Appendix A

Glossary of Selected Terms

Allopatry – species not occupying overlapping geographic areas.
Anthropogenic– caused or produced by humans.
Catastrophic event–a rare destructive event or episode involving many populations and occurring suddenly.
Clade-a group of organisms that includes all descendants of one common ancestor.
Demographic stochasticity–the variability of population growth rates arising from related random events such as birth rates, death rates, sex ratio, and dispersal, which, may increase the risk of extirpation in small populations.
Ecological diversity– the variation in habitats occupied by the species.
Effective population size– a theoretical measure of the number of breeders in the population that contribute to genetic diversity.
Environmental stochasticity–the variation in birth and death rates from one season to the next in response to weather, disease, competition, predation, or other factors external to the population.
Extant–a population that is still in existence.
Extirpation–the loss of a population or a species from a particular geographic region.
Population fragmentation– a form of population segregation, occurring when populations become separated from other populations of the same species.
Genetic diversity– the total number of genetic characteristics in the genetic makeup of a species, species, or population.
Genetic drift– the random change in gene frequencies in a population.
Headwaters– a tributary stream of a river close to or forming part of its source.
Hydrology–the movement or distribution of water on the surface and underground, and the cycle involving evaporation, precipitation, and flow.
Inbreeding– the interbreeding of closely related individuals.
Life history– the full range of changes, habits, and behaviors of a living thing over the course of its life.
Morphological–the structure or form of an organism.
Parapatry– relationship between organisms whose ranges do not significantly overlap but are immediately adjacent to each other.
Pool– a portion of a stream with deeper water and slower flows than riffles or runs.
Persistence– the ability of a population to sustain itself over time.
Piscivorous– fish eating.
Predation– to prey upon.
Range–the geographic region throughout which a species naturally lives or occurs.
Recruitment– the number of fish growing to maturity in a population.
Redundancy–the ability of a species to withstand catastrophic events.
Repatriation– the process of repopulating an area of historical habitat.
Representation–the ability of a species to adapt to changing environmental conditions.
Resiliency–the ability of the species to withstand stochastic events.
Riffles– a fast flowing, shallow portion of a stream.

Runoff– the flow of water from rain, snowmelt, or other sources over land.
Spawn– to produce or lay eggs in water.
Stochastic events–arising from random factors such as weather, flooding, or fire.
Sympatry–species occupying overlapping geographic areas.
Taxonomic–the classification of animals and plants.
Viability– a description of the ability of a species to persist

Appendix B

Cause and Effects Analysis

Template for Cause and Effects Evaluation

THEME: ?			
[ESA Factor(s): ?]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
SOURCE(S)	*What is the ultimate source of the actions causing the stressor?*	See next page for confidences to apply at each step.	Literature Citations, with page numbers , for each step.
- Activity(ies)	*What is actually happening on the ground as a result of the action?*		
STRESSOR(S)	*What are the changes in environmental conditions on the ground that may be affecting the species?*		
- Affected Resource(s)	*What are the resources that are needed by the species that are being affected by this stressor?*		
- Exposure of Stressor(s)	*Overlap in time and space. When and where does the stressor overlap with the resource need of the species (life history and habitat needs)?*		
- Immediacy of Stressor(s)	*What's the timing and frequency of the stressors? Are the stressors happening in the past, present, and/or future?*		
Changes in Resource(s)	*Specifically, how has(is) the resource changed(ing)?*		
Response to Stressors: - INDIVIDUALS	*What are the effects on individuals of the species to the stressor? (May be by life stage)*		
POPULATION & SPECIES RESPONSES	*[Following analysis will determine how do individual effects translate to population and species-level responses? And what is the magnitude of this stressor in terms of species viability?]*		
Effects of Stressors: - POPULATIONS [RESILIENCY]	*What are the effects on population characteristics (lower reproductive rates, reduced population growth rate, changes in distribution, etc)?*		
- SCOPE	*What is the geographic extent of the stressor relative to the range of the species/populations? In other words, this stressor effects what proportion of the rangewide populations?*		
Effects of Stressors: - SPECIES (Rangwide) [REDUNDANCY]	*What are the expected future changes to the number of populations and their distribution across the species' range?*		
Effects of Stressors: - SPECIES (Rangwide) [REPRESENTATION]	*What changes to the genetic or ecology diversity in the species might occur as a result of any lost populations?*		
RISK OF EXTIRPATION 2023	*Based on this analysis, how do we characterize the risk of populations being extirpated from this stressor over the next 10 years (by 2023)?*		

This table of Confidence Terminology explains what we mean when we characterize our confidence levels in the cause and effects tables on the following pages.

Confidence Terminology	Explanation
Highly Confident	We are more than **90% sure** that this relationship or assumption accurately reflects the reality in the wild as supported by documented accounts or research and/or strongly consistent with accepted conservation biology principles.
Moderately Confident	We are **70 to 90% sure** that this relationship or assumption accurately reflects the reality in the wild as supported by some available information and/or consistent with accepted conservation biology principles.
Somewhat Confident	We are **50 to 70% sure** that this relationship or assumption accurately reflects the reality in the wild as supported by some available information and/or consistent with accepted conservation biology principles.
Low Confidence	We are less than **50% sure** that this relationship or assumption accurately reflects the reality in the wild, as there is little or no supporting available information and/or uncertainty consistency with accepted conservation biology principles. Indicates areas of high uncertainty.

Evaluation of Causes and Effects for the Headwater and Roundtail Chubs Species Status Assessment

THEME: Nonnative Species			
ESA Factor	C, D, E	Supporting Information	Confidence / Uncertainty
SOURCE(S)	Introduction, survival and spread of nonnative aquatic species into southwestern waterbodies.	See literature cited below	
- Activity(ies)	**Historic**-nonnative stocking program for sport fishing, baitfish escapement, and release for biological control. **Current and future**-nonnative stocking for sportfishing, unauthorized anthropogenic movement of fish, baitfish escapement, release for biological control and by aquarium hobbyist~~,~~ construction and failure of fish barriers. **Future**-nonnative species will continue to be introduced and translocated, and successful abatement of such activities are limited and costly but there are several streams that have constructed fish barriers.	Clarkson et al. 2005, p. 20; Miller 1961, p. 365; Lachner et al. 1970, pp. 1-4; Ono et al. 1983, p. 90; Minckley and Deacon 1991; Carlson and Muth 1989, p. 220; Cohen and Carlton 1995, p. 1; Fuller et al. 1999, pp. 1-3; Mueller 2005, pp. 10-12; Olden and Poff 2005, p. 75; Minckley and March 2009, pp. 50-51	**Moderately to Highly Confident**
STRESSOR(S)	Predation on all life stages of chubs; competition for prey and habitat; displacement from habitat; habitat degradation; and harassment on foraging, breeding, and resting behavior.	Clarkson et al. 2005, p. 20; Miller 1961, p. 365; Lachner et al. 1970, pp. 1-4; Ono et al. 1983, p. 90; Minckley and Deacon 1991; Carlson and Muth 1989, p. 220; Cohen and Carlton 1995, p. 1; Fuller et al. 1999, pp. 1-3; Mueller 2005, pp. 10-12; Olden and Poff 2005, p. 75; Minckley and March 2009, pp. 50-51; Meffe et al. 1983, p. 316; Meffe 1985; Marsh and Brooks 1989, p. 188; Propst et al. 1992, 177; Blinn et al. 1993, p. 139; Rosen et al. 1995, p. 251; Lydeard and Belk 1993, p. 370; Baltz and Moyle 1993, p. 246; Scoppotone 1993, p. 139; Douglas et al 1994, pp. 15-17; Karp and Tyus 1990, p. 25; Hurlbert et al 1972, p. 639; Fernandez and Rosen 1996, p. 3; Fausch et al 2006, p. 19; Clarkson et al 1997, p. 66; Robinson et al. 1998, p. 599; Rosen et al. 1995, p. 259; Rinne 2004, pp. 121-122; Pool et al 2010, p. 1802; Gertzen et al. 2008, pp.1268-1269; Fuller 1999, p. 59; Stefferud 2000, p. 1; Tellman 2002, p. 43; Voeltz 2002, pp. 15-88; Creed 1994, p. 2098; Snow and Witmer 2010, p. 86; Jones and Timmons 2010, pp. 473-474; Arizona Game and Fish Department 2006, p. 41; Arizona Game and Fish Department 2015, p. 10; Service 2008, p. 264	**Highly Confident that some nonnatives will have these effects, but less confident that other nonnatives will have this affect.**
Affected Resource(s)	Deep pools for adults, shallow backwaters for juveniles, pool -riffle habitat for spawning, forage and prey, cover resources needed to avoid predation,	Lydeard and Belk 1993, p. 370; Balz and Moyle 1993, p. 246; Scoppotone 1993, p. 139; Douglas et al. 1994, pp. 15-17; Meffe 1984, p. 1525; Karp and Tyus 1990, p. 25; Hurlbert et al. 1972, p. 639; Fernandez and Rosen 1996, pp. 3-12; Minckley and Marsh 2009, p. 50; Fausch et al. 2006, p. 19	**Highly Confident that some nonnatives will have these effects, but less confident that other nonnatives will have this affect.**
- Exposure of Stressor(s)	Nonnative aquatic species that may affect chub occur throughout the range of GIRO and GINI~~, a~~nd will continue to co-occur. Nonnative species impact all life stages, age classes, and life cycle functions. Nonnatives impact all habitat components used by GIRO and GINI. The exposure to this stressor is constant. However, during low flow the exposure is increased due to reduced habitat.	Miller 1961, p. 365; Minkley and Marsh 2009, p. 51; Meffe et al 1983, p. 316; Meffe 1985, p. 173; Marsh and Brooks, p. 188; Propst et al 1992, p. 177; Blinn et al 1993, p. 139; Rosen et al 1995, p. 251-259; Lydeard and Belk 1993, p. 370; Balz and Moyle 1993, p. 246; Scoppotone 1993, p. 139; Douglas et al. 1994, pp. 15-17; Meffe 1984, p. 1525; Karp and Tyus 1990, p. 25; Hurlbert et al. 1972, p. 639; Fernandez and Rosen 1996, pp. 3-12; Minckley and Marsh 2009, p. 50; Fausch et al. 2006, p. 19; Service 2008, p. 264; Arizona Game and Fish Department 2006, p. 41; Rinne et al 1998, p. 3; Tellman 2002, p. 43; Inman et al 1998, p. 3; Voeltz 2002, pp. 15-88; Desert Fish Team 2003, p. 1; Clarkson et al. 2005, p. 20-25; Minkley 1983, p. 182; Johnson et al. 1993, p. 1139	**Highly Confident**

THEME: Nonnative Species			
ESA Factor	C, D, E	Supporting Information	Confidence / Uncertainty
- Immediacy of Stressor(s)	Nonnatives have historically impact chubs and currently continue to impact chubs. Impacts from nonnatives will continue into the future. Once established, most nonnative species are difficult or impossible to remove from large aquatic systems. The frequency of the stressor is constant.	Clarkson et al. 2005, p. 20; Miller 1961, p. 365; Lachner et al. 1970, pp. 1-4; Ono et al. 1983, p. 90; Minckley and Deacon 1991; Carlson and Muth 1989, p. 220; Cohen and Carlton 1995, p. 1; Fuller et al. 1999, pp. 1-3; Mueller 2005, pp. 10-12; Olden and Poff 2005, p. 75; Minckley and March 2009, pp. 50-51; Meffe et al. 1983, p. 316; Meffe 1985; Marsh and Brooks 1989, p. 188; Propst et al. 1992, 177; Blinn et al. 1993, p. 139; Rosen et al. 1995, p. 251; Lydeard and Belk 1993, p. 370; Baltz and Moyle 1993, p. 246; Scoppotone 1993, p. 139; Douglas et al 1994, pp. 15-17; Karp and Tyus 1990, p. 25; Hurlbert et al 1972, p. 639; Fernandez and Rosen 1996, p. 3; Fausch et al 2006, p. 19; Clarkson et al 1997, p. 66; Robinson et al. 1998, p. 599; Rosen et al. 1995, p. 259; Rinne 2004, pp. 121-122; Pool et al 2010, p. 1802; Gertzen et al. 2008, pp.1268-1269; Fuller 1999, p. 59; Stefferud 2000, p. 1; Tellman 2002, p. 43; Voeltz 2002, pp. 15-88; Creed 1994, p. 2098; Snow and Witmer 2010, p. 86; Jones and Timmons 2010, pp. 473-474; Arizona Game and Fish Department 2006, p. 41; Arizona Game and Fish Department 2015, p. 10; Service 2008, p. 264	**Highly Confident that some nonnatives will have these effects, but less confident that other nonnatives will have this affect.**
Changes in Resource	Prey base in reduced, habitat for completion of life history functions and life stages are reduced and fragmented, abundance reduced	Lydeard and Belk 1993, p. 370; Balz and Moyle 1993, p. 246; Scoppotone 1993, p. 139; Douglas et al. 1994, pp. 15-17; Meffe 1984, p. 1525; Karp and Tyus 1990, p. 25; Hurlbert et al. 1972, p. 639; Fernandez and Rosen 1996, pp. 3-12; Minckley and Marsh 2009, p. 50; Fausch et al. 2006, p. 19; Clarkson et al. 2005, p. 21; Marsh and Pacey 2005, p. 59Arizona Game and Fish Department 2006, p. 41;Lodge et al. 1994, p. 1270; Creed 1994, p. 2098; Carpenter 2005 pp. 338-340; Inman et al 1998, p. 17; Desert Fish Team 2003, p.1	**Highly Confident that some nonnatives will have these effects, but less confident that other nonnatives will have this affect.**
Response/effect to Stressors: INDIVIDUALS	**Direct fatality** - Chub eggs are consumed by a suite of nonnative predators that are present in spawning areas (pools), fish fry developing in shallow backwater may be consumed by a different suite of nonnative predators. **Harassment**-Adult chub are often victims of harassment, competition, and displacement from pooled habitats. Harassment effects all life history functions such as foraging, breeding, refuge (cover)and resting. Harassment displaces chubs from preferred habitat.	Clarkson et al. 2005, p. 20; Miller 1961, p. 365; Lachner et al. 1970, pp. 1-4; Ono et al. 1983, p. 90; Minckley and Deacon 1991; Carlson and Muth 1989, p. 220; Cohen and Carlton 1995, p. 1; Fuller et al. 1999, pp. 1-3; Mueller 2005, pp. 10-12; Olden and Poff 2005, p. 75; Minckley and March 2009, pp. 50-51; Meffe et al 1983, p. 316; Propst et al. 1992, p. 177; Rosen et al. 1995, p. 251; Ledeard and Belk 1993, p. 370; Douglas et al 1994, pp. 15-17; Meffe 1984, p. 1525; Karp and Tyus 1990, p. 25; Minkley and Marsh 2009, p. 50; Fausch et al, p. 19; Clarkston et al 1997, p. 66	**Moderately Confident**
Compounded Effects of Climate Change	Alterations of flow and drought conditions are predicted to increase in the range of GIRO and GINI, resulting in stream drying and disruption of natural hydrological processes. Such alteration to base flow and predicted water temperature increases will result in further range expansion of nonnative species because formally uninhabitable areas will become habitable. Such alteration will constrain chub and nonnative species into closer proximity as each species searches out and uses the same refuge pools. This proximity will increase predatory and competitive interactions. Additionally, increased water temperatures will likely increase aquatic organisms metabolic needs and thus increase predation rates, resulting in predatory nonnative species exhibiting increased predation and aggression toward chub. Nonnative species that can tolerate high temperatures and compete with and prey on chub are expected to expand their range by 7.4 to 33.3 percent.	Rinne and Stefferud 1998, p. 3; Matthews and Marsh-Matthews 2003, p. 1243-1245; Propst et al. 2008, entire; Stefferud et al. 2011, p. 1403-1410; Magoulick and Kobza 2003, p. 1198-1191; Rahel *et al.* 2008, entire; Rahel and Olden 2008, p. 525-555; Ebey et al. 2003, p. 1572; Carveth et al. 2006, p. 1438	**Somewhat confident**
POPULATION & SPECIES EFFECTS			

THEME: Nonnative Species			
ESA Factor	C, D, E	Supporting Information	Confidence / Uncertainty
Effects of Stressors: POPULATIONS [RESILIENCY]	Nonnative predators can limit population sizes through lowering survival rate, recruitment, fecundity, habitat availability. Nonnative competitors can also similarly limit chub populations depending upon the number of nonnatives present.		**Moderately confidant**
SCOPE	We estimate that nearly 100 of GIRO habitat historically occupied by GINE and GIRO has been invaded either purposefully or indirectly through introduction or dispersal of nonnative fishes and other aquatic species. The effects of nonnative aquatic species are a serious concern to every population and across the entire southwestern range of GIRO and GINI. Currently, 88% of GINI and 92% of GIRO streams contain nonnative species of impact to chubs. However, 16% and 10% of the GINI and GIRO streams, respectively, have very low impacting nonnatives. There are efforts to reduce the threat from nonnatives including: nonnative remove and barrier installations and maintenance in some streams.		**Highly Confident**
Effects of Stressors: [REDUNDANCY]	If populations are lost due to nonnatives then the redundancy will be reduced.		**Highly confident**
[REPRESENTATION]	Any future loss of populations will continue to reduce overall genetic and ecological diversity of the species, further limiting the species' representation.		**Highly confident**
Risk of Extirpation (2046)	Based on this analysis we expect the risk of extirpation to increase over time; we are unable to predict how many GIRO or GINI populations would be lost due to this factor.		

Evaluation of Causes and Effects for the Headwater and Roundtail Chubs Species Status Assessment

THEME: Water Availability			
ESA Factors	A, D, E	Supporting Information	Confidence / Uncertainty
SOURCE(S)	Surface water withdrawal, groundwater pumping, diversion dams, drought, increased temperatures, climate change.		**Highly Confident**
- Activity(ies)	Surface water withdrawal, groundwater pumping, diversion dams, drought, increased temperatures.	Jaeger et al. 2014, p. 13894; Lake 2003, p. 1163; Magoulick and Kobza 2003, pp. 1187-1188; Davey and Kelly 2007, p. 1719; Magoulick 2000, pp. 395-397; Schwemm 2006, p. 28; Fagan et al 2002, p. 3250-3254	**Highly Confident**
STRESSOR(S)	Reduced streamflows and available habitat, fragmentation within a stream (i.e. dry segments), isolation of pool habitat, particularly in late spring/early summer, after snowmelt runoff but prior to summer monsoon rains. If monsoon rains fail to produce precipitation, the drying trend can extend into fall.	Jaeger et al. 2014, p. 13894; Lake 2003, p. 1163; Magoulick and Kobza 2003, pp. 1187-1188; Davey and Kelly 2007, p. 1719; Magoulick 2000, pp. 395-397; Schwemm 2006, p. 28; Fagan et al 2002, p. 3250-3254; Shaffer 1987; Goodman 1987; Dallas 2008, pp. 395-397; Matthews and Marsh-Matthews 2003; Power 1984, 1987; Harvey and Stewart 1991;	**Highly Confident**
Affected Resource(s)	Decrease in flow, riverine habitat, hydrologic connectivity, habitat quantity (deep pools for adults, shallow backwaters for juveniles, pool -riffle habitat for spawning, forage and prey, shelter, and cover resources needed to avoid predation), habitat quality. Increase in isolated habitat and fragmentation within stream. Effects will vary by stream and habitat type.	Lake 2003, p. 578 and 1163; Magoulick and Kobza 2003, pp. 1187-1188; Davey and Kelly 2007; 1719; Labbe and Fausch 2000, pp. 1784-1788; Dallas 2008, pp. 395-397	**Highly Confident that these things will happen. Moderately confident that all of these will happen to each stream**
- Exposure of Stressor(s)	Water loss occurs across the range of the species with different streams more or less affected by human uses of water. However, water availability is most limiting in the late spring/early summer. Water is needed for all life history functions and all life stages. Summer is monsoon season and precipitation is usually increased. Aquatic habitat is likely most sensitive to drying following a dry winter prior to the monsoon precipitation.	Lake 2003, p. 578 and 1163; Magoulick and Kobza 2003, pp. 1187-1188; Davey and Kelly 2007; 1719; Labbe and Fausch 2000, pp. 1784-1788; Dallas 2008, pp. 395-397	**Highly Confident**
- Immediacy of Stressor(s)	**Past**-numerous dams were constructed and have altered the natural hydrology in some rivers, most surface water in streams adjacent to human development (including agriculture) has been allocated, streams outside of those areas face less risk from future human uses. **Current:** Dams remain in place, human demand for water has increased over the past demands, impacting water quality and quantity. **Future:** Dams will remain in place, human demand for water will increase; also drought is projected to increase (see below).	Jaeger et al. 2014, p. 13894; Glennon 1995, pp. 133-139; Wheeler et al. 2005, pp. 149-155; Simmons and Reynolds 1982, p. 1752; Wang et al. 2000, p. 255; 2003, p. 825	**Highly Confident**

THEME: Water Availability			
ESA Factors	A, D, E	Supporting Information	Confidence / Uncertainty
Changes in Resource	Fish habitat is reduced when streams are dewatered. Habitat complexity, such as riffle, run, and pool morphology, may also be lost, which is important for GIRO and GINI that require different habitat types depending on life stage. Additionally, such alterations to habitat can directly impact chub forage base such as aquatic insects. Loss of riverine habitat, fragmentation of habitat, isolation of habitat, reaches of perennial stream reaches may become ephemeral, loss of hydrologic connectivity, microhabitat destruction (i.e. pools), timing and lifecycles of chub prey species such as insect, reduced water quality of remaining waters. NOTE: Full flows are less important to chub survival and reproduction than removal of nonnatives.	Lake 2003, p. 578 and 1163; Magoulick and Kobza 2003, pp. 1187-1188; Davey and Kelly 2007; 1719; Labbe and Fausch 2000, pp. 1784-1788; Dallas 2008, pp. 395-397; Cantrell 2009, p. 18; Glennon 1995, pp. 133-139; Dunne and Leopold 1978, p.173; Horak 1989, pp. 41-43; Medina 1990, p. 351-359; Reid 1993, pp. 48-50; Waters 1995, pp. 52-53; Wheeler et al. 2005, pp. 149-155; Marks et al 2009 p.x.	**Highly Confident**
Response/effect to Stressors: INDIVIDUALS	Loss of surface water in streams results in loss of habitat for every life stage of chub, starting with backwaters needed for larval and juvenile fish development and ending with loss of pools needed for adult fish. Alterations to water quality may result in areas that become uninhabitable for all life-stages of chubs. Decreased fitness of all life-stages of fish could result from alterations to food-web dynamics and the before mentioned loss of habitat. Reduction in prey and forage could lead to qualitative and quantitative dietary shifts. Increase in predation of chubs.	Cantrell 2009, p. 18; Glennon 1995, pp. 133-139; Dunne and Leopold 1978, p.173; Horak 1989, pp. 41-43; Medina 1990, p. 351-359; Reid 1993, pp. 48-50; Waters 1995, pp. 52-53; Wheeler et al. 2005, pp. 149-155; Jaeger et al. 2014, p. 13894; Lake 2003, p. 1163; Magoulick and Kobza 2003, pp. 1187-1188; Davey and Kelly 2007, p. 1719; Magoulick 2000, pp. 395-397; Schwemm 2006, p. 28; Fagan et al 2002, p. 3250-3254	**Highly Confident**
Compounded Effects of Climate Change	The southwestern U.S. is a mostly arid region with extreme climate variability, and is especially vulnerable to effects of climate change. Most climate change models predict increased variability and increased drought conditions that will result in profound effects to aquatic systems. Extreme and pervasive droughts are likely and will result in loss of water, making perennial streams ephemeral, and ephemeral streams dry. Summer base flow will decrease due to decreased snowpack and increased human use of what water remains. Loss of vegetation from arid conditions will result in increased sedimentation of streams; filling in pools, smothering fish eggs, and effecting aquatic insects, which fish rely on for food. Altered hydrology resulting in water loss and increased temperatures caused by climate change is and will be a driving force on GIRO and GINA distribution and range. Permanent water in streams with habitat complexity is essential for the continued survival of GIRO and GINI. An estimated decrease of instream flow is predicted for the Colorado River basin; 25 percent decrease by 2030 and 45 percent decrease by 2060. Flowing portions of streams are projected to decrease by 8% by mid-century and by 20% by the end of the century.	Coe et al. 2012, p. 1; Hoerling and Eischeid 2007, p. 35; Christensen and Lettenmaier 2006, p. 1423; Seager et al. 2007, pp. 1181-1184; Rahel and Olden 2008, p. 526; Poole et al. 2001, p.3; Carveth et al. 2006, p. 1438; Mohseni et al. 2003, p. 389; Sheppard et al. 2002, pp. 219-229; Coe et al. 2002, p. 1; Goode et al. 2011, p.1-5; Garfin and Lenart 2007, p. 16; Melillo at al. 2014, pp. 464-465; Rahel and Olden 2008, p. 526-527; Matthews and Marsh-Matthews 2003, p. 1245; Propst et al. 2008, pp 1246-1249; Carveth et al. 2006, p. 1438	**Moderately Confident**
POPULATION & SPECIES EFFECTS			
Effects of Stressors: POPULATIONS [RESILIENCY]	Loss of available habitat reduces carrying capacity. Loss of habitat and degradation of habitat reduces survival rate, reduces population growth, due to reduction in forage, shelter, and space. If drought is longer and/or there is a lack of refugia, extirpation of the population is likely. Historically, drought has occurred and streams have dried, but populations were able to be recolonized from other reaches.	Marks et al. 2009	**Moderately to Highly Confident**

THEME: Water Availability			
ESA Factors	A, D, E	Supporting Information	Confidence / Uncertainty
SCOPE	Water withdrawals for human use occurs in or near most streams where known populations of GIRO and GINI exist. The magnitude of those withdrawals varies greatly from minor (some stockpond uses only) to major (support for municipal and agricultural uses), and both species are in danger of the effects of stream drying and habitat loss.		**Moderately to Highly Confident**
Effects of Stressors: [REDUNDANCY]	If pops are lost due to stream drying, redundancy will decrease.		**Highly Confident**
[REPRESENTATION]	Reduction in size of populations and isolation of populations due to fragmentation can contribute to a loss of genetic diversity within that unit. If pops are lost due to stream drying, representation will decrease.		**Moderately confident**
Risk of Extirpation (2046)	Loss of habitat is the second biggest threat to GIRO and GINI, after the direct effects of nonnative species interactions. Based on this analysis, we expect the risk of extirpation cause by stream drying and habitat loss to have particular effects to streams that already have limited habitat availability or are subject to drying into isolated pools during the summer.		

