Report

In re Aravaipa Canyon Wilderness Area (W1-11-3342), in the General Adjudication of All Rights to Use Water in the Gila River System and Source, Ariz. Sup. Ct., Case Nos. W1-W4

Aravaipa Canyon Wilderness Area FRWR CLAIMS: Protection of Fish Resources

By Scott A. Bonar PhD. [1] and Norman Mercado-Silva PhD.[2]

[1] United States Geological Survey, Arizona Cooperative Fish and Wildlife Research Unit, University of Arizona. 104 Biosciences East, Tucson AZ 85721 (Email: sbonar@ag.arizona.edu).

[2] School of Natural Resources and the Environment, University of Arizona. 325 Biosciences East, Tucson AZ 8572 (Email: nmercado@u.arizona.edu).

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Summary

On request by the Environment and Natural Resources Division of the Department of Justice, in the adjudication of water rights in the case of *In re Aravaipa Canyon Wilderness Area (*W1-11-3342), in the *General Adjudication of All Rights to Use Water in the Gila River System and Source,* Ariz. Sup. Ct., Case Nos. W1-W4, we report hydrological requirements for native fish in Aravaipa Canyon, Arizona. The fisheries requirements were derived from existing literature, aided by the authors' experience studying fish communities in Arizona, Nevada, California, Eastern Washington, and Mexican deserts. We compiled numerous studies from peer-reviewed and "grey" (e.g., agency reports) literature to help determine habitat requirements for each native fish species in Aravaipa Creek throughout their ontology. Further, we analyzed existing literature to document effects of altered hydrographs on long term viability of fish communities. This information shows that fishes of the Aravaipa fish community use a variety of habitats in the creek and all parts of the natural hydrograph are important to various species and life stages. Unaltered flow conditions are especially important for desert fishes that have evolved under the natural hydrographs of desert streams. All native species require habitats and stream conditions that result from floods in early spring. These floods are key trigger events that 1) signal native species the start of their growing and reproductive seasons, 2) create habitat heterogeneity that favors the appearance of food resources and nesting habitats for these species, and 3) aid in providing the main channel with nutrients derived from inundated areas, that will be used by all components of the in-stream foodwebs, including native fishes. Maintenance of low flows during the dry season are key to the reproductive success of numerous native species, as most larval fish require 1) areas with low water velocities and fine sediments, 2) areas with warm temperatures relative to the rest of the channel in which to grow, 3) areas where algal growth provides them with food resources and coverage, and 4) cover from terrestrial and aquatic predators. The periodic flooding typical of desert streams during early spring and the monsoon season is important for displacing non-native fish predators and competitors and depressing their populations. Native fishes are adapted to flash flooding characteristic of desert streams. Those nonnative fishes typically stocked into Southwestern streams have been introduced from habitats outside the desert (e.g. lakes and backwaters of large river systems) that are characteristically more stable and do not experience the degree of flash flooding present in desert systems. Modifying the natural hydrograph will result in the disappearance of the flow conditions required by native species to survive in the long term. We conclude that long term viability of valuable native Aravaipa Creek fishes requires that the natural hydrograph is maintained unaltered.

Intact Riparian Areas are Critically Important for Arizona's Fish and Wildlife Populations and Economy

Riparian areas are critical for fish and wildlife of the desert Southwest. Only 0.4% of Arizona's total area consists of riparian areas (Zaimes 2007). However, 80% of vertebrates in Arizona spend some portion of their life cycle in riparian areas (Hubbard 1977), signifying their great importance to the state's fish and wildlife. Arizona's fish and wildlife are an important heritage of the state, their well-being contributes to the quality of life for the people of Arizona, and they are of considerable economic importance to the state as well. Annual expenditure in 2006 on wildlife watching, fishing and hunting in Arizona was estimated at $1.96 billion dollars (USFWS 2008). For comparison, this figure is greater than the revenue generated by all the state's livestock production in 2006 ($1.32 billion, USDA 2006), all the state's crop production in 2006 ($1.5 billion, USDA 2006), and 2007 Arizona spring baseball training ($0.3 billion, The Cactus League 2007).

Native desert fishes in Arizona are unique, most found nowhere else on the planet. Yet most of these fishes are highly imperiled. Of the 150 full species included in the fish fauna of the West (Lee et al. 1980, Lee et al. 1983), as of 1990, 122 taxa west of Rocky Mountains have disappeared, or were listed as threatened or endangered (Minckley and Douglas 1991). Although some of these taxa represent subspecies, not full species, the reduction in their numbers remains considerable.

The Native Fish Community of Aravaipa Creek is Recognized as Exceptional

Of few remaining riparian areas of Arizona, Aravaipa Creek and its fish community stands out as exceptional. Aravaipa Creek is one of the last remaining streams in the upper Sonoran Desert to sustain an intact diverse assemblage of native fishes (Eby et al. 2003, Turner and List 2007). The stream is often considered the best native fish habitat in Arizona (Bureau of Land Management 2013), and is extraordinarily popular with the public due to its distinct nature as an intact, preserved stream system. Because of its popularity, the Bureau of Land Management manages visitor use of the creek through a permit system. Because of the unique nature of the intact native fish community, the U.S. Bureau of Reclamation invested almost 2.7 million dollars on a fish barrier at the downstream end of the canyon, to protect the native fish community from intrusion from nonnative fishes (USBR 2001).

Natural Hydrology is Important for the Evolution and Maintenance of Desert Fish Communities

To sustain a natural desert fish community, such as that exists in Aravaipa Creek, maintenance of the natural hydrograph, to the extent possible, is critical. Native fish communities have evolved to live in the natural conditions present at a site. Specific species of desert spring fishes, such as pupfishes, topminnow and pool fishes have evolved to high temperature, low dissolved oxygen and often highly saline conditions in individual desert pools. Desert stream fish communities have evolved to hydrographs that contain adequate water base flows punctuated by flash floods. Fishes that live in desert rivers have evolved to live in warm turbid waters with high volumes, low visibility and huge flash floods. Below we discuss numerous studies showing specifically how maintaining natural conditions is important for the desert fishes of Aravaipa Canyon, and altering these conditions has had negative consequences for desert fish communities.

