek Lineage	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**2**	**2**	**3**	**3**	**3**	**3**	**2**	**2**	**2**
Iron Creek (remnant)	→	B,R	→	→	S	→	→	→	→	→	→	→	→	→	→	→	→	H? →	→	→
Sacaton Creek											S	→	→	→	→	→	Xf			
White Creek (upper)														R,S	→	→	→	→	→	→
Spruce Creek Lineage	**1**	**1**	**1**	**1**	**1**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**3**
Spruce Creek (remnant)	→	→	→	→	→	→	→	→	→	→	→	→	→	→	E →	→	→	→	→	→
Big Dry Creek					R	R,S	→	→	→	→	→	→	→	→	→	→	→	→	→	→
Dude Creek																				S
Total Number of Populations	**7**	**7**	**7**	**7**	**7**	**8**	**8**	**9**	**9**	**8**	**8**	**8**	**9**	**10**	**11**	**10**	**9**	**10**	**11**	**12**

Footnotes:

[1] South Diamond Creek includes the headwater stream in Burnt Canyon

[2] Mogollon Creek is an interconnected stream complex that consists of Mogollon Creek and tributaries including (from upstream to downstream) Woodrow Canyon, Trail Canyon, and South Fork Mogollon Creek.

Key to Codes:
→ = extant population
X = extirpation of population (see Extirpation Causes for modifier definitions)
B = barrier construction or modification
R = removal of nonnative trout by piscicide application or electrofishing
S = initial stocking following renovation or extirpation
E = evacuation of Gila trout
F = population opened to recreational angling
H = hybridization detected

Extirpation Causes:
Xf = wildfire effects (direct and indirect)
Xd = stream drying
Xq = major flood events

Upper Mogollon Creek and Trail Canyon were selected as sites for replicating the South Diamond Creek population of Gila trout. Trail Canyon was treated with Antimycin A in October 1986 and the stream was treated again in July 1987 to remove remaining nonnative trout (Table J1). In September 1987, Trail Canyon was found to be fishless and 305 Gila trout were transported by helicopter from South Diamond Creek to the stream. In October 1988, fish from South Diamond were used to supplement the Trail Canyon population (Propst *et al.*, 1992). Mogollon Creek from its source to the confluence with Trail Canyon was initially treated with Antimycin A in July 1987 to remove nonnative trout. Nonnative trout survived the initial treatment of upper Mogollon Creek and the stream was treated again in July 1988. At the same time Woodrow Canyon, a renovated tributary of upper Mogollon Creek, was stocked with Gila trout from South Diamond Creek. In April 1989, Gila trout brood stock were obtained from South Diamond Creek and taken to Mescalero National Fish Hatchery, and a third Antimycin A treatment was applied in upper Mogollon Creek. Eradication of nonnative trout in upper Mogollon Creek was confirmed in May 1989 and, in October 1989, the creek was stocked with

100 fingerling Gila trout from Mescalero National Fish Hatchery and 93 Gila trout from Trail Canyon.

In 1987, it appeared that down-listing criteria were rapidly being achieved, so the species was proposed for down-listing from endangered to threatened status (U.S. Fish and Wildlife Service, 1987). In July 1989, a large portion of the 24,762 ha (61,190 ac) Divide Fire burned through the Main Diamond Creek watershed. An emergency evacuation operation during the peak of the fire removed 566 Gila trout from the stream to Mescalero National Fish Hatchery. Main Diamond Creek was sampled extensively in October 1989 and again in May 1990. The results of these surveys confirmed that the population of Gila trout in Main Diamond Creek had been extirpated. In October 1989, 200 of the evacuated Gila trout from Main Diamond Creek were stocked into McKnight Creek. The Divide Fire and loss of Gila trout prompted postponement of the down-listing proposal.

Monitoring of extant populations of Gila trout was conducted (Turner and McHenry, 1985; Turner, 1989) and numerous studies on the systematics, biology, habitat, and ecology of Gila trout were completed (Lee and Rinne, 1980; Rinne, 1980; Rinne, 1981*a*; Rinne, 1981*b*; Rinne, 1982; Mpoame and Rinne, 1984; Loudenslager *et al.*, 1986; McHenry, 1986; Medina and Martin, 1988; Nankervis, 1988; Van Eimeren, 1988). A genetics study, including analysis of mitochondrial and nuclear DNA of all known Gila trout populations, suspected Gila trout populations, and related species was initiated in January 1988. Tissue samples for the study were collected in 1988 and 1989.

