Gila Chub
(*Gila intermedia*)
DRAFT RECOVERY PLAN

Illustration credit: Randy Babb

Southwest Region
U.S. Fish and Wildlife Service
Albuquerque, New Mexico

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Prepared by:
Gila Chub Recovery Team,
Technical Subgroup

Prepared for:
Southwest Region
U.S. Fish and Wildlife Service
Albuquerque, New Mexico

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Recovery plans delineate such reasonable actions as may be necessary, based upon the best scientific and commercial data available, for the conservation and survival of listed species. Plans are published by the U.S. Fish and Wildlife Service, and are sometimes prepared with the assistance of recovery teams, contractors, state agencies, and others. Recovery plans do not necessarily represent the views, official positions or approval of any individuals or agencies involved in the plan formulation, other than the U.S. Fish and Wildlife Service. They represent the official position of FWS only after they have been signed by the Regional Director. Recovery plans are guidance and planning documents only; identification of an action to be implemented by any public or private party does not create a legal obligation beyond existing legal requirements. Nothing in this plan should be construed as a commitment or requirement that any federal agency obligate or pay funds in any one fiscal year in excess of appropriations made by Congress for that fiscal year in contravention of the Anti-Deficiency Act, 31 U.S.C. 1341, or any other law or regulation. Approved recovery plans are subject to modification as dictated by new findings, changes in species status, and the completion of recovery actions.

Literature citation of this document should read as follows:

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Additional copies may be obtained from:
http://www.fws.gov/southwest/es/arizona/GilaChub.htm

PLAN PREPARATION

This draft recovery plan was developed by the Gila Chub Recovery Team. The Recovery Team is composed of a Technical Subgroup and a Stakeholder Subgroup. The Technical Subgroup provided expertise in fish biology, hydrology, land management, captive care, and conservation biology. The Stakeholder Subgroup provided a practical basis for the recovery plan, utilizing fish biology techniques, water- and land-management principles, and conservation biology. All subgroup members had the opportunity to contribute to this recovery plan, and many took the advantage of that opportunity over the duration of meetings that resulted in the completion of this document.

ACKNOWLEDGMENTS

The Service gratefully acknowledges the contributions from the Technical Subgroup members (see Current List) whose commitment, dedication, and expertise were invaluable in developing this recovery plan. We thank everybody who provided valuable time, and shared their expertise in Gila chub ecology and management, genetics, captive care, and land management practices that contributed to the completion of this draft recovery plan.

We specifically thank Rob Clarkson, the Team Leader and primary author and editor of this plan. We also thank Tom Dowling for providing genetic expertise, which essentially formed the foundation of specific Gila chub management in this plan, and Leslie Uhr (Bureau of Land Management) for providing Recovery Unit maps. Michelle Black (AZGFD), Mary Richardson (USFWS), and Nichole Englemann (USFWS) spent countless hours providing meeting notes for our Team. Jennifer Smith-Castro translated the Executive Summary into Spanish. The artwork on the cover of this plan was provided by Randy Babb (AZGFD).

Ryan Gordon (USFWS) was the co-team leader/author on this plan. Final review was provided by Wendy Brown (Retired) and Julie McIntyre of the Southwest Regional Office.

EXECUTIVE SUMMARY

Current Status:

The Gila chub was listed throughout its range as endangered with critical habitat in 2005. The species has a recovery priority number of 2C, which indicates a high degree of threat, a high potential for recovery, and a taxonomic classification as a species. The species occurs in rivers, streams, and spring-fed tributaries throughout the Gila River basin in southwestern New Mexico, central and southeastern Arizona, and possibly occurs into the northeastern tip of Sonora, Mexico. Gila chub is listed as endangered by The Republic of Mexico; however, a recovery plan, or Program de Acción para la Conservación de las Especies (PACE), has not been developed for this species in Mexico.

Habitat Requirements and Limiting Factors:

Gila chub commonly inhabits pools in smaller streams and cienegas throughout its range at elevations between 610 to 1,676 meters (m) (2,000 to 5,500 feet [ft]). Riparian plants typically associated with these habitats include willows, tamarisk, cottonwood, seep-willow, and ash. The species is highly secretive and is dependent on undercut banks, terrestrial vegetation, boulders, root wads, fallen logs, and thick overhanging or aquatic vegetation for cover. Representing 10-15% of its known historical range, 22 Gila chub populations are assumed to remain, including 3 populations that were repatriated in 1995 (2 populations) and 2005 (1 population). Eighteen of these populations occur within designated critical habitat. These extant small and fragmented populations are susceptible to environmental conditions such as drought, flood events, and wildfire.

Currently, the establishment of nonnative fishes within the Gila River basin is a primary threat to the persistence of Gila chub. The species historically experienced little or no predation from other native fishes. Although hydrologic connectivity among populations is the preferred management condition, isolation management (e.g., fish barriers) is the best approach for conservation of Gila chub populations threatened by nonnative fishes. Secondary threats are habitat alteration, destruction, and fragmentation.

The evolutionary and taxonomic complexity of the roundtail chub complex highlights the need to prevent hybridization and collectively consider each species' needs when designing and implementing management and recovery actions. In addition, the analysis of molecular variation of Gila chub proves that local adaptations played a significant role in the evolution of the species. To preserve genetic variation for this species, it is important to conserve extant remnant populations and carefully consider appropriate locations to replicate each population throughout the Gila River basin.

Recovery Goal:

Ensure the persistence of Gila chub within its currently occupied historical range and recover the species by protecting remnant populations, expanding the existing distribution through replication of distinct lineages, and protecting and improving habitats for existing and future populations so that the species no longer meets the definition of endangered or threatened.

Recovery Strategy:

The specific recovery strategy for Gila chub is to ensure that existing habitat integrity and genetic diversity of the species are adequately protected, represented, and replicated within each of the major subbasins in the greater Gila River basin. The subbasins are covered by five Recovery Units (RUs) within Arizona, New Mexico, and northern Mexico; these delineate areas supporting the species at present or historically. Each RU functions as a management subset of the species to carry out management actions necessary for both the survival and recovery of Gila chub. The recovery strategy further relies upon identifying, preserving, and replicating genetic Management Units (MUs) that are distributed among the Recovery Units.

Implementation of the recovery strategy will involve protection of remnant populations through management and agreements[1] with agencies and partners; captive rearing with appropriate genetic, demographic, and health management for population establishment and supplementation; control of threats of nonnative fish predation and competition as well as potential hybridization with other chub species; establishment of replicated populations in refuges and selected streams; monitoring of populations under a scientifically-based, standardized protocol; and cooperation and education with agencies, partners, Tribes, and Mexico to ensure habitat quantity and quality are maintained and adaptively managed into the future.

Recovery Criteria: (a more explanatory version of criteria can be found in section II.4 Recovery Criteria of this document)

Downlisting Criteria

Downlisting of Gila chub from endangered to threatened may be warranted when all of the following downlisting criteria are met:

Demographic Criteria:

A-1. *Remnant populations* (those naturally occurring in the wild)
All available remnant populations within each RU are maintained in a protected stream, and trends of recruitment and population size indices are considered stable or positive over the most recent rolling 10-year period. The protection of remnant populations is the priority, followed by the replication criteria below.

i. Trends of recruitment may be adequate if the regression slope of catch-per-unit-effort (CPUE) estimates of young-of-year present during autumn monitoring is zero or positive over the 10-year period, and the regression slope of CPUE for the total population is not negative over that same period.
ii. Remnant populations that are augmented will follow the same criteria as above except that the rolling 10-year period begins after the last augmentation event.

[1] Agreements may include agency management plans or documents that have undergone NEPA.

A-2. *Replicate populations* (refuge and repatriation populations)
Each MU (consisting of one or more extant populations according to Table II.1) is replicated into either two streams or one stream and one artificial refuge located within the same RU.
i. Replicate populations are established and maintained in a protected stream, and meet recruitment and population size CPUE trends described above for remnant populations over a 10-year period. Artificial refuges are established and meet recruitment and population size CPUE trends described above over a 10-year period.

Threats-based Criteria:

A-3. All available remnant populations and their replicates are protected against nonnative fish predation and competition, as measured by the achievement of the demographic criteria (A-1.i, A-1.ii, and A-2.i). Each remnant and replicate population has its own unique set of challenges and management requirements that will be necessary to adequately protect the population from nonnative fishes. Therefore, protection for each site will be evaluated on a case-by-case basis using the applicable standards defined below (see the summary of down- and delisting criteria terms section).

A-4. The recruitment and survival rates described in criteria A-1.i., A-1.ii., and A-2.i. will be used to determine when significant threats to remnant and replicate populations (e.g., water availability, habitat alteration, and fragmentation) are controlled to manageable levels such that the threats do not pose imminent or chronic downward pressures on population sizes.

Delisting Criteria

Delisting of Gila chub may be warranted when both downlisting and delisting criteria are met. The major difference between downlisting and delisting criteria is that two stream replicates of each remnant population are required for delisting and artificial refuge populations are no longer necessary. Delisting criteria are as follows:

Demographic Criteria:

B-1. *Remnant populations* (those naturally occurring in the wild)
All available remnant populations within each RU are maintained in a protected stream, and trends of recruitment and population size indices are considered stable or positive over the most recent rolling 10-year period.
i. Trends of recruitment may be adequate if the regression slope of CPUE estimates of young-of-year present during autumn monitoring is zero or positive over the 10-year period, and the regression slope of CPUE for the total population is not negative over that same period.
ii. Remnant populations that are augmented will follow the same criteria as above except that the rolling 10-year period begins after the last augmentation event.

B-2. *Replicate populations* (refuge and repatriation populations)
Each MU (consisting of one or more extant populations according to Table II.1) is replicated in at least two streams.

i. Replicate populations are established, and maintained in at least two protected repatriation streams, and meet the recruitment and population size CPUE trends described above for remnant populations over a 10-year period. Replicate streams are located within the geographic boundaries of their respective RUs with the exception of RU2 (Verde River subbasin), which can also utilize the lower Salt River subbasin (as defined in Section II.1) for replications.
ii. Maintenance of refuge populations is not required once each MU has been replicated twice into repatriation streams. However, refuge populations are recommended to be maintained past delisting to provide additional population redundancy.

Threats-based Criteria:

B-3. Continuation of A-3. and A-4. from downlisting criteria.

Recovery Objectives:

1. Maintain and protect all remnant populations in the wild.
2. Ensure representation, resiliency, and redundancy by expanding the size and number of populations within Gila chub historical range via replication of remnant populations within each RU.
3. Manage or eliminate threats of predation and competition with nonnative fishes and associated habitat-related modifications or loss.
4. Improve and develop new State regulations or agreements that conserve or improve quality Gila chub habitat.
5. Work with stakeholders to improve and conserve existing and newly established Gila chub populations and their habitats and ensure that appropriate management plans or agreements are in place.
6. Promote conservation of Gila chub in Mexico and on Tribal lands by forming partnerships and supporting research, outreach, and conservation management.
7. Monitor remnant, repatriated, and refuge populations to inform adaptive management strategies.

Total Cost of Recovery (minimum): $6,998,500

Costs, in thousands of dollars:

Year	Minimum Costs ($000s)
2016	752.5
2017	747.5
2018	729.5
2019	734.5
2020	744.5
2021+	To be determined

Date of Recovery: 2075

If recovery efforts are fully funded and carried out as outlined in this plan, then each remnant population will be replicated twice in a protected stream. Time estimates for this process are identified in the Implementation Schedule, and we estimate 50 years will be necessary to repatriate Gila chub to new protected streams as required to meet the recovery criteria and delist the species. Over the last few years, application of piscicides for stream renovation and nonnative fish control in Arizona has become more difficult and time consuming than it was in the past, as a result of Arizona legislative and administrative concerns over their use. We therefore anticipate that those recovery actions identified in this plan that involve the removal of nonnative fishes through piscicide application may experience delays in scheduling and could preclude treatments in some areas altogether. The delisting criteria for replicate populations will add an estimated 10 years past the last significant stocking event. Based on these factors, we estimate that delisting for Gila chub could be initiated by 2075.

RESUMEN EJECUTIVO

Estado Actual:

La Carpita de Gila (*Gila intermedia*) fue listada como en peligro de extinción a través de todo su rango con hábitat crítico en el 2005. La especie tiene un número de prioridad para la recuperación de 2C, la cual indica un alto nivel de riesgo, un nivel alto de potencial para la recuperación y una clasificación taxonómica como especie. La especie ocurre en ríos, riachuelos, y tributarios alimentados por manantial por toda la cuenca del Rio Gila en el suroeste de Nuevo México, el centro y sureste de Arizona, y posiblemente ocurre en la punta noreste de Sonora, México. La Carpita de Gila esta listada como en peligro de extinción por la Republica de México, pero no se ha desarrollado para esta especie un plan de recuperación o un Programa de Acción para la Conservación de las Especies (PACE) en México.

Requisitos de Habitat y Factores Limitantes:

La Carpita de Gila comúnmente habita en pozas de riachuelos pequeños y ciénagas a través de todo su rango a elevaciones entre 610 a 1,676 metros (m) (2,000 a 5,000 pies [ft]). Plantas ribereñas típicamente asociados con estos hábitats incluye sauces, pinos salados, álamos, azumiates, y fresnos. La especie es muy reservada y depende de las orillas socavadas, vegetación terrestre, rocas grandes, raíces de árboles caídos, troncos caídos, y vegetación densa y sobresaliente o acuática para cobertura. Representando de 10 a 15 % de su rango histórico conocido, se presume que 22 poblaciones de la Carpita de Gila se mantienen, incluyendo 3 poblaciones que fueron repoblados en 1995 (2 poblaciones) y 2005 (1 población). Dieciocho de estas poblaciones ocurren dentro del hábitat designado como crítico. Estas existentes poblaciones pequeñas y fragmentadas son susceptibles a condiciones ambientales como sequías, inundaciones, e incendios.

Actualmente, el establecimiento de peces no nativos dentro de la cuenca del Rio Gila es una amenaza principal a la persistencia de la Carpita de Gila. La especie históricamente experimentaba poco o no depredación de otros peces nativos. Aunque la conectividad hidrológica entre poblaciones es la condición del manejo preferida, el manejo de aislamiento (p.ej. barreras de peces) es el mejor enfoque para la conservación de las poblaciones de la Carpita de Gila amenazadas por especies de peces no nativas. Amenazas secundarias son la alteración, destrucción y fragmentación del hábitat.

La complejidad evolucionaria y taxonómica del *Gila robusta* recalca la necesidad de prevenir hibridación y colectivamente considera las necesidades de cada especie cuando se diseñe e implementan las acciones de manejo y recuperación. Además, el análisis de la variación molecular de la Carpita de Gila comprueba que las adaptaciones locales jugaron un rol significante en la evolución de la especie. Para preservar la variación genética de esta especie, es importante conservar las poblaciones existentes remanentes y considerar cuidadosamente las ubicaciones adecuadas para replicar cada población a través de toda la cuenca del Río Gila.

Meta de la recuperación:

Asegurar la persistencia de la Carpita de Gila dentro de su rango histórico actualmente ocupado y recuperar la especie por medio de proteger las poblaciones residuos, expandir la distribución existente por replicación de linajes distintas, y proteger y mejorar hábitat para existentes y futuras poblaciones para que la especie ya no llene la definición de en peligro o amenazada.

Estrategia de la recuperación:

La estrategia específica de recuperación de la Carpita de Gila es asegurar que la integridad del hábitat ya existente y la diversidad genética de la especie están adecuadamente protegidas, representadas y replicadas dentro de cada uno de las cinco subcuencas principales en la Cuenca del Rio Gila. Las subcuencas están cubiertas por cinco Unidades de Recuperación (RUs por sus siglas en inglés) dentro de Arizona, New Mexico, y el norte de México; estas áreas delineadas son las que sostienen la especie en el presente o las que apoyaban la especie históricamente. Cada RU funciona como un subgrupo de manejo de la especie para hacer las acciones de manejo necesarias para la sobrevivencia y la recuperación de la Carpita de Gila. La estrategia de recuperación además depende de la identificación, preservación, y duplicación de las Unidades de Manejo genéticas (MUs por sus siglas en inglés) que están distribuidas entre las RUs.

La implementación de la estrategia de la recuperación involucrara la protección de poblaciones residuos por medio de manejo y acuerdos[2] con agencias y socios; reproducción en cautiverio con adecuado manejo genético, demográfico, y de salud para el establecimiento y suplementación de poblaciones; el control de amenazas de depredación y competición de especies de peces no nativas tal como la potencial hibridación con otros especies de carpitas; el establecimiento de poblaciones duplicadas en refugios y riachuelos seleccionados; el monitoreo de poblaciones bajo un protocolo estandarizado basado en ciencia; y la cooperación y educación de agencias, socios, Tribus, y México para asegurar que la cantidad y calidad de hábitat están mantenidos y manejados de forma adaptativa hacia el futuro.

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[2] Los acuerdos pueden incluir planes de manejo de las agencias o documentos que se han analizado por medio del proceso de NEPA.

Criterio para la Recuperacion: (una versión con más explicación de los criterios se encuentra en sección II.4 Criterio para la recuperación en este documento)

Criterio para la reclasificación a amenazado

Para reclasificar la Carpita de Gila de en peligro a amenazada pueda ser indicada cuando se cumplen todos los siguientes criterios para la reclasificación:

Criterios Demográficos:

A-1. *Poblaciones remanentes* (los que ocurren naturalmente en lo silvestre)

Todas las poblaciones remanentes dentro de cada RU están mantenidas en un riachuelo protegido, y las tendencias de reclutamiento y los índices del tamaño de la población se consideran estables o positivos por el periodo de 10 años consecutivos más reciente. La protección de poblaciones remanentes es la prioridad, seguida por el siguiente criterio.

i. Las tendencias de reclutamiento puedan ser adecuadas si la pendiente de la regresión de un estimado de la captura por unidad de esfuerzo (CPUE) de los juveniles menores de un año presentes durante el monitoreo en el otoño es cero o positivo durante el periodo de 10 años y la pendiente de la regresión de CPUE para la población total no es negativa durante el mismo periodo.

ii. Las poblaciones remanentes que están aumentadas seguirán el mismo criterio de arriba excepto que el periodo de 10 años consecutivos empieza después del último evento de aumentación.

A-2. *Poblaciones duplicadas* (poblaciones de refugio y repatriación)

Cada MU (consistiendo de uno o más poblaciones existentes según la Tabla II.1) esta duplicada en ya sea dos riachuelos o un riachuelo y un refugio artificial ubicado dentro del mismo RU.

i. Las poblaciones duplicadas están establecidas y mantenidas en un riachuelo protegido, y reúnen las tendencias de CPUE de reclutamiento y tamaño de población descritos arriba para las poblaciones remanentes por un periodo arriba de 10 años. Los refugios artificiales están establecidos y reúnen las tendencias de CPUE de reclutamiento y tamaño de población descrita arriba por un periodo de 10 años o más.

Los criterios basados en amenazas:

A-3. Todas las poblaciones remanentes disponibles y sus duplicaciones están protegidos contra la depredación y la competencia de las especies de peces no nativas, como medido por el logro de los criterios demográficos (A-1.i, A-1.ii, and A-2.i). Cada población remanente y duplicada tiene su único conjunto de retos y requisitos de manejo que serán necesarios para proteger la población adecuadamente de las especies de peces no nativas. Así que, la protección para cada sitio será evaluada en base de cada caso usando los estándares aplicables definidos abajo (vea la sección con el resumen de términos de reclasificación).

A-4. El reclutamiento y tasa de sobrevivencia descritos en criterios A-1.i., A-1.ii., y A-2.i. se usara para determinar cuándo las amenazas significantes a las poblaciones remanentes y duplicadas (p.ej., disponibilidad del agua, alteración de hábitat, y fragmentación) están controladas a niveles manejables así que las amenazas no representan presiones inminentes o crónicas hacia abajo en los tamaños de las poblaciones.

Criterio para exclusión de la lista

La exclusión de la Carpita de Gila pueda ser indicada cuando se cumplan ambos criterios para la reclasificación y para la exclusión de la lista. La mayor diferencia entre los criterios para reclasificación a amenazada y para la exclusión de la lista es que se requiere dos duplicaciones de riachuelos de cada población remanente para el criterio para la exclusión de la lista, y las poblaciones de refugio artificiales ya no son necesarias. Los criterios para la exclusión de la lista siguen:

Criterios Demográficos:

B-1. *Poblaciones remanentes* (los que ocurren naturalmente en lo silvestre)
Todas las poblaciones remanentes disponibles dentro de cada RU están <u>mantenidas</u> en un riachuelo <u>protegido</u>, y las tendencias de reclutamiento y los índices del tamaño de la población se consideran estables o positivos por el periodo de 10 años consecutivos más reciente.

i. Las tendencias de reclutamiento puedan ser adecuadas si la pendiente de la regresión de un estimado de la CPUE de los juveniles menores de un año presentes durante el monitoreo en el otoño es cero o positivo durante el periodo de 10 años y la pendiente de la regresión de CPUE por la población total no es negativo durante el mismo periodo.
ii. Las poblaciones remanentes que están aumentadas seguirán el mismo criterio de arriba excepto que el periodo de 10 años consecutivos empieza después del último evento de aumentación.

B-2. *Poblaciones duplicadas* (poblaciones de refugio y repatriación)
Cada MU (consistiendo de uno o más poblaciones existentes según la Tabla II.1) esta duplicada en al menos dos riachuelos o un riachuelo y un refugio artificial.

i. Las poblaciones duplicadas están establecidas y mantenidas en por lo menos dos riachuelos de repatriación protegidos y cumplan con las tendencias de CPUE de reclutamiento y tamaño de población descritos arriba para poblaciones remanentes de más de un periodo de 10 años. Los riachuelos duplicados se ubican dentro de las fronteras geográficas de sus respectivas RUs con la excepción de RU2 (subcuenca Rio Verde), lo cual puede también utilizar la subcuenca baja del Rio Salt (como definido en Sección II.1) para duplicaciones.
ii. No se requiere mantenimiento de las poblaciones de refugio cuando cada MU ha sido duplicada dos veces dentro de los riachuelos de repatriación. Sin embargo, se recomienda mantener las poblaciones de refugio después de la exclusión de la lista para proveer la redundancia de las poblaciones adicionales.

Los criterios basados en amenazas:

B-3. La continuación de A-3. y A-4. de los criterios para reclasificación a amenazada.

<u>**Objetivos de Recuperación**</u>**:**

1. Mantener y proteger todas las poblaciones remanentes en lo silvestre.
2. Asegurar representación, resistencia y redundancia por expandir el tamaño y número de poblaciones dentro del rango histórico de la Carpita de Gila por medio de duplicación de poblaciones remanentes dentro de cada RU.
3. Manejar o eliminar las amenazas de depredación y competencia con especies de peces no nativas y la modificación o pérdida de hábitat asociada.
4. Mejorar y desarrollar nuevas regulaciones o acuerdos estatales que conserven o mejoren la calidad de hábitat de la Carpita de Gila.
5. Trabajar con los interesados para mejorar y conservar las poblaciones de la carpita de Gila existentes y nuevamente establecidas y su hábitat y asegurar que los planes de manejo o acuerdos adecuados están en efecto.
6. Promover la conservación de la Carpita de Gila en México y en las tierras tribales por medio de formar alianzas y apoyar la investigación científica, la comunicación y el manejo de la conservación.
7. Monitorear las poblaciones remanentes, repatriadas, y refugios para informar las estrategias de manejo adaptativo.

<u>**Costo Total de Recuperación (mínimo)**</u>**:** $6,998,500

Costos, en miles de dólares:

<u>Año</u>	<u>Costos Mínimos</u> ($000s)
2016	752.5
2017	747.5
2018	729.5
2019	734.5
2020	744.5
2021+	Por ser determinado

<u>**Fecha de recuperación**</u>: 2075

Si los esfuerzos de recuperación son completamente financiados y realizados como descrito en este plan, entonces cada población remanente será duplicada dos veces en un riachuelo protegido. Los estimados del tiempo para este proceso se identifican en el Programa de Implementación, y estimamos que 50 años serán necesarios para repatriar la Carpita de Gila a nuevos riachuelos protegidos como requerido para reunir los criterios de la recuperación y remover la especie de la lista. Durante los últimos años, la aplicación de piscicidas para renovación de riachuelos y control de especies de peces no nativas en Arizona ha llegado a ser más difícil y llevar mucho tiempo que en el pasado como resultado de las preocupaciones legislativos y administrativos de Arizona sobre su uso. Así que, anticipamos que las acciones de recuperación identificadas en este plan que incluyen la eliminación de peces no nativos por medio de aplicación de piscicidas pueden experimentar atrasos en la programación y puede excluir por completo el tratamiento en algunas áreas. Los criterios para la exclusión de la lista para las poblaciones duplicadas añadirán un estimado de 10 años después del último significante evento de aumento. En base de estos factores, estimamos que la exclusión de la Carpita de Gila podía ser iniciada en 2075.

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List of Figures. Figure labels beginning with Roman numerals are found in the corresponding Recovery Plan Part; those beginning with a capital letter are found in the corresponding Appendix.

List of Tables

SECTION I. BACKGROUND

The Endangered Species Act (ESA) of 1973, as amended, requires preparation of recovery plans for listed species likely to benefit from directed management efforts. This draft recovery plan for Gila chub (*Gila intermedia*) establishes recovery goals and objectives, describes site-specific recovery actions recommended to achieve those goals and objectives, estimates the time and cost required for recovery, and identifies partners and parties responsible for implementation of recovery actions. A recovery plan presents a set of recommendations endorsed by the U.S. Fish and Wildlife Service (USFWS). This plan was developed by the Gila Chub Recovery Team (Recovery Team) and USFWS. The Recovery Team consists of a Technical Subcommittee of experts on Gila chub and its habitats, and a Stakeholder Subcommittee comprised of representatives of interested public and private organizations and concerned citizens appointed by USFWS (see "List of Contacts" for membership of each subcommittee).

This recovery plan will follow a modular approach, in which each section (e.g., Background, Recovery, Recovery Actions, Implementation Table, Appendices) serves as its own module, and can be updated independently of the rest of the Recovery Plan. Updated modules will be posted at (*http://ecos.fws.gov/tess_public/*).

Certain terms within this recovery plan may be bolded or underlined. Throughout the Recovery Plan, the first use of technical terms and words are given in bold, and are defined in the glossary on pages 93 through 96. Underlined terms in the Recovery Criteria module are defined under the Summary of Down- and Delisting Criteria Terms subsection at the end of the Recovery Criteria module beginning on page 45.

I.1 Regulatory History

On December 30, 1982, a Notice of Review of vertebrate candidate species was published in the Federal Register that included Gila chub in category 1, a designation comprising taxa for which there was substantial information to support a proposal to list the species as endangered or threatened (USFWS 1982). The species was moved into category 2 (taxa for which information suggested that listing as endangered or threatened was possibly appropriate, but for which conclusive data on biological vulnerability and threat were not available to support a proposed rule) in 1985 in response to an Arizona Game and Fish Department (AZGFD) letter stating there were substantial information gaps concerning the status of Gila chub (USFWS 1985).

In 1996, USFWS discontinued the designation of multiple categories of candidates, and only those taxa that met the definition for former category 1 candidates were considered candidates for listing (USFWS 1996). Gila chub was approved as a candidate on August 17, 1997, and was included in the Candidate Notice of Review (CNOR) published on September 19, 1997 (USFWS 1997).

The Southwest Center for Biological Diversity (CBD) submitted petitions to USFWS to list Gila chub as endangered and to designate critical habitat for the species in June 1998. USFWS responded in July 1998 that, pursuant to its 1996 Petition Management Guidance, candidate species were considered already to be under petition and covered by a ''warranted but precluded'' finding under section 4(b)(3)(B)(iii) of the ESA.

In August 1999, CBD filed a complaint against the Department of the Interior that USFWS had not made petition findings for Gila chub and Chiricahua leopard frog (*Lithobates chiricahuensis*). On June 20, 2001, the U.S. Court of Appeals for the Ninth Circuit (Court) held that the 1999 CNOR (USFWS 1999) did not constitute valid warranted but precluded 12-month petition findings for Gila chub and Chiricahua leopard frog (Center for Biological Diversity v. Norton, 2001 U.S. App. LEXIS 13736). In response to the Court's decision, USFWS revised the October 30, 2001 (USFWS 2001), and June 13, 2002 (USFWS 2002a), CNORs to address the Court's concerns.

On August 29, 2001, USFWS agreed to submit to the Federal Register on or by July 31, 2002, a 12-month finding and accompanying proposed listing rule and proposed critical habitat designation for Gila chub. This agreement was entered by the court on October 2, 2001, (Center for Biological Diversity, et al. v. Norton, Civ. No. 01–2063 (JR) (D.D.C.)). The proposed rule was to constitute USFWS's 12-month finding for the petition to list Gila chub.

On May 18, 2004, CBD filed another complaint against the Department of the Interior because USFWS had not published a final rule for Gila chub in a timely manner. On August 3, 2004, the U.S. District Court of Arizona ordered USFWS, via a stipulated settlement agreement, to publish a final rule by October 21, 2005 (Center for Biological Diversity v. Norton, No. CV 04–2061 TUC CRP). On August 31, 2005 (USFWS 2005a), USFWS reopened the public comment period on the August 9, 2002, proposed rule for 30 days and announced the availability of the draft economic analysis, draft environmental assessment, and hearing dates for the proposed listing and critical habitat designation for Gila chub.

Gila chub was listed as endangered throughout its range with critical habitat on November 11, 2005 (USFWS 2005b). The species has a recovery priority number of 2C. This ranking, determined in accordance with the Recovery Priority Criteria (USFWS 1983a, b), is based on a high degree of threat, high potential for recovery, taxonomic classification as a species, and potential for conflict over resources (primarily water) and economic development. Gila chub is included on AZGFD's draft species of concern (AZGFD 1996), and possession of Gila chub in Arizona is prohibited except where such collection is authorized by special permit. The species was listed by the New Mexico Department of Game and Fish (NMDGF) as endangered in 1988 (NMDGF 1988). Gila chub is listed as endangered by The Republic of Mexico (SEDESOL 1994); a recovery plan, or Program de Acción para la Conservación de las Especies (PACE), has not been developed for this species in Mexico.

I.2 Species Description

Gila chub (*Gila intermedia* Girard) is a member of the roundtail chub (*Gila robusta*) complex (see *Taxonomic History* below) in the Gila River basin that also includes headwater chub (*G. nigra*). Gila chub is a thick-bodied species, chunky in aspect (see drawing on coverpage), whereas roundtail chub is slender and elongate, and headwater chub is intermediate in meristic and morphometric characteristics (Rinne 1969, 1976, Minckley 1973, DeMarais 1986, Minckley and DeMarais 2000, Minckley and Marsh 2009). Females can reach 250 millimeters (mm) (10 inches [in]) in **total length**[3] (TL), but males rarely exceed 150 mm (6 in; Minckley 1969, 1973, Minckley and Rinne 1991, Schultz and Bonar 2006). Scales are large, thick, overlap broadly, and usually bear strong **basal radii**. There are typically 62 to 74 scales in the **lateral line** (usually fewer than 70, extremes 51 and 83). Head length divided by **caudal peduncle** depth is 3.0 mm (0.1 in) or less. The number of post-**Weberian** vertebrae is usually 38 or fewer (extremes 35 and 41). **Gill rakers** number 9 or fewer (extremes 6 and 13) and the number of dorsal and anal fin rays is typically 8 (both rarely 7 or 9). Fins are small in size, darkly-pigmented, and the margins are rarely convex, mostly rounded, and sometimes square. Body coloration is typically dark overall, sometimes black or with diffuse, longitudinal stripes, with a lighter belly speckled with gray. The lateral scales often appear to be darkly outlined, lighter in center. The now extinct Monkey Spring Gila chub **population** was markedly different from other populations, with larger scales, males much smaller than females, and other body feature differences (Minckley 1973).

Breeding males, and to a lesser extent females, develop red or orange on lower parts of the head and body and on bases of the pectoral, pelvic, and anal fins. Small **tubercles** also may develop on breeding males dorsally from the head to near the origin of the dorsal fin and laterally over the **opercular** region, as well as on paired fins, the dorsal and anal fins, and in extreme cases, distributed as far posteriorly as the caudal peduncle and caudal fin. Tuberculation on females is generally restricted to the head, dorsal region anterior to the origin of the dorsal fin, and to the pectoral fins (Bestgen 1985). The degree of tuberculation may be extremely variable between populations and sexes.

I.3 Taxonomic History

The roundtail chub complex has had a turbulent and controversial taxonomic history that includes an assortment of classification schemes. Much of the debate has centered on whether the complex represents a number of nominal species or subspecies of *G. robusta*. Gila chub has long been recognized as distinct. Miller (1945), following the arrangement of Jordan and Evermann (1896), supported full generic rank for the genus *Gila* (Baird and Girard 1853) with a "*Gila robusta* complex" that included Gila chub. Miller (1946) considered Gila chub to be a subspecies of *G. robusta* (i.e., *G. r. intermedia*). Rinne (1969, 1976), using univariate analyses of morphological and **meristic** characters, argued for recognition of both *G. robusta* and *G. intermedia* as distinct species. This approach was supported by some (e.g. Minckley 1973, Minckley et al. 1986), but it was not until further evidence was generated by DeMarais (1986, 1995) that the specific status for *G. intermedia* was generally accepted. DeMarais (1995) supported continued recognition of *G. intermedia* based on the following arguments: (1) phenotypic extremes between *G. intermedia* and *G. robusta* are widely divergent and each possesses many morphologically uniform populations; (2) the geographic distributions of both species are an overlapping mosaic, therefore subspecies status for *G. intermedia* is inappropriate under traditional geographic criteria; and (3) contiguous populations of *G. intermedia* and *G.*

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[3] The first use of technical terms and words with arcane meanings in the lexicons of science and government are given in bold, and are defined in the glossary on pages 93-96.

robusta show no evidence of genetic exchange, thus each species maintains its evolutionary independence.

Gila chub was described as *Tigoma intermedia* on the basis of specimens collected from the "Rio San Pedro, Arizona" (Girard 1856). A **nomenclatorial synonymy** for Gila chub can be found in Minckley (1973).

I.4 Genetics

It has been further speculated that taxonomic problems associated with the roundtail chub complex arise from a complicated evolutionary history (as described above), confounded by hypothesized impacts of ancient hybridization and subsequent morphological divergence in different habitats (DeMarais 1992, 1995, Dowling and DeMarais 1993, Minckley and DeMarais 2000). The use of molecular characters of *G. robusta*, *G. intermedia*, and other members of the roundtail chub complex neither support nor refute the hybrid origin hypothesis, as high levels of variation at assayed molecular markers within nominal species precluded identification of diagnostic characters for these species (DeMarais 1995, Schwemm 2006, Dowling et al. 2008). Given the evolutionary and taxonomic complexity of the *Gila robusta* complex and therefore the strong potential for mismanagement, it is important that *G. intermedia*, *G. nigra*, and *G. robusta* be considered collectively when designing and implementing conservation and recovery actions.

Analyses of molecular variation in *G. intermedia* allowed for diagnosis of local regional populations. Schwemm (2006) used sequence variation in mitochondrial and nuclear genes to characterize patterns of variation in *Gila*, and microsatellites provided even finer scale differentiation (Dowling et al. 2008, Dowling 2013). These results are consistent with a significant role for local evolutionary processes (e.g., drift in small headwater populations, local adaptation) in the evolution of this species. The hierarchical nature of variation was consistent with isolation by distance, with proximal samples exhibiting more similarity based upon hierarchical analysis of assignment probabilities (Dowling et al. 2008). This result is consistent with intermittent contact among geographically-proximate populations, leading to the designation of subbasins as recovery units (RUs) and distinct local populations as management units (MUs) (see *Recovery Strategy* section below).

I.5 Habitat Characteristics

Gila chub is considered a habitat generalist (Schultz and Bonar 2006), and commonly inhabits pools in smaller (higher-order) streams and **cienegas** throughout its range in the Gila River basin at elevations between 609 and 1,676 meters (m) (2,000 to 5,500 feet [ft]) (Miller 1946, Minckley 1973, Rinne 1976, Weedman et al. 1996). Common riparian plants associated with these habitats include willows (*Salix* spp.), tamarisk (*Tamarix* spp.), cottonwoods (*Populus* spp.), seep-willow (*Baccharis glutinosa*), American sycamore (*Platanus wrightii*), and ash (*Fraxinus* spp.). Typical aquatic vegetation includes watercress (*Nasturtium officinale*), horsetail (*Equisetum* spp.), rushes (*Juncus* spp.), and speedwell (*Veronica anagallis-aquatica*) (USFWS 1983a, Weedman et al. 1996).

Gila chub is a highly secretive species, remaining near cover comprised of undercut banks, terrestrial vegetation, boulders, root wads, fallen logs, and thick overhanging or aquatic vegetation in deeper waters, especially pools (Minckley and Rinne 1991, Nelson 1993, Weedman et al. 1996). Recurrent flooding and a natural hydrograph are important in maintaining **native** fish habitats and in helping native fishes maintain a competitive edge over invading **nonnative** aquatic species (Propst et al. 1986, 2008, Minckley and Meffe 1987). Gila chub can survive in larger stream habitats, such as the San Carlos River (Minckley 1985, Minckley and Rinne 1991), and at least in the short term in artificial habitats like the Buckeye Canal (Stout et al. 1970, Rinne 1976). Gila chub also regularly interact with spring and small-stream fishes (Meffe 1985).