Peak flow, mean volume of flow, variability of flow, morphology of canyon-bound and broad alluvial reaches, dams, and introduced fishes are all either directly or indirectly related to the wellbeing of native fish assemblages in Southwestern rivers and streams (Rinne and Miller 2006, Propst et al. 2008, Gido et al. 2013). Habitat modification is known as a major factor threatening the majority of native species that can be found in Aravaipa Creek (Propst and Bestgen 1991, Rees et al. 2005, Arizona Game and Fish Department 2006, Turner and List 2007, Propst et al. 2008, Arizona Game and Fish Department 2002c). Habitat modification in rivers and streams is caused by water diversion, channelization, and degradation of riparian areas, among other factors (Rees et al. 2005, Turner and List 2007). Natural stream habitats are the result of a long hydrologic and geologic history. Fish assemblages have adapted to these habitats via long-duration evolutionary processes (Lytle and Poff 2004, Gido et al. 2013). Thus, the native fauna of a stream is adapted to, *and in need of*, the natural processes that allow their persistence. Any anthropogenic modification to the geology or hydrology of a stream and its basin will result in modifications to its native fish assemblage. Alterations to the chemical, physical or biological attributes of a river lead to changes in the structure, composition and behavior of biotic communities. These changes are reflected in a loss of biotic integrity in the river (Karr and Dudley 1981), and a loss of the "naturalness" of an ecosystem.

A natural hydrograph is key in maintaining a natural, unaltered, fish assemblage (Lytle and Poff 2004, Gido et al. 2013). A significant volume of literature has documented that non-native fishes take advantage of altered stream flows, hydrology, and temperature gradients to invade novel environments (Rees et al. 2005, Propst et al. 2008, Gido et al. 2013). Native species are more likely to benefit from free-flowing conditions, whereas human modified flows likely favor nonnative species (e.g., Minckley and Meffe 1987, Bunn and Arthington 2002, Schultz et al. 2003, Olden et al. 2006). For example, small-bodied nonnative species with opportunistic life-history strategies can benefit from unnaturally stable low flows during summer in the San Juan River, New Mexico and Utah, presumably because low flows are associated with stable spawning substrates and increased water temperature (Gido and Propst 2012). Reductions in hydrological variability (i.e., more consistent flows) favor non-native species (Eby et al. 2003, Schultz et al. 2003, Gido et al. 2013). Drought and long-term reductions in stream flow variability likely play critical roles in the persistence of nonnative fishes in systems with naturally variable flow regimes (Gido et al. 2013).

Natural and human-induced changes to flow regimes are major factors influencing abundance and recruitment of lotic organisms because they alter spawning habitat availability and quality, modify food resources, and constrain dispersal (Poff et al. 1997, Bunn and Arthington 2002, Gido and Propst 2012). Functional composition of stream communities is often influenced by flow attributes such as magnitude, predictability, and intermittency (Poff and Allan 1995, Bunn and Arthington 2002, Tedesco et al. 2008, Craven et al. 2010).

Intact Base Flows and Peak Flows are Both Important.

Both base flow, contributed chiefly by groundwater, and surface runoff, contributed by storm events and other factors, contributes to natural fluctuations in water levels essential for maintaining native desert stream fish communities. Natural regimes that include high peak flows are beneficial to fishes because they provide connectivity to floodplain habitats, clean spawning habitats of fine sediments, and stimulate ecosystem productivity (Junk et al. 1989, Poff et al. 1997, King et al. 2009, Gido et al. 2013). Large magnitude and long duration spring flows benefit recruitment of some native species adapted to naturally high discharge during spring (Gido et al. 2013). Many fishes native to the Southwest spawn on the ascending limb of the hydrograph in spring, when water temperature is relatively cool (Gido and Propst 1999, Brouder 2001, Kiernan et al. 2012). This allows larvae and juveniles access to off

channel habitats, increased abundance of clean spawning substrates and backwaters, or decreased risk of predation (Gido et al. 2013).

Natural hydrological regimes in Southwestern streams include periods of low flows that are also key for native species. After spawning in the ascending limb of the hydrograph, larval and juvenile fish require habitats where they can feed (usually on algal materials and macroinvertebrates) and grow. These habitats are usually found in relatively shallow, low velocity, warm water areas where algal mats and associated microfauna can develop. Once they have attained a certain body size, native fish can move to mid-channel habitats where they can find suitable cover and larger-sized food items. Furthermore, the base flow is fundamentally important for governing the amount of fish that can live in a stream. The base flow and available food determine the stream's carrying capacity, or weight of fish that the water body can support. Lowering the base flow of a stream lowers the number of fish that a stream can support. Because fish populations naturally fluctuate, low base flows in a year a fish population is in a downward trend can result in the extirpation of the fish due to high temperature effects, low food availability, interspecies competition or some other factor.

As mid-summer monsoonal rains arrive, spates occur in the hydrograph. These low duration high-flow conditions are beneficial to native fishes as they allow the appearance of new food resources in their habitats, and allow movement and dispersal to other areas of the creek.

Each flow condition is thus important for the completion of a fish species' life cycle. The long term viability of the population of a given species in desert streams depends on the existence of natural flow conditions throughout several generations.

Aravaipa Creek has maintained relatively intact and unique native fish assemblage thanks to its natural hydrological regime and, among other conservation efforts, to the installation in 2001 of a fish barrier that impedes non-native fish movement upstream into Aravaipa Creek (Bureau of Reclamation 1998; http://www.usbr.gov/lc/phoenix/biology/azfish/aravaipacreek.html). The existence of seasonal floods that are too intense for non-native species to withstand have also helped conserve a natural fish community (Eby et al. 2003, Turner and List 2007). A main reason that nonnative fishes have failed to dominate the creek is their apparent lack of resistance to high velocities, sediment loads, and other features of flooding in the canyon-bound system. Floods exceeding base flow by 10 or more times displace nonnative species, but have little apparent effect over natives (Meffe 1982, Meffe and Minckley 1987). Reduced flow stability and increased frequency of spates (e.g., a sudden increase in river flood) have negative effects on nonnative fishes (Gido et al. 2013). This can be explained because their spawning periods can be disrupted by flooding, and because their food sources can be diminished after such events (Bestgen et al. 2006). Nonetheless, periodic invasions have occurred in upper areas of Aravaipa (Minckley 1981, Stefferud and Reinthal 2005), but nonnative species disappear after a few seasons or years.