Evaluation of Causes and Effects for the Headwater and Roundtail Chubs Species Status Assessment

THEME: Parasites			
ESA Factor	C	Supporting Information	Confidence / Uncertainty
SOURCE(S)	External parasites such as, but not limited to; Asian tapeworm, anchor worm, Ich, and black and yellow grub.		
- Activity(ies)	Introduction of nonnative parasites introduced by nonnative host species. Introduction of host species are caused by stocking programs for sport fishing, baitfish escapement, and release for biological control and by aquarium hobbyist. Parasites can also spread by birds (e.g. grub) and other animals.	Marcogliese 2001; Rahel et al. 2008, p.555; Mohant et al. 2010, p. 124; USGS 2004, p. 1; USGS 2005, p. 2; Linder et al. 2012, p. 123; Durham et al. 2002, pp. 95-96; Brouder 1999, p. 13 and 303; Traxler et al. 1998, p. 143	**Moderately Confident**
STRESSOR(S)	Nonnative parasites threaten fish health and populations of GIRO and GINI in the lower Colorado River basin. Documented parasites that are of concern are: Asian tapeworm, anchor worm, Ich, and black and yellow grub. External parasites, such as anchor worm, ich and black and yellow grub, can cause tissue hemorrhaging and muscle necrosis. Internal parasites, such as Asian tapeworm, can block or perforate intestines, reduce growth and reproductive rates, cause emaciation, anemia and chronic infections, as well as cause behavioral alterations such as weakened swimming ability. Both internal and external parasites can cause physiological stress to the host and render the fish more susceptible to other dangers, such as, bacterial and fungal infections or ultimately death.	Brouder 1999, p. 303; Brouder 2000, p. 13; Rahel et al. 2008, p. 555; McAllister et al. 2011, p. 38; Linder et al. 2012, p. 123; USGS 2004, p. 1; USGS 2005, p. 2; Piasecki et al. 2004, p. 195; Traxler et al 1998, p. 143	**Moderately confident**
Affected Resource(s)	Parasites have direct effects to fish health by rendering fish physically unwell and making them less able to take advantage of resources, such as cover and food.	Linder et al. 2012, p. 123; Brouder et al. 2000, p. 13; Archdeacon et al. 2010, p. 227	**Moderately confident**
- Exposure of Stressor(s)	Asian tapeworm, anchor worm, Ich, and black and yellow grub are found throughout the range of GIRO and GINI. These parasites have the potential to infect individual fish of every age-class; however, young fish are usually the most susceptible to parasite infection and the associated health risks.	McAllister et al. 2011, p. 38; Durham et al. 2002, pp. 95-96; Hoffnagle et al. 2006, p. 190; Archdeacon et al. 2010, p. 227; Brouder et al 2000, p. 13	**Moderately confident**

THEME: Parasites			
ESA Factor	C	Supporting Information	Confidence / Uncertainty
- Immediacy of Stressor(s)	Asian tapeworm, anchor worm, ich, and black and yellow grub are found throughout the range of GIRO and GINI. The main vector of parasite introductions into the southwest U.S. is most likely introduction of nonnative fish species used for sport, bait, management and hobby aquaria. Future, parasites infestations are expected to increase in number and geographic region, with increase of temperatures caused by climate change. This change in temperature may cause increased maturation rates in parasites. Additionally, effects of parasites to host fish may be amplified by environmental stressors, such as temperature fluctuations, habitat availability and reduced food, which may cause death to individual GIRO and GINI.	Marcogliese 2001; Rahel et al. 2008, p. 555; Mohant et al. 2010, p. 124; Kline 2007, p. 4; McAllister et al. 2001, p. 38	**Moderately confident**
Changes in Resource	The direct effects to fish health by parasites may render fish physically unwell and unable to take advantage of resources. An example is the reduced growth rate and swimming speed of fish infected with Asian tapeworm. Such infected fish may be less likely to avoid predation by nonnative fish or capture swimming prey	Linder et al. 2012, p. 123; Brouder et al. 2000, p. 13; Archdeacon et al. 2012, p. 227	**Somewhat confident**
Response/effect to Stressors: INDIVIDUALS	These parasites have the potential to infect individual fish of every age-class; however, young fish are usually the most susceptible to parasite infection and the associated health risks. Health risks may include; tissue hemorrhaging, muscle necrosis, blocked or perforate intestines, reduce growth and reproductive rates, emaciation, anemia and chronic disease such as bacterial and fungal infections or ultimately death.	Brouder 1999, p. 303; Brouder 2000, p. 13; Rahel et al. 2008, p. 555; McAllister et al. 2011, p. 38; Linder et al. 2012, p. 123; USGS 2004, p. 1; USGS 2005, p. 2; Piasecki et al. 2004, p. 195; Traxler et al 1998, p. 143	**Moderately confident**
Compounded Effects of Climate Change	Future, parasites infestations are expected to increase in number and geographic region, with increase of temperatures caused by climate change. This change in temperature may cause increased maturation rates in parasites. Additionally, effects of parasites to host fish may be amplified by environmental stressors, such as temperature fluctuations, habitat availability and reduced food, which may cause death to individual GIRO and GINI.	Marcogliese 2001; Rahel et al. 2008, p. 555; Mohant et al. 2010, p. 124; Kline 2007, p. 4; McAllister et al. 2001, p. 38	**Moderately confident**
POPULATION & SPECIES EFFECTS			
Effects of Stressors: POPULATIONS [RESILIENCY]	We do not know of any evidence or papers that talk about the effects of parasites to chub at the population level, there have been no documented extirpations of chub due to disease or parasites. In a population under stress from other factors, disease and parasites may increase the rate of mortality of individuals; this rate is likely to vary significantly across streams. Effects of parasitism to resiliency of GIRO and GINI species are expected to be minimal because of the lack of response expected at the population level.		**Somewhat Confident**

THEME: Parasites			
ESA Factor	C	Supporting Information	Confidence / Uncertainty
SCOPE	Parasites are found in every drainage that contains GIRO and GINI.		
Effects of Stressors: [REDUNDANCY]	Effects of parasitism to redundancy of GIRO and GINI species are expected to be minimal because of the lack of response expected at the population level.		**Somewhat Confident**
[REPRESENTATION]	Effects of parasitism to representation of GIRO and GINI species are expected to be minimal because of the lack of response expected at the population level.		**Somewhat Confident**
RISK OF EXTIRPATION 2046	We have not identified populations at risk of extirpation due to the effects of parasitism.		

Evaluation of Causes and Effects for the Headwater and Roundtail Chubs Species Status Assessment

THEME: Recreation			
ESA Factor	A, C, D	Supporting Information	Confidence / Uncertainty
SOURCE(S)	Recreation on Federal, State, and Tribal lands		
- Activity(ies)	Recreation; including, but not limited to, hiking, camping, swimming, and off-highway vehicles (OHV) in designated camping or recreational use areas or those open for use but without facilities		**Somewhat confident**
STRESSOR(S)	In the arid Southwest, recreation in and near water is increasing as population rates increase. The severity of the effect of recreation on streams varies with the amount and type of activity. Recreational activities such as light hiking result in a low level of impact on aquatic systems by trampling vegetation and reduction of water quality, such as, but not limited to increased sediment load and turbidity. The use of OHVs along banks and in stream channels can alter the floral community, reduce infiltration rates, increase erosion and sedimentation, and reduce habitat connectivity. Sport fish recreation may result in angling -fatality of individual fish caught and introduction of nonnative species that prey on or compete with chub (See nonnative species section for full description of effects). The direct effects of recreation on GIRO and GINI are unknown but potentially adverse on a local scale	Voeltz 2002, entire; Paradzick et al. 2006, pp. 107–108; American Rivers 2007, pp. 1–4; Ouren et al. 2007, pp. 6–7, 11, 16; Cantrell 2009, p. 15; AZ BO entire, NMGF, 2006, entire; Rinker et al. 2009, p. 5; Ouren et al. 2007, pp. 6–22; Weedman et al. 1996, p. 33; Youtz 2010, p. 1	**Somewhat confident**
Affected Resource(s)	Quality and quantity of chub habitat and water quality can be affected by heavy and improper recreational use. Changes water quality may have to potential to affect chub habitat. This link has not been explicitly made in the literature and is based more on site specific information.	Voeltz 2002, entire; Paradzick et al. 2006, pp. 107–108; American Rivers 2007, pp. 1–4; Ouren et al. 2007, pp. 6–7, 11, 16; Cantrell 2009, p. 15; Rinker 2009, et al. p. 5; Weedman et al. 1996, p. 33	**Somewhat confident**
- Exposure of Stressor(s)	Recreation occurs across the current range of GIRO and GINI with some streams only seeing very low use and others much higher use, and specific problems resulting from overuse have been documented in the Tonto, Webber, Oak, and Fossil Creek, Upper Gila River, and Williamson Valley Wash. However, the majority of recreation in areas that contain chub populations is light to moderate.	Voeltz 2002, entire; Weedman et al. 1996, p. 33; Ouren et al. 2007, pp. 6–22; Paradzick et al. 2006, pp. 107–108; American Rivers 2007, pp. 1–4; Cantrell 2009, p. 15	**Moderately confident**

THEME: Recreation			
ESA Factor	A, C, D	Supporting Information	Confidence / Uncertainty
- Immediacy of Stressor(s)	Recreation in streams containing GIRO and GINI continues to increase with the increased human population rate and development of the Southwest. Although recreational use has increased, resulting in damage to fish habitat in particular streams, current and future land management practices are being developed and implemented to assuage this effect. As a result of these newly adopted land management practices OHV use may be contained to existing trails in national forests.	Voeltz 2002, entire; Paradzick et al. 2006, pp. 107–108; American Rivers 2007, pp. 1–4; Ouren et al. 2007, pp. 6–7, 11, 16; Cantrell 2009, p. 15; Rinker 2009, et al. p. 5; Ouren et al. 2007, pp. 6–22; Weedman et al. 1996, p. 33	**Moderately confident**
Changes in Resource	Chub habitat may be damaged as a result of the more severe forms of recreation, such as OHV use. Vegetation around streams may be lost causing changes to channel morphology. Resulting changes such are erosion and sedimentation can reduce pooled areas which are necessary for chub survival.	Voeltz 2002, p. 39, 59, 77; Ouren et al. 2007, pp. 6–22; Weedman et al. 1996, p. 33	**Somewhat confident**
Response/effect to Stressors: INDIVIDUALS	Fish habitat may be lost and water quality may decline in areas that receive high levels of recreation. Loss of habitat may affect all life stages of chub, with backwaters needed for larval and juvenile fish development and pools needed for adult fish. Alterations to water quality may result in areas that become uninhabitable for all life-stages of fish. Effects of recreation are likely localized events that can easily be managed by exclusion of the more detrimental forms, such as OHV use.	Voeltz 2002, p. 39, 59, 77; Ouren et al. 2007, pp. 6–22; Weedman et al. 1996, p. 33	**Somewhat confident**
Compounded Effects of Climate Change	With increased recreation and the tendency for this recreation to focus around water in the southwest, it would stand to reason that the effects of recreation will continue and increase in severity as surface water diminishes due to the effects of climate change. Increased active management of recreation may be needed to address increases in use particularly where there are decreases in water availability.		**Somewhat confident**
POPULATION & SPECIES EFFECTS			

THEME: Recreation			
ESA Factor	A, C, D	Supporting Information	Confidence / Uncertainty
Effects of Stressors: POPULATIONS [RESILIENCY]	Effects of recreation (excluding nonnative introduction that may accompany sport fish angling) to resiliency of GIRO and GINI species are expected to vary significantly over the range of the species due to the amount and types of recreation occurring in proximity to the stream. Where there are established campgrounds or other intensive use areas, effects to habitat in the immediate vicinity of the use area can be significant from sedimentation and trampling of banklines. Unless the stream is very small, these effects should not affect a significant portion of the total available area. In streams where recreational use is lighter, the effects are unlikely to be significant beyond the individual level.		**Moderately confident**
SCOPE	Significant amounts of recreational activity that have habitat-altering effects occur in only a small number of occupied streams, and, generally, the entire stream is not affected.		**Highly confident**
Effects of Stressors: [REDUNDANCY]	Effects of recreation (excluding nonnative introduction that may accompany sport fish angling) to redundancy of GIRO and GINI species are expected to be minimal because of the lack of response expected at the population level that could lead to extirpation.		**Highly confident**
[REPRESENTATION]	Effects of recreation (excluding nonnative introduction that may accompany sport fish angling) to representation of GIRO and GINI species are expected to be minimal because of the lack of response expected at the population level that could result in loss of genetic diversity.		**Highly confident**
RISK OF EXTIRPATION 2046	We have not identified populations at risk of extirpation due to the effects of recreation on chub habitat.		

Evaluating Cause and Effect Pathways for Roundtail and Headwater Chub Species Status Assessments

THEME: Wildfire			
[ESA Factor(s): A,E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
SOURCE(S)	Wildfire frequency and intensity has been increasing due to past forest management and climate change (drier, warmer regional climate). Wildfire frequency is locally influenced by forest management.	**Highly confident** that fire is a natural, regular part of the ecosystem and that the incidence of large, hot fires has increased. **Moderately confident** that climate change will exacerbate the rate of burning even further.	Westerling et al. 2006 p. 941 Bachelet et al. 2007 IPCC 2007a (pg 15)
- Activity(ies)	Risk of wildfires in the past was likely increased by some forest management activities and fire suppression. Forest management (thinning, prescribed burns, and forest restoration activities) as currently conducted can reduce the conditions suitable for high-intensity and high-severity wildfires.	**Highly confident** that management (i.e., thinning, prescribed fire) influences fire frequency and intensity	USFS 2014; Cooper 1960;
STRESSOR(S)	When natural or human-caused wildfires burn within watersheds upstream of or adjacent to GIRO and GINI populations, subsequent rainstorms can produce ash and debris-laden runoff of water from the burned forest into streams occupied by these fishes. Stormwater runoff following wildfire can result in highly sedimented and ash-laden waters and very unstable stream channels. Additionally, fire retardant is often dropped in wildfire areas, and those chemicals (such as surfactant foams and fire retardants) can cause fish mortality. Wildfire can have dramatic effects on streams and on populations of native fishes. Fatalities have been associated with the direct effects of severe fires, but these consequences have been most frequently observed in relatively small streams and over limited extent (1-2 km). In general, however, the effects of wildfire are typically far less dramatic. In some cases, the effects of wildfires have been difficult to measure, and in others, populations that were initially depressed have rebounded dramatically, even increasing in abundance or extent relative to prefire conditions.	**Somewhat confident** that this situation can occur, but the observed spatial pattern of effects depends on the extent and severity of fire and size of the watershed.	Reiman et al. 2012 Rinne and Carter 2008
- Affected Resource(s)	Clean, oxygenated water and stable stream channels.	**Highly confident**	Rinne 1996; Reiman et al. 2012
- Exposure of Stressor(s)	A wildfire event can happen at any time, but forest conditions of some areas makes the probability of high-severity wildfire effects greater. Wildfires may be patchy and burn hotter in some places than in others, allowing some portions of the population to survive and recolonize downstream reaches after ash flow effects have been ameliorated. The amount of ash flow from a fire depends on the severity of the fire, proximity to the stream habitat, stream channel morphology, quality of riparian vegetation, timing, and amount of rainfall following the fire in relation to timing of vegetation recovery on slopes above the stream channel. The extent of one or more populations being affected depends on the location of the fire relative to the occupied stream reaches.	**Highly confident**	

THEME: Wildfire			
[ESA Factor(s): A,E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
- Immediacy of Stressor(s)	**Historic:** Wildfires have not resulted in documented extirpations of chub populations in the past 10 years, with increasing fire severity in modern times due to past land management practices. **Current:** Wildfires are continuing to occur. Several large fires have occurred in recent years within the range of GIRO and GINI. **Future:** Climate change is predicted to cause southwestern forests to be hotter and drier in coming decades, which could result in higher risks of high-severity fires. Land managers are making efforts to reduce fire risks, particularly with landscape level forest restoration projects, such as the Four Forest Restoration Project.	**Historic: Highly confident** **Current: Highly confident** **Future: Moderately confident**	Westerling et al. 2006 p. 941 IPCC 2007a (pg 15) USFS 2014
Changes in Resource(s)	Ash-filled flood waters can make stream habitat unhabitable and can kill fish in a stream. Stream channel changes and water quality impacts can make streams unsuitable for years following the fire and flood event. Extent of the impact of a particular event depends on the local conditions and nature of the fire and flood relative to habitat. If a stream is sufficiently long, fish may survive in an unburned upstream reach or tributary, then recolonize the burned reach when habitat becomes suitable. However, in some cases we have noted that although conditions post-fire likely impacted fish, fatalities did not occur at the population level and fish rebounded quickly post-ash flow.	**Highly confident**	Reiman et al. 2012 Rinne and Carter 2008 USFS 2014
Response to Stressors: - INDIVIDUALS	All life stages of fishes in the reach exposed to significant ash flow may be killed and eliminated.	**Somewhat confident -** We still do not understand in all systems what constitutes a "significant" ash flow. In some cases, extremely heavy ash flows have not resulted in the loss off populations , such as high ash flows in West Fork Oak Creek following the Slide Fire. In other cases there have been instances of loss of fish populations, such as in upper Whitewater Creek following the Whitewater-Baldy Complex Fire.	
POPULATION & SPECIES RESPONSES			
Effects of Stressors: - POPULATIONS [RESILIENCY]	A GIRO or GINI population can be eliminated from the area impacted by the ash flow.	**Moderately confident**	

THEME: Wildfire			
[ESA Factor(s): A,E]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
- SCOPE	**Historic:** Fire is a part of the forested ecosystems in the Gila and Little Colorado watersheds. Wildfires have always occurred, although historically they burned at much lower severity. **Current and Future:** The frequency and intensity of wildfire is increasing rangewide. As drought frequency increases due to climate change, forests will be more likely to burn and burn hotter than in the past. However, any one stream has a low likelihood of experiencing wildfire during any single year. We expect wildfire to occur, although we are unable to predict the location. However, forest management at large landscape scales across the range of GIRO and GINI is currently being conducted (4FRI) or in the planning stages (4FRI Phase 2) to reduce the effects of high severity wildfire on watersheds.	**Historic: Highly confident** **Future: Moderately confident**	Westerling et al. 2006, pp. 940-941; Swetnam et al. 1996; Millar et al. 2007
Effects of Stressors: - SPECIES (Rangwide) [REDUNDANCY]	If future populations are lost due to wildfire, then overall redundancy will continue to decline. The number of populations experiencing wildfire is expected to increase due climate change, but this may be ameliorated if land managers can reduce forest fuels. In some cases, the population elimination resulting from ash flows can provide restoration opportunities where nonnative species occur with GIRO and GINI.	**Highly confident**	USFS 2014
Effects of Stressors: - SPECIES (Rangwide) [REPRESENTATION]	Any future loss of populations can reduce overall genetic and ecological diversity of the species, further limiting the subspecies' representation, although this is dependent on the timing and location of fires and ash flows.	**Moderately confident**	Reiman et al. 2012
RISK OF EXTIRPATION 2023	Populations with a **moderate wildfire risk or those being treated now to reduce fire risk, long occupied stream lengths, and some stream connectivity** have a very low risk of extirpation due to the effects of wildfire by 2023. Populations with **high fire risk, short occupied stream lengths, and no stream connectivity** have a high risk of extirpation due to the effects of wildfire by 2023.	**Moderately confident**	

Evaluating Cause and Effect Pathways for Roundtail and Headwater Chub Species Status Assessments

THEME: Land Management			
[ESA Factor(s): A]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
SOURCE(S)	Forest Practices	**Highly confident** that forest practices within the range of GIRO and GINI will occur.	USFS 2014
- Activity(ies)	Forest management 1. Thinning 2. Prescribed fire	**Highly confident** that forest thinning and prescribed fire will occur in watersheds where GIRO and GINI occur.	USFS 2014
STRESSOR(S)	Logging can affect riparian ecosystems through tree falling, log skidding, road construction, and direct removal of vegetation, all of which add can add sediment to streams. However, forest management for the last 20 years in the Southwest has been more focused on thinning trees to reduce high-severity wildfire effects and restore forest structure, function, and composition. While prescribed fire has the ability to have direct effects to stream channels, land managers typically do not conduct ignitions within riparian areas or along stream channels, but fire is allowed to back downslope into these areas. If fire burns riparian areas, there is the potential for some ash and localized erosion to occur; however, these effects should be minor in degree and extent, particularly if best management practices are followed.	**Highly confident** that forest practices will not result in stressors to GIRO and GINI populations.	USFS 2014; Ziemer et al. 1991
- Affected Resource(s)	Aquatic habitat (providing breeding, feeding, and sheltering areas). Clean gravels and cobbles on stream bottom are vital for producing aquatic insects for food and serving as spawning areas for egg incubation.	**Highly confident**	Brouder et al. 2000; Bestgen and Probst 1989
- Exposure of Stressor(s)	Forest management is unlikely to affect stream conditions or result in long-term changes in the stream conditions that could affect all life stages of GIRO and GINI.	**Highly confident** that the stressors are not impacting GIRO and GINI populations.	MacDonald 2013

THEME: Land Management			
[ESA Factor(s): A]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
- Immediacy of Stressor(s)	Land management activities have occurred in the past, present, and future. Past forest management practices were likely more severe than current practices. Direct effects of vegetation management on stream systems should be minor when Best Management Practices are followed. These include providing an adequate buffer from harvest operations, designation of all channel crossing locations by mechanized equipment, and designation of skid trails, to avoid crossing stream channels (ephemeral and intermittent). Limiting vegetation management activities from impacting stream courses should lead to minor or inconsequential direct effects to stream habitat and associated biota.	**Highly confident** forest management would be conducted to reduce the potential for stressors to occur.	MacDonald 2013 (Region 3 FSH 2509.22 -Best Management Practices);
Changes in Resource(s)	Decrease in food availability and decrease in adequate spawning areas due to siltation in substrates. Sedimentation and erosion are natural processes and ecosystems have evolved to handle the natural background levels and the episodic events of fire. However, when land management activities alter the natural levels in a watershed, deleterious effects to the habitat and biota can occur, and this can be compounded when a system's natural resiliency has been degraded by past activities, such as fire suppression, drought, road building, grazing, etc. Vegetation management can contribute to the deterioration of soil stability and porosity, increasing erosion and compaction. These factors can lead to increased sedimentation into streams and changes in the hydroperiod.	**Moderately confident.**	Anderson 1996; Bisson et al. 2003; Swank et al. 1989
Response to Stressors: **- INDIVIDUALS**	Reduced fitness of individuals if food supply is limited. Reduced survival of young and juvenile stages. Reduced reproductive success due to limited spawning areas.	**Moderately confident.**	
POPULATION & SPECIES RESPONSES			
Effects of Stressors: **- POPULATIONS [RESILIENCY]**	We do not expect an effect of forest management on GIRO or GINI resiliency because of lack of response expected at the population level.	**Highly Confident** that forest management activities are not having any significant population-level effects, other than reducing the risk of high-severity wildfire effects to GIRO and GINI.	

