RECLAMATION

Managing Water in the West

The Development of a Bonytail Fish Population in Lake Powell

Research and Development Office
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Final Report ST-2015-2372-1

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Mission Statements

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The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Bonytail *Gila elegans* is one of four endangered fish species in the Colorado River basin. To date, there has been no measurable success in recovering, or developing stable populations of this fish species outside of a hatchery or controlled pond-type settings. Since 1996, nearly 250,000 Bonytail have been stocked into the upper Colorado River basin. Despite these stocking efforts less than 10,000 (<4%) individuals have been captured or detected via various sampling methods. The longest period between captures was 7 years with most others being at-large less than one year. Due to the poor survival and recruitment biologists from the upper and lower Colorado River basins discussed research-based approaches that may be beneficial to increase survival and recruitment of the species. One supported approach was to release Bonytail into coves within Lake Powell that provide turbidity and cover near the Colorado inflow. The goal would be to establish a population that reproduces in areas that contain habitat necessary for rearing, growth, and potentially recruitment. Under this approach stocked fish would be tracked, reproduction assessed, and recruitment measured through continued monitoring. These approaches are aimed at improving recovery potential.

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Peer Reviewer: I have reviewed the assigned items/sections(s) noted for the above document and believe them to be in accordance with the project requirements, standards of the profession, and Reclamation policy.

Comments:
The report is well done and accurately describes the ecology and biology of bonytail. It is also proposing to do an interesting stocking experiment in an attempt to increase the success of recovery for this species.

Reviewer (Signature) ______________________

Date October 10, 2015

Executive Summary

Bonytail *Gila elegans* is one of four endangered fish species in the Colorado River basin. To date, there has been no measurable success in recovering, or developing stable populations of this fish species outside of a hatchery or controlled pond-type settings. Since 1996, nearly 250,000 Bonytail have been stocked into the upper Colorado River basin. Despite these stocking efforts less than 10,000 (<4%) individuals have been captured or detected via various sampling methods. The longest period between captures was 7 years with most others being at-large less than one year. Due to the poor survival and recruitment biologists from the upper and lower Colorado River basins discussed research-based approaches that may be beneficial to increase survival and recruitment of the species. One supported approach was to release Bonytail into coves within Lake Powell that provide turbidity and cover near the Colorado inflow. The goal would be to establish a population that reproduces in areas that contain habitat necessary for rearing, growth, and potentially recruitment. Under this approach stocked fish would be tracked, reproduction assessed, and recruitment measured through continued monitoring. These approaches are aimed at improving recovery potential.

Introduction

The US Bureau of Reclamation (Reclamation) operates several dams and irrigation projects where the federally endangered Bonytail *Gila elegans* is found. Reclamation is also responsible for aiding species recovery and conservation efforts for the Upper Colorado River Recovery Program (UCRRP) and the Lower Colorado Multi-Species Conservation Program (LCR MSCP) in compliance with the Endangered Species Act (ESA). Bonytail is one of four endangered fish species in both the upper and lower Colorado River basins and, as such, Reclamation has several Biological Opinions and programs that mandate species conservation efforts. To date, there has been no measurable success in recovering or even developing stable populations of this fish species anywhere in the lower Colorado River basin outside of hatchery or predator-free, pond-type settings. This proposal explores different approaches for conserving and recovering Bonytail, as outlined below.

The Bonytail background and life history information presented here was largely derived from a species profile that BIO-WEST, Inc. (BIO-WEST) prepared for the LCR MSCP (BIO-WEST 2005). That document provides a fairly extensive literature review of Bonytail (Appendix A), which was updated with more recent information by Bestgen et al. (2008) and the UCRRP research framework report by Valdez et al. (2011). Because information on Bonytail is scarce, we have included the literature review to provide fairly a complete background on this rare species and show the current state of knowledge regarding Bonytail in the Colorado River basin (Appendix A). As demonstrated by that background information, any endeavors that benefit species would clearly be time and effort well spent—if species conservation and recovery are to progress.

<u>Insights from Current Upper Colorado River Recovery Program (UCRRP) Bonytail Records</u>

We evaluated all available data (1996–2014) for Bonytail that were stocked into the upper Colorado River basin (UCRB) to help provide this proposal and the current state of the species with additional context. The Bonytail data evaluated include the following:

- number stocked,
- number of contacted post-stocking,
- number contacted more than 1 year post-stocking (to gain insight into adult stocking and survival success),
- movement patterns and distance from stocking locations,
- stocked fish hatchery origin,
- stocking date, and
- documented protocol changes that may have impacted stocking success.

We obtained the 1996–2014 Bonytail stocking and capture data from the current US Fish and Wildlife Service UCRRP database manager, Travis Francis. The data contain records of all Bonytail stocked and include stocking sources and locations, as well as fish passive integrative transponder (PIT) tag numbers, lengths, weights, and ages. Additionally, data were provided for all Bonytail captured from 1996–2014 under various sampling regimes and methods. These data include capture locations, PIT tag numbers, and fish lengths and weights, and indicate whether the fish was recaptured or untagged at the time of capture. All captured, untagged fish were assumed to be stocked individuals that were either too small to tag at the time of stocking or suffered PIT tag loss.

Since 1996, 245,417 Bonytail have been stocked into the UCRB (Table 1). Near-annual stocking efforts have mostly occurred in the Green and Colorado rivers (approximately 90%). Other rivers, such as the Dolores, San Rafael, and Yampa Rivers, were not stocked until 2014 (Table 1) when the integrated stocking plan was revised to try and bolster Bonytail survival while reducing predator- and high-flow-related stress (UCREFRP 2015; T. Francis, USFWS, personal communication). Despite stocking efforts only 9,796 individuals, or less than 4% of the Bonytail stocked, have been captured or detected via various sampling methods, including PIT-tag arrays, since 1996. Not surprisingly, about 97% of those fish were captured in the Colorado River or Green River where the majority of stocking occurred.