The Variety of Fishes in Aravaipa Creek Use Different Parts of the Natural Hydrograph Throughout Their Life History

The fish community in Aravaipa Creek has been studied since 1943 (Stefferud and Reinthal 2005) and there is a wealth of information about its composition, conservation and economic importance, and management (e.g., Eby et al. 2003, Weber and Berrens 2006, Turner and List 2007). The fish community of Aravaipa Creek includes 7 native species and at least 5 established nonnative species (Table 1) (Stefferud and Reinthal 2005). Aravaipa Creek has a perennial length of 36 km, 100% of which is occupied by the full complement of native species (Turner and List 2007). Up to nine nonnative species have been collected for Aravaipa Creek, but not all have established populations, and have only

been collected sporadically since 1943 (the first recorded sampling effort in the mainstem Aravaipa Creek) (Table 1). Nonnative species are restricted to the lowermost sections of Aravaipa Creek, preventing native species from facing well-documented negative interactions with nonnative species (Eby et al. 2003, Unmack and Fagan 2004). Five native species have probably been extirpated from the creek: Colorado pikeminnow *Ptychocheilus lucius*, razorback sucker *Xyrauchen texanus*, flannelmouth sucker *Catostomus latipinnis*, Gila topminnow *Poeciliopsis occidentalis*, and desert pupfish *Cyprinodon macularis* (Stefferud and Reinthal 2005).

Native fish in Aravaipa Creek each have specific habitat requirements. Each species has evolved to utilize different habitats in the stream, and different habitats are used differentially throughout a species' life history. Habitat selectivity arises from a species need to 1) locate food items necessary for their development, 2) locate areas that have adequate reproductive conditions, 3) evade predators or competitors, and 4) locate areas where water temperature and velocity for example, minimize their use of energy resources, among others. These needs are not mutually exclusive and all determine an individuals' location within a creek.

In Aravaipa Creek, *Rhinichthys cobitis* typically inhabit the fastest sections of the creek within riffles. *Rhinichthys osculus* and *Catostomus clarkii* also tend to inhabit relative fast flowing water, with the latter preferring deeper fast sections. *Meda fulgida* and *Agosia chrysogaster* are generally found in the tails of riffles, or in runs. Both *Gila robusta* and *Catostomus insignis* tend to predominately inhabit pools (P.J. Unmack, at www.peter.unmack.net, Accessed on June 11, 2013; Velasco 1997, Stefferud and Reinthal 2005). This general description of habitat use by native fishes sheds light on the diversity of habitats that exists in Aravaipa Creek (See Appendix 1 for details on the habitat attributes required by native species in Aravaipa Creek). This habitat diversity is the product of a combination of natural geological, biological and hydrological processes that continue to occur in the Aravaipa Creek basin. Any departure from these natural conditions will impose changes to the biotic communities that exist in the ecosystem.

Habitat preferences for fishes in Aravaipa are not static and change seasonally and throughout their ontology. Fishes in Aravaipa Creek exhibit a distinct pattern of seasonal movement (Siebert 1980). In this process fishes move into a canyon from broad valley reaches above and below and then return to valley reaches in winter. This pattern is probably the result of fishes moving in summer to avoid high water temperatures and possibly injurious intense solar radiation in broad, shallow valley reaches, and moving in winter to avoid the colder canyon reaches (Siebert 1980).

We provide specific habitat requirements by life stage for the fishes found in Aravaipa Canyon to show the importance of various parts of the hydrograph for different life stages and species in Appendix 1. This data emphasizes the variability in requirements of different species of the Aravaipa fish community.

Table 1. Fishes species of Aravaipa Creek, their origin (native to the creek or nonnative to the creek) and native species' designation under the U.S. Endangered Species Act (ESA status). Under ESA, "na" = not applicable for this report. Annotations for superscripts: ^{e} = species is established in Aravaipa Creek, ^{n} = species is not established in Aravaipa Creek, $^{?}$ = it is unknown if the species is established in Aravaipa Creek.

Scientific name	Common name	Origin	ESA
Agosia chrysogaster	longfin dace	Native	--
Catostomus clarkii	desert sucker	Native	--
Catostomus insignis	Sonora sucker	Native	--
Gila robusta	roundtail chub	Native	--
Meda fulgida	spikedace	Native	Threatened
Rhinichthys (= *Tiaroga*) *cobitis*	loach minnow	Native	Threatened
Rhinichthys osculus	speckled dace	Native	--
Cyprinella lutrensis^{e}	red shiner	Nonnative	na
Ameiurus natalis^{e}	yellow bullhead	Nonnative	na
Lepomis cyanellus^{e}	green sunfish	Nonnative	na
Pimephales promelas^{e}	fathead minnow	Nonnative	na
Gambusia affinis^{e}	central mosquitofish	Nonnative	na
Micropterus salmoides$^{?}$	largemouth bass	Nonnative	na
Ameiurus melas^{n}	black bullhead	Nonnative	na
Cyprinus carpio$^{?}$	common carp	Nonnative	na
Ictalurus punctatus^{n}	channel catfish	Nonnative	na

Altering Natural Hydrology has Resulted in Severe Consequences to Other Native Desert Fish Communities

Southwestern rivers have a long history of man-made modification. As a consequence of human modifications, ranges of almost all native desert fishes have diminished, and many species have been locally extirpated. We discuss examples below of how fish communities occurring in the major desert streams and rivers in Arizona have been affected when their hydrology has been altered from its natural state. In the concluding paragraph we cite several more studies of fish communities in other regions that have been negatively impacted when hydrographs have been altered. To date, the natural hydrograph of Aravaipa Creek has been affected considerably less than the streams and rivers we discuss below. However, negative effects or local extirpation of native fish communities, similar to those we discuss, is a likely outcome if the Aravaipa hydrograph is altered.