THEME: Land Management			
[ESA Factor(s): A]	**Analysis**	**Confidence / Uncertainty**	**Supporting Information**
- SCOPE			
Effects of Stressors: - SPECIES (Rangwide) [REDUNDANCY]	We do not expect an effect of forest management on GIRO or GINI redundancy because of lack of response expected at the population level.	**Highly confident**	
Effects of Stressors: - SPECIES (Rangwide) [REPRESENTATION]	We do not expect an effect of forest management on GIRO or GINI representation because of lack of response expected at the population level.	**Highly confident**	
RISK OF EXTIRPATION 2023	We have not identified any populations at risk of extirpation due to the effects of forest management. Forest management is not a high enough risk to the subspecies to analyze further.	**Highly confident**	

Evaluation of Causes and Effects for the Headwater and Roundtail Chubs Species Status Assessment

THEME: Livestock Grazing			
ESA Factor	A, D	Supporting Information	Confidence / Uncertainty
SOURCE(S)	Land management actions		
- Activity(ies)	Unmanaged or improper livestock grazing	Kauffman and Krueger 1984, pp.433-435; Weltz and Wood 1986, pp. 367-368; Hereford 1992, p. 17; Waters 1995, pp. 22–24; Tellman et al. 1997, pp. 88-89; Pearce et al. 1998, p. 307; Belsky et al. 1999, p. 1	
STRESSOR(S)	Unregulated or poorly managed livestock grazing can have direct negative effects to fish habitats which include streams and surrounding riparian areas. Such effects include removal or degradation of riparian vegetation, reduced bank stability, increased erosion and sedimentation, increased water temperatures, and changes in channel morphology that affect the availability of suitable habitat conditions by increased erosion and sedimentation. Sedimentation of chub habitat fills in interstitial spaces in the substrate and affects the amount and size of pools. Changes to the physical characteristics of stream habitats can lead to altered aquatic community structure, food webs, and nutrient cycling that can affect the amount and quality of food available to chubs. The effects of excessive grazing can also result in long-term impacts that change hydrology and soils, leading to downcutting or headcutting. Additionally, areas that allow livestock grazing are at an increased risk to have nonnative species introductions due to uncontrolled stocking of nonnative fish in stockponds few from or connected to the streams.	Clary and Webster 1989, p. 1; Clary and Medin 1990, p. 1; Schulz and Leininger 1990, p. 295; Armour et al. 1991, pp. 8–10; Fleishner 1994, pp. 630–631; Swanson et al. 1982, pp. 288-289; Kauffman and Krueger 1984, p. 432; Minckley and Rinne 1985, p. 150; Platts and Nelson 1989, p. 455; Meehan 1991, p. 91; Belsky et al. 1999, pp. 1– 28, 419; Weltz and Wood 1986, pp. 367–368; Waters 1995, pp. 22–24; Pearce et al. 1998, p. 307; Trimble and Mendel 1995, pp. 243–250; Li et al. 1987, pp. 627, 638-639; Rahel and Hubert 1991, p. 326; Gorman and Karr 1978, p. 507; Bestgen and Propst 1989, p. 209; Rinne and Minckley 1991, pp. 2–5; Baltz and Moyle 1993, p. 246; Lawler et al. 1999, p. 621; Li et al. 1994, pp. 638–639; Hoorman and McCutcheon 2005, p. 3; American Fisheries Society 2009; 77 FR 21260, April 9, 2012, pp.21264-21285	**Somewhat confident**
Affected Resource(s)	Fish habitat and forage-base is affected as a result of reduced stream structural complexity caused by improper or unregulated livestock grazing.	Li et al. 1987, pp. 627, 638-639; Rahel and Hubert 1991, p. 326; Gorman and Karr 1978, p. 507; Bestgen and Propst 1989, p. 209; Rinne and Minckley 1991, pp. 2–5; Baltz and Moyle 1993, p. 246; Lawler et al. 1999, p. 621; Li et al. 1994, pp. 638–639; Hoorman and McCutcheon 2005, p. 3	**Somewhat confident**
- Exposure of Stressor(s)	Current livestock grazing practices most often include rest-rotation grazing systems, which often exclude livestock from streams and riparian galleries for whole or part of the year. Although past livestock grazing practices have had deleterious affects across the range of both species, current grazing systems are unlikely to affect all life stages of GIRO and GINI species. Although damaging effects from livestock grazing has been documented at streams in which GIRO and GINI populations exist, this threat is largely from past practices of unregulated grazing practices. Current livestock grazing practices are regulated and managed by land management agencies to avoid such deleterious effects.	FWS BO 2014; American Fisheries Society 2009	Moderately confident

THEME: Livestock Grazing			
ESA Factor	A, D	Supporting Information	Confidence / Uncertainty
- Immediacy of Stressor(s)	Unregulated livestock grazing practices have had profound effects on streams containing chub species in the southwest. These grazing activities have had acute and relatively short-term effects such as removal of riparian vegetation, and chronic secondary effects such as nonnative species introduction and loss of habitat. Current grazing activities focus on responsible management that includes sustainability of properly functioning streams and riparian areas. Responsible management also includes monitoring such areas to insure that these goals are being met. As such, the current and future danger of effects from livestock grazing is likely past, and is not likely a central issue effecting GIRO and GINI populations in the southwest.	Stromberg and Chew 2002, p. 198; Trimble and Mendel 1995, pp. 243-244; Platts 1989, p. 103; Vavra 2005, p. 128; American Fisheries Society 2009; 77 FR 21260, April 9, 2012, pp.21264-21285	**Moderately confident**
Changes in Resource	Fish habitat is affected as a result of reduced stream structural complexity. Habitat, such as pools and riffles, is necessary for fish foraging, breeding, and sheltering behaviors. Habitat complexity is particularly important for GIRO and GINI which require different habitat types depending on life stage. Additionally, such alterations to habitat can directly impact chub forage base such as aquatic insects, leading to qualitative and quantitative dietary shifts.	Li et al. 1987, pp. 627, 638-639; Rahel and Hubert 1991, p. 326; Gorman and Karr 1978, p. 507; Bestgen and Propst 1989, p. 209; Rinne and Minckley 1991, pp. 2–5; Baltz and Moyle 1993, p. 246; Lawler et al. 1999, p. 621; Li et al. 1994, pp. 638–639; Hoorman and McCutcheon 2005, p. 3	**Somewhat confident** that livestock grazing will result in these effects
Response/effect to Stressors: INDIVIDUALS	Habitat complexity is necessary to accommodate all life stages of chub. While adult chub prefer deep pools fry and juvenile chub may grow out in shallow backwaters that are warm and provide protection from predation by larger fish. Habitat complexity is also warranted for chub forage base, in which, different species of insects inhabit different areas of the stream, such as riffles. Effects to individual fish may include; reduced survival of young and juvenile age classes, reduced fitness due to limited food supply, and limited reproductive success due to limited spawning areas.	Li et al. 1987, pp. 627, 638-639; Rahel and Hubert 1991, p. 326; Gorman and Karr 1978, p. 507; Bestgen and Propst 1989, p. 209; Rinne and Minckley 1991, pp. 2–5; Baltz and Moyle 1993, p. 246; Lawler et al. 1999, p. 621; Li et al. 1994, pp. 638–639; Hoorman and McCutcheon 2005, p. 3	**Somewhat confident** that livestock grazing will result in these effects
Compounded Effects of Climate Change	Climate change may affect the amount of water available in streams and stockponds on livestock allotments. This could have impacts to the amount of water used by livestock and thus reductions in flow or the size of pools in areas where they can access the stream. Reduced precipitation may also affect the quality of forage on the allotment, requiring changes to grazing patterns. Adjustments to livestock use on Federal lands are more likely to occur than on State or private lands due to the requirement of Federal laws.		**Low confidence**
POPULATION & SPECIES EFFECTS			
Effects of Stressors: POPULATIONS [RESILIENCY]	Effects of livestock grazing to resiliency of GIRO and GINI species are expected to be minimal because of the lack of response expected at the population level. There are some streams with significant legacy effects on the watershed as a whole and those effects have already affected chub populations to the extent they are likely to. Improvements to grazing and remediation work on affected watersheds may, over time, reduce those continuing effects. Absent any significant adverse change to the watershed, it is unlikely that a chub population would be lost to the legacy effects of livestock grazing.		**Moderately confident**

THEME: Livestock Grazing			
ESA Factor	A, D	Supporting Information	Confidence / Uncertainty
SCOPE	Grazing allotments are in the watersheds of all known populations of GIRO and GINI. In some streams, for example, the Three Forks area for GINI, there is no livestock grazing in portions of the Wilderness. Other streams are in canyons where livestock cannot access; in those situations, the watershed condition influences stream conditions. That effect can range from virtually none to significant depending on the stream.		**Highly confident**
Effects of Stressors: [REDUNDANCY]	Effects of livestock grazing to redundancy of GIRO and GINI populations are expected to be minimal because of the lack of response expected at the population level. We do not expect any populations to be lost because of past or current livestock grazing.		**Moderately confident**
[REPRESENTATION]	Effects of livestock grazing to representation of GIRO and GINI species are expected to be minimal because of the lack of response expected at the population level. We do not expect any population to be lost due because of past or current livestock grazing.		**Moderately confident**
RISK OF EXTIRPATION 2046	We have not identified populations at risk of extirpation due to the effects of livestock grazing.		

Evaluation of Causes and Effects for the Headwater and Roundtail Chubs Species Status Assessment

THEME: Urban and rural development impacts on chub habitat			
ESA Factor	A, D	Supporting Information	**Confidence / Uncertainty**
SOURCE(S)	Land Management actions related to human population growth		
- Activity(ies)	Urban, Suburban and Rural Development		
STRESSOR(S)	Urban, suburban, and rural development is a threat-to GIRO and GINA in the southwest. Development affects streams by direct alteration of stream channel morphology, hydrology, and water quality, and increases in nonnative species introductions and recreational use. Additionally, such alterations to stream habitats can negatively impact stream productivity, food base, eliminate rearing habitats, and fill in pool habitat.	Tellman et al. 1997, pp. 92-93; Cantrell 2009, p. 18; Glennon 1995, pp. 133-139; Dunne and Leopold 1978, p.173; Horak 1989, pp. 41-43; Medina 1990, p. 351; Reid 1993, pp. 48-50; Waters 1995, pp. 43-53; Wheeler et al. 2005, pp. 149-155; U.S. Census Bureau 2005, p. 1	
Affected Resource(s)	Quality and quantity of water and fish habitat are affected by urban, suburban and rural development. Development results in increase well use, reducing base flow, while increasing runoff and contamination of water, this can result in increased levels of sedimentation and/or lowered water quality, and therefore decreases available habitat.	Tellman et al. 1997, pp. 92-93; Cantrell 2009, p. 18; Glennon 1995, pp. 133-139; Dunne and Leopold 1978, p.173; Horak 1989, pp. 41-43; Medina 1990, p. 351-359; Reid 1993, pp. 48-50; Waters 1995, pp. 52-53; Wheeler et al. 2005, pp. 149-155	**Moderately confident**
- Exposure of Stressor(s)	Current increases in the human population and resulting development are occurring in only portions of GIRO and GINI southwest range. For example, development is increasing in areas surrounding Oak Creek, Verde River, Lower West Clear Creek, Dry Beaver Creek, and sections of the Gila River. However, there are streams containing chub that are on public land and have little to no development such as Fossil Creek, lower Tonto Creek, and Haigler Creek.	Tellman et al. 1997, pp. 92-93; Cantrell 2009, p. 18; Horak 1989, pp. 41-43; Medina 1990, p. 351; Reid 1993, pp. 48-50; Waters 1995, pp. 43-53; Wheeler et al. 2005, pp. 149-155; Girmendock and Young 1993, p. 47; American Rivers 2006; Paradzick et al. 2006, p. 89	**Highly confident**
- Immediacy of Stressor(s)	Development, in one form or another, has occurred near chub habitat since the late 1800's. However, the rate of human population increase in the southwest continues to drastically increase. Arizona increased its population by 394 percent from 1960 to 2000. Growth rates in Arizona counties with historical or extant GIRO and GINI populations are also significantly increasing; Maricopa (463 percent); Cochise (214 percent); Yavapai (579 percent); Gila (199 percent); Graham (238 percent); Apache (228 percent); Navajo (257 percent); Yuma (346 percent); La Paz (142 percent); and Mohave (1,904 percent). Population growth trends in Arizona are expected to continue into the future.	Census Bureau 2005, p. 1; McKinnon 2006; Girmendonk and Young 1993, p. 47; American Rivers 2006; Paradzick et al. 2006, p. 89	**Moderately confident**
Changes in Resource	Chub habitat is lost through dewatering of stream reaches caused by increased demand and water use and diversion to human population centers. Water quality may decline due to anthropogenic modification and urban effluent runoff. Changes in stream morphology, rates of sedimentation and erosion may increase, resulting in shifts in the aquatic insect community on which fish rely for food.	Cantrell 2009, p. 18; Glennon 1995, pp. 133-139; Dunne and Leopold 1978, p.173; Horak 1989, pp. 41-43; Medina 1990, p. 351-359; Reid 1993, pp. 48-50; Waters 1995, pp. 52-53; Wheeler et al. 2005, pp. 149-155	**Highly confident**
Response/effect to Stressors: INDIVIDUALS	Fish habitat is affected by dewatering of stream reaches, stream channel alteration, and decreased water quality. Loss of surface water in streams results in loss of habitat for every life stage of chub, starting with backwaters needed for larval and juvenile fish development and ending with loss of pools needed for adult fish. Alterations to water quality may result in areas that become uninhabitable for all life-stages of fish. Decreased fitness of all life-stages of fish could result from alterations to food-web dynamics and the before mentioned loss of habitat.	Cantrell 2009, p. 18; Glennon 1995, pp. 133-139; Dunne and Leopold 1978, p.173; Horak 1989, pp. 41-43; Medina 1990, p. 351-359; Reid 1993, pp. 48-50; Waters 1995, pp. 52-53; Wheeler et al. 2005, pp. 149-155	**Highly confident**

THEME: Urban and rural development impacts on chub habitat			
ESA Factor	A, D	Supporting Information	**Confidence / Uncertainty**
Compounded Effects of Climate Change	With increased population growth and development focused around water in the southwest, it is likely that the effects of development will continue and increase in severity as surface water diminishes due to the effects of climate change.		**Somewhat confident**
POPULATION & SPECIES EFFECTS			
Effects of Stressors: POPULATIONS [RESILIENCY]	Effects of urban, suburban, and rural development to resiliency of GIRO and GINI species are expected to be moderate to high where they occur. Reduced population growth and changes in distribution are expected for GIRO and GINI due to reductions in flows to support increased human populations. Some populations are more in danger of the effects due to geographic proximity to development on private lands, while others are on public lands managed by state and federal agencies and are unlikely to experience a loss of resiliency due to development on those lands.		**Somewhat confident**
SCOPE	Arizona is one of the fastest growing states in the U.S., with the population expected to increase 109 percent by 2030. Areas near streams and riparian corridors are at an increased danger of development. Development alongside occupied chub streams occurs mostly in the Verde River drainage; GIRO may be in greater danger due to the species proximity to human developed areas.		**Moderately confident**
Effects of Stressors: [REDUNDANCY]	Effects of urban, suburban, and rural development to redundancy of GIRO and GINI species are expected to be moderate to high. Reduced total number of populations are expected for GIRO and GINI. Some populations are more in danger of the affects due to geographic proximity to development, while other populations are on public lands managed by state and federal agencies.		**Moderately confident**
[REPRESENTATION]	Effects of urban, suburban, and rural development to representation of GIRO and GINI species are expected to be moderate to high. Decreases in genetic and ecological diversity are expected as number of fish and populations decrease. Some populations of chub may be more affected due to geographic proximity to development		**Low confidence**
Risk of Extirpation 2046	We anticipate that urbanization in the Verde River and its tributaries is likely to increase over time with the result that flows in the streams may be reduced due to increased groundwater pumping. Both headwater and roundtail chub may be affected. In the Bill Williams and Little Colorado Rivers streams, there is much less urbanization in the stream corridors and while there may be some additional water uses (see grazing section), the extent of the change from human uses alone is not significant. For headwater chub in Tonto Creek, there is some opportunity for additional water use in the tributaries associated with development of private land. Because the availability of those lands is restricted, we do not anticipate a large enough decrease for most streams (Gordon and Marsh Creeks may be the exceptions) to result in extirpation.		

Appendix C

Headwater and Roundtail Chub Status Assessment Model

1. Introduction

As a part of the species status assessment (SSA) for the headwater and roundtail chub, we developed a model to conduct an analysis characterizing the current status and future condition of the headwater and roundtail chubs to assess their viability in terms of resiliency, redundancy, and representation for each species. This is not a population viability model or a probability of persistence model. Given the limited available data for these species we did not consider these types of model the best tool. The model we developed analyzes the physical and biological components of occupied chub habitat and the condition of the chubs in the occupied areas. The model objectives were: 1) to assess the current status of each extant headwater and roundtail chub population (defined as analysis units, see Chapter 2 of the SSA Report) relative to a series of condition categories; and 2) to project the future condition of the headwater and roundtail chub species by analyzing the baseline status with a set of future scenarios relative to the risk categories over a 30 year time frame. This report documents the analysis we undertook to in developing and implementing the assessment model. The results of this model assessment are in the SSA Report. We constructed one model to assess both headwater and roundtail chub. We think the similarities of habitat selection, life history, and current condition categories for the two species are similar enough to allow both species to be assessed using the same metrics.

The purpose of this model assessment is to reflect our understanding of the future viability of these chub species by applying the best available information to assess the status of these species in a standardized and transparent method. Those reflections may be qualitative or quantitative depending upon the best available scientific and commercial information to conduct the assessment. Models are representations of a system that allows for investigation of the properties of that system and, in some cases, projection of future outcomes. Our model is an analysis based on the data available and our understanding of that data. We understand there are limitations to the model due to the limitation of data, and we do not claim this analytical tool provides highly certain predictive outcomes. Instead, it is designed to explicitly portray our understanding of the current and future condition of the two chub species given our assumptions about the risks that we think most influence the viability of these species. We developed a core group of Service biologists to work on developing the SSA and the model. We used the best commercial and scientific data to develop the model and applied our best professional judgment in assessing and incorporating this data into the model.

The information contained in this Assessment Model document is a summary of the more detailed discussions contained in the Model Supporting Documentation report in Appendix E. Where additional information on any subject discussed herein is needed, we refer the reader to the Model Supporting Documentation document in Appendix E.

2. Model Development

We developed a Microsoft EXCEL spreadsheet model to implement (run) the condition categories and their metrics to obtain a qualitative description for the current condition and projected future condition of each AU. The type and complexity of the SSA Model is dependent on the data available and the quality of that data, which is limited. Therefore, our model is limited to those metrics where sufficient information was available. We recognize that there are uncertainties with these metrics and assumptions had to be made in using these metrics. Our model consists of two components: (1) analysis of the current condition of each analysis unit (AU) based on the chub population structure, and primary past and current threats to the species with population or AU level impacts, and (2) forecasting the future condition based on project risk of the ongoing and future threats to the species based on the current condition as a baseline.

2.1 Condition Categories

Based on the primary risks or stressors to chub, and the available stream habitat and survey data for chubs we identified three condition categories to assess the current condition of both chub species. The three current condition categories were: chub population structure (abundance and recruitment), nonnative species, and water availability (drought). We also incorporated the past conservation measures implemented for the species. For the future condition, we identified the ongoing and future risks to the species that were likely having or will have population level impacts. We identified three future condition categories: nonnatives species, water availability. And conservation measures. Given the uncertainties of the future, we analyzed four potential future scenarios where impacts from nonnatives and loss of water increased over time. We assessed the current condition of the headwater and roundtail chub by stream and AUs using the metrics in the condition categories described above.

2.2 Condition Category Metrics

After the current and future condition categories were established, we identified metrics to measure these condition categories. There are one or more metrics for each condition category that relates to a specific component of the condition category and how it affects chub AUs.

2.3 Current Condition Ranking Criteria for Metrics

To standardize the application of the metrics we also established specific ranking criteria. This allows for consistent assessment of the condition of each headwater and roundtail chub AU. Each metric had three or four ranking levels with a quantitative and qualitative value for each ranking level. Each of these ranking levels has qualitative and/or quantitative descriptions of the conditions. Further, each ranking level is identified with a numerical value, a qualitative value, qualitative description, and color as shown in an example (Table C-1). Some ranking criteria has a quantitative description as displayed in Table C-1. The higher the ranking number, the worse conditions are for the chubs.

The numerical ranking values allowed a final score to be determined and for AUs to be compared. The assignment of ranking values of the different metrics to a stream reflects our best professional judgment on the current and future condition of the species and the risk to the species to provide an explicit way to communicate our understanding. Further, we identify the assumptions made and uncertainties in our process and the data to provide transparency to our process. Our EXCEL modeling analysis of the current condition is in attached to this assessment model.

Table C-1. Example of Metric Measurement Ranking Table Displaying Numeric Value, Qualitative Value, Quantitative Description, Qualitative Description, and Color Coding.

Numeric Value	**Qualitative Value**	**Quantitative Description- Percentage of positive survey**	**Qualitative Description**
3	Poor	0-33%	Percentage of positive surveys over time does not show reliable presence of chub in the stream
2	Good	34-66%	Percentage of positive surveys over time shows reliable but not consistent long term presence of chub in the stream
1	Best	67-100%	Percentage of positive surveys over time shows consistent long term presence of chub in the stream

There are other risk categories that impact chubs at a population level but we were not able to capture in the assessment model. These include wildfire, additional climate change impacts, anthropogenic actions, and the demographic effects from these risks. However, we did consider these in the SSA Report. This evaluation is in the Cause and Effects Tables in Appendix B, and in Chapter 5 of the SSA Report.

2.4 Analysis Units (AUs)

As described in Chapter 1 in the SSA Report, our analysis assessed the condition of each species by AUs. Past assessments, including our 12-month findings and CNORs, evaluated the species by occupied stream, as if they operated independently of each other. In developing this assessment, we recognized that hydrologically connected streams did not operate completely independent of each other since chubs (and other native and nonnative species) could move between streams utilizing resources present within the entire unit.

There are two types of analysis units (AUs); Individual AUs containing one stream that is not hydrologically connected to another occupied stream, and Complex AUs containing multiple streams that are hydrologically connected. For the model, each streams (whether in an individual

or complex AU) were first run separately through the model and the numerical rankings for each stream in an AU were combined into a single numerical rankings for the AU. All known occupied streams with wild and reintroduced or augmented populations were evaluated.

Headwater chub currently occupy 22 streams across its range and roundtail chub occupy 35 streams across its range. This includes the renovated site, Fossil Creek, for headwater and roundtail chub.

Table C-2: Headwater chub AUs

Drainage Basin	Analysis Unit	Streams Included in the Unit
Gila River	Three Forks Complex	East, Middle, and West Forks Gila River and Diamond Creek (tributary to the East Fork)
	San Carlos Complex	Ash Creek, San Carlos River
	Turkey Creek	Turkey Creek, tributary to Gila River in New Mexico
Salt River	Upper Tonto Creek Complex	Gordon, Haigler, Marsh, Buzzard Roost, Rock, Spring, Turkey, and upper Tonto Creek
	Lower Tonto Creek Complex	Lower Gunn Creek and lower Tonto Creek
	Upper Gunn Creek	Gunn Creek above natural barrier
Verde River	Upper Fossil Creek	Fossil Creek above constructed fish barrier
	Upper Wet Bottom Creek	Wet Bottom Creek above natural barrier
	Upper West Clear Creek	West Clear Creek above the natural barrier
	East Verde River Complex	Gorge, Pine, Rock and Webber creeks and East Verde River

Table C-3: Roundtail chub AUs

Drainage Basin	Analysis Unit	Streams Included
Bill Williams	Burro Creek Complex	Burro, Conger, and Francis Creeks, lower Boulder Creek
	Boulder Creek Complex	Upper Boulder to Warm Springs, Small Cabin (tributary to Wilder Creek), and Wilder Creeks;
	Trout Creek Complex	Cow, Fort Rock, and Trout Creeks
	Santa Maria Complex	Cottonwood Canyon, Kirkland and Sycamore Creeks, Santa Maria River
Gila River	Aravaipa Creek	Aravaipa Creek
	Eagle Creek	Eagle Creek
	Upper Gila River	Gila River from AZ-NM border to the Gila Forks confluence.

Little Colorado River	Chevelon Creek	Chevelon Creek below Chevelon Canyon Lake to the Little Colorado River
	Clear Creek	East Clear Creek below Yeager Canyon which becomes Clear Creek to the Little Colorado River
Salt River	Salome Creek	Salome Creek
	Upper Salt River Complex	Canyon, Carrizo, Cherry, Lower Cibecue, and Corduroy Creeks, Black, White, and Salt River above Roosevelt Lake
Verde River	Upper Fossil Creek	Fossil Creek above the constructed fish barrier
	Upper West Clear Creek	West Clear Creek above waterfall
	Confluence Reach Complex	Lowermost Salt and Verde Rivers from Bartlett and Stewart Mountain Dams to Granite Reef Dam
	Verde River Complex	Beaver and Wet Beaver Creeks, Oak, lower West Clear and Fossil Creeks, mainstem Verde River from headwaters to the full pool elevation of Horseshoe Reservoir

We also analyzed past conservation measures. This includes the four streams where roundtail chub new populations are being established (Ash Creek, Blue River, Gap Creek, and Roundtree Canyon). Information on these streams is included in the Conservation Actions section of Chapter 5 and in Master Current Status Workbook for roundtail chub. Each of these is a separate AU and are analyzed in the SSA Model for current and future condition.

Table C-4. Conservation stream AUs for roundtail chub

Drainage Basin	Analysis Unit	Stream Included
Bill Williams	Boulder Creek	Boulder Creek above Warm Springs
Gila River	Blue River	Blue River
Salt River	Ash Creek	Ash Creek
Verde River	Gap Creek	Gap Creek
	Roundtree Canyon	Roundtree Canyon

2.5 Information Sources

In developing this model, we reviewed the best available scientific and commercial data to identify the current condition and stressors to chubs. Our review included the 12-month findings (Service 2006, and Service 2009), subsequent annual Candidate Assessments for the Candidate Notice of Review (Service 2007, 2008, 2009, 2010a and b, 2011a and b, and 2012a and b, entire), Jones et al. (2014) and Voeltz (2002). We also considered numerous other published and gray literature, including survey reports, field notes, and personal communication with experts. A brief discussion of this information is in Chapter 5, with more extensive information presented in Appendix B (Cause and Effects Evaluations) and Appendix E (Model Supporting Documentation) to this SSA.

Where data was lacking for these species, we used data from other fish species (primarily Apache trout, Rio Grande Cutthroat Trout, and Gila trout) facing the same conditions and risks, our best professional judgment, or sought input from experts. We recognize that using information developed on other species or to discuss a topic in a general sense that relates across animal groups in our assessment for the chubs is not ideal and we must make assumptions on how that information relates to the chubs, and acknowledge that a level of uncertainty comes with using that information. However, this is the best available commercial and scientific data. We note the key uncertainties and assumptions we made in using this information for the chubs in this SSA Model. Additional information on the uncertainties and assumptions can be found in the Model Supporting Document Appendix E.

For the water availability condition category, we identified wetted reaches of a stream during the May-June time period. We determined this time period was the driest time of year and would have the least water available and be a limiting factor for chubs. We were able to use the watered (perennial) stream lengths in Jones et al. (2014, pp. 113-115) for some entirely perennial streams. For streams that were not entirely perennial during the May-June period, we used satellite imagery available from Google Earth and used the path creation feature to measure the portions of the stream that had water during that period.

For climate change, we identified two current, regional downscaled models that predict the hydrologic connectivity where roundtail and headwater chub occur. One study focuses on the Verde River Basin (VRB), in Arizona, that provides a demonstration of projected changes in regional climate regimes that will have significant consequences to patterns of intermittence and hydrologic connectivity in dryland streams in the southwest in 1988-2006 and 2046-2064 (Jaeger et al. 2014). In another study, Garfin et al. (2014) focused on the Gila River in Arizona and New Mexico within similar time periods (1971-2000 and 2041-2070).

2.6 Information Compilation for Streams

We compiled the information from the published and gray literature for each stream into three spreadsheets. This information was used in the chub population structure, water availability, and nonnative species condition categories. One spreadsheet captured all the data regarding survey information, the second captured all the data regarding the stream condition, and the third captured the stream length data. The completed three spreadsheets-Survey Workbook, Stream Workbook, and Stream Length Workbook-contain the compiled physical and biological information from surveys and water availability, and information on other relevant information that affects the streams and their ability to provide habitat for chubs. The Survey Workbook and Stream Workbook for the individual streams were summarized into the Master Current Status Workbooks for each species. Information from the individual and Master Current Status Workbooks was used to populate the SSA Model EXCEL worksheets (attached to this Assessment Model). The worksheets in the SSA Model show the data, ranking of the data using the identified metrics, calculations, and stream and AU scores.

3 Time Frame Analyzed

3.1 Current status

2015 (and the next 5 years)-This is considered the current condition of populations. All the forecasting for future time intervals related to analysis of the risk categories are based on the current conditions of the populations.

3.2 Future status

2046-This is about 30 years from the present. This timeframe was used by Jaeger et al. (2014) in their analysis of climate change impacts on the flows in the Verde River. We selected Jaeger et al. (2014) because it analyzed the potential effects of climate change on a watershed important to both species. Availability of water is and will continue to be an important consideration for chubs. Further, the effects of climate change on flows are expected to generally exacerbate the existing impact of nonnatives to chubs, which is also an important consideration for chubs.

4 Current Condition

We used the best available information and expert judgment to develop the condition categories, individual metrics, and ranking criteira to measure the condition of chub AUs. These judgments were based on our understanding of the information contained in the Risk Categories section (Chapter 5), the Cause and Effect Analysis Tables (Appendix B), and the Model Supporting Documentation in Appendix E. Our EXCEL modeling analysis of the current condition is in attached to this assessment model. The results of the current condition assessment are presented in Chapter 4 of the SSA.