<u>1990 through 1999</u>

Studies on the habitat (Stefferud, 1994) and population dynamics (Propst and Stefferud, 1997) of Gila trout were completed in the 1990s. Also during this time considerable information was developed on the molecular genetics of Gila trout (Nielsen *et al.*, 1998; Riddle *et al.*, 1998; Leary and Allendorf, 1999; Leary *et al.*, 1999).
Stream habitat improvements were constructed and willow cuttings were planted in McKnight Creek in 1989 and 1990 by the U.S. Forest Service and New Mexico State University. The Iron Creek population of Gila trout was replicated at Sacaton Creek in May 1990, when 40 fish were stocked into the barren stream (Table 1). A second stocking of 60 Gila trout from Iron Creek was made into Sacaton Creek in June 1991. Persistence of the brown trout population in Iron Creek, preliminary results of the 1988 and 1989 tissue sample analysis that indicated introgressive hybridization of rainbow trout in the McKenna Creek population, and extirpation of populations caused by catastrophic forest fire, resulted in a reevaluation and withdrawal of the 1987 down-listing proposal in 1991. A previously unknown population of Gila trout was discovered in an unnamed tributary to the West Fork Gila River in 1992. The tributary, referred to as Whiskey Creek, is in the upper West Fork Gila River drainage.

A fish barrier was improved on Mogollon Creek in July 1993 to prevent upstream movement of brown trout. A reach of White Creek above a waterfall barrier was renovated with three treatments of Antimycin A and 265 Gila trout from Iron Creek were transported to the stream on 21 October 1993. A second stocking was made in 1995. Evidence of illegal angling was discovered in Iron Creek in October 1993. The Gila trout Recovery Plan was revised in 1993 to incorporate new information about the ecology of the species and recovery methods obtained since the 1984 revision. Criteria for down-listing remained essentially the same as in the 1984 revision but were more specific. The 1993 plan specified that down-listing would be considered "when all known indigenous lineages are replicated in the wild" and when Gila trout were "established in a sufficient number of drainages such that no natural or human-caused event may eliminate a lineage."

In May 1994, recovery team members and advisors to the team convened public meetings in Reserve, Silver City, and at Willow Creek to discuss recovery actions and address local concerns about stream renovation and the use of Antimycin A. Substantial opposition to stream renovations had been building and resulted in the postponement of removing nonnative trout from Mineral and Mogollon creeks. One-hundred and fifty Gila trout were evacuated from Spruce Creek during a forest fire in the upper watersheds of Spruce and Big Dry creeks in June 1994. The fish were transported to Mescalero National Fish Hatchery, where they suffered a high rate of mortality. The wild Spruce Creek and Big Dry Creek populations survived the fire. Monitoring of watershed condition at Main Diamond Creek indicated that the stream had recovered to the point that Gila trout could be repatriated to the stream (Wood and Turner, 1992; Wood and Turner, 1994; Jacobi, *in litt*.). In September 1994, 195 Gila trout were translocated from McKnight Creek to Main Diamond Creek to reestablish a population.

Substantial efforts were made by recovery team members, participating agencies, and team advisors to inform local government staff and concerned public about the use and effects of Antimycin A, the Gila trout recovery program, and stream renovation. These efforts included meetings, personal contacts, dissemination of fact sheets, publication of an article in New Mexico Wildlife (Propst, 1994), and publication of peer-reviewed articles that summarized recovery efforts and conservation status of the species (Propst *et al.*, 1992; Turner, 1996). Public meetings on Gila trout recovery activities were convened in Las Cruces, Silver City, and Reserve in March 1995. The purpose of these meetings was to provide information about the recovery program. Recovery team members also met with the Grant County Commission in July and November. The November meeting was also attended by the Gila Rod and Gun Club. Gila trout recovery issues, including removal of nonnative trout and use of Antimycin A, were discussed at these meetings.

A forest fire (the Bonner Fire) caused the extirpation of the South Diamond Creek population of Gila trout in summer 1995. The fire also eliminated nonnative trout from Black Canyon. Another fire in the Mogollon Creek watershed resulted in marked reductions of Gila trout numbers in Corral and Trail canyons. About 430 Gila trout were removed from Trail Canyon and Mogollon Creek during the fire. The fish were transported to Mescalero National Fish Hatchery. Approximately 50 Age 0 Gila trout of Main Diamond lineage, which were raised at

Mescalero National Fish Hatchery, were stocked into Main Diamond Creek in September 1995. Another 150 Gila trout were collected from Iron Creek and stocked into White Creek in October 1995.