Gila River Fish Community

The Upper Gila River (a sub-basin of the Colorado River Basin) historically supported relatively few fish species, but many of these were endemics, occurring nowhere else on earth. The fish community in this river includes roundtail chub, Gila chub, headwater chub, spikedace and loach minnow, among others. Spikedace, as well as other endemics have seen their range reduced as a consequence of habitat changes and negative interactions with non-native species (Rinne 1991, Douglas et al. 1994, Paroz and Propst 2007). The reasons for the decline of the spikedace are in part intimately related to land and water use practices in the region (Propst et al. 1986). Diversion of water for irrigation caused the desiccation of some reaches and reduction of flows in others. Ground-water pumping lowered water tables, and caused the dewatering of many streams and reductions of flow in others (Hendrickson and Minckley 1984, Propst et al. 1986). Streams were channelized to accelerate water transport and, ostensibly, to reduce the effects of floods. Dams inundated many lotic habitats and altered the amplitude and periodicity of natural fluvial regimes (Propst et al. 1986). All these effects contributed to increased siltation in the habitats used by spikedace and other native fish, stream fragmentation that inhibited population contact, invasion by predatory nonnative fishes, and elimination of the hydrographic characteristics required for spikedace and other native fish reproduction. These conditions were especially severe in the lower Gila River, where the system is now ephemeral and flows only in response to precipitation events or water releases from upstream dams (AZDWR 2005).

Colorado River Fish Community

The Colorado River had one of the most unique fish communities in the world. Seventy-five percent of those species were found nowhere else on the planet. Settlement of the lower basin brought dramatic changes to both the river and its native fish. Those changes began more than 120 years ago as settlers began stocking nonnative fishes. By 1930, nonnative fish had spread throughout the lower basin and replaced native communities. However, the ability of native species to persist at any level was further impacted with the construction of Hoover Dam in 1935 and other large water development projects (Mueller and Marsh 2002) that diverted water from the river, and led to the loss of its natural hydrograph. The Colorado River, once a warm, turbid river subject to huge flash floods -conditions which favored native fishes – was altered into a river containing a series of reservoirs that regulated flow and water temperatures. Water all along the river was strictly allocated and diverted to supply human populations. The combination of nonnative fish introduction, hydrograph alterations and physical

habitat modifications led to the decline of native fishes such as the razorback sucker, bonytail, humpback chub, and the Colorado pikeminnow (Mueller and Marsh 2002, Osmundson et al. 2002).

Santa Cruz River Fish Community

The fish communities in the Santa Cruz river in southern Arizona have been affected by increasing water demands, altered streamflow regimes and the introduction of non-native species (Jackson Meyers 2010). While the river contains several stretches of natural and treated-effluent-supported river flow, many areas are desiccated. The Santa Cruz supports the endangered Gila topminnow and Gila chub, and also longfin dace, and desert and Sonora suckers. River fragmentation (due to groundwater pumping), introduced non-native species, and degraded water quality have led to declines for all native species (The Sonoran Institute 2010). Nonnative fish now dominate several areas of the Santa Cruz.

San Pedro River

The San Pedro River once contained a diverse native fish assemblage. Dewatering and other habitat alterations resulted in the demise of the spikedace, loachminnow, and most other native fishes (USFWS 1990a; 1990b)

Conclusion

Alterations to native freshwater fish communities or species due to hydrologic regime alterations are not exclusive to the Southwest. Numerous cases exist throughout the U.S. where damming, water extractions and deviations have negatively affected native fish and many times favored nonnative species. For example, hydrograph and habitat alterations have led to the decline of salmon runs and salmon populations in numerous California, Oregon, and Washington rivers (Raymond 1979, Quinn and Adams 1996, Kareiva et al. 2000), and declines in sturgeon populations in the midwestern U.S (Duke et al. 1999, Jacobson and Galat 2008). Any human derived departure from natural physical, chemical, and biological conditions in an aquatic ecosystem will have short and long term consequences to its native biota.

In summary, Aravaipa Creek is recognized as containing perhaps the best intact native fish community in Arizona. Fishes of Aravaipa Creek use all parts of the hydrograph for their varied life histories, including high spring flows, low base flows, and monsoon storm events. Flooding events in this canyon bound system are thought to have prevented dominance of nonnative fishes. Human alterations to natural hydrology have had severe consequences to most other native fish communities of Arizona. Protecting the health of the native fish community in Aravaipa Creek depends on preserving the natural hydrology of the system.

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Appendix 1. Habitat Requirements for Native Fish Species in Aravaipa Creek, Arizona

This section presents a species-specific account of habitat needs for native fishes in Aravaipa Creek. In creating this appendix we bring together existing literature on species habitat selectivity and requirements (peer reviewed and non-peer reviewed documents), field data, and literature on species' biology. In summary, loach minnow *Rhinichthys cobitis* typically inhabit the fastest sections of Aravaipa Creek within riffles. Speckled dace *Rhinichthys osculus* and desert sucker *Catostomus clarkii* also tend to inhabit relatively fast flowing water, with the latter preferring deeper fast sections. Spikedace *Meda fulgida* and longfin dace *Agosia chrysogaster* are generally found in the tails of riffles, or in runs. Both roundtail chub *Gila robusta* and Sonora sucker *Catostomus insignis* tend to predominately inhabit pools.