In largely canyon-bound streams such as Bonita Creek, Sabino Creek, and Redfield Canyon, Arizona, adult Gila chub use habitats roughly in proportion to their availability, and occupy runs, pools, and riffles (Griffith and Tiersch 1989, Dudley and Matter 2000, Schultz and Bonar 2006). Juveniles appear to avoid riffles and select for habitats with an abundance of cover (Dudley and Matter 2000, Schultz and Bonar 2006). In the more wetland-like Cienega Creek, Arizona, Gila chub mostly use pool habitats and are not typically found in marsh and run habitats (Schultz and Bonar 2006).

I.6 Life History and Population Ecology

Spawning time and temperatures

While most reproductive activity by Gila chub occurs during late spring and summer, in some habitats it may extend from late winter through early autumn (Minckley 1973). Data from Bonita and Cienega creeks suggested that multiple spawning attempts per year per individual were likely, with a major spawn in late February to early March followed by a secondary spawn in autumn after monsoon rains (Schultz and Bonar 2006). Reproductive activities in Monkey Spring (population now **extirpated**) reportedly occurred for longer periods than in other populations, as breeding appeared to last virtually all year (Minckley 1969, 1973, 1985). Gila chub displayed a single cycle of spawning and gonad development in Turkey Creek, New Mexico, where eggs reached maximum development before spawning in mid-April and were smallest and least developed in September (Bestgen 1985).

Bestgen (1985) concluded that temperature was the most significant environmental factor triggering spawning. In the lab, Gila chub initiated spawning at 14.9 degrees Celsius (°C) (58.8 degrees Fahrenheit [°F]), spawned at temperatures ranging from 15 to 26°C (59.0 to 78.8°F), but appeared reluctant to spawn at temperatures above 24°C (Schultz and Bonar 2006). Gila chub in Turkey Creek, New Mexico, expressed gametes upon handling at water temperatures of 22°C (75.2°F; Bestgen 1985). In 2012, Turkey Creek Gila chub were mature and expressed gametes when water temperatures were between 8 to 25°C (46.4 to 77.0°F); water temperature in Turkey Creek varied substantially depending on the proximity of sample sites to the influx of hydrothermal vents (NMDGF 2013).

Spawning behavior

Minckley (1973) reported that presumed breeding activities included large females closely followed by several males over beds of aquatic vegetation in a pond. Nelson (1993) also suspected deep pools with vegetation were important sites for spawning, but did not witness any breeding behavior near submerged vegetation. He did observe fish chasing each other in a formation; a lead fish was followed by two fish on either side. The two pursuing fish butted their nape area against the lower abdominal region of the lead fish, suggesting that the two male fish were physically testing the female for receptivity or ripeness. Similar breeding behavior was observed in the laboratory; before spawning, several presumed males chased what appeared to be a lone female (Schultz and Bonar 2006).

Maturation

In Redfield Canyon, Arizona, some Gila chub reached sexual maturity by the end of their first year, but most did not mature until their second or third year. Smallest total length of ripe males and females in Redfield Canyon was 90 to 95 mm (3.5 to 3.7 in; Griffith and Tiersch 1989), and perhaps as small as 69 to 75 mm (2.7 to 2.9 in) in other streams (Nelson 1993, Schultz and Bonar 2006). In Turkey Creek, New Mexico, threadlike testes were observed in fish 50 to 60 mm (1.9 to 2.4 in) TL (Bestgen 1985). Seventy percent of males in Turkey Creek were reproductively mature in their second year (mean TL=104 mm [4.0 in]) and all fish in their third year were mature (Bestgen 1985).

Eggs and Fecundity

For Gila chub, production of viable **oocytes** (functional fecundity) may differ from true reproductive potential. Schultz and Bonar (2006) noted a marked disparity between estimates of fecundity from the enumeration of actual spawns in the laboratory and extrapolation of total ova from ovaries of sacrificed Gila chub. Bestgen (1985) found that as eggs developed throughout the year it was obvious that not all eggs developed at the same rate. Throughout all seasons except July, large numbers of very small, nucleated bodies were present in the ovary and did not appear to develop much throughout the year. These oocytes outnumbered the combined total of the two larger classes of eggs in mature ovaries. Mature eggs apparently segregated themselves even though the largest eggs were found randomly distributed throughout the ovary, and it appeared that only mature eggs were extruded during spawning. The oocytes were not carried over and developed during the next spawning season (Bestgen 1985), and therefore presumably were resorbed.

Mean fecundity of Turkey Creek, New Mexico, Gila chub (number of eggs greater than 0.3 mm [0.01 in]) ranged from 600 to 3,546 eggs for age-2+ to age-4+ chub that were 110 to 215 mm (4.3 to 8.5 in) TL (Bestgen 1985). Average reproducing females were 3.2 years old (mean TL=152 mm [6.0 in]) and produced a mean of 5,449 eggs. Schultz and Bonar (2006) estimated the fecundity of Gila chub spawned in the laboratory (110 to 170 mm [4.3 to 6.7 in] TL) as 300 to 2,000 eggs per individual; estimated mean fecundity of sacrificed fish (mean TL=164 mm [6.5 in]) was 10,392 (n=4).

Eggs are **demersal**, adhesive, **ovoid**, and translucent, with the inner 80 to 90 percent of the egg a light yellow cream color and the remaining colorless (Schultz and Bonar 2007). Eggs stripped from ripe females were orange colored. Bestgen (1985) showed mature/maturing eggs (0.59 to 1.51 mm [0.02 to 0.06 in] in diameter) were more yellow than recruiting eggs (0.31 to 1.02 mm [0.01 to 0.04 in]) which were white to pale yellow. In the lab, spawned eggs less than a day old measured 2 mm [0.07 in] or less in diameter (mean=1.93 mm [0.07 in]; n=5)(Schultz and Bonar 2007). Primary oocytes, the smallest class (0.10 to 0.21 mm [0.003 to 0.008 in]), remained small, clear, nucleated bodies (Bestgen 1985).

Growth and Longevity

In the lab, a strong inverse linear relationship exists between mean incubation temperature of Gila chub eggs and time to hatch (Schultz and Bonar 2007). Eggs hatched in about 6 days at 22°C (71.6°F). Upon emergence, the slight yolk quickly reduced, and mean length and weight of larvae within 6 hours of hatch was 6.55 mm (0.25 in) TL and 1.69 milligrams (mg) (0.0006 ounces [oz]). Growth of larval chub increased as temperature increased up to 28°C (82.4°F) but decreased markedly at 32°C (89.6°F), indicating that thermal stress occurs in the upper temperature range.

Griffith and Tiersch (1989) and Bestgen (1985) examined scales to determine age and size class structure in Gila chub from Redfield Canyon, Arizona, and Turkey Creek, New Mexico (Table I.1). Back-calculated mean TL at the end of the growing season of Redfield Canyon fish were for ages 1 to 4. This population was composed mainly of age-1 and age-2 individuals; age-3 and age-4 fish were about 10 percent of the population. Scale analysis of Gila chub in Turkey Creek indicated five, post-age-0 age classes were present. Percentage representation in collections was 17, 52, 19, 5, 5, and <1, for age classes 0 to 5, respectively.

Table I.1. Age of Gila chub based on calculated size at the end of the growing season from two populations in Arizona and New Mexico.

Population Examined	**Age and Size Class Structure**				
	Year 1	Year 2	Year 3	Year 4	Year 5
Redfield Canyon, AZ	90 mm (3.5 in)	135 mm (5.3 in)	160 mm (6.3 in)	183 mm (7.2 in)	
Turkey Creek, NM	65 mm (2.5 in)	98 mm (3.8 in)	133 mm (5.2 in)	162 mm (6.3 in)	186 mm (7.3 in)

Food Habits

Young Gila chub are active throughout the day and feed on small invertebrates as well as aquatic vegetation (especially filamentous algae) and organic debris (Bestgen 1985, Griffith and Tiersch 1989, Minckley and Rinne 1991). Adult Gila chub are **crepuscular** feeders, consuming a variety of terrestrial and aquatic invertebrates, and fishes (Bestgen 1985, Griffith and Tiersch 1989, Minckley and Rinne 1991). Diatoms (algae) were most common by volume. Benthic feeding may also occur, as suggested by presence of small gravel particles in digestive tracts.

Diseases and Pathogens

Asian tapeworm (*Bothriocephalus acheilognathi*) was introduced into the United States via imported grass carp in the early 1970s. Asian tapeworm is present in the Colorado River basin in the Virgin (Heckman et al. 1986) and Little Colorado rivers (Clarkson et al. 1997), and more recently has invaded most subbasins of the Gila River basin (Archdeacon et al. 2010) where Gila chub occur. This parasite can infest many species of fish, which then carry it into new areas from contaminated areas. The definitive host in the life cycle of Asian tapeworm is cyprinid fishes and it therefore is a potential threat to Gila chub. Asian tapeworm can impede the digestion of food as it passes through the intestinal tract. When large enough numbers of worms are present in a fish, emaciation and starvation can occur. Fish weakened by Asian tapeworm are more susceptible to infection by other pathogens.

The protozoan parasite *Ichthyophthirius multifiliis* (Ich) has been detected in several Arizona streams (Mpoame 1981, Robinson et al. 1998), with these streams probably favored due to high temperatures and crowding because of drought. This protozoan embeds under the skin and within gill tissues of infected fish and causes fluid loss, physiological stress, susceptibility to infection by other pathogens, and occasionally mortality. If Ich individuals are present in large enough numbers, they can also impact respiration by causing damage to gill tissue. This parasite does not appear to be host specific and can be transmitted by other species.

Anchor worm (*Lernaea cyprinacea*), an external copepod parasite, is unusual in that it has little host specificity and can infect a wide range of fishes and amphibians. Infection has been known to kill large numbers of fish due to tissue damage and secondary infection of the attachment site (Hoffnagle and Cole 1999). In degraded habitats, fish may be more susceptible to this parasite due to physiological stress. The parasite is nearly ubiquitous in the Gila River basin, and is specifically known to infest Gila chub in Bonita Creek and Harden Cienega, Arizona.

Thermal Tolerance

Gila chub thermal tolerance studied by Carveth et al. (2006) showed a final loss of equilibrium at 38.5°C (101.3°F) under laboratory conditions. As critical thermal maximum tests typically overshoot the tolerance of fish in the wild by 3 to 4°C (37.4 to 39.2°F; Beitinger and Bennet 2000, Selong et al. 2001), the actual upper thermal limit of this species is estimated at 34.5 to 35.5°C (94.1 to 95.9°F). Gila chub also has a relatively low acclimation response ratio compared to other native and nonnative fishes studied, indicating a limited ability to alter thermal tolerance with changing acclimation temperature (Carveth et al. 2006).

Fish Community Interactions

Gila River basin native fishes, including Gila chub, evolved in a fish community with low species diversity and few predators, and as a result developed few or no mechanisms to deal with predation (Marsh and Pacey 2005, Olden et al. 2006). Prior to the widespread introduction of nonnative fishes, Gila chub was probably the most predatory fish within the habitats it occupied. In the presence of nonnative green sunfish in lower Sabino Creek, Arizona, Gila chub failed to recruit young (Dudley and Matter 2000). Direct predation by green sunfish on young Gila chub was the acknowledged cause of this observation. The green sunfish is a particularly problematic fish for native species in the Gila River basin due to its natural and human-assisted colonizing abilities, its tolerance of a wide variety of environments including headwater streams occupied by native fishes, and its piscivorous habits (it is the most piscivorous member of its genus; Carlander 1977, Werner 1977, Lemly 1985, Fausch and Bramblett 1991, Lohr and Fausch 1996, Dudley and Matter 2000). See the *Reasons for Listing/Threats* section (below) for additional information concerning interactions between native and nonnative fishes.

Historically, Gila chub rarely occurred in streams where it was the sole species of native fish present (e.g., San Simon River); it more typically occurred with from 1 (e.g., Sheehy Spring) to up to 11 other native species (e.g., San Pedro River). Today, the species co-exists with a variable array of natives that include Gila topminnow (*Poeciliopsis occidentalis*), longfin dace (*Agosia chrysogaster*), speckled dace (*Rhinichthys osculus*), desert sucker (*Pantosteus clarki*), and Sonora sucker (*Catostomus insignis*).

Stream Connectivity

The longitudinal distributions of flows in streams of the Gila River basin are subject to seasonal expansion and contraction according to patterns of precipitation and runoff. During summer low-flow periods, surface waters may dwindle to a series of disconnected pools with accompanying reductions in fish population sizes (Minckley 1973, Carpenter and Maughan 1993, Dudley and Matter 2000). Floods reconnect fragmented habitats and expand habitat availability and connectivity. Under certain conditions, flooding can displace some nonnative fishes downstream, but typically, upstream reinvasion occurs relatively quickly where physical barriers do not prevent it (Minckley 1973, Minckley and Meffe 1987, Dudley and Matter 2000).

Hydrologic connectivity among habitats within a stream and among stream systems is a typical requirement for sustaining aquatic biodiversity (Pringle 2001, Hermoso et al. 2011). Connectivity ensures that populations can exchange genetic material necessary for evolutionary processes, and allows for population colonization/expansion/contraction according to environmental conditions. However, as discussed by Fausch et al. (2009) for salmonids and by Clarkson et al. (2012) for Gila River basin native fishes, hydrologic connectivity can have negative impacts if nonnative fishes are a threat (see *Reasons for Listing/Threats* section below for further discussion) and if native populations are **remnants** found mostly in small tributaries. Gila chub populations are highly threatened by nonnative fishes and all **extant** populations are tributary remnants. In this situation, isolation management (Novinger and Rahel 2003) is the optimal alternative, where natives are intentionally isolated from nonnatives with fish barriers.

I.7 Critical Habitat

Critical habitat for Gila chub is designated for approximately 257.9 kilometers (km) (160.3 miles [mi]) of stream reaches in Arizona and New Mexico. Critical habitat includes the area of bankfull width plus 91 m (300 ft) on either side of the banks. The bankfull width is the width of the stream or river at bankfull discharge (i.e., the flow at which water begins to leave the channel and move into the floodplain) (Rosgen 1996, USFWS 2005b). Critical habitat is organized into seven areas or river units (USFWS 2005b):

- Area 1 - Upper Gila River, Grant County, New Mexico, and Greenlee County, Arizona, includes Turkey Creek (New Mexico), Eagle Creek, Harden Cienega Creek, and Dix Creek;
- Area 2 - Middle Gila River, Gila and Pinal Counties Arizona, includes Mineral Creek;
- Area 3 - Babocomari River, Santa Cruz County, Arizona includes O’Donnell Canyon and Turkey Creek;
- Area 4 - Lower San Pedro River, Cochise and Graham counties, Arizona, includes Bass Canyon, Hot Springs Canyon, and Redfield Canyon;
- Area 5 - Lower Santa Cruz River, Pima County, Arizona, includes Cienega Creek, Mattie Canyon, Empire Gulch, and Sabino Canyon;
- Area 6 - Upper Verde River, Yavapai County, Arizona, includes Walker Creek, Red Tank Draw, Spring Creek, and Williamson Valley Wash; and
- Area 7 - Agua Fria River, Yavapai County, Arizona, includes Little Sycamore Creek, Sycamore Creek, Indian Creek, Silver Creek, Lousy Canyon, and Larry Creek.

There are seven primary constituent elements of critical habitat, which include those habitat features required for the physiological, behavioral, and ecological needs of the species (USFWS 2005b):

(1) Perennial pools, areas of higher velocity between pools, and areas of shallow water among plants or eddies;
(2) Water temperatures for spawning ranging from 17.2°C to 23.9 °C (63°F to 75 °F), and seasonally appropriate temperatures for all life stages (varying from about 10°C to 30 °C [50°F to 86 °F]);
(3) Water quality with reduced levels of contaminants, including excessive levels of sediments adverse to Gila chub health, and adequate levels of pH (e.g. ranging from 6.5 to 9.5), dissolved oxygen (i.e., ranging from 3.0 to 10.0 parts per million) and conductivity (i.e., 100 millimhos [mmhos] or milli Siemens per unit volume – units used to measure conductivity in water] to 1,000 mmhos);
(4) Prey base consisting of invertebrates (i.e., aquatic and terrestrial insects) and aquatic plants (i.e., diatoms and filamentous green algae);
(5) Sufficient cover consisting of downed logs in the water channel, submerged aquatic vegetation, submerged large tree root wads, undercut banks with sufficient overhanging vegetation, large rocks and boulders with overhangs, a high degree of stream bank stability, and a healthy, intact riparian vegetation community;
(6) Habitat devoid of nonnative aquatic species detrimental to Gila chub or habitat in which detrimental nonnative species are kept at a level that allows Gila chub to continue to survive and reproduce; and
(7) Streams that maintain a natural flow pattern including periodic flooding.

I.8 Population Trends and Distribution

Historically, Gila chub was recorded from nearly 50 higher-order streams throughout the Gila River basin in southwestern New Mexico, central and southeastern Arizona, and northern Sonora, Mexico (Miller and Lowe 1967, Rinne and Minckley 1970, Minckley 1973, Rinne 1976, DeMarais 1986, Sublette et al. 1990, Weedman et al. 1996). Recent literature indicates approximately 25 of these localities are considered occupied, and most are small, isolated, and face one or more threats (Weedman et al. 1996, USFWS 2005b, Clarkson et al. 2012). Gila chub historically occurred at more sites and across a more expansive distribution than at present (DeMarais 1995); the species now occupies an estimated 10 to 15 percent of its historical range (Weedman et al. 1996, USFWS 2005b).

Gila chub is a member of the roundtail chub complex, including roundtail and headwater chubs that are widely distributed in the Gila River basin. These latter two species are also under consideration for protection under ESA, making it critical that we consider the remaining two species when designing the recovery plan for Gila chub. Since members of the genus *Gila* have strong potential to hybridize with each other (Gerber et al. 2001), they cannot be stocked into the same **refuges** or streams. There is limited space for establishing **protected populations** of the three chub species within the Gila basin, further complicating the design of the recovery program for Gila chub. These factors were all considered in the development of this recovery plan, specifically in assigning priorities to management units and identifying population replication streams.

Weedman et al. (1996) categorized the status of Gila chub populations into four categories:

(1) Stable-secure – Gila chub is common, data over the last 5 to 10 years show a stable reproducing population, no nonnative fish predatory or competitive species are present, and no current or future land use threats were identified;
(2) Stable-threatened – Gila chub is common to uncommon, potential threats by nonnative fishes exist, some habitat-altering land and water uses were identified, or lack of recruitment (i.e., reproduction and survival of young) was detected within the population;
(3) Unstable-threatened – Gila chub is rare, has a limited distribution, predatory or competitive nonnative fishes are present, or the habitat is modified or threatened;
(4) Extirpated – Gila chub is no longer found within a particular stream system.

At the time of the 1996 status review of 37 historically-known populations, only the upper Cienega Creek population was considered stable-secure, 8 other populations were deemed stable-threatened, 6 were considered unstable, and the rest (22) were designated extirpated or unknown (Weedman et al. 1996). In the 2005 listing package (USFWS 2005b), the number of populations considered extant was decreased to 32, the Cienega Creek population was downgraded to stable-threatened, 11 other populations shared a stable-threatened designation, the number of unstable populations increased to 19, and one population had no information. Sixteen populations were considered extirpated or believed extirpated (USFWS 2005b).

Definitive determinations of extirpation have been problematic with fishes in general and with Gila River basin fishes in particular. For example, loach minnow (*Tiaroga cobitis*) was first collected from Eagle Creek, Arizona, in 1950, but despite extensive sampling of the stream in the 1970s and 1980s (Marsh et al. 1990), the species was not again detected until 1994 (Marsh et al. 2003). Loach minnow was repeatedly found there through 1997, but has not been captured since, despite considerable annual sampling efforts. Occupancy of Eagle Creek by spikedace (*Meda fulgida*) was not detected until 1985, where it was common and widespread for several years, but has not been captured again since 1997.

<u>Population status definitions</u>

Extirpated (EX) - Certain management decisions are contingent upon a determination of whether or not a population is extirpated (e.g., when to translocate a different **stock** into a stream if a **remnant population** has not been detected over a long time interval). For the purpose of this recovery plan we define *extirpated* as a population that has not been detected in the past 50 years (Table I.2). This definition was adapted from the definition of *extinct* adopted by the American Fisheries Society (AFS; Jelks et al. 2008), which refers to a taxon (e.g., species) of which no living individual has been documented in its natural habitat for 50 or more years. However, because the sampling effort involved in detecting the presence of a rare species within a wide and complex distribution can be much greater than for a single population with a restricted and simple distribution, we have defined several instances where the 50-year detection criterion may be relaxed (for recovery purposes) when declaring a population extirpated:

(1) the population has not been detected in the past 50 years;

(2) the population has not been detected in presence/absence surveys conducted expansively (across the entire distribution of the population), intensively (sampling all suitable habitats), and effectively (suitable habitats were sampled with appropriate gears) over a minimum period of 10 consecutive years or 10 surveys in total if not sampled in consecutive years;
(3) a known catastrophic event such as a chemical spill, wildfire, or desiccation occurred that eliminated the population. In this case, a single expansive survey of the population range post-event would be sufficient to conclude extirpation; or
(4) the population was intentionally removed from the wild and placed into managed refuges in an attempt to salvage its genetic legacy in the face of severe population decline and apparent imminent extirpation.

Not detected recently (NDR) - This definition is modeled after the AFS definition of *possibly extinct,* which is defined as a taxon suspected to be extinct as indicated by more than 20 but fewer than 50 years since individuals were observed in nature. *NDR* does not imply it is extirpated, but the population is rare and may require management action to address limiting factors. Therefore, we prefer to be cautiously optimistic about the status of a rare population rather than prematurely declare its extirpation (Table I.2). There are two levels of classification:
(1) if a population has not been detected within the past 20-49 years, and if extirpation criteria do not fit into the exceptions described above; or
(2) if a known or suspected catastrophic event severely affected the population, and expansive survey criteria have not been met.

Assumed present (AP) - We categorized a population as *assumed present* (Table I.2) if it was last detected 10 or more years ago but there is no recent information available to suggest that the population has been extirpated.

Small (S), Medium (M), or Large (L) Extant population - If a population has been detected recently, we categorized the population status as either small (fewer than 500 adults), medium (500-5000 adults), or large (greater than 5000 adults; Table I.2). These qualitative population size estimates are based on spatially-limited surveys that extrapolate relative abundance estimates with qualitative estimates of suitable habitat availability along the length of stream potentially occupied, in combination with expert opinion. The estimates are provided solely for the purpose of identifying which populations may be most prone to genetic and demographic consequences associated with small population size, and thus how they may need to be prioritized for population replications or implementation of threat abatement measures. We also caution that population sizes naturally may fluctuate widely over short periods of time depending on biotic or abiotic disturbance events (e.g., Platts and Nelson 1988, Eby et al. 2003).

Table I.2. Definitions of status designations of Gila chub used in Table I.3. See text for further explanation.

Designation	Sub-category	Description
Extirpated (EX)	1	Population not detected in past 50 years
	2	Population not detected in 10 or more expansive, intensive, and effective surveys
	3	A known catastrophic event eliminated the population, confirmed by at least one expansive survey
	4	Population was intentionally removed from the wild and placed into managed refuges
Not Detected Recently (NDR)	1	Population not detected in the past 20-49 years, and extirpation criteria above have not been met
	2	A known or suspected catastrophic event severely affected the population, expansive survey criteria have not been met
Assumed Present (AP)	-	Last occupation was confirmed 10 or more years ago, but there are no recent data to suggest the population has been extirpated
Small (S)	-	Population extant, size estimated at fewer than 500 adults
Medium (M)	-	Population extant, size estimated between 500-5000 adults
Large (L)	-	Population extant, size estimated at greater than 5000 adults

The status of Gila chub populations as of 2014 is presented in Table I.3. We abandoned the Weedman et al. (1996) definitions because we believe that potential or known threats to populations should not enter into status definitions. Also, in most cases we do not have adequate population trend data to determine if a population is stable, increasing, or decreasing in abundance.

Not all streams with recent records of Gila chub occupancy are considered **self-sustaining populations** independent of an adjacent, larger source population. Some of these records appear to reflect sporadic or transitory occupancy suggestive of interactions with a local source population. Without the presence of the larger source population, it is unlikely the species would be found there. This type of occupancy pattern fits a **metapopulation** model of population dynamics, defined as a set of local populations that interact via individuals moving among populations (Hanski and Gilpin 1991). Although these smaller metapopulation habitats may not be independently sustainable, they do not necessarily diminish their importance toward fulfilling certain life history functions of the species.

Specifically, sporadic capture records of Gila chub from small, poorly-watered tributaries to Hot Springs/Bass canyons (Double R and Wildcat canyons) are suggestive of transitory populations associated with the core metapopulation in Hot Springs/Bass canyons (Appendix D, Figure D.4). The same situation holds for Gila chub captured in Mattie Canyon, Empire Gulch, and lowermost Cienega Creek, which we believe are sustained by the main population found in upper Cienega Creek (Appendix D, Figure D.3). We also consider historical capture records of Gila chub from Post Canyon and Turkey Creek (Arizona) metapopulations dependent upon the major source population in O'Donnell Canyon for their persistence. The capture record for Gila chub from the San Francisco River was at the immediate confluence with Harden Cienega Creek, and no other records from the San Francisco River exist (Appendix D, Figure D.5). We therefore assume the San Francisco River locality is representative of occasional migration from Harden Cienega Creek, and is thus considered a minor component of the Harden Cienega metapopulation. In subsequent tables therefore, Double R Canyon, Post Canyon, Wildcat Canyon, lower Cienega Creek, Mattie Canyon, and San Francisco River are not listed as independent populations.

Table I.3. Population status of Gila chub at known historically occupied localities, showing the last year of confirmed occupancy and source of occupancy information (literature citations or museum collection numbers). Localities in parentheses are considered subpopulations whose statuses are not considered separately from their major source metapopulation. Streams are located in Arizona unless marked otherwise. Asterisks (*) denote localities located within designated critical habitat. See Table I.2 and the text for descriptions of status designations. Museum acronyms are ANSP=Academy of Natural Sciences Philadelphia, ASU=Arizona State University Collection of Fishes, SMNH=Southwest Museum of Natural History, UMMZ=University of Michigan Museum of Zoology.

Locality	**Status**	**Last Confirmed Occupation**	**Sources**
Agua Fria River basin			
(Agua Fria River)	NDR-1	1966	Rinne (1969)[1]
Indian Creek*	S	2013	Timmons and Upton (2013)
Larry Creek (repatriation 1995)*	M	2013	Carter (2014)
Lousy Canyon (repatriation 1995)*	M	2013	Carter (2014)
Silver Creek*	S	2013	Carter (2014)
Sycamore/Little Sycamore creeks*	M	2012	Timmons and Upton (2013)
Salt River basin			
Cave Creek/Seven Springs Wash	NDR-1	1978	ASU 7764
Fish Creek	NDR-1	1965	ASU 2246
Haunted Canyon	EX-1	1959	UMMZ 176179
San Pedro River basin			
Babocomari River	NDR-1	1968	ASU 4845
Birmingham Pond	EX-1	1943	UMMZ 146648
Cienega Los Fresnos (Mexico)	NDR-1	1990	Varela-Romero et al. (1992)
Hot Springs/Bass canyons* (Double R Canyon) (Wildcat Canyon)	L	2013 2012 2010 2012	Robinson (2014)
O'Donnell Creek* (Post Canyon) (Turkey Creek)	S	2012 1989 1991	Crowder and Robinson (2012) ASU 12401 Crowder and Robinson (2012)
Redfield Canyon*	L	2013	Robinson (2014)
Rio San Pedro (Mexico)	EX-1	1950	UMMZ 162676
San Pedro River	EX-1	1912	SMNH 73717
T4 Spring	EX-4	2009	Robinson (2009)
Santa Cruz River basin			
Cienega Creek (upper)* (Cienega Creek-lower*) (Mattie Canyon*)	L	2013 2012 2011 2008	Robinson (2014) Ehret and Dickens (2009) Ehret and Dickens (2009)
Monkey Spring	EX-2	1967	ASU 4849
Romero Canyon (repatriated 2005)	S	2012	Timmons and Upton (2013)
Sabino Canyon*	M	2012	Timmons and Upton (2013)
Santa Cruz River	NDR-1	1977	ASU 7143

Locality	Status	Last Confirmed Occupation	Sources
Sheehy Spring	S	2013	Robinson (2014)
Upper Gila River basin			
Apache Creek, NM	EX-1	1872	ANSP 20448
Arnett Creek	EX-1	1945	SMNH 132268
Blue River (San Carlos) [2]	L	2013	Clarkson pers. comm. (2013)
Bonita Creek	L	2012	Blasius and Conn (2013)
Dix Creek*	L	2011	Robinson (2012)
Duck Creek, NM	EX-1	Pre-1900	ANSP 19452
Eagle/East Eagle Creek*	S	2009	Coleman (2010)
Harden Cienega Creek* (San Francisco River)	L	2013 2012 1983	Robinson (2014) ASU 13430
Mineral Creek	NDR-2	2000	Robinson et al. (2010)
Queen Creek	EX-1	1938	UMMZ 125041
San Simon Cienega	EX-1	1939	UMMZ 137093
Tularosa River, NM	EX-1	Pre-1990	ANSP 19449[3]
Turkey Creek, NM* (Sycamore Creek)	L	2012 2012	USFWS et al. (2012)
Verde River basin			
Big Chino Wash	EX-1	1950	UMMZ 162834
Red Tank Draw*	S	2012	Timmons and Upton (2013)
Spring Creek (Verde)*	L	2011	Rinker (2011)
Walker Creek*	S	2011	Rinker (2011)
Williamson Valley Wash*	AP	2003	Leibfried pers. comm. (2004)

[1] Rinne (1969) reported that W.L. Minckley saw specimens from the mainstem Agua Fria River in 1966, but there are no preserved specimens or specific locality information available. We include this record as a valid Gila chub locality because it is likely that the Agua Fria River was at least occasionally occupied when hydrological conditions facilitated connections among the tributary populations.

[2] Located on San Carlos Apache Indian Reservation

[3] The locality of the ANSP 1949 museum record is listed as San Francisco River, but we believe it more likely was from Tularosa River in that the valid Apache Creek locality is a tributary to Tularosa, and the confluence area formerly was a large cienega, a habitat frequented by Gila chub. There are several museum records for *G. robusta grahami* from San Francisco River, which further supports the contention that Gila chub did not occur there.

Population Viability Analysis

Population viability analysis (PVA) is a method of risk assessment that can inform which populations may be most important to protect according to ecological and evolutionary criteria and population extirpation risks under different management scenarios. Several PVA models are available that can simulate effects of deterministic forces as well as demographic, environmental, genetic, and stochastic events, and certain management actions on long-term extinction risk of **wild populations**.

No formal PVA has been conducted for Gila chub. Our current knowledge of the life history and population dynamics of Gila chub is incomplete and basic demographic data are wanting, so inputs to a PVA model would necessarily be based on expert opinion or surrogate species, if available, which could limit accuracy and utility of a model.

I.9 Reasons for Listing/Threats

Gila chub was listed as endangered with critical habitat in the final rule (USFWS 2005b) due to one or more of the five listing factors identified in Section 4(a)(1) of the ESA. The final rule cites collection records, historical habitat data, the 1996 AZGFD Gila chub status review (Weedman et al. 1996), and USFWS information documenting currently occupied habitat to conclude that Gila chub has been eliminated from 85 to 90 percent of formerly occupied habitat. The final rule also notes that 90 percent of the currently occupied habitat is degraded due to the presence of nonnative species and land management actions. Due to fragmented and often small population sizes, extant populations are susceptible to environmental conditions such as drought, flood events, and wildfire. Primary threats to Gila chub such as predation by and competition with nonnative fishes and secondary threats identified as habitat alteration, destruction, and fragmentation are all factors identified in the final rule that contribute to the consideration that Gila chub is likely to become extinct throughout all or a significant portion of its range (USFWS 2005b).

The reasons for listing (threats) identified above remain applicable today, and without proper management and protections these threats will continue to impact Gila chub. The following discussion outlines the five factors (A through E) and is a brief summary of current threats (see the final rule [USFWS 2005b] for a complete summary of threats at the time of listing), including any updated information, and any new threats that were not considered at the time of listing. See Table I.4 for a complete list of Gila chub recovery units and streams that are influenced or impacted by the threats identified in Factors A through E below.

A. The Present or Threatened Destruction, Modification, or Curtailment of Its Habitat or Range

Habitat loss due to water diversions, groundwater pumping, impoundments, dams, channelization, improperly managed livestock grazing, agriculture, mining, road building, and residential development are all recorded as historical and ongoing activities that have contributed to the decline of Gila chub populations (Weedman et al. 1996, Propst 1999). These human-caused disturbances create long-lasting environmental changes that affect ecological structure and stream functions (FISRWG 2001). These changes include altered hydrographs and lowered water tables (Dobyns 1991, Bahre 1991, Rabeni 1992), which affect watershed processes such as runoff, erosion, infiltration, and aquifer recharge. These processes in turn determine flood regime, base flow discharge, stream channel geometry, sediment transport, nutrient inputs, water quality, and ultimately determine the extent and character of fish habitat (Leopold et al. 1964, Leopold 1997, Rosgen 1996, DeBano and Schmidt 1989). When the hydrograph is altered greatly, the dynamic equilibrium of the stream is upset and can lead to alteration of stream channels through incision, widening, straightening, and **avulsion** (Leopold et al. 1964, Rosgen 1996, Leopold 1997, Poff et al. 1997). Channel instability brought on by changes in watershed characteristics may persist for decades (Swanston 1991). As human populations continue to increase in all counties occupied by Gila chub except Greenlee in Arizona (U.S. Census Bureau 2011), we expect that local and regional effects to Gila chub habitat will continue concomitant with the growing human population.

Groundwater and Surface Water Withdrawals

Growing water demands in the Gila Basin threaten the existence of perennial surface water and the species that depend on it (USFWS 2005b, Marshall et al. 2010). The removal of groundwater by wells changes the long-term average rates of inflow to and outflow from the aquifer system through time (USGS 2010). When comparing groundwater withdrawals via pumping to other natural groundwater losses (evapotranspiration and inter-basin flow to downgradient basins), pumping accounted for the largest share of water withdrawn (approximately 2.4 million acre-ft per year) in a study that encompassed the entire range of Gila chub (Tillman et al. 2011). In the San Pedro River, one of the known factors that contributed to the loss of Gila chub is groundwater extraction for agriculture and municipal uses (USFWS 2005b). Not only does excessive groundwater extraction impact surface water and dry up streams, but it degrades riparian vegetation that affects channel morphology (as above), reduces or eliminates the biochemical and physical filtering functions of the **hyporheic zone** that can result in groundwater pollution, and decimates biotic communities that are dependent upon perennial surface and hyporheic flows (Hancock 2002).

Other types of surface water withdrawal or diversions that have the potential to adversely impact Gila chub or its habitat are stream channelization for flood control, irrigation, irrigation diversions, or larger dams (Table I.4). Channelization is the straightening of a stream or dredging within the stream to divert water (Emerson 1971), which reduces habitat heterogeneity and increases stream gradient. Flood control and irrigation can have dramatic effects on the geomorphology and hydrology of a watershed and the stream corridor morphology within it, and disrupt riffle and pool complexes needed for aquatic organisms (Simpson 1982, FISRWG 2001). Irrigation dams or larger dams interrupt and alter a significant portion of a river's ecological and geomorphological processes, including changing the flow of water, reducing or eliminating water in existing fish habitat, diverting fish away from the natural stream course into irrigation ditches that eventually dry out, or preventing fish from moving among populations resulting in genetic isolation (Ligon et al. 1995, USFWS 2005b).

Livestock Grazing

Domestic cattle are adapted to mesic habitats, and given the opportunity will spend a disproportionate amount of time in riparian areas for water, shade, and cooler temperatures compared to those in adjacent upland habitat (Clary and Medin 1990, Armour et al. 1991, Fleischner 1994, Belsky et al. 1999). Excessive grazing can reduce or eliminate riparian vegetation; that affects fish habitat by increasing stream temperatures and sedimentation, eroding soils, destabilizing banks, and degrading water quality (Armour et al. 1991, Platts 1991). Streambank alteration due to livestock trampling may negatively impact water quality and aquatic habitat (Platts (1991). Excessive trampling can lead to an increase in stream width, making the stream wider and shallower (Clary et al. 1996). Steep vertical banks that develop undercut banks are easily sheared off by hoof action (Rosgen 1996). Poor livestock management practices are among the most significant factors that influenced regional stream channel downcutting that has altered stream-floodplain relationships, reduced habitat heterogeneity, dried streams, and drained cienegas that are important Gila chub habitats (reviewed in part by Hendrickson and Minckley 1984, Minckley and Rinne 1991). Currently, Federal agencies, Tribes, and private cattle growers are working to implement stricter management of livestock by excluding livestock grazing from many riparian areas and streams or only permitting limited season grazing (USFWS 2009). Application of similar grazing practices throughout the historical range of Gila chub could significantly improve watershed and stream corridor conditions.

Mining activities

Arizona has the best copper deposits in the United States and for many years has led the Nation in copper production. The state also ranks in the top five in other non-fuel mineral production for molybdenum, sand and gravel, gemstones, perlite, silver, zeolites, and pumice (ADMMR 2008, 2010). Water is required for all mining and processing, with sources coming from underground aquifers, surface water, precipitation, or a combination of sources (ADMMR 2010). Water extraction associated with mining activities within the Gila River basin is not expected to diminish, and will continue to be a potential threat to Gila chub.