Of the fish that were captured or detected, 9,065 were recaptured fish with PIT tags (Table 2), and the data obtained allow for more detailed analyses of their time at large, growth, and movement. Again, nearly all of the recaptured fish were found in the Green and Colorado rivers. As suspected, recapture rates appear to be higher in years when more fish were stocked, suggesting that most PIT-tag detections and captures were of fish stocked in that same year. The use of PIT-tag antennas increased the number of detections of tagged fish (e.g., 2011 in the Green River, Table 2).

According to the capture history data, only 34 individual Bonytails were at large for more than a year before being recaptured. The longest period between captures was 7 years: a single fish stocked into the Colorado River in 2007 at river mile 111 and later recaptured in 2014 at river mile 69.2. During this period the fish grew 229 mm. Another fish stocked into the Colorado River in 2007 from that same cohort was located in Lake Powell after being at large almost 6.5 years. At the time of recapture, this male was in spawning condition and had grown 258 mm. Additionally, the recapture data show that another fish was at large nearly 4 years, four fish were at large approximately 2 years, and 25 fish were at large between 1 and 2 years.

Large-scale movements of stocked Bonytail appear to be uncommon. However, movement has occurred between rivers as well as upstream or downstream of the initial stocking location. Fish movement from Colorado River tributaries (Dolores and Green rivers) into the mainstem river has been documented (Table 3). Fewer fish that were originally stocked into the mainstem Colorado River have been recaptured in tributaries (Table 3).

In summarizing the literature review (Appendix A) and recapture data analysis, Bonytail survival is exceptionally low regardless of whether stocking efforts occur in the lower or upper Colorado River subbasins. So low, in fact, that we hesitate to draw inferences from this evaluation. Furthermore, it is evident that adult survival is rare. According to the literature reviewed (Appendix A), the following items could be improved to benefit the species:

- Stock fish into areas with protective cover (turbidity, vegetative cover, rip-rap- or boulder-laden locations).

- Stock fish into areas that offer complex and dynamic habitat types (increased niche space) such as those found within and near river and lake inflow areas.

- Stock fish experimentally within habitat types that would be energetically efficient for this apparently susceptible species, stocking fish acclimated to flow, and/or experimentally stocking fish that have been conditioned/trained to predator avoidance.

Outlined below are technical approaches for furthering Bonytail conservation and recovery efforts that address low survival rates and emphasize habitats and techniques that are highlighted as important for survival and recruitment in the literature (Appendix A).

Study Area

Drawing on our review of Bonytail research data, we have developed two approaches for furthering Bonytail conservation and recovery efforts within an inflow area on Lake Powell or Lake Mead. Because of the potential for integration of Bonytail and Humpback Chub *Gila cypha* via the Grand Canyon, and potential concerns with species interaction, Lake Powell was selected as the more feasible location for inflow-area stocking at present.

Methods

An experimental strategy and approach that will allow adult Bonytail to spawn in relatively protected (netted, predator-free) areas, allow the resulting larvae and young to leave these areas to recruit nearby, and influence the young to imprint on an area that will likely maintain cover types that have been documented to be important for this species is outlined herein. This soft-release technique should allow for imprinted young to learn to feed in the wild and potentially recognize and/or avoid nonnative predators, thus increasing their chance of survival and recruitment. All of the stocking-related activities can, and perhaps should, be conducted by incorporating a variety of sizes and life stages and conducted to quantify results to the extent practical.

Identifying habitats that promote recruitment and utilizing such habitats to bolster reproduction and survival would be a major step forward for Bonytail. Areas ideal for native fishes often include inflow areas where food is available, cover is available (usually in the form of turbidity), and habitat heterogeneity offers both spawning and recruitment habitats (Kaemingk et al. 2007). Similar habitat also exists in off-channel floodplains where young can take refuge, avoid some predation, feed, and grow (Mueller 2006). Utilizing turbid coves and off-channel habitats as spawning and nursery areas may allow for reproduction, imprinting, and continued use of a specific spawning area as Bonytail become established. The availability of areas near flowing water also allows Bonytail to utilize the lentic and lotic habitats that are most beneficial to survival.

The goal is to develop a recruiting population of Bonytail within its native range. Since habitats have been altered and provide less cover and heterogeneity, thus making the species more susceptible to nonnative predators, the opportunity for Bonytail to spawn and recruit successfully appears to be highly reduced. Since the species can spawn in both lotic and lentic environments, researchers hypothesize that off-channel or oxbow habitats may be important for survival, spawning, and recruitment (Mueller 2011). In fact, Mueller (2011) suggests that off-channel habitats provide the most logical research and management opportunity for the species, whereas mainstem stocking has lacked in efficacy. Large lake systems have created huge backwater-like conditions, especially near inflow areas, such as the coves and backwater habitats near the Colorado and San Juan River inflow areas of Lake Powell.

This approach seeks to identify and potentially manipulate lentic cove habitats for stocking Bonytail while designing and closely monitoring experiments to improve their survival and reproduction. Examples of potentially viable lentic cove habitats are North Wash, White Canyon, and Farley Canyon within Lake Powell. The ideal locations are (1) bays that are either naturally or artificially cut off or partially cut off from the river or lake, (2) coves that can be manipulated with piscicides to eliminate impacts of nonnative predators, (3) near areas with recruitment habitat, and (4) able to hold fish, perhaps for several years, to allow naturally spawned young a chance to grow large enough to avoid predation. This information, along with other applicable findings, could diminish the need and costs associated with continued, repeated stockings of hatchery- reared Bonytail that simply do not persist in the wild. The objective of this approach is to enable the young to (1) survive and grow before being released into the wild and (2) return to spawn as adults.

This approach will consist of multiple tasks over a 4-year period (Table 4). This is necessary to ensure that spawning occurs while assessing progeny survival and the return of spawning individuals (both original stock and progeny) in subsequent years. The first task of this approach involves evaluating possible sites near the Colorado or San Juan river inflows to Lake Powell.