Agosia chrysogaster (longfin dace)

Longfin dace are considered habitat generalists and can be found over multiple depths, water velocities, and substrates, and have a relatively wide range of temperature tolerance (Bonar et al. 2010). Although longfin dace are known to prefer water of 20.0 cm in depth when spawning (Minckley and Barber 1971, Sublette et al. 1990), they are often found in deeper or shallower waters (Lewis 1978, Arizona Game and Fish Department 2006). Like other fishes, longfin dace may avoid deeper water when predators are present (Power 1987, Gelwick et al. 1997). In Aravaipa Creek, Arizona, Rinne (1992) found longfin dace occupying relatively shallow (12.0 – 22.0 cm) waters with water velocities of up to 40 $cm \cdot s^{-1}$ over pebble substrate. Longfin dace can swim against water velocities of up to 73.5 $cm \cdot s^{-1}$ (Ward et al. 2003). Minckley (1973) referred to longfin dace as the 'most successful, highly adaptable, cyprinid fish native to the deserts of the American Southwest'. However, their adaptability has not prevented their populations from declining throughout Arizona (Arizona Game and Fish Department 2006). In response to the onset of a flooding event, longfin dace will move directly into the margins of the current and move back into the channel as discharge declines: they are rarely caught in flood pools or backwaters (Minckley and Barber 1971, Rinne 1975). During low flows, they sometimes take refuge in moist detritus and algal mats until flow increases (Sublette et al. 1990). Longfin dace prefer gravel, sand, and pebble substrate, but can also be found among boulders (especially if finer substrates are found in the interstices of boulders (Barber and Minckley 1966, Lewis 1978, Meffee and Minckley 1987, Grimm 1988). Thus, suitable habitat for longfin dace includes water velocities between 0.0 - 30 $cm \cdot s^{-1}$, depths between 8.0 – 55.0 cm, and substrates from silt to cobble (Bonar et al. 2010). Longfin dace are generally found in water less than 24° C, but are tolerant of high temperatures and low dissolved oxygen (Arizona Game and Fish Department 2006).

Longfin dace spawn throughout the year but primarily in winter and spring from December to July, and perhaps until September or November, in low-desert habitats (Minckley and Barber 1971, Lewis 1978, Arizona Game and Fish Department 2006). During spawning, they excavate nests in shallow water 2-4 inches (5-20 cm) deep with a slight current and over sandy bottoms; eggs are buried by the spawning act (Arizona Game and Fish Department 2006). Larval longfin dace have a preference for areas with no-to-very low water velocities. Areas with abundant longfin dace larvae are usually encountered along streambanks, in shallow backwaters where dominant substrate is sand. They are especially abundant in areas where filamentous algal mats accumulate in the spring (Mercado-Silva et al., in preparation).

Species: *Agosia chrysogaster* (longfin dace)				
Life Stage:	Spawning	Larvae	Juvenile	Adult
Preferred Habitat	Shallow (5 -20 cm) areas in stream margins over sandy substrates, and low water velocities.	Sandy shorelines of streams in areas with no flow, but connected to the main stream. Commonly at depths < 13.5	Stream margins, in areas with sandy substrates, usually in shorelines, with very slow (0.0 – 15 cm/s) flow.	Areas with depth 8 – 55 cm, with low (0.0 to 30 cm/s) water velocities. Substrates: sand to pebbles. Can be found among boulders when fine sediments are found in the interstices.
Time of Year	Year round – but most common in December – July.	Early spring and throughout the summer, depending on timing of spawning.	Throughout the spring and summer, depending on time of spawning.	Year round
Water Velocity	Spawning will occur in areas where water velocities are slow.	Habitat for larvae in areas with very low water velocities	Areas with very slow (0.0 – 15 cm/s) flow.	0.0 – 30 cm/s

SRP16903

Catostomus clarkii (desert sucker)

In general, catostomids are benthic organisms, found in pools, slow runs or deep riffles of desert streams over gravel to boulder-sized substrate (Barber and Minckley 1966, Griffith and Tiersch 1989, Bonar et al. 2004). Both species of suckers reported for Aravaipa have similar habitat requirements. Adults desert sucker live in pools, moving at night to swift riffles and runs to feed (Arizona Game and Fish Department 2002a). Desert suckers occur at depths of 30 cm in water with a velocity of up to 25 $cm \cdot s^{-1}$ (Rinne 1992), but have been found in deeper pools with depths up to 45 (Bonar et al. 2010) and 65 cm (Fisher et al. 1981). Desert suckers can swim against water with velocities of up to 93.1 cm/s (Ward et al. 2003). They have been collected in waters with velocities of up to 38 cm/s, but most often 22-30 cm/s. Bonar et al. (2010) suggested a maximum suitable water velocity between 0.0 to 15.6 cm/s for desert suckers. Desert suckers feed by scraping stones using their cartilage-sheathed jaws. Some studies have indicated that desert suckers exhibit little seasonal movement and are resistant to downstream displacement despite floods (Arizona Game and Fish Department 2002a).

Desert suckers generally spawn in late winter and early spring where adults congregate in large numbers on riffles. Spawning usually occurs between March and May (Snyder and Muth 2004). Adhesive eggs are deposited in a shallow depression made in the gravel. Eggs hatch in a few days. Young tend to congregate along the banks in quiet water in tremendous numbers, then progressively move into the mainstream as they increase in size. Larval (12.8 – 20.1 mm TL) desert suckers have been collected in habitats 6.25 to 40 cm deep, predominantly in areas with sand to gravel, and water velocities between 0.0 to 13 cm/s (Mercado-Silva, in preparation). Juveniles are mature by their second year of life at a length of about 10.2-12.7 cm (TL) (Arizona Game and Fish Department 2002a). Juveniles occupy substrates with gravel to cobble in riffles, feeding primarily on chironomid larvae; however, adults are primarily herbivorous, scraping aufwuchs (diatoms and algae) from stones as well as ingesting plant detritus.

Desert suckers are thermally labile, but will usually select for temperatures between 13 and 22° C depending on the time of acclimation (Deacon et al. 1987). Bonar et al. (2010) found suitable temperatures for desert suckers between 14 and 19° C in Cherry Creek, Arizona.

Species: *Catostomus clarkii* (desert sucker)				
Life Stage:	Spawning	Larvae	Juvenile	Adult
Preferred Habitat	Adults congregate in riffle areas for spawning.	Larvae are found predominantly in areas with sand, but also occur in areas with boulders, cobble and gravel. At depths of up to 40 cm deep, but generally shallower than 15 cm.	They occupy riffles with gravel to cobble substrates.	They occur at depths of up to 65 cm, and water velocities of up to 38 cm/s, in areas with gravel to boulders. Can be found in pools adjacent to riffle areas.
Time of Year	Late Winter and early spring (March – May).	Late Spring to early summer.	Early summer – late summer	Year round, but congregate in riffles when spawning.
Water Velocity	Water velocities 20 – 30 cm/s	Usually in flows of 0.0 cm/s up to 13 cm/s.	Water velocity of up to 38 cm/s.	In flows 0.0 – 38 cm/s, but can resist flows of up to 93.1 cm/s.