Sand and gravel mining can result in stream disturbance and modifications that are similar to stream channelization (Brown et al. 1998). Specific changes to channel geomorphology include increased bankfull widths, surface area increase of downstream pools (but not depth), increased distance between riffles, and lateral erosion of stream banks that can remove vegetation and undercut riparian trees (Brown et al. 1998). Sand and gravel mining operations were identified in the final rule as having serious effects to the Santa Cruz, San Pedro, and Babocomari rivers in the past, and continue, although at reduced levels (USFWS 2005b). At this time, mining is a threat to the Cienega Creek population.

Development and Roads

With increasing human population growth within the Gila River basin, construction and maintenance of roads servicing human communities are expected to follow, along with increased off-road travel on designated or unauthorized user-created road systems. Development alters the watershed through surface water and groundwater reductions, and water consumption by home subdivisions ultimately reduces streamflow of perennial streams (Medina 1990). Other factors such as paved streets, parking lots, and roofs on homes can alter natural runoff patterns, causing large quantities of water to rapidly enter a river, and increasing flood potential and bank destabilization (Tellman et al. 1997).

Unpaved forest roads collect and channel stormwater runoff into streams, causing physical changes such as channel widening and downcutting. Road networks often cross tributary streams at perpendicular angles or are parallel to mainstream segments, which can alter the geometric interactions involving peak flows (floods) and debris flows (soil, sediment, and wood), and increase the magnitude and frequency of flood flows (Jones et al. 2001). Construction of slab or culvert crossings has reduced or precluded movement of fish (Warren and Pardew 1998, Wheeler et al. 2005), resulting in reduced genetic diversity (Wheeler et al. 2005). Culverts can destabilize stream channels and interrupt the transport of woody debris, sediment, substrate, and water (Wheeler et al. 2005).

Table I.4. Matrix of threats, for remnant populations of Gila chub that are identified in Factors A-E. The table is used to indicate the presence of a potential or documented occurrence of a threat and is not intended to indicate severity of threats. Score is the sum across rows of the number of threats identified for each population that is used in Table C.2.*. *Ongoing environmental threats such as Drought and Wildfire are not factored in the overall score.*

Population	Drought	Water Withdrawal	Water Diversion	Mining	Residential Development	Roads	Wildfire	Fire Suppression	Grazing	Nonnative Species	Parasites	Score
Agua Fria subbasin												
Indian Creek	x					x	x	x	x			3
Sycamore/Little Sycamore creeks	x	x					x	x	x	x		4
Silver Creek	x		x				x	x	x	x		4
Verde subbasin												
Red Tank Draw	x						x	x	x	x		3
Spring Creek	x	x	x		x	x	x	x	x	x		7
Walker Creek	x		x				x	x	x			3
Williamson Valley Wash	x	x			x	x	x	x	x	x		6
Santa Cruz subbasin												
Cienega Creek	x	x	x	x		x	x	x		x		6
Sabino Canyon	x					x	x	x				2
Sheehy Spring	x						x	x	x	x		3
San Pedro subbasin												
Hot Springs Canyon	x					x	x	x			x	3
O'Donnell Canyon	x	x				x	x	x		x		4
Redfield Canyon	x						x	x		x		2
Upper Gila subbasin												
Blue River	x					x	x	x	x	x		4
Bonita Creek	x	x				x	x	x	x	x	x	6
Dix Creek	x						x	x	x		x	3
East Eagle/Eagle Creek	x	x				x	x	x	x	x	x	6
Harden Cienega	x						x	x	x	x	x	4
Turkey Creek, NM	x						x			x		1

*Higher score indicates a greater sum of threats

Excessive sediment has the potential to fill backwaters and deep pools used by Gila chub, and may cause stream braiding that can reduce adult Gila chub habitat (USFWS 2005b). Excessive sediment has the potential to alter the availability of food production by smothering aquatic insects (Newcombe and MacDonald 1991). Increased turbidity can reduce the ability of chubs to see and capture food (Barrett et al. 1992).

B. Overutilization for Commercial, Recreational, Scientific, or Educational Purposes

The overutilization for commercial, recreational, scientific, or educational purposes is not considered a threat to Gila chub (USFWS 2005b). AZGFD, NMDGF, and USFWS have appropriate permits and regulations necessary to protect Gila chub from collection or incidental capture where they are found (USFWS 2005b). Commercial uses for Gila chub do not exist, and although scientific collection occurs, it does not pose a threat since the species is regulated by both Arizona and New Mexico (USFWS 2005b).

C. Disease and Predation

Disease
Nonnative parasites such as Asian tapeworm, Ich, and anchor worm are found within the Gila basin (USFWS 2005b). The effects of nonnative parasite infections can be exacerbated when combined with other environmental stressors such as temperature variations and food reduction, which lead to increased mortality of infected fish (USGS 2004, 2005). See section I.6 *Life History and Population Ecology* (above) for a more detailed description of the impacts of parasites on Gila chub and native fishes in general. No diseases have been identified that appear to affect Gila chub survival.

Predation
Historically, Gila chub experienced little or no predation from other native fishes (USFWS 2005b). However, introductions of nonnative fishes that prey upon Gila chub have become a primary threat to persistence of Gila chub and other native fish populations (Minckley 1985, Williams et al. 1985, Moyle et al. 1986, Minckley 1991, Dudley and Matter 2000, Clarkson et al. 2005, 2012, Olden and Poff 2005, Olden et al. 2006, Minckley and Marsh 2009). Nonnative fishes originate from different biotic communities that have no previous evolutionary history with the native community. Establishment of nonnative fishes within streams of the Gila River basin negatively affects Gila chub and other native biota (e.g., other native fish species, gartersnakes, leopard frogs) via avenues such as predation, competitive exclusion, niche displacement, hybridization, and can ultimately result in extinction (Mooney and Cleland 2001, Strauss et al. 2006, USFWS 2002b, 2013). Nonnative fishes have the potential to impact **ecosystem** processes relating to energy and nutrient flux that can occur at the level of individual organisms (e.g., habitat use and foraging), at the population level (e.g., alteration in abundance or distribution of species), and at the community level (e.g., interactions among populations) (Simon and Townsend 2003). Nonnative fishes have been detected in 13 of the 19 known remnant Gila chub populations identified in Table I.4, and were likely primary factors in the extirpation of several historical populations shown in Table I.3 (Minckley 1973, Stefferud et al. 2009).

Introduced fishes are typically **piscivorous** (Pacey and Marsh 1998, Marsh and Pacey 2005), and natives are predator-naive, lacking behavioral mechanisms to avoid predation (Johnson et al. 1993, Johnson and Hines 1999). In addition, most natives (including Gila chub) lack sophisticated life history traits, such as nest building and parental care, which might afford them a level of protection against predation on early life stages (Pacey and Marsh 1998, Marsh and Pacey 2005, Olden et al. 2006). Nonnative fishes are nearly ubiquitous across the Gila River basin (ASU 2002, Minckley and Marsh 2009) and nearly all nonnative species that inhabit streams and rivers of the Gila River basin are likely predators on at least some life stages of natives (e.g., Schooley et al. 2008). For these and other reasons, nonnative fishes in general appear responsible for declines and replacement of native species like Gila chub (Minckley 1985, Williams et al. 1985, Moyle et al. 1986, Minckley 1991, Dudley and Matter 2000, Marsh and Pacey 2005, Clarkson et al. 2005, 2012, Olden and Poff 2005, Olden et al. 2006, Minckley and Marsh 2009).

D. The Inadequacy of Existing Regulatory Mechanisms

A number of Federal and State laws and regulations provide some protection for Gila chub and its habitat, including the ESA, National Environmental Policy Act, Lacey Act, Federal Land Policy Management Act, National Forest Management Act, Clean Air Act, Clean Water Act, and wildlife special permits administered by the States in Arizona and New Mexico (USFWS 2005b). The benefits to Gila chub from these laws and policies, however, are limited, and their significance in reducing threats to the species or its habitat is difficult to measure or predict. The final rule listing Gila chub as endangered stated that regulatory mechanisms have not been adequate to prevent the continuing decline of Gila chub (USFWS 2005b).

<u>Impacts of Nonnative Fishes</u>
Legal pathways for nonnative fish introductions include authorized or permitted stocking activities by Federal, state, local and tribal governments, private citizens, and businesses, all of which have the potential to contribute to natural (through hydrological connectivity) or unauthorized (via “bait bucket” transfers) movements of nonnative fishes to Gila chub waters. Illegal introductions of nonnative fishes may result from releases by the baitfish industry, anglers, and the public, or escapes from commercial shipping, ornamental ponds and aquaria, private aquaculture, or live food fish. Historically, legal and illegal stocking throughout Arizona has resulted in the establishment of at least 60 nonnative fish species (Fuller et al. 1999), most of which were introduced and authorized by AZGFD or the Federal government (USFWS 2011).

A recent Biological and Conference Opinion (BCO) between USFWS and AZGFD regarding fish stocking identified the Agua Fria River (Little Sycamore, Sycamore, Indian, Silver, Larry, and Lousy creeks), Big Chino Wash (Williamson Valley Wash), Middle Verde River (Spring Creek, Red Tank Draw, and Walker Creek), and Santa Cruz River (Bear Canyon and Sabino Canyon) complexes as areas where Gila chub populations may be affected by sportfish stocking actions (USFWS 2011). Conservation measures to reduce potential impacts of nonnative fish stockings to Gila chub included converting to sterile **triploid trout** stockings (which will reduce the potential for **augmentation** of existing nonnative trout populations), assessment and risk analysis of statewide live bait use, and identification of conservation needs for Gila chub relative to nonnative fish species for the development of this recovery plan. These measures will be beneficial to Gila chub, but nonnative fish impacts will continue to exist as long as legal and illegal stockings continue, and extant populations remain.

Historical Mining Impacts and Current Policies

Historically, uncontrolled emissions from copper smelters in the United States and Mexico were found to be a major source of atmospheric distribution of metals and organic compounds, resulting in acid precipitation (Blanchard and Stromberg 1987, Haines 1981). Since the early 1900s, metal smelting operations in Arizona have been increasing (Anthony et al. 1995). Nash et al. (1996) estimated at least 10 small smelters were in operation prior to 1900 and 3 large smelters operated between 1900 and 1950 within the Prescott National Forest area. They predicted smelter smoke contamination in the early days was abundant and found that soils and vegetation within a 5 to 10 mile distance from smelters contained high concentrations of metals. Blanchard and Stromberg (1987) collected rain samples over a 13-month period within approximately 100 km (62 mi) of two copper smelters in Douglas, Arizona, and Cananea, Sonora, Mexico; both with uncontrolled emissions. Results of their rain samples documented a mean pH of 4.63, which is a level known to cause acute mortality, reduced growth, and reproductive failure in several fish species (Haines 1981). However, depending on the alluvium deposits (such as calcite or other carbonate minerals) where these minerals occur, the natural hydrologic process can be very effective at mediating acidic waters and consequently decreasing metal concentrations (Nash et al. 1996). Prior to current regulations (such as the Clean Air and Water Acts), it is possible long term cumulative effects of smelting operations and subsequent soil contamination and acid precipitation changed the pH in water sources to levels that would impact Gila chub; however, such occurrences were not tracked historically.

As stated previously, a number of current Federal and State laws and regulations provide some protection for Gila chub and its habitat. In 2011, the U.S. Environmental Protection Agency (USEPA) released the first national standards for mercury and air toxics (i.e., arsenic, acid gas, nickel, selenium, and cyanide) for power plant emissions that represent the largest remaining sources of toxic air pollutants in the United States. The new standards will influence the compliance of smelters and other sources nationwide (USEPA 2011). In addition, the Mexican legislature recently passed a climate change bill with sweeping provisions to mitigate climate change, including mandatory emissions reporting by the country's largest polluters (Vance 2012). At present, we believe atmospheric pollution continues to be a current but minor impact to Gila chub and its habitat.

Water Policies and Protections

Surface water withdrawals in Arizona and New Mexico are regulated through the doctrine of prior appropriation whereby waters first put to beneficial use have senior rights to subsequent appropriations. Surface waters historically were legally appropriated via diversion from a natural path to a place where it would produce revenue or sustain human life. The result was that surface waters nearest human population centers were exploited with little regard for fishes, and many streams and rivers were desiccated (Minckley and Marsh 2009). The doctrine of prior appropriation did have an unintentional effect that stream reaches upstream of legal diversions were often protected against further depletions in order to protect senior downstream rights. Recently-recognized instream flow rights in Arizona (not requiring diversion, in part to benefit fish and wildlife), New Mexico's 2005 Strategic Water Reserve (that provides a mechanism for the State to buy or lease water or storage rights from willing sellers to facilitate interstate stream compact compliance and to benefit threatened and endangered species), and federally-reserved water rights on Federal and Indian lands have potential to protect waters within some Gila chub streams. Most major surface diversions likely have already occurred, but new diversion impacts to some Gila chub populations are still possible despite these and ESA protections.

Despite these policies, regulation of groundwater withdrawals that impact surface flows is basically non-existent. Arizona's 1980 Groundwater Management Act (ADWR 2009) attempts to eliminate severe groundwater overdraft, but has little effect on preserving surface flows. New Mexico recognizes the connection between groundwater and surface water as it relates to protection of senior water rights, but does not protect surface waters from dewatering otherwise. Neither Arizona nor New Mexico legally recognizes the connection between groundwater and surface water, and many properties off city water sources have unlimited underground water rights via wells; thus, there is little protection to Gila chub watersheds that might be mined for groundwater.

E. Other Natural or Manmade Factors Affecting Its Continued Existence

Previous and ongoing factors affecting Gila chub and its habitat include random and non-random events such as drought, floods, wildfire, fire retardant use, mining, beaver extirpation, genetic bottlenecking, and climate change. These events are all influenced by manmade and natural factors and can severely impact water quantity and quality, resulting in the isolation or elimination of Gila chub populations.

<u>Drought</u>

Drought is a natural occurrence that influences water quality and availability, and increases susceptibility to wildfire, flooding, and interactions with nonnative fishes. Model projections for southwestern North America show a sustained warmer and drier climate that began in the late 20^{th} and early 21^{st} centuries that is expected to consistently become drier (Seager et al. 2007). These warmer and drier trends are expected to increase water temperatures and alter streamflow patterns (Rahel and Olden 2008), which can reduce habitat availability and pool depth and subsequently lead to fragmented Gila chub populations. In addition, periods of drought will increase biotic interactions and interspecific competition in dwindling pools. Increasing water temperatures may alter life history functions such as timing and periodicity of spawning, change elevational distributions within stream systems, and impact the life cycles and availability of food resources. Elevated water temperatures and extension of summer low-flow conditions can exacerbate competitive and predatory interactions with nonnative fishes and the potential virulence of some diseases (Propst et al. 2008, Rahel and Olden 2008).

<u>Wildfire and Post-fire Erosion and Flooding</u>

The southwestern United States is currently experiencing a drying trend that is predicted to continue well into the latter part of the 21st century (IPCC 2007, 2013, Seager et al. 2007). Drought stresses trees and can leave them susceptible to insects, disease, wildfire, or mortality because of limited soil moisture (Rogstad et al. 2012), which increases the likelihood of wildfire. An analysis of trends in wildfire and climate in the western United States from 1974 to 2004 shows that both the frequency of large wildfires and fire season length increased substantially after 1985 (Westerling et al. 2006). These changes were closely linked to advances in the timing of spring snowmelt and increases in spring and summer air temperatures. Fire frequency and severity may be exacerbated if temperatures increase, precipitation decreases, and overall drought conditions become more common.

Fish populations that are currently compromised by a variety of human influences (i.e. habitat loss, degradation, fragmentation, and nonnative species invasion) are more severely impacted by the effects of fire (Dunham et al. 2003). Several fires in the Gila River basin (Aspen Fire in 2003, Cave Creek Complex Fire in 2005, Wallow Fire in 2011, Miller Fire in 2011, Whitewater/Baldy fire in 2012) have adversely impacted Gila chub populations and their habitats. These and other fires resulted in downstream habitat modification and mortality of Gila chub in Eagle/East Eagle creeks, O'Donnell Canyon, Silver Creek, Sabino Canyon, Turkey Creek in New Mexico, and others. Portions of these watersheds received moderate and high severity burns that resulted in high mortality or complete removal of vegetation, and may have created localized hydrophobic soil conditions. Such areas are highly susceptible to post-fire erosion and flooding and can transport extremely large volumes of water and debris (including wood, sediment, and ash) into occupied Gila chub habitat. Increased sediment can have negative effects, including burial of existing habitat and direct mortality of aquatic biota (Benda et al. 2003). Ash-laden flows increase nutrient inputs (such as nitrates and ammonium) and decreased oxygen levels in affected streams (Earl and Blinn 2003), and are known to be fatal to aquatic biota (Rinne 1996, Rinne and Neary 1996).

<u>Fire Suppression</u>

The Four Forest Restoration Initiative recognizes that the fire regime in Arizona has been disrupted by fire suppression over the last century, which is largely responsible for the deteriorating health of the ponderosa pine ecosystems (USDA 2012) and partly responsible for rapid conversion of grasslands to shrublands in Arizona and New Mexico (Swetnam and Betancourt 1990). In the latter part of the 19th century, fire management was one of the practices (along with logging and grazing) that started to shift the fire regime on the landscape as well as the structure and composition of landscape components (USDA 2012). Since the early 20th century, fire suppression has been the management policy (Korb et al. 2012). With fire suppression, pine litter accumulates (compacting litter, duff, and dead and down woody debris), and seedlings and saplings continue to grow and create dense thickets of suppressed trees in once open stands of ponderosa pine. These near continuous stands of fuel from understory to canopy provide fuel ladders that carry fire into the tree canopy and ultimately shift the fire regime from frequent, low-intensity/low severity surface fires to infrequent, high-intensity/high severity crown fires (USDA 2012, Schoennagel et. al. 2004, Swetnam and Betancourt 1990). Because of the long-term history of fire suppression, over the last decade unnaturally intense wildfires have increased in the Gila River basin, threatening Gila chub and its habitat.

Fire suppression activities such as construction of roads and firebreaks, and application of fire retardant and other suppression activities can adversely affect fish and aquatic ecosystems (Dunham et al. 2003). When retardant chemicals are released by helicopters or airplanes, they can enter aquatic systems and affect aquatic organisms. Currently, the most toxic chemical used in aerial applications is ammonia (McDonald et al. 1995), and studies show it can remain toxic for more than 21 days, depending on the substrate to which the fire retardant is applied (Little and Calfee 2002). Several laboratory and controlled field studies concluded that significant mortality of fish and other aquatic organisms results from ammonia exposure (Little and Calfee 2000, 2004, 2005, Buhl and Hamilton 2000, Ward et al. 2013).

In 2000, the USFS, USFWS, and National Marine Fisheries Service (NMFS) developed the Guidelines for Aerial Application of Fire Retardant and Foams in Aquatic Environments. These guidelines established a buffer area of 91 m (300 ft) adjacent to waterways in which no retardant was to be applied, with certain specified exceptions. In 2011, USFWS finalized a nationwide consultation on the use of approved fire retardant chemicals on National Forest lands. USFWS concluded that future fire retardant misapplications were likely to occur in occupied Gila chub habitat. Based on information provided by USFS, USFWS estimated that Gila chub would be harmed from 21 unintentional fire retardant applications on Forest Service lands in Arizona and New Mexico over the next 10 years (USFWS 2011).

<u>Mining Impacts</u>
Studies on mining activities and potential impacts to human health and the environment are ongoing within the Gila subbasin where Gila chub occur (USEPA 2013, 2014, ADEQ 2012), although no studies specific to the effects of mining on Gila chub have been completed. Some of the commonly released toxic chemicals by industrial facilities in Arizona are zinc, copper, lead, and other related compounds. With copper mines among the top seven of industrial facilities releasing to the atmosphere (AZPM 2013), and with two of those facilities within the Gila River basin, copper mining is a likely source of environmental pollution to Gila chub streams, through atmospheric pollution and mining waste discharge.

Once in the stream, acute copper toxicity to fish is affected by water hardness, pH, and dissolved organic matter. In acidified waters, acute mortalities of fish have been observed when there is a rapid change in pH; however, sublethal effects such as reproductive failure are more common (Haines 1981). Both calcium and hydrogen ions compete with copper for binding sites on fish gills (Rattner and Heath 2003). In fish, the biotic ligand model has been designed to describe the acute toxicity of copper. The biotic ligand model describes a specific receptor within an organism, like the gill, where metal complexation leads to acute toxicity (Santore et al. 2001). In fish, gills have an affinity for cations such as copper, contributing to its low acute toxicity threshold in fish. Other sources of toxic chemicals released into the environment (i.e., atmospheric) are not expected to result in acute mortalities of Gila chub but may contribute to their overall decline.

Current Reporting of Air and Water Quality Standards
A release of toxic chemicals into the environment can occur through on-site disposal or releases to the air, water, or land from USEPA permitted activities (USEPA 2014), and can potentially impact Gila chub and its habitat. Although they are permitted, industries may at times exceed the limit of chemical releases into the environment. Recently the USEPA identified areas across the United States that are in violation of the 2010 Sulfur Dioxide National Ambient Air Quality Standard (NAAQS; USEPA 2013). USEPA monitoring data from 2009 to 2011 indicated the areas around Hayden (in parts of Gila and Pinal County, Arizona) and Miami (in parts of Gila County, Arizona) were in violation of the NAAQS standard and were subsequently designated as "nonattainment" areas. The Clean Air Act defines nonattainment areas as those that do not meet

an ambient air quality standard or that are contributing to ambient air quality in a nearby area that does not meet the standard (USEPA 2013). In addition, the 2010 Status of Water Quality report for Arizona lists Mineral Creek (from Devils Canyon to Gila River) as an impaired water based on dissolved oxygen, selenium, and copper (ADEQ 2012). ADEQ's report does not list the possible causes of impairment.

Sources of Pollution
One possible source of atmospheric pollution is smelting operations, which involve the extraction of metal ore. Sorooshian et al. (2012) described impacts to public and environmental health in the Southwest from harmful metals and metalloids (i.e., arsenic, copper, and zinc) that are enriched in aerosol particles because of smelting and fossil fuel combustion. They collected ambient aerosol particles near an active copper smelting site and mine tailings near the towns of Hayden and Winkelman, Arizona. Their studies indicated that emissions from the point source could reach southern Arizona and possibly New Mexico, depending on prevailing winds and seasonal weather patterns (Sorooshian et al. 2012), although the enriched aerosol particles are more concentrated near the source of the emissions. Blanchard and Stromberg (1987) linked emissions to deposition (in rain samples) at two sites within 100 km (62 mi) of two of the largest copper smelters in the Gila River basin (one in Douglas, Arizona, and the other in Cananea, Sonora, Mexico). During smelting operations, metals (i.e., copper, nickel, selenium, and zinc) can be released into the air as vapor (adhering to atmospheric dust particles or particles produced by the smelting operation) and eventually reach aquatic systems by dry or wet deposition (Germani et al. 1981, Small et al. 1981, Lemly 2004). Large-scale metal smelting operations should be viewed as an important contributor of gas phase selenium pollution that could eventually reach aquatic systems and bioaccumulate in the food chain (Lemly 2004). Smelting is also a potential source of sulfur dioxide emissions (USEPA 2013, Cole 1994). Sulfur dioxide is an extremely soluble gas that is easily oxidized to form sulfuric acid (Cole 1994).

In comparison to air particles, a release of toxic chemicals on land or water likely will have a higher risk of contaminating a water source. Lewis and Burraychak (1979) related equipment breakdowns, accidental discharges, or unusually high rainfall to events that resulted in the release of heavy metals that were toxic enough to kill aquatic species. Discharges from tailing ponds that store wastes from ore refinement are potential sources of heavy metal contamination. Lewis and Burraychak (1979) described one toxic release that killed fish in Pinto Creek (Gila County, Arizona) and compared the results to other known contamination events in nearby intermittent streams (Pinal and Mineral creeks, Arizona). One population of Gila chub in Mineral Creek is suspected but unconfirmed to be severely impacted by mining waste discharge (J. Sutter, AZDEQ, pers. comm. 2011). Gila chub, longfin dace, and green sunfish were observed in Mineral Creek during 2000, but during surveys in 2006 no fish were found (AZGFD 2007).

Beaver Extirpation
Not only can the introduction of novel species impact the ecosystem, but so can the extirpation of important species such as beaver. Historically, beaver was abundant along many mainstem and tributary streams in the basin (Dobyns 1991, Brown et al. 2009), and beaver ponds slowed floodwaters, detained water for slow release to stream channels, and backed up flood water and sediment in wide valley bottoms that created cienega wetlands with large storage capacity

(Dobyns 1991, Hendrickson and Minckley 1984). These benefits disappear after beavers leave an area or otherwise are extirpated, and potentially could negatively affect Gila chub via dewatering during droughts, loss of pool habitat, channel entrenchment, etc.

Genetic Bottlenecking

Reduction in population size can have a significant impact on persistence of populations. Loss of genetic diversity can lead to loss of adaptability to changing environments and may even lead to extirpation due to reduced survivorship associated with inbreeding. Loss of geographically discrete evolutionary units reduces the overall ability of the species to cope with environmental change; therefore, maintenance of these distinctive genetic lineages is critical for overall health and well-being of the species.

Climate Change

One of the Intergovernmental Panel on Climate Change models (IPCC 2007, 2013) projected regional impacts for North America that included warming in the western mountains that likely will result in decreasing snowpack, more winter flooding, and reduced summer flows. Dominguez et al. (2010) found statistically significant temperature increases and negative precipitation trends in the southern region (which includes Arizona and New Mexico) during the 21st century, and predicted that future El Niño years will be characterized by higher precipitation and lower temperatures, while La Niña winters will be warmer and drier. Another study described similar findings where increasing temperatures in the southwest are expected to directly influence the long term availability of water in rivers and streams that are already affected by current drought conditions (Gutzler and Robbins 2011, Gutzler 2013). Increasing temperatures affect evapotranspiration demand, directly influencing the severity of drought during the hot-dry foresummer and hot-wet monsoon seasons in the southwest (Weiss et al. 2009). Twenty-first century droughts are predicted to be driven more by temperature than were historical droughts, and these higher temperatures and subsequent evaporation increases combined with multiple year precipitation deficits will continue to impede drought recovery (Gutzler and Robbins 2011).

Ecosystem Stressors

Factors A and E above describe individual and cumulative impacts to Gila chub within the Gila River basin. However, we believe the synergistic effect of all ecosystem stressors should be understood or considered when implementing future management actions. Below we identify ecosystem stressors and the reality of implementing effective recovery actions to achieve ecosystem restoration.

The ecosystem is a well-recognized management unit for conserving species (Meffe and Carrol 1997). For fish, the watershed is the support system for aquatic and riparian habitat and is the minimum and basic ecosystem unit used for resource management (Williams et al. 1997, Odum and Barrett 2005). Stream habitats have a functional dependency and interrelationship with their surrounding watersheds, and reflect cumulative impacts of all hydrologic, geomorphic, and vegetative conditions within those watersheds (Leopold et al. 1964, Swanston 1991, Brooks et al. 2003).

A major ecosystem stressor is physical watershed degradation that may arise from human habitation, road construction and maintenance, ungulate overgrazing, lowered water tables, timber harvest practices, fire suppression activities, and other actions that can alter or sever relationships among biotic communities, physical ecosystem processes, and therefore ecosystem function. Where degraded, these processes need to be reestablished to ensure the long-term survival of Gila chub and other listed aquatic species. Therefore, understanding which natural and anthropogenic processes negatively influence watersheds where Gila chub occurs will help facilitate recovery actions and improve aquatic species management in the future.

Although restoration of degraded watershed function will provide obvious benefits to Gila chub and native fishes, complete restoration may take decades or centuries under natural conditions (Hilderbrand et al. 2005). In addition, human population expansion, nonnative species, historical disturbance regimes, and past and future changes in climate and landscape succession make it impossible to restore an ecosystem to a single repeatable and predictable end point (Hilderbrand et al. 2005). In other words, it is likely unrealistic to define exactly what ecosystem restoration should look like, and when we will know when the ecosystem has been restored.

For these reasons, this recovery plan does not include complete ecosystem restoration as a definable objective in the Gila chub recovery step-down outline (see Section III). We qualitatively know that nonnatives must be controlled or eradicated, that groundwater extraction trends must be reversed, and that other physical habitat degradations must be minimized, but defining costs, timelines, and endpoints to such restoration is beyond the purview of this recovery plan. Instead, where these impacts are known to be exerted upon individual Gila chub populations, we attempt to identify specific threat-reduction methods. Ultimately, the status and trends of those populations will inform us of the condition and functioning of their supporting ecosystems. We assume here that if major threats have been addressed and that populations are expanding in available stream habitat and/or numbers over a period of years, ecosystem processes are functioning reasonably. When they do not, we assume the status of populations will reflect that degradation and compel further implementation of specific recovery actions identified in the step-down outline.

I.10 Previous and Ongoing Conservation Measures

<u>Federal Regulatory Actions</u>
Recognition of Gila chub as an endangered species under the ESA encourages and results in public awareness and conservation actions by Federal, State, Tribal, and local agencies, private organizations, and individuals. The ESA provides for possible land acquisition and cooperation with the States and requires that recovery actions be developed for listed species.

Section 7 Consultations
Section 7(a) of the ESA requires Federal agencies to evaluate their actions with respect to any species listed as endangered or threatened and with respect to its critical habitat, if any has been designated. For Gila chub, critical habitat was designated at the time of final listing in 2005, for approximately 257.9 km (160.3 mi) of stream reaches in Arizona and New Mexico (see *Section I.7 Critical Habitat* of this document for more information).

Section 7(a)(2) requires Federal agencies to ensure that activities they authorize, fund, or carry out are not likely to jeopardize the continued existence of a listed species or to destroy or adversely modify its critical habitat. If a Federal action may affect a listed species or its critical habitat, the responsible Federal agency must enter into formal consultation with USFWS.

Gila chub primarily occurs on Federal lands managed by the USFS and the U.S. Bureau of Land Management (BLM). Examples of Federal actions that may affect Gila chub include travel management, land and resources management, livestock grazing programs, logging and other vegetation manipulation activities, flood protection and repair measures, channelization, water development, construction and management of recreation sites, road and bridge construction and maintenance, fish stocking, issuance of rights-of-way, prescribed fire and fire suppression, and actions authorizing mining. These and other Federal actions require consultation under Section 7 if the action agency determines that the proposed action may affect listed species. The outcome of Section 7 consultation often involves inclusion of reasonable and prudent measures into project plans to minimize take of listed species or otherwise reduce potential adverse effects to the species and its habitat. In biological opinions, USFWS also provides conservation measures that Federal action agencies can implement on a voluntary basis.

Since Gila chub was listed, USFWS has consulted with several National Forests in Arizona and New Mexico on the Forest's Land and Resources Management Plans, Travel Management Plans, Fire Retardant Plans, proposed operations of grazing leases, and various prescribed fire and fire suppression projects. Consultation with the Bureau of Reclamation (Reclamation) on impacts of Central Arizona Project-related nonnative fish transfers to the Gila River basin resulted in adoption of several significant conservation measures that have potential to assist with Gila chub conservation and recovery.

Also subject to Section 7 consultation are development activities on private and State lands when such activity is conducted, funded, or permitted by a Federal agency. Examples include permits issued under section 404 or 402 of the Clean Water Act from the U.S. Army Corps of Engineers or USEPA, respectively. Federal actions not affecting the species, as well as actions on private lands that are not federally-funded or permitted, do not require Section 7 consultation. However, prohibitions under Section 9 of the ESA (discussed below) apply.

Section 9 Prohibited Acts

Section 9 of the ESA and its implementing regulations set forth a series of general prohibitions and exceptions that apply to all endangered and threatened wildlife. These prohibitions make it illegal for any person subject to the jurisdiction of the United States to take (including harass, harm, pursue, hunt, shoot, wound, kill, trap, or collect, or attempt any such conduct), import or export, transport in interstate or foreign commerce in the course of a commercial activity, or sell or offer for sale in interstate or foreign commerce any threatened species unless provided for under a special rule. It is also illegal to possess, sell, deliver, carry, transport, or ship any such wildlife that has been taken illegally. Certain exceptions apply to persons acting in an agency capacity on the behalf of USFWS and to activities associated with cooperative State conservation agencies.

Section 10 Permits
Permits may be issued to carry out otherwise prohibited activities involving endangered and threatened wildlife species under certain circumstances. Such permits are available for scientific purposes, to enhance the propagation or survival of the species, and/or allow incidental take in connection with otherwise lawful activities.

State Regulatory Actions

Arizona
AZGFD closed Bonita and Cienega creeks to fishing to protect Gila chub and other native fishes, and also has adopted several rules that curtail the transport and introduction of nonnative fishes (AZGFD 2014). A person can import live baitfish for personal use in several counties, but cannot release excess live baitfish into any Arizona water, and cannot transport live baitfish from the waters where taken except as allowed in regulation. No live baitfish may be used or possessed while on any waters in Coconino, Navajo, Apache, Pima, and Cochise counties. In addition, rules prohibit the transport of live crayfish from the site where taken. Movement of live sport fish from one body of water to another is also prohibited. The rules include a long list of fish species that are restricted live wildlife and cannot be possessed live without a special permit. Individuals are permitted to stock aquatic species onto private land if a permit is granted by AZGFD. No live baitfish can be transported to the Salt River above Roosevelt Diversion Dam, and no live baitfish can be used above Tuzigoot Bridge on the Verde River.

New Mexico
NMDGF regulations also help to curtail the transport and introduction of nonnative fishes (17-4-35 NMSA 1978 and 19.30.14 NMAC). Importation of eggs and fish into New Mexico is prohibited without first obtaining a permit from NMDGF. The retention of game species or state endangered species in a live condition is prohibited except by permit or license issued by the director of NMDGF for specific purposes. NMDGF regulations prohibit releasing baitfish into any water containing game fish, although the prohibition does not cover waters with non-game fish or endangered species. Legal baitfish in the Gila and San Francisco drainages is limited to fathead minnows (*Pimephales promelas*).

Habitat, Management, Conservation, and Recovery Plans
There is one Habitat Conservation Plan that is expected to promote conservation of Gila chub in Arizona. The Pima County Multi-species Conservation Plan is intended to minimize the impact of nonnative aquatic organisms and loss of habitat and water quality on Gila chub in Cienega Creek.

NMDGF has adopted the Colorado River Basin Chubs Recovery Plan to benefit and recover Gila and other chubs by determining distribution, monitoring current populations and changes in current and historical habitat, preventing and repressing the invasion of nonnative species, informing the public on fishing regulations, filling in information gaps, and coordinating with landowners and managers. Parties involved in writing this recovery plan included state, federal, and local governments, as well as non-governmental organizations and private citizens.

Protection of Existing Populations

Installation of Fish Barriers
Reclamation funded the construction of a fish barrier on Bonita Creek to protect native fishes in 2008. Subsequently a chemical renovation was performed, where native fish including Gila chub were salvaged prior to treatment and returned to Bonita Creek after the chemical treatment. Another fish barrier was constructed in Hot Springs Canyon in 2011, protecting the existing native fish assemblage (including Gila chub) and the repatriated spikedace, loach minnow, and Gila topminnow in this canyon. A barrier is anticipated to be constructed in 2015 in lower Redfield Canyon to protect its Gila chub population and facilitate the removal of green sunfish. Fish barriers also are in planning stages for Spring Creek in the Oak Creek (Verde River) drainage, and for upper Eagle Creek to protect remnant Gila chub populations.

Salvage and Population Replication

New Mexico
In 2011, the Miller Fire had the potential to impact Gila chub in Turkey Creek, New Mexico, due to ash flows from runoff. A collaborative effort from NMDGF, USFS, and USFWS salvaged fish from that stream, and in the spring of 2012 returned them to Turkey Creek after the threat was believed to have passed. However, later that year the Whitewater-Baldy Fire burned several canyons in the Turkey Creek watershed, compelling additional salvage; salvaged fishes were returned to Turkey Creek in autumn 2012. In addition, NMDGF and USFWS have been surveying streams that historically had Gila chub to determine the presence of fish and/or if suitable habitat exists for repatriation.

AZGFD collected Gila chub in 2010 and 2011 from Dix Creek, Arizona, and transferred them to NMDGF to stock into Red Rock Cienega (Red Rock Wildlife Area) with the intent of establishing a **refuge population**. Subsequent surveys in Red Rock Cienega determined that Gila chub is present but uncommon. AZGFD also collected Gila chub from Harden Cienega in 2012 and transferred them to NMDGF to replicate the population into Mule Creek, New Mexico. Small numbers of Gila chub were detected in Mule Creek during 2013 monitoring, and an augmentation stocking is planned for Fall 2014.

Arizona
Gila chub was repatriated to four streams in Arizona to replicate existing populations. Gila chub was collected from Silver Creek and subsequently stocked into Larry Creek and Lousy Canyon in 1995. Both **replicated populations** appear to have become **established**, and exhibit genetic characteristics representative of their source population. Gila chub was collected from Sabino Canyon in 2003 and introduced in Bear and Romero canyons in 2005. Subsequent surveys have determined that only the Romero Canyon replicated population has persisted and is reproducing.

Gila chub from T4 Spring were brought to the International Wildlife Museum (IWM) in 2009 to establish a refuge population. In 2010, Gila chub from T4 Spring and O'Donnell Canyon were stocked into a pond on The Nature Conservancy's Lower San Pedro River Preserve near Dudleyville, Arizona. The IWM and the Preserve were stocked with the intent of establishing two refuge populations.