It must be feasible to manually cut off the site from the lake to contain fish, and the site must have adequate water, water quality, and cover. Measurements of turbidity and other cover features, as well as depth and water elevation changes, temperature, spawning substrate availability, and general habitat would be made. Fish sampling may be conducted to determine overall community structure and predator load and ensure that the selected habitats are conducive to harboring fish populations. Some of this information may be available through recent or ongoing studies, thus reducing the need for new information gathering. During this site-evaluation period, Bonytail will be reared to spawning condition in anticipation of stocking. Assuming that suitable sites are located, the experimental design will allows for an evaluation of different treatments relative to control scenarios. Control scenarios will include those that do not eliminate or exclude nonnative fishes in the presence of stocked Bonytail. Experimental scenarios will include the elimination or reduction of nonnative predators at the sites in which Bonytail will be stocked and an exclusion mechanism (e.g., nets, berms, screening, etc.) to prevent or reduce the reintroduction of nonnative fishes among stocked Bonytail.

Exclusion devices will also serve as a means to retain stocked Bonytail in the area selected to better ensure spawning within a controlled environment. Fish will be stocked in the spring prior to spawning, and all stocked Bonytail will be PIT tagged and a subset of individuals will be sonic tagged to enhance our tracking abilities. We anticipate two results from implementation of this approach: (1) that the young produced by the stocked adults will imprint on that spawning site and, if they recruit, will return to that site to spawn; and (2) that active larval fish sampling, sonic telemetry, and PIT-taginterrogational techniques may increase our understanding of nonnative predation (fish and birds), larval fish survival, and spawning site fidelity.

At age-1 or age-2 (depending on habitat quality and security), fish in each of the cove habitats will be released—either by natural means or by manual capture and release—into Lake Powell. During study years 2–4, Bonytail returning to spawn in the same habitats will be assessed through sonic telemetry, PIT-tag arrays, active capture, nonlethal aging, and other methods. It is anticipated that stocking efforts and the related assessment of reproduction, site fidelity, and potential recruitment will be monitored for a minimum of 4 years.

Cost

The cost estimates contained herein are based on a perceived highest-cost scenario that includes a contractor during all portions of the work. Depending on agency or cooperator participation and in-kind contributions, the cost may be reduced by others covering some aspects of the field work and providing equipment. That said, it is critical that this work include development of a synthesized, detailed report to guide future Bonytail recovery and conservation efforts.

Year 1

The initial year of this approach includes labor and travel necessary for identifying viable habitats, stocking Bonytail with the intent to monitor spawning and track stocked fish, and producing an annual report that outlines the study design, details the results, and discusses future recommendations. Additional costs include larval sample identification, purchase of small tools and supplies, and administrative services.

• LABOR	$148,195.00
• TRAVEL	$15,564.00
• TOOLS, SUPPLIES, ADMIN	$15,877.50
TOTAL (Year 1)	**$179,646.50**

Years 2–4

Costs for study years 2–4 include labor for moving Bonytail progeny into the lake, assessing the adult and progeny use of the spawning area the subsequent year(s) and producing annual reports. The fourth annual report will be more comprehensive, outline the study design, detail the results, and discuss future recommendations. Additional costs during these years include larval sample identification, purchase of small tools and supplies, and administrative services.

• LABOR	$141,807.20
• TRAVEL	$14,874.00
• TOOLS, SUPPLIES, ADMIN	$15,660.00
TOTAL (Per Year)	**$172,341.20**

Products

Deliverables for this project will include a final report due by the end of each study year as well as a comprehensive report due at the end of the final study year. The comprehensive report will serve as the final annual report.

Table 1. Number of Bonytail stocked into the Upper Colorado River basin from 1996–2014.

STOCKING LOCATION	YEAR																			TOTALS
	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	
Butch Craig Pond																1,236				1,236
Colorado R.	1,980	2,168	6,139	15			8,100	4,174	8,219	6,023	5,559	5,433	5,208	1,594		8,371	5,451	2,935	9,081	80,450
Dolores R.																			5,256	5,256
Green R.			2,867				20,708	5,982	13,093	7,665	6,720	10,798	12,941	10,771	2,813	21,343	5,522	6,278	10,664	138,165
Gunnison R.								2						1,124	1,128				2,861	5,115
San Rafael R.																			5,125	5,125
White R.																		925	6,111	7,036
Yampa R.																			3,034	3,034
TOTALS	**1,980**	**2,168**	**9,006**	**15**	**0**	**0**	**28,808**	**10,158**	**21,312**	**13,688**	**12,279**	**16,231**	**18,149**	**13,489**	**3,941**	**30,950**	**10,973**	**10,138**	**42,132**	**245,417**

Table 2. Number of recaptured Bonytail from the Upper Colorado River basin from 1996–2014.

CAPTURE LOCATION	YEAR																			TOTALS
	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	
Colorado R.	17				2			32	35	35	8	5	20	15	4	110	95	169	206	753
Green R.				5	10	10	4	7	25	152	12	21	21	108	27	7,722	13	24	77	8,238
Gunnison R.								1						1		12			17	31
Green R. Wetlands								21	2											23
Lake Powell																			4	4
San Rafael R.					2															2
Stweart Lake										5										5
White R.																			6	
Yampa R.																1			2	3
TOTALS	**17**	**0**	**0**	**5**	**14**	**10**	**4**	**61**	**62**	**192**	**20**	**26**	**41**	**124**	**31**	**7,845**	**108**	**193**	**312**	**9,065**

Table 3. Number of Bonytail stocked and captured showing movement from stocking location to capture location. Gray cells indicate no movement.

		CAPTURED									
		Butch Craig Pond	Colorado R.	Dolores R.	Green R.	Gunnison R.	Lake Powell	Stewart Lake	San Rafael R.	White R.	Yampa R.
STOCKED	Butch Craig Pond					3					
	Colorado R.		665		1	8	2				
	Dolores R.		45				1				
	Green R.		4		8,086			5			1
	Gunnison R.					18					
	Lake Powell										
	Stewart Lake										
	San Rafael R.				3		1				
	White R.				2					6	
	Yampa R.										

Table 4. Timeline for cove experimental stocking and assessment of Bonytail reproduction and survival.