SRP16905

Catostomus insignis (Sonora sucker)

Like desert suckers, Sonora suckers are benthic organisms and are commonly found in pools, slow runs or deep riffles of desert streams over gravel to boulder-sized substrate (Barber and Minckley 1966, Griffith and Tiersch 1989, Bonar et al. 2004). They have habitat requirements similar to those of desert suckers. Sonora suckers occur at depths of 30 cm in water with a velocity of up to 25 $cm \cdot s^{-1}$ (Rinne 1992). The highest water velocity they can swim against is 55.9 $cm \cdot s^{-1}$ (Ward et al. 2003). For Cherry Creek, Arizona, Bonar et al. (2010) suggested a maximum suitable water velocity of 50 $cm \cdot s^{-1}$ for Sonora suckers. Sonora suckers have an affinity for gravelly or rocky pools, or at least for relatively deep, quiet waters" (Minckley 1973). Adults tend to remain near cover in daylight, but move to runs and deeper riffles at night. Young live and utilize runs and quiet eddies (Minckley 1973). They are considered intolerant of lake conditions, although a few specimens were collected at Roosevelt Lake, Arizona, during netting and electrofishing surveys of the late 1980s (Arizona Game and Fish Department 2002c). The reason for this intolerance could be that sediments in lakes tend to be too fine (e.g., silt) and the species cannot find suitable food resources (e.g., crustaceans, ephemeropterans, protozoans, diatoms and algae (Minckley 1973, Clarkson and Minckley 1988).

The Sonora sucker is known to spawn in late winter through mid-summer (Sublette et al. 1990), generally in small streams or in riffles of larger streams (but see Minckley 1973). Eggs are deposited in riffles, fall into the interstices between gravels, and incubate (Reughard 1920 in Sublette et al. 1990). Importantly, Sonora suckers are a main component of the larval drift that occurs in the Gila River (Propst et al. 1987 cited in Sublette et al. 1990). Spawning does not appear to be correlated with any specific pattern of stream flow or temperature (Arizona Game and Fish Department 2002c). Young tend to congregate in great numbers along the margins of streams (Minckley 1973) and can also live and utilize runs and quit eddies (Arizona Game and Fish Department 2002c). Larval Sonora suckers (total length = 7 - 26 mm) have been found occupying shoreline areas with water velocity = 0.0 cm/s at depths < 13.75 cm (Mercado-Silva, in preparation).

Sonora suckers are tolerant of temperatures as low as 10°C, and up to 30°C for short periods (Rinne et al. 2001). Bonar et al. (2010) documented that Sonora suckers inhabit waters between 20 and 28° C, in Cherry Creek, AZ. Sonora suckers are tolerant of much higher temperatures than desert suckers found in that system.

Species: *Catostomus insignis* (Sonora sucker)				
Life Stage:	Spawning	Larvae	Juvenile	Adult
Preferred Habitat	Small streams or riffle areas in larger streams. Can also spawn in lentic habitats.	Found in sand to cobble substrates in shallow areas in the edge of streams	Pools, slow runs or deep riffles over sand to boulder size substrate.	Pools, slow runs or deep riffles over sand to boulder size substrate. Preferred habitats are in areas 13 – 60 cm deep, with water velocities 3.1 to 26.8 cm/s, but the species can occur in areas with slower/faster water velocities and in deeper pools.
Time of Year	Late winter through mid-summer.	Early spring to mid summer.	Early spring to mid/late summer.	Adults occupy these habitats year round.
Water Velocity	Water velocities from 0.0 cm/s to over 50 cm/s.	Found in areas with water velocity 0.0 – 13 cm/s	In areas with water velocities 0.0 - > 50 cm/s.	Maximum suitable water velocity of 50 cm/s, but usually found in slower areas and pools with no measureable flow.

SRP16907

Gila robusta (roundtail chub)

Roundtail chub are often found in stream reaches that have a complexity of pool and riffle habitats (Bezzerides and Bestgen 2002). Juveniles and adults are typically found in relatively deep, low-velocity habitats that are often associated with woody debris or other types of cover (Vanicek and Kramer 1969, McAda et al. 1980, Miller et al. 1995, Beyers et al. 2001, Bezzerides and Bestgen 2002). Sigler and Sigler (1996) reported that substrate in roundtail chub habitat may range from rock and gravel to silt and sand. Roundtail chub have been collected from depths from 20 to 200 cm over generally coarse substrates (e.g., cobble, pebbles, boulders), but occasionally over sand and gravel (Barber and Minckley 1966, Griffith and Tiersch 1989, Sublette et al. 1990, Rinne 1992, Barrett and Maughan 1995, Brouder et al. 2006). They select for relatively swift waters but also require calm deep pools, and have been collected at water velocities of 0.0 – 96 cm/s (Griffith and Tiersch 1989, Barrett and Maughan 1995). In Cherry Creek, AZ, Bonar et al. (2010) found them in pools adjacent to riffle or run areas and estimated their suitable velocity maximum at 30 cm/s. Beyers et al. (2001) documented a significant difference in localized diel movement patterns for roundtail chub with adults moving from shallow habitat at night to deeper habitat during the day (Rees et al. 2005). Temperature tolerance of roundtail chub has been reported up to 39°C (Deacon et al. 1987), but preferred temperature is between 22°C and 24°C (Weitzel 2002). However, Bonar et al. (2010) found them occupying sites with lower temperatures (14-22°C).