Nonnative Fish Removal
In 1999, AZGFD and USFS chemically renovated Sabino Canyon to remove green sunfish. Post treatment, Gila chub are thriving in Sabino Canyon even after salvage and repatriation following the 2003 Aspen fire. In 2002, O'Donnell Canyon was similarly renovated to remove green sunfish, and today the Gila chub population there remains stable.

The Nature Conservancy, in cooperation with AZGFD, has been mechanically removing green sunfish from Redfield Canyon since 2007. Removal efforts there should be enhanced by the planned fish barrier construction in 2015. The Gila chub population in Redfield Canyon has remained stable during this period.

As noted under *Installation of Fish Barriers* above, AZGFD, in cooperation with BLM, USFWS, and Reclamation renovated a section of Bonita Creek between a constructed fish barrier and the City of Safford's infiltration gallery during 2008. Salvaged native fish were returned to the stream after the renovation, but nonnative fishes were again found in the treated portion of the stream in 2009. Since the reinvasion of nonnative fishes, BLM has led weekly efforts to mechanically remove nonnative fishes from the treated reach.

In a collaborative effort, USFS, NMDGF, and USFWS removed nonnative fishes in Turkey Creek (New Mexico) in 2012, 2013, and 2014. The removal of green sunfish below the hot springs (lower reaches) and rainbow trout (*Oncorhynchus mykiss*) above the hot springs (upper reaches) occurred in Sycamore, Brush, and Manzanita creeks, and Miller Springs Canyon.

I.11 Biological Constraints and Needs

The biological constraints and needs of Gila chub are limiting factors that are inherent within the species, are non-modifiable, and must be honored when designing any management/recovery program for the species. These limiting factors are not necessarily identified threats that contributed to listing of the species under the ESA, but they may be intricately tied to those identified threats and present challenges to recovery planning and implementation for the species. Based on known needs for the species, we attempt to identify the constraints to be considered during recovery planning and implementation.

The focus of biological constraints within the context of recovery involves response by a given species to environmental conditions. When environmental conditions fall outside the tolerance limits for the species, these conditions become environmental stressors.

Perennial flow
Gila chub is a fish and thus an obligate aquatic species that cannot survive without water. The species is unknown from ephemeral systems, and cannot persist continuously under conditions of intermittent wetting. Little information is available about the ability of Gila chub to colonize or re-colonize desiccated habitats after they are re-watered, but continuous occupation of any given site is possible only where flow is perennial and habitats are otherwise suitable.

Water Chemistry and Thermal Properties

Gila chub is considered a "warm water" fish, but a wide range of water temperatures can be tolerated by the species during parts of the year. However, Bestgen (1985) concluded that temperature was the most significant environmental factor triggering spawning in Gila chub. Gila chub has been observed spawning at temperatures between 15 and 26°C (59.0 and 79.8°F), but appears reluctant to spawn above 24°C (75.2°F) and spawning is unlikely to occur below 15°C (59.0°F) (Bestgen 1985, Schultz and Bonar 2006). This temperature range should be present for a minimum of 60 to-90 days during the reproductive cycle to allow for gamete development, incubation of fertilized ova, hatching, and development of larval fish. Temperatures that exceed 37°C (98.6°F) for sustained periods of time should not be considered as viable habitat capable of maintaining a self-sustaining population of Gila chub (Carveth et al. 2006).

Dissolved oxygen can become a limiting factor and detrimental to fishes in some environments. Saturation and super-saturation of dissolved oxygen in natural waters does not pose a limiting factor on most fish, but dissolved oxygen super-saturation likely accompanies super-saturation of other atmospheric gases such as nitrogen that can lead to chronic and acute stress. Gila chub likely requires sustained dissolved oxygen levels above 4 mg per liter (mg/L) throughout most of the year to survive and reproduce. Primary freshwater fishes such as Gila chub typically require salinities of less than 10 parts per thousand (ppt) and pH between 6.5 to 8.5. A discussion of the physico-chemical limitations of desert fishes was provided by Deacon and Minckley (1974).

Intra- and Interspecific Interactions

As with most stream fishes, Gila chub partitions habitat **ontogenetically**, through its life stages. Larval fish occupy shallow areas, along stream margins, with little to no flow, while juvenile fish tend to occupy deeper areas with more measurable flows. Older age classes typically occupy the deepest pools in which flows often are not measurable.

Gila chub evolved with depauperate fish communities and the species has not developed behavioral mechanisms to compensate against or avoid competition and predation with nonnative fishes. A biological constraint of Gila chub is an inability to reproduce and recruit successfully in the presence of nonnative fishes, especially green sunfish (e.g., Dudley and Matter 2000). Recovery actions should focus on areas that contain only native species or areas where problematic nonnative fishes can be removed.

Connectivity and Movement

Many populations of Gila chub are currently isolated from other populations, but historically that was not completely the case. As previously mentioned, connectivity is an important component of long-term evolution and short-term adaptation to changing environments. The relatively recent invasion of nonnative fishes, however, has compelled the adoption of management by isolation that requires human intervention to maintain the potential for species-level adaptation. Short-term maintenance of Gila chub populations does not require connectivity, but connection and gene exchange among populations are important for maintaining long-term evolutionary potential.

SECTION II. RECOVERY

II.1 Recovery Strategy

Background

A basic tenet of recovery planning in conservation biology is to ensure that recovery criteria address the biodiversity principles of representation, resiliency, and redundancy (Shaffer and Stein 2000). Representation concerns the protection of the breadth of genetic variability of a species by ensuring that populations are distributed across the full ecological gradient of a species' historical range in order to conserve its adaptive capabilities. Resiliency is the assurance that each population is sufficiently large to withstand most stochastic disturbance events, which usually is directly related to size of the habitat it occupies. Redundancy ensures that there are a sufficient number of population replicates to guard against irreplaceable losses of representative populations from catastrophic events. Redford et al. (2011) articulated these concepts as "maintaining multiple populations across the range of the species in representative ecological settings, with replicate populations in each setting. These populations should be self-sustaining, healthy, and genetically robust—and therefore resilient to climate and other environmental changes."

While these biodiversity principles (representation, resiliency, and redundancy) combine to provide security for a species to persist on the landscape, they also are a proxy of a species' viability. Viability describes the ability of a species to persist over time, and conversely, avoid extinction; viability takes into account what is viable now and into the future for a species. By protecting and replicating the remaining genetic variability and population distribution within the historical range, the viability of Gila chub is more assured, which will contribute to the species' recovery. The combination of these biodiversity principles are factored into the down- and delisting criteria in section II.4 Recovery Criteria.

Gila chub recovery may be accomplished by implementing the following expansive actions:

(1) protect and maintain remnant populations to provide representation and resiliency;
(2) replicate genetically-distinctive populations into new or historically occupied, protected streams where threats have been removed or minimized to provide population representation and redundancy as appropriate;
(3) establish refuge populations within each subbasin as needed to ensure population redundancy and to assist with population replications until the species is delisted; and,
(4) establish assurances that will continue recovery efforts post-delisting.

Recovery Strategy

The specific recovery strategy for Gila chub is to ensure that existing habitat is consistently available and properly functioning; habitat conditions allow for improvement of the species' status; and genetic diversity of the species is sufficiently represented and resilient by protecting and replicating all remnant populations within each of the major subbasins in the greater Gila River basin. This recovery strategy involves managing or eliminating threats of nonnative fish predation and competition and associated habitat-related modifications or loss. Cooperation and education with agencies, partners, Tribes, and Mexico are necessary to promote conservation of Gila chub and ensure habitat quantity and quality will be maintained and adaptively managed into the future. Other actions necessary to support the recovery strategy include captive rearing with appropriate genetic, demographic, and health management for population establishment and supplementation; control of threats related to potential hybridization with other chub species; establishment of replicated populations in refuges and selected streams; and monitoring of populations under a scientifically-based, standardized protocol.

Geographical distribution, habitat characteristics, and genetic variability can interact to produce the variation in life history, behavior, morphology, and other features that facilitate a species' ability to adapt to and persist within changing environments (reviewed in Hughes et al. 2008, Frankham 2010). Without such variability, local and range-wide probabilities of extinction increase (Frankham 2005) and the species' viability decreases. Therefore, it is imperative that the breadth of geographic distribution, ecological setting, and genetics be preserved where possible to secure the viability of the species. To preserve the geographic distribution, ecological settings, and genetic variability of the species (Figure II.1), we have designated recovery units (RU) that correspond to major Gila River subbasins currently inhabited by Gila chub. Preservation of this variability in each RU is necessary because it is estimated that Gila chub has been eliminated from approximately 90 percent of its formerly occupied habitat; many remaining populations are considered small, isolated, and subject to some form of threat; and the species' conservation status continues to decline (USFWS 2005b, Clarkson et al. 2012). If Gila chub populations and their habitats are protected, maintained, and replicated across the species' historical range, indicating that the primary threats to the species have been managed or eliminated, then the species will no longer be endangered throughout a significant portion of its range and will warrant downlisting or delisting.

Recovery Units

Representative ecological settings for Gila chub occur in the major subbasins of the Gila River basin that presently or historically supported the species (Agua Fria, Verde, Salt, Santa Cruz, San Pedro, middle Gila, and upper Gila). To our knowledge, all populations in the Salt River subbasin have been extirpated, and thus there are no remnant populations left to replicate there. We devised five RUs from the remaining six subbasins. The San Pedro and middle Gila subbasins were combined to form a single RU to provide additional replication streams for the San Pedro River subbasin remnant populations. The five designated RUs will advance the recovery concepts of representation, resiliency, and redundancy. Each of the six currently occupied subbasins captured within the five RUs is necessary for recovery of the species as a whole. For purposes of this recovery plan, RUs function as management subsets of the species created to carry out management actions necessary for both the survival and recovery of Gila chub (Figure II.1 and Figures D.1 – D.6). The RUs provide a diversity of habitats and represent groupings of Gila chub populations within which gene flow may have been common historically. Designation of RUs is intended to ensure the species remains distributed across its historical range in representative ecological settings, and will sustain the remaining genetic, demographic, morphological, behavioral, and other life history elements of the species necessary for the long-term conservation of the entire listed taxon.

Suitable streams in the Salt River subbasin (Figure D.6) will be utilized to assist with recovery of Gila chub populations from the Verde RU, which may have an insufficient number of suitable repatriation streams (see Appendix C, Table C.1.) within its geographic boundaries to meet down- and/or delisting criteria. This is due to the Verde subbasin's occupation by roundtail and headwater chubs, which may also require replication streams in the future. The Verde drainage is a tributary to the Salt River, and is the Salt River's nearest geographic neighbor within which to translocate populations. Repatriation of Gila chub to the Salt River repatriation area will further the restoration of the species into representative ecological settings across its historical range. Use of the Salt subbasin for this purpose will be geographically limited to the watershed upstream from the confluence with Gila River, exclusive of the Verde River subbasin and south-flowing tributaries to Salt River upstream of Roosevelt Dam (Figures II.1 and D.6). The latter exclusion is to limit contact of Gila chub populations with headwater chub in Tonto basin streams and roundtail chub in the mainstem Salt River and south-flowing tributaries upstream, including the White and Black river drainages. It is critical that conservation of headwater and roundtail chubs be considered, and herein we attempt to ensure that an adequate number of suitable streams remain available for their future conservation needs.

Management Units

The strategy to recover Gila chub further relies upon identifying, preserving, and replicating genetic Management Units (MUs) that are distributed among the RUs (Table II.1). MUs are defined as populations or groups of populations with sufficient allele frequency differences at either nuclear or mitochondrial loci to suggest low levels of gene flow and functional independence (Moritz 1994). A **population** is defined as a group or groups of individuals that have interbred at sufficient levels to prevent genetic divergence. Therefore, individuals at different geographically-isolated locations can be members of the same population if they were once physically connected and exchanged genes in the recent past. Under this scenario, individuals occurring at different locations would be considered members of subpopulations within a single MU, differentiated by location, with all subpopulations members of one MU metapopulation. In this usage, metapopulations can be maintained by management actions, where individuals are exchanged among populations that are geographically isolated. These populations are important for the long-term persistence of the species, but do not exhibit long-term independent evolution or strong adaptive radiation (Allendorf and Luikart 2007). From this point forward in the document, our usage of the term "population" accommodates these nuances of MU subpopulations and MU metapopulations.

Using the recommendations of Dowling (2013), who incorporated previous work by Schwemm (2006) and Dowling et al. (2008), there are a total of 17 genetically distinct conservation MUs of Gila chub spread across the 5 RU subbasins (Table II.1). Note that based on these data, multiple MUs exist in all of the major subbasins currently inhabited by Gila chub, with the exception of the Salt River subbasin, as described above. Only populations within four management units (1A, 3B, 4A, and 5D) currently have more than one genetically-representative population, and thus some redundancy against loss of genetic variability. The goal of Gila chub recovery (i.e., delisting) is to ensure the persistence of all remnant populations and their MUs by replicating them in the wild.

Figure II.1. Gila Chub Recovery Units. The Salt River subbasin is considered a replication area, and not a RU, to assist with recovery of Gila chub populations from the Verde RU.

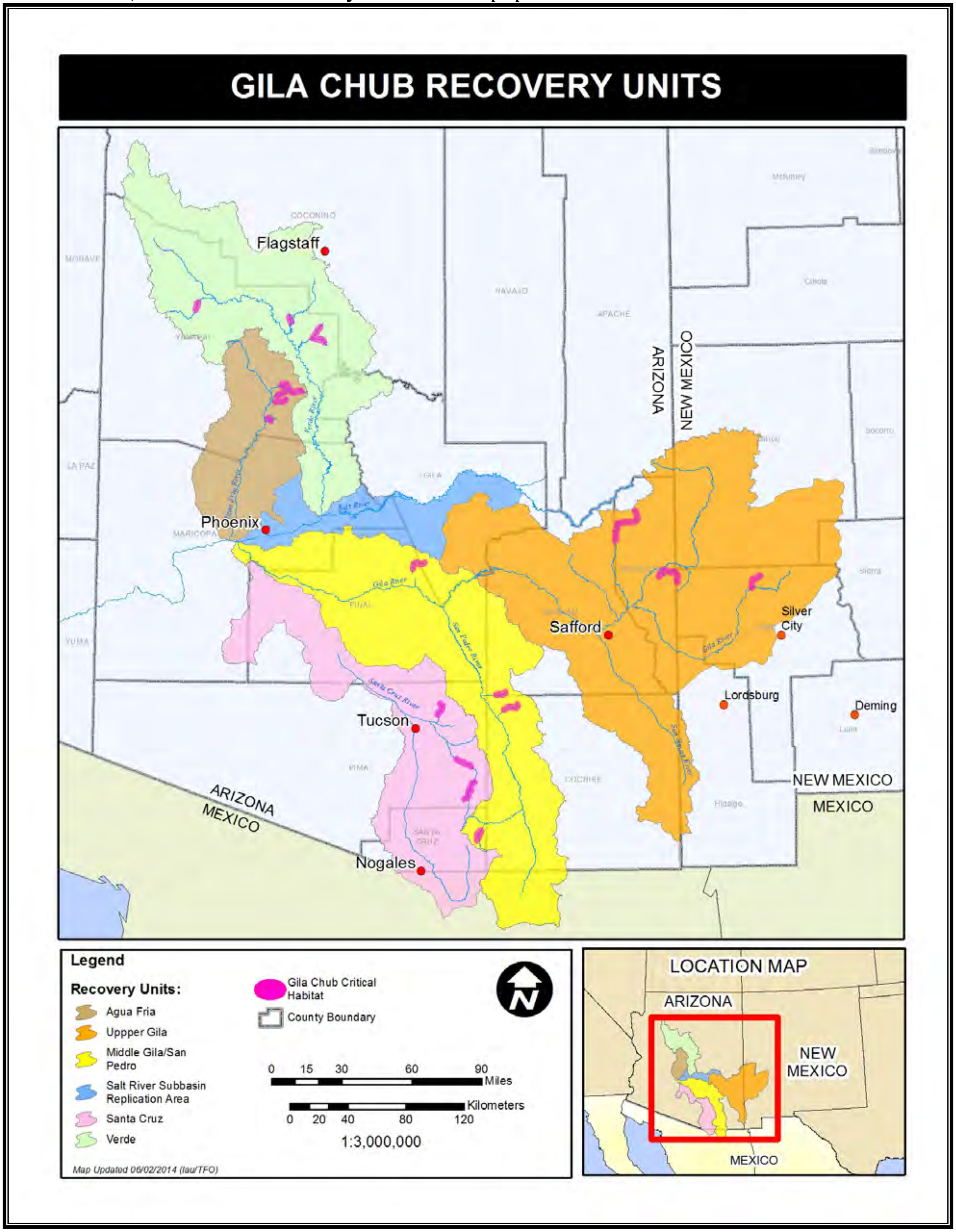

Table II.1 Management Unit designations for known extant populations of Gila chub (as identified in Minckley and DeMarais, 2000) to conserve genetic diversity, based on recommendations of Dowling (2013). Existing replicate and refuge populations are also shown.

Subbasin (RU)	**MU**	**Populations Examined** (remnant populations)[1]	**Other Extant Replicate Populations with Similar Genetic Information**	**Existing Refuge Populations**[3]
Agua Fria (1)	1A	Silver Creek Sycamore/Little Sycamore creeks	Larry Creek[2] Lousy Canyon[2]	
	1B	Indian Creek		
Verde (2)	2A	Walker Creek		
	2B	Williamson Valley Wash[5]		
	2C	Spring Creek		
	2D	Red Tank Draw		
Santa Cruz (3)	3A	Cienega Creek		
	3B	Sabino Canyon	Romero Canyon[2]	
	3C	Sheehy Spring		
San Pedro/ Middle Gila (4)	4A	O'Donnell Creek		San Pedro Preserve pond International Wildlife pond
	4B	Hot Springs/Bass canyons		
	4C	Redfield Canyon		
Upper Gila (5)	5A	Blue River (San Carlos)		
	5B	Eagle/East Eagle creeks		
	5C	Bonita Creek		
	5D	Dix Creek Harden Cienega Creek	Mule Creek, NM[4]	Red Rock Cienega, NM[4]
	5E	Turkey Creek, NM		

[1] **Remnant** populations are naturally-occurring wild populations.

[2] **Replicated** population, created to increase redundancy; a replicated population is redundant to its source population relative to genetic and morphological similarity. When a population is replicated in the wild in this recovery plan, we assume it is within the historical range of Gila chub, so is also considered a **repatriated** population.

[3] Existing **refuge** populations are separate, protected populations, typically in the form of artificial or semi-natural facilities that require some level of human assistance to maintain over the long term.

[4] Gila chub are present but the population is not considered established according to the recovery criteria outlined below.

[5] Assumed present; no data since 2003.

Replication of MUs
Identification of potential repatriation streams is just the first step in getting a population replicated and protected in the wild. Potential repatriation (or replicate) streams are streams known to occur within each of the RU subbasins but the suitability of each site for Gila chub replication is unconfirmed. Unfortunately, most potentially available and suitable streams for repatriation of Gila chub already have nonnative fishes present. Some nonnative fishes, such as fathead minnow, appear to have few negative impacts on native fishes, and others, such as mosquitofish (*Gambusia affinis*), may have effects on only certain native species such as Gila topminnow. Most other species (the most offensive probably being green sunfish and smallmouth bass [*Micropterus dolomieu*]), would have to be eradicated (typically via application of piscicides) and prevented from reinvading prior to repatriation of Gila chub to ensure the population is protected. Experience has shown this process is neither straightforward nor swift (AZGFD 2012, Finlayson et al. 2010, NMDGF 2005a, b). Streams may require construction of a fish barrier to prevent reinvasion, an activity that typically can add several years and potentially millions of dollars to the repatriation process.

For these reasons, establishment of refuge populations may be a simpler and faster means to establish initial redundancy of remnant populations. However, as refuges typically require sustained human management to ensure they remain suitable for Gila chub over time and they often are "atypical" habitats that potentially could select for certain traits that may not be adaptive in the wild, they are less desirable long-term alternatives to replicating populations in streams. Both options should be pursued simultaneously, but we expect that refuge establishment will result in the fastest establishment of population redundancy.

II.2 Recovery Goal

Ensure the persistence of Gila chub within its currently occupied historical range and recover the species by protecting remnant populations, expanding the existing distribution through replication of distinct lineages, and protecting and improving habitats for existing and future populations so that the species no longer meets the definition of endangered or threatened.

II.3 Recovery Objectives

1) Maintain and protect all remnant populations in the wild.
2) Ensure representation, resiliency, and redundancy by *maintaining genetic diversity*[4] and expanding the *size and number of populations* within Gila chub historical range via replication of remnant populations within each RU.
3) *Manage or eliminate* nonnative fish predation and competition and associated habitat-related modifications or loss.
4) Improve or develop new State regulations or agreements[5] that conserve or improve quality Gila chub habitat for as long as necessary.

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[4] Italicized phrases in the Recovery Objectives section are further described under similar topics (Genetic Representation, Population Parameters, Threat Reductions or Elimination, Outreach and Education, and Adaptive Management) found in the Justification for Recovery Criteria and Recovery Objectives section.
[5] Agreements may include agency management plans or documents that have undergone NEPA.

5) Work with stakeholders to improve and conserve existing and newly established Gila chub populations and their habitats and ensure that appropriate management plans/agreements are in place post-delisting.
6) Promote conservation of Gila chub in Mexico and on Tribal lands by forming partnerships and supporting research, *outreach*, and conservation management.
7) Monitor remnant, repatriated, and refuge populations to inform *adaptive management* strategies.

II.4 Recovery Criteria

Although protecting and replicating all known remnant populations of Gila chub is a primary objective, if one or more remnants or MUs within a RU become extirpated during the recovery period prior to them being replicated into either the wild or a refuge, this will not preclude recovery of the species, provided that all RUs are sufficiently represented. To minimize the potential for loss of remnant populations, replication priority should be directed first toward small or highly threatened populations that may have the greatest probability of extirpation. In many cases it may be quicker to replicate populations into refuges, and thus attention should be directed toward refuge development first, but not at the exclusion of protecting existing populations and readying streams for replication. Replication of all available remnant populations into protected streams is the ultimate recovery criterion. The down- and delisting criteria language below refers to all *available* populations, to accommodate the possibility that some remnant populations may become extirpated prior to their replication. Because each RU is considered to be essential to the recovery of a species, if an RU is lost, representing the loss of unique genetic ecotypes of that watershed, recovery as defined in this document cannot be achieved and the Gila chub's long-term viability could be jeopardized. If an RU becomes extirpated, we will re-visit the recovery plan to determine if the remaining population sizes, genetics, and habitat available could still lead to down- and delisting and determine if a recovery plan revision is warranted.

In addition, the prospects to protect remnant Gila chub populations (e.g., control sympatric nonnative fishes) are variable (Clarkson et al. 2012). Where options to protect remnants are few or complex, the need to replicate them becomes greater and more immediate, as threats will have more time to intensify and act negatively on the populations. This reality further compels a rapid replication process to insure against remnant population losses. Replicate populations act as a buffer against extirpation of specific MUs and they do not lessen the value of extant remnant populations. It is imperative that all efforts be made to prevent loss of remnant, wild populations.

We developed a prioritization scheme to direct management efforts toward population replications by assigning weighted population size scores (low, medium, high, according to Table I.3), totaling the number of threats to each population from Table I.4, and ranking populations according to conservation priority, as developed by Clarkson et al. (2012). We then added the three parameters to derive replication priority scores that are shown in Table C.2 (Appendix C). We recommend that initial replication efforts be directed first toward those remnant populations that have the highest priority according to Table C.2. Information in the tables in Appendix C will change as recovery of the species progresses and in response to natural stochastic events; thus data in these tables will be updated as needed, and will function as a separate module located on the USFWS Arizona website.

Terms underlined in the criteria are defined more explicitly in the justification section below.

Downlisting Criteria
Downlisting of Gila chub from endangered to threatened may be warranted when all of the following downlisting criteria are met:

Demographic Criteria:

A-1. *Remnant populations* (those naturally occurring in the wild)
All available remnant populations within each RU are maintained in a protected stream, and trends of recruitment and population size indices are considered stable or positive over the most recent rolling 10-year period. The protection of remnant populations is the priority, followed by the replication criteria below.

i. Trends of recruitment may be adequate if the regression slope of catch-per-unit-effort (CPUE) estimates of young-of-year present during autumn monitoring is zero or positive over the 10-year period, and the regression slope of CPUE for the total population is not negative over that same period.
ii. Remnant populations that are augmented will follow the same criteria as above except that the rolling 10-year period begins after the last augmentation event.

A-2. *Replicate populations* (refuge and repatriation populations)
Each MU (consisting of one or more extant populations according to Table II.1) is replicated into either two streams or one stream and one artificial refuge within the same RU.

i. Replicate populations are established and maintained in a protected stream, and meet recruitment and population size CPUE trends described above for remnant populations over a 10-year period. Artificial refuges are established and meet recruitment and population size CPUE trends described above over a 10-year period.
ii. Artificial refuges are located within the geographic boundaries of the RU from where the MU is being replicated, although quarantined hatchery populations can be excepted from this restriction, as can refuges of RU2 (Verde River subbasin), which may also be located in the Salt River repatriation area. Because the recovery objective is to have the species persist without continual human management intervention, only a single refuge population per MU can count toward downlisting, although establishment of additional refuges is encouraged to provide additional redundancy.

Threats-based Criteria:

A-3. All available remnant populations and their replicates are protected against nonnative fish predation and competition, as measured by the achievement of the demographic criteria (A-1.i, A-1.ii, and A-2.i). Each remnant and replicate population has its own unique set of challenges and management requirements that will be necessary to adequately protect the population from nonnative fishes. Therefore, protection for each site will be evaluated on a case-by-case basis using the applicable standards defined below (see the summary of down- and delisting criteria terms section).(addresses Listing Factors C and D; see the summary of down- and delisting criteria terms section).

A-4. The recruitment and survival rates described in criteria A-1.i., A-1.ii., and A-2.i. will be used to determine when significant threats to remnant and replicate populations (e.g., water availability, habitat alteration, and fragmentation) are controlled to manageable levels such that the threats do not pose imminent or chronic downward pressures on population sizes (addresses Listing Factors A, C, D, and E).

Delisting Criteria

Delisting of Gila chub may be warranted when both downlisting and delisting criteria are met. The major difference between downlisting and delisting criteria is that two stream replicates of each remnant population are required for delisting and refuge populations are no longer necessary. Delisting criteria are as follows:

Demographic Criteria:

B-1. *Remnant populations* (those naturally occurring in the wild)
All available remnant populations within each RU are <u>maintained</u> in a <u>protected</u> stream, and trends of recruitment and population size indices are considered stable or positive over the most recent rolling 10-year period.

i. Trends of recruitment may be adequate if the regression slope of CPUE estimates of young-of-year present during autumn monitoring is zero or positive over the 10-year period, and the regression slope of CPUE for the total population is not negative over that same period.
ii. Remnant populations that are augmented will follow the same criteria as above except that the rolling 10-year period begins after the last augmentation event.

B.2. *Replicate populations* (refuge and repatriation populations)
Each MU (consisting of one or more extant populations according to Table II.1) is replicated in at least two streams.

i. Replicate populations are established, and maintained in at least two protected repatriation streams, and meet the recruitment and population size CPUE trends described above for remnant populations over a 10-year period. Replicate streams are located within the geographic boundaries of their respective RUs with the exception of RU2 (Verde River subbasin), which can also utilize the lower Salt River subbasin (as defined in Section II.1) for replications.
ii. Maintenance of refuge populations is not required once each MU has been replicated twice into repatriation streams. However, refuge populations are

recommended to be maintained past delisting to provide additional population redundancy.

Threats-based Criteria:

B-3. Continuation of A-3. and A-4. from downlisting criteria (addresses Listing Factors A, C, D, E).

II.5 Justification For Demographic Recovery Criteria

These following demographic explanations also relate back to Section II.3 Recovery Objectives

The primary objective for each RU is to maintain, replicate, and protect all remnant populations (or MUs). However, during what may be a long recovery process, some remnant populations may be eliminated by unforeseen natural events (e.g., wildfire) prior to them being replicated. Although such losses would diminish the genetic variability inherent within the species, they would not preclude down- and delisting of the species, provided a RU still has a remnant population that could serve as the basis for the species' recovery in a RU.

Establishment of population redundancy to guard against irreplaceable losses of representative MU populations from catastrophic events is a major tenet of conservation biology. This is best accomplished by replicating remnant populations into suitable replication streams that will not require continual human intervention to maintain them. For downlisting, because it may be more expedient to replicate MUs into artificial refuge populations as opposed to natural streams where threats must first be eliminated or controlled, population redundancy in the form of refuges can significantly advance the recovery process until a sufficient number of repatriation streams are readied. A minimum of two redundant populations for each MU remnant (rather than just one) is necessary to preclude crisis management in the event that one population is lost and only a single population remains. The minimum number of individuals needed for redundant populations is described in the Population Parameters section below.

The primary functional difference between down- and delisting criteria is the replacement of downlisting-established refuge sites with additional stream repatriation sites for delisting so that each MU is replicated at least twice with wild stream populations. This change removes the requirement for sustained human management of artificial refuges after the species is delisted, while retaining the preferred recovery goal of double redundancy of all MUs.

The additional requirement that all replicate populations be established for 10 years past the last significant stocking event is to ensure each has persisted through at least three generations and a variety of hydrological and disturbance events. Table II.2 lists the current status and needs for population replication and refuge establishment for down- and delisting criteria for each MU. Although Table II.2 (or Table C.3 for future updates) quantifies the numbers of populations needed to meet down- and delisting criteria, it does not consider threats to the populations that must be abated or controlled before the populations qualify for down- or delisting.

Table II.2. Status and minimum needs for establishment of wild replicate and refuge populations for downlisting and delisting of Gila chub according to recovery criteria (two wild populations plus one refuge to downlist, three wild populations to delist). The number of replicates needed to delist are in addition to those needed for downlisting. See Table II.1 for a description of management units (MU). n/a denotes not applicable. *Information presented in this table is based on the status at the time of the final recovery plan. A copy of this table is provided in Appendix C (Table C.3) and will be updated as the situation changes.*

			No. of stream replicates			No. of refuges			Currently meets criteria to	
		No. of		Needs to			Needs to			
Recovery Unit	MU	remnants	Extant	Downlist	Delist	Extant	Downlist	Delist	Downlist?	Delist?
Agua Fria (1)	1A	2	2	0	0	0	0	n/a	Yes	Yes
	1B	1	0	1	1	0	1	n/a	No	No
Verde (2)	2A	1	0	1	1	0	1	n/a	No	No
	2B	1	0	1	1	0	1	n/a	No	No
	2C	1	0	1	1	0	1	n/a	No	No
	2D	1	0	1	1	0	1	n/a	No	No
Santa Cruz (3)	3A	1	0	1	1	0	1	n/a	No	No
	3B	1	1	0	1	0	1	n/a	No	No
	3C	1	0	1	1	0	1	n/a	No	No
San Pedro (4)	4A	1	0	1	1	2	0	n/a	No	No
	4B	1	0	1	1	0	1	n/a	No	No
	4C	1	0	1	1	0	1	n/a	No	No
Upper Gila (5)	5A	1	0	1	1	0	1	n/a	No	No
	5B	1	0	1	1	0	1	n/a	No	No
	5C	1	0	1	1	0	1	n/a	No	No
	5D	2	0	0	1	0	1	n/a	No	No
	5E	1	0	1	1	0	1	n/a	No	No
Cumulative total	**17**	19	3	**14**	**16**	2	**15**	n/a	1	1

Here we reiterate that if an extant remnant population is extirpated during the period covered by this Recovery Plan, it does not preclude down- or delisting, provided that the other criteria are met. However, if several MU populations within a given RU are extirpated in advance of them being replicated into refuges or repatriated streams (and thus their genetic legacy is lost or severely depleted), and such losses suggest that the evolutionary legacy of the species within a RU has been damaged to the point that the species cannot ever be down- or delisted according to the existing plan, other alternatives would have to be considered. If all of the MU populations within a given RU are extirpated; down- or delisting of Gila chub would not be attainable. Should either scenario occur, we would revisit the Recovery Plan and determine if a Recovery Plan revision is needed. To minimize the chances of losing remnant populations, establishment of refuge populations should be the top recovery action priority in MUs where only a single population is extant, unless it is more expedient to repatriate populations in protected streams.

Several terms such as a protected, established, maintained, recruitment and population size, and stable or positive are mentioned in the downlisting and delisting criteria above. Here we expand on the purpose and meaning of these terms related to recovery criteria and also describe where there are specific limitations. The descriptions below support the down- and delisting criteria.

Protected

A protected stream or population is one where all of the major limiting factors that may exert downward pressure on population size are eliminated or controlled (See Figure II.2 above). These factors do not include normal characteristics of the environment such as extremes of weather or predation/competition among the native biotic assemblages, but rather those under the primary control of humans. Foremost among these are: (1) elimination or control of introduced nonnative fishes (see further descriptions in A through C below); (2) determination that water uses are not reducing or altering natural stream flow availability or variability; and (3) administration of land uses that may affect vegetation, sedimentation, or water quality. Many of the remnant populations currently do not meet these criteria because they are threatened by nonnative fishes and other factors. Impacts from nonnative fishes are not only one of the most significant threats to populations, but management of that threat is a complex and difficult undertaking. Management of threats may be the most intractable aspect of Gila chub recovery, but is ultimately the primary action necessary to conserve and recover the species.

Because the elimination or control of introduced nonnative fishes is such a complex issue, we further define the protection of a Gila chub population from predation and competition from nonnative fishes as follows: (A) nonnative fishes have a minimal presence within a stream reach occupied by a population; or (B) nonnative fishes have a low potential to invade the occupied stream, or the most offensive nonnative species have been removed from a protected stream reach; or (C) management agencies have made a long-term commitment to actively suppress nonnative fishes for a given stream through mechanical or other means of removal. Because there are specific challenges for each population with respect to nonnative fish management, we believe any combination of A through C is sufficient as long as remnant or replicate populations are supported via evidence of an established and stable or positive population index (i.e., recruitment and population size indices).

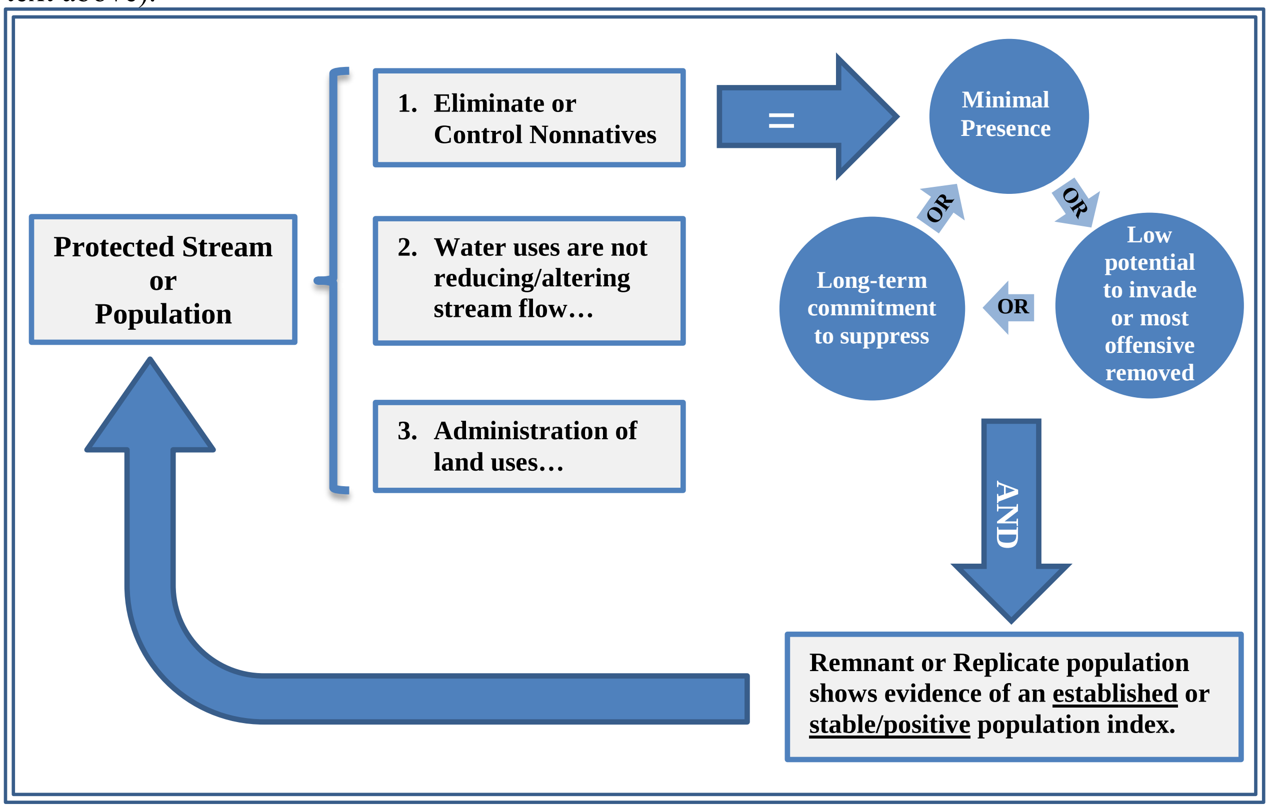
In the Population Parameters section (below), we state that our ability to provide reliable estimates of absolute population sizes and recruitment rates is limited. A stable or positive population is difficult to measure directly since we do not have adequate absolute population size and trend data. For this reason, we rely upon estimates of CPUE as an index of population size. This reliance will lessen potential negative effects of repeated sampling on populations and reduce the costs of monitoring. Therefore, recruitment will be considered adequate if the regression slope of CPUE estimates of young-of-year present during autumn monitoring is zero or positive over the 10-year period; and the population size will be considered adequate when the regression slope of CPUE for the total population is not negative over that same period.

