Grand Canyon Hydraulics and Humpback Chub

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Abstract

The installation of Glen Canyon Dam on the Colorado River in 1963 was detrimental to the native humpback chub (*Gila cypha*) fish populations because the flow, sediment, and temperature regimes the fish evolved with were drastically altered. The humpback chub is listed as an endangered species, which has prompted a number of studies to better understand its lifecycle and behavior. Several efforts aim to restore humpback chub populations so it can be down listed. Humpback chub partially motivated recent high flow experiments that will continue through 2020. Roughly 90% of the Grand Canyon humpback chub population is concentrated near the Little Colorado River confluence, where there is access to seasonally varied flows and temperatures.

Objectives

The main goal is to assess the status of humpback chub (HBC) populations in the Grand Canyon below Glen Canyon Dam (GCD), and consider their response to changes in the environment. In addition, what physical processes govern hydraulics in the Grand Canyon where HBC reside?

Literature Synthesis

Background

The construction of GCD created Lake Powell and drastically altered the downstream environment and ecological networks. Some effects include disconnected riverine habitat, increased sand bar erosion, and decreased debris fan removal due to a dampened hydrograph. Spring snowmelt once surged through the Grand Canyon, transporting sediment, replenishing nutrients, and creating beaches and important backwater habitat. Low summer flows once warmed easily, which aided juvenile HBC survival and maintained the insect food supply. Annual pre-dam flows ranged from 1,000 - 100,000 cfs compared to post-dam flows of 7,000 - 20,000 cfs (Webb et al., 1999). Similarly, the variability in water temperature was greatly reduced from 32 - 85 °F pre-dam to 44 - 59 °F post-dam (Webb et al., 1999). Nowadays, the water temperature released from GCD stays around 48 °F year round due to the location of water intake. Installation of a selective withdrawal would allow better river temperature management, which would affect habitat and invertebrate food sources (Kennedy et al., 2013). Fortunately for the chub, water temperature and turbidity increase further downstream from the dam, mostly due to warm water and suspended sediment inputs from tributaries.

The HBC is a quirky-looking cyprinid fish endemic to the Colorado River Basin (Miller, 1946), which can live up to 40 years and grow to be 20 inches in length. The species is currently listed as “endangered” under the Federal Endangered Species Act of 1973, and it was previously included in the List of Endangered Species issued by the Office of Endangered Species in 1967 (Valdez et al., 2002). Based on archeological evidence and testimony, the HBC is believed to have existed throughout most of the Colorado River Basin for millions of years. Today, only six wild populations remain, five of which are in the Upper Colorado River Basin, including canyons within the Yampa and Green River tributaries. The sixth population resides bbelow Lake Powell, primarily near the confluence with the Little Colorado River at river mile 61.5

(Figure 1). The fish have been especially difficult to study due to their rarity and residence in fast, turbid waters in inaccessible river reaches (Converse et al., 1998). Currently, the USGS Grand Canyon Monitoring and Research Center oversees monitoring and research for the Grand Canyon population under the sponsorship of the GCD Adaptive Management Program.