Mogollon Creek, from Woodrow Canyon downstream to a waterfall, Trail Canyon, and South Fork Mogollon Creek were treated with Antimycin A in August 1996 to remove nonnative trout (Table 1). Questions regarding the genetic purity of several Gila trout populations were raised in summer 1996. Dr. Robb Leary, University of Montana, was retained to resolve the genetics questions and conduct molecular genetics analyses of tissues taken from all extant populations. Initial results indicated that the Mogollon Creek population, which was established from the South Diamond lineage, had recently been contaminated with rainbow trout.

A memorandum of understanding between the U.S. Forest Service, New Mexico Trout, New Mexico Department of Game and Fish, and the Rio Grande Chapter of Trout Unlimited was executed in early 1997. The memorandum described a framework for cooperative efforts between the signatories to conserve native trout and their habitats. Progress on the molecular genetics work by Dr. Robb Leary indicated that the South Diamond lineage could be salvaged by conducting paired mating of Mogollon Creek fish. In November 1997, 500 Age 0 Main Diamond lineage Gila trout from Mescalero National Fish Hatchery were stocked into Main Diamond Creek to supplement that population. Two Antimycin A treatments of Mogollon Creek from the headwaters downstream to a waterfall barrier were completed in summer 1997. Prior to the first treatment, 650 Gila trout were removed from Mogollon Creek and taken to Mescalero National Fish Hatchery. These fish and Gila trout from Trail Canyon were used in paired mating to restore the South Diamond lineage. Mogollon Creek was then stocked with about 1,200 Age 0 South Diamond lineage Gila trout from Mescalero National Fish Hatchery in October. Another 500 Age 0 South Diamond lineage fish were stocked from the hatchery into South Diamond Creek in November. Results of the molecular genetics investigations indicated that both the McKenna Creek and Iron Creek populations were introgressed with rainbow trout. Rainbow trout hybridization had occurred to the point that paired mating could not be employed to restore the pure Gila trout lineage of either stream.

Introduction of rainbow trout into the McKenna Creek population was identified by Riddle and others (1998) through analysis of mitochondrial DNA. Leary and Allendorf (1999) also reported hybridization with rainbow trout in the McKenna Creek and Iron Creek populations and hypothesized that one or two introductions of rainbow trout had likely occurred sometime between 1930 and 1950. The proportion of rainbow trout genes in these two introgressed populations was estimated to be about 10 percent. The molecular genetics investigations also identified unique genetic material in each of the other remnant populations, reinforcing the need to replicate each lineage.

A gabion waterfall barrier was constructed in June and July 1998 on Black Canyon, with considerable assistance from volunteers (Propst, 1999). Prior to completion of the barrier, brown and rainbow trout were found to have been recently introduced into the stream. Nonnative salmonids were removed by intensive electrofishing (Brooks and Propst, 1999). In November, 13,000 Age 0 Main Diamond lineage Gila trout were stocked into the stream above the barrier. Little Creek was treated with Antimycin A in November 1998 to remove the population of Gila x rainbow trout that was established in 1982 with fish from McKenna Creek. A meeting was convened in Silver City on 21 October 1998 with the New Mexico Department of Game and Fish, U.S. Fish and Wildlife Service, U.S. Forest Service, Grant County Commission, Gila Rod and Gun Club, and People for the U.S.A. to discuss the status of Gila trout recovery. Broodstock development for the extant lineages of Gila trout was initiated at Mora National Fish Hatchery.

All extant populations of Gila trout, except Whiskey Creek, were sampled in 1999 to assess density and population structure. Little Creek was treated again with Antimycin in 1999 to remove the Gila x rainbow trout hybrid population. In late September 1999, 126 Gila trout were collected from Spruce Creek and translocated to Dude Creek in Arizona, to establish a second replicate population of the Spruce lineage. The Dude Creek population was supplemented in early November 1999 with 17 Age 0 Gila trout of Spruce Creek lineage, which were raised at Mora National Fish Hatchery. About 20,000 Age 0 Main Diamond lineage Gila trout were stocked into Black Canyon on 20 October 1999.