4.1 Current Condition Categories

We first identified condition categories that provided an assessment of the current condition of chubs based on the available information for these species. The three current condition categories are: chub population structure (abundance, persistence over time, and recruitment), nonnative species, and water availability (drought) (Table C-5 below). The specifics of each Condition Category, and how they were determined and used are described below.

4.2 Current Condition Category Metrics

We then identified metrics for each condition category. These are listed in Table C-5 below. There are one or more metrics for each condition category that relates to a specific component of the condition category and how it affects chub AUs. The specifics metrics for each Condition Category and how they were determined and used are described below.

4.3 Current Condition Ranking Criteria for Metrics

Next, we developed ranking criteria for each metric within each Condition Category (Table C-5). The qualitative or quantitative ranking measurements were developed specifically for each

condition category (Table C-5). The specifics ranking values for each metric and how they were determined and used are described below.

Table C-5. Current Condition Categories and Metrics.

Condition Category	Metrics
Nonnative species	• Nonnative community level effects to chub
Water availability	• Total wetted length of the stream • Percentage of total wetted length with perennial flows • Number of stream segments (fragments) in the total wetted length
Chub population structure	• Percent presence of chub in survey datasets over time • Abundance of chub in the stream • Presence of multiple size classes (as a surrogate for age classes)

4.4 Assessment of Condition Categories

4.4.1. Chub Population Structure Condition Category

This condition category evaluates our understanding of the population structure of the chub AUs. Density or population size, nor fecundity or survival rates of chubs are available for all the streams with chubs. Consequently, different metrics are necessary to assess the condition of chub populations or AUs. For this condition category, we reviewed all the available survey and research reports (gray literature) and published literature pertaining to chub survey data from 1990 to 2015. We selected this period for our analysis because it represents a shift in the focus of surveys to look at native species in particular and the reporting record is more robust with information on gear types, survey locations, and providing more information on numbers and sizes of the fish captured. Survey reports used were primarily from AGFD, New Mexico Department of Game and Fish, the Gila River Native Fish Conservation Program, Bureau of Land Management, and research projects where survey data is presented. These survey reports, with citations, are detailed in the individual stream survey workbooks and summarized in the Master Survey and Stream Workbook. The majority of survey reports did provided various qualitative or quantitative descriptions of the presence of chubs and the age or size classes present. In addition, from these survey reports we were able to determine the percent of positive surveys over time. There are multiple years of survey data throughout the range of both chub species. However, these surveys varied in target species, equipment, timing, surveyors, duration, and location, and were collected over numerous years. Further, survey reports varied in the information provided.

We identified three metrics to assess chub population structure: percent positive surveys, general abundance, and the number of size classes of chub. Each metric has equal weight in the model. The sections below provide more detail on these metrics and how they were established. We

acknowledge that the information and understanding that we have on chub population size and structure is limited, and there is variation in survey methods and reporting, and that this creates uncertainties. However, this is the best available information, and we used this data to develop metrics to measure chub population structure. We present key uncertainties and assumptions in our discussion below; more detail on assumptions and the uncertainties in these datasets are presented in the Model Supporting Documentation in Appendix E. The HWC abundance and RTC abundance tabs in the Model Assessment Worksheet provides the analysis for this condition category.

Metric 1: Percentage of positive chub surveys

This metric evaluates our understanding of the percent of surveys that were positive since 1990 as an indicator of the persistence of chubs over time. We used all available survey reports to calculate the percent positive surveys for chubs. We assumed that the greater the number of surveys conducted over time, the greater the opportunity to contact chub if they are present in the system.

We identified three value rankings for this metric- best, good, and poor. We identified three because having two ranking categories (greater or less than 50%) provide little value in assessing this condition category but having more ranking categories indicates more precision than the data has. Table C-6 describes the ranking criteria for this metric.

The number of positive and negative surveys conducted from 1990 to 2015 was counted from the survey spreadsheets for each stream (Master Survey and Stream Workbook). From this data, we calculated the percent positive surveys over this time period. Where data appeared to be presented twice (i.e., the same data under two different authors), we only used one record. For more than one record in the same year for the same location, we counted these as separate records.

Table C-6. Ranking Criteria of Percentage of Positive Chub Surveys Conducted Since 1990

Numeric Value	Qualitative Value	Quantitative Description- Percentage of positive survey	Qualitative Description
3	Poor	0-33%	Percentage of positive surveys over time does not show reliable presence of chub in the stream
2	Good	34-66%	Percentage of positive surveys over time shows reliable but not consistent long term presence of chub in the stream
1	Best	67-100%	Percentage of positive surveys over time shows consistent long term presence of chub in the stream

Example

Table C-7 Boulder Creek Analysis Unit Percent Positive Surveys

Streams Included	Number of Surveys post 1990 positive	Number of Surveys post 1990 negative	Total Surveys	Percent of positive surveys	Quantitative Assessment of positive surveys
Boulder Creek-above barrier	10	0	10	100%	1
Wilder Creek	3	0	3	100%	1
Stone Corral Canyon	1	0	1	100%	1

Metric 2: General abundance of chubs reported by recent surveys

This metric evaluates our understanding of the abundance of chubs as an indicator of the size of chub populations over the assessed time period (1990-2015). We used all available survey reports to calculate the abundance of chubs. We assumed that survey reports containing indications (visual or by catch) of chub abundance over the assessment period provides a measure of the size of the chub population in the stream. The evaluation of the dataset and its resultantong uncertainties and our assumptions for this metric required several complex considerations. This was particularly apparent in the range of data available from survey reports where subjective status (low, common, or abundant) was presented in some reports, and specific numbers of chub present in relation to other fish species was presented in other reports.

We identified three ranking categories for this condition category, abundant, common, and low, based on the terminology used in reports and our assessment of the numerical values presented. For the ranking categories, we assume that a stream that supports an abundant population is contributing more value to the species long-term status than one with a low population. This is discussed more in the Model Supporting Documentation Appendix E.

Table C-8. Ranking of Chub General Abundance

Numeric Value	Qualitative Value	Qualitative Description
3	Low	Chub population is at a low level where they are uncommon or rarely captured or seen and may be missed by even targeted surveys due to their rarity. Value of the stream for chub is lower compared to other streams with higher chub abundance.
2	Common	Chub population is at moderate levels where they are commonly captured or seen but are less abundant with than other species present. Value of the stream for chub is better compared to other streams with lower chub abundance.

1	Abundant	Chub population is robust with numerous individuals present throughout the occupied area in the available habitats. Value of the stream for chub is higher compared to other streams with lower chub abundance.

Example

Table C-9. Boulder Creek Analysis Unit Chub Abundance

Streams Included	Summary of Chub Abundance	Quantitative Assessment of Abundance
Boulder Creek-above barrier	common	2
Wilder Creek	abundant	1
Stone Corral Canyon	abundant	1

Metric 3: Number of size classes of chubs present

This metric evaluates our understanding of the number of chub size classes as an indicator of recruitment within chub populations over the assessed time period (1990-2015). We used all available survey reports to calculate the abundance of chubs. We assume that streams with a range of size classes documents spawning and successful survival of young fish through to adult size are more likely to be of higher value to the species than a stream where a full range of size classes is not often documented.
The life span of both headwater and roundtail chub (5-7 and 5-10 years, respectively) allows that they do not have to have a significant recruitment event (where spawning leads to an Age 0 year class that can later be tracked by surveys as they move to adulthood) every year. Annual year classes can be missing for one or more years provided that other year classes contain sufficient numbers to support the population.

For this assessment, we identified three size classes to represent young/juvenile, sub-adult and adult age classes. The size categories were: <100 mm, 100-200 mm, and >200 mm. These size class categories were based on literature as cited in the Model Supporting Documentation in Appendix E. Ranking values represent our relative understanding of the effects of lack of year classes has to chub populations.

For this metric, we reviewed survey reports from 1990 - 2015 for age class data. If an age class was reported in any survey during this time period we considered this age class present. Meaning that all size classes did not need to be present in one survey effort, rather if one of the three size classes was documented over the assessment period in different survey reports we considered the age class present. Further, we are not counting the number of individuals of the three size classes, only that they were documented as being present in at least one survey over the assessment period (1990-2015). Where there is no data on lengths given, we assumed that two size classes are present. The optimal condition is to have all three classes present. We

recognize that this could over or underestimate the recruitment of a stream and AU. The methods are detailed in the Model Supporting Documentation in Appendix E.

Table C-10. Ranking of Number of Size Classes Present

Numeric Value	Qualitative Value	Quantitative Description-Number of size classes present	Qualitative Description
3	Poor	1	Stream supports physical and biological conditions that do not regularly support recruitment.
2	Good	2	Stream supports physical and biological conditions that support recruitment in some years.
1	Best	3	Stream supports physical and biological conditions that support recruitment in most years.

Example

Table C-11. Boulder Creek Analysis Unit Chub Size Classes

Streams Included	Number of Size Classes (Unknown = 2)	Quantitative Assessment of Age/Size Classes
Boulder Creek-above barrier	3	1
Wilder Creek	3	1
Stone Corral Canyon	3	1

Chub Population Structure Summary

Table C-12. Assessment Category Calculation Methods for Boulder Creek

Streams Included	Quantitative Assessment of positive surveys	Quantitative Assessment of Abundance	Quantitative Assessment of Age/Size Classes	Overall Quantitative Assessment
Boulder Creek-above barrier	3	1	2	6 (3+1+2=8)
Wilder Creek	3	1	1	5 (3+1+1=8)
Stone Corral Canyon	3	1	1	5 (3+1+1=8)
TOTAL				16.00

Key Assumptions and Uncertainties:

Our key assumption is that the information available from surveys over time can be used to assess the population structure of chubs in a given stream or AU. While this is true, the quality of the data available plays a significant role in the accuracy of the results. Regardless though, these are the only data available to assess chub populations across the range. We therefore devised this analysis to best utilize the best available data. We discuss our assumptions and uncertainties with this data in the Model Supporting Documentation in Appendix E.

4.4.2. Nonnative Species Condition Category

This condition category evaluates our understanding of the effects of competition, predation, and harassment by nonnative species on the chubs. Data or expert knowledge on the presence or absence of nonnatives is available for most streams; however, the population size or density of nonnatives is not known for all streams within the range of the chubs. We relied on published literature, gray literature, and survey reports, along with the best professional judgment of experts familiar with these streams to assess the impacts to chubs from specific nonnative species and the level of impacts from the nonnative community on chubs within a given stream.

For this condition category, we assume that the effects to headwater and roundtail chub from nonnative species are similar to that for other native fish. We base this on the overall literature and our compilation of the potential overlap in habitat and resource use (Table C-13) between chubs and nonnative species. Nonnative fish and invertebrate species are well documented as having a potential for adverse effects ranging from minor (impacts to a few individual fish) to extreme (impacts are at a level sufficient to extirpate a population) to populations of native fish species in Arizona and across the southwest. We recognize that local habitat conditions influence the relationship of specific nonnatives to chubs and those actual effects will vary by stream and over time.

We further recognize that there are streams containing chubs and nonnatives that have co-occurred for decades under what must be suitable conditions and that the reasons for this continued co-occurrence is not understood. However, we assume that streams or AUs with nonnative species documented as having high impacts to native species are at a higher risk of being negatively affected than streams or AUs that without nonnatives or with nonnatives that have low impact to native species (as described in Table C-13 below). Chapter 5-Risk Categories and Appendix B-Cause and Effects Analysis Table in the SSA describe the impacts of nonnatives on native fish and provide citations. The HWC nn and RTC nn tabs in the Model Assessment Worksheet provides the analysis for this condition category.

Impact from Specific Nonnative Species to Chubs

For this condition category, we first evaluated our understanding of the impacts from specific nonnative species on chubs. We assume that the effects to headwater and roundtail chub from nonnative species are similar to that for other native fish. We used the same data sources as used in the Population Structure Category to determine the nonnatives present in occupied streams. Different nonnative species, by virtue of their life history and behavior, have differing levels of potential impacts to chubs as described in Chapter 5-Risk Categories and Appendix B-Cause and Effect Table. To capture these differences we assessed the specific level of concern to chubs for a specific nonnative species on chubs.

We focused our analysis on nonnatives present within occupied chub streams that literature documents or suggests have the potential to impact individual chubs or have a population level effect. In our analysis, we omitted the nonnative species with information documenting only a low to no impact on individual chubs or population level. However, we included those nonnative species where the information on the effect was uncertain. Table C-13 lists these species, as well as the information on the potential for predation or competition with chubs.

This analysis does not include an evaluation of abundance data of nonnatives in streams or AUs. This data is available in varying quality for streams through the survey reports. However, we recognize the complexity of considering population size of even the higher risk nonnatives in our SSA Model. The complexity arises because we cannot form an assumption that after a certain population size, a particular nonnative species becomes more of a threat to chubs. Additionally, because there are situations were both species co-occur with varying population sizes and that is likely the result of local physical habitat conditions, our uncertainty in setting a metric of nonnative population size was very high. As a result, for this category we wanted to focus on the degree of potential effects of nonnatives on chubs, not on the site specific responses since these are variable. We acknowledge that in doing this that the rankings represent the theoretical maximum level of effects possible. However, this nonnative species ranking is not used to populate the model; rather it is used to demonstrate the potential impacts to chubs from these species and provides the basis for the metric that ranks the nonnative community impacts to chubs per stream and AU. The community level impacts to chubs assess our understanding of the on-the-ground impacts to chubs from the nonnatives present in each stream and AU that takes into account some of the physical conditions that may be operating to promote co-occurrence in those streams.

Table C-13. Nonnative species and their potential effects on chubs

Nonnative Species	Age Classes Of Chub Preyed On By Nonnative Species	Sizes Of Nonnatives That Prey On Chubs	Nonnative Habitat Overlap With Chubs	Competition: Harassment (Displacement And Or Injury)
Black bullhead	Larvae to juvenile	Adults	Yes: also defends nests	Displace from pool habitat. Consumes invertebrates.
Brown trout (wild)	Larvae to sub-adult	Sub-adult to adult	Yes: pools	Consumes invertebrates.
Bullfrog	Larvae to juvenile	Adults	Yes: uses shallow margin areas	Found mostly in shallow waters where YOY or small juveniles may be present.
Channel catfish	Juveniles to sub-adults	Adults	Yes: deep water areas	Uses deep, quite habitat. Consumes invertebrates.
Common carp	Eggs primarily	Sub-adult to adult	Yes: uses most habitat types	Consumes invertebrates.
Crayfish	Larvae, small sub-adult	Adults	Yes: uses all habitat types	Attacks fish that come too close, will injure/kill fish that cannot escape from them. Aggressive defender of shelter. Consumes invertebrates.
Green sunfish	Larvae to juveniles	Juveniles to adults	Yes: uses multiple habitat types	Consumes invertebrates.
Fathead minnow	Larvae	Adults	Yes: uses slow water habitats	Consumes invertebrates.
Flathead catfish	Sub-adults and adults	Sub-adult, adult	Yes: uses slow and deep areas	Consumes invertebrates.
Largemouth bass	Larvae to sub-adults	Sub-adult to adult	Yes: low velocity areas	Consumes invertebrates.
Mosquitofish	Larvae	Adults	Yes: shallow vegetated areas	Displaces from pool habitat.

Rainbow trout (wild)	Larvae to juveniles	Adults	Yes: pools	Uses pool habitat.
River otter	Sub-adult to adult; chub may not be preferred prey due to their speed.	Sub-adult to adult	Uses all habitats	Attacks fish that come too close, will injure/kill fish that cannot escape from them
Red shiner	Larvae	Adult	Yes: shallow habitats	Consumes invertebrates.
Rock bass	Larvae to juveniles	Sub-adult to adult	Yes: pools	Uses pool habitat. Consumes invertebrates.
Smallmouth bass	Larvae to sub-adults	Sub-adult to adult	Yes	Prefers pools with cover, intolerant of turbidity, may exclude chub from preferred pools. Consumes invertebrates.
Yellow bullhead	Larvae to juvenile	Sub-adult to adult	Yes	Uses pool habitat. Defends nest and young. Consumes invertebrates.

We identified four ranking categories-very high, high, moderate, and low. There are nonnative species that demonstrate a high level of impact to chubs and those that demonstrate a low level. However, there are those nonnatives that demonstrate a moderate impact to chubs. These moderate impacts can be low to moderate or moderate to high. To capture these levels of impacts we identified four value rankings to assess the impacts from specific nonnatives to chubs. The ranking values in Table C-14 represent our understanding of the effects of the specific nonnative species to chub.

The ranking scores for the specific nonnative metric is in worksheet Nonnative Rank of the SSA Model Workbook attached to this appendices and in Chapter 5-Viability of the SSA Report. The ranking scores for the nonnative community impacts is in worksheet HWC NN and RTC NN, for headwater and roundtail chubs respectively, of the SSA Model Workbook.

Table C-14. Ranking Criteria for Nonnative Species Effects on Chubs

Numeric Value	Qualitative Value	Qualitative Assessment of Magnitude of Effects
4	Very high	Potential for high levels of predation on more than one chub size classes by one or more nonnative species size classes that increase with population size of the nonnative species; high overlap in preferred habitats with chub that leads to competition and harassment displacing chub from preferred habitats.
3	High	Potential for moderate to high levels of predation on one or more chub size classes by one or more nonnative species size classes that increase with population size of the species; moderate amount of habitat overlap with chubs that leads to competition and harassment displacing chub from preferred habitats.
2	Moderate	Potential for low to moderate levels of predation on one or more chub size classes regardless of size of population; low level of habitat overlap has limited opportunity for competition or harassment.
1	Low	Low risk of predation on and competition for habitat with chub.

From the information presented in Table C-13, Service biologists familiar with chubs and nonnative species ranked the impacts of the specific nonnatives to chubs. Table C-15 shows which of the nonnative species in Table C-13 were assigned which ranking.

Table C-15. Category rankings for nonnative species

Qualitative Value	Numeric Value	Nonnative Species in Category
Very High	4	Green sunfish, flathead catfish, smallmouth bass

High	3	Black bullhead, yellow bullhead, brown trout, largemouth bass, crayfish
Moderate	2	Channel catfish, rainbow trout, rock bass, red shiner, western mosquitofish, river otter
Low	1	Bullfrog, common carp, fathead minnow.

Metric 1: Nonnative Community Level Effects to Chubs

This metric evaluates our understanding of the level of impacts from the particular nonnative community present in a stream or AU on chubs. Our first level assumption is that streams or AUs with more nonnative species with high impacts to chubs are at a higher risk of being negatively affected than streams or AUs that with no or fewer nonnative species with high impacts to chubs. For example, if black bullhead, green sunfish, and smallmouth bass are all present in a given stream there is a greater probability that chubs will be in smaller numbers, have fewer recruitment events, and be less able to recover from the effects of additional stressors than in streams with a community of lower ranking nonnatives. As we noted earlier, there are streams where chubs and the nonnative community are co-existing successfully. The local physical and biological conditions and other stochasticity are likely the primary drivers of this co-existence. We do not understand these complex interactions but acknowledge that the presence of nonnative species does not automatically result in significant adverse impacts to chub populations.

We used three ranking classes: high, medium and low. We used three, rather than four, for this assessment because the information available supported the two extremes (large and small effects) and intermediate effects but was not robust enough to differentiate two intermediate values.

In this metric, Service biologists reviewed the suite of nonnative species present in each stream and based on the nonnative species present and their knowledge of the potential consequences of that community on chubs, considered the synergistic effects of that community on chubs reproductive success, recruitment and ultimately on long term abundance. The ranking was based on our understanding of the data in the Master Current Status Workbooks, that contain the specific information available for each stream) and our best professional judgment.

Table C-16. Ranking of Nonnative Community on Chubs

Numeric Value	Qualitative Value	Qualitative Description
3	High	Nonnative community contains several very high or high impact species that may work cumulatively to have significant adverse effects on chub populations
2	Medium	Nonnative community contains a mix of high and moderate impact species that may work in synergy to have adverse effects on chub populations.
1	Low	Nonnative community contains a mix of mostly low impact species that together have a more limited affect to chub populations, primarily effects to individuals.

Example

Table C-17. Nonnative community ranking for Boulder Creek Analysis Unit

Stream Name	Nonnative Species in the Stream	Quantitative Assessment (Mode or Average)
Boulder Creek-above barrier	Crayfish, Fathead minnow	1.00
Wilder Creek	Crayfish	1.00
Stone Corral Canyon	none	0.00

Key Assumptions and Uncertainties:

The literature on the effects of nonnative species on native fish species in Arizona and New Mexico documents that the presence of certain nonnative predators and competitors in streams with native fish has adverse effects on the native fish. The magnitude of that effect can extend from changes in native fish behavior to extirpation of the native fish. We discuss these effects in Chapter 5-Risk Categories of the SSA and in Appendix B-Cause and Effects tables.

We recognize that there are streams where chubs and nonnative species co-exist successfully; however, the intricate balances in the situations where chub and nonnative species co-exist successfully is not understood. The effects of any nonnative species on chubs are influenced by a number of factors that create uncertainties in our ability to predict the outcome of any interaction in any stream. In our development of the two metrics for this category, we used the available information and best professional judgment to assess the potential for effects to chubs from nonnative species on both the individual and community levels. We acknowledge that the potential for adverse effects in each stream is not driven solely by the suite of nonnative species present but also by the specific conditions in each stream that influence the interactions. We also

acknowledge that different native fish species have different responses to the nonnative community, and their response may not be the same as that for the chub to the same species. We included this concept in our ranking of the level of effects from specific nonnative species in Table C-13, using both literature data and expert opinion. Overall, we think our assessment of the effects of nonnative fish on chubs is supported by the documented history of the spread of nonnative species in the western United States including Arizona and New Mexico. For the effects of nonnative species in specific streams, we acknowledge that our assessment does not incorporate the stream-specific relationships and thus may not reflect the actual potential for effects.

4.4.3. Water Availability Condition Category

This condition category describes our understanding of the effects of water availability (amount and distribution) on chubs. Habitat quality and quantity data for all streams occupied by chubs is limited. While some data exists on flows and physical conditions of some streams, this data is not consistent or available for all streams and therefore not complete enough to use as a metric. Consequently, different metrics are necessary to assess available habitat. The data that is available or can be determined is total stream length, perennial stream length, watered segments, and dry segments during various times of the year. Water is the most basic need of individual chubs and populations as without it, there is no habitat for fish. Thus, for this assessment category, we are focusing on how much water is available in a stream as a surrogate for the amount of habitat available with the understanding that stream length is not the main driver of habitat quality. Specifically, we focused our analysis on the length of watered and dry segments in each stream during the season when flows are generally at their lowest. This is typically post-spring runoff and pre-monsoon season, generally May-June. This concept allows us to consider the minimum amount of potential for habitat. The amount of watered area at that minimum flow period controls the number of fish that can be supported. Streams that maintain continuous surface flow during the driest period are the highest value (in terms of water availability) for chub.

Some streams occupied by chubs have continuous perennial flows throughout the stream. However, most streams have seasonally dry reaches. We focused on determining the amount and segmentation of surface water present within each stream. We used Google Earth satellite imagery to examine streams with seasonal drying. The pattern of drying was irregular with shorter or longer dry streambed between watered areas. Where the dry areas were shorter or fewer, there would be more time with continuous flow than in areas with dry areas that were longer or greater in number. Further, the Google Earth data was a snapshot in time, while recent, does not capture the annual fluctuation in precipitation. There are years where there could be more water and therefore the small dry reaches could be continuous. To clearly articulate the watered areas that we examined during the driest time of year, we have defined our terminology below. These terms refer to the watered segments or reaches within a stream and the not the stream as a whole; a stream may have one or more of these “segments” present as defined by the terms below. We identified three water categories defined as follows:

1. “Perennial segments” where the water flow within a specific reach in the stream was continuous or near continuous (<0.1 km dry stream bed between watered reaches) during

the driest period. Perennial segments have the greatest amount of length with surface water present due to the lower amount of dry streambed.

2. "Interrupted perennial segments" where the water flow is interrupted by dry sections that were on average between 0.1 and 0.4 km in length. We assumed that during most of the year, at least some of these sections would be connected long enough to benefit a larger population over the whole stream. Interrupted perennial segments had less surface water present within the segment due to the greater amount of dry streambed.
3. "Intermittent segments" where the water flow is significantly interrupted by dry reaches longer than 0.5 km. We assumed that the dominance of dry reaches in these segments did not allow for any persistent summer connections between the remaining isolated pools, and that wet season connections might also be significantly limited in extent.

By using the perennial and interrupted perennial segments, we targeted the best habitats in the stream. In our model, we did not include intermittent reaches that may have isolated pools with chubs because these areas would likely be small, may not contain sufficient habitat throughout all seasons to allow for a full life cycle (egg to adult), and are only rarely connected to more suitable reaches that would allow for movement. We acknowledge that for some streams where these intermittent areas are common this may not be the case; however, because so much of their length was dry, their value to chubs was significantly less than for the other two types.

Water availability is a complex concept with a number of factors that influence how well a stream supports a large enough population of chubs to avoid the effects of deterministic and stochastic processes. We understand that water availability does not directly correlate to the presence of physical conditions that create "habitat" for chubs. "Habitat" includes the physical and biological components that create conditions for the chub to live and complete their life cycle in a particular stream. Each stream will naturally have an amount of suitable habitat based on the amount of flow over the year and the physical components that allow for the creation of pools and other features that support chubs. For example, Aravaipa Creek has good flows but is mostly a sand-bedded stream with few opportunities for pool formation and has a naturally low abundance of chub. Comparing that stream to Fossil Creek, which also has good flows but has many more pools and the chubs are abundant. However, we do not have this information for all streams.

We understand that the watered areas in a stream range between years due to weather, water removal, and climate change, and vary even through the dry season. In determining perennial and interrupted perennial segments using Google Earth we started measuring at the first sign of water and created a continuous path along the stream looking at the distances between watered areas. When a change in the dry reaches <.1 km occurred we continued measuring and classified these segments as perennial segment. When a change in the dry reaches was between 0.1-0.4 km we continued measuring but classified these as interrupted perennial segment. When a change in the dry reach was >0.4 km then the segment was ended and another begun. We included as the entire measured length of that segment the dry and wetted areas. In doing so, we recognize that this overestimates the actual watered areas available to chubs during this time of year, particularly for the interrupted perennial segments where there is more dry streambed. Our inclusion of the entire measured path addresses some of the uncertainty from the fact that that

water availability varies between years and we assume that the water locations and sizes we documented are most likely to be present in most or all years.