Task	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Habitat Selection	→									→	→	→
Experimental Design, Nonnative Removal, Stocking		→	→	→	→							
Assessment of Reproduction				→	→	→	→	→				
Release or harvest of Bonytail recruits									→	→	→	→
Assessment of return spawning			→	→	→	→	→	→				

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APPENDIX A. ADDITIONAL BONYTAIL LIFE HISTORY

Bonytail *Gila elegans* were historically widespread and common throughout the larger rivers and tributaries of the Colorado River basin, and historical captures have been documented from Mexico to Wyoming (Behnke and Benson 1980; Minckley and Deacon 1991; Mueller and Marsh 2002). The first recorded capture of Bonytail from the upper Colorado River basin (UCRB) was by Jordan (1891), who collected one specimen from the Green River. Subsequent historical collections, albeit limited largely to anecdotal and historical fishing creel interviews, in conjunction with limited scientific collection information, demonstrate the once-expansive range of Bonytail inhabitance (USFWS 2002). During the 1950s Bonytail populations began a rather large, yet poorly documented decline in abundance following numerous biotic and abiotic habitat modifications. Holden (1991) described the effects of a large-scale rotenone treatment in the upper Green River and provided insight into the rather large population of Bonytail present until 1962, at which time the large piscicide treatment in the UCRB occurred. Bonytail numbers were drastically reduced following the closure of Flaming Gorge Dam in 1963, and very few, sporadic captures of Bonytail have occurred in the UCRB since then (Vanicek and Kramer 1969; Holden and Stalnaker 1975; Tyus et al. 1982; Valdez 1990; Bestgen et al. 2008).

Bonytail captures in the lower Colorado River basin (LCRB) followed similar trends. The U.S. Fish and Wildlife Service (USFWS) documented early captures of 16 individuals from the Grand Canyon (USFWS 2002). Jonez and Sumner (1954) documented a large aggregation of an estimated 500 adults spawning over a gravely shelf in Lake Mohave. Thirty-four Bonytail were captured in Lake Mohave from 1976 to 1988, and 11 of these fish (6 female and 5 male fish) were incorporated in the establishment of a hatchery broodstock, the progeny of which are presently being stocked into Lakes Mohave and Havasu, as well as in the UCRB (Minckley et al. 1989; Minckley et al. 1991; USFWS 2002). Bestgen et al. (2008) document that Kaeding et al. (1986) were the last to capture a Bonytail in the UCRB (in 1984). This illustrates that very little documentation of wild Bonytail captures has occurred recently and, therefore, little is known about the specific habitat requirements of this unique species. The USFWS (2002) hypothesizes that Bonytail use habitats similar to those described for other Colorado River native fishes. Valdez et al. (2011) concur with this hypothesis and provide a conceptual life-history model based largely on what is known about Razorback Sucker *Xyrauchen texanus*, as both species seem to use both lotic and lentic habitats. However, current habitat use information is largely based on anecdotal, as well as speculative, evidence as to the applicability of the unique morphological characteristics of the Bonytail physiology (Miller 1946).

Historical Habitat Modifications

Numerous researchers have identified that the major factor contributing to the decline of Bonytail and other large-river fishes has been the construction of mainstem dams and the resultant cool tailwaters that replaced once warm, riverine habitats (Holden and Stalnaker 1975; Minckley et al. 1991; Mueller and Marsh 2002; USFWS 2002; Bestgen et al. 2008). Competition with and predation by nonnative fishes that are successfully established in the Colorado River and its reservoirs have also contributed to their decline (Minckley and Deacon 1991; USFWS 2002; Bestgen et al. 2008). For further detailed information including examples, ramifications, and research needs pertaining of the effects of habitat modifications on native Colorado River fishes, please see Tyus (1982), Minckley and Deacon (1991), Mueller and Marsh (2002), USFWS (2002), and Bestgen et al. (2008).

Systematics and Morphometrics

The following species description is based on information supplied by the USFWS (2002).

> Bonytail were first collected from the Zuni River, New Mexico, in 1853 by Baird and Girard during their early expeditions to the Colorado River basin (Sitgreaves 1853; Girard 1856). *Gila elegans* is commonly known as the Bonytail, a name that has been shared by numerous other native chubs of the Colorado River. Bonytail is a streamlined fish, typified by its small head, slender body, and thin, pencil-like caudle peduncle. The head is compressed and the snout overhangs the mouth. Bonytail also have a small, smooth hump (smaller than that of the Humpback Chub) located directly posterior to the head of adult fish. Bonytail may reach lengths greater than 550 mm and may weigh over 1,100 g (Bozeck et al. 1984). Coloration is typically grey dorsally, fading to white ventrally, with yellowish pigmentation near the base of the pectoral and pelvic fins. Adult spawning fish (males and females) display tuberculation on the head and fins. Dorsal and anal fin rays are typically 10 (Holden 1968; Holden and Stalnaker 1970; Rinne 1976) with caudle peduncle length divided by head length equaling 1.0 (or head length divided by caudle peduncle depth usually being 5.0 or more) (Minckley 1973). Bonytails are mostly scaled throughout the body surface, with 75–88 scales along the lateral line. Scales are not as deeply embedded as those of the Humpback Chub, and their pharyngeal teeth formula is 2,5–4,2. Young Bonytails are easily confused with Roundtail Chubs and Humpback Chubs, particularly at smaller size classes and in areas of known coexistence (Holden 1968). As adults Bonytails are often mistaken due to what appears to be a high level of morphological plasticity among the endemic species of the Colorado River Gila complex and due to understudied levels of introgressive hybridization of the various species of Colorado River Gila (Dowling and DeMarais 1993; Douglas et al. 1998). The unique morphology of the Bonytail has been hypothesized to be the result of historical torrential flows thought to have been typical of the Colorado River (Miller 1946; Beckman 1963).