Roundtail chub in the Upper Colorado River Basin begin spawning when water temperatures reach about 18.3 °C (64.9 °C) (Vanicek and Kramer 1969, Joseph et al. 1977). In most Colorado River tributaries this increase in temperature coincides with a decrease in discharge after peak runoff (Bezzerides and Bestgen 2002). Spawning in the Yampa River at Dinosaur National Monument, CO, occurs between mid-May and early July. The time of spawning in other drainages and locations is probably similar and can go into the summer but is influenced by water temperature and the hydrograph (Kaeding et al. 1990, Moyle 2002, Rees et al. 2005, Carman 2006). Roundtail chub may or may not carry out upstream or downstream migrations close to the time for spawning; spawning related movement may depend on location and population, and may range from minimal localized movements to movement of more than 30 km (Rees et al. 2005). Eggs are potentially deposited near eddies or shallow pools with boulder or cobble substrate (Rees et al. 2005). Larvae have been reported in low velocity areas associated with backwater habitats (Haines and Tyus 1990, Ruppert et al. 1993); however, there has been no specific study to determine the importance or necessity of this habitat to larvae (Rees et al. 2005). Carter et al. (1986) suggested that roundtail chub actively drift during the mesolarval stage of development in the Upper Colorado River. Drifting occurs primarily after mid-July and appears to become more frequent as water temperatures initially increase. It was not determined whether the increase in drift was related to an increase in activity or an actual increase in larval abundance (Rees et al. 2005).

Species: *Gila robusta* (roundtail chub)				
Life Stage:	Spawning	Larvae	Juvenile	Adult
Preferred Habitat	At spawning, they prefer eddies or shallow pools with boulder or cobble substrate.	Low velocity areas associated with backwater habitats. Substrates in these areas are generally fine (e.g., sand)	They inhabit pool and riffle habitats that are often associated with woody debris or other types of cover. Depth between 20 to 200 cm.	They inhabit pool and riffle habitats that are often associated with woody debris or other types of cover. Depth between 20 to 200 cm.
Time of Year	Mid May to early July	June - August	Year Round	Year round
Water Velocity	0.0 to ~30 cm/s	Areas with low flow (0.0 cm/s), but can be drift downstream.	0.0-96 cm/s	0.0 – 96 cm/s

SRP16909

Meda fulgida (spikedace)

An endemic species to the Gila River Basin, spikedace is a fish that has seen its range severely reduced as a consequence of habitat changes and negative interactions with non-native species (Rinne 1991, Douglas et al. 1994). The preferred habitat of the spikedace is found in low-to-moderate gradient, intermediate sized streams, over sand, gravel or cobble substrates and where water velocities are slow to moderate (Rinne and Magaña 2002). They are known to attain greater abundance in streams with gradients between 0.4 – 0.6 %, which usually form low gradient runs to riffles (Neary et al. 1996). In Aravaipa Creek, such habitats are frequently associated with "shear zones" where two (or more) braids of streams converge (Rinne 1991). These areas and those along canyon walls or downstream of large boulders provide physical structure that produce eddying and sometimes pool formation (Rinne 1991). Investigations in Aravaipa Creek have shown that spikedace occupy deeper (24.9 ± 13 cm) and slower (29.8 ± 17 cm/s) waters over small sized (gravel and pebble) (3-64 mm diameter) substrates than are available (Rinne and Kroeger 1988, Rinne 1991). However, this habitat selectivity is not strong in other Gila Basin streams where the species occurs (Rinne 1991, Neary et al. 1996). Spikedace can be found in areas 15 - 30 cm deep, in areas where water velocity can vary between ~ 5 – 37 cm/s, and where substrate can be sand to bedrock (Rinne 1991). These quantitative descriptions support earlier qualitative descriptions by Miller and Hubbs (1960); Barber et al. (1970); and Minckley (1973) that described the species as inhabiting "deep (0.6-1.3 m), moving waters as those found in swift deep pools or the deeper parts of long pools, near riffle mouths over sandy or gravelly bottoms". Velocity is more important for habitat selectivity than depth (Neary et al. 1996). In the Verde River, spikedace were most common in velocities 55-85 cm/s (Neary et al. 1996) (but see Ward and Hilwig 2004).

Spikedace spawning is presumably cued by changes in discharge and temperature in spring-summer (Marsh 1996). During spawning females inhabit deeper pools and eddies, while males occupy riffles over sand or gravel beds (Barber et al. 1970), although it has been suggested that there is a preference for gravel over sand substrates (Neary et al. 1996). Young of the year have been observed in backwater areas over sand-silt bottoms, adjacent to pools. Rinne (1991) collected larval spikedace in slow currents in the immediate vicinity of riffles containing adults. Propst et al. (1988) reported that water depths and velocities occupied by larval spikedace in the upper Gila basin were significantly less (8.4 cm and 8.4 cm/s, respectively) than those occupied by either juveniles (16.8 cm and 16.1 cm/s, respectively) or adults (19.3 cm and 49.1 cm/s, respectively. Similarly, adults and juveniles occupy significantly different habitat than larvae in Aravaipa Creek (Rinne 1991). Spikedace are intolerant of high temperatures (>30° C)(Carveth et al. 2006, Carveth et al. 2007).

Species: *Meda fulgida* (spikedace)				
Life Stage:	Spawning	Larvae	Juvenile	Adult
Preferred Habitat	Slowly flowing waters less than 15 cm deep, over sand and gravel bottoms in water ~ 19 C. Females occupy deeper pools and eddies and males occupy riffles flowing over gravel and sand	Most occupy backwaters with sand-silt bottoms, adjacent to pools. But some occupy over gravel or cobble. Reported depths are around 8.4 cm	Young spikedace occur in backwater areas and shallow peripheral portion of streams that have slow currents along stream margins and sand or fine gravel substrates adjacent to swift pools. On average they are found at depths of 16.8 cm	They are most commonly found in shear zones where two riffle areas converge to form eddying currents. In larger rivers they occupy riffle areas of moderate velocities and gradient over grave - pebble substrates At depths of 19.3 cm on average.
Time of Year	March to May	March to May	April - June	Year round
Water Velocity		8.4 cm/s, or < 7 cm/s)	Usually found at water velocities of 16.1 cm/s	Reported in waters with velocities of 49.1 cm/s, but "preferred" flow are at >20 cm/s. Rinne (1991)reported them from water velocities 30.1 cm/sec. Neary et al. (1996) reported them in velocities 55 – 85 cm/s.