For this category, we make three key assumptions: 1)that the potential amount of habitat available to the chubs is directly related to the amount of water in the stream; 2) that the watered length of the stream during the lowest flow period is a limiting factor on the size of the chub population able to be supported by the stream; and 3) that the distribution of the quality and quantity of the watered area across the total length of the stream influences the quantity and quality of the habitat available for chubs in that stream. The uncertainties associated with these assumptions focus on the physical conditions in the stream that actually create suitable habitat for chubs and how much habitat is needed. These uncertainties are related to our use of stream length as a measure of potential habitat, and how fragmentation (segmentation) of the watered areas in the stream relates to the quality and quantity of habitat available. Chapter 5-Risk Categories and Appendix B-Cause and Effects Analysis Table in the SSA describe the impacts of nonnatives on native fish and provide citations. The HWC water and RTC water tabs in the Model Assessment Worksheet provides the analysis for this condition category.

We developed the following three metrics for this condition category: (1) total perennial and interrupted perennial watered stream length (2) percentage of perennial watered in stream, and (3) number of perennial and intermittently perennial watered segments. Based on our understanding of the importance of these metrics to chubs we weighted the ranking value of these metrics accordingly. We think that the total perennial and interrupted perennial watered stream length and percentage of perennial water in streams during the driest time of the year (early summer) is the most limiting factor for chubs because without sufficient quantity and quality of water chubs will be adversely impacts. Consequently, we weighted these two metrics at 40%. We think the number of watered segments is important but less important than the other two metrics and we weighted this at 20%. The sections below provide more detail on these metrics and how they were established.

Metric 1: Total Perennial and Interrupted Perennial Watered Length within the Stream

This metric evaluates our understanding of the perennial and interrupted perennial watered reaches within streams on chubs within AUs. We assume that the longer the stream length the more likely the population will survive a stream drying (Roberts et al. 2013, p. 1388) because it is more likely to have some stream reaches not affected by the loss of flow, and it is more likely to have sufficient habitat diversity in the stream to provide refugia for individuals to survive if some reaches become uninhabitable for some time period.

The length of a stream needed to support a viable population of chubs is dependent largely on the quality and quantity of preferred habitats present within the length of the stream. There is no scientific research on this topic for chubs; however, we did make use of information from the literature on the management and conservation of the western cutthroat trouts (*Oncorhynchus clarki* ssp.) regarding stream lengths needed for successful trout populations. The Model Supporting Documentation in Appendix E provides the details of our discussions and decisions on stream length categories to use.

We identified 3 ranking categories: low, intermediate, and high. Analysis units <3 km are not considered to have sufficient resiliency to withstand a stochastic event. Analysis units >20 km have high resiliency and are likely to be able to withstand stochastic events. The AUs between 3 and 20 km have increasing resiliency as the size increases. For example, a stream of 4 km has less resiliency than a stream of 19 km. To account for this difference in the model we assigned a fractional numerical value. To determine the fractional numerical value we used the following formula in the EXCEL model.

Numerical value of stream or AU=IF(Stream A>=20,1,(IF(Stream A <=3,3,(((1-((Stream A - 3)/17))*2)+1))))

Meaning that streams <3km scored a 3 and streams >20 km scored a 1. Those streams that ranged from 3 to 20 km received a score proportional to their length. For example, a stream that was 8.75 km long scored a 2.32 and a stream that was 16.8 km long scored a 1.38.

Table C-18. Ranking of stream length for chub populations

Numeric Value	Qualitative Value	Quantitative Description-Watered length of stream (km)	Qualitative Description
3	Low	0-2 km	Streams and/or complexes of this length may not contain sufficient flows and suitable habitat areas to support large numbers of chubs and have a higher risk of not having refuge areas for localized events.
1.1-2.9	Intermediate range	3-20 km	Streams and/or complexes with moderate amounts of watered length will likely be sufficient to support populations of chubs, These longer streams are more likely to have refuge areas for localized events.
1	High	> 20 km	Streams and/or complexes with the greatest amount of watered length are thought to have more robust flows, more suitable habitats for all life stages, and are therefore more likely to support a large population of chubs. Longer watered length are also at less risk from localized adverse events

Example

Table C-19. Boulder Creek Analysis Unit Total Watered Available to Chub in AU (km) (P=perennial and IP=interrupted perennial)

Streams Included	**Total Watered Available to Chub in AU (km)** (P and IP)	**Quantitative assessment of total watered length** (weight 40%)
Boulder Creek-above barrier	9	3
Wilder Creek	11	2
Stone Corral Canyon	3	3

Metric 2: Percentage of Perennial Watered Area in Stream

This metric evaluates our understanding of the higher value of perennial reaches to support chubs versus those reaches that are interrupted-perennial. Perennial reaches likely have the best conditions to support chub throughout the year because they likely support more complex habitats with areas for all life stages, likely have flows at a level that support better water quality throughout the available habitat area and maintain connectivity, and have larger overall habitat areas that can minimize the effects of overcrowding. Interrupted perennial reaches had longer dry reaches between the watered areas, thus reducing the value of interrupted perennial particularly during the summer dry period for the factors noted above.

We identified four categories of perennial flow described in Table C-20 below.

Table C-20. Ranking of Percentage of Perennial Watered Area

Numeric Value	**Qualitative Value**	**Quantitative Description- Percent of total watered area that is perennial**	**Qualitative Description**
4	Poor	<24%	Low % of perennial even in a large stream results in significantly less available habitat available
3	Fair	25-49%	Less than half of stream is perennial; medium and small length streams more affected by this level of perennial flow available
2	Good	50-74%	Majority of length is perennial; medium length streams more affected by this level of perennial flow available
1	Best	75-100%	Best possible status is entirely perennial regardless of stream length.

Example

Table C-21. Boulder Creek Analysis Unit Percentage of Watered Area that is Perennial in AU (P=perennial and IP=interrupted perennial)

Streams Included	**Total Watered Available to Chub in AU (km)** (P and IP)	**Amount Perennial in AU (km)** (does not include IP, dry, ephemeral)	**Percentage of Watered Area that is Perennial in AU** (does not include IP, dry, ephemeral)	**Quantitative assessment of percent perennial water** (Weight 40%)
Boulder Creek-above barrier	8.75	0.00	0	4
Wilder Creek	11.50	0.00	0	4
Stone Corral Canyon	2.80	2.80	100	1

Metric 3: Number of Perennial and Interrupted Perennial Watered Segments

This metric evaluates our understanding of the perennial and interrupted perennial watered segments within streams as a measure of water availability through connectivity within AUs. We assume that the more fragmented or segmented the perennial and interrupted perennial waters are within a stream reach, rather than a continuous stream reach, the less suitable conditions for chubs. This is because fragmentation of perennial and interrupted perennial reaches contributes to isolation and smaller individual sizes of habitat. These small areas contribute to poor water quality and crowding of fish during the most severe season (summer due to high heat and evaporation rates) where food resources may become limiting. Further, stressed fish more susceptible to diseases and parasites. We acknowledge that in some occupied streams, this is the current normal condition and chub are present in these streams. Our assumption is not that streams with many fragments of habitat cannot support chub, but that having more fragments reduces the ability of chub in these small segments to withstand deterministic and stochastic processes and reduces the likelihood of persistence over the long-term.

Using Google Earth as described above we counted the number of perennial and interrupted perennial watered segments in a stream. We identified four ranking levels described below in Table C-22.

Table C-22. Ranking of the Number of Perennial and Interrupted Perennial Watered Segments

Numeric Value	**Quantitative Value**	**Quantitative Description-Number of watered area fragments**	**Qualitative Description**

4	Poor	5 or more	Wetted area of stream has many reaches that are likely far apart and small, significantly reducing opportunity for movement
3	Fair	3-4	Wetted area of stream is divided into multiple reaches with reduced opportunity for movement between them
2	Good	2	Wetted area of stream is only in 2 reaches that has some opportunity for movement between them
1	Best	1	Entire wetted area of stream consists of one reach that has best opportunity for movement within the entire area

Example

Table C-23. Boulder Creek Analysis Unit Number of Segments in AU

Streams Included	**Number of Segments in AU** (P & IP)	**Quantitative assessment of # of segments** (weight 20%)
Boulder Creek-above barrier	3	3
Wilder Creek	4	3
Stone Corral Canyon	1	1

Condition Category Calculation Method

We used the following calculation to determine the score for each analysis unit for the water availability condition category. Remember that the three metrics carry different weights based on our determination of their importance to the quality of a stream for chubs: 40% each for total watered length and percentage perennial, and 20% for the number of segments in the stream. The formula using the three metric rankings is:

(Total watered available*0.4)+(Percent perennial*0.4)+(number of segments*0.2) = water availability score per analysis unit

Table C-24. Water availability score for Boulder Creek Analysis Unit

Streams Included	**Total Watered Available to Chub in AU (km)** (P and IP)	**Amount Perennial in AU (km)** (does not include IP,	**Percentage of Watered Area that is Perennial in AU**	**Number of Segments in AU** (P & IP)	Quantitative assessment of total watered length (weight 40%)	Quantitative assessment of percent perennial water (weight 40%)	Quantitative assessment of # of segments (weight 20%)	Current Condition
Boulder Creek-above barrier	8.75	0.00	0%	3	2.32	4	3	2.61
Wilder Creek	11.50	0.00	0%	4	2	4	3	3.29
Stone Corral Canyon	2.80	2.80	100%	1	3	1	1	0.48
TOTAL FOR ANALYSIS UNIT	**23.05**	**2.80**	**x**	**x**	**x**	**x**	**x**	**6.39**

Key Assumptions and Uncertainty:

While there is considerable literature on the role fragmentation of habitats plays in the persistence of viable populations in streams, there is much less on the determination of what is, and is not, enough habitat and how to determine that for a variety of stream situations. Our primary assumption for this condition category is that habitat with more perennial reaches and contiguous length (fewer fragments) provides more certainty of chub being able to maintain large populations that support genetic diversity and protect from stochastic processes than does the opposite set of conditions. We understand that this is at a gross scale and individual streams even of the same category of all metrics may support different populations.

As noted in our discussions for establishing the background for these metrics and their ranking, we are uncertain about the specific accuracy of these metrics in application because of the wide variety of in-stream conditions that combine to determine the quality and quantity of habitat available for the chubs. Our metrics provide an assessment based on measurable information on watered stream length and how it is segmented in the occupied portion of the streams. We are highly certain of what those measurements are, and less so about what they mean to the chubs. The highest uncertainty is in the actual ranking categories we used within each metric. The ranking systems, including the selection of stream length categories are the result of our examination of available information and expert judgment. We have documented our assumptions, uncertainties, and decisions in this document and in the supporting documents in Appendix E.

4.5 Weighting Condition Categories

As stated above some AUs have a single stream and some have multiple streams of varying lengths. Consequently, different streams within an AU contribute a different amount of support to the AU. To account for this inconsistency we weighted the ranking of each condition category per stream by the percent the stream contributes to the AU. For Individual AU s that only have one stream, the weighting factor is 1. The streams contribution weight was applied to each stream for each condition category. The stream contribution weight was multiplied by the overall quantitative assessment score. Table C-25 and 26 provides an example of this calculation for Boulder Creek Analysis Unit. The Percent of AU column is the stream contribution weight.

Calculation of percent of AU: Boulder Creek Analysis unit has 3 streams totaling 23 km, stream 1=8.75 km and stream 2=11.5 km, stream 3=2.8 km. The 8.75 km stream contributes 38%, the 11.5 km contributes 50%, and the 2.8 km contribute 12%.

Calculation of weighted stream score: Stream 1 overall quantitative assessment score =8, this is multiplied by the stream contribution weight, 0.1, for a score of 0.78.

As stated in the SSA Report, nonnatives and water availability are the primary risks impacting chubs now and in the future. Further, we stated that the chub population structure was a component of the condition of the stream or AU. However, we do not think these components have an equal impact to chubs. Based on the best professional judgment of species experts the

impacts from nonnatives are about 7 times greater than impacts from poor population structure and about 5 times greater than water availability, and impacts from water availability is about 2 times greater than impacts from poor chub population structure. To account for this varying level of impacts from the condition categories, the scores for nonnatives was weighted by about 7, the scores for water availability were weighted by about 2, and chub population structure was weighted by 1. Table C-25 and 26 provides an example of this calculation for Boulder Creek Analysis Unit.

Calculation of weighted impacts for water availability: (Weighted Stream Score) x (Nonnative Species Weighting of 7) = Current Nonnative Score

Example:

Table C-25. Weighting of percent contribution of streams to AU and weighting of nonnative species condition category score for Boulder Creek Analysis Unit

Stream Name	Nonnative Fish in the Stream	Stream Level Score	% of AU	Weighted Stream Score	Nonnative Species Weighting	Current Nonnative Score
Boulder Creek-above barrier	Crayfish, Fathead minnow	1	38	1.19	7	2.81
Wilder Creek	Crayfish	1	50	1.50	7	3.69
Stone Corral Canyon	none	0	12	0.22	7	0.00
TOTAL FOR ANALYSIS UNIT		**x**	**x**	**x**	**x**	**6.50**

Table C-26. Weighting of percent contribution of streams to AU and weighting of water availability condition category score for Boulder Creek Analysis Unit

Stream Name	Nonnative Fish in the Stream	Stream Level Score	% of AU	Weighted Stream Score	Water Availability Weighting	Current Water Availability Score
Boulder Creek-above barrier	Crayfish, Fathead minnow	3.13	38	1.19	2	2.61
Wilder Creek	Crayfish	3.00	50	1.50	2	3.29
Stone Corral Canyon	none	1.80	12	0.22	2	0.48
TOTAL FOR ANALYSIS UNIT		**x**	**x**	**x**	**x**	**6.39**

4.6 Analysis Unit Calculation

Table C-27. Calculation for the Boulder Creek Analysis Unit

Stream Name	Current Nonnative Species Score	Current Water Availability Score	Chub Abundance Score	Total Score
Boulder Creek-above barrier	2.81	2.61	1.52	6.94
Wilder Creek	3.69	3.29	1.50	8.48
Stone Corral Canyon	0.00	0.48	0.36	0.85
TOTAL FOR ANALYSIS UNIT	**x**	**x**	**x**	**16.27**

4.7 Ranking of Analysis Unit Score

To provide context for the final AU ranking scores we developed ranking categories. Four categories were identified based on the risk of extirpation - minor, low, moderate, and high extirpation risk. The extirpation risk is the likelihood that an AU will be extirpated based on the level of risk to the AU. For example, an AU with minor risks will have a 0-5% likelihood of being extirpated. For each risk threshold, we qualitatively defined the risk in terms of the condition categories used in the model- nonnatives, water availability, and chub population structure.

Table C-28. Ranking categories to assess AU risk of extirpation

Category	Nonnative	Water Availability	Chub abundance
Minor Risk Extirpation 0-5%	Nonnative species community level 0 or 1 Potential expansion of new nonnatives into AU is unlikely.	>10km perennial habitat mostly contiguous	Chubs are abundant or common, and survey data indicates a stable, reproducing population with successful recruitment.
Low Risk Extirpation 6-30%	Nonnative species community level 1 or 2 Not applicable for every stream within the AU because some streams may have chub and nonnative co-existence for a length of time.	>10 km perennial habitats some interrupted perennial sections, but mostly contiguous	Chubs are abundant or common, and survey data indicates a reproducing, although recruitment may be limited.
Moderate Risk Extirpation	Nonnative species community level 2 (but some streams could have a level 1).	<10km perennial habitat, but consists of interrupted	Chubs may be common, but survey data indicates that

31-60%	Some streams may have chub and nonnative co-existence for a length of time but recent survey information is showing an increase in nonnative abundance and/or distribution, to the point that further increases in nonnative or stochastic events places these populations much more at risk for extirpation	perennial reaches with disconnected pools	distribution, recruitment, and population demographics are diminished.
High Risk Extirpation >61%	Nonnative species community level 3 some individual streams within the AU may have level 2 (or lower). As the % of streams scoring a level 3 within the AU increases, as does the overall risk to the entire AU.	<3km perennial habitat, that may be continuous or consist of interrupted, perennial pools	Chubs are uncommon to rare with a limited distribution; survey data indicates a declining population with limited recruitment.

Table C-29. Scoring range for risk of extirpation categories

	AU Scoring Range	
Extirpation Risk	minimum	maximum
high	>36	
moderate	24	36
low	14	23
minor	0	13

5 Future Condition Projection

For projecting future condition we used the current condition information on AUs, and evaluated it against a set of future scenarios to assess resiliency over a specific time period. The same metrics used to assess the current conditions were used to assess future conditions for the resiliency analysis. We developed four scenarios to assess the resiliency of each AU at year 2046.

5.1 Changes to Nonnative Species

The future scenarios incorporate an increase in impacts from nonnatives to a percentage of streams. There are two factors to consider in projecting future impacts from nonnatives, the number (or percentage) of streams that could be invaded by nonnative species not currently present, and how much of a change in the nonnative community risk factor could result from that invasion. It is unlikely that all streams will suffer from increased impacts from nonnative species. It is more realistic that a percentage of streams will suffer from impacts. Using the best professional judgment of species experts, a percentages of streams potentially impacted from

nonnatives was estimated, based on minor, moderate and high impact levels from nonnatives. A minor impact from nonnatives was estimated to consist of 13% of the streams occupied by a chub species, moderate impacts was estimated at about 45%, and high impacts was estimated at 70%. Using the EXCEL Random function, 13% and 45% of the streams for each chub species was randomly selected for the increase in impacts from nonnatives. However, we first eliminated from consideration those streams with a nonnative community risk of 3, since they were already at maximum risk, even if another species came in, the risk level could not be increased to document the change. For headwater, 13% and 45% of the streams is 2 and 9 streams respectively, and for roundtail it is 4 and 14 streams, respectively. We did not analyze the high impact from nonnatives (the 70% of streams) because we did not think this was a realistic scenario. Impacts from nonnatives in the future scenarios are evaluated as an increase in the community level impacts from nonnatives across a percentage of streams.

5.2 Changes to Water Availability

Impacts due to reduction in water availability was assumed to occur throughout all streams because climate change is likely to impact all streams. Impacts from water availability in the future are based on progressively deceasing linear length of watered habitat. The quantitative decrease is based on Jaeger et al. (2014). During the spring and early monsoon seasons, flowing regions are projected to diminish between 4%, 8%, and 20% during 1988–2006 and 2046-2064 time periods, respectively. However, to account for the various projections of the severity of climate change on streams we established scenarios that project the various levels of severity of climate change. The future scenarios also capture conservation efforts.

5.3 Additional Conservation Measures

For the future scenarios, we also included the potential for additional conservation actions for securing a population (eliminating nonnative threats) or establishing a new population in an unoccupied stream. The number of attempted actions of either type is unknown; for our analysis we made an assumption that either four (for the high management level) or one action (for the low management level) per species would be successful. We identified two levels of conservation: a high management option and a low management option. The high management option projects that there will be 2 streams that are renovated or secured (eliminating nonnative threats) and another 2 streams where new populations will be established per species. The low management only projects one new population will be established. We assumed each would be successful. Using the EXCEL Random function, 2 streams for each chub species was randomly selected for renovation. However, we first eliminated occupied streams where barriers or other securing actions were not feasible or were already secure from the list of potential sites.

For the two reintroduction streams for each chub, we did not select real streams but identified the following set of conditions to represent a proxy stream similar to what would be considered in selecting a reintroduction site. We did randomly select drainage basins where the reintroduction sites would be implemented. Each site is considered an independent AU and not connected to any other occupied stream as in the current reintroduction sites..

- For headwater chub, the proxy would be 5 km long, entirely perennial with only one segment, no nonnatives, 100% positive survey, abundant population of chubs, and three size classes present.
- For roundtail chub, the proxy would be 10 km long, entirely perennial with only one segment, no nonnatives, 100% positive survey, abundant population of chubs, and three size classes present.

Our future scenarios attempt to capture a scenario in the year 2046 that projects a relatively positive outlook for chubs and a relatively negative outlook, and two intermittent scenarios.

Scenario	**Nonnative**		**Water Availability**	**Conservation**
	% of streams impacted by nonnatives	**Nonnative Community level increase**	**Decrease in stream length**	**Reintroduction, renovation, securing**
Low NN impact to a few stream, low water loss, high mngt	13%	1	-4%	High mgmt.
Moderate NN impact to a few stream, moderate water lass, high mngt	13%	2	-8%	High mngt
Moderate NN impact to a few stream, moderate water lass, low mngt	13%	2	-8%	Low mngt.
High NN to a high # of stream, high water loss, low mngt	45%	1	-20%	Low mngt.

6 Assessment of Condition Categories

The model was populated with the above scenario conditions to determine the future condition score per AU.

7 Weighting Condition Categories

Weighting calculations were the same as those under current condition in section 4.5.

8 Analysis Unit Calculations

Analysis Unit scoring calculations were the same as those under current condition in section 4.6.

9 Results

Results are presented in the SSA Report under Current Conditions and Viability

Appendix D
Literature Cited for the Species Status Assessment Report for the Headwater Chub and Lower Colorado River Basin Roundtail Chub Distinct Population Segment

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Appendix E
Supporting Documentation for Model Assessment of Headwater and Roundtail Chub

Introduction

This document contains the Service's documentation on the development and implementation of the Assessment Model for the headwater and roundtail chub Species Status Assessment (SSA).

Consideration of Earlier Status Assessments for Chubs

We recognize that this Assessment Model method is different than the method we used in the 12-month findings and subsequent annual status assessments for the Candidate Notice of Review (CNOR), (Service 2007, 2008, 2009, 2010a, b, 2011a, b, 2012a, b, and 2013a, b) for headwater and roundtail chubs (Service 2006, 2009, respectively), which relied extensively on the information in the Voeltz 2002 status assessment for the chubs prepared by Arizona Game and Fish Department (AGFD). Voeltz (2002) compiled and assessed the known information on chub historical and current occupancy, survey data, presence of nonnative fish species, and land and water uses that could affect chubs and their habitats. This Assessment Model builds on the process presented by Voeltz (2002).

Information and Sources

Where specific information on the chubs was available, primarily in their life history and habitat selection, we used this data. We note that while there may be some information specific to chubs, it is incomplete and we will have to rely on information pertaining to similiar fish species. In looking for other usable data, we first looked to other members of the genus *Gila* that are close relatives to headwater and roundtail. Beyond other *Gila*, we then looked at the *Salmonidae*, particularly the cutthroat trouts (*Oncorhynchus clarki* ssp.), as they share some habitat preferences and life history similarities and have overlapping ranges with some *Gila* species that could allow information obtained in research and monitoring to be applicable for the chubs. We also used general data regarding fish life history, ecology, and behavior. Where data is not specific to the chubs, we note the overall applicability in general, and we recognize that we are making the assumption that the information is applicable for our purposes in this SSA or the Assessment Model. However, this is the best available scientific and commercial data.

For information on fish communities and habitat for the chub population structure and potential for nonnative effects relevant to the Condition Categories we primarily used the following information:

- Results of research projects in the peer-reviewed literature;
- Results of research projects in graduate student Master's Theses or PhD Dissertations;
- Federal Agency funded research and monitoring reports (these can range from specific research projects to survey reports depending upon the intention of the project and the funding source);
- Federal Agency funded habitat improvement project reports that can include surveys or other information on native and nonnative fish populations;

- State game and fish agency reports on general or targeted fish community structure or assessments to improve habitat conditions (the latter may be targeted to sport fish or native fish)

For the chub population structure and nonnative condition categories, the primary source of information is the survey dataset, which included information from survey and monitoring reports as well as some research reports. AGFD conducted most of the surveys on Arizona streams used in this report and fully shared this information with us. For the Upper Gila River in New Mexico, we used the survey information from New Mexico Department of Game and Fish (NMDGF) developed for their Gila River monitoring program. We also examined survey data gathered during research and other monitoring efforts, as it was available.

For information on water availability relevant to the Condition Categories we primarily used the following information:

- Literature and discussions of the normal hydrological cycle of streamflows in Arizona and New Mexico.
- U.S. Geological Service stream gauge data;
- Arizona Department of Water Resources' surface water rights databases, groundwater wells databases, and the Arizona Water Atlas
- New Mexico same
- GIS layers describing perennial stream flow developed by Arizona Department of Environmental Quality and ADWR as well as other layers developed from these primary sources;
- Google Earth satellite imagery to assess the availability of water in occupied streams during designated times of the year.

There are several existing GIS layers documenting the categories of streams. These existing layers use different assumptions and definitions of what is considered perennial, what season is used to document flow in the stream, the resolution of the layers, and other factors that influence what is termed perennial.

Voeltz (2002) included an estimate of total stream length for occupied streams that was used in our 12-month findings to determine the historical and current stream length to assess the reduction in the range over time for each species. Jones et al. (2014, pp. 113-115) provided an estimate of the total length of the streams and the amount of that length considered to have perennial flow. This compilation also provided the amount and percent of the total of the perennial reach surveyed and the percent of the surveyed length that contained chub. To determine the historical and current stream length to assess the reduction in range Jones et al used perennial flows as historic and occupied lengths of the perennial flows as current.

Our examination of the existing GIS layers and information from Jones et al. (2014) indicated that the definition sets used in those efforts produced information on perennial status that did not meet our needs in most cases. This became evident in our using satellite imagery from Google Earth with the overlay of perennial status from The Nature Conservancy. The result of this is that we accepted the perennial status of some streams from the existing datasets where our

review showed that to be the case during our target period (May-June), and developed our own measurements for the remaining streams.

We compiled all of the stream data and survey data for each stream into an EXCEL spreadsheet. We refer to these as Stream Spreadsheet and Survey Spreadsheet and we reference these documents throughout this document. Within each of these spreadsheets are multiple worksheets containing data per stream. For example, the Survey Spreadsheet there are individual worksheets for each agency that surveyed that stream and for the Stream Spreadsheet there are multiple worksheets for the physical and biological components of the stream. We then summarized this information into a Master Stream Workbook.

Options for Assessment Model

The type and complexity of the assessment model that could be developed is entirely dependent on the available data and the quality of that data. With that level of data on headwater and roundtail chub populations and the uncertainties associated with it, the Service considered a complex model to assess the future status of each of the identified populations and project persistence over time was not appropriate.

Development of the Model

We built upon the previous status assessments for chubs conducted by the AGFD but developed specific condition categories to assess the current and future condition of populations or Analysis Units (AU), and developed metrics to standardize our evaluation of chub populations. This provides a transparent approach that relies on showing the data used, creating definitions for assignment to ranking values within the metric of the condition categories, and acknowledging our assumptions and uncertainties relative to the data and our assignments. The Service identified a core group of Service biologists to work on developing the SSA and the Assessment Model for chubs.