Hybridization

As reviewed by USFWS (2002), hybridization between Bonytail and other native Colorado River *Gila* species appears to have been common. For example, within the *Gila* species complex, inter- and intraspecific morphological variation is apparently extensive where Bonytail, Roundtail Chub *Gila robusta*, and Humpback Chub *Gila cypha* occur sympatrically. The result of this apparently high degree of hybridization is a relatively high level of phenotypic plasticity, with multiple authors reporting multiple morphologic intergrades present in samples collected throughout the Colorado River (Holden 1968; Holden and Stalnaker 1970; Smith et al. 1979; Douglas et al. 1989; Kaeding et al. 1990; Douglas et al. 1998). Such genetic intermixing was likely common historically and plausibly served to promote phenotypic plasticity and adaptability of the various species to their environments (Dowling and DeMarais 1993). Furthermore, Miller (1946) suggested evidence of species intergrades prior to anthropogenic influences. Recent mitochondrial- and allozyme-based DNA research efforts suggest that Bonytail is a uniquely adapted extension of the Roundtail Chub complex (Dowling and Demarais 1993). The extent of current and ongoing hybridization and its impacts to wild Bonytail populations is unknown due to the lack of recent captures, but hybridization and its effects may become important as populations become established through hatchery introductions and overall species recovery, particularly as increasing populations of *Gila* species become potentially and increasingly intermixed due to compressed habitat availability (USFWS 2002).

Habitat

Information pertaining to Bonytail habitat preferences is very limited, presumably due to the extirpation of this species prior to extensive sampling of the Colorado River and its fishery (Bestgen et al. 2008). Limited, early fisheries surveys indicate that Bonytail tended to be found in higher-gradient, gravelly riverine sections, but this observation may be based on the locations of the last few wild fish captured in the UCRB (Bestgen et al. 2008). For example, Bonytails are widely characterized as being adapted to the swifter sections of the Colorado River, with affinity for areas of high flow and rocky habitat types. Similar to other native fishes, backwaters and other slackwater habitat types are also thought to serve as important nursery areas for young Bonytails (USFWS 2002). Available information suggests that adult Bonytails display similar habitat affinities to those of other native fishes, with particular preference for deep, fast-water sections, as well as eddy and pool habitats. For example, Vanicek (1967) noted Bonytail habitat selection coincided with habitats occupied by another native chub, the Roundtail Chub, and found these species not only in pools and eddies near "fast-flowing" riverine areas but also in slower sections. Valdez (1990) reported Bonytail habitat use as being similar to that of Humpback Chub, with collections being made in shoreline eddy habitats, boulders and cobble, and near swift water sections (in Cataract and Desolation canyons). Bestgen et al. (2008) found stocked Bonytails occupying nearly all habitat types, including riffles, which were thought to likely be too demanding for this species energetically and likely an atypical habitat choice of stocked individuals. Interestingly, a study conducted by Pimentel and Bulkley (1983) suggests that Bonytails, when given the opportunity, tend to select water with high levels of total dissolved solids (TDS). Bonytails in particular are able to persist in water with TDS of 4,700 mg/L, the highest tolerance reported for any of the *Gila* species of Colorado River.

Bonytails have been documented spawning over rocky habitat types in reservoir situations (Jonez and Sumner 1954) and are hypothesized to perform similarly in lotic environments. Mueller (2011) describes Bonytails with the ability to spawn in both flowing and standing water. Most recently in the LCRB, documentation of successful, natural, reproduction in Cibola High Levee Pond suggests that Bonytails select shoreline associated with riprap materials (large-diameter gravel, cobble, and boulder substrates) in water 2–3 m deep for spawning activities (Mueller et al. 2003a). Furthermore, sonic-telemetry studies have revealed that adult Bonytail prefer interstitial spaces associated with shoreline riprap during daylight hours, whereas open-water areas are more commonly utilized during the nighttime hours (perhaps due to the water clarity associated with this off-channel pond). Individuals spawning in Lake Mohave displayed similar diel habitat shifts: adults were found in deeper habitats during the day, and at dark they formed congregations along shoreline habitats (Mueller and Marsh 2002). Intensive telemetry surveillance suggests a high degree of site-specific habitat fidelity, with individually marked Bonytails consistently returning to the same cavities formed within the riprap-type shoreline. Young Bonytails were most commonly associated with areas of dense overhead cover in depths greater than 1 m, and they displayed schooling in warm, shallow areas of an oxbow pond (Mueller et al. 2003a; Mueller 2006). These findings suggest that habitat for Bonytails should have similar components in terms of riprapped shoreline materials, and that Bonytails are a highly cover-affiliated (likely vegetation and/or turbidity) species with one of the few specific habitat preferences that has been fairly well documented to date. For example, in Lake Havasu, near the Bill Williams inflow/delta, as well as in the LCRB, near Topock Marsh, sonic-tagged Bonytail appeared to actively seek cover components (Jim Stolberg, LCR MSCP, personal communication).

Diet

The Bonytail's diet is reportedly composed of a wide variety of aquatic and terrestrial insects, worms, algae, plankton, and plant debris (Mueller and Marsh 2002). This information is corroborated by McDonald and Dotson (1960) and Vanicek (1967) ,who also found that Colorado River chubs to fed omnivorously. More detailed and quantitative descriptions of the Bonytail's diet preferences, including shifts in diet composition by life stage, are limited. However, Bonytails stocked into Cibola High Levee Pond fed omnivorously, with adult Bonytails consuming algae, vegetative material, small fish, and crayfish, while young Bonytails fed near the pond surface, with smaller size classes consuming zooplankton and invertebrates (Mueller et al. 2003a).

Reproductive Ecology

Vanicek and Kramer (1969) documented the last substantial spawning of a wild, riverine population of Bonytail in Dinosaur National Monument. Ripe fish were collected from mid-June through early July in water temperatures around 18 °C. Bonytail estimated between 5 and 7 years old were found ripe (Vanicek 1967), whereas in controlled hatchery environments, Hamman (1985) found that Bonytails began to mature sexually at age 2. Johnston (1999) classified Bonytails as being broadcast spawners and suggested that the loss of eddy habitat types due to the construction of impoundments may contribute to the apparent reproductive failure of a closely related species, the Humpback Chub. Marsh (1985) reported that Bonytail eggs are adhesive and apparently remain so throughout the incubational period, which is thought to be an adaptive strategy to swift-moving currents of the mainstem Colorado River.