<u>2000 through 2010</u>

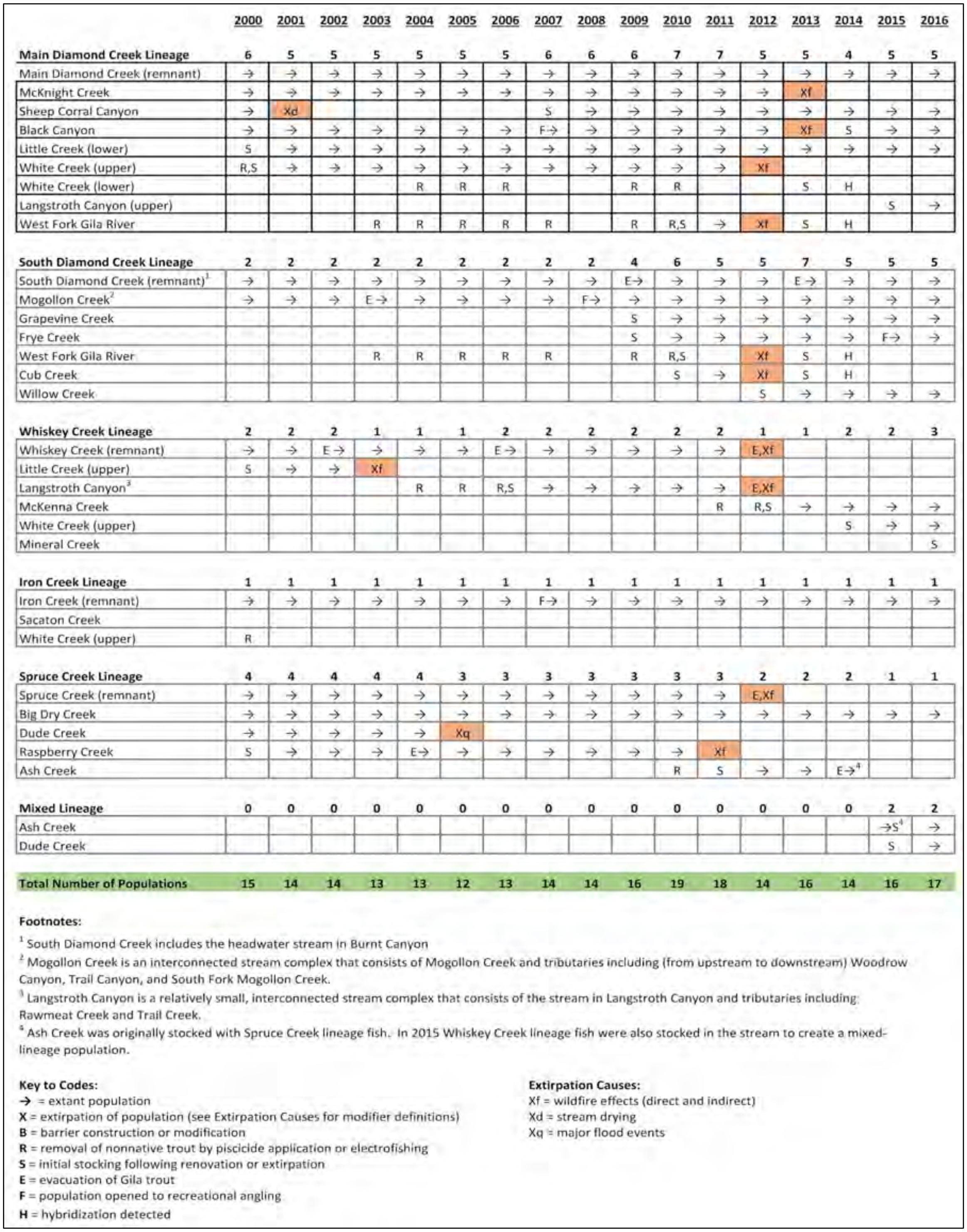
White Creek was renovated using Antimycin A in June and July 2000 to remove the Gila x rainbow trout (Table 2), which was established with fish from Iron Creek in 1993. The renovated stream was stocked with approximately 1,625 Gila trout of Main Diamond lineage that were produced at Mescalero National Fish Hatchery. Main Diamond lineage Gila trout were stocked from Mescalero National Fish Hatchery into lower Little Creek in April and October 2000. Also in April 2000, approximately 30 Gila trout were translocated from Whiskey Creek to upper Little Creek. Another 10 Gila trout were collected from Whiskey Creek and transferred to the Mora National Fish Hatchery. These captive fish were spawned and 13 Gila trout reared from the spawn were stocked into upper Little Creek in October 2000. In May 2000, 22 adult Gila trout were collected from Spruce Creek, spawned, and then translocated to Dude Creek. The fertilized eggs from the spawn were taken to Mescalero National Fish Hatchery. One-hundred and thirteen Age 0 fish produced from these fertilized eggs were stocked in late November 2000 into Raspberry Creek, a tributary to Blue River in Arizona. This stocking established the third replicate of the Spruce Creek lineage. White Creek was renovated in 2000 (Table J2).

Operations at Mescalero National Fish Hatchery were suspended in September 2000 because of flood damage. All Gila trout brood stock held at the facility were transferred to the Mora National Fish Hatchery, which took over Gila trout production activities for recovery of the species.