Established

Populations will be considered established when their size and recruitment, as evidenced by CPUEs, remain stable at acceptable levels considered appropriate for their respective habitats, or they exhibit increasing trends. Remnant populations are already considered established; however, replicate populations will need to show evidence of stable or increasing (see description below) trends of CPUE in order to be considered established. Evidence of recruitment documents that reproduction is occurring and annual cohorts are surviving across years to replace the aging population of reproducing adults. Successful reproduction and recruitment need not occur every year, but the trend in recruitment CPUE must be neutral or positive over the most recent rolling 10-year period to assure that the population remains viable over time. For purposes of this plan, evidence for recruitment is based upon detection of young-of-year during autumn.

Maintained
We assume that if major threats have been addressed and are verified by the applicable demographic criteria above, a population will be considered protected and maintained, and therefore Gila chub will be eligible for down- or delisting when replication criteria are achieved.

Figure II.2. Abbreviated flow chart depicting Protected Stream or Population Criteria (based on text above).



Genetic Representation
An essential aspect of Gila chub recovery is ensuring that all wild and refuge populations are genetically representative of the source MU populations. Most wild populations have been genetically characterized and reported (Schwemm 2006, Dowling et al. 2008, Dowling 2013). Remaining wild populations must be genetically characterized prior to delisting to ensure that all MUs have been correctly identified and replicated as necessary. Newly-replicated and refuged populations will also need to be characterized as they become established. It is expected that periodic transfers, using a standardized protocol, of small numbers of individuals among remnant, repatriated, and refuge populations will be needed over time to ensure they are and remain representative of each other.

Gila chub is a member of the roundtail chub complex, including roundtail and headwater chubs that are widely distributed in the Gila River basin. These latter two species are also under consideration for protection under ESA, making it critical that we consider them when designing the recovery plan for Gila chub. Since these three species will likely hybridize, they cannot be stocked into the same refuges or stream reaches. There is limited space for establishing protected populations of chub within the Gila basin, further complicating the design of the recovery program for Gila chub. These factors were all considered in the development of this recovery plan, specifically in assigning priorities to management units and identifying population replication streams.

Morphology and meristics of the *G. robusta* complex (*G. robusta*, *G. nigra*, and *G. intermedia*) in the Gila River basin have not been fully characterized. Due to strong similarities in the physical appearance of taxa within the complex, in some cases it is uncertain which species inhabits which streams. Therefore, to correctly assign all populations to the correct species, morphometric and osteological analysis of the complex must be completed prior to delisting of Gila chub. That analysis also will aid in the genetic characterization of the complex, facilitate species assignments, and document the morphological and genetic breadth of variation within and among these species.

Population Parameters

A self-sustaining population is defined as one that successfully reproduces on a near-annual basis and recruits young into older age classes that then reproduce themselves, thereby maintaining a relatively consistent age-class structure over time. Self-sustaining also implies that population sizes vary above a minimum level reflective of their respective habitat carrying capacities and will persist through most environmental perturbations. Populations should also be genetically robust, characterized by the genetic capacity to survive and respond to environmental changes within populations, among populations, and across the range (Redford et al. 2011). This implies that populations are large and genetically diverse, with no evidence of severe genetic bottlenecking. Finally, healthy populations are those that are minimally impacted by parasites and disease.

A pragmatic goal based on a minimum viable population size criterion is for each population to be comprised of 5,000 or more sexually-mature adults (Traill et al. 2010). A population with fewer than 5,000 adults has reduced capacity to adapt to changing environments and increased vulnerability to extirpation. However, many remnant Gila chub populations are found in habitats that likely could never support such numbers (e.g., Indian Creek, Sheehy Spring). For these populations, where feasible, the goal is to replicate them into new protected habitats so that total combined sizes of the source and replicate population within an MU is at least 5,000 adults. Periodic translocations of individuals among the source and replicate populations will be necessary to maintain genetic variability within these source-replicate populations. Optimally, minimum population size objectives for individual replicate populations should be 500 adults, which is a size needed to reduce the likelihood of inbreeding and stochastic loss of genetic variation (Franklin 1980).

Although these population size goals are quantitatively expressed here, we do not intend they be required or quantified as criteria for down- and delisting. Not only will the amount of sampling effort needed to statistically quantify population sizes of dozens of remnant and wild replicate populations over a sufficient monitoring timeframe be extreme (e.g., requiring multiple mark/recapture or pass-depletion surveys over a period of many years), but those intensive efforts also could negatively impact those populations through repeated disturbances and increased mortality. Realistic and achievable recovery options for Gila chub indicate that the habitats of some remnant or replicate populations may not always be large enough or of sufficient suitability to support population sizes of even 500 adults. Therefore, this approach to recovery relies more upon ensuring that there are sufficient numbers of representative and redundant populations maintained in MUs across the species' historical range rather than insisting they be of a certain minimum size that may affect resiliency. As a result, Gila chub should be considered a "conservation-reliant" species where certain MUs may require periodic management intervention against stochastic losses, loss of genetic variability, and threats such as groundwater withdrawal and nonnative species even after delisting (Scott et al. 2005, Rohlf et al. 2014). The recovery process for Gila chub therefore will require implementation of a post-delisting management plan/agreement (in addition to the ESA required post-delisting monitoring plan) to prevent the species from requiring future ESA protections that might otherwise be necessary due to stochastic losses of small populations or new threats

Regardless of our attempts to reduce or eliminate threats the landscape, we expect periodic management intervention will be necessary to maintain the nuances of a protected population for as long as necessary. Scott et al. (2005) recommend the implementation of a post-delisting recovery management agreement (RMA) for "conservation reliant" species that includes biological standards and a set of legal requirements that is drafted by willing partners who agree to fulfill the long-term obligations of the RMA. The recovery team supports the adoption of a similar management plan/agreement to further the conservation practices post-delisting. Therefore, a post-delisting management plan/agreement will be developed and implemented at a minimum of five years prior to delisting. The agreement should include a set of similar recovery criteria standards (i.e., protected, established, maintained, and stable or positive) for each MU to prevent the species from requiring future ESA protections that might otherwise be necessary due to stochastic losses of small populations or new threats (Scott et al. 2005). The management plan/agreement should be drafted and signed by State, Tribal, Federal, and private landowners, who are willing partners to implement periodic management activities to prevent Gila chub from requiring future ESA protections.

Population Replication

Establishment of redundant MU populations within the geographic boundaries of their respective RUs is essential to maintain discreet and genetically-related ecological segments within a RU. This requirement eliminates the potential for escape of individuals into waters where they could potentially interact reproductively with other MUs that are genetically unique. Hatcheries with suitable barriers that prevent escape of fishes into the surrounding watershed can be exempted from this criterion. The exception for RU2 population repatriations into the Salt River subbasin is to both enhance recovery prospects of that RU by identifying additional repatriation streams that are rare within the RU boundaries, and also to restore the species into the formerly-occupied lower Salt River subbasin. Re-occupation of the Salt River subbasin can restore additional ecological representativeness and geographic distribution for the species and facilitate its continued evolution.

Time Frame

The requirement for a minimum rolling 10-year period with trends of neutral or positive recruitment and population indices is to ensure the population is established, self-sustaining, and is not being negatively influenced by threats. The 10-year criterion was established by the International Union for Conservation of Nature (IUCN) as a guideline to categorize degrees of species rarity in their Red List by ensuring that population status and trend accommodates passage of a minimum of three generations or 10 years, whichever is greatest (IUCN 2014). We employ this same criterion to assist us with determining when a repatriated population is stable enough to be considered established. Generation length is defined as the average age of parents of the current cohort, and is the average time it takes one age class of breeding individuals to be replaced by its progeny (IUCN 2014). Generation length of Gila chub is approximated at three years, based upon age at first reproduction between 1 to 3 years and longevity greater than 4 years (Bestgen 1985, Griffith and Tiersch 1989). Therefore the 10-year period is needed to assess population status and persistence following cessation of each repatriation effort.

Trend Estimates

There are no mortality schedules available for Gila chub to determine how many fish need to be added to a population via reproduction and recruitment over what frequency to maintain a stable population over time. Relative abundance of young-of-year (age-0) fish collected in autumn appears an accurate index of that cohort strength in future years, and thus may be a reasonable index of recruitment (e.g., Willis 1987, Smith et al. 2005). Recruitment will be considered successful and adequate if the regression slope of CPUE estimates of young-of-year present during autumn is zero or positive over the 10-year period, as long as the regression slope of CPUE for the total population is not negative over that same period. The latter situation would indicate that the level of recruitment is not great enough to overcome mortality rates of older age classes, and the population is in decline. We recommend that sampling to determine CPUE be conducted every other year so that regression slopes of recruitment and population size indices covering the 10-year monitoring period would be based on a sample size of at least five using a 95 percent confidence level in our trends. If the resultant slopes are negative, the monitoring period must continue until the slope is zero or is positive over the most recent rolling 10-year monitoring period in order for the population to be considered stable or established. In order for this recommended sampling regime to be valid, size-class sampling biases inherent with certain gear types must be carefully avoided to ensure autumn samples are representative of the population structure.

We are measuring recovery by the number of populations established, and not by a perpetual expansion of the size of each population. Inclusion of the neutral terms "stable" and "zero" (above) relative to population size trends (as estimated by regression slopes of CPUE) is necessary because the populations cannot be expected to exhibit perpetual positive increases. There are habitat carrying capacity limitations that will always place a "check" on population sizes. In other words, once a population reaches its carrying capacity (which can fluctuate depending on environmental conditions), its size will stabilize, which explains the need to retain the "stable" and "zero" terms. This is especially true for established, remnant populations, but also will hold for newly replicated populations once they reach carrying capacity. As long as the slope of the population trend lines over the rolling 10-year monitoring period are not negative, the population will be considered stable.

Monitoring Plan

We recognize that in most cases we do not have adequate population trend data to determine if a population is stable, increasing, or decreasing in abundance. The development of a scientific monitoring plan is a necessary recovery action (see Recovery Actions below) that will focus on monitoring Gila chub populations and natural and anthropogenic processes that negatively influence the species and its habitat. The monitoring plan will also explicitly develop guidelines to monitor and maintain genetic variability of Gila chub populations that conserve the maximum genetic representation, as well as monitor natural and anthropogenic threats that may influence populations. Wild populations that have not yet been genetically characterized as well as newly-replicated and refuged populations will be genetically and morphologically characterized to assess genetic representation prior to delisting and ensure that all MUs have been correctly identified and replicated as necessary. The monitoring plan should include strategies to guide future recovery actions and should be reviewed and updated every five years. Once this plan is developed, we may have more definable quantitative standards that will support recovery objectives.

Justification For Threats-based Recovery Criteria

Management of threats to the continued existence of Gila chub is necessary to ensure that the underlying causes of decline have been addressed and mitigated prior to considering the species for delisting. The courts have affirmed the intent of Congress that the five statutory factors considered during the federal listing process should also be addressed in the delisting process (Fund for Animals v. Babbitt, 903 F. Supp. 96 (D.D.C. 1995)). Considerable case history has demonstrated that the presence of certain nonnative aquatic organisms, in particular many nonnative fishes, is the most important factor contributing to continued decline of the native fish fauna of the American southwest, and is the most serious impediment to its conservation and recovery. Published studies and anecdotal evidence support this conclusion specifically for Gila chub. Other threats such as water withdrawals and wildfire are known primary factors in losses and declines of Gila chub populations. The specific identification of threats and methods to eliminate or manage them will significantly enhance recovery prospects for Gila chub if threat reduction techniques are implemented.

<u>Threat Reduction or Elimination</u> - The following threats also relate back to Section II.3 Recovery Objectives

<u>Stream Desiccation</u>
A fundamental strategy in almost all recovery plans is to eliminate or manage factors that threaten a species' persistence. For any fish, the persistence of water is the primary element necessary for survival, and this limiting factor is especially critical in the arid Gila River basin against the backdrop of continued human population growth and predicted climate change (IPCC 2007, 2013). Many streams occupied by Gila basin fishes have succumbed to desiccation (Miller 1961), and protection of flows within remaining streams is of utmost importance for their conservation. The highest level of protection is where ground water withdrawal in excess of recharge rate has been prevented or reversed via mechanisms such as application of Federal Reserved Water Rights or conservation easements.

<u>Management Agreements</u>
For refuges that require periodic or long-term management intervention, the development of one or more recovery management agreements from government (Federal, State, or Tribal), NGOs, and the public will be necessary. These agreements are intended to ensure that water quantity

and quality in refuges occupied by Gila chub are maintained at levels required to sustain the species and that threats are minimized or eliminated.

Nonnative fishes
Where perennial streams remain, the most significant and common threat to Gila chub is the presence of nonnative fishes that suppress or eliminate populations via predation, competition, and other mechanisms. Nonnative fishes will be considered eliminated when a stream reach that supports a population is nonnative-free and protected against future invasion by a natural or constructed fish barrier. Threats from nonnative fishes may be considered managed: 1) when nonnative fishes have a minimal presence within an occupied stream; or 2) when the most offensive nonnative species have been removed from a protected stream reach; or 3) where there is a long-term commitment to actively suppress nonnative fishes through mechanical or other means of removal; and 4) when removal/suppression efforts show positive results in the reduction of nonnative fish numbers and distribution and an increase in Gila chub abundance and distribution.

Fragmentation/genetic isolation
An essential element for long-term survival of a species is connectedness among populations that allows for exchange of genetic material that can enhance a species' ability to adapt to changing environments (Pringle 2001, Hermoso et al. 2011). Evidence from genetic studies (Schwemm 2006, Dowling et al. 2008, Dowling 2013) indicates Gila chub likely exhibited a metapopulation distribution with movement of individuals among populations in the same subdrainages during pluvial times and isolation during drier periods. Most Gila chub populations are now mostly isolated from each other due to interference by nonnative fishes, desiccation of connecting habitats, and other factors.

Given the degree of human impacts to streams of the Gila River basin, natural connectivity among populations of Gila chub is unlikely now and in the foreseeable future. In fact, the near-ubiquity of nonnative fishes across the Gila River basin that are known to suppress or eliminate populations of Gila chub (e.g., Dudley and Matter 2000) requires that the native and nonnative taxa be segregated (see Fausch et al. 2009 for a discussion of the tradeoffs between connectedness and isolation relative to threats of nonnative fishes). Such isolation management (Novinger and Rahel 2003) is typically practiced via placement of artificial barriers that prevent upstream movements of fishes, management upstream of natural barriers, or directed control of nonnative fishes where barriers do not exist. Provision for genetic connection among such segregated tributary populations will likely occur only from human-assisted transfers, guided by genetic information to inform managers of levels of past connectivity. In the absence of nonnative fishes, retention of connectivity among populations is the preferred management condition. However, where nonnative fishes threaten persistence of Gila chub, isolation management is the inelegant but compelling approach to conservation.

Anthropogenic development
Most if not all stream habitats within the greater Gila River basin have been significantly altered as a result of human land uses such as road construction, livestock grazing, silvicultural practices, dam emplacement, water diversion, groundwater pumping, and introduction of nonnative fishes. These continuing uses largely caused the endangerment of Gila chub, and thus

the potential for recovery of the species is greatly diminished as long as these practices continue unabated.

Assumptions

If major threats have been addressed and populations remain stable or expand over a period of years, we assume that ecosystem processes are functioning reasonably. When they do not, we assume the status of populations will reflect that degradation and compel further implementation of specific recovery actions identified in the step-down outline.

Outreach and Education

For recovery to be implemented and be sustainable, support for the recovery program by government agencies, non-governmental organizations , and the public must be developed. Because Gila chub populations will need to be replicated and expanded across a variety of landscapes held by various landowners to achieve recovery, acceptance of and support for the recovery program by those landowners will be necessary. In addition, more general support for the program by the public will be beneficial to ensure that management actions are successful and sustainable. USFWS, Federal land owners, and State wildlife management agencies should lead these outreach efforts. Cooperation with the San Carlos Apache Tribe will be necessary to replicate the Blue River MU (5A) according to recovery criteria in section II.4. Coordination with other Indian nations and Mexico needs to occur, since Gila chub historically occupied and may still occupy portions of their lands. It would be highly desirable to have those entities repatriate and manage Gila chub populations within their borders.

Adaptive Management

Not all information necessary to recover Gila chub is known, and circumstances across the recovery landscape will undoubtedly change over time. Thus the recovery process will need to be flexible and adaptable to changing conditions. Such uncertainty can be accommodated within an adaptive management process, whereby management actions and responses are modified according to receipt of incoming information. Recovery Plan revisions will undoubtedly become necessary over time, and they will document such changing conditions. If recommended changes to the recovery plan do not represent a major change in the recovery direction (i.e., changes do not indicate a shift in the overall direction of recovery), then it can be considered an "update" that can be documented among the recovery team members. If recommended revisions constitute significant modification in the direction of the recovery plan, then a "revision" of a relevant portion or portions of the recovery plan may be warranted, which can be accomplished through replacement of the appropriate module within the recovery plan, or addressed through 5-year recovery plan reviews.

II.5 Recovery Unit Description and Needs

Recovery Units are defined in the Interim Endangered and Threatened Species Recovery Planning Guidance (NMFS 2010) as "management subsets of the listed species that are created to establish recovery goals or carry out management actions." Here we also stipulate that RUs are necessary for both the survival and recovery of the species, and that implementation of recovery criteria in each is a requirement for down- and de-listing.

There are five RUs that correspond to the major subbasins of the Gila River drainage that currently are occupied by Gila chub (Figure II.1.), and thus they are within historical range and have potential to contribute toward recovery of the species. Populations within these units are now essentially isolated from other units, and thus they form discreet, disconnected, and genetically-related ecological segments from which to manage the species. All but RU2 (Verde River subbasin) contain a potentially suitable variety of perennial streams for sustaining the number of remnant and/or replicate populations necessary for recovery. We have set aside the historically-occupied but now vacant lower Salt River subbasin to assist with repatriations of RU2 remnant populations.

Implementing the overall recovery design to replicate each MU twice into repatriation streams will be challenging given the paucity of suitable streams available, the degree of threat to streams within the catchments, the number of native fishes needing recovery habitat, potential conflicts with established nonnative sport fisheries, and the high cost of implementing protective measures. Long-term actions to improve watershed function in occupied and recovery stream drainages should be initiated.

Brief descriptions and critical recovery needs for each RU are presented below.

Recovery Unit 1: Agua Fria River Subbasin

Description

RU1 includes the entire Agua Fria River watershed upstream from the confluence with Gila River (Figure D.1). The Agua Fria subbasin is the system furthest downstream in the Gila River basin that currently supports or is historically known to have supported Gila chub. Elevations within the subbasin range from 277 m (909 ft) at the confluence with the Gila River to approximately 2,382 m (7,815 ft) at Mingus Mountain that forms part of the drainage divide with the Verde River subbasin to the east. The Agua Fria subbasin is arid and poorly watered, and perennial reaches are mostly short and have low base discharges. The watershed drains approximately 7,164 km^2 (2,766 mi^2). A single major reservoir (Lake Pleasant) is situated on the mainstem in the lower portion of the basin. Land ownership is approximately 46 percent federal, 34 percent private, and 19 percent state lands (Figure D.1).

There are three remnant populations in the Agua Fria subbasin that comprise two MUs. Silver and Sycamore/Little Sycamore creeks form MU1A, with Silver Creek serving as the source population for two established replications (Larry Creek and Lousy Canyon). Indian Creek forms MU1B; there are no replications into either wild or refuge sites for this population. The Agua Fria River mainstem was historically occupied, but that population is now considered extirpated, as is an historical population (designated *G. robusta* in the museum record, but likely *G. intermedia*) from Ash Creek (Table I.3). The three extant populations are found in tributaries to the east of the Agua Fria River near the town of Cordes Junction, Arizona. The northernmost population, Sycamore Creek and its tributary Little Sycamore Creek, are likely part of the same interconnected population. The other populations are mostly hydrologically disconnected due to ephemeral discharge of the intervening mainstem Agua Fria River.

Recovery Needs
MU1A already meets the down- and delisting goals of having been replicated at least twice in the wild (Table II.2). MU1B requires establishment of at least one wild replication and one refuge replication for downlisting goals, and replacement of the refuge with another stream replication for delisting. Three potential refuges and eight potential replication streams have been identified within the geographic boundaries of the RU that might serve as redundant populations for the Indian Creek remnant population (Table C.1); none have potential to interfere with headwater or roundtail chub conservation as neither species is native to the subbasin.

A general lack of water that limits Gila chub distribution within the subbasin, and presence of nonnative fishes at some localities are the primary threats to the remnant populations in RU1. Weedman et al. (1996) noted that cattle grazing and recreational uses within some of the streams may be additional potential threats to the populations. A natural fish barrier (waterfall) on Silver Creek has prevented invasion of nonnative fishes into the uppermost reaches, but the protected reach has only a few kilometers of perennial water (Weedman et al. 1996). The replicated populations in Lousy Creek and Larry Canyon are persisting, and there are no threats from nonnative fishes.

Natural barriers on Sycamore Creek have protected a portion of the population from warmwater nonnative fishes, but nonnative rainbow trout is present upstream, and a suite of warmwater nonnative fishes below the lowermost barrier may prevent reproduction and recruitment of Gila chub there (Weedman et al. 1996).

The Indian Creek population was not detected until 1995, and in 2005 a portion of the population was salvaged as a precaution following the Cave Creek Fire Complex and later successfully returned. Surveys of the Indian Creek population conducted in 2012 suggest the population sustains fewer than 500 sexually-mature adults, and therefore it has a relatively high susceptibility to random extinction events and bottlenecking. Indian Creek ranked sixth among the 13 remnant populations prioritized for replication need (Table C.2). The USFS has implemented long-term actions to improve watershed function in occupied and recovery stream drainages on land they manage.

Recovery Unit 2: Verde River Subbasin

Description
RU2 includes the entire Verde River watershed upstream from the confluence with Salt River (Figure D.2). The Verde subbasin drains approximately 17,158 km^2 (6,625 mi^2) in the north-central Gila River basin between the Agua Fria and Salt subbasins. Elevations range from 402 m (1,319 ft) at the confluence with Salt River to 3,850 m (12,632 ft) at Humphrey’s Peak north of Flagstaff, Arizona. The Verde mainstem downstream from Sullivan Lake is mostly perennial to its confluence, and several large tributary systems contribute perennial flows, primarily from the eastern side of the drainage. There are two major reservoirs on the mainstem (Horseshoe and Bartlett) in the lower portion of the system. Land ownership is approximately 65 percent federal, 23 percent private, 10 percent state, and 2 percent tribal (Figure D.2).

Gila chub populations are recently known from only four sites within the Verde River subbasin: Red Tank Draw, Spring Creek, Walker Creek, and Williamson Valley Wash. A population historically collected from Big Chino Wash is considered extirpated (Table I.3). All extant populations have been examined genetically, and all display sufficient allelic differences to be considered separate MUs (Table II.1; Dowling 2013). Spring Creek is in the Oak Creek subbasin, and Williamson Valley Wash is tributary to Big Chino Wash upstream of Sullivan Lake. The Red Tank Draw population is a tributary to Wet Beaver Creek 1-2 km (0.62-1.24 mi) downstream from where Walker Creek enters Wet Beaver Creek.

Recovery Needs
There have been no replications of any Verde subbasin populations, nor have any refuges been established, but 11 streams might be available for wild replications within the boundaries of the RU (Table C.1), eight of which would be needed to replicate each of the four remnant populations twice to meet preferred delisting goals. These streams are exclusive of streams that already contain extant populations of roundtail chub (Verde River, Deadman Creek, lower Fossil Creek, Gap Creek, West Clear Creek, lower Wet Beaver Creek, Oak Creek, and Sycamore Creek near Perkinsville) and headwater chub (entire East Verde River subbasin, upper Fossil Creek). There appear to be enough opportunities within RU2 and the Salt River subbasin repatriation area to replicate each MU twice in the wild to meet delisting goals.

Population replications should occur in geographic proximity to the source populations when possible in order to establish regional MU complexes of similar genetic origin within the Verde basin. Configuration of these complexes must account for the presence of other chub species within the watershed and ensure they are **allopatric**.

The Williamson Valley Wash population, which is a separate MU (2B), was tentatively considered extirpated by Weedman et al. (1996), but Bagley (2002) captured 50 individuals from the site in 2001, and the site was still occupied when last examined in 2003 (Table I.3). A thorough evaluation of the population and its habitat needs to be undertaken, but the population is on private land where access recently has been denied. A pressing recovery objective is to acquire a subset of that population to initiate off-site propagation and population redundancy as insurance against possible extirpation of the source population.

The Spring Creek MU (2C) appears stable; however, nonnative green sunfish have been recorded recently (2014) from above a low (~0.5 m) diversion dam located near the mouth. Efforts are underway to quickly remove nonnative fishes and protect the population from further upstream invasion. The potential to construct a new barrier to better protect against nonnative fish invasions is being investigated. The Walker Creek MU (2A) appears stable and nonnative-free based on a number of surveys conducted between 1978 and 2001, but new surveys are needed. The nearby Red Tank Draw population (MU2D) was surveyed in 2012, and 45 individuals were captured (Timmons and Upton 2013). Long-term actions to improve watershed function in occupied and recovery stream drainages should be initiated.

Recovery Unit 3: Santa Cruz River Subbasin

Description

RU3 includes the entire Santa Cruz River watershed upstream from the confluence with Gila River (Figure D.3). A north-flowing catchment, the Santa Cruz River drains approximately 12,504 km^2 (4,828 mi^2) of south-central Arizona and extreme northern Sonora, Mexico. The watershed lies between the San Pedro River to the east, Santa Rosa Valley to the west, and the Río Concepcíon to the south. Maximum elevation in the subbasin is 2,881 m (9,453 ft) in the Santa Rita Mountains, and the confluence with the Gila River lies at approximately 305 m (1,001 ft). The Santa Cruz mainstem is largely ephemeral for most of its course except in the headwater reaches in southernmost Arizona and northernmost Sonora. There are no mainstem impoundments; the largest tributary impoundment is Patagonia Lake on Sonoita Creek. Land ownership in Arizona is approximately 65 percent federal, 23 percent private, 10 percent state, and 2 percent tribal; land ownership statistics for the Mexican portion of the drainage are unavailable (Figure D.3).

A morphologically-distinctive Gila chub population in Monkey Spring is considered extirpated, and the population in the mainstem Santa Cruz River has not been detected recently (Table I.3). The three known extant populations in RU3 each form their own MUs. The population in Cienega Creek (MU3A) and its tributaries is the largest and most geographically widespread. The Sabino Canyon population (MU3B) experienced recent reductions in population size associated with impacts from post-fire runoff, although the population was replicated into nearby Romero Canyon. Sheehy Spring (MU3C) is a small system that likely never supports more than 1000 adults.

Recovery needs

The Sabino Canyon population has been successfully replicated in Romero Canyon, but no other refuges or replications have been established. Two potential refuge sites and 11 possible replication streams have been identified within the boundaries of the RU (Table C.1). There are no other native chub species within the Santa Cruz subbasin.

Cienega Creek is protected against nonnative fishes by at least two natural barriers, and the Gila chub population appears stable. However, headcutting along lower Wood Canyon threatens to capture Cienega Creek, which would initiate headward erosion up Cienega Creek that likely would significantly diminish Gila chub habitat. Gila chub habitat in Sabino Canyon seems to be recovering since the Aspen fire in 2003 as evidenced by a rebound of the Gila chub population, and the stream is protected against upstream invasions of nonnative fishes by a low-head dam. Sheehy Spring has been invaded by nonnative mosquitofish, which has displaced Gila topminnow, but the species does not appear to be significantly affecting Gila chub. Sheehy Spring, however, is a tiny drainage and is close to the mainstem Santa Cruz River, possibly enhancing its potential for upstream invasions by additional nonnative fishes. Construction of a fish barrier is not a viable option at this time due to private landowner concerns, so the best alternative is to replicate the population into protected habitats elsewhere in the Santa Cruz subbasin. Population replications should occur in geographic proximity to the source populations when possible in order to establish regional MU complexes of similar genetic origin within the Santa Cruz subbasin. Long-term actions to improve watershed function in occupied and recovery stream drainages should be initiated.

Recovery Unit 4: San Pedro/Middle Gila River Subbasin

Description

RU4 includes the entire San Pedro River watershed upstream from the confluence with Gila River, and the Gila River drainage downstream of Coolidge Dam to the confluence with the Salt River (Figure D.4). The San Pedro/Middle Gila River subbasin encompasses approximately 18,370 km^2 (7,093 mi^2) of southeastern Arizona and extreme northern Sonora, Mexico. It drains several "sky islands" of the Madrean Archipelago between the Santa Cruz subbasin to the west, the San Simon subbasin and the closed basin Sulphur Springs Valley to the east, and the ríos Yaqui and Concepcíon to the south. The highest point in the watershed is 2,335 m (7,661 ft) in the Galiuro Mountains, and the lowest point is at approximately 280 m (920 ft) at the confluence with Salt River. There are no large reservoirs in the basin. Land ownership in the United States portion of the drainage is approximately 40 percent state, 26 percent private, 25 percent federal, and 9 percent tribal; land ownership statistics for the Mexican portion of the drainage are unavailable (Figure D.4).

Four Gila chub populations within the subbasin are classified as extirpated, and an additional three have not been detected recently and may be extirpated (Table C.1). The three known extant populations (Redfield, Hot Springs/Bass, and O'Donnell canyons) form separate MUs. One population (Hot Springs/Bass) is protected behind a fish barrier, and planning for emplacement of barriers on the other two is advancing. A small population of green sunfish in Redfield Canyon is currently being mechanically removed with the goal of eliminating it after a fish barrier has been constructed. Nonnative mosquitofish have invaded O'Donnell Canyon, which was previously chemically renovated in 2002 to remove green sunfish. The barrier-protected Hot Springs Canyon has no nonnative fishes present, although the nonnative bullfrog has recently invaded the lower reaches. There are two refugia sites established for Gila chub within the basin, the International Wildlife Museum and The Nature Conservancy's Lower San Pedro River Preserve, that both have replicated the O'Donnell Canyon population.

Recovery needs

There are 3 potential refuge sites and 16 streams that might be available for wild replication within the boundaries of RU4 (Table C.1), 6 of which would be needed to replicate each of the three remnant population twice to meet preferred delisting goals. These streams have been carefully selected so as to not interfere with recovery needs of headwater and roundtail chubs.

Population replications should occur in geographic proximity to the source populations when possible in order to establish regional MU complexes of similar genetic origin within the San Pedro/Middle Gila basins. Configuration of these complexes must account for the presence of other chub species within the watershed and ensure they are allopatric.

Recovery Unit 5: Upper Gila River Subbasin

Description
RU5 includes the entire Gila River watershed upstream of Coolidge Dam (Figure D.5). Major subdrainages include the San Carlos, San Simon, San Francisco, and upper Gila rivers (including its three forks). Drainage area of the RU is approximately 33,602 km^2 (12,974 mi^2). Elevation of the spillway at Coolidge Dam is 769 m (2,523 ft), and the highest point in the watershed is 3,321 m (10,896 ft) in the Mogollon Mountains in New Mexico. Land ownership is approximately 60 percent federal, 17 percent tribal, 13 percent private, and 10 percent state (Figure D.5).

There are six remnant populations of Gila chub within this unit that form five MUs (Table II.1), and six historically-occupied streams are considered extirpated (Table 1.3). Only MU5D has a remnant replicate (Dix and Harden Cienega creeks), which also has been repatriated (but not yet certainly established) into a single wild stream (Mule Creek, New Mexico) and a single refuge pond (Red Rock Cienega, New Mexico). The Blue River (San Carlos subbasin) population is entirely on San Carlos Apache Tribal (SCAT) lands, and there is little information available regarding its status, although it is considered large. There is a constructed fish barrier on Bonita Creek, although nonnative fishes remain present in the lower stream pending a renovation. Harden Cienega also appears free of nonnatives, although there is no barrier preventing their encroachment. The Eagle Creek population was significantly impacted by severe runoff following the 2011 Wallow Fire, and it has not been re-detected since. The Turkey Creek (New Mexico) population appears large and relatively stable, although rainbow trout inhabits the upper reaches and some warmwater nonnative species inhabit the lower reaches.

Recovery needs
Nine additional wild repatriation populations are needed to attain the preferred delisting goal of two wild replicate populations for each MU (Table C.1). A total of 23 streams have been identified within the RU boundaries that have potential for Gila chub repatriations, which should be adequate to implement the preferred delisting goal.

A major recovery objective for RU5 is to acquire a sample of Gila chub from SCAT from Blue River for either direct transfer to other streams in the RU or to the Bubbling Ponds Native Fishes Conservation Facility for propagation and later repatriation to protected streams. Lower Bonita Creek needs to be re-renovated to remove nonnatives, after which that population should be relatively secure from nonnative fishes. However, surface flows in Bonita Creek are at risk from water withdrawals and continuing drought. Following new surveys, it may be necessary to translocate or augment Gila chub from another stream in RU5 to reestablish a population in upper Eagle Creek. Emplacement of a fish barrier on upper Eagle Creek is being considered to assist with protection of that population. The Harden Cienega population appears large and currently unoccupied by nonnative fishes, and the Dix Creek population also is large and appears stable, but emplacement of a fish barrier to prevent future invasions should be considered for both populations. Turkey Creek is currently under consideration for emplacement of a fish barrier, but there do not appear to be suitable sites downstream of the Gila Wilderness Area boundary. Possible impacts of a barrier on roundtail chub in the area also need to be investigated further.

Replication of the Blue River population may be the greatest challenge in recovering Gila chub in RU5. Coordination and assistance from SCAT will be essential to reach this recovery objective. Long-term actions to improve watershed function in occupied and recovery stream drainages should be initiated.

Salt River Subbasin Replication Area

Description
The Salt River Subbasin Replication Area includes the Salt River watershed upstream from the confluence with Gila River, exclusive of the Verde River subbasin and south-flowing tributaries to Salt River upstream of Roosevelt Dam (Figure D.6). The latter exclusion is to limit contact of Gila chub populations with headwater chub in Tonto basin streams and roundtail chub in the mainstem Salt River and south-flowing tributaries upstream into the White and Black river drainages. The Salt River subbasin drains approximately 4,777 km^2 (1,844 mi^2). Drainage direction primarily is to the west and south off approximately 18,440 km^2 of the White Mountains, the Mogollon Rim, and Natanes Plateau. Maximum elevation on Mt. Baldy is 3,476 m (11,404 ft), and the confluence with Gila River is at 281 m (921 ft). There are four major reservoirs on the Salt River (Roosevelt, Apache, Canyon, and Saguaro). Land ownership is 56 percent federal, 25 percent private, 16 percent tribal, and three percent state, with other ownership categories comprising less than one percent of the land area (Figure D.6).

Gila chub was known historically from three streams in the lower portion of the Salt subbasin: Cave Creek/Seven Springs Wash, Fish Creek, and Haunted Canyon. All are now considered extirpated, and thus the Salt subbasin is considered unoccupied by Gila chub.

SECTION III. RECOVERY ACTIONS

The seven major actions identified in the Recovery Strategy needed to recover Gila chub are repeated here in Table III.1. Each action essentially addresses aspects of each of the original listing factors that were considered threats to Gila chub during the listing process. The listing factors impacting Gila chub are: A) present or threatened destruction, modification, or curtailment of its habitat or range, B) disease and predation, C) inadequacy of existing regulatory mechanisms, and D) other natural or manmade factors affecting its continued existence. The Service has determined that overutilization for commercial, recreational, scientific, or educational purpose (Factor B) is not a threat to Gila chub (USFWS 2005b).

Major recovery actions are broken down in the Narrative Outline below into discreet sub-activities to which time and cost estimates are assigned in the Implementation Schedule (Section III). Management of threats of desiccation and nonnative fishes are the highest priority actions because these have the greatest potential to quickly eliminate populations. As these factors are managed and recovery proceeds, other actions may become relatively more important.

Table III.1 Major recovery objectives needed to recover Gila chub.

Recovery Objectives
1. Maintain and protect all remnant populations in the wild.
2. Ensure representation, resiliency, and redundancy by expanding the size and number of populations within Gila chub historical range via replication of remnant populations within each RU.
3. Manage or eliminate nonnative fish predation and competition and associated habitat-related modifications or loss.
4. Improve or develop new State regulations or firm agreements that conserve or improve quality Gila chub habitat for as long as necessary.
5. Work with stakeholders to improve and conserve existing and newly established Gila chub populations and their habitats and ensure that appropriate management plans/agreements are in place post-delisting
6. Promote conservation of Gila chub in Mexico and on Tribal lands by forming partnerships and supporting research, outreach, and conservation management.
7. Monitor remnant, repatriated, and refuge populations to inform adaptive management strategies.

III.1 Minimization of Threats to Gila Chub through Implementation of Recovery Actions

Table III.2. Gila chub threats tracking table. Threats related to recovery actions and criteria are identified as predation (P), disease (D), habitat loss (H), management through habitat modification (M), information needs (I), inadequacy of regulation (IR), and other natural or manmade factors (O).