As stated previously, Jonez and Sumner (1954) reported active spawning of a large (approximately 500 individuals) aggregate of Bonytail in Lake Mohave. Spawning fish were observed over gravel substrates near shore and in water up to 30-feet deep. Eggs were described as being adhesive, and one individual female contained over 10,000 eggs, suggesting a high level of fecundity, a trait that appears to be typical for Colorado River endemic species. Even higher levels of fecundity were found in hatchery settings, with individual egg production averaging over 25,000 eggs per female (Hamman 1982). Spawning Bonytails in Cibola High Levee Pond were observed utilizing shoreline riprap materials, typically in mid-April, frequently during nighttime hours, in water temperatures ranging from 20.4-21.6 °C. Bonytails were observed consuming their own gametes, as well as young Razorback Sucker larvae (Mueller et al. 2003a). Bonytail egg survival appears to be highly influenced by incubation temperature. Hamman (1982) found 90% survival at water temperatures of 20–21 °C, 55% survival at 16–17 °C, and only 4% survival when temperatures were held between 12 and 13 °C. Incubation periods ranged from 99 hours to nearly 500 hours, depending upon water temperatures. Newly hatched fry averaged 6.8 mm (Hamman 1982). This research is corroborated by Marsh (1985), who found that Bonytail embryos have the highest survival rates at temperatures near 20 °C and indicated that newly hatched larvae averaged 6.0–6.3 mm in size. In summary, the literature and hatchery evidence show that strong reproductive output and production of young are key characteristics of this species in the absence of predators.

Age and Growth

Little detailed information exists pertaining to naturally recruited Bonytail age and growth patterns. Following information reviewed by USFWS (2002), the only substantial findings regarding Bonytail age and growth are those reported by Vanicek (1967). He aged 67 Bonytails using scales and found the largest to be 7-years old, 338-mm long, and weighing 422 g. Ulmer (1983) used otoliths to determine that two Lake Mohave Bonytails were 32- and 39-years old. This finding was corroborated by Rinne et al. (1986), who estimated four Lake Mohave fish to be between 34 and 49 years old. Available data suggest that captured Bonytails are typically between 338 and 535 mm total length (USFWS 2002). In any case, Bonytail have long lives, demonstrating another trait that researchers have been speculated to be an adaptation to an extremely harsh and unpredictable environment (e.g., Mueller and Marsh 2002).

Disease

The effect of disease vectors on the various life stages of native fishes remains relatively unknown and understudied. However, information pertaining to diseases in catostomids native to the Colorado River drainage likely provides insight into potential vectors of disease that may impact highly jeopardized fish populations. For example, Minckley (1983) provides information on Lake Mohave Razorback Sucker injuries and diseases. He reports that a large number of individuals were blind in one or both eyes. This condition was attributed to bacterial and protozoan infections. Minckley (1983) further describes other common infestations, such as those of the parasitic copepod *Lernaea cyprinacea*, and less common osteo-deformative problems associated with nematodes, cestodes, and trematodes. Infections were also reported as being most common in females captured during the spawning season. Other researchers have noted similar afflictions but have not attributed disease as a hindrance to native fish recovery efforts (Flagg 1982). Disease-related information specific to the Bonytail is limited to the documentation of Lernaea species on individuals collected by Vanicek (1967). Furthermore, Mueller et al. (2003) noted an 18% intestinal tapeworm infestation rate in an experimental Bonytail population in the LCRB. Cross (1975) describes infestations of Lernaea species as being the most common parasite observed in Desert Sucker *Catostomus clarkii* in the Virgin River. Interestingly, researchers working in Lake Powell have collected several Bonytails, which were noted as being in exceptionally good health at time of capture (T. Francis, USFWS, personal communication).

Predation and Competition

Historically, predatory impacts to native fishes were likely restricted to predation by other native fishes including Roundtail Chub, Bonytail, and Colorado Pikeminnow *Ptychocheilus lucius*. Colorado Pikeminnow likely represented the largest historic predator to young, native Colorado River fishes (Bestgen 1990; Holden 1999). More than 70 nonnative fish species have been introduced into the Colorado River during the last century (Minckley 1982; Minckley and Deacon 1991; Tyus and Saunders 1996; USFWS 1998; USFWS 2002). Many of these newly introduced species are large, piscivorous, adaptable fish desired by anglers but thought to be deterrents to native fish propagation. For example, native fish habitat restoration and other recovery efforts have been hampered, particularly when viewed in light of the drastic physical habitat modifications that have occurred during the past century on the Colorado River and coupled with the predatory impacts of introduced, nonnative fishes infiltrating newly created and restored habitats designated for native fishes (e.g., Minckley 1983; Taylor et al. 1984; Tyus 1990; Minckley and Deacon 1991; Minckley et al. 1991; Johnson et al. 1993; Mueller and Marsh 2002).