A Memorandum of Understanding was developed in 2000 between the Apache-Sitgreaves National Forest, Arizona Game and Fish Department, U.S. Fish and Wildlife Service, Wildlife Conservation Council, Eastern Rocky Mountain Council of the Federation of Flyfishers, Old Pueblo Chapter of Trout Unlimited, and the Arizona State Council of Trout Unlimited (Arizona A.G. Contract No. KR001230-EQS, Forest Service Agreement No. 00-MU-11030121-005). The Memorandum of Understanding was developed to create a partnership for recovery of both Apache trout and Gila trout, as well as watershed restoration within the historic range of the two species on the Apache-Sitgreaves National Forest.

Monitoring in 2001 documented mixed age-class populations of Gila trout in Main Diamond Creek, South Diamond Creek, Black Canyon, McKnight Creek and Whiskey Creek. Reproduction and recruitment was documented in the South Diamond Creek population, which was repatriated to the stream in 2000. Main Diamond Creek lineage fish (Age 0) were stocked into Black Canyon on 31 October 2001 (N = 2,000), three locations in Little Creek on 1 November 2001 (N = 2,000), and White Creek on 18 November (N = 1,000; Table J2). Mora National Fish Hatchery produced 1,690 Gila trout in 2001, primarily of Main Diamond Creek lineage (N = 1,590). The remaining 100 fish produced by the hatchery in 2001 were South Diamond Creek lineage Gila trout. A study was initiated at the hatchery to determine the feasibility and effectiveness of hatchery spawning period compression using photoperiod adjustment, temperature cues, and hormone injection.

Table I 2. Status of Gila trout populations, 2000 through 2016. Numbers in each lineage row indicate the number of extant populations of that lineage.



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Main Diamond Creek Lineage	**6**	**5**	**5**	**5**	**5**	**5**	**5**	**6**	**6**	**6**	**7**	**7**	**5**	**5**	**4**	**5**	**5**
Main Diamond Creek (remnant)	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→
McKnight Creek	→	→	→	→	→	→	→	→	→	→	→	→	→	Xf			
Sheep Corral Canyon	→	Xd						S	→	→	→	→	→	→	→	→	→
Black Canyon	→	→	→	→	→	→	→	F→	→	→	→	→	→	Xf	S	→	→
Little Creek (lower)	S	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→
White Creek (upper)	R,S	→	→	→	→	→	→	→	→	→	→	→	Xf				
White Creek (lower)					R	R	R			R	R			S	H		
Langstroth Canyon (upper)																S	→
West Fork Gila River				R	R	R	R	R		R	R,S	→	Xf	S	H		
South Diamond Creek Lineage	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**4**	**6**	**5**	**5**	**7**	**5**	**5**	**5**
South Diamond Creek (remnant)[1]	→	→	→	→	→	→	→	→	→	E→	→	→	→	E→	→	→	→
Mogollon Creek[2]	→	→	→	E→	→	→	→	→	F→	→	→	→	→	→	→	→	→
Grapevine Creek										S	→	→	→	→	→	→	→
Frye Creek										S	→	→	→	→	→	F→	→
West Fork Gila River				R	R	R	R	R		R	R,S		Xf	S	H		
Cub Creek											S	→	Xf	S	H		
Willow Creek													S	→	→	→	→
Whiskey Creek Lineage	**2**	**2**	**2**	**1**	**1**	**1**	**2**	**2**	**2**	**2**	**2**	**2**	**1**	**1**	**2**	**2**	**3**
Whiskey Creek (remnant)	→	→	E→	→	→	→	E→	→	→	→	→	→	E,Xf				
Little Creek (upper)	S	→	→	Xf													
Langstroth Canyon[3]					R	R	R,S	→	→	→	→	→	E,Xf				
McKenna Creek												R	R,S	→	→	→	→
White Creek (upper)															S	→	→
Mineral Creek																	S
Iron Creek Lineage	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Iron Creek (remnant)	→	→	→	→	→	→	→	F→	→	→	→	→	→	→	→	→	→
Sacaton Creek																	
White Creek (upper)	R																
Spruce Creek Lineage	**4**	**4**	**4**	**4**	**4**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**2**	**2**	**2**	**1**	**1**
Spruce Creek (remnant)	→	→	→	→	→	→	→	→	→	→	→	→	E,Xf				
Big Dry Creek	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→
Dude Creek	→	→	→	→	→	Xq											
Raspberry Creek	S	→	→	→	E→	→	→	→	→	→	→	Xf					
Ash Creek											R	S	→	→	E→[4]		
Mixed Lineage	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**2**	**2**
Ash Creek																→S[4]	→
Dude Creek																S	→
Total Number of Populations	**15**	**14**	**14**	**13**	**13**	**12**	**13**	**14**	**14**	**16**	**19**	**18**	**14**	**16**	**14**	**16**	**17**

Footnotes:

[1] South Diamond Creek includes the headwater stream in Burnt Canyon

[2] Mogollon Creek is an interconnected stream complex that consists of Mogollon Creek and tributaries including (from upstream to downstream) Woodrow Canyon, Trail Canyon, and South Fork Mogollon Creek.