Listing Factor	**Threats**	**Recovery Criteria**		**Recovery Actions**
		Demographic	**Threats-Based**	
Factor A	P, H, M, I	A-1., B-1.	A-3., A-4., B-3.	1.1. Identify threats to each remnant population
	M	A-1.		1.2. Prioritize remnant populations for recovery actions
	P, M	A-1., A-2.		1.3.2.1. Designate watershed occupied by Gila chub for native fish management emphasis, and where unaccompanied by native sport fishes, close them to fishing
	P, M		A-3., B-3.	1.3.2.2 Enforce existing or develop new regulations, policies, and outreach to prevent illegal stocking of nonnative aquatic organisms
	P, M		A-3., B-3.	1.3.2.3 Ban the transport of live nonnative baitfish and crayfish to streams occupied by Gila chub
	P, M	A-1., A-2., B-1., B-2.	A-3., B-3.	1.3.2.4. Investigate potential to emplace fish barriers on streams occupied by Gila chub that are vulnerable to nonnative invasion
	P, M	A-1., A-2., B-1., B-2.	A-3., B-3.	1.3.2.5. Construct fish barriers on appropriate streams

Listing Factor	Threats	Recovery Criteria		Recovery Actions
		Demographic	Threats-Based	
	P, M		A-3., B-3.	1.3.2.6. Develop a rapid response protocol and identify team members to facilitate response to newly detected nonnatives in occupied Gila chub streams
	P, H, M	A-1., A-2., B-1., B-2.		1.3.3. Develop and implement contingency plans to ensure persistence of each population in case of environmental disaster
	H, M	A-1., A-2., B-1., B-2.		1.3.4. Enhance carrying capacity of streams with small populations through habitat improvements.
	H, M	A-1., A-2., B-1., B-2.	A-4., B-4., B-4.	1.3.5. Restore or protect hydrology
	P, H, M	A-1., A-2., B-1., B-2.	A-3., B-3.	2.1. Prepare and protect streams appropriate for replication
	M	A-2., B-2.		2.2. Repatriate Gila chub to new protected streams
	M	A-1., A-2., B-1., B-2.		3.1. Prepare a monitoring plan to guide monitoring efforts
	I	A-1., A-2., B-1., B-2.		3.2. Conduct monitoring
	I			3.3. Prepare and disseminate reports for monitoring
	I			3.4. Store monitoring data within a standardized database
	I	A-2., B-2.		4.1. Identify suitable refuge sites for each RU and MU as appropriate
	M	A-2., B-2.		4.2. Stock refuges from appropriate source stocks
	M	A-2., B-2.		4.3. Maintain refuge population until the species is delisted
	P, M	A-2., B-2.		5. Ensure replicate and refuge populations are genetically representative of source populations
	I			6.1. Post and maintain signs to inform the public of stream restrictions
	I			6.2. Develop outreach materials to educate the public and build support for Gila chub recovery
	I, M			6.3. Amplify outreach by including coalitions with other species and ecosystem projects
	I			7. Use adaptive management practices to guide future recovery actions where uncertainty exists

Listing Factor	Threats	Recovery Criteria		Recovery Actions
		Demographic	**Threats-Based**	
Factor C	D, P	A-1., B-1.	A-3., A-4., B-3.	1.1. Identify threats to each remnant population
	D, P		A-3., B-3.	1.3.1. Eliminate or control problematic nonnative aquatic organisms
	P	A-1., A-2.		1.3.2.1. Designate watershed occupied by Gila chub for native fish management emphasis, and where unaccompanied by native sport fishes, close them to fishing
	P		A-3., B-3.	1.3.2.2 Enforce existing or develop new regulations, policies, and outreach to prevent illegal stocking of nonnative aquatic organisms
	P		A-3., B-3.	1.3.2.3 Ban the transport of live nonnative baitfish and crayfish in streams occupied by Gila chub and connecting waters
	P	A-1., A-2., B-1. B-2.	A-3., B-3.	1.3.2.4. Investigate potential to emplace fish barriers on streams occupied by Gila chub that are vulnerable to nonnative invasion
	P	A-1., A-2., B-1., B-2.	A-3., B-3.	1.3.2.5. Construct fish barriers on appropriate streams
	P		A-3., B-3.	1.3.2.6. Develop a rapid response protocol and identify team members to facilitate response to newly detected nonnatives in occupied Gila chub streams
	D, P	A-1., A-2., B-1., B-2.	A-3., B-3.	2.1. Prepare and protect streams appropriate for replication
	P			6.1. Post and maintain signs to inform the public of stream restrictions
Factor D	IR	A-1., A-2.		1.3.2.1. Designate watershed occupied by Gila chub for native fish management emphasis, and where unaccompanied by native sport fishes, close them to fishing
	IR		A-3., B-3.	1.3.2.2 Enforce existing or develop new regulations, policies, and outreach to prevent illegal stocking of nonnative aquatic organisms
	IR		A-3., B-3.	1.3.2.3 Ban the transport of live nonnative baitfish and crayfish in streams occupied by Gila chub and connecting waters
	IR			6.1. Post and maintain signs to inform the public of stream restrictions

Listing Factor	Threats	Recovery Criteria		Recovery Actions
		Demographic	Threats-Based	
Factor E	O	A-1., B-1.	A-3., A-4., B-3.	1.1. Identify threats to each remnant population
	O	A-1., A-2., B-1., B-2.		1.3.3. Develop and implement contingency plans to ensure persistence of each population in case of environmental disaster
	O	A-1., A-2., B-1., B-2.	A-3., B-3.	2.1. Prepare and protect streams appropriate for replication
	O	A-2., B-2.		2.2. Repatriate Gila chub to new protected streams
	O	A-2., B-2.		4.1. Identify suitable refuge sites for each RU and MU as appropriate
	O	A-2., B-2.		4.2. Stock refuges from appropriate source stocks
	O	A-2., B-2.		4.3. Maintain refuge population until the species is delisted
	O	A-2., B-2.		5. Ensure replicate and refuge populations are genetically representative of source populations

III.2 Narrative Outline for Recovery Actions

1. Protect and manage remnant populations and their habitats
    1.1. Identify threats to each remnant population
    Primary, immediate threats to a population include desiccation of habitat via natural (e.g., drought or climate change) or manmade (e.g., diversion or excessive groundwater pumping) influences, presence of or threat of invasion by problematic nonnative fishes or other nonnative aquatic organisms (including parasites and pathogens), or other destructive threats to habitat (e.g., channelization, dam construction, wildfire, phreatophyte removal, etc.). Secondary threats include more long-term effects to habitat and ecosystem processes via overgrazing by domestic livestock of the uplands or riparian corridor, excessive silvicultural practices that destabilize soils, road alignments along or crossing the stream, etc. The table of individual threats for each population (Table I.4) should be monitored over time to prioritize, manage, and track threats over the long term.
    1.2. Prioritize remnant populations for recovery action
    Funding to implement Gila chub recovery is limited, so identifying which populations have the greatest need for protection will ensure funds are disbursed to highest-priority populations first. Table C.2 in Appendix C was developed to help serve this purpose. This action will ensure that management is directed first toward populations with greatest evolutionary legacy and/or degree of threat.
    1.3. Ameliorate threats to each remnant population
        1.3.1. Eliminate or control problematic nonnative aquatic organisms

Where problematic nonnatives are sympatric with native fishes (including Gila chub), case history shows that native populations become depressed or are eliminated (Marsh and Pacey 2005, Eby et al. 2003, Propst et al. 2008). For native populations to remain healthy and persist, nonnatives must be removed or controlled. Where it is unlikely that extant nonnatives will reinvade, salvage of natives followed by piscicide application is the most proven method to eliminate nonnative fishes. Piscicides are ineffective against species such as nonnative crayfish, however, and it may not be possible to completely rid a stream of all unwanted nonnatives. Mechanical control of nonnatives may be practical in certain limited circumstances. Novel control methods should be considered for implementation as they are developed.

1.3.2. <u>Protect habitats against invasion by nonnative aquatic organisms</u>

1.3.2.1. <u>Designate watersheds occupied by Gila chub for native fish management emphasis, and where unaccompanied by native sport fishes (e.g., Apache trout, Gila trout), close them to fishing</u>
State wildlife management agencies should consider designating all Gila chub recovery streams and their watersheds as under primary management for native fishes, and close them to angling. Gila chub is not a legal sport fish, and such designation will make it unequivocal to the public that inhabited streams are protected from sport fishing, thereby reducing potential for unauthorized nonnative fish introductions (Ludwig and Leitch 1996) and baitfish transfer.

1.3.2.2. <u>Enforce existing or develop new regulations, policies, and outreach to prevent illegal stocking of nonnative aquatic organisms</u>
Unauthorized stocking of nonnative fishes is illegal, and State and Federal wildlife management agencies should enforce existing or develop new regulations, policies, and outreach to minimize the potential for introductions.

1.3.2.3. <u>Ban the transport of live nonnative baitfish and crayfish to streams occupied by Gila chub</u>
Nonnative baitfish (e.g., red shiner, sunfish spp., common carp) can negatively affect Gila chub populations. As such, the transport of nonnative baitfish should be banned throughout watersheds with occupied Gila chub streams.

1.3.2.4. <u>Investigate potential to emplace fish barriers on streams occupied by Gila chub that are vulnerable to nonnative invasion</u>
Emplacement of fish barriers to prevent upstream invasions by nonnative fishes and other aquatic organisms should be considered for all vulnerable Gila chub streams.

1.3.2.5. <u>Construct fish barriers on appropriate streams</u>
Where feasible and appropriate, fish barriers should be erected in suitable Gila chub streams to prevent upstream invasions by nonnative fishes and other aquatic organisms.

1.3.2.6. Develop a response protocol and identify team members to facilitate response to newly detected nonnatives in occupied Gila chub streams

Key staff positions and funding should be identified to minimize the time required to respond when nonnative fishes are found in occupied Gila chub streams. Individuals will be trained in chemical and mechanical renovation, and in monitoring methods. Templates for environmental compliance documents will be developed for occasions in which National Environmental Policy Act or ESA compliance is required, as well as an outline detailing appropriate public coordination procedures.

1.3.3. Develop and implement contingency plans to ensure persistence of each population in case of environmental disaster (drought, fire, toxic spill, etc.)

Contingency plans should be developed to salvage or otherwise protect wild Gila chub populations against catastrophic loss and ensure their persistence. Plans should identify steps involved in the entire salvage/repatriation process, including equipment needs, key personnel, and holding facilities. After the disaster, streams should be monitored to assess when they are capable of sustaining fish, to be followed by repatriations.

1.3.4. Enhance carrying capacity of streams with small populations through habitat improvements.

Populations smaller than 500 adults are especially susceptible to stochastic loss. Where feasible, habitat characteristics could be altered to potentially elevate carrying capacity. Habitat alterations might include actions to remove or diminish livestock use to encourage pool formation and enhance stream permanency, installation of habitat “improvement” structures within stream channels, or other actions that remove factors that may limit population size.

1.3.5. Restore or protect hydrology

Where natural hydrologic regimes have been disrupted through channel and watershed alterations, actions that restore natural conditions should be conducted to improve or restore Gila chub habitats. These might include acquisition of water rights, removal of diversion structures, restoration of riparian or upland vegetation, retirement of wells, development of conservation easements or Habitat Conservation Plans, acquisition of available properties, etc.

2. Replicate remnant populations as appropriate into new protected streams within their respective RUs according to MU criteria

A high priority for recovery of Gila chub is to replicate remnant populations to both broaden their geographic distribution and ensure redundancy of remaining genetic variation. Replication streams need to be identified, repatriated, and protected.

2.1. Prepare and protect streams appropriate for replications

Where RUs do not already contain adequate numbers of remnant or replicated populations to meet down- or delisting criteria, streams must be prepared to replicate and protect additional populations. Candidate replication streams must possess characteristics appropriate for establishment and persistence of Gila chub, including permanency of water, absence or low abundance of nonnatives (or can be renovated to meet this criterion) and other identified threats, and suitable macrohabitat elements such as deep pools with cover.

2.2. Repatriate Gila chub to new protected streams

Using either a wild or refuge source of appropriate stock from within each respective RU and MU, replication streams should be initially stocked with a minimum of 500 individuals (either singly or with multiple stockings to eventually reach 500) distributed into those stream reaches assessed as most suitable for Gila chub establishment. Additional Gila chub should be stocked as appropriate and available for a period of up to five years (or more to accommodate unforeseen events) and then monitored for an additional 10 years until the population is either considered established or failed.

3. Monitor remnant and replicated populations to ensure they are persisting and threats are being managed

Monitoring is an essential element of the recovery plan to ascertain the status of wild populations to determine if they meet down- and delisting criteria. Monitoring also will assess the success of threat abatement, the continued suitability of habitats for persistence of Gila chub, and the status of Gila chub populations.

3.1. Prepare a monitoring plan to guide monitoring efforts

The monitoring plan should establish what parameters to monitor and how they will be monitored, establish acceptable bounds for those parameter values, and define protocols to determine if monitored parameters are maintained within established bounds. The plan should also define actions to be taken to return parameter values to normality in the event they stray outside of established limits. Nominal parameters to monitor include abundance, age-class structure, evidence of annual reproduction, and distribution. The monitoring plan should identify land ownership along each stream to be monitored, and establish right-of-entry procedures where granted.

3.2. Conduct monitoring

Wildlife management agencies or a contractor should be identified to ensure that monitoring is performed using trained individuals and is conducted consistently over the long-term. Monitoring of replicated populations should occur at least at annual intervals until it has been determined they have established or failed. Annual wet-dry surveys should be conducted in late spring or prior to the onset of summer monsoonal storms to determine patterns and trends of surface water availability and habitat suitability.

3.3. Prepare and disseminate reports of monitoring

The results of monitoring should be assembled into annual or semi-annual reports that fully describe what was monitored and the values of monitored parameters. These reports should be distributed to recovery team members and management agencies.

3.4. Store monitoring data within a standardized database

Develop or utilize an existing database to store and manage Gila chub monitoring data. Identify appropriate party to maintain the database. It is critical that monitoring data be collected and stored in a consistent manner to facilitate long-term data evaluation and that they be readily available to all management agencies and parties associated with recovery actions for the species.

4. Establish and maintain refuge populations in protected ponds or hatcheries as appropriate
Establishment of refuge populations is a necessary step for downlisting until all available remnant populations are replicated sufficiently in the wild to meet delisting criteria. Refuge populations in theory should be simpler to establish than wild populations, but they require greater human involvement to maintain over a long period of time. Refuges can provide suitable short-term population redundancy until wild sites are established.
    4.1. Identify suitable refuge sites for each RU and MU as appropriate
    For MUs that do not have sufficient replications of remnant populations, a hatchery or semi-natural site should be identified to replicate populations. Semi-natural sites should replicate remnant stocks within the geographic boundaries of each respective RU, while hatchery populations do not necessarily have to meet this siting criterion. Semi-natural sites should be of sufficient size and depth, and exhibit suitable water quality and habitat features to facilitate reproduction and persistence of Gila chub over a period of at least several consecutive years, and perhaps decades. Hatchery sites need to be isolated from potential contact with other genetically-distinctive Gila chub populations housed there, and should also allow for *in situ* natural reproduction. If artificial propagation of hatchery populations becomes necessary to maintain them, strict protocols that will prevent inbreeding and maintain existing genetic diversity must be adhered to. These protocols should be developed in consultation with a conservation geneticist with direct experience with Gila chub.
    4.2. Stock refuges from appropriate source stocks
    Where remnant populations are large enough, a minimum of 500 Gila chub should be translocated to each refuge population.
    4.3. Maintain refuge populations until the species is delisted
    Maintenance of refuge populations should consist of annual evaluations of reproduction (and recruitment). Periodic (every other year) augmentations from remnant populations should be made as necessary to assure genetic representativeness of source and replicate populations (see Recovery Action 5). Genetic variability of refuge stocks should be assessed at least once every five years and compared with baseline data for wild source stocks, and additional augmentations made if refuge stock diversity falls below a predetermined acceptability level. Once all MUs are adequately replicated within each RU according to downlisting criteria, refuge populations can be stocked back into remnant or replicate populations in the wild if appropriate.

5. Ensure replicate and refuge populations are genetically representative of source populations
Replicate and refuge populations within each MU or RU must be characterized (using morphometric and osteological analysis) to ensure that they are genetically representative of their source remnant populations. If they are not (based on an evaluation of a qualified geneticist), and as a periodic routine, translocations of fish from remnant populations to their

replicate and refuge populations should be undertaken to generate representativeness. Guidelines for monitoring and implementing genetic management actions will be incorporated into the monitoring plan to be developed under Task 3.1.

6. Develop governmental and public support for the recovery effort
   The USFWS recognizes that successful recovery of this species cannot occur without wildlife management agencies, land management agencies, other permitting agencies, non-governmental organizations, affected municipalities, private landowners, and the general public. Therefore, an outreach program that solicits and encourages the support and participation from potential partners and others who could influence recovery implementation is essential.
   - 6.1. Post and maintain signs to inform the public of stream restrictions
     For all recovery streams that may be closed to fishing, nonnative live bait use, etc., signs should be posted along major access points to fully inform the public about those restrictions and why they have been restricted, and to direct the reader to additional sources of information. More detailed brochures should be made available to better educate the public about why restrictions have been emplaced.
   - 6.2. Develop outreach materials to educate the public and build support for Gila chub recovery
     A variety of outreach venues should be developed with the purpose of building understanding and support for biological conservation in general and species-specific recovery in particular, and to keep the public abreast of the progress of key recovery actions. Because such outreach development is typically beyond the training of technical biologists, a qualified outreach committee should be assembled to develop and implement outreach, with appropriate feedback from Technical Subcommittee members. An important component of this outreach should be to educate the public about the myriad problems caused by introductions of nonnative aquatic organisms, groundwater overdraft, and watershed degradation, which constitute the primary threats to Gila chub.
   - 6.3. Amplify outreach by including coalitions with other species and ecosystem projects
     Recovery efforts for Gila chub will often align with conservation of other aquatic or riparian species such as other native fishes, leopard frogs, gartersnakes, etc. Recovery projects are more likely to be funded if they address conservation of a suite of species or an ecosystem. By joining forces and resources with other recovery efforts we can amplify recovery of all species by sharing resources.

7. Use adaptive management practices to guide future recovery actions where uncertainty exists
   Adaptive management is a process whereby the recovery plan is revised based on relevant new information suggesting that recovery can be achieved more efficiently or sooner if the recovery strategy, actions, or other elements of the plan are revised. Recovery plan monitoring results will track plan implementation and provide potentially new or revised management or technical approaches to facilitate recovery. Any aspect of the recovery plan may need to be revised to include or adapt to this information. In addition, site-specific conditions undoubtedly will change over time that might facilitate new or preclude existing management prescriptions. The recovery strategy and actions may need to be updated or revised to accommodate such changing conditions.

This recovery plan relies heavily on preserving the genetic diversity of the species by replicating distinct lineages (remnant populations) as reflected in MU designations. As new genetic information is obtained, or if remnant populations become unavailable due to extirpation, lack of genetic viability, land ownership, or other reasons, MU designations may need to be adjusted, requiring recovery team member to reconvene and document the changes through an update or revision of the plan.

SECTION IV. IMPLEMENTATION SCHEDULE

The following implementation schedule outlines priorities, potential or responsible parties, and estimated costs for the specific actions for recovering Gila chub. It is a guide to meeting the goals, objectives, and criteria from the Recovery Criteria section of this plan. The schedule: (a) lists the specific recovery actions, corresponding outline numbers, the action priorities, and the expected duration of actions; (b) recommends agencies or groups for carrying out these actions; and (c) estimates the financial costs for implementing the actions. These actions, when complete, should accomplish the goal of this plan – recovery of Gila chub.

Over the last few years, application of piscicides for stream renovation and nonnative fish control in Arizona has become more difficult and time consuming than it was in the past, as a result of Arizona legislative and administrative concerns over their use. We therefore anticipate that those recovery actions identified in this plan that involve the removal of nonnative fishes through piscicide application may experience delays in scheduling and could preclude treatments in some areas altogether.

IV.1. Responsible Parties and Cost Estimates

The value of this plan depends on the extent to which it is implemented; the USFWS has neither the authority nor the resources to implement many of the proposed recovery actions. Recovery of Gila chub is dependent upon the voluntary cooperation of many other organizations and individuals who are willing to implement the recovery actions. The implementation schedule identifies agencies and other potential “responsible parties” (private and public) to help implement the recovery of this species. This plan does not commit any “responsible party” to carry out a particular recovery action or to expend the estimated funds. It is only recognition that particular groups may possess the expertise, resources, and opportunity to assist in the implementation of recovery actions. Although collaboration with private landowners and others is called for in the recovery plan, no one is obligated by this plan to any recovery action or expenditure of funds. Likewise, this schedule is not intended to preclude or limit others from participating in this recovery program.

The cost estimates provided are not intended to be a specific budget but are provided solely to assist in planning. The total estimated cost of recovery, by priority, is provided in the Executive Summary. The schedule provides cost estimates for each action on an annual or biannual basis. Estimated funds for agencies included only project-specific contract, staff, or operations costs in excess of base budgets. They do not include ordinary operating costs (such as staff) for existing responsibilities.

IV.2. Recovery Action Priorities and Abbreviations

Priorities in column 1 of the following Implementation Schedule are assigned as follows:

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 significant negative impact short of extinction.

Priority 3 - All other actions necessary to provide for full recovery of the species.

The assignment of these priorities does not imply that some recovery actions are of low importance, but instead implies that lower priority items may be deferred while higher priority items are being implemented.

The following abbreviations are used in the Implementation Schedule:

AZGFD = Arizona Game and Fish Department
BLM = Bureau of Land Management
BOR = Bureau of Reclamation
NMDGF = New Mexico Department of Game and Fish
PL = Private Landowners
SCAT = San Carlos Apache Tribe
USFWS = U.S. Fish and Wildlife Service
USFS = U.S. Forest Service

Implementation Schedule

Priority Number	Action Number	Action Description	Species Benefitting (if multi-species plan)	Recovery Criterion Number	Action Duration (Years)	Responsibility		Cost Estimate by FY (by $1,000s)						Comments
						Parties	Is FWS Lead?	Total Cost ($1,000s)	2016	2017	2018	2019	2020	
1	1.1	Identify primary and secondary threats to remnant populations	No	A-1., A-3., A-4., B-1., B-3.	2	AZGFD, NMDGF, USFWS, BLM, USFS, BOR, SCAT	Yes	6	3	3				
1	1.2	Prioritize remnant populations for recovery actions		A-1.	0	Recovery Team								See Table C.2 for current priorities. Priorities may change as conditions change, but can be revised as a separate module or in future plan updates.
1	1.3.1	Eliminate or control problematic nonnative aquatic organisms		A-3., B-3.	Ongoing	AZGFD, NMDGF, USFWS, BLM, USFS, BOR, SCAT		200+	40	40	40	40	40	Actions are similar to and can be combined with 2.1 and 2.2 below. All total ~120/year.
2	1.3.2.1	Designate watersheds occupied by Gila chub for native fish management		A-1., A-2.	14	AZGFD, NMDGF, USFWS, BLM, USFS, SCAT		70	5	5	5	5	5	Expected to be designated in Arizona once Fisheries Watershed Management plans are completed.
2	1.3.2.2	Enforce existing or develop new regulations, policies, and outreach to minimize and prevent illegal stockings of nonnatives.		A-3., B-3.	Ongoing	AZGFD, NMDGF, SCAT, USFS, USFWS		250+	50	50	50	50	50	
2	1.3.2.3	Ban the transport of live nonnative baitfish to Gila chub streams		A-3., B-3.	10	AZGFD, NMDGF, SCAT		200	20	20	20	20	20	

Priority Number	Action Number	Action Description	Species Benefitting (if multi-species plan)	Recovery Criterion Number	Action Duration (Years)	Responsibility: Parties	Responsibility: Is FWS Lead?	Cost Estimate by FY (by $1,000s): Total Cost ($1,000s)	2016	2017	2018	2019	2020	Comments
1	1.3.2.4	Investigate potential fish barrier opportunities in Gila chub streams		A-1., A-2., A-3. B-1., B-2., B-3.	10	BOR, AZGFD, NMDGF, USFWS, BLM, USFS, PL, SCAT, SLD, NMSLD		200	20	20	20	20	20	
1	1.3.2.5	Construct fish barriers in Gila chub streams that are vulnerable to nonnative invasion		A-1., A-2., A-3. B-1., B-2., B-3.	Ongoing	BOR, AZGFD, NMDGF, USFWS, BLM, USFS, BOR, PL		1250+	250	250	250	250	250	250+ per barrier
2	1.3.2.6	Develop a rapid response protocol to nonnative invasion		A-3., B-3.	1	AZGFD, NMDGF, USFWS, BLM, USFS, BOR, SCAT	Yes	15	15					
1	1.3.3	Develop and implement contingency plans to protect populations from environmental disasters		A-1., A-2., B-1., B-2.	1	AZGFD, NMDGF, USFWS, BLM, USFS, BOR, SCAT	Yes	15	15					
2	1.3.4	Enhance carrying capacity of streams with small populations		A-1., A-2., B-1., B-2.	Ongoing	AZGFD, NMDGF, USFWS, BLM, USFS, BOR, PL		250+	50	50	50	50	50	Habitat restoration (planning + implementation)
2	1.3.5	Restore or protect hydrology		A-1., A-2., A-4. B-1., B-2., B-3	Ongoing	AZGFD, NMDGF, USFWS, BLM, USFS, BOR, PL		500+	100	100	100	100	100	Water rights, riparian restoration (planning and implement)

Priority Number	Action Number	Action Description	Species Benefitting (if multi-species plan)	Recovery Criterion Number	Action Duration (Years)	Responsibility: Parties	Responsibility: Is FWS Lead?	Cost Estimate by FY (by $1,000s): Total Cost ($1,000s)	2016	2017	2018	2019	2020	Comments
3	2.1	Prepare and protect streams appropriate for replications		A-1., A-2., A-3. B-1., B-2., B-3	30	AZGFD, BOR, NMDGF, USFWS, BLM, USFS, PL		1,200	40	40	40	40	40	Actions are similar to and can be combined with 1.3.1 and 2.2. All total ~120/year.
1	2.2	Repatriate Gila chub to new protected streams		A-2., B-2.	50	AZGFD, NMDGF, USFWS, BLM, USFS, BOR, PL		2,000	40	40	40	40	40	Actions are similar to and can be combined with 1.3.1 and 2.1. All total ~120/year.
2	3.1	Prepare a monitoring plan		A-1., A-2., B-1., B-2.	1	AZGFD, NMDGF, USFWS, BLM, USFS, BOR		20		20				Recommend one year duration with ongoing adaptive monitoring strategies.
2	3.2	Conduct monitoring		A-1., A-2., B-1., B-2.	Ongoing	AZGFD, NMDGF, Contractors, USFWS, BLM, USFS		300+	50	55	60	65	70	Will increase over time as more replications occur and require monitoring.
3	3.3	Prepare and disseminate reports of monitoring			Ongoing	AZGFD, NMDGF, Contractors, USFWS, BLM, USFS		10+	2	2	2	2	2	
3	3.4	Store monitoring data within a standardized database			Ongoing	AGFD, NMDGF, USFWS		2.5+	.5	.5	.5	.5	.5	
2	4.1	Identify suitable refuge sites for each RU and MU		A-2., B-2.	30	AZGFD, NMDGF, USFWS, BLM, USFS, BOR, PL		150	5	5	5	5	5	

Priority Number	Action Number	Action Description	Species Benefitting (if multi-species plan)	Recovery Criterion Number	Action Duration (Years)	Responsibility: Parties	Responsibility: Is FWS Lead?	Cost Estimate by FY (by $1,000s): Total Cost ($1,000s)	2016	2017	2018	2019	2020	Comments
2	4.2	Stock refuges from appropriate source stocks		A-2., B-2.	30	AZGFD, NMDGF, USFWS		150	5	5	5	5	5	
2	4.3	Maintain refuge populations until delisting		A-2., B-2.	?	AZGFD, NMDGF, USFWS		100+	20	20	20	20	20	
2	5	Ensure replicate and refuge populations are genetically representative of source populations		A-2., B-2.	Ongoing	Contractors, AZGFD, NMDGF, USFWS		50+	10	10	10	10	10	
3	6.1	Post and maintain signs to inform the public of stream restrictions			Ongoing	AZGFD, NMDGF, USFWS, BLM, USFS, BOR, SCAT, PL		25+	5	5	5	5	5	
3	6.2	Develop Gila chub outreach and education materials			Ongoing	AZGFD, NMDGF, USFWS, BOR, BLM, USFS		25+	5	5	5	5	5	
3	6.3	Amplify outreach by including coalitions with other species and ecosystem projects			Ongoing	AZGFD, NMDGF, USFWS, BLM, USFS, SCAT, BOR		10+	2	2	2	2	2	
3	7	Use adaptive management practices to guide future recovery actions			Ongoing	AZGFD, NMDGF, USFWS, BLM, USFS, BOR, SCAT, PL	Yes							Coincides with 5-year Review.

SECTION V. LITERATURE CITED

A.D.E.Q. (Arizona Department of Environmental Quality). 2012. 2010 Status of Water Quality, Arizona's Integreated 305(b) Assessment and 303(d) listing Report. Middle Gila Watershed. Available at: http://www.azdeq.gov/environ/water/assessment/assess.html (accessed 9 April, 2014).

A.D.M.M.R. (Arizona Department of Mines and Mineral Resources). 2008. Arizona Mining Update 2007. Circular 129. 8pages

A.D.M.M.R. (Arizona Department of Mines and Mineral Resources). 2010. Water Consumption at Copper Mines in Arizona. State of Arizona Department of Mines and Mineral Resources. Special Report 29. 16pages

A.D.W.R. (Arizona Department of Water Resources). 2009. Arizona Water Atlas. Volumes 1, 3, 5, and 8. Available at: http://www.azwater.gov/AzDWR/StatewidePlanning /WaterAtlas/default.htm (accessed 20 September 2012).

Allendorf, F.W., and G. Luikart. 2007. Conservation and the genetics of populations. Blackwell Publishing, Malden, Massachusetts.

Anthony, J. W., S.A. Williams, R.A. Bideaux., and R.W. Grant. 1995. Mineralogy of Arizona. Third edition. University of Arizona Press. Tucson, Arizona. Available at:http://books.google.com/books?hl=en&lr=&id=MHGBs2ORVgMC&oi=fnd&pg=PR9&dq=metal+mining+smelting+arizona&ots=xnJa73Jx9L&sig=OtBFoayuiiyp3-XpZliNaCPTsxg#v=onepage&q&f=false (accessed 15 April 2014)

Archdeacon, T.P., A. Iles, S.J. Kline, and S.A. Bonar. 2010. Asian fish tapeworm *Bothriocephalus acheilognathi* in the desert southwestern United States. Journal of Aquatic Animal Health 22:274-279.

Armour, C.L., D.A. Duff, and W. Elmore. 1991. The effects of livestock grazing on riparian and stream ecosystems. Fisheries 16(1):7-11.

AZ.G.F.D. (Arizona Game and Fish Department). 1996. Wildlife of special concern in Arizona. Draft: March 16, 1996. Available at: http://www.azgfd.gov/pdfs/w_c/heritage/heritage_special_concern.pdf (accessed 22 February 2013).

AZ.G.F.D. (Arizona Game and Fish Department). 2007. Mineral Creek, Big Box Dam Reservoir Survey, prepared by Anthony Robinson, AZGFD, Research Branch April 11-12, 2007. 4pages

AZ.G.F.D. (Arizona Game and Fish Department). 2012. Piscicide treatment planning and procedures manual. May 2012. 45pages

AZ.P.M. (Arizona Public Media) 2013. EPA: AZ 10th for Toxic Chemical Releases. Story by Mark Duggan. Available at: https://www.azpm.org/s/13396-epa-az-10th-in-nation-for-toxic-chemical-releases/ (accessed 3 March, 2014).

A.S.U. (Arizona State University) 2002. Lower Colorado Basin fish database. Produced for the U.S. Bureau of Reclamation and U.S. Fish and Wildlife Service by Arizona State University, Tempe, Arizona.

Bagley, B. 2002. Survey of Verde River drainage, Arizona for loach minnow (*Tiaroga cobitis*). Final Report to U.S. Fish and Wildlife Service, Contract No. 22410-0-M525.

Bahre, C.J. 1991. A legacy of change: historic human impact on vegetation in the Arizona borderlands. The University of Arizona Press, Tucson, Arizona.

Baird, S.F. and C. Girard. 1853. Descriptions of some new fishes from the River Zuni. Proceedings Academy Natural Sciences Philadelphia 6:368-369.

Barrett, J.C., G. Grossman, and J. Rosenfeld. 1992. Turbidity-induced changes in reactive distance of rainbow trout. Transactions of the American Fisheries Society 121:437-443.

Beitinger, T.L., and W.A. Bennet. 2000. Quantification of the role of acclimation temperature in temperature tolerance of fishes. Environmental Biology of Fishes 58:277-288.

Belsky, A.J. A. Matzke, and S. Uselman. 1999. Survey of livestock influences on stream and riparian ecosystems in the western United States. Journal of Soil and Water Conservation 54:419-431.

Benda, L., D. Miller, P. Bigelow, and K. Andras. 2003. Effects of post-wildfire erosion on channel environments, Boise River, Idaho. Forest Ecology and Management 178:105-119.

Bestgen, K.R. 1985. Distribution, biology and status of the roundtail chub, *Gila robusta*, in the Gila River basin, New Mexico. Unpublished Master's Thesis, Colorado State University, Fort Collins, 104 pages.

Blanchard, C.L. and M.R. Stromberg. 1987. Acidic precipitation in southeastern Arizona: sulfate, nitrate and trace-metal deposition. Atmospheric Environment 21:2375-2381.

Blasius, H.B. and J.A. Conn. 2013. Bonita Creek fisheries monitoring report, 2012. Bureau of Land Management, Safford Field Office, Safford, Arizona.

Brooks, K.N., P.F. Ffolliot, H.M. Gregersen, and L.F. DeBano. 2003. Hydrology and the management of watersheds. Fourth edition. Blackwell Publishing, Iowa State University Press, Ames Iowa. 574 pages.

Brown, A.V., M.M. Lyttle, and K.B. Brown. 1998. Impacts of gravel mining on gravel bed streams. Transactions of the American Fisheries Society 127:979-994.

Brown, D.B., N. Carmony, and W.L. Minckley. 2009. Arizona wildlife: the territorial years 1863-1912. Arizona Game and Fish Department. Phoenix, Arizona.

Buhl, K.J., and S.J. Hamilton. 2000. Acute toxicity of fire-control chemicals, nitrogenous chemicals, and surfactants to rainbow trout. Transactions of the American Fisheries Society 129:408-418.

Carlander, K.D. 1977. Handbook of freshwater fishery biology, Volume 2. Iowa State University Press, Ames, Iowa

Carpenter, J. and O.E. Maughan. 1993. Macrohabitat of Sonora chub (*Gila ditaenia*) in Sycamore Creek, Santa Cruz County, Arizona. Journal of Freshwater Ecology 8:265-278.

Carter, C.D. 2014. Annual report to the US Fish and Wildlife Service on Gila chub and critical habitat on the Agua Fria National Monument 2013-2014. Unpublished Report. Bureau of Land Management, Phoenix District.

Carveth, C.J., A.M. Widmer, and S.A. Bonar. 2006. Comparison of upper thermal tolerances of native and nonnative fish species in Arizona. Transactions of the American Fisheries Society 135:1433-1440.

Clarkson, R. W. 2013. Clarkson comments, December 10, 2013 Gila chub recovery team meeting minutes. U.S. Fish and Wildlife Service, Phoenix, Arizona.

Clarkson, R.W., P.C. Marsh, S.E. Stefferud, and J.A. Stefferud. 2005. Conflicts between native fish and nonnative sport fish management in the southwestern United States. Fisheries 30(9):20-27.

Clarkson, R.W., P.C. Marsh, and T.E. Dowling. 2012. Population prioritization for conservation of imperiled warmwater fishes in an arid-region drainage. Aquatic Conservation: Marine and Freshwater Ecosystems 22:498-510.

Clarkson, R.W., A.T. Robinson, and T.L. Hoffnagle. 1997. Asian tapeworm (*Bothriocephalus aceilognathi*) in native fishes from the Little Colorado River, Grand Canyon, Arizona. Great Basin Naturalist 57:66-69.

Clary, W.P., and D.E. Medin. 1990. Differences in vegetation biomass and structure due to cattle grazing in a northern Nevada riparian ecosystem. USDA Forest Service Intermountain Research Station Research Paper INT-427.

Clary, W.P., C.I. Thornton, and S.R. Abt. 1996. Riparian stubble height and recovery of degraded streambanks. Rangelands 18:137–140.

Cole, G.A. 1994. Textbook of Limnology. Pages 239-315 in G.A. Cole (Fourth Edition). Oxygen and Other Dissolved Gasses, Chapter 12. Waveland Press, Inc. Prospect Heights, Illinois. .

Coleman, S.M. 2010. Eagle Creek aquatic survey July 20-22, 2009, Clifton Ranger District. Unpublished trip report. U.S. Forest Service, Clifton Ranger District, Clifton, Arizona.

Crowder, C.D. and A.T. Robinson. 2012. O'Donnell Canyon and Turkey Creek fish surveys during 2011. Report to Gila River Basin Native Fishes Conservation Program under task 3-60, to U.S. Fish and Wildlife Service Cooperative Agreement No. F09AC00084. Arizona Game and Fish Department, Phoenix, Arizona.

Deacon, J.E., and W.L. Minckley. 1974. Desert fishes. Pages 385-488 *In* G.W. Brown, Jr., (Editor) Desert biology, Volume II: special topics on the physical and biological aspects of arid regions. Academic Press, San Francisco, California.