Our model is an analysis based on the data available and our understanding of that data. We understand there are limitations to the model due to the limitations in the data and the uncertainties associated with some of the data, and we do not claim this analytical tool provides highly certain predictive outcomes. Instead, it is designed to explicitly portray our understanding of the current and future condition of the two chub species given our assumptions and uncertainties about the risks factors that we think most influence the viability of these species. The assignment of ranking values reflects our best professional judgment on the applicability of available knowledge and information on the current and future condition of the species and the risk to the species to provide an explicit way to communicate our understanding.

Methods of Assessment: Condition Category

Condition Category: Chub Population Structure

Background

Fish populations vary in the number of individuals present (the size of the population) and the distribution of those individuals into size or age classes (the structure of the population). The size and structure of the chub population in a stream is an indicator of how the physical and biological components and history of changes in those components combine to support the chubs over time (Fausch 2010, pp. 199-202; Grossman and Sabo 2010, pp. 401-403). Since the physical and biological components are subject to changes on both short-term and longer-term scales, the size and structure of the chub population will change in response. This condition category focus on the general abundance, persistence, and recruitment of chubs in a stream and AU.

Assumptions and Uncertainties

Our key assumption is that the information available from surveys over time can be used to assess the quality of a particular stream for chubs. While this is true in the most abstract sense, the quality of the data available plays a significant role in the accuracy of the results. Regardless though, these are the only data available to assess chub populations across the range. We therefore devised this analysis to best utilize the best available data.

We acknowledge that the information and understanding that we have on chub population size and structure, and how the physical and biological components of the environment work to influence that size and structure is limited and thus contains uncertainties that can affect the confidence in the outcomes.

The information from the chub survey datasets varies in quantity and quality for each stream. Variables include:

- the purpose of the survey conducted (community overview, chub-specific, or other species-specific),
- effort expended on the survey (spanning ad hoc day visits to multi-year systematic study plans),
- the method of the survey (visual observation from the shoreline to multi-gear types),
- age of the survey (how long ago it was completed),
- gear selection (different capture techniques work better or worse for chubs or different sizes of chub),
- the amount of habitat surveyed,
- density of chub in that stream at that particular time (fewer chub present can equate to lower catches),

    - timing (which affects both the catchability and the presence of age/size classes), and
    - the type and detail of information recorded and presented in a report or database.

- *Type of survey conducted:* survey efforts vary from a one day visit with visual observations to complex and systematic study plans with statistical site selection with equipment selection to best obtain the desired data and multi-year repeated site visits. That is not to say that anything less than a systematic study does not provide useful data for the consideration of chub status; with limitations on time and staff, many surveys fall into the middle ground and contain the majority of the information available for the chubs. Further, where there is a systematic and repeatable effort ongoing over a number of years, the particulars of that effort may not be focused to adequately address the distribution and abundance of chub since these survey efforts may have focused on the community of fish in the stream and did not focus on chubs in particular. We examined and used data from all available surveys in our assessment from 1990 to 2015. We understand that because of this variance in the type of survey, there is the potential that the number of chub present in a stream could be underrepresented.

- *Survey methodology:* survey methodology varies among survey efforts. The type of equipment used in the survey has considerable influence on what sizes and species of fish are most likely to be captured. Different streams have different physical conditions that support the use of one technique over another (difficulty of access that limits equipment choices, physical habitats targeted for sampling are more or less adequately evaluated by different equipment and the susceptibility of different life stages to different types of equipment). Survey methods employed for the chub range from visual inspection of habitat from the land, use of small dip nets, snorkeling, various fish traps, and types of nets (gill nets, seines), and electroshocking. Electroshocking methods also vary from backpack units used in smaller systems to canoe or boat mounted ones for larger streams. Further, the catchability of chub in any system by any method is affected by the local physical conditions, the size of the chub, and behavioral factors (e.g., chubs may not enter a trap containing predatory nonnative fish). Makinster et al. (2013, p. 2) observed headwater chub and desert sucker outside of a hoop net containing green sunfish and suggested that the presence of the sunfish could reduce the capture of chub. In their nets, they took 168 green sunfish, 5 headwater chub, and 4 desert sucker. Equipment varies in the size of the chub likely to be captured (small individuals can swim out of some nets and traps), which affects information related to size distribution, as well as abundance data. We used data from all types of survey methodologies in our assessment. We understand that because of this variance in the type of gear used, there is the potential that the number of chub present in a stream could be underrepresented.

- *Area surveyed*: some surveys cover larger portions of the potentially occupied habitat area[1] than other survey efforts. Greater coverage (regardless of type or methodology) enhances knowledge of the distribution of chubs throughout the potentially occupied

[1] We are using the term potentially occupied reach to mean the extent of stream that could be occupied by chub. Generally this would be the entire watered area

reach. Logistical concerns limit most surveys to either random or selected sites that are either repeated over time or selected anew each year. Where surveys have not occurred, we do not know the status of chub in that portion of the potentially occupied habitat area. Some streams have more area surveyed than others and we can be more confident that the data is representative of chub status throughout the survey area. We understand that because of this variance in the amount of area surveyed, there is the potential that the number of chub present in a stream could be underrepresented.

- *Number of surveys over time*: the greater number of surveys in a stream provides a more robust dataset to show how chub populations have or have not changed over time. The chubs' survey database varies from 1 to upwards of 40 or more survey events for a stream. Surveys can be closely spaced or have gaps of several years between events. While most data from Arizona is compiled into one database, some older data may just list presence/absence or numbers of fish without additional context. While limiting, this older data provides a history of capture that can help us to evaluate the current conditions. Where a dataset goes back over 10 or 15 years, there may be indications of a change in abundance or size class over time that is informative to our analysis. For example, older surveys in lower West Clear Creek documented chub every survey. After smallmouth bass moved into the stream, the number of surveys documenting chub present decreased. In looking at the percent of positive versus negative over time, the larger number of earlier surveys with chub outweighs the fewer, more recent negative surveys within the surveyed area. Subsequently, the current status of chub may appear somewhat better than it is. Consequently, for abundance assessment we used the most recent survey data. In examining the datasets, we also looked to see if there might be a bias from using older surveys for presence since we do not have a full listing for negative surveys during those early years, only for positive ones. Our review of the older data indicated the low number of records and the likelihood of additional surveys occurring in those streams during the period was low. Therefore, we did not identify any bias or the bias is low. The catalog of more recent surveys (those initiated in the 1990s) does contain those with both positive and negative results. In addition, the 1990s saw the addition of comprehensive watershed surveys and ones focused on specific species. We understand that because of this variance in the number of surveys overtime, there is the potential that the number of chub present in a stream could be underrepresented.

- *Defining age or size classes*: the timing of surveys and the type of gear used affect the range of sizes captured. Further, there is no consistency in how size classes are defined or discussed in the surveys. The range includes surveys that delineate Age 0 and Age 1+; young-of-the-year, juvenile, sub-adult, and adult; juvenile and adult; "many" or "several" size classes, and no mention at all. The lengths that are used to define these "size classes" are generally not given. While generally, roundtail chub reach larger sizes than headwater chub, there are streams where adult roundtail chub may not reach the 200 mm plus range. We acknowledge that this situation may occur; however, where we do know that this is the maximum size achievable in those streams (based on survey data), we will examine the survey data and as appropriate assign the largest chubs to the adult size class. We understand that because of this variance in the ability to detect all size classes, there

is the potential that the recruitment of chub present in a stream could be underrepresented.

Data and Method

For this category and its metrics, the data on chub population structure is from field surveys in occupied chub streams. We used survey data from 1990 to 2015 because this is when survey data become more robust and survey efforts were concentrated on chubs and the community of fish present. We examined our own files, and then reviewed Jones et al. (2014) for citation of surveys we did not have. We also looked in Abarca and Weedman (1995), Girmandonk and Young (1996) and Voeltz (2002) for information on older surveys. Some of the survey records were cited in other reports but the actual survey record was not available. Where the document was not available, we used the records from the reports. We also used survey data from other agencies. For the Upper Gila River in New Mexico, we used the survey information from New Mexico Department of Game and Fish (NMDGF). We also used information from theses, dissertations and other research or monitoring projects since these documents often had useful information on chubs, other native fish, and nonnative species in the studied streams.

For Tribal streams, the post-1990 dataset for was limited; therefore, we used all available survey data regardless of year. Because of the dated survey information, our uncertainty on the current status of these streams is higher. However, we consider these areas occupied based on the best available data. There is one exception, based on recent information communicated by the White Mountain Apache Tribe to Jeremy Voeltz, Cedar Creek is extirpated and is not analyzed.

From the data presented in the survey reports we determined if chub were captured, if so how many, and their size if it was provided. All survey information was compiled by stream into a Survey Spreadsheet. We also included in the Survey Spreadsheets any reported information on other native or nonnative species present to provide a full picture of the fish community present. We tried to share all of these Survey Spreadsheets with our partners for their comments. Comments received were incorporated into the final versions. Where a new stream was documented, or new survey reports provided to us, that information was added to the Survey Spreadsheets.

As described above the information from the chub survey datasets varies in quantity and quality for each stream. This disparity is not just found in the oldest surveys where presence and abundance might be noted but little else (see Madsen 1935), but in more recent reports of day-trips or other short duration efforts that provide limited information on numbers or size classes. Further, the physical conditions during the survey may have reduced effectiveness or time spent gathering information in some locations. In addition, there is observer bias, albeit unintentional, in visual observation relating to abundance as well as sizes observed. This variation in quality and quantity in the dataset for each stream contributes to uncertainties.

The potential effect of these uncertainties on the resulting dataset varies among AUs. However, for most streams, the survey efforts were targeted to chub or the overall fish community, and thus had a reasonable chance to contact chubs. To limit the uncertainty associated with the sometimes limited information in older survey datasets, the age of the data, and its relevance to assessing the current status of the chub populations, we are limiting our use of the datasets to

information collected from 1990 to 2015. This encompasses most of the available survey information, and, in general, there is more relevant information contained in the survey reports. The older data has value in determining the first time chubs were recorded from a stream, but that is not necessary for our assessment.

We note that the mainstem Verde River below Tapco and above Horseshoe Lake (Verde River AU) and the upper Salt River (Upper Salt River AU) are large rivers and are inadequately surveyed for most species (including chubs). For the Upper Salt River, the decline of native fish including chubs has been documented due to the expansion of smallmouth bass and flathead catfish (Minckley 1973, p. 101; Voeltz 2002, p. 49) and the recent survey data is likely representative of chub populations. For the Verde River, we do not have such documentation; thus the Verde information could over or under-estimate the chub population measurements.

We identified three metrics to assess chub population structure; percent of positive surveys since 1990, general abundance reported by recent surveys, and the number of size classes of chub reported by surveys. The sections below provide more detail on these metrics and how they were established. The assumptions and uncertainties are also presented. In the model, equal weight is assigned to the three metrics.

Metric 1: Percentage of positive chub surveys conducted since 1990

Background

This metric provides some context to the potential for changes over time in chub and nonnative abundance reflected in other metrics. For example, if all the positive surveys were from early in the period of record, and more recent surveys had fewer or no detections even using gears and methods that could have detected them, that can be an indication of a change in abundance over time. Lower West Clear Creek is an example of this. In the 1990s, chub were found from Bullpen Campground downstream to near the confluence with the Verde River. A 2015 survey from the waterfall barrier toward Bullpen Campground found chub of all three size classes dominated the creek in the first 1.6 km below the waterfall but only adults were documented at 2.6 km below the waterfall where smallmouth bass numbers increased (Rinker et al. 2015, p. 2). No chub were taken after 3.2 km below the falls (Rinker et al. 2015, p. 10). Our focus for this metric is to gain an impression of the presence of chub in a particular stream over the known period of record (1990-2015) but recognizing that the survey data contains variability that creates uncertainty.

Assumptions and Uncertainties

We assume that the greater the number of surveys conducted over time, the greater the opportunity to contact chub if they are present in the system. However, the variables among survey efforts create uncertainties with this assumption as described above. The potential effect of these uncertainties on the resulting datasets varies among AUs based on their survey history. There is a bias in this metric where recently documented streams (those where chub were first

found after candidate status was established) have 100% positive surveys based on their first location survey and targeted surveys thereafter. In addition, for some streams, the data shows 100% positive surveys. Those streams may have more or fewer surveys than a stream with a 50% positive survey result. These biases could over or underestimate chub persistence.

Data and Method:

The data on chub population structure is from field surveys in occupied chub streams. We used survey data from 1990 to 2015 because this is when survey data become more robust and survey efforts were concentrated on chubs and the community of fish present.

The number of surveys conducted since 1990 were counted, as well as the number of surveys that were positive. The Service lead biologist reviewed and populated the survey data for each stream to provide for consistency of interpretation. Where data appeared to be presented twice (the same data under two different authors), we only counted this once. For more than one record in the same year for the same location, we included all surveys and all results.

Metric 2: General abundance of chubs reported by recent surveys

Background

The relative abundance of individual fish species that make up a stream community will vary by stream because each stream is different in its capacities to support those species. Every stream has a different community abundance of native species based on the amount of habitat available for each native fish that dictates the abundance of each fish species in the stream. Aravaipa Creek has limited pool habitat for roundtail chub (Stefferud and Reinthal 2005, p. 3) so the abundance of chub is lower than in upper West Clear Creek where pools are more abundant (Rinker 2010, p. 2).

With the addition of a nonnative fish community to a stream, the amount of habitat and resources used by the nonnatives changes the amount available to the native community, including chubs and affects the population size of chubs that can be supported by the stream. There is a certain amount of habitat overlap between the chubs and the suite of nonnative species present, as well as dietary overlap, particularly for invertebrates. The available habitat and other native and nonnative species in the stream influence the potential population size of chubs in that stream.

Assumptions and Uncertainties

We assume that chub survey reports containing indications (visual or by catch data) of chub abundance over the period of record can give a relative measure of the size of the chub population in the stream. Uncertainties associated with this assumption are the same ones regarding the quality of survey data, described above, since the same survey reports are used for this metric. In addition, the reporting methods of chub abundance vary among survey reports.

Some reports provide visual estimations with undefined terms relating to observed numbers (rare, few, uncommon, common, lots, many, and abundant), visual counts, capture data presented using undefined terms, and capture data with numbers of chub alone or with the other species captured also numbered and percentages of the catch provided. A stream may have survey data in one or more of these categories, which further complicates the analysis.

Finally, the data presented often included abundance information on other native and nonnative species present with the chubs. The abundance of any species in a stream is primarily governed by the suitability of the habitat to meet the life history needs of that species. For example, Aravaipa Creek in Arizona has limited suitable pool habitat and the potential size of the population of chub there is naturally going to be lower than in Fossil Creek where pools are much more abundant. In Aravaipa Creek, riffle-dwelling species have much more habitat available, and their populations can be correspondingly larger. In addition, size of the individuals of each species have a significant influence in the overall numbers present; at less than 100 mm adult size, longfin and specked dace can sustain much larger populations per unit of suitable habitat than the 200+ mm chubs. Where there are few to no native or nonnative species to compete for food and space such as in portions of Burro and Wilder Creeks, roundtail chub numerically dominate the fish fauna (Partridge 2012, pp. 3-4, Partridge 2014, pp. 2-3). The reason for the absence of the rest of the native community in these streams is unclear.

The above discussion indicates that there is no normal population size for chubs that can be used to assess an abundance level across streams. The conditions in the stream drive the numbers of chub and other species present. Adding individuals from nonnative species (including crayfish) to the community in a stream alters the native community dynamic in response to the specific nonnatives present and how they interact with the native community for food and habitat.

Data and Method

The data on chub population structure is from field surveys in occupied chub streams. We used survey data from 1990 to 2015 because this is when survey data become more robust and survey efforts were concentrated on chubs and the community of fish present.

We recognize that the differences of chub abundance between streams are the result of a complex interaction of habitat and fish community composition, including nonnative fish. However, we do not have stream-specific information on habitat quality or the abundance of nonnatives on all streams. We used the best available scientific and commercial information for this condition category metrics.

Survey reports vary in their description the amount of chub based on the survey methods. Visual observations can be numeric (presented as the number of fish counted or seen) or subjective (use of subjective categories such as abundant, common, uncommon or rare). Further, the report may not contain equal information on all species observed. Some visual observations are supported by a small amount of catch data; small handnets or other portable equipment. There are established survey protocols for visual data collection; these usually require snorkeling or other in-water counting of individual fish, but aside from Fossil Creek, little of the available data is from this type of survey. Surveys that use various gear types may also vary in specificity. A

survey report can provide a specific number of fish of each species captured, or a subjective amount (categories as used in visual observations). Again, the report may not contain equal information on all species observed.

and the ability of the observer to clearly see the entire observation area

These two types of information (numerical and subjective) require different approaches to assess them. The use of subjective terminology without specific definitions create inconsistency related to the linguistic uncertainty of these terms among the different observers. Definitions of what is considered "abundant" or "common" or "few" vary by individual and most often are not defined in the survey reports. For the categories of visual observations and capture data with undefined terms, we consistently applied these subjective values to the ranking categories.

Where there is numerical catch data presented, the percent of the total catch made up of chub can be used as an index of abundance within that stream. This becomes more uncertain if the gear used has a greater or lesser probability of capturing chubs of different size classes. For a number of recent chub surveys, capturing chubs has been an important focus, so this supports that the more recent information from targeted surveys may be better used to determine this metric. We understand that as the native apex predator, the numbers of chub in a stream will commonly be less than the other members of the community; the suckers and dace. Numerically, the small native dace can often dominate a stream and sucker abundance can be quite high. The "natural" pattern of individual species population abundance for the native fish community containing the chubs will vary by stream depending on the physical and biological conditions; essentially, there is no one "natural" standard to compare streams. For example, Aravaipa Creek is a high value stream for roundtail chub, yet, due to the limited amount of preferred habitat (pools), the population size in the stream is low. At the other end of the spectrum, some surveys in Burro and Wilder creeks report that roundtail chub is the numerically dominate fish and few species or individuals of other natives are present (Partridge 2012, pp. 3-4, 2014, pp. 2-3).

For both visual and numerical data, we reviewed the survey report in its entirety for information that provided clarity as to the findings of the observer. Where multiple recent records exist or there is a gradient of abundance within the surveyed areas, we examined all the information and other data from the reports that provided insight into the results. We then made a decision based on the information and our interpretation of it and assigned a ranking category. Generally, our decisions went to the middle range of the summed information unless there was significant information suggesting another path. For example, in a stream with an "abundant" reach and a "common" reach, the decision to assign one category ranking would seek the middle ground, which would class the entire reach as "common."

Additional complexity is present due to the potential for chub abundance to have changed over the 1990-2015 time period. While having a longer time period could be helpful in assessing if there was a trend in abundance, the differences in the survey methods over that period added additional variability in understanding what was actually present during that time record. Our intention is to document the current status of the chub populations, so we used the most recent data for a stream that gave us the best information on abundance, regardless of the category of

the data. Where there was more than one recent survey with and more than one category of data available, we assessed the combination of that data to derive our assignment.

We also had to consider the spatial distribution of surveys in a stream; some streams were consistent in where the majority of the surveys were performed and in other streams there was more than one survey area. Results (as based on survey type and category of data) needed to be considered for the sites, and then extrapolated across the entire stream. This was done using the data, and any discussions of abundance contained within the survey reports contributing the data.

Metric 3: Number of size classes of chubs present as reported in recent surveys.

Background

The presence of multiple size classes indicates that spawning is happening and young fish are surviving to grow into adults. The presence of more than one size class indicates that some level of recruitment over time is occurring although the amount of recruitment likely varies by year. Streams where multiple size classes are not routinely seen at the times of year they should be visible may be subject to elimination or severe reduction in the young-of-the-year and/or juvenile size classes. Those missing year classes can affect the long term presence of sufficient adults to maintain the population over time and not result in the loss of genetic variation from low population size. The life span for the chubs is approximately 5-10 years; to sustain a population there must be successful recruitment events within that life span. Missing smaller size classes over a period of years and a skewed dominance of large adult fish suggests that recruitment of young fish to adulthood is not happening regularly. Low overall population size is also indicative of limited recruitment.

We understand that moderately long-lived fish like the chub (with a 5-7 or 10 year life span) do not need to have a successful recruitment event every year to maintain their populations. There can be a number of years with small recruitment events, or even no recruitment as long as there are sufficient adults to spawn when conditions are appropriate to have a large recruitment event. Missing size classes over a number of years (when they could have been contacted by the survey) or a skewed dominance of large adults are indications of reduced recruitment events or success of young fish moving to adulthood (Bonar 2002, p. 1089). As discussed in Chapter 3, Life History, at least roundtail chub recruitment is influenced by high spring flows that may not happen every year, and a low level of annual recruitment with survivorship of some young fish to adulthood can keep the population from becoming extirpated. However, this situation does have a higher risk of loss of genetic diversity or the inability to respond after a stochastic event

Assumptions and Uncertainties

We assume that streams that consistently contain a range of size classes that documents spawning and successful survival of young fish through to adult size are more likely to have a higher potential for long-term persistence than a stream where the full range of size classes is not often documented.

The uncertainties in the survey data continue to be present for this metric in terms of detectability/catchability of chubs from the larval to adult life stage. In addition, the data presented in the survey reports was variable in terms of size classes identified. However, even in survey reports where only Age 0 and Age 1+ are the focus, the report may contain considerable information from observation or capture on the actual sizes of the chubs present (from general categories to measurements and length distribution figures). Reliable and repeatable information linking age to size for chubs is lacking; growth rates vary tremendously and change over time (becoming slower with age). Growth rates between streams and years within streams are also variable, so a chub of Age 1 in one instance may be 70 mm and 120 in another. Therefore, we used length (size) categories for this metric because length (size) categories are both visible and measurable and lack the bias of estimating the age of individual fish.

Data and Method

The data on chub population structure is from field surveys in occupied chub streams. We used survey data from 1990 to 2015 because this is when survey data become more robust and survey efforts were concentrated on chubs and the community of fish present.

We selected three size classes to represent the range of young/juvenile (<100 mm; Brouder et al. 2000, p. 11 back calculated size at Age 1 to be ~107 mm), sub-adult (100-200 mm; Brouder et al. 2000, p. 11 back calculated size as Age 2 to be ~ 176 mm), and adult (>200 mm) chubs. Because growth rates will differ over time and by stream individuals of different ages may not be in these size classes. For example, in some streams adult size might be reached at less than 200 mm (Bezzerides and Bestgen 2002, pp. 18, 21; Brouder et al. 2000, p. 13). Where adults can normally exceed 200 mm and individuals over that size are documented, the smallest size at maturation is not biasing the results. However, where there are no adults over 200 mm (data indicates that larger fish not generally present due to habitat limitations), we allowed for the adult size class to be documented if smaller classes were present. We considered the optimum condition was that all three size classes would be present during the period of record of the surveys, from 1990 to 2015. As with the abundance metric, the more recent survey data was more likely to contain information on size classes and we used the most recent survey data with size class information.

For some streams, the majority of the survey data included two age/size classes and gave no indication of what the size used to differentiate the two classes. Aravaipa Creek data is given as adult/juvenile not young-of-year, Eagle Creek does not include size of individuals captured, and the Upper Verde River data either does not mention size, or uses other size/young-of-the-year. For streams with little or no fish length data in the survey report, we examined other records that reported on captures and did provide this information. For example, the targeted efforts to obtain roundtail chub for a broodstock and stocking into the Blue River did record “young-of-the-year and several larger size classes, all less than 250 mm” (Clarkson et al. 2009, p. 7). There are 6 headwater chub streams and 14 roundtail chub streams where the existing survey data does not have any information on the sizes of chub captured. Seven of these are Tribal streams. For these streams, we assumed that at least two size classes were present; thus not assuming the best or worst case.

For this metric, we are not counting the number of individuals of the three size classes present, only that they were documented as being present in at least one survey in the period of record. For example, if survey data from a stream documented the presence of the 0-100 mm size class in 2003, the 101-200 mm size class in 2004 and 2010, and the >200 size class in 2003, 2004, and 2009, we considered all three size classes present for the assessment model. This method assists in addressing the uncertainties coming from survey data as included under Metric 1 by not requiring all size classes to be present in every survey report. This allows for consideration of size class presence over time since chubs have a life span that does not require large recruitment every year. However, missing year classes are a concern for long-term sustainability (Hilderbrand and Kershener 2000, p. 513; Cowley 2007, pp. 8, 11) of similarly age-spanned cutthroat trout and we think that having all three size classes present every year represents the best condition. Historically, chub populations did not have the additional stressors of nonnative species present influencing the success of recruitment in low and high recruitment years. With that influence operating, documentation of success even over the 5-8 year cycle allows for greater certainty.

Condition Category: Nonnative Species

Background

Based on the best available information the presence of nonnative aquatic species can adversely affect chub populations through predation on chub, competition for food and preferred habitats, and behavioral changes from harassment. Nonnative fish and crayfish species are well documented in the peer-reviewed and grey literature as having varying levels of adverse effects to populations of native fish species in Arizona and across the southwest. We recognize that the physical and biological conditions of the stream also influence the abundance of nonnative species just as they do chubs and other native species. For this condition category, we wanted to focus on the degree of potential effect of nonnative species on chubs, not on the site specific responses since those are so variable. We acknowledge that in doing this that the rankings represent the theoretical maximum level of effects possible. Chapter 5 of the SSA and the Cause and Effects Table in Appendix B summarize the impacts of nonnative aquatic species on native fish. This condition category focuses on the impact from nonnative aquatic species to chubs.

There are several streams where nonnatives and chubs co-exist, but the mechanisms for this are unclear. The combinations of physical and biological conditions that result in the co-occurrence of native and nonnative species are unknown. Further, the current conditions may not be maintained into the future, thus altering the relationship between the chubs and other native species to the nonnative species. We mention the other native species because nonnative interactions with native species may influence how that nonnative affects the chubs. Further, the community of nonnative species present may also influence the type and magnitude of effects on chubs. For example, the presence of abundant crayfish in a stream may influence the foraging behavior of smallmouth bass such that they prey less on native fish including chubs. For whatever reason, that result may not occur equally across streams. The known potential interactions from predation, competition for food and competition for preferred habitats (which

can also lead to harassment that alters behavior) are universal; however, how each plays out in a stream is locally determined.