[3] Langstroth Canyon is a relatively small, interconnected stream complex that consists of the stream in Langstroth Canyon and tributaries including Rawmeat Creek and Trail Creek.

[4] Ash Creek was originally stocked with Spruce Creek lineage fish. In 2015 Whiskey Creek lineage fish were also stocked in the stream to create a mixed-lineage population.

Key to Codes:

→ = extant population
X = extirpation of population (see Extirpation Causes for modifier definitions)
B = barrier construction or modification
R = removal of nonnative trout by piscicide application or electrofishing
S = initial stocking following renovation or extirpation
E = evacuation of Gila trout
F = population opened to recreational angling
H = hybridization detected

Extirpation Causes:

Xf = wildfire effects (direct and indirect)
Xd = stream drying
Xq = major flood events

Gila trout were confirmed present in Dude Creek in 2002, established with fish from the Spruce Creek population, but no recruitment was documented. Raspberry Creek was also confirmed to have Gila trout. It too was stocked with fish from the Spruce Creek population. Little Creek, established with Main Diamond lineage fish, was monitored and Gila trout were found to persist there. Monitoring in 2002 found the Sheep Corral Canyon population, a replicate of the Main Diamond lineage, to be extirpated. The population was likely lost as a result of drought acting in concert with habitat degradation caused by livestock grazing. Monitoring in 2002 found viable populations of Gila trout in Spruce Creek, South Diamond Creek and Mogollon Creek. Hatchery-raised Main Diamond lineage Gila trout were stocked in Black Canyon, lower Little Creek and White Creek in November 2002. The stocked fish were raised at the Mora National Fish Hatchery.

A draft emergency evacuation plan for Gila trout populations threatened by wildfire, drought, or nonnative trout invasion was developed in 2002 for review by the recovery team. The Arizona Game and Fish Department initiated efforts to allow for restoration of Gila trout to West Fork Oak Creek, tributaries to the Blue River, and Chitty Creek. Gila trout were evacuated from Whiskey Creek in July 2002 to safeguard against potential loss of the population due to the Cub Fire (Table J2). Some of the fish were taken to the Mora National Fish Hatchery (N = 17) and the remainder (*ca*. 75) were transplanted in upper Little Creek (Brooks, 2002). The perennial section of Whiskey Creek inhabited by Gila trout was not affected or only minimally impacted by the Cub Fire.

Environmental compliance work was completed in 2003 for restoration of Gila trout to approximately 34 km (21 mi) of stream habitat in the upper West Fork Gila River drainage. The upper West Fork Gila River from Whiskey Creek confluence downstream to Packsaddle Canyon confluence was treated with Antimycin A in September and October 2003. The Cub and Dry Lake Complex fires had eliminated fish in the West Fork Gila River upstream from Whiskey Creek and from Cub Creek. Speckled dace were salvaged from the project area prior to piscicide treatment and were repatriated following completion of stream renovation.

Monitoring in 2003 confirmed the loss of the Sheep Corral Canyon population and low numbers of Gila trout in Little Creek. Black Canyon was stocked with approximately 2,500 Age 0 Gila trout (Main Diamond lineage) in November 2003. Whiskey Creek was monitored in June 2003 and the population of Gila trout there was confirmed to have survived the 2002 Cub Fire. Emergency evacuation of approximately 120 Gila trout from Mogollon Creek was conducted in July 2003 during the Dry Lakes Complex Fire. Monitoring conducted in November 2003 indicated that the population in Mogollon Creek survived the wildfire. Upper Little Creek was monitored following the Dry Lakes Complex Fire and only four Gila trout were found. These fish were taken to Mora National Fish Hatchery. Post-fire flooding and sediment input eliminated fish from upper Little Creek and rendered habitat in the reach unsuitable for trout. Naturalistic rearing methods were implemented at Mora National Fish Hatchery. These methods included placement of gravel and cobbles in rearing tanks, woody cover, painting the sides of the tanks, provision of live food, and addition of native suckers which provided a cleaning function.