DeBano, L.F. and L.J. Schmidt. 1989. Improving southwestern riparian areas through watershed management. General Technical Report RM-182, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Ft. Collins, Colorado.

DeMarais, B.D. 1986. Morphological variation in Gila (Pisces: Cyprinidae) and geologic history: lower Colorado River basin. Unpublished Master's Thesis, Arizona State University, Tempe, Arizona. 86 pages.

DeMarais, B.D. 1992. Genetic relationships among fishes allied to the genus Gila (Teleostei: Cyprinidae) from the American southwest. Unpublished Ph.D dissertation, Arizona State University, Tempe, Arizona.

DeMarais, B.D. 1995. Taxonomic history and status of the Gila chub, *Gila intermedia* (Girard). A Report to Arizona Game and Fish Department.

Dobyns, H.F. 1991. From fire to flood: historic human destruction of Sonoran Desert riverine oases. Anthropological Papers No. 20, Ballena Press, Socorro, New Mexico.

Dominguez, F.J., J. Canon, and J. Valdez. 2010. IPCC-AR4 climate simulations for the Southwestern US: the importance of future ENSO projections. Climate Change 99:499-514.

Dowling, T.E. 2013. Preliminary report on microsatellite and mtDNA variation within and among locations of Gila chub, *Gila intermedia*. Report to the Gila Chub Recovery Team. Arizona State University, Tempe, Arizona.

Dowling, T.E. and B.D. DeMarais. 1993. Evolutionary significance of introgressive hybridization in cyprinid fishes. Nature 362(6419):444-446.

Dowling, T.E., P.C. Marsh, C.D. Anderson, M.S. Rosenberg, and A.T. Kelsen. 2008. Population structure in the roundtail chub (*Gila robusta* complex) of the Gila River basin as determined by microsatellites. Final Report to Arizona Game and Fish Department, Phoenix, Contract No. AGR 4/21/04 through funding provided by U.S. Fish and Wildlife Service Agreement 20101-4-J824F and Bureau of Reclamation Agreement 1425-97-AA-3.2-00420.

Dudley, R.K. and W.J. Matter. 2000. Effects of small green sunfish (*Lepomis cyanellus*) on recruitment of Gila chub (*Gila intermedia*) in Sabino Creek, Arizona. The Southwestern Naturalist 45:24-29.

Dunham, J.B., M.K. Young, R.E. Gresswell, and B.E. Reiman. 2003. Effects of fire on fish populations: landscape perspectives on persistence of native fishes and nonnative fish invasions. Forest Ecology and Management 178:183-196.

Earl, S.R. and D.W. Blinn. 2003. Effects of wildfire ash on water chemistry and biota in south-western U.S.A. streams. Freshwater Biology 48:1015-1030.

Eby, L.A., W.F. Fagan, and W.L. Minckley. 2003. Variability and dynamics of a desert stream community. Ecological Applications 13:1566-1579.

Ehret, S. and B. Dickens. 2009. Romero Canyon Survey Trip Report June 1-2, 2009. Arizona Game and Fish Department, Tucson, Arizona. 14pages.

Emerson, J.W. 1971. Channelization: a case study. Science 173:325-326.

Fausch, K.D., and R.G. Bramblett. 1991. Disturbance and fish communities in intermittent tributaries of a western Great Plains river. Copeia 1991:659-674.

Fausch, K.D., B.E. Rieman, J.B. Dunham, M.K. Young, and D.P. Peterson. 2009. Invasion versus isolation: trade-offs in managing native salmonids with barriers to upstream movement. Conservation Biology 23:859-870.

Finlayson, B., R. Schnick, D. Skaar, J. Anderson, L. Demong, D. Duffield, W. Horton, and J. Steinkjer. 2010. Planning and standard operating procedures for the use of rotenone in fish management—rotenone SOP manual. American Fisheries Society, Bethesda, Maryland.

F.I.S.R.W.G. (Federal Interagency Stream Restoration Working Group). 2001. Stream corridor restoration: principles, processes, and practices. GPO Item No. 0120-A; SuDocs No. A 57.6/2:EN3/PT.653.

Fleischner, T.L. 1994. Ecological costs of livestock grazing in western North America. Conservation Biology 8:629-644.

Frankham, R. 2005. Genetics and extinction. Biological Conservation 126:131-140.

Frankham, R. 2010. Challenges and opportunities of genetic approaches to biological conservation. Biological Conservation 143:1919-1927.

Franklin, I.R. 1980. Evolutionary change in small populations. Pages 135-149 *In* M.E. Soule and B.A. Wilcox (Editors) Conservation biology: an evolutionary-ecological perspective. Sinauer Associates, Sunderland, Massachusetts.

Fuller, P.L., L.G. Nico, and J.D. Williams. 1999. Nonindigenous fishes introduced into inland waters of the United States. American Fisheries Society, Special Publication 27, Bethesda, Maryland.

Gerber, A.S., C.A. Tibbets, and T.E. Dowling. 2001. The role of introgressive hybridization in the evolution of the *Gila robusta* complex (Telostei: Cyprinidae). Evolution 55:2028-2039.

Girard, C. 1856. Researches upon the cyprinoid fishes inhabiting the fresh waters of the United States of America, west of the Mississippi Valley, from specimens in the Museum of the Smithsonian Institution. Proceedings of the Academy of Natural Sciences of Philadelphia 8:165-213.

Germani, M.S., M. Small., and W.H. Zoller. 1981. Fractionation of Elements during Copper Smelting. Environmental Science and Technology. Volume 15, Number 3, pages 299-305.

Griffith, J.S. and T.R. Tiersch. 1989. Ecology of fishes in Redfield Canyon, Arizona, with emphasis on *Gila robusta intermedia*. The Southwestern Naturalist 34:131-134.

Gutzler, D.S. 2013. Regional climatic considerations for borderlands sustainability. Ecosphere 4(1):7. Available at: http://dx.doi.org/10.1890/ES12-00283.1

Gutzler, D.S., and T.O. Robbins. 2011. Climate variability and projected change in the western United States: regional downscaling and drought statistics. Climate Dynamics 37:835-849.

Haines, T.A. 1981. Acidic precipitation and its consequences for aquatic ecosystems: a review., Transactions of the American Fisheries Society 110(6):669-707.

Hancock, P.J. 2002. Human impacts on the stream-groundwater exchange zone. Environmental Management 29:763-781.

Hanski, I. and M. Gilpin. 1991. Metapopulation dynamics: brief history and conceptual domain. Biological Journal of the Linnean Society 42:3-16.

Heckman, R.A., J.E. Deacon, and P.D. Greger. 1986. Parasites of the woundfin minnow *Plagopterus argentissimus*, and other endemic fishes from the Virgin River, Utah. Great Basin Naturalist 46:662-676.

Hendrickson, D.A., and W.L. Minckley. 1984. Ciénegas ─ vanishing climax communities of the American southwest. Desert Plants 6:130-175.

Hermoso, V., S. Linke, J. Prenda, and H.P. Possingham. 2011. Addressing longitudinal connectivity in the systematic conservation planning of fresh waters. Freshwater Biology 56:57-70.

Hilderbrand, R.H., A.C. Watts, and A.M. Randle. 2005. The myths of restoration ecology. Ecology and Society 10(1): 19. [online] URL: http://www.ecologyandsociety.org/vol10/iss1/art19/.

Hoffnagle, T.L. and Cole, R.A. 1999. Distribution and prevalence of *Lernaea cyprinacea* in fishes of the Colorado River and tributaries in Grand Canyon, Arizona. Proceedings of the Desert Fishes Council 29:45-46.

Hughes, A.R., B.D. Inouye, M.T.J. Johnson, N. Underwood, and M. Vellend. 2008. Ecological consequences of genetic diversity. Ecology Letters 11:609-623.

I.P.C.C. (Intergovernmental Panel on Climate Change). 2007. Climate change 2007: synthesis report. Contribution of Working Groups I, II and III to the fourth assessment report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A.(Editors)]. IPCC, Geneva, Switzerland. 104 pages. Available at: *http://www.ipcc.ch/publications_and_data/ar4/syr/en/contents.html* (accessed 6 February 2013).

I.P.C.C. (Intergovernmental Panel on Climate Change). 2013. Climate change 2013: the physical science basis. Contributions of Working Group I to the Fifth Assessment Report of the IPCC. Edited by T.F. Stocker and nine co-editors. Cambridge University Press, New York.

I.U.C.N. (International Union for Conservation of Nature). 2014. Guidelines for using IUCN Red List categories and criteria, version 11(February 2014). Prepared by the Standards and Petitions Subcommittee. Available at: http://www.iucnredlist.org/documents/RedListGuidelines.pdf (accessed 14 March 2014).

Jelks, H.L., and 15 coauthors. 2008. Conservation status of imperiled North American freshwater and diadromous fishes. Fisheries 33:372-407.

Johnson, J.E. and R.T. Hines. 1999. Effect of suspended sediment on vulnerability of young razorback suckers to predation. Transactions of the American Fisheries Society 128:648-655.

Johnson, J.E., M.G. Pardew, and M.M. Lyttle. 1993. Predator recognition and avoidance by larval razorback sucker and northern hog sucker. Transactions of the American Fisheries Society 122:1139-1145.

Jones, J.A., J.S. Frederick, J.S., B.C. Wemple, and K.U. Snyder. 2001. Effects of roads on hydrology, geomorphology, and disturbance patches in stream networks. Conservation Biology 14:76-85.

Jordan, D.S. and B.W. Evermann. 1896. The fishes of North and Middle America. Part 1. Bulletin of the U.S. National Museum 47:1-1240.

Korb, J.E., P.Z. Fule, and M.T. Stoddard. 2012. Forest restoration in a surface fire-dependent ecosystem: an example from a mixed conifer forest, southwestern Colorado, USA. Forest Ecology and Management 269:10-18.

Leibfried, B. 2004. August 18, 2004 email from B. Leibfried, SWCA, to Sophia Fong, Arizona Game and Fish Department, re: Williamson Valley Wash.

Lemly, A.D. 1985. Suppression of native fish populations by green sunfish in first-order streams of Piedmont North Carolina. Transactions of the American Fisheries Society 114:705-712.

Lemly, A.D. 2004. Aquatic selenium pollution is a global environmental safety issue. Ecotoxicology and Environmental Safety 59 (2004) 44-56.

Leopold, L.B. 1997. Water, rivers and creeks. University Science Books, Sausalito, California.

Leopold, L.B., M.G. Wolman, and J.P. Miller. 1964. Fluvial processes in geomorphology. Freeman Press, San Francisco, California.

Lewis, M.A. and R. Burraychak. 1979. Impact of Copper Mining on a Desert Intermittent Stream in Central Arizona: A summary. Journal of the Arizona-Nevada Academy of Science 14(1):22-29.

Ligon, F.K. W.E. Dietrich, and W.J. Trush. 1995. Downstream ecological effects of dams. BioScience 45(3):183-192.

Little, E.E. and R.D. Calfee. 2000. The effects of UVB radiation on the toxicity of fire-fighting chemicals. U.S. Geological Survey, Columbia Environmental Resource Center, Columbia, MO. Final report submitted to USDA Forest Service. 72 pages.

Little, E.E. and R.D. Calfee. 2002. Effects of fire-retardant chemical products on fathead minnows in pond enclosures. U.S. Geological Survey, Columbia Environmental Resource Center, Columbia, Missouri. 28 pages.

Little, E.E. and R.D Calfee. 2004. Effects of fire-retardant chemical products on fathead minnows in experimental streams. Report No. ECO-04, U.S. Geological Survey, Columbia Environmental Research Center, Columbia, Missouri. 28 pages.

Little, E.E. and R.D. Calfee. 2005. Environmental persistence and toxicity of fire-retardant chemicals, Fire-Trol GTS-R and Phos-Chek D75-R to fathead minnows. CERC Ecological Branch Fire Chemical Report ECO-05. U.S. Geological Survey, Columbia Environmental Resource Center, Columbia, Missouri. 52 pages.

Lohr, S.C. and K.D. Fausch. 1996. Effects of green sunfish (*Lepomis cyanellus*) predation on survival and habitat use of plains killifish (*Fundulus zebrinis*). The Southwestern Naturalist 41:155-160.

Ludwig, H.R. and J.A. Leitch. 1996. Interbasin transfer of aquatic biota via angler's bait buckets. Fisheries 21(7):14-18.

Marsh, P.C., B.E. Bagley, G.W. Knowles,G. Schiffmiller, and P.A. Sowka. 2003. New and rediscovered populations of loach minnow, *Tiaroga cobitis* (Cyprinidae), in Arizona. The Southwestern Naturalist 48:666-669.

Marsh, P.C., J.E. Brooks, D.A. Hendrickson, and W.L. Minckley. 1990. Fishes of Eagle Creek, Arizona, with records for threatened spikedace and loach minnow (Cyprinidae). Journal of the Arizona-Nevada Academy of Science 23:107-116.

Marsh, P.C., and C.A. Pacey. 2005. Immiscibility of native and nonnative species. Pages 59-63 *In* Restoring native fish to the lower Colorado River: interactions of native and nonnative fishes. U.S. Fish and Wildlife Service, Albuquerque, New Mexico, and U.S. Bureau of Reclamation, Boulder City, Nevada.

Marshall, R.M., M.D. Robles, D.R. Majka, and J.A. Haney. 2010. Sustainable water management in the southwestern United States: reality or rhetoric? PLoS One 5(7): ee11687.doe:10.1371/journal.pone.0011687.

McDonald, S.F., S.J. Hamilton, K.J. Buhl, and J.F. Heisinger. 1995. Acute toxicity of fire-retardant and foam-suppressant chemicals to *Hyalella azteca* (Saussure). Environmental Toxicology and Chemistry 16:1370-1376.

Medina, A.L. 1990. Possible effects of residential development on streamflow, riparian plant communities, and fisheries on small mountain streams in central Arizona. Forest Ecology and Management 33/34:351-361.

Meffe, G.K. 1985. Predation and species replacement in American southwestern fishes: A case study. The Southwestern Naturalist 30:173-187.

Meffe, G.K., and C.R. Carroll. 1997. Genetics: conservation of diversity within species. Principles of Conservation Biology 2:161-202

Miller, R.R. 1945. A new cyprinid fish from southern Arizona, and Sonora, Mexico, with the description of a new subgenus of Gila and a review of related species. Copeia 1945 (2):104-110, Plate 1.

Miller, R. R. 1946. *Gila cypha*, a remarkable new species of cyprinid fish from the Colorado River in Grand Canyon, Arizona. Journal of the Washington Academy of Sciences. 36(12):409-415.

Miller, R.R. 1961. Man and the changing fish fauna of the American southwest. Papers of the Michigan Academy of Science, Arts, and Letters XLVI:365-404.

Miller, R.R., and C.H. Lowe. 1967. Fishes of Arizona, Part 2. Pages 133 – 151 *In* The vertebrates of Arizona, second printing, C.H. Lowe (Editor). . University of Arizona Press, Tucson, Arizona.

Minckley, W.L. 1969. Aquatic biota of the Bonita Creek Basin, Santa Cruz County, Arizona. The Nature Conservancy, Ecological Studies Leaflet, 15:1-8.

Minckley, W.L. 1973. Fishes of Arizona. Arizona Game and Fish Department, Phoenix, Arizona.

Minckley, W.L. 1985. Native fishes and natural aquatic habitats in U.S. Fish and Wildlife Service Region II west of the Continental Divide: Report to the U.S. Fish and Wildlife Service, Albuquerque, New Mexico. Department of Zoology, Arizona State University, Tempe, Arizona. Pages. ix+158, processed.

Minckley, W.L. 1991. Native fishes of the Grand Canyon region: an obituary? Pages 124-177 *In* Colorado River Ecology and Dam Management. National Academy Press, Washington, D.C.

Minckley, W.L. and DeMarais, B.D. 2000. Taxonomy of Chubs (Teleostei, Cyprinidae, Genus *Gila*) in the American Southwest with Comments on Conservation. Copeia 2000:251-256.

Minckley, W.L., D.A. Hendrickson, and C.E. Bond. 1986. Geography of western North American freshwater fishes: description and relationships to intracontinental tectonism. Page 519 - 613 *In* C.H. Hocutt and E.O. Wiley (E,ditors). Zoogeography of North American Freshwater Fishes. John Wiley and Sons, New York.

Minckley, W.L. and P.C. Marsh. 2009. Inland Fishes of the Greater Southwest: Chronicle of a Vanishing Biota. The University of Arizona Press, Tucson, Arizona.

Minckley, W.L. and G.K. Meffe. 1987. Differential selection by flooding in stream fish communities of the arid American Southwest. Pages 93 – 104 *In* Community and evolutionary ecology of North American stream fishes, W.J. Matthews and D.C. Heins (Editors). University of Oklahoma Press, Norman, Oklahoma.

Minckley, W.L. and J.N. Rinne. 1991. Native fishes of arid lands: a dwindling resource of the desert southwest. USDA Forest Service General Technical Report RM-206.

Mooney, H.A. and E.E. Cleland. 2001. The evolutionary impact of invasive species. Proceedings of the National Academy of Sciences 98:5446-5451.

Moritz, C. 1994. Defining "evolutionarily significant units" for conservation. Trends in Ecology and Evolution 9:373-375.

Moyle, P. B., H.W. Li, and B.A. Barton. 1986. The Frankenstein effect: impact of introduced fishes on native fishes in North America. Pages 415 - 426 *In* R.H. Stroud (Editor) Fish culture in fisheries management. American Fisheries Society, Bethesda, Maryland.

Mpoame, M. 1981. Parasites of some fishes native to Arizona and New Mexico, with ecological notes. Ph.D. Dissertation, Arizona State University, Tempe, Arizona.

Nash, J.T., W.R. Miller, J.B. McHugh, and A.L. Meier. 1996. Geochemical Characterization of Mining Districts and Mining-related Contamination in the Prescott National Forest area, Yavapai County, Arizona: a preliminary assessment of environmental effects. Open-file report 96-687. U.S Geological Survey. 81pages.

N.M.F.S. (National Marine Fisheries Service). 2010. Interim Endangered and Threatened Species Recovery Planning Guidance. Version 1.3. Original (1.0): October 2004.

Nelson, B. 1993. Spawning characteristics of Gila chub (*Gila intermedia*) in Cienega Creek, Pima County, Arizona. Report for USDI Bureau of Land Management, Tucson Resource Area, Arizona.

Newcombe, C.P. and D.D. MacDonald. 1991. Effects of suspended sediments on aquatic ecosystems. North American Journal of Fisheries Management 11:72-82.

N.M.A.C. (New Mexico Administrative Code). 2009. 19.30.14 NMAC. Available at: http://164.64.110.239/nmac/parts/title19/19.030.0014.htm (accessed 20 October 2014)

N.M.D.G.F. (New Mexico Department of Game and Fish). 1988. Handbook of Species Endangered in New Mexico, C-128:1-2.

N.M.D.G.F. (New Mexico Department of Game and Fish). 2005a. Procedure for deployment of piscicide during restoration of lentic waters. March 2005. 7 pages.

N.M.D.G.F. (New Mexico Department of Game and Fish). 2005b. Protocol for deployment of piscicides during restoration of native fisheries in lotic waters. Amended March 2005. 5 pages.

N.M.D.G.F. (New Mexico Department of Game and Fish). 2013. Gila River Basin Native Fishes Conservation Program, New Mexico activities 2012-2013. Annual Report to U.S. Fish and Wildlife Service, Contract No. 20181-6-J811. 25 pages.

N.M.S.A. (New Mexico Statutes Annotated). 1978. 17-4-35. Aquatic invasive species control. New Mexico Public Access Law. Available at: http://public.nmcompcomm.us/nmpublic/gateway.dll/?f=templates&fn=default.htm (accessed 20 October 2014)

Novinger, D.C. and F.J. Rahel. 2003. Isolation management with artificial barriers as a conservation strategy for cutthroat trout in headwater streams. Conservation Biology 17:772-781.

Odum, E.P. and G.W. Barrett. 2005. Fundamentals of Ecology. Fifth Edition. Belmont, Brooks/Cole. 598 pages.

Olden, J.D. and N.L. Poff. 2005. Long-term trends of native and nonnative fish faunas in the American southwest. Animal Biodiversity and Conservation 28:75-89.

Olden, J.D., N.L. Poff, and K.R. Bestgen. 2006. Life-history strategies predict invasions and extirpations in the Colorado River basin. Ecological Monographs 76:25-40.

Pacey, C.A. and P.C. Marsh. 1998. Resource use by native and nonnative fishes of the lower Colorado River: literature review, summary, and assessment of relative roles of biotic and abiotic factors in managment of an imperiled indigenous ichthyofauna. Final Report to U.S. Burea of Reclamation, Lower Colorado Region, Contract 7-MT-30-R0012. Arizona State University, Tempe, Arizona.

Platts, W.S. 1991. Livestock grazing. Pages 389-423 *In* Influences of forest and rangeland management on salmonid fishes and their habitats. W.R. Meehan (editor). American Fisheries Society Special Publication 19, Bethesda, Maryland.

Platts, W.S. and R.L. Nelson. 1988. Fluctuations in trout populations and their implications for land-use evaluation. North American Journal of Fisheries Management 8:333-345.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The natural flow regime: a paradigm for river conservation and restoration. BioScience 47:769-784.

Pringle, C.M. 2001. Hydrologic connectivity and the management of biological reserves: a global perspective. Ecological Applications 11:981-998.

Propst, D.L. 1999. Threatened and endangered fishes of New Mexico. New Mexico Game and Fish Department, Santa Fe, NM. 84 pages.

Propst, D.L., K.R. Bestgen, and C.W. Painter. 1986. Distribution, status, biology, and conservation of the spikedace (*Meda fulgida*) in New Mexico. U.S. Fish and Wildlife Service Endangered Species Report Number 15.

Propst, D.L., K.B. Gido, and J.A. Stefferud. 2008. Natural flow regimes, nonnative fishes, and native fish persistence in arid-land river systems. Ecological Applications 18:1236-1252.

Rabeni, C.F. 1992. Habitat evolution in a watershed context. American Fisheries Symposium 13:57-68.

Rahel, F.J. and J.D. Olden. 2008. Assessing the effects of climate change on aquatic invasive species. Conservation Biology 22:521-533.

Rattner, B.A. and A.G. Heath. 2003. Environmental Factors Affecting Contaminant Toxicity in Aquatic and Terrestrial Vertebrates. In: Handbook of Ecotoxicology, 2nd Edition. Rattner, G.A. Burton, Junior, J. Cairns Junior. CRC Press LLC. Boca Raton, Florida. edition. Edited by DJ Hoffman, BA.

Redford, K.H. and 19 coauthors. 2011. What does it mean to successfully conserve a (vertebrate) species? BioScience 61:39-48.

Reinert, H.K. 1991. Translocation as a conservation strategy for amphibians and reptiles: some comments, concerns, and observations. Herpetologica 47:357-363.

Rinker, M. 2011. Arizona Game and Fish Department Spring Creek fish sampling report, 2011 fish sampling. Region II Fisheries Program.

Rinne J.N. 1969. Cyprinid fishes of the genus Gila from the lower Colorado River basin. Master's Thesis, Arizona State University, Tempe, Arizona.

Rinne, J.N. 1976. Cyprinid fishes of the genus Gila from the Lower Colorado River Basin. Wasmann Journal of Biology 34(1):65-107.

Rinne, J.N. 1996. Short-term effects of wildfire on fishes and aquatic macroinvertebrates in the southwestern United States. North American Journal of Fisheries Management 16:653-658.

Rinne, J.N. and W. L. Minckley. 1970. Native Arizona fishes: Part III - chubs. Wildlife Views 17(5):12-19.

Rinne, J.N. and D.G. Neary. 1996. Fire effects on aquatic habitats and biota in Madrean-type ecosystems, southwestern United States. Pages 135-145 *In* P.F. Ffolliott, L.F. DeBano, M.B. Baker, G.J. Gottfried, G. Solis-Garza, C.B. Edminster, D.G. Neary, and R.H. Hamre (Editors). Effects of fire on Madrean province ecosystems: a symposium proceedings, March 11-15, 1996, Tuscon, Arizona. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station General Technical Report RM-289.

Robinson, A. 2009. Gila River Basin Native Fishes Conservation Program: Cooperative Agreement 201816J808 Quarterly Report for the period July 1, 2009---September 30, 2009. Report by Arizona Game and Fish Department to U.S. Fish and Wildlife Service, Arizona Ecological Services, Tucson, Arizona.

Robinson, A. 2012. Gila River Basin Native Fishes Conservation Program: Cooperative Agreement 201819J853 Semi-Annual Report for the Period May 1 thru October 31, 2011. Report by Arizona Game and Fish Department to U.S. Fish and Wildlife Service, Arizona Ecological Services, Tucson, Arizona.

Robinson, A. 2014. Gila River Basin Native Fishes Conservation Program: Cooperative Agreement F09AC00084 Draft Annual Report for the Period Nov. 1, 2012 thru February 5, 2014. Report by Arizona Game and Fish Department to U.S. Fish and Wildlife Service, Arizona Ecological Services, Tucson, Arizona.

Robinson, A., O. David, and C. Crowder. 2010. Devils Canyon and Mineral Creek Fish Surveys in 2009. Report by Arizona Game and Fish Department. 11 pages.

Robinson, A.T., P.P. Hines, J.A. Sorensen, and S.D. Bryan. 1998. Parasites and fish health in a desert stream, and management implication for two endangered fishes. North American Journal of Fisheries Management 18:599-608.

Rogstad, A., M. Crimmins, and G. Garfin. 2012. Climate change and wildfire impacts in southwest forests and woodlands. Arizona Cooperative Extension, University of Arizona College of Agriculture and Life Sciences. 4 pages.

Rohlf, D.J., C. Carroll, and B. Hartl. 2014. Conservation-reliant species: toward a biology-based definition. BioScience 64:601-611.

Rosgen, D. 1996. Applied river morphology. Wildland Hydrology, Pagosa Springs, Colorado.

Santore, R.C., D.M. Di Toro., P.R. Paquin., H.E. Allen, and J.S. Meyer. 2001. Biotic ligand model of the acute toxicity of metals. 2. Application to acute copper toxicity in freshwater fish and *Daphnia*. Environmental Toxicology and Chemistry 20(10):2397-2402.

Schoennagel T., T.T. Veblen, and W.H. Romme. 2004. The interaction of fire, fuels, and climate across Rocky Mountain forests. BioScience 54:661-676.

Schooley, J.D., A.P. Karam, B.R. Kesner, P.C. Marsh, C.A. Pacey, and D.J. Thornbrugh. 2008. Detection of larval remains after consumption by fishes. Transactions of the American Fisheries Society 137:1044-1049.

Schultz, A.A. and S.A. Bonar. 2006. Spawning and Culture of Gila Chub. Final Report to the Arizona Game and Fish Department. Fisheries Research Report 02-07. Arizona Cooperative Fish and Wildlife Research Unit, U.S. Geological Survey, University of Arizona, Tucson, Arizona.

Schultz, A.A. and S.A. Bonar. 2007. Selected aspects of the natural history of the Gila Chub. Final Report to the Bureau of Land Management. Fisheries Research Report 02-06. Arizona Cooperative Fish and Wildlife Research Unit, U.S. Geological Survey, University of Arizona, Tucson, Arizona.

Schwemm, M.R. 2006. Genetic variation in the *Gila robusta* complex (Teleostei: Cyprinidae) in the lower Colorado River. Master's Thesis, Arizona State University, Tempe, Arizona. 117 pages.

Scott, J.M., D.D. Goble, J.A. Wiens, D.S. Wilcove, M. Bean, and T. Male. 2005. Recovery of imperiled species under the Endangered Species Act: the need for a new approach. Frontiers in Ecology and the Environment 3:383-389.

Seager, R. and 11 coauthors. 2007. Model projection of an imminent transition to a more arid climate in southwestern North America. Science 316:1181-1184.

SEDESOL. (Secretaria de Dessarrollo Social). 1994. NORMA Official Mexicana NOM-059-ECOL-1994, que determina las species y subspecies de flora y fauna sylvestres terrestres y acuaticas en peiigro de extinction, amenazadas, raras y las sujetas a proteccion especial y que establece especificaciones para su proteccion. Dario Oficial, Lunes 16 de Mayo de 1994, 448 pages.

Selong, J.H., T.E. McMahon, A.V. Zale, and F.T. Barrows. 2001. Effect of temperature on growth and survival of bull trout, with application of an improved method for determining thermal tolerances in fishes. Transactions of the American Fisheries Society 130:1026-1037.

Shaffer, M.L. and B.A. Stein. 2000. Safeguarding our precious heritage. Pages 301-322 *In* B.A. Stein, L.S. Kutner, and J.S. Adams (Editors). Precious heritage: the status of biodiversity in the United States. Oxford University Press.

Simon, K.S. and C.R. Townsend. 2003. Impacts of freshwater invaders at different levels of ecological organization, with emphasis on salmonids and ecosystem consequences. Freshwater Biology 48:982-994.

Simpson, P.W. 1982. Manual of stream channelization impacts on fish and wildlife. U.S. Department of the Interior, Fish and Wildlife Service.

Small, M., M.S. Germani, A.M. Small., and W.H. Zoller. 1981. Airborne plume study of emissions from the processing of copper ores in southeastern Arizona. Environmental Science and Technology 15:293-298.

Smith, S.M., J.S. Odenkirk, and S.J. Reeser. 2005. Smallmouth bass recruitment variability and its relation to stream discharge in three Virginia rivers. North American Journal of Fisheries Management 25:1112-1121.

Sorooshian, A., J. Csavina, T. Shingler, S. Dey, F.J. Brechtel, A.E. Saez, and E A. Betterton. 2012. Hygroscopic and chemical properties of aerosols collected near a copper smelter: implications for public and environmental health. Environmental Science and Technology 46:9473-9480.

Stefferud, J.A., P.C. Marsh, S.E. Stefferud, and R.W. Clarkson. 2009. Fishes: historical changes and an imperiled native fauna. Pages 192-214 *In* J.C. Stromberg and B. Tellman (Editors). Ecology and conservation of the San Pedro River. The University of Arizona Press, Tucson, Arizona.

Stout, G.G., E.C. Bloom, and J.K. Glass. 1970. The Fishes of Cave Creek, Maricopa County, Arizona. Journal Arizona Academy Science 6(2):109-113.

Strauss, S.Y., J.A. Lau, and S.P. Carroll. 2006. Evolutionary responses of natives to introduced species: what do introductions tell us about natural communities? Ecology Letters 9:357-374.

Sublette, J.E., M.D. Hatch, and M. Sublette. 1990. The fishes of New Mexico. University of New Mexico Press, Albuquerque, New Mexico. 347 pages.

Sutter, J.W. 2011. May 10, 2011 email from J. Sutter, AZDEQ, to Tony Robinson, AZGFD re: Request for information about Mineral Creek and Gibson Mine cleanup.

Swanston, D.N. 1991. Natural processes. Pages 139-179 *In* W.R. Meehan (Editor) Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society, Special Publication 19.

Swetnam T.W. and J.L. Betancourt. 1990. Fire - southern oscillation relations in the southwestern United States. Science 249:1017-1020.

Tellman, B., R. Yarde, and M.G. Wallace. 1997. Arizona's changing waters: how people have affected the rivers. Water Resources Research Center, College of Agriculture, University of Arizona, Issue Paper 19. 198 pages.

Tillman, F.D., J.T. Cordova, B.E. Thomas, and J.B. Callegary. 2011. Water availability and use pilot: methods development for a regional assessment of groundwater availability, southwest alluvial basins, Arizona. U.S. Geological Survey Scientific Investigations Report 2011-5071. 118 pages.

Timmons, R.T. and L.J. Upton. 2013. Fish monitoring of selected streams within the Gila River basin, 2012. Final Report to Bureau of Reclamation, Contract No. R12PC32007. Arizona Game and Fish Department, Nongame Branch, Phoenix. Arizona.

Traill, L.W., B.W. Brook, R.R. Frankham, and C.J.A. Bradshaw. 2010. Pragmatic population viability targets in a rapidly changing world. Biological Conservation 143:28-34.

U.S. Census Bureau. 2011. Population change for counties in the United States and for municipios in Puerto Rico: 2000 to 2010. CPH-T-1. Available at: http://www.census.gov/population/www/cen2010 /cph-t/CPH-T-1.pdf (accessed 21 September 2011).

U.S.D.A. (United States Department of Agriculture). 2012. Fire ecology, fuels, and air quality specialist report. Four-Forest Restoration Initiative. Forest Service, Southwest Region. 332 pages.

U.S.E.P.A. (U.S. Environmental Protection Agency). 2011. EPA issues first national standards for mercury pollution from power plants/Historic 'mercury and air toxics standards' meet 20-year old requirement to cut dangerous smokestack emissions. Available at: http://yosemite.epa.gov/opa/admpress.nsf/d0cf6618525a9efb85257359003fb69d/bd8b3f37edf5716d8525796d005dd086!opendocument (accessed 26 February 2013).

U.S.E.P.A. (U.S. Environmental Protection Agency). 2013. Air Quality Designations for the 2010 Sulfur Dioxide Primary National Ambient Air Quality Standard. Federal Register 78:47191-47205.

U.S.E.P.A. (U.S. Environmental Protection Agency). 2014. 2012 Toxic Release Inventory National Analysis Overview. 45 pages.

U.S.F.W.S. (U.S. Fish and Wildlife Service). 1982. Endangered and threatened wildlife and plants; review of vertebrate wildlife for listing as endangered or threatened species. Federal Register 47:58454-58460.

U.S.F.W.S. (U.S. Fish and Wildlife Service). 1983a. Endangered and threatened species listing and recovery priority guidelines . Federal Register 48:43098-43105.

U.S.F.W.S. (U.S. Fish and Wildlife Service). 1983b. Endangered and threatened species listing and recovery priority guidelines: correction. Federal Register 48:51985.

U.S.F.W.S. (U.S. Fish and Wildlife Service). 1985. Endangered and threatened wildlife and plants; review of vertebrate wildlife. Federal Register 50:37958-37962.

U.S.F.W.S. (U.S. Fish and Wildlife Service). 1996. Endangered and threatened wildlife and plants; review of plant an animal taxa that are candidate for listing as endangered or threatened species. Federal Register 61:7596-7613.

U.S.F.W.S. (U.S. Fish and Wildlife Service). 1997. Endangered and threatened wildlife and plants; review of plant and animal taxa that are candidates or proposed for listing as endangered or threatened, annual notice of findings on recycled petitions, and annual description of progress on listing actions. Federal Register 62:49398-49411.

U.S.F.W.S. (U.S. Fish and Wildlife Service). 1999. Endangered and threatened wildlife and plants; review of plant and animal taxa that are candidates of proposed for listing as endangered or threatened; annual notice of findings on recycled petitions; and annual description of progress on listing actions. Federal Register 64:57534-57547.

U.S.F.W.S. (U.S. Fish and Wildlife Service). 2001. Endangered and threatened wildlife and plants; review of species that are candidates or proposed for listing as endangered or threatened, annual notice of findings on recycled petitions, and annual description of progress on listing actions. Federal Register 66:54808-54832.

U.S.F.W.S. (U.S. Fish and Wildlife Service). 2002a. Endangered and threatened wildlife and plants; review of species that are candidates or proposed for listing as endangered or threatened; annual notice of findings on recycled petitions; annual description of progress on listing actions. Federal Register 67:40657-40679.

U.S.F.W.S. (U.S. Fish and Wildlife Service). 2002b. Endangered and threatened wildlife and plants; listing of the Chiricahua leopard frog (*Rana chiricahuensis*); final rule. Federal Register 67:40790-40811.

U.S.F.W.S. (U.S. Fish and Wildlife Service). 2005a. Endangered and threatened wildlife and plants; listing the Gila chub as endangered with critical habitat. Federal Register 70:51732-51738.

U.S.F.W.S. (U.S. Fish and Wildlife Service). 2005b. Endangered and threatened wildlife and plants; listing Gila chub as endangered with critical habitat. Federal Register 70:66664-66721.

U.S.F.W.S. (U.S. Fish and Wildlife Service). 2007. Chiricahua Leopard Frog (*Rana chiricahuensis*) Recovery Plan. U.S. Fish and Wildlife Service, Southwest Region, Albuquerque, NM. 149 pages. + Appendices A-M.

U.S.F.W.S. (U.S. Fish and Wildlife Service). 2009. Endangered and threatened wildlife and plants; 12-month finding on a petition to list a distinct population segment of the roundtail chub (*Gila robusta*) in the lower Colorado River basin; proposed rule. Federal Register 74:32352-32387.

U.S.F.W.S. (U.S. Fish and Wildlife Service). 2010. Rio Grande Silvery Minnow (*Hybognathus amarus*) Recovery Plan, First Revision. Albuquerque, New Mexico. Viii + 210 pages.

U.S.F.W.S. (U.S. Fish and Wildlife Service). 2011. Biological and Conference Opinion for Wildlife and Sport Fish Restoration Funding of Arizona Game and Fish Department's Statewide and Urban Fisheries Stocking Program for 2011-2021. 781 pages.

U.S.F.W.S. (U.S. Fish and Wildlife Service). 2013. Endangered and threatened wildlife and plants; threatened status for the northern Mexican gartersnake and narrow-headed gartersnake. Federal Register 78(132):41550-41608.

U.S.F.W.S. (U.S. Fish and Wildlife Service), U.S. Forest Service, and New Mexico Department of Game and Fish. 2012. Turkey Creek fish survey summary, New Mexico, 4-6 April 2012.