The abundance of any potential predator is a factor as are their degree of piscivory, and the availability of preferred prey besides chubs. Persistence of chubs to date in occupied streams may represent conditions where predation of any size class is not at "worst-case" levels for that particular nonnative species. Why that is so may be the result of poor habitat conditions for that nonnative that do not allow expansion to abundance levels that have greater predation via numbers or other conditions. Some nonnatives have high enough predation rates that even at low numbers they are highly effective in reducing chub numbers. Further, local conditions may allow for what we see as long-term compatibility of chub with the existing suite of nonnatives due to continued persistence of the chub in the stream. We have also seen fairly rapid declines in chub populations following the introduction of a nonnative species (Minckley 1973. p. 101). The dynamics of the native-nonnative community are complex and subject to adjustments in successful persistence on both sides as the biological and physical conditions in that stream change. There may be physical settings where chub can be successful and maintain their population alongside nonnative species as well as those where chub become extirpated. Any changes to the dynamics of the relationship could alter chub or nonnative success.

Assumption and Uncertainties

For this condition category, we assume that the effects to headwater and roundtail chub from nonnative species are similar to that for other native fish. We base this on the overall literature and our compilation of the potential overlap in habitat and resource use between chubs and nonnative species. We understand that there are streams where chubs and nonnative species have co-occurred for decades under what must be suitable conditions. We do not know what specific changes to those conditions would result in a change in status.

Our uncertainties for this category are based in the complex interaction of physical conditions and biological conditions in a stream. The response of specific native and nonnative species lead to three general patterns of co-occurrence of chubs and nonnatives:

1. Chubs are currently maintaining large populations through regular recruitment in streams where nonnatives are present; or
2. Chubs are currently maintaining small populations through periodic recruitment in streams where nonnatives are present; or
3. Chubs are apparently have little successful at maintaining a population through recruitment in streams where nonnatives are present. These streams are maintaining individuals in the stream through limited recruitment in most years or from individuals moving into the stream from other occupied streams.

Data and Method

The data on nonnatives is from field surveys in occupied chub streams. We used survey data from 1990 to 2015 because this is when survey data become more robust and survey efforts were

concentrated on chubs and the community of fish present. For Tribal streams, again we used all available information.

Our first step was to determine which nonnative aquatic species were identified in the literature as having adverse effects to native fish (including chub) and which of those are present in chub streams. We focused on the overall literature evaluation of the effects and risks from specific nonnatives to chubs (and where there was no specific information, the effects and risks to other native fish species). This eliminated the nonnative aquatic species that are currently considered benign or of very low risk[2]. Our selection is based on the potential for effects from the nonnative aquatic species on chubs. We recognize that the actual effects from a particular nonnative species on chubs in any stream result from the complex interactions of physical and biological conditions in the stream. The nonnative species listed in the SSA are documented in the literature as of concern for native fish; the extent of that concern varies. We included citations for those species that are not normally considered as having effects to chubs in footnotes in the SSA.

Based on the considerations described above, the risk metric to rank each nonnative species should focus on degree of piscivory including the breadth of age classes that can be preyed on since it is the most well-known and supported data we have. Habitat overlap is also a factor; nonnative predators that are found in the preferred habitats for one or more of the chub age classes have a greater exposure to chub as potential prey than those that do not have habitat overlaps. The competition for the same habitat where the nonnatives are either more aggressive in commanding space, or are very abundant can have consequences of displacement from preferred habitats. These consequences include higher predation risk, loss of foraging opportunities, and increased energy expenditures. Ranking of the impacts from specific nonnatives was done by Service biologists familiar with chubs and nonnative species using standardized ranking categories.

Metric 1: Nonnative Community Level Effects to Chubs

Background

As discussed above, our first step was to determine which nonnative aquatic species were identified in the literature as having adverse effects to native fish (including chub). We then determined which of these nonnative species were present in each stream. However, this does not address the impact to chubs from the community of nonnatives present in a stream. The focus of this metric was to assess the level of impacts from the community of nonnative aquatic species within a stream and AU on chubs.

[2] These species include bluegill (*Lepomis macrochirus*), redear sunfish (*Lepomis microlophus*), and golden shiner (*Notemigonus crysoleucus*) where the available information did not support them as predators. Golden shiners might be a competitor.

Assumptions and Uncertainties

The effects of any nonnative species on chubs are influenced by a number of factors including the community of nonnatives present in a stream. The magnitude of that effect can extend from extirpation of the native fish to changes in its behavior. Again, we recognize that the potential and the actual level and type of impact from nonnative species on chubs will vary due to the physical and biological conditions in a particular stream. This metric does not attempt to incorporate that variability, as the extent is so great and the reasons for the variation within streams unknown.

Referring back to the three situations resulting from the interaction of chubs and nonnative species, there are many unknowns in how those situations develop and how long they remain in place. We do not understand the intricate balances in the situations where chub and nonnative species co-exist successfully.

In our development of the metrics for this category, we used the available information and our expert opinion to assess the potential for effects to chubs from nonnative species on both the individual and community levels. We acknowledge that the potential for adverse effects in each stream is not driven solely by the suite of nonnative species present but also by the specific conditions in each stream that influence the interactions. We also acknowledge that different native fish species have different responses to the nonnative community, and their response may not be the same as that for the chub to the same species. For the effects of nonnative species in specific streams, we acknowledge that our assessment does not incorporate the stream-specific relationships and thus may not reflect the actual potential for effects.

Data and Method

This metric derives from the previous evaluation that assessed each nonnative species individually for their effects to chubs. The abundance of the nonnative species in the stream was not considered in this metric because this data is not available for all streams. The available information on distribution of the river otter is not of high quality. We made the assumption that all streams in the Verde River drainage except those associated with the East Verde River contained river otters. There are no documented records for Louisiana river otter from East Clear Creek or the Tonto Creek drainage.

For this metric, Service biologists reviewed the community of nonnative species present in each stream and based on the specific nonnative species present and their knowledge of the potential consequences of that community on chubs, considered the synergistic effects of that community on chubs reproductive success, recruitment, and ultimately on long-term abundance. This enabled us to consider differences in the potential of long-term effects to chubs relative to the presence of a community of low impacting nonnatives compared to that where a community of high impacting nonnatives was present. For example, if black bullhead, green sunfish, and smallmouth bass are all present in a given stream, the information that resulted in the high impact rankings for these species indicates there is a greater potential probability that chubs will be in smaller numbers, have fewer recruitment events, and be less able to recover from the

effects of additional stressors than in streams with a community of lower ranking nonnatives like western mosquitofish and common carp.

We used three ranking classes, rather than four, for this metric because the information available supported the two extremes (large and small effects) but was not robust enough to differentiate two classes in the middle. As we noted earlier, there are streams where chubs and the nonnative community are co-existing successfully, so the presence of a particular community of nonnative species is not a definitive indicator of responses in the chub population. The local physical and biological conditions and other stochasticity are likely the primary drivers of this co-existence. We do not understand these complex interactions but acknowledge that the presence of nonnative species does not automatically result in significant adverse impacts to chub populations.

Condition Category: Water Availability

Background

Data on the physical components of habitat (the amount of preferred physical conditions such as pools and suitable temperatures and water quality) are limited for chubs. The best available data has some information on flows and physical conditions of habitat in the occupied streams, but this is not complete enough for us to use habitat quality as a metric. Thus, for this condition category, we are focusing on how much water is available in a stream as a surrogate for the amount of habitat available during the driest time of year with the understanding that stream length is not the main driver of habitat quality. This allows the model to compare streams across the range of the chubs for their potential to maintain a resilient population over time.

Fish need to have sufficient habitat of the appropriate types available throughout the year to enable successful completion of life history functions to function as resilient populations. Habitat includes the physical and biological components that create conditions for the chub to live and complete their life cycle in a particular stream. Water is the basic component of fish habitat. The quality and quantity of the habitat available in any stream across the year is determined by the physical and biological components of the stream. These components define the quantity and quality of the habitat available for each species found in the stream.

The extent of available habitat (as measured by stream length, width, or other measurements and as refined by the quality of habitat present to support the target species) is important to the long-term presence of fish populations through:

- Maintaining genetic diversity by supporting population levels of fish in the stream that meet at least the minimum genetically effective population size (N_e) through maintaining a suitably large census population size.
- Containing a sufficient amount of preferred habitat components (physical and biological) over the entire year for all age classes to allow for continuing recruitment to the adult population.

- Supporting areas of "refuge" for individuals in the event of adverse stochastic environmental effects (runoff after a wildfire, drought,) to avoid the affected area. These refuges allow survival of some part of the population to re-establish throughout the stream after the event has ended and the habitat has recovered.

The potential population size of chub in any stream is dependent upon the total amount of suitable habitat available. The size of any chub population in a specific stream is limited by the available habitat (which is partly a component of the watered area) present during the driest and most stressful time of the year. The amount of watered area and habitat available during the wettest time can contribute to larger spawning events, but sufficient habitat is needed to sustain those numbers at the driest times. In comparing two streams with similar physical and biological components that create habitat for a particular species, the stream with greater length containing those components would be able to support a larger population of the target species than a shorter stream with the same amount of those components. A shorter stream with more of the essential habitat components than a longer stream would be able to support a larger population of chubs than the longer stream.

Each occupied chub stream has its own combination of physical and biological components that create the current baseline level of habitat availability. For example, Aravaipa Creek has 44 km of watered area with natural flows. The stream channel is alluvial; deep sands with high groundwater that support surface flows largely consisting of shallow riffles (Stefferud and Reinthal 2005, p. 3). The deeper pools and runs sought by the roundtail chub are rare; however, there are scour pools along the canyon walls and behind irrigation diversions or other backwaters. In contrast, Boulder Creek also has natural flow but at a lower discharge than Aravaipa Creek. The stream channel is less alluvial and supports a string of large and small pools across its length and during the summer, watered connections between the pools may occur only immediately after a monsoon storm and not last beyond a few hours or a day. In Aravaipa Creek, the higher baseflow provides flows to maintain connection between the pools through riffles and runs. Both streams support roundtail chubs; however, the local conditions influence the size of those populations.

Streamflows that provide suitable water quality (dissolved oxygen, pH, temperature) throughout the stream provide more habitat than in areas with adverse water quality conditions (Lake 2000, p. 578; Lake 2003, p. 1165). Adverse water quality conditions can increase the mortality rate of chubs directly (through temperatures, pH, or low dissolved oxygen that reach lethal levels) or indirectly through sub-lethal levels that affect the available food base that may not be sufficient to meet the metabolic needs of the chub to maintain body condition (especially where a large number of fish [of the extant community of native and nonnative species] are confined into a limited habitat area such as an isolated pool) (Dallas 2008, pp. 395-397; Power 1984; Power 1987; Harvey and Stewart 1991; Magoulick 2000, p. 30).

Assumptions and Uncertainties

We assume that watered stream length during the driest time of year represents the minimum habitat available to chubs annually. There are uncertainties associated with this assumption, most importantly that it is not stream length that alone determines the amount of potentially

suitable habitat. We understand that water availability does not directly correlate to the presence of physical conditions that create habitat for chubs. Other biological factors come into play where the available habitat provides differing levels of suitability for each species (plants, invertebrates, and fish) that will also influence the size of the chub population through competition for resources. Habitat includes the physical and biological components that create conditions for the chub to live and complete their life cycle in a particular stream. However, water is the most basic component as without it, there is no habitat for fish.

Our assumption is based on the concept that the longer the stream length the more likely the population will survive a stream drying (Roberts et al. 2013, p. 1388) because it is more likely to have some stream reaches not affected by the loss of flow, and it is more likely to have sufficient habitat diversity in the stream to provide refugia for individuals to survive if some reaches become uninhabitable for some time period. While Roberts was examining stream reaches isolated by physical barriers and unable to connect at any time with other reaches, the concept of increased risk to persistence of fish (in that case, trout) tied to decreases in available stream length is applicable to the chubs.

We understand that the normal condition for desert streams varies between completely perennial and intermittent, and this is related to the availability of water for that stream. Many streams in Arizona are intermittent to some degree and while this is the natural condition for desert streams (Minckley and Marsh 2009, pp. 20-24), changes in flows due to human uses of surface and groundwater resources that supported the historical flows have altered those conditions (Minckley and Marsh 2009, pp. 29-46).

Our primary assumption for this condition category is that more habitat with more perennial reaches, more contiguous length (fewer fragments) and having connections to multiple streams in different watersheds provides more certainty of chub being able to maintain large populations that support genetic diversity and protect from stochastic processes than does the opposite set of conditions. We understand that this is at a gross scale and individual streams even of the same category of all metrics may support very different populations.

Data and Methods

For the water availability condition category, an understanding of stream hydrology and classification is needed. Streams in Arizona and New Mexico fall into three categories[3] based on the extent of flow: perennial, intermittent, and ephemeral. Surface flow is subject to a number of conditions within a stream including the amount runoff from the watershed, input from springs and groundwater to saturate the alluvium and allow for water to surface, geological features that bring sub-flow to the surface in an otherwise unsaturated alluvium, and the effects of surface water withdrawal and groundwater pumping from the alluvial aquifer. Along with the runoff from the watershed, the amount of surface diversion and groundwater pumping vary seasonally.

In Arizona, the driest period (or lowest rates of flow) is the post-spring runoff and pre-monsoon period (USGS gage data). This period leads into the monsoon period (which starts in late June

[3] As defined by USGS and Rosgen etc

and can run through September [ADWR: Central Highlands Water Atlas 2009, p.22]), which is characterized by brief but potentially intense thunderstorms that provide rain across the high and low elevations of Arizona and New Mexico. The vagaries of the monsoon are such that one stream may receive rainfall to augment flows and the adjacent drainage may receive nothing from the same storm. Normally, these additional flows runoff the landscape within a few hours and do not provide a long lasting respite from low flows. The monsoon period is important to the maintenance of flow in streams during the summer. Even with the monsoon providing additional flows to occupied streams, conditions of temperature and water quality are likely to increase when the full effects of summer temperatures and evaporation rates are realized in September.

The Arizona Department of Water Quality (ADWR) prepared a Water Atlas that compiled data on water resources in 7 planning areas across the state of Arizona. Each planning area has a differing component of streams that contain various amounts and permanency of flowing water. The Water Atlas volumes contain information on both surface and groundwater uses that can affect streamflow in occupied chub streams. These volumes contain information specific to issues of concern for the chubs relating to water availability and human uses. Chub streams are found across 4 of the 7 ADWR planning areas: the Central Highlands, Eastern Plateau, Southeastern Arizona, and Upper Colorado. In the Central Highlands (which includes the Salt and Verde Rivers), average annual rainfall is 16.8 inches with over 37% of that coming during the monsoon period; however, this precipitation is less hydrologically effective than winter precipitation because of greater evaporation rates and spatial discontinuity of the storms (ADWR/CHWA 2009, pp. 21-22). Temperatures in the Central Highlands have been warming over the last 70 years, which contribute to increasing evaporation (p. 21). In the Eastern Plateau (which includes the Little Colorado River) average annual rainfall is 36 inches with 43% falling in the monsoon (ADWR/EP, 2009, p. 12). The Southeast Arizona planning area (which includes Aravaipa Creek, Blue River, and Eagle Creek) has the most important contribution from the monsoon; of the average annual rainfall, 52% falls then. This is because this region is closest to the core monsoon region in northwestern Mexico (ADWR/SE 2009, pp. 19-21). The Upper Colorado (containing the Bill Williams River) has average annual rainfall is 10 inches with 32 % coming during the monsoon period (ADWR/UCWA, 2009, p. 16). Each of these planning areas has experienced wide variance in annual precipitation in the period 1930-2002 with droughts and wet periods alternating.

To obtain the watered stream lengths used in this analysis, we first looked for existing documentation of perennial streams[4] in Arizona and New Mexico. The Arizona Water Atlas (ADWR 2000s) shows perennial streams within Arizona. The Nature Conservancy (Turner and List 2007), also has mapped perennial streams across Arizona and that information is in GIS layers that fit over Google Earth imagery. Arizona Game and Fish Department also has a GIS based perennial stream layer they used in Jones et al. (2014, pp. 113-115) to show the amount of perennial stream length for chub streams.

[4] The USGS has established definitions for perennial, intermittent, and ephemeral streams that were used in the development of GIS layers for the efforts cited in this paragraph. In using this term in this part of the discussion, we are using it as defined by USGS.

We recognized that some streams identified as perennial in the GIS layers were, in May-June, perennial throughout their lengths and the entire length was available for occupancy by chubs. For these streams, we used the perennial length provided in Jones et al. (2014, p. 113-115). When we looked at the perennial stream information in the above sources, we realized there were issues of accuracy of determining perennial status within streams. For example, overlaying the TNC perennial stream layer in Google Earth showed a line along the stream course but looking at the underlying satellite imagery from Google Earth, dry portions of stream bed could be seen. We examined the GIS layers for the streams showing ADWR, TNC, and AGFD determinations of perennial flow and they did not overlap; thus there was no single database we could use to establish the extent of perennial flow. Also, using Google Earth we were able to measure those specific lengths of a stream that were occupied by chubs rather than the entire length. For example, the headwaters of Tonto Creek historically supported headwater chub but they are currently extirpated from there so was not included as available habitat (it is above a waterfall barrier), and there are two AUs in that stream that had to be defined for length.

By using the path feature in Google Earth[5] we could measure the length of stream and determine which parts of streams contained water during the May-June period, and how that water was distributed across the landscape. We used the most recent imagery date (as shown on the bottom of the screen) that provided the clearest view of the stream channel. Where riparian vegetation was abundant and the channel could not be seen, our best estimate was that this was a perennial reach. Paths were saved online as kmz files and retained on Google Earth for later access and transformation into GIS layers.

In our first examinations of streams using Google Earth imagery, was that while there were true "hydrologically perennial" streams occupied by chub, many "hydrologically perennial" streams actually had varying amounts of seasonal dryness that resulted in no surface flow between watered areas. The distance between watered areas varied within a stream depending on local conditions of subflow and overall dryness of the watershed. This information led us to our method to assess the amount of wetted habitat available that is discussed below.

For our Google Earth measurements, one person was selected to do the measurements, and he was responsible for the majority of them. That person set up the method of measuring and the treatment of wet and dry reaches within streams. With the documentation of dry areas in streams through the satellite imagery, we determined that we needed clear definitions for the terms we were using to categorize stream conditions. We used the terms: perennial, interrupted perennial and intermittent stream reaches. These definitions were not intended to replace the standard definitions of perennial, interrupted perennial and intermittent streams. Our stream classifications are based on a point in time estimate of surface water available during the driest period typically observed in southwest streams (May-June). We understand the range of surface flow changes depending on the season and climate change; therefore, we assume the observations were at the lowest or driest period for the year observed.

1. "Perennial" is where the water flow was continuous throughout the measured area or close to being continuous with only short dry stream reaches (<0.1 km) between watered

[5] The path feature is accessed through the Ruler on the toolbar. Selecting the "path" option one can mark a line along the stream course that provides a measurement of the length of that line.

areas. So, using the Google Earth measurement tool, the wetted stream area was measured and included dry patches that were <0.1 km in length.

2. "Interrupted perennial" is where the dry sections between watered areas were longer (0.1 and 0.4 km) than seen in the perennial stream reaches, thus there was more separation between wetted areas than in the perennial condition. A "rule of thumb" was applied that included in the measurement of watered area dry stream reaches as part of the watered area if they averaged between 0.1 and 0.4 km long. We did not physically measure all such dry areas: the single person doing the measurements developed his own visual estimation for this that he used throughout his work. The concept of the 0.1 to 0.4 km measurement was communicated to any other person doing a stream to assist in their efforts. As with the perennial category, the path measure was continuous along the measured reach and thus included both wet and dry areas. We assumed that while there was less actual water available within the measured length, that there was enough to consider interrupted perennial reaches as providing habitat benefits to support the overall chub population in the stream.

3. "Intermittent" is where the dry reaches between watered areas became longer than 0.5 km. In these reaches, the amount of actual watered area between the dry reaches was much less than the total measurement. We assumed that dry reaches of this size were too long to allow for any persistent summer connections between the pools present or opportunity for these wetted areas to significantly contribute to the size of the chub population. These isolated pools can be refugia for chubs that when connected to other areas, allow for repatriation after stochastic events. We did not measure or include intermittent reaches. We decided that while the watered areas in these intermittent reaches could support chub, we were unsure about their ability to allow for a full life cycle and contribute to the population.

Our implementation of the above measurement technique identified two conditions of watered area within streams; the first was the amount of watered area composed of perennial and interrupted perennial reaches, and second, that how those reaches were distributed across the length of the stream. As part of the method, if during the measurement of a stream a dry reach of over 0.5 km was detected, the measurement of the watered area was stopped at that point. A new path was created when a watered area that met the criteria for perennial or interrupted perennial was detected. This created a set of "segments" of watered area of either perennial or interrupted perennial status in the measurement record. Each of these segments also has a measured length, and it is the total of the length of these segments that add up to the total watered stream length used in the model.

We developed three metrics for this condition category that examine facets of water availability related to abundance and permanence of water, and its distribution across the stream.

Metric 1: Total Perennial and Interrupted Perennial Watered Stream Length

Background

There is limited research on what is the optimum or minimum stream length or habitat for chubs or for fish that overlap chubs. Where work has been done, it is largely on the interior cutthroat trout (*Oncorhynchus clarki ssp*.) (Harig et al. 2000a, b; Fausch et al. 2006; Williams et al. 2007; Peterson et al. 2013; and Roberts et al. 2013). We acknowledge that there are difference in the ecology of chubs and trout, and information on stream length gained in studies of the interior cutthroat trout subspecies may not reflect exactly what is needed by chub. However, this is the best available data we have.

Assumption and Uncertainties

The greater the amount of watered area in a stream (understanding the relationship between water and habitat quality), the higher the probability of persistence of chub populations over time.

We understand that stream length alone does not mean a chub population is secure. The presence of nonnative species in each stream has a profound influence on the status of chub in a stream or an AU comprised of several streams. For example, those units with large streams (such as the Verde River) have many times more than 20 km of potential habitat but if the nonnative risk is high, those results negate the value of having that extensive habitat area. However, this is the best available data.

Data and Method

As with the other condition categories and metrics, our first level of evaluation is on the individual stream level. This enables us to look at the individual conditions within each stream to gauge the robustness of each stream. Our metric for stream length is the total perennial and interrupted perennial watered area in the AU. After considerable discussion, we selected the following length categories. The selection was based in part on the data on occupied chub streams, cutthroat trout information available, and literature on the effects of small population size.

- 0-2 km: While streams of this length may support chubs, through having sufficient amounts of quality habitat, they may not contain enough habitats to be as resilient to stochastic or other types of events, when compared to streams of longer lengths. There are chub populations currently present in streams in this category. These are the lowest value streams to chubs.
- 3-20 km: Streams within this length range have increasing certainty of being able to support large populations of chubs. Greater length allows for a greater amount of suitable habitat to support chub and to have refuge areas for localized events. These are the moderate value streams to chubs.

- Streams over 20 km are likely to provide sufficient suitable habitat to support a large population. The length of the stream across the landscape also reduces the risk of a stochastic event affecting the entire stream with the unaffected areas able to act as refuge areas to re-populate the rest of the stream once habitats have recovered. In the event of long-term loss of that affected area, the remaining length should still be sufficient to support a resilient population over the long term. These are the highest value streams to chubs.

For our rankings, we assigned a numeric value of 1 for the lowest value streams (0-2 km), and a ranking of 3 for our highest value streams (> 20 km). For the moderate value streams (3-20 km), because that length is the transition between the extremes, and streams nearer to one or the other end points would be more likely to represent the stream conditions of that ranking, we elected to do a fractional ranking system that uses actual stream length.

Metric 2: Percentage of Perennial Watered Area in Stream

Background

Our metric for stream length is the total perennial and interrupted perennial watered area in the AU. In this metric, we compared the amount of that length that maintains perennial flows. We did not include interrupted perennial reaches. Interrupted perennial reaches had longer dry reaches between the watered areas within the reach. This reduces the value of interrupted perennial particularly during the summer dry period for the factors noted above.

Assumption and Uncertainties

We assume that the perennial reaches have the best conditions to support chub throughout the year because they likely support more complex habitats with areas for all life stages, likely have flows at a level that support better water quality throughout the available habitat area and maintain connectivity, and have larger overall habitat areas that can minimize the effects of overcrowding.

Data and Method

Streams determined to be completely perennial were first identified and grouped together. We then looked as all other streams and our dataset on the lengths of perennial and interrupted perennial segments. We added up the lengths of the perennial segments and divided by the total stream length to obtain the percentage of that total length that was perennial.

Metric 3: Number of Perennial and Interrupted Perennial Watered Segments

Background

We also looked at the number of perennial and interrupted perennial watered segments in a stream as a measure of water availability through connectivity. While there is considerable literature on the role fragmentation of habitats plays in the persistence of viable populations in streams, there is much less on the determination of what is, and is not, enough habitat and how to determine that for a variety of stream situations. Segmentation of perennial and interrupted perennial reaches contributes to isolation, and smaller individual sizes of habitat areas that contribute to poor water quality and crowding of fish during the most severe season (summer due to high heat and evaporation rates) where food resources may become limiting and stressed fish more susceptible to diseases and parasites. The lengths of the segments also influence their quality, as the longer the length, the more opportunity for sufficient habitat to support the chubs during the driest time of the year. Further, very small segments may be more prone to drying and poor water quality that put stress on fish.

Assumption and Uncertainties

We assume that the more fragmented the perennial and interrupted perennial waters are within a stream reach, rather than a continuous stream reach, the less suitable conditions for chubs. We acknowledge that in some occupied streams, this is the current normal condition and chub are present in these streams. Our assumption is not that streams with many fragments of habitat cannot support chub, but that having more fragments reduces the likelihood of persistence over the long-term and are less resilient.

There is we are uncertain about the specific accuracy of these metrics in application because of the wide variety of in-stream conditions that combine to determine the quality and quantity of habitat available for the chubs. Our metrics provide measurable information on watered stream length and how it is distributed in the occupied portion of the streams. We are highly certain of what those measurements are, and less so about what they mean to the chubs. We used the best available data and our best professional judgment to determine the ranking categories and recognize that there is uncertainty with these ranking categories.

Data and Method

We again looked at each stream that was not entirely perennial, as these were the ones that would have segments of perennial and interrupted perennial waters. The total number of such segments was counted for each stream.

Methods of Assessment: Climate Change

Climate Change in the Southwest

Background

In the SSA Report and the assessment model, we incorporated climate change impacts but recognize the uncertainties and clarify our assumptions regarding those uncertainties in our analysis. The literature for climate change in the southwest is summarized in Chapter 5 of the SSA. We incorporated the potential effects of climate change into the themes of the Cause and Effects tables in Appendix B. Here we provide additional information and background.

Assumptions and Uncertainties

Assumption 1: Increasing aridity across the southwest will lead to reduced streamflows that will lead to reductions in the amount (as described by our water availability metrics) and quality of wetted reaches in occupied chub streams. This reduction would differentially affect flows across the seasons of any year and across years.