Renovation treatments were continued in the upper West Fork Gila River drainage in 2004 (Propst, 2005). In June 2004, Antimycin A was applied to the West Fork Gila River from Packsaddle Canyon downstream to the waterfalls near White Creek Cabin, White Creek from the waterfall at the lower limit of Gila trout downstream to the West Fork Gila River, and Langstroth Canyon (including Rawmeat Creek and Trail Creek). Post-treatment sampling conducted in October 2004 found that both rainbow and brown trout persisted in the project area in the lower reaches of the West Fork Gila River, White Creek and Langstroth Canyon (Propst and Paroz, 2007). Thirty-one Gila trout were evacuated from Raspberry Creek during the KP Fire in 2004, and were taken to Mora National Fish Hatchery. Over half of the evacuated fish died, and the surviving 14 Gila trout evacuated were returned to Raspberry Creek in November 2004. Post-fire monitoring of Raspberry Creek found that the population survived the fire.

In August 2005, the entire West Fork Gila River drainage upstream from the waterfall near White Creek Cabin was treated with Antimycin A (Propst and Paroz, 2007). Monitoring conducted in October 2005 revealed that nonnative trout persisted in the lower portion of the West Fork Gila River in the project area as well as in lower White Creek. Mogollon Creek was stocked in July 2005 with 319 Age 0 and 53 Age I Gila trout of South Diamond lineage. In November 2005 Black Canyon was stocked with 2,815 Age 0 Gila trout of Main Diamond lineage. The West Fork Gila River at the Heart Bar Wildlife Area was stocked with 2,791 Gila trout of Main Diamond lineage (2,704 Age 0 and 87 Age I) for recreational fishing. The Gila trout population in Dude Creek was confirmed extirpated in 2005 following flooding in that drainage. The New Mexico Department of Game and Fish developed a survey for anglers with the Gila trout stamp to gather recreational fishing data.

Gila trout was reclassified from endangered to threatened in July 2006 (Service, 2006). The down-listing included a rule under section 4(d) of the Endangered Species Act that provided the opportunity for the states of Arizona and New Mexico to establish regulations for recreational angling for Gila trout. Renovation of the upper West Fork Gila River drainage from Packsaddle Canyon to the waterfall near White Creek Cabin was continued in June 2006 but was interrupted by the Bear Fire. Antimycin A treatment of White Creek, Langstroth Canyon and the West Fork Gila River from Cub Creek downstream to Packsaddle Canyon were completed prior to crews evacuating the project area (Propst and Paroz, 2007). Renovation resumed in July 2006 with Antimycin A treatment of the West Fork Gila River from Cub Creek downstream to the waterfall near White Creek Cabin. Langstroth Canyon was stocked with 37 Gila trout translocated from Whiskey Creek. Monitoring in 2005 and 2006 found no Gila trout in Dude Creek. The stream was stocked in 1999 and 2000, adult fish (but no young-of-year) were observed in 2002, and major flood events occurred in 2004 and 2005. Low abundance of Gila trout was documented in Raspberry Creek in 2006. An angling mortality study was conducted at Mora National Fish Hatchery using surplus brood fish. No stocking of hatchery-raised Gila trout was conducted in

2006 as a precaution arising from placement of rainbow trout and Gila trout in close proximity in the hatchery facility. Genetic testing was conducted and it was determined that integrity of Gila trout stocks at the hatchery was maintained.

In 2007 the Aspen Fire burned into the Black Canyon watershed but did not result in notable impacts to the Gila trout population. Black Canyon was opened for recreational fishing in 2007 with catch-and-release and barbless, single-hook, artificial lure regulations, and an open season of July 1 through September 30. Iron Creek was also opened to angling with a two fish limit and terminal gear restriction of a barbless, single-hook artificial lure. Anglers were required to have a free angling authorization to fish in either stream. The New Mexico Game Commission approved regulations establishing Special Trout Waters in Willow Creek, Gilita Creek, Iron Creek (downstream from the fish barrier) and Black Canyon. Black Canyon was stocked with 588 Main Diamond lineage Gila trout in August 2007. Also in August 2007, 134 Gila trout were collected from South Diamond Creek and transported to Mora National Fish Hatchery for use as broodstock. Sheep Corral Canyon was stocked with 99 Gila trout (Main Diamond lineage) in September 2007. In November 2007, catchable-size Main Diamond lineage fish were stocked in Gilita Creek (N = 350), Willow Creek (N = 1,112), East Fork Gila River at Grapevine Campground (N = 500), West Fork Gila River near the Wilderness Visitor Center (N = 200), Sapillo Creek (N = 200), and the West Fork Gila River at the Forks Campground (N = 85). Thirty-eight Gila trout were translocated from Whiskey Creek to Langstroth Canyon.