U.S.G.S. (U.S. Geological Survey). 2004. Endangered fish threatened by Asian fish tapeworm: the Asian fish tapeworm may inhibit the recovery of the humpback chub in the Grand Canyon. NWHC Information Sheet, August 2004.

U.S.G.S. (U.S. Geological Survey). 2005. Fisheries and aquatics bulletin: a publication of the U.S. Geological Survey. Fisheries: Aquatic and Endangered Resources (FAER) Program IV(1), Spring 2005. 8 pages.

U.S.G.S. (U.S. Geological Survey). 2010. Possible effects of groundwater pumping on surface water in the Verde Valley, Arizona. Fact Sheet 2010-3108.

Vance, E. 2012. Mexico passes climate-change law. Nature: International Weekly Journal of Science. Avaiable at: http://www.nature.com/news/mexico-passes-climate-change-law-1.10496 (accessed 26 February 2013).

Varela-Romero, A. and nine coauthors. 1992. Rediscovery of *Gila intermedia* and *G. purpurea* in the north of Sonora, Mexico. Proceedings of the Desert Fishes Council XXII (1990):33

Ward, D.L., R. Morton-Starner, and S.J. Hedwall. 2013. An evaluation of liquid ammonia (ammonium hydroxide) as a candidate piscicide. North American Journal of Fisheries Management 33:400-405.

Warren, M.L. and M.G. Pardew. 1998. Road crossings as barriers to small-stream fish movement. Transactions of the American Fisheries Society 127:637-644.

Weedman, D.A., A.L. Girmendonk, and K.L. Young. 1996. Status review of Gila chub, *Gila intermedia*, in the United States and Mexico. Technical Report 91, Nongame and Threatened Wildlife Program, Arizona Game and Fish Department, Phoenix, Arizona.

Weiss, J., C.L. Castro., and J.T. Overpeck. 2009. Distinguishing pronounced droughts in the southwest United States: seasonality and effects of warmer temperatures. Journal of Climate 22:5918-5932.

Werner, E.E. 1977. Species packing and niche complementarity in there sunfishes. American Naturalist 111:553-578.

Westerling, A.L., H.D. Hidalgo, D.R. Cayan, and T.W. Swetnam. 2006. Warming and earlier spring increases western U.S. forest fire activity. Science 313:940-943.

Wheeler, A.P., P.L. Angermeier, and A.E. Rosenberger. 2005. Impacts of new highways and subsequent urbanization on stream habitat and biota. Reviews in Fisheries Science 13:141-164.

Williams, J.E., D.B. Bowman, J.E. Brooks, A.A. Echelle, R.J. Edwards, D.A. Hendrickson, and J.J. Landye. 1985. Endangered aquatic ecosystems in North American deserts with a list of vanishing fishes of the region. Journal of the Arizona-Nevada Academy of Science 20:1-61.

Williams, J. E., C. A. Wood, and M. P. Dombeck, editors. 1997. Watershed restoration: principles and practices. American Fisheries Society, Bethesda, Maryland.

Willis, D.W. 1987. Use of gill-net data to provide a recruitment index for walleyes. North American Journal of Fisheries Management 7:591-592.

SECTION VI. APPENDICES

Appendix A. LIST OF CONTACTS

All current and former recovery subgroup members are listed. Those no longer participating are noted with an asterisk.

Recovery Team Technical Subgroup

Andrew Monie
Gila Non-Game Fish Biologist
NMDGF
Santa Fe, New Mexico

Clayton Crowder
AZGFD- Nongame Wildlife Branch
Phoenix, Arizona

David Boyarski*
AZGFD
Phoenix, Arizona

Eddie Alford, Ph.D.
Arizona State University-College of Technology and Innovation
Mesa, Arizona

Eliza Gilbert*
San Juan Non-Game Fish Biologist
NMDGF
Santa Fe, New Mexico

Jeff Simms
Fishery Biologist
BLM
Tucson, Arizona

Melissa Mata (Liaison)
Fish and Wildlife Biologist
USFWS-New Mexico Ecological Service Field Office
Albuquerque, New Mexico

Peter Reinthal
The University of Arizona- Department of Ecology and Evolutionary Biology
Tucson, Arizona

Rob Clarkson (Team Leader)
Fish Biologist
Bureau of Reclamation-Phoenix Area Office
Glendale, Arizona

Ryan Gordon (Co-Team Leader)
Fish and Wildlife Biologist
USFWS-Arizona Ecological Service Field Office
Phoenix, Arizona

Ron Maes
USFS-Southwestern Region
Albuquerque, New Mexico

Tom Dowling
Wayne State University
Detriot, Michigan

Recovery Team Stakeholder Subgroup

Albert Sillas
Fisheries Biologist
USFS-Prescott National Forest
Camp Verde, Arizona

Codey Carter
Wildlife Biologist
BLM
Phoenix, Arizona

Craig Roepke
Deputy Director
New Mexico Interstate Stream Commission
Santa Fe, New Mexico

Eric Borowsky
Spring Creek Ranch
Scottsdale, Arizona

John Kraft
Wildlife Biologist
USFS-Coronado National Forest
Hereford, Arizona

Michael Childs
Fish Biologist
USFS-Coconino National Forest
Sedona, Arizona

Mickey Byrne
Government Springs Ranch
Globe, Arizona

April Howard*
SCAT
San Carlos, Arizona

Stephanie Coleman
Fisheries Program Manager
USFS-Apache-Sitgreaves National Forest
Springerville, Arizona

Terrence Enk
Sr. Environmental Scientist
Freeport-McMoRan Copper and Gold
Oro Valley, Arizona

Tony Robinson
CAP Projects Program Manager
AZGFD
Phoenix, Arizona

Appendix B. GLOSSARY OF TERMINOLOGY

Acousticolateralis system: a network of open and/or enclosed canals and tubes with pores connecting to the outside, containing nervous system components for detecting and transmitting vibrations (sounds) to the ear.

Allopatric: geographically isolated from one another.

Assumed present (AP): a population last detected 10 or more years ago but with no recent information available to suggest the population is extirpated.

Augmentation: a supplemental stocking of individuals into an established or newly replicated population for the purpose of bolstering population size or genetic variation.

Avulsion: a shift in the course of a stream as a result of a flood.

Basal radii: grooves radiating outward from the scale center on the anterior (hidden) field.

Caudal peduncle: the posterior part of the body, from the posterior base of the anal fin to the end of the **hypural plate**.

Cienega: a mid-elevation (1,000-2,000 m) wetland characterized by permanently saturated, highly organic, reducing soils, and a depauperate flora dominated by low sedges highly adapted to such soils (Hendrickson and Minckley 1984).

Crepuscular: referring to an animal that is active primarily during twilight hours (dawn and dusk).

Demersal: eggs that are deposited at or near the bottom of a body of water.

Ecosystem: a community of living organisms (biotic factors) interacting with their physical environment (abiotic factors).

Established population: one that successfully reproduces on a near-annual basis and recruits young into older age classes that then reproduce themselves, and thereby maintains a relatively consistent age-class structure over time and will persist through most environmental perturbations. Preferentially (see text), population size of an established population should exceed 5000 sexually-mature adults to limit the potential for genetic bottlenecking. Relative to recovery criteria and replicated populations, a population must exhibit these characteristics for a minimum of 10 years past the last significant augmentation event.

Extant: a geographic area or population where Gila chub is still considered to be present.

Extirpated: a formerly established population that has not had a capture recorded within the past 50 years, or 1) where the population has not been detected in presence/absence surveys conducted both expansively (across the entire distribution of the population) and intensively (sampling all suitable habitats) over a period of 10 years, and where habitat complexity is relatively low (i.e., habitats were effectively sampled with appropriate gears); 2) where sampling effort over a period of 10 years has been high and where only nonnative species have been detected or they dominate the fish assemblage to the point that even common native species (e.g., longfin dace, desert sucker) are only rarely encountered, or where no fish of any kind have been captured; or 3) where a known catastrophe has occurred such as a chemical spill or desiccation event that obviously eliminated the population.

Gill arches: bony structures that support the gills.

Gill rakers: slender and rodlike to stubby and blunt projections, scarce to profuse in numbers, projecting from the anterior surfaces of the **gill arches**.

Historical range: a broad geographic area, usually watershed based, where the best available information indicates a species occurred before the factors causing the species' decline began; for Gila chub, historical range is the Gila River basin.

Hyporheic zone: the zone of exchange between surface and ground waters

Hypural plate: expanded, often fused bony neural and/or hemal spines of the last caudal vertebrae, forming a "plate" supporting the caudal fin.

Lateral line: the tubular portion of the **acousticolateralis system**, extending from the operculum to the end of the **hypural plate** and sometimes beyond. Scales may bear lateral line pores or not.

Meristic: referring to features that can be counted quantitatively, such as the number of fin rays or scales.

Metapopulation: all individuals occurring within a hydrologic subbasin, or other definable geographic unit, with some probability of intermittent gene flow within the unit, but mostly isolated from other gene pools (other subbasins). Usually refers to a group of geographically-distinct populations that are likely to experience periodic genetic exchange.

Native: a species within its historical range.

Nomenclatorial Synonymy: the historical record of classifying a taxonomic group or species

Nonnative (exotic): a species outside of its historical range.

Not Detected Recently (NDR): a population that has not had a capture recorded within the past 20 to 50 years.

Ontogeny: the developmental history of an individual organism from embryo to adult.

Oocytes: immature eggs found in the ovary prior to fertilization.

Opercular: pertaining to the operculum, which is a complex of bones and soft tissue that forms an external cover for the bronchial chamber and gills.

Ovoid: egg-shaped.

Piscivorous: Feeds on fish; fish-eating.

Population: a group or groups of individuals of a species that have interbred at sufficient levels to prevent genetic divergence.

Protected population: a protected population is one where all of the major limiting factors that may exert downward pressure on a population are eliminated or controlled. These factors do not include normal characteristics of the environment such as extremes of weather or predation/ competition among the native biotic assemblages, but rather those under the primary control of humans, including nonnative predatory and competitive species.

Refuge: an artificial (e.g. a hatchery) or semi-natural (e.g. a man-made pond) facility that requires some level of human assistance to maintain populations of fish.

Refuge population: a population established for the primary purpose of preventing extinction of the species or extirpation of a population. A refuge population typically is held within artificial (e.g., a hatchery) or semi-natural (e.g., a man-made pond) facilities that require some level of human assistance to maintain over the long term. A refuge population should reflect genetic characteristics of its source population, and is protected.

Remnant population: a naturally-occurring wild population that is a vestige of a formerly more widespread distribution of populations, typically found in isolated or headwater tributaries.

Repatriated population: a population intentionally established within an area formerly occupied by that species (Reinert 1991).

Replicated population: a population intentionally established to be redundant to its source population, especially relative to genetic and morphological similarity.

Self-sustaining population: a population that successfully reproduces on a near-annual basis and recruits young into older age classes that then reproduce themselves, thereby maintaining a relatively consistent age-class structure over time.

Stock: refers to the origin of a reestablished population and identifies the natural population from which it was established.

Total Length (TL): the greatest distance from the tip of the snout to the posterior end of the depressed caudal fin.

Translocation: the intentional release of individuals of a species in an attempt to establish or augment a population.

Triploid trout: trout produced in hatcheries to have three sets of chromosomes and are incapable of reproduction.

Tubercles: hardened, thorn-like projections on the skin of heads, fins, and scales, usually forming during the breeding season.

Weberian apparatus: the anterior-most vertebrae, modified into a structure that connects air bladder and inner ear in characids, minnows, and catfishes and allies.

Wild population: Either a remnant or replicated population established within historical range in a natural (i.e., not man-made) habitat.

Appendix C. TABLES

Table C.1. Potential refuge and repatriation sites for Gila chub, segregated by subbasins (Recovery Units). In most cases, potential replication streams have not yet been assigned to specific MUs. Asterisks (*) denote potential repatriation streams in the Salt River subbasin. BPNFCF denotes Bubbling Ponds Native Fish Conservation Facility.

Subbasin (RU)	Potential refuge Sites	Potential replication streams
Agua Fria (1)	Black Canyon Heritage Park Phoenix Zoo BPNFCF	Black Canyon Creek New River Grapevine Canyon (Tonto NF) Poland Creek/Horsethief Canyon Yellow Jacket Creek Ash Creek Little Ash Creek/Dry Creek Agua Fria River
Verde (2)	BPNFCF	Camp Creek Sycamore Creek (Maricopa County) Alder Creek Sheep Creek/South Fork Sheep Creek Sycamore Creek (Sheep Bridge) Tangle Creek Munds Canyon Black Canyon Lime Creek (upper) Roger's Canyon* Pinto Creek* Cave Creek/Seven Springs Wash* West Fork Pinto Creek* Haunted Canyon* Fish Creek* Reavis Creek*
Santa Cruz (3)	Clyne Pond BPNFCF	Temporal Gulch Nogales Spring Peck Canyon Parker Canyon Sonoita Creek Redrock Canyon Bear Canyon Canada del Oro Fresno Canyon Sharp Spring Santa Cruz River (upper)
San Pedro/Middle Gila (4)	White House Pond Jack Daniels Tank Steen Pond BPNFCF	Ash Creek Murray Spring T 4 Spring Don Levi Spring Buehman Canyon Copper Creek Dick Spring Canyon Mineral Creek Devils Canyon Mescal Creek Ash Creek (SCAT)

Subbasin (RU)	Potential refuge Sites	Potential replication streams
		Hawk Canyon (SCAT) Queen Creek Lewis Springs Turkey Creek Babocomari River
Upper Gila (5)	BPNFCF	Sands Draw Upper Fishhook Canyon Markham Creek Cold Creek Cave Creek (Cochise County) S Fork Cave Creek (Cochise County) Oak Creek (Cochise County) Whitetail Creek (Cochise County) E Turkey Creek (Cochise County) Silver Creek (Cochise County) Pigeon/Turkey Creek (Blue River) Squaw/Thomas Creek (Blue River) Coal Creek (San Francisco River) Bear Creek, New Mexico Blue Creek, New Mexico Mogollon Creek, New Mexico Mangas Creek, New Mexico Ash Creek (Graham County) Marijilda Canyon (Graham County Frye Canyon (Graham County Deadman Canyon (Graham County) Jacobson Canyon (Graham County) Sycamore Creek (Blue River) Strayhorse Creek (Blue River) Dutch Blue Creek (Blue River) McKittrick Creek (Blue River) Hannah Hot Springs (Blue River) Sardine Creek (San Francisco River)

Table C.2. Scoring to prioritize needs to replicate Management Unit population groupings according to estimated population size, the number of threats to each population from Table I.4, and ranks of population priority for conservation action from Clarkson et al. (2012). Scores are based on the sum of size, threat, and rank scores; ties were ranked identically. Size scores were weighted to provide this criterion a similar overall magnitude as threat and rank scores; population size estimates are small (S) = <500 adults (Score of 6), medium (M) = 500-5000 adults (Score of 4), and large (L) = >5000 adults (Score of 2). X denotes the population already is replicated, and thus is not considered in the scores.

Subbasin (RU)	Remnant populations	MU	Size	Threat	Rank	Score	Priority
Santa Cruz (3)	Sheehy Spring	3C	6 (S)	3	7	16	1
Upper Gila (5)	Eagle/East Eagle creeks	5B	6 (S)	6	4	16	1
Verde (2)	Williamson Valley Wash	2B	6 (S)	6	4	16	1
Verde (2)	Walker Creek	2A	6 (S)	3	6	15	2
Santa Cruz (3)	Cienega Creek	3A	2 (L)	6	7	15	2
Agua Fria (1)	Indian Creek	1B	6 (S)	3	5	14	3
Verde (2)	Red Tank Draw	2D	6 (S)	3	4	13	4
Verde (2)	Spring Creek	2C	2 (L)	7	4	13	4
San Pedro/Middle Gila (4)	Hot Springs/Bass canyons	4B	2 (L)	3	6	11	5
Upper Gila (5)	Blue River (San Carlos)	5A	2 (L)	4	4	10	6
San Pedro/Middle Gila (4)	Redfield Canyon	4C	2 (L)	2	5	9	7
Upper Gila (5)	Turkey Creek, NM	5E	2 (L)	1	5	8	8
Upper Gila (5)	Dix Creek	5D	2 (L)	3	5	X	
	Harden Cienega	5D	2 (L)	4	3	X	
San Pedro/Middle Gila (4)	O'Donnell Canyon	4A	6 (S)	4	5	X	
Santa Cruz (3)	Sabino Canyon	3B	4 (M)	2	5	X	
Agua Fria (1)	Silver Creek	1A	6 (S)	4	7	X	
	Sycamore/Little Sycamore creeks	1A	4 (M)	4	4	X	

Table C.3. Current status and minimum needs for establishment of wild replicate and refuge populations for downlisting and delisting of Gila chub according to recovery criteria (two wild populations plus one refuge to downlist, three wild populations to delist). The number of replicates needed to delist are in addition to those needed for downlisting. See Table II.1 for a description of management units (MU). n/a denotes not applicable.

Recovery Unit	MU	No. of remnants	No. of stream replicates			No. of refuges			Currently meets criteria to	
			Extant	Needs to Downlist	Needs to Delist	Extant	Needs to Downlist	Needs to Delist	Downlist?	Delist?
Agua Fria (1)	1A	2	2	0	0	0	0	n/a	Yes	Yes
	1B	1	0	1	1	0	1	n/a	No	No
Verde (2)	2A	1	0	1	1	0	1	n/a	No	No
	2B	1	0	1	1	0	1	n/a	No	No
	2C	1	0	1	1	0	1	n/a	No	No
	2D	1	0	1	1	0	1	n/a	No	No
Santa Cruz (3)	3A	1	0	1	1	0	1	n/a	No	No
	3B	1	1	0	1	0	1	n/a	No	No
	3C	1	0	1	1	0	1	n/a	No	No
San Pedro (4)	4A	1	0	1	1	2	0	n/a	No	No
	4B	1	0	1	1	0	1	n/a	No	No
	4C	1	0	1	1	0	1	n/a	No	No
Upper Gila (5)	5A	1	0	1	1	0	1	n/a	No	No
	5B	1	0	1	1	0	1	n/a	No	No
	5C	1	0	1	1	0	1	n/a	No	No
	5D	2	0	0	1	0	1	n/a	No	No
	5E	1	0	1	1	0	1	n/a	No	No
Cumulative total	17	19	3	14	16	2	15	n/a	1	1

Appendix D. FIGURES OF RECOVERY UNIT DETAILS

Figure D.1. Agua Fria Recovery Unit 1 with Land Ownership

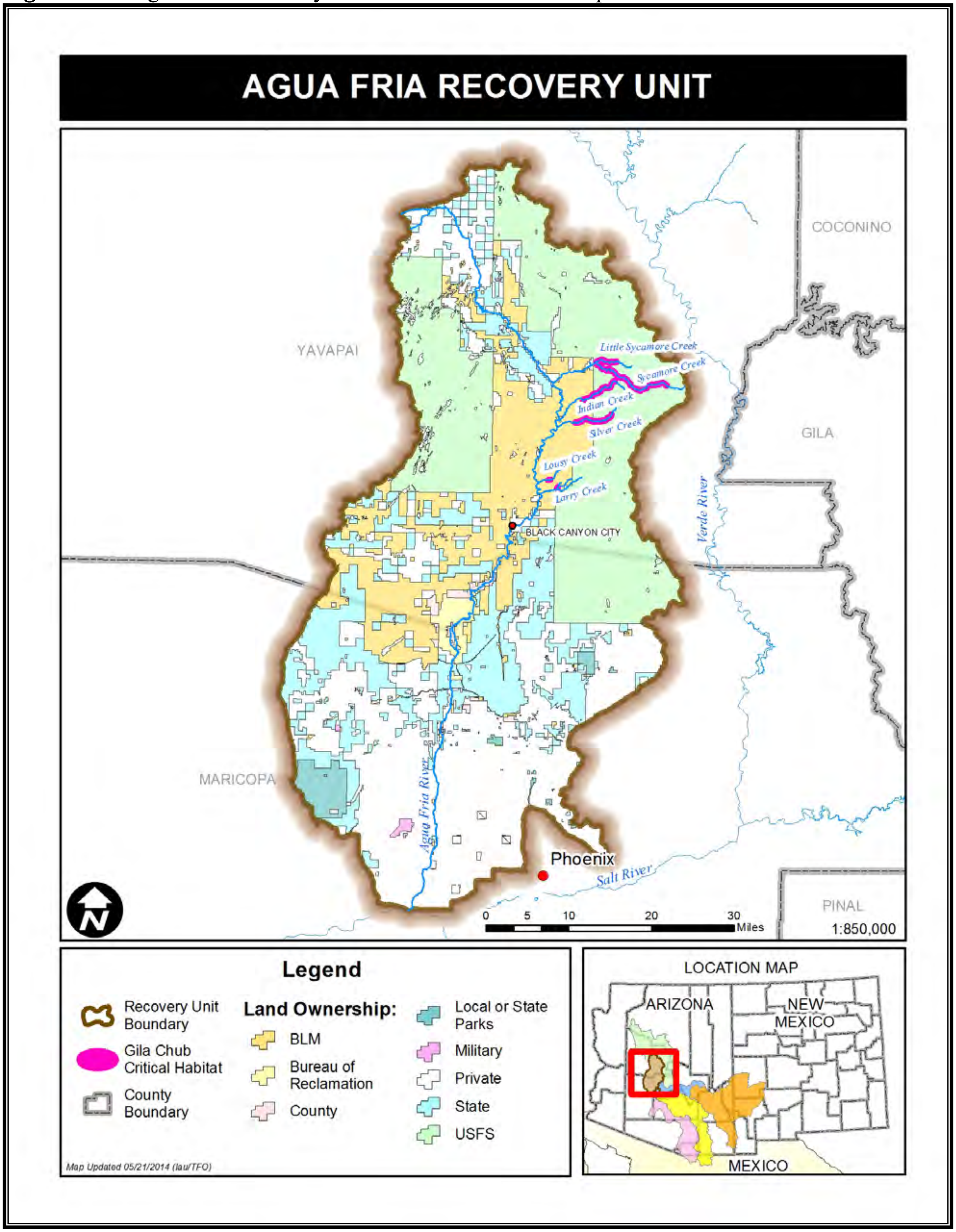


Figure D.2. Verde Recovery Unit 2 with Land Ownership

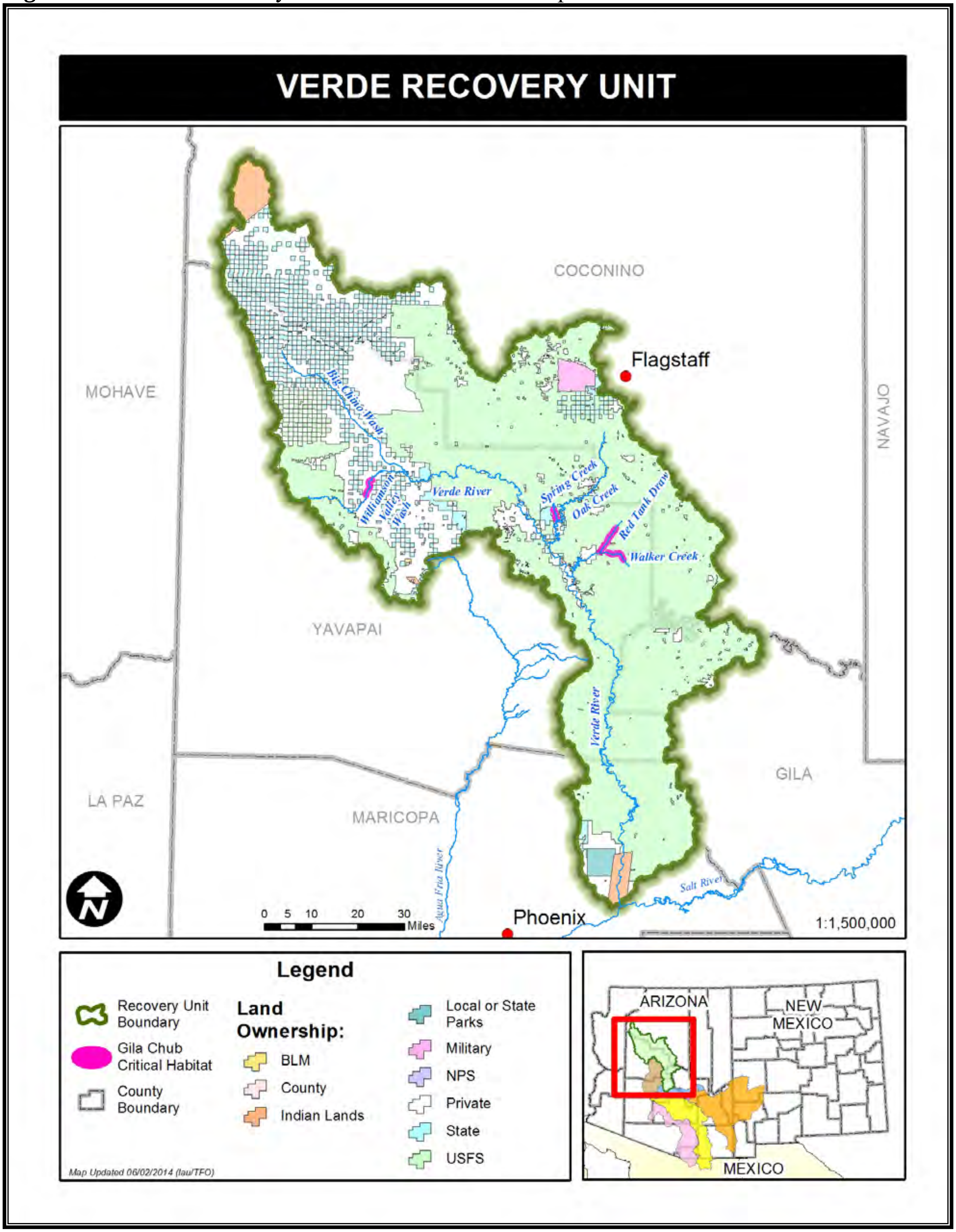


Figure D.3. Santa Cruz Recovery Unit 3 with Land Ownership

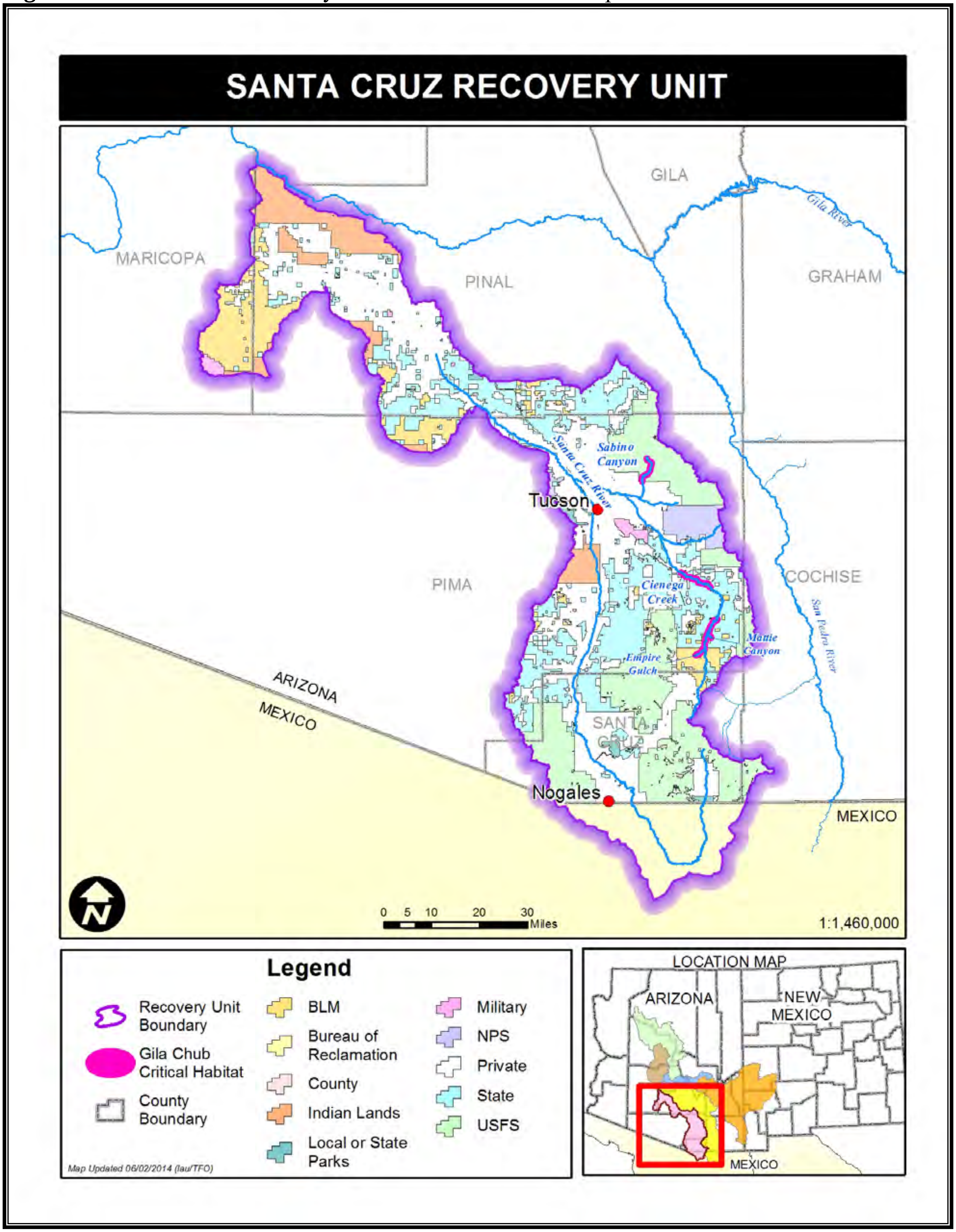


Figure D.4. Middle Gila/San Pedro Recovery Unit 4 with Land Ownership

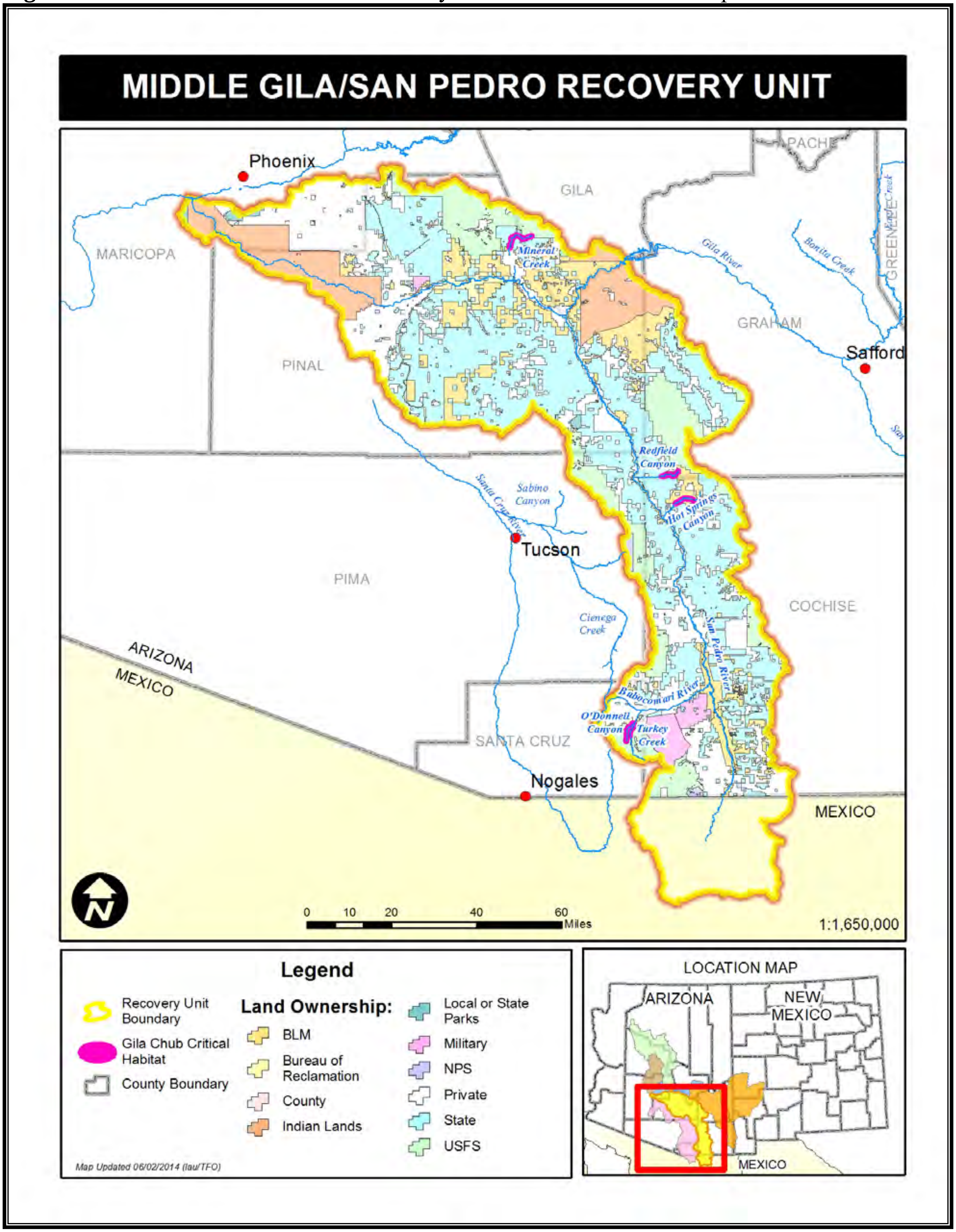


Figure D.5. Upper Gila Recovery Unit 5 with Land Ownership

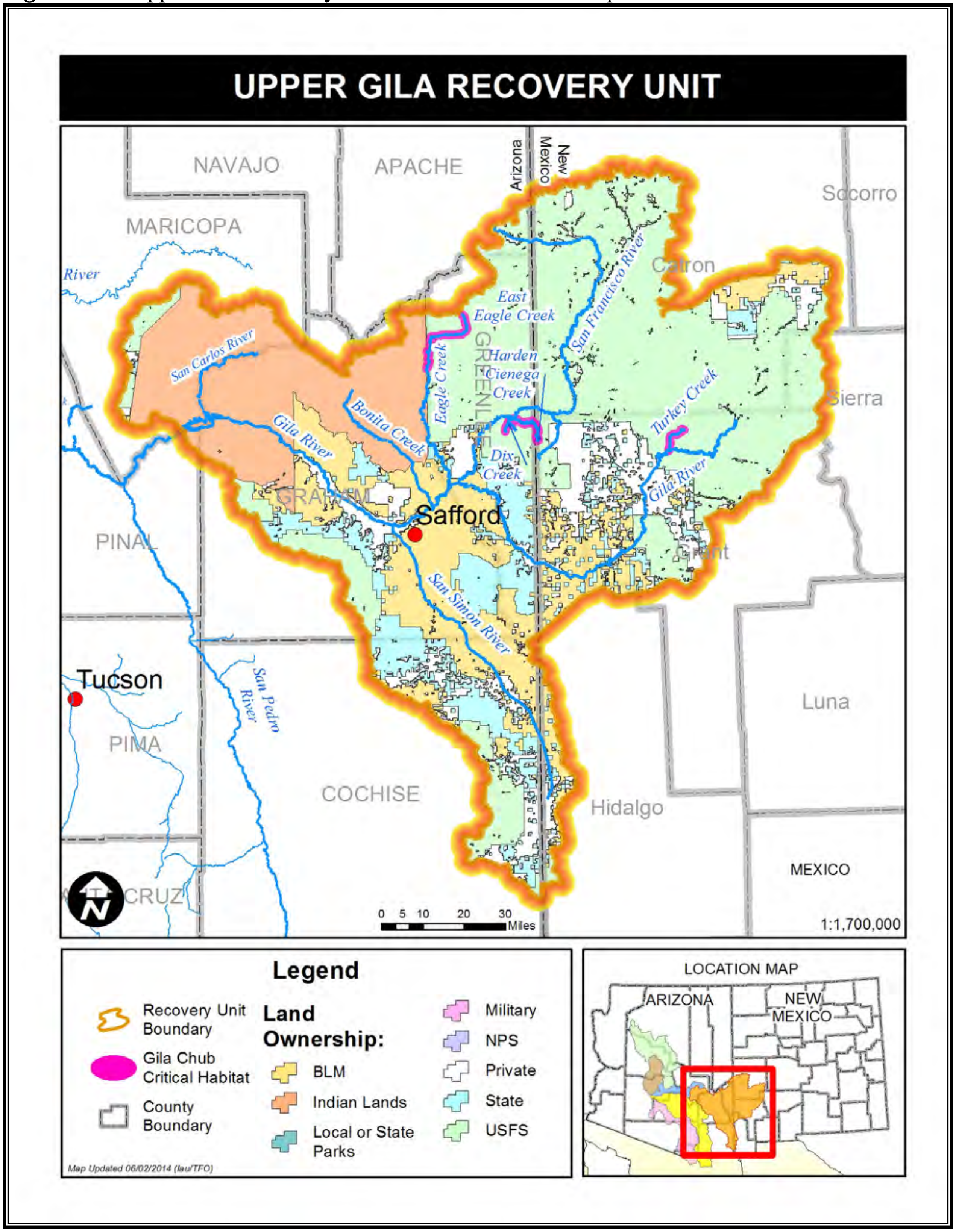


Figure D.6. Salt River Subbasin Replication Area with Land Ownership