For example, Mueller and Marsh (2002), as well as numerous other researchers, report that when Bonytails are stocked into ponds by themselves, they do extremely well and produce multitudes of young. However, if they are stocked in the presence of other species, young native fish (e.g., Bonytails) quickly fall prey to nonnative predators. Furthermore, Mueller et al. (2003b) documents that small predators (crayfish and tadpoles) can decimate native fish at both the egg and fry stages, and nearly 100% of Razorback Sucker eggs and fry were consumed by tadpoles and crayfish in laboratory experiments. Similarly, the largest known population of Razorback Suckers from Lake Mohave now shows virtually no wild recruitment, a condition likely attributable to nonnative predators and lack of protective cover (Minckley et al. 1991). Marsh and Langhorst (1988) report that larval Razorback suckers in Lake Mohave survived and grew better in the absence of predators. Several researchers have documented the apparent lack of escape and defense mechanisms displayed by young Razorback Suckers and Bonytails when subject to predation (Laudermilk 1985; Johnson et al. 1993; David Ward, USGS, 2013, personal communication). Wesp and Gibb (2003) tested the hypothesis that larval Razorback Sucker had poor escape performance compared with nonnative, introduced Rainbow Trout *Oncorhynchus mykiss*. These researchers found that Razorback Suckers had similar escape performance to Rainbow Trout, and in some cases Razorback Sucker larvae showed greater performance, swimming velocities, and acceleration rates. It was concluded that while Razorback Suckers appear to perform as well, if not better, than Rainbow Trout in terms of swimming performance at temperatures of 12 $^{\circ}$C and 18 $^{\circ}$C, Razorback Sucker larvae did not grow as quickly. This increased the duration of their vulnerability to predation, a phenomenon that likely influences recruitment success and may also apply to Bonytail populations. In contrast, Johnson et al. (1993) show that larval Razorback Suckers exhibited less predator response and avoidance than Northern Hogsuckers *Hypentelium nigricans* of the same age, suggesting that differences in predatory avoidance among fishes can be linked to the historical fish assemblage and ecological settings in which a fish has evolved. Razorback Suckers apparently evolved in a predator-poor community, while it is suggested that Northern Hogsuckers evolved in a predator-rich environment, with both fish experiencing differences in evolutionary pressures brought on by unique biological and physical community structures. Such information specific to the Bonytail is unfortunately not currently available, but similar ecological and evolutionary processes that sculpted the susceptibility of Razorback Sucker young to predatory impacts most likely helped to mold the predator-avoidance mechanisms of the other endemic Colorado River fishes.

Potentially more applicable to the Bonytail, research on Humpback Chub identified that Brown Trout *Salmo trutta*, Channel Catfish *Ictalurus punctatus*, Black Bullhead *Ameiurus melas*, and Rainbow Trout are the principal predators of wild Humpback Chub populations in the Grand Canyon. It has been hypothesized that in some cases, entire year classes of Humpback Chub may be decimated by nonnative predatory impacts (Marsh and Douglas 1997; Valdez and Ryel 1997; USFWS 2002) and, given the lack of Bonytails captured in the wild, the same logic could be applied to Bonytail. It has also been suggested that Red Shiner

Cyprinella lutrensis, a widespread, nonnative species that often is captured in nursery habitats used by young native fishes, may threaten Bonytails during early development. This is particularly important given that young of all native species tend to inhabit backwater and shoreline habitat types in riverine settings (Ruppert et al. 1993; Holden 1999).

The effects of competition and predation between native and nonnative fish species are difficult to separate and identify. Predation is typically easier to quantify (i.e., gut-content analysis), while interspecific competitive interactions remain largely understudied. For example, small-bodied nonnative species such as Red Shiner and Fathead Minnow *Pimephales promelas* display aggressive behaviors towards native catostomids (Karp and Tyus 1990; Sabo et al. 1996). This also appears to be the case for young Bonytails (Marsh and Mueller 2002; Mueller et al. 2003a). Furthermore, competition for food may be an important factor that determines native fish recruitment (Papoulias and Minckley 1990; Mueller et al. 2003a). However, Marsh and Langhorst (1988) suggest that food is unlikely a limiting factor and indicate that predation by introduced fishes appears to be a significant cause of larval mortality. In any case, it appears as though complex habitats reduce nonnative fish predation, as was documented by the presence of juvenile Razorback Suckers in turbid, heavily vegetated habitat types in Lake Mead (Holden et al. 1997; Albrecht et al. 2013; Shattuck and Albrecht 2014; Kegerries et al. 2015).

Various biological studies have documented the significance of delta habitats to aquatic ecosystems and fish populations. Delta habitats can support large numbers of species and life stages, presumptively through habitat diversity and associated increases in niche availability. One example of this concept was reported by Kaemingk et al. (2007). They describe the importance of deltas as maintaining natural river function and “ecological hotspots” within the highly modified Missouri River system. They also hypothesize that the diversity of habitats found within river deltas leads, in turn, to increases in fish species diversity, particularly though the maintenance of complex and diverse habitat types (niches) that provide habitat occupancy opportunities for a diversity of fishes (Kaemingk et al. 2007).

In 2008, large-scale efforts to restore delta habitat diversity were implemented on the Williamson River delta where it enters Oregon’s Upper Klamath Lake (Erdman and Hendrixson 2010). This project, which initially began around 1996, focused on restoring complex marsh and rearing habitat to improve survival and recruitment of larval and juvenile Shortnose Sucker *Chasmistes brevirostris* and Lost River Sucker *Deltistes luxatus* (endangered fish species with life history characteristics and habitat needs similar to Colorado River endemic species). The recent phase of the Williamson project involved breaching several miles of constructed levees to facilitate the restoration of 7,500 acres of wetlands. Post-project biological monitoring indicated that larval suckers appear to prefer restored delta habitats over preexisting wetlands along the lake shore (Erdman and Hendrixson 2010). Also, the abundance of larval fish captured in the restored delta in 2009 was greater than that captured along the shoreline of the lake (Burdick and Brown 2010; Erdman and Hendrixson 2010).

In consideration of an endangered Colorado River fish species with lentic and riverine life-history requirements similar to Bonytail, Razorback Sucker habitat use in Lake Mead also highlights the importance of river/lake interface features. Albrecht et al. (2010a) demonstrated that vegetative cover and turbidity commonly associated with areas of Lake Mead that have inflow features (e.g., confluences of the Virgin River/Muddy River and Las Vegas Wash with Lake Mead proper) support the only remaining, self-sustaining, and naturally recruiting population of Razorback Sucker within the Colorado River basin known to date. Wild recruitment of this species has been documented through direct capture of small, juvenile individuals as well as nonlethal aging techniques. Lake Mead is the only currently known location in which this life stage of Razorback Sucker continues to be collected on a routine basis (Albrecht et al. 2010a). More recently, a population of Razorback Sucker was found in Lake Mead at the Colorado River inflow, which further underscores the importance of river/lake interface areas to this rare species (Albrecht et al. 2010b). Lake Mead is a functioning example of how, given appropriate habitat features, a highly sensitive species can demonstrate wild recruitment and persist despite major habitat modifications and competition pressure from and predation by a thriving nonnative sportfish population within the same locations (Albrecht et al. 2010a, 2010b). To date, experimental stocking of Bonytail has only occurred in the LCRB at the Bill Williams inflow area to Lake Havasu. Those efforts provide some of the most informative research regarding stocking fate, predation, and the use of cover for Bonytail in the LCRB to date (Jim Stolberg, LCR MSCP, 2015, personal communication).