The West Fork Gila River from Cub Creek downstream to near White Creek Cabin was treated again with Antimycin A in June 2007. Efficacy of the treatment was questionable and it was later learned that the Antimycin A formulation had less than 10 percent of label strength (Propst and Paroz, 2007). Consequently, it was determined that Antimycin A treatments made from 2005 through June 2007 involved compromised formulations. The West Fork Gila River from the falls near White Creek Cabin upstream to near Packsaddle Canyon was treated again in September 2007, but post-treatment monitoring found brown trout persisted in the project area.

In 2008 Mogollon Creek downstream from Trail Canyon was designated as a Special Trout Water for recreational fishing from 1 July through 31 October, bringing the number of Gila trout populations open to angling to three (the other two being Black Canyon and Iron Creek). Surplus hatchery production of Gila trout was used to stock recreational fisheries in the West Fork Gila River near the Heart Bar Wildlife Area, Willow and Gilita creeks and Sapillo Creek. Approval to use rotenone to renovate the West Fork Gila River was granted by the New Mexico Water Quality Control Commission in August 2008. Monitoring in the upper West Fork Gila River project area found brown trout in Langstroth Canyon, White Creek and the West Fork Gila River (Paroz and Propst, 2008).

Monitoring in May 2009 found rainbow trout near the confluence of Trail Creek and Langstroth Canyon, and no fish in Langstroth Canyon above the Forest Trail 302 crossing (located approximately 1.3 km [0.8 mi]) upstream from the Trail Creek confluence). Brown trout were found throughout the West Fork Gila River from the waterfall near White Creek Cabin upstream to the confluence of Whiskey Creek (Paroz and Propst, 2009). Twenty-five Gila trout were collected from Spruce Creek in 2009 and taken to Mora National Fish Hatchery to develop a broodstock for that lineage. Gila trout (N = 250) were evacuated from South Diamond Creek in June 2009 to safeguard the population, which was threatened by the Meason-Diamond Fire. The West Fork Gila River drainage from the falls near White Creek Cabin upstream to the confluence of Whiskey Creek was treated with rotenone in June 2009 (Paroz and Propst, 2009). Over 1,500 brown trout, 10 rainbow trout, and approximately 950 speckled dace were enumerated following the rotenone application. Brown trout were taken from Cub Creek, the West Fork Gila River, White Creek and Langstroth Canyon. Rainbow trout were taken from White Creek and Langstroth Canyon, and one was taken from the West Fork Gila River hear the confluence of White Creek (Paroz and Propst, 2009).

Frye Creek, located in the Pinaleño Mountains in Graham County, Arizona, was assessed in 2008 and was determined to be fishless. The stream was stocked with 500 South Diamond lineage Gila trout in November 2009 (Table 2). Grapevine Creek, another fishless stream located on the Prescott National Forest, was stocked with 160 South Diamond lineage Gila trout in November 2009. In 2009, Main Diamond lineage Gila trout were stocked in Black Canyon both above (N = 900) and below (N = 110) the fish barrier. Sheep Corral Canyon was also stocked with Main Diamond lineage fish (N = 100) in 2009. Gila trout recreational fisheries stocked in 2009 included the Gila River forks area (N = 752) and Sapillo Creek (N = 200). Stocking of nonnative trout in the Gila River drainage streams in New Mexico was ended in 2009. Sterile (all-female triploid) rainbow trout continue to be stocked in reservoirs in the drainage.

The West Fork Gila River and its tributaries upstream from the waterfall near White Creek Cabin were treated with rotenone again in August 2010. The renovation was successful and the West Fork Gila River was stocked in October with fish translocated from Main Diamond and South Diamond creeks. Main Diamond Creek fish were stocked near the confluence of Cub Creek and the South Diamond Creek fish were stocked near the confluence of White Creek. Brown trout were found to have been introduced in Black Canyon upstream from the fish barrier, and efforts were undertaken in August 2010 to manually remove the species from the stream. Mechanical removal of Apache trout was conducted in Coleman Creek, a tributary in the headwaters of the Blue River drainage, in an effort to make the stream suitable for restoration of Gila trout. Ash Creek, located in the Pinaleño Mountains on the Coronado National Forest, was treated with rotenone in October 2010 to remove nonnative trout. Post-treatment monitoring verified that the stream was fishless.

Cutthroat trout virus was isolated from ovarian fluid of Main Diamond and South Diamond lineage brood stock at Mora National Fish Hatchery in April 2010. Concerns regarding the presence of cutthroat trout virus resulted in suspension of stocking from the hatchery during most of 2010. Stocking was conducted in stream reaches known to have had previous introductions of cutthroat trout virus-positive fish. These stream reaches included the West Fork Gila River near the Heart Bar Wildlife Area, Sapillo Creek, Gilita Creek and Willow Creek, which were all stocked with Gila trout from Mora National Fish Hatchery in 2010.