SRP16911

Rhinichthys cobitis (loach minnow)

Loach minnow are small benthic stream fish endemic to the Gila River basin in Arizona and New Mexico and the San Pedro River basin in Arizona and Sonora, Mexico (Minckley 1973, Propst et al. 1988). Loach minnow prefers turbulent, rocky riffles of mainstream rivers and tributaries up to about 2500m elevations. Most habitat occupied by loach minnow is relatively shallow, has moderate to swift current velocity and gravel-to-cobble substrate (Barber and Minckley 1966, Minckley 1973, Propst et al. 1988, Rinne 1989, Propst and Bestgen 1991). The species is rare or absent from habitats where fine sediments fill the interstitial spaces (small, narrow spaces between rocks or other substrate) (Propst and Bestgen 1991). On average, larvae, juvenile and adult loach minnow have been found in habitats with water velocities of 7.3 (± 9.1 SD), 33 (± 23.2) and 57. 3 (± 21.9) cm/s, respectively. Larval loach minnow have been found to occupy depths 16.4 ± 6.7 SD cm, while juveniles and adults occupy depths of 14.9 ±7.0 cm, and 18.3 ± 6.7 cm, respectively. Larvae are generally found in areas where sand is the dominant substrate, while juveniles occupy areas with gravel to cobble (Propst and Bestgen 1991).

Loach minnows occur in habitats with temperatures 9-12° C in winter to 21-24.5° C in summer (Propst and Bestgen 1991). Loach minnow have been observed dying in Aravaipa Creek at water temperatures of 30.58°C (Deacon and Minckley 1974) and 34.58°C (July 2002; observation by Widmer, Carveth, and Simms). These mortalities were attributed to thermal stress, although other biotic and abiotic factors cannot be discounted (Widmer et al. 2006).

Loach minnow reach sexual maturity at age one. Spawning occurs in late winter-early spring in Aravaipa Creek (Minckley 1973) and from late March into early June in New Mexico (Britt 1982; Propst *et al.* 1988). Spawning is in the same riffles occupied by adults. Adhesive eggs are deposited on the underside of flattened rocks; cavities usually are open on the side while the upstream portion of the rock is embedded in the substrate. As larvae emerge, they move to nursery areas with finer substrate particles, and lower velocities.

Species: *Rhinichthys cobitis* (loach minnow)				
Life Stage:	Spawning	Larvae	Juvenile	Adult
Preferred Habitat	Spawning is in the same riffles occupied by adults	Shallow (~ 16.4 cm) areas in areas with relatively slow flows (7.3 cm/s), and typically sand as substrate	Habitats are relatively shallow (~ 14.9 cm), have moderate to swift current velocity (~ 33 cm/s) and gravel-to-cobble substrate.	Habitats are relatively shallow (~ 18.3 cm), have moderate to swift current velocity (~ 57 cm/s) and gravel-to-cobble substrate
Time of Year	Late winter to early spring, but can extend into early June.	Mid spring to early summer	Year round	Year round
Water Velocity	Water velocities of approximately	Water velocities of approximately 7.3 ± 9.1 cm/s	Water velocities of approximately 33 ± 23.2 cm/s	Water velocities of approximately 57.3 ± 21.9 cm/s

SRP16913

Rhinichthys osculus (speckled dace)

Speckled dace usually live in clear, well-oxygenated water with abundant deep cover and moving water, most often occupying water less than 60 cm deep in riffles and runs (Valdez et al. 2001, Moyle 2002). Rinne (1992), Mullen and Burton (1995), Gido and Propst (1999), and Moyle and Baltz (1985) collected them from waters shallower than 32.0 cm and reported that water velocities preferred by speckled dace are relatively fast. Breeding adults prefer swift water (Arizona Game and Fish Department 2002b). Mullen and Burton (1995) found that speckled dace avoided velocities slower than 10 $cm \cdot s^{-1}$ and selected for velocities faster than 50 cm/s. Speckled dace cannot swim against water currents with velocities greater than 70.4 cm/s (Ward et al. 2003). Bonar et al. (2010) found that speckled dace had a maximum suitable velocity of 50 cm/s, and selected for depths between 9 and 30 cm, usually in areas with cobble to boulder substrates. They often congregate below riffles and eddies (Arizona Game and Fish Department 2002b). Speckled dace are often found among boulders and cobble, although they can also be occasionally found in soft substrates (Gido and Propst 1999). Speckled dace usually inhabit relatively cold waters in desert streams and have been collected at temperatures between 9 and 28°C (Deacon et al. 1987, Bonar et al. 2010).

Speckled dace are known to have two breeding periods, one in spring and the other in late summer. They spawn over coarse substrate using a broadcast spawning method. At the time of spawning speckled dace congregate in large groups and release many eggs in gravel areas (Arizona Game and Fish Department 2002b; Kaeding et al. 1990, Moyle 2002, Carman 2006). They are able to spawn in waters 18 – 29°C and can be induced to spawn by increasing water temperatures (Kaya 1991). During their larval stages speckled dace drift downstream along the shores of rivers, usually in areas with low water velocities, and often drift during night time (Robinson et al. 1998). Speckled dace larvae have been collected at water depths between 6 and 21 cm, in water velocities of 0.0 up to 11 cm/s, generally over sand or gravel substrates, although they can also occur in larger sediments (Mercado-Silva, in preparation).

Species: *Rhinichthys osculus* (speckled dace)				
Life Stage:	Spawning	Larvae	Juvenile	Adult
Preferred Habitat	Stream areas with swift currents, at depths < 30 cm, and gravel to cobble substrates.	Low velocity, shallow nearshore areas with gravel or sand substrates.	Habitats for juveniles are similar to those of adults. They inhabit relatively shallow (<30 cm) areas, in relatively fast water velocities between 10 and 30 cm/s, and are usually over cobble or pebbles, but can also live over fine substrates.	Habitats are relatively shallow (<30 cm), have relatively fast water velocities between 10 and 30 cm/s, and are usually over cobble or pebbles, but can also live over fine substrates.
Time of Year	Spring and summer	Late spring to early fall	Year round	Year round
Water Velocity	In areas with swift water currents (~30 cm/s).	Areas with no-flow to water velocities of up to 11 cm/s.	Water velocities of 10 – 30 cm/s.	Water velocities of 10 – 30 cm/s.