Finally, as with the majority of ecological studies, it is evident that the effects of predation, competition, and habitat complexity, compounded by ongoing, dramatic physical and environmental changes, are likely interconnected and should not be treated as mutually exclusive causes. While direct effects (such as predation) are evident, indirect and less visible impacts (such as inter- and intraspecific competition) may have substantial ramifications on habitat development and restoration/recovery efforts. Future research will likely allow for further conclusions to be drawn concerning the complex interactions between native fish recruitment and predation, competition, and ongoing habitat modification. This is particularly true in regard to Bonytail research, given that available information is very limited and the applicability of general ecological truths needs to be tested in order to apply correct management actions conducive to promoting survival and persistence of all Bonytail life stages and native fishes in general. Research in the UCRB has identified methodologies that allow managers to give native fishes the opportunity to exist despite nonnative fish presence in existing key backwater habitats and by manipulating flow regimes and annually draining nursery habitats (e.g., Modde 2005). Furthermore, opportunities may exist to create/modify inchannel habitats (in combination with manipulating flow regimes) that enable highly adapted native fish assemblages to express advantageous, evolutionary-honed traits and thereby promote a potential shift in competitive advantage towards these native species (e.g., Holden 1999).

Valdez et al. (2011) provide the following conceptual model (Figure A-1) to depict Bonytail life history. We include this information here for summarization and species account completeness; we recommend readers review Valdez et al. (2011) for additional details.

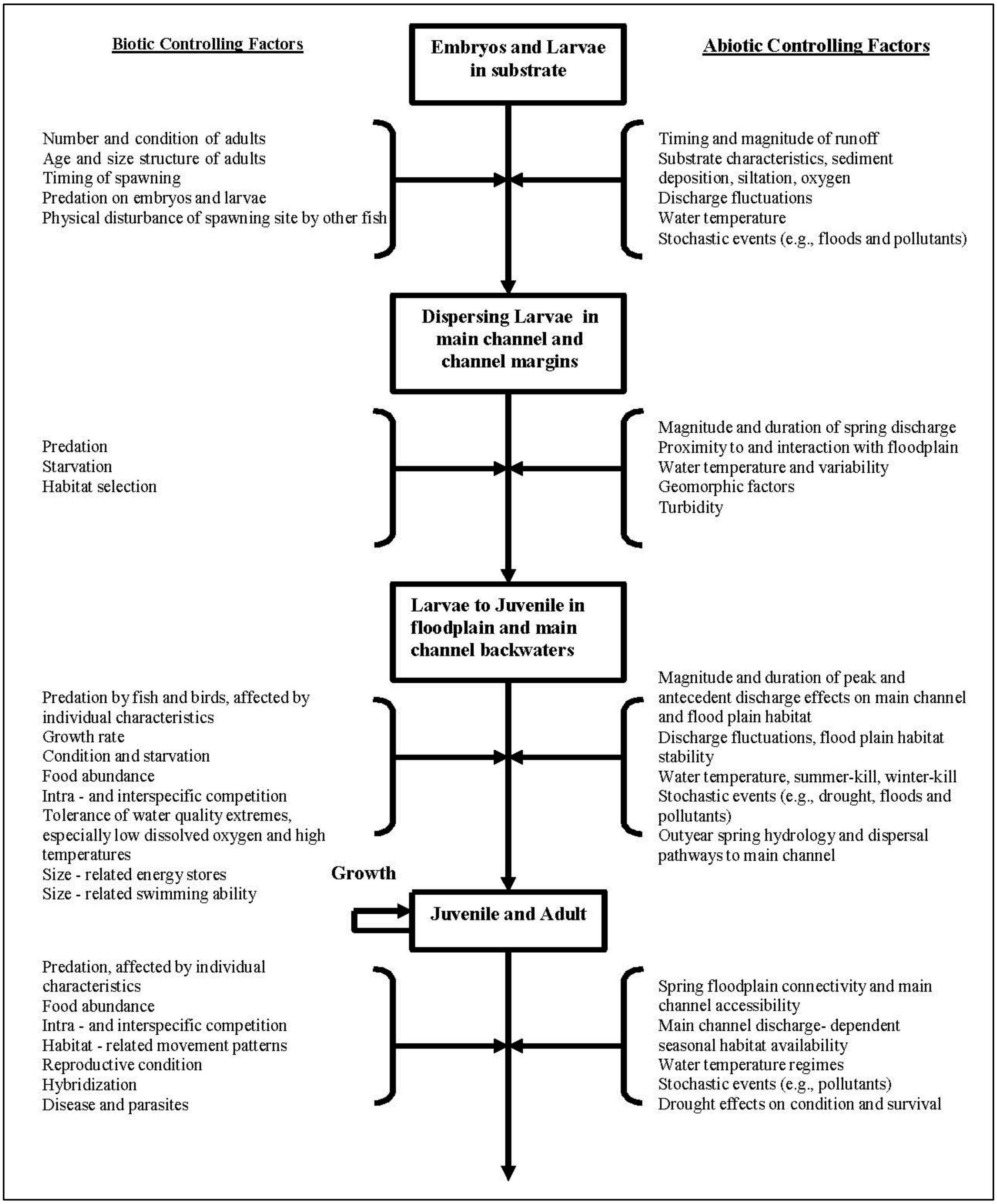

Figure A-1. Conceptual life history model for Bonytail, as found in Valdez et al. (2011).