Prolonged droughts (below-average rainfall) and wet periods (above-average rainfall) are common in the climate record of the Southwest (Sheppard *et al*. 2002, p.229), however, climate projections are suggesting even greater temperature extremes and aridity as a result of climate change (Coe *et al*. 2012, p. 1). In the southwest, future flows in the Colorado River (and three other southwest rivers) are projected to decline as a result of climate conditions (Garfin et al. 2014). Precipitation changes are less certain in these models, with areas being wetter, drier, or not changing.

Hoerling and Eischeid (2007, p. 35) examined 42 climate simulations for the Colorado River basin, and projected reductions in streamflow, show a 25 percent decline by 2030, and 45 percent by 2060. Christensen and Lettenmaier (2006, pp. 1423) applied changes in temperature and precipitation from 11 climate models and reported an 8 percent to 11 percent decrease in runoff by the 21st century across the entire basin. Seager *et al*. (2007, pp. 1181-1184) analyzed 19 different climate change models to determine how anthropogenic inputs will affect hydroclimate in the arid regions of the southwestern United States. A drying trend was projected in all but one of the 19 models. A series of model projections were also simulated and of the 49 projections, all but three predict intensified aridity in the Southwest as early as 2021-2040 (Seager *et al*. 2007, p. 1183).

In smaller dryland streams, surface flows are predominantly susceptible to slight changes in climate (Jaeger et al. 2014); such as, increased temperatures and evaporation, less snow, less persistent snow pack (Garfin et al. 2014), amount of precipitation, and seasonality of precipitation changes (Gori et al. 2014, and Christensen and Lettenmaier 2006). Even modest warming and reduced precipitation impacts the frequency and extent of dry streambeds and reduced hydrologic connectivity (Jaeger et al 2014). Also the changes in the temperature and

precipitation patterns results in smaller peak flows in the spring, earlier snowmelt, base flow and runoff, and lower summer flows (Ashfaq et al. 2013 and Gori et al. 2014). Winter precipitation falling as rain instead of snow, and earlier peak spring snowmelt is predicted along with hotter droughts (Garfin and Lenart, 2007, p. 16; Melillo *et al*. 2014, pp. 464-465). Changes in the amount or type of winter precipitation may reduce streamflow as snowpacks provide a source of runoff necessary to sustain spring and early summer baseflows in arid regions (Rahel and Olden 2008, p. 526). The overall reduction of the snowmelt recession period and lower flows extends and intensifies the summer low flow period which inevitably leads to higher water temperatures, reduced depth and velocity of available water; likely leading to pools interspersed and connected by shallow water habitats (Gori et al. 2014) in those streams currently considered fully perennial[6] and increased intermittency and dryness in those where we made measurements for stream reaches under our definitions for perennial and interrupted perennial status. Declining and diminished summer baseflows reduce instream habitat for fish and invertebrates, a primary food source for roundtail and headwater chubs.

Essentially, the entire range of the roundtail and headwater chubs in the lower Colorado River basin is predicted to be at risk of becoming more arid (Seager *et al*. 2007, pp. 1183–1184), which has severe implications to the integrity of aquatic and riparian ecosystems and the water that supports them. Perennial streams in the region may become intermittent and streams that are currently intermittent may become unsuitable or dry completely. Increased aridity is expected to have negative consequences on the flora and fauna, especially on those species dependent on water.

In our assumptions for the Water Availability Metrics, hydrologic connectivity was considered in the metric for total watered length and for the number of stream segments present in that watered length.

<u>Assumption 2</u>: Changes in air temperature as a consequence of climate change will alter existing evaporation rates for surface water and will lead to additional reductions in surface flow (including reduction in pool size and depth) and increase the water temperatures present in the remaining areas.

Stream temperatures vary spatially and temporally and are influenced by multiple natural factors including, groundwater inputs, snowmelt, substrate, riparian vegetation, and ambient air temperature (Johnson 2004, pp. 916-921). Stream temperatures are also influenced by the amount of water in the stream, as streams that transport large amounts of water resist heating and cooling, whereas temperatures change more readily in small streams (Poole et al. 2001, p. 3). As the climate warms, stream temperatures and evapotranspiration are expected to increase along with periods of low flow and stream drying (Rahel and Olden 2008, p. 526). Carveth *et al*. 2006, p. 1438, conducted thermal tolerance tests on 11 fish species native to Arizona, including roundtail chub and headwater chub, and seven nonnative fish species. Unexpectedly, native cyprinids were less tolerant to high temperatures than nonnative cyprinids and centrarchids, suggesting that increasing stream temperatures may favor those nonnative species with higher thermal tolerances. These effects from changing climatic conditions may have profound effects on the amount, permanency, and quality of habitat for roundtail and headwater chubs.

[6] Using the definition from USGS

Other water quality concerns associated with higher water temperatures include changes to ph and ability of the water to hold dissolved oxygen, both of which need to be within certain levels to support fish.

Assumption 3: The total population of chubs potentially supported in any stream is determined by the quality and quantity of the habitat available at the time of year when those resources are most limiting.

The May-June period is typically the driest time of year within the chubs range and therefore have the lowest baseflow. This is likely the most limiting factor affecting chub populations since the maximum carrying capacity at this time is most limited. Since baseflows are partially driven by runoff, reductions in size and quality of watered area during this time can be expected during those years when spring flow is reduced or otherwise altered by changes in precipitation type and timing of the runoff. This period is not the one with highest air or water temperatures, which comes in July-September.

As the summer progresses and the monsoon season begins in July, the increasing heat increases: water temperatures in the streams (mitigated in part by the amount of riparian shading), velocity and amount of the flow, and the temperature of the water coming from the alluvium or springs. For each stream, the likelihood of getting a short-term pulse of flow from rainfall events of the monsoon varies greatly. Monsoon storms can be small and localized on one portion of the watershed, or larger and affect a greater drainage area. The number of such storms that occur in each watershed in any year will vary.

In between monsoon events, the increase in air and water temperature is likely to reduce the extent of connected reaches (through the loss of shallower riffles or runs that connect the deeper pools) and the depth and extent of existing pools. Pools supported by the alluvial subflow would be less affected than those perched on bedrock with more limited sources of additional water. Where the sub-flow declines, the pools supported by it will also be affected and have less water and more issues with water quality.

Based on the above information in our Water Availability Metrics, we evaluated the available habitat based on the stream length during this driest time of year.

Assumption 4: We assume that all streams will receive equal impacts from climate change.

We recognize that in reality, all streams will respond differently to the effects of climate change on flows and the level of impacts from climate change on individual streams will vary. However, the best available information provides landscape level impact analysis and does not provide stream level impacts. Consequently, we assumed that climate change would affect streams equally at the landscape level. However, we recognized that there could be different levels of landscape level impacts.

Based on this information we analyzed three different reductions in stream length in our projected future Water Availability Metrics. In the discussion of the results for each AU in the

SSA Report, we discuss local factors that influence the actual potential for effects. This will include both physical and human uses of water in that AU.

Data and Method

We reviewed a number of climate change publications relevant to potential changes to water availability in the AUs for the chubs. As our first step, we first looked at the distribution of occupied AUs across the major watersheds.

For headwater chub, AUs were in four watersheds; the Upper Gila in New Mexico (Three Forks Complex and Turkey Creek); middle Gila in Arizona (San Carlos Complex); Salt River in Arizona (Upper Tonto Complex, Lower Tonto Complex, upper Gunn Creek); and Verde River (East Verde River Complex, Upper Fossil Creek, Upper West Clear Creek, and Wet Bottom Creek). For roundtail chub, AUs were in five watersheds; the Bill Williams River in Arizona (Boulder Creed Complex, Burro Creek Complex, Santa Maria Complex, and Trout Creek Complex); middle Gila River (Aravaipa Creek, Eagle Creek (both in Arizona), and Upper Gila in New Mexico; Little Colorado River (Chevelon Creek and Clear Creek Complex); Salt River (Salome Creek and Salt River Complex); and the Verde River (Upper Fossil Creek, Upper West Clear Creek, Confluence Reach Complex, and Verde River Complex).

The Verde River watershed has a recent publication addressing potential changes in flows (Jaeger et al. 2014). The upper Gila River in New Mexico also has recent information (Garfin et al. 2004, Gutzler 2013, 2014) on predictions for changes in stream flows. The Bill Williams, Little Colorado River, and Salt River do not have publications specific to them for climate change predictions.

The proximity of occupied chub streams in the Little Colorado, Salt, and middle Gila rivers to the Verde River enables us to consider that hydrological changes due to climate change are not likely to be significantly different across the region. Further, these three systems are subject to similar rainfall patterns across the year, including the summer monsoon period. We therefore propose to use the potential changes in flows we derived from Jaeger et al. 2014 for these drainages as well as for the Verde River.

The Bill Williams River watershed has the same summer and winter periods of precipitation (Klawon 2002, p. 7) as the Verde River, but has lower total annual precipitation than the Verde River or the other drainages that extend across Mogollon Rim. Normal annual precipitation for the lower portions of the Bill Williams River watershed experience 10-15 inches (250-325 mm) of annual precipitation and the uppermost portion centered on the Hualapai Mountains gets 15-20 inches (325- 500 cm). Because we have no climate change data for the Bill Williams River, we propose to extend the changes in flows derived from Jaeger et al. (2014) to this area.

The data from Jaeger et al. (2014) modeled potential network-wide declines in flowing portions of the Verde River network of a mean of 8% and maxiumum of 20% during the spring and early summer months, and 4% annually. The Service is using these network-wide projected declines and applying them to specific tributaries and mainstem portions of rivers within the occupied river basins for both chubs to simulate the effects of climate change in the Assessment Model.

It is important to articulate that the Service used the results from Jaeger et al. (2014) in the modeling exercise to denote reductions in specific tributary and mainstem perennial stream lengths due to climate change. The intent of Jaeger et al. (2014) was to quantify potential climate-induced shifts in stream drying and connectivity across a large river network; however, the Service's intent is to use this data on a much smaller scale, as indicated above. We understand the limitations of the data for this use, but have chosen to use this data to simulate climate change effects in our model because Jaeger et al.'s (2014) study area includes a large portion of the roundtail and headwater chub ranges. It is also important to note that we are not caveating the data itself, but our use of the data.

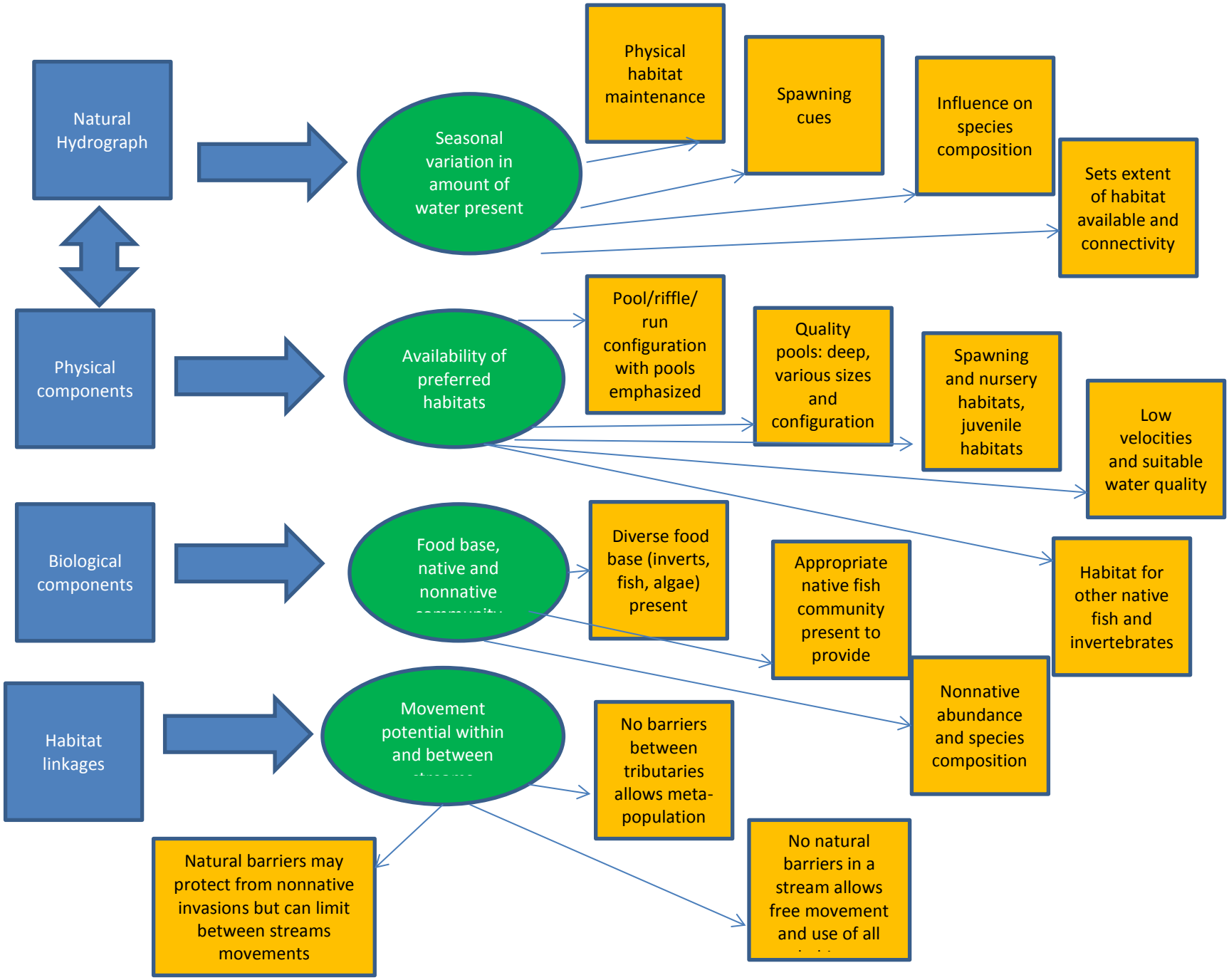
We propose to use three levels of change in flows for our Assessment Model; 4%, 8%, and 20% to represent the potential for changes in the future. We did not select a negative value, as the timing of the year when there would be increased flow was in the late summer and fall period, so did not reflect conditions during our May-June measurement period.

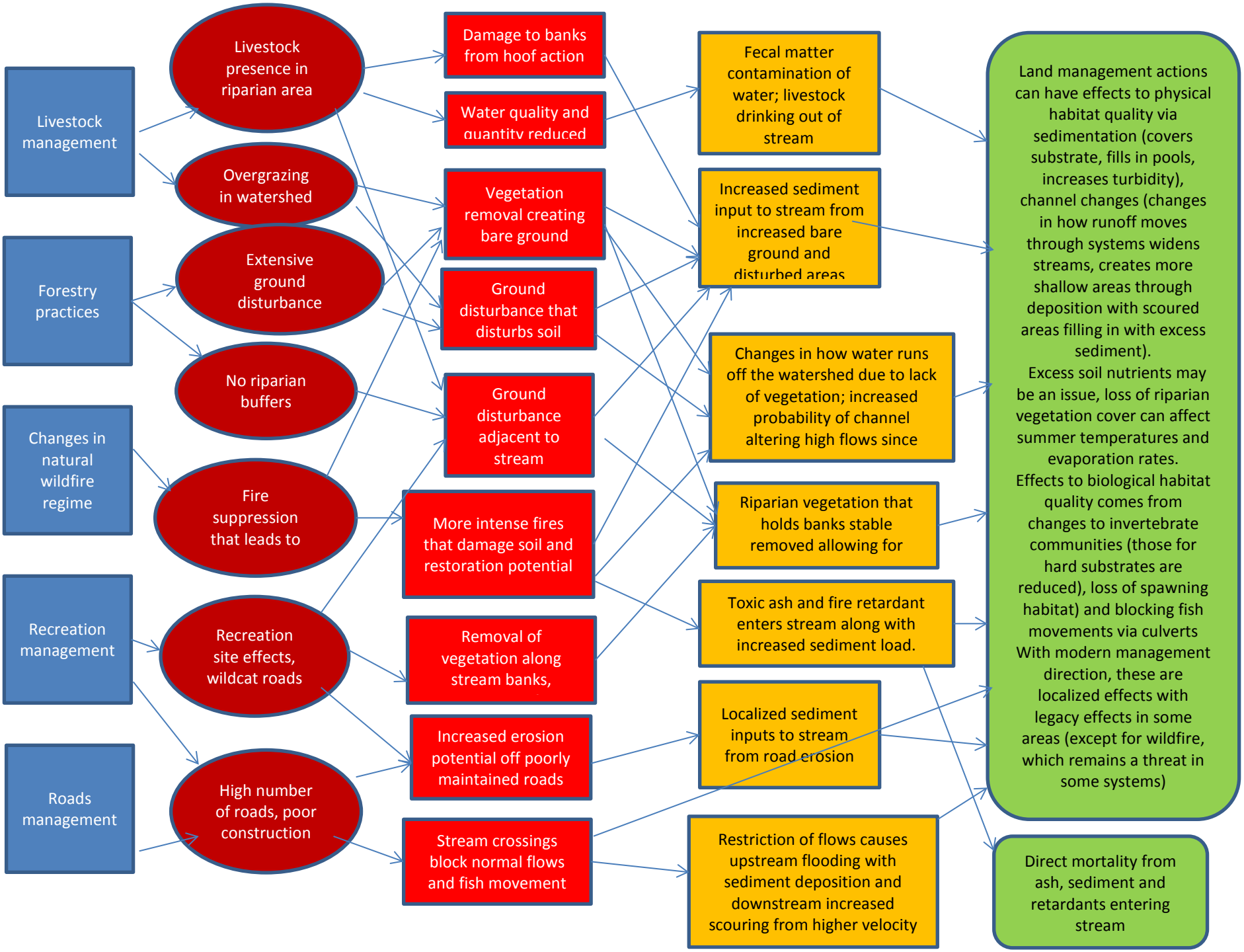
Uncertainties for using data from Jaeger et al. (2014) for climate change predictions in the Service's Assessment Model:

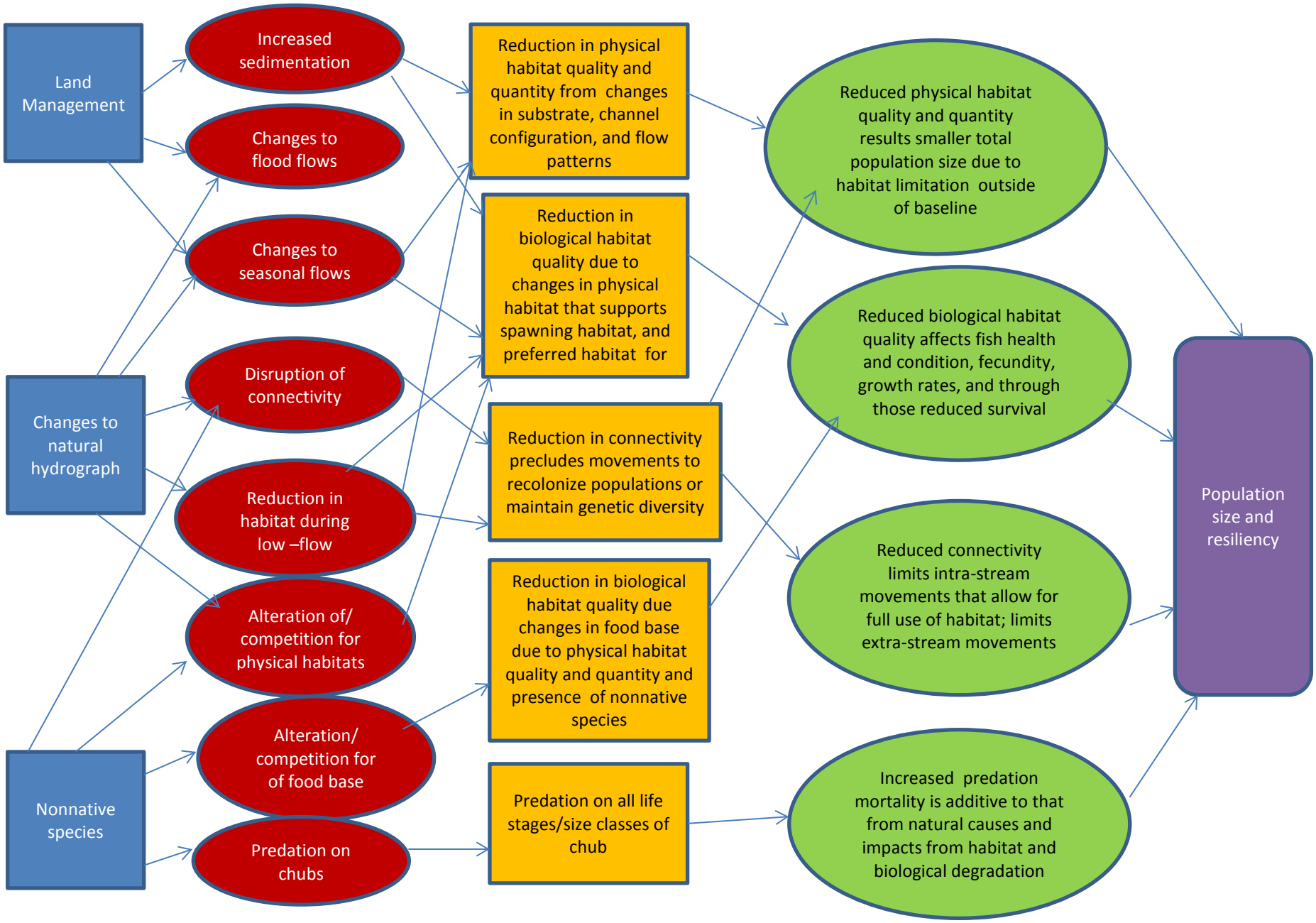
- The reported values are summarized for the entire Verde River network as a whole, not on a stream-by-stream analysis. The authors did this intentionally as this was a modeling exercise without field-validated data so they did not want to focus or put too much emphasis on output from a specific tributary. In addition, Fossil Creek, a perennial stream that contributes 45 cfs of surface flow to the Verde Watershed, was not included in the Soil Water Assessment Tool (SWAT) model used by Jaeger et al. (2014), so the surface inputs in the model likely underestimate perennial surface flow.
- The Verde, Salt, Little Colorado, Bill Williams, and Gila Rivers (the analysis areas in the SSA) are all very different watersheds. We are using information from a modeling exercise on the Verde watershed and extrapolating that data to the other watersheds. We acknowledge the inherent issues with extrapolating modeled data across such vastly different watersheds.
- The SWAT modeling exercise in the Verde Watershed is a generalization, as all modeling exercises are; Jaeger et al.'s work put some bounds on potential reductions in the surface water runoff-induced portion of streamflow on the Verde River, but the model does not include all inputs and outputs of flow in the Verde Watershed. Specifically, the model does not account for the groundwater discharge dominated flow regime in the Verde stream network; the model does not quantitatively address groundwater use in the watershed; and, the model does not address additional surface flow inputs resulting from ongoing land management activities that are expected to result in increased surface flow in the future (Robles et al. 2014; Wyatt et al. 2015).

Appendix F

Conceptual Model of Effects Pathways


Natural Hydrograph
Physical components
Biological components
Habitat linkages
Seasonal variation in amount of water present
Availability of preferred habitats
Food base, native and nonnative
Movement potential within and between
Physical habitat maintenance
Spawning cues
Influence on species composition
Sets extent of habitat available and connectivity
Pool/riffle/ run configuration with pools emphasized
Quality pools: deep, various sizes and configuration
Spawning and nursery habitats, juvenile habitats
Low velocities and suitable water quality
Diverse food base (inverts, fish, algae) present
Appropriate native fish community present to provide
Habitat for other native fish and invertebrates
Nonnative abundance and species composition
No barriers between tributaries allows meta-population
No natural barriers in a stream allows free movement and use of all
Natural barriers may protect from nonnative invasions but can limit between streams movements


Livestock management
Forestry practices
Changes in natural wildfire regime
Recreation management
Roads management
Livestock presence in riparian area
Overgrazing in watershed
Extensive ground disturbance
No riparian buffers
Fire suppression that leads to
Recreation site effects, wildcat roads
High number of roads, poor construction
Damage to banks from hoof action
Water quality and quantity reduced
Vegetation removal creating bare ground
Ground disturbance that disturbs soil
Ground disturbance adjacent to stream
More intense fires that damage soil and restoration potential
Removal of vegetation along stream banks,
Increased erosion potential off poorly maintained roads
Stream crossings block normal flows and fish movement
Fecal matter contamination of water; livestock drinking out of stream
Increased sediment input to stream from increased bare ground and disturbed areas
Changes in how water runs off the watershed due to lack of vegetation; increased probability of channel altering high flows since
Riparian vegetation that holds banks stable removed allowing for
Toxic ash and fire retardant enters stream along with increased sediment load.
Localized sediment inputs to stream from road erosion
Restriction of flows causes upstream flooding with sediment deposition and downstream increased scouring from higher velocity
Land management actions can have effects to physical habitat quality via sedimentation (covers substrate, fills in pools, increases turbidity), channel changes (changes in how runoff moves through systems widens streams, creates more shallow areas through deposition with scoured areas filling in with excess sediment).
Excess soil nutrients may be an issue, loss of riparian vegetation cover can affect summer temperatures and evaporation rates.
Effects to biological habitat quality comes from changes to invertebrate communities (those for hard substrates are reduced), loss of spawning habitat) and blocking fish movements via culverts
With modern management direction, these are localized effects with legacy effects in some areas (except for wildfire, which remains a threat in some systems)
Direct mortality from ash, sediment and retardants entering stream


Land Management
Changes to natural hydrograph
Nonnative species
Increased sedimentation
Changes to flood flows
Changes to seasonal flows
Disruption of connectivity
Reduction in habitat during low –flow
Alteration of/ competition for physical habitats
Alteration/ competition for of food base
Predation on chubs
Reduction in physical habitat quality and quantity from changes in substrate, channel configuration, and flow patterns
Reduction in biological habitat quality due to changes in physical habitat that supports spawning habitat, and preferred habitat for
Reduction in connectivity precludes movements to recolonize populations or maintain genetic diversity
Reduction in biological habitat quality due changes in food base due to physical habitat quality and quantity and presence of nonnative species
Predation on all life stages/size classes of chub
Reduced physical habitat quality and quantity results smaller total population size due to habitat limitation outside of baseline
Reduced biological habitat quality affects fish health and condition, fecundity, growth rates, and through those reduced survival
Reduced connectivity limits intra-stream movements that allow for full use of habitat; limits extra-stream movements
Increased predation mortality is additive to that from natural causes and impacts from habitat and biological degradation
Population size and resiliency