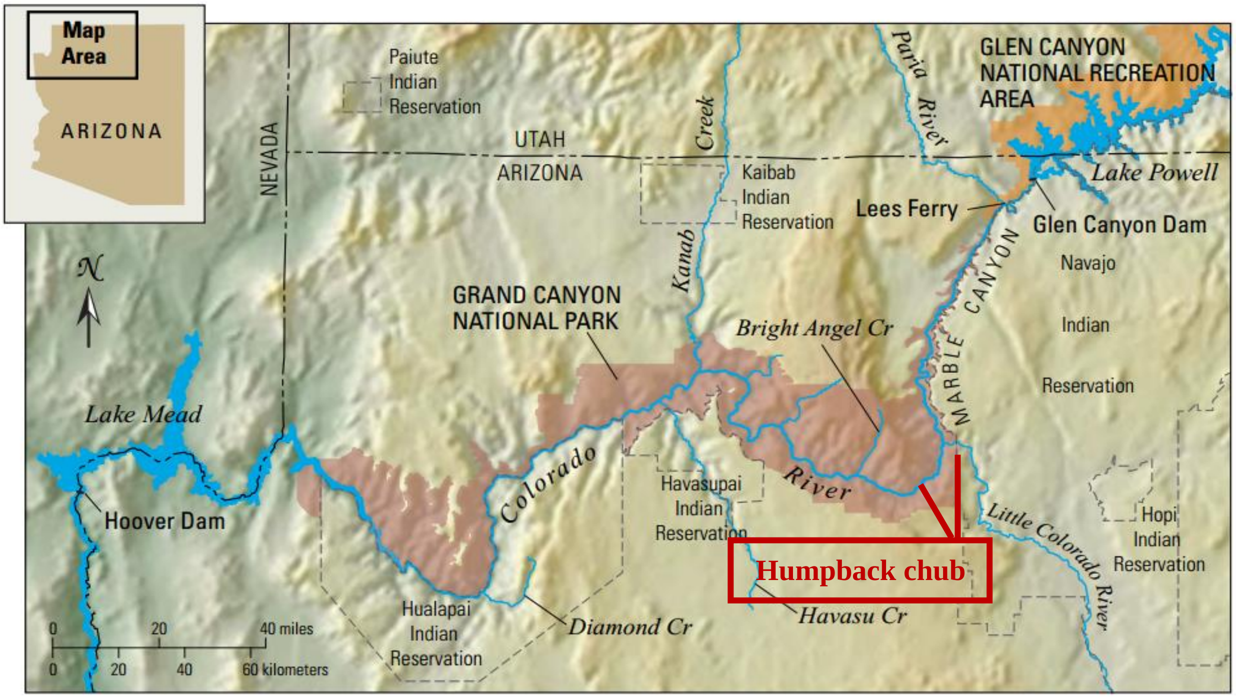


Figure 1. The Grand Canyon below Glen canyon Dam. The humpback chub population is indicated were the Little Colorado River joins the Colorado River.

Humpback chub life

Figure 2. Drawing of a humpback chub (www.coloradoriverrecovery.org)

The morphology of the HBC is quite striking (Figure 2). The dominant feature is the large hump above its head, which is thought to be an adaptation for maintaining stability in fast currents and/or reducing the chances of being swallowed by predators (Kaeding and Zimmerman, 1983). It is streamlined and has a thin caudal peduncle. The small eyes and poor vision are likely a response to the high historic turbidity of the Colorado River. It is characterized as being a sedentary fish that is well adapted for variety of flow conditions (Valdez and Hoffnagle, 1999). Figure 3 shows the estimated HBC population from 1989 to 2008 (Coggins and Walters, 2009). The HBC population reached a low of below 5,000 individuals around 2001 and rebounded to roughly 7,500 by 2008. According to the USGS, the population increase was due to a combination of high flow experiments, nonnative fish removal, and warmer water released due to drought. As water levels in Lake Powell dropped, intake drew more water near the surface that was warmed by the sun.

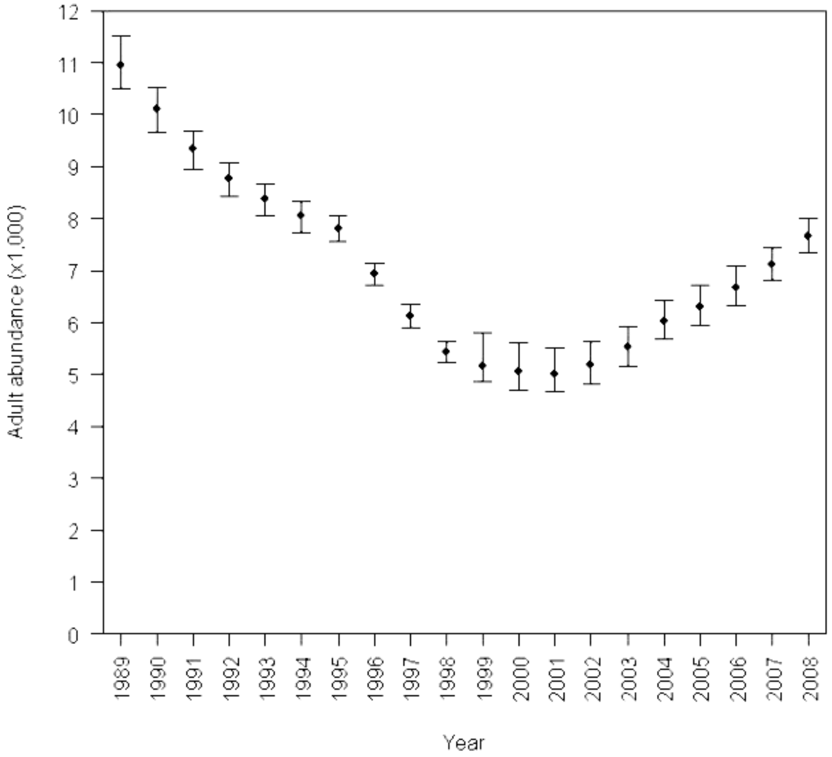


Figure 3. Estimated adult HBC abundance (Coggins and Walters, 2009).

Reproduction occurs in spring only in the seasonally warmed LCR, however, spawning is suspected at the mouths of other tributaries and near warm springs (Valdez and Hoffnagle, 1999). Fishing is prohibited half a mile upstream and downstream of the junction with the LCR in an attempt to reduce the stress on the native humpback. There are several ongoing experiments and restoration projects to aid the chub's recovery. For example, since 2009, there have been efforts to translocate young HBC to other tributaries of the Colorado River: Shinumo and Havasu creeks. Spawning occurs on the descending limb of the spring hydrograph from March-June in water between 16 and 22 C (Valdez and Hoffnagle, 1999; Valdez et al., 2002). High spring-time flows used to maintain channel and habitat diversity, flush sediments from spawning areas, rejuvenate food production, and deposit cobble and gravel for spawning habitat. Some researchers inject passive integrated transponder (PIT) tags into fish abdomen to allow tracking and later identification.

HBC are opportunistic omnivores and will eat from all levels of the water column. Non-lethal stomach pumps revealed they consume primarily invertebrates (blackflies and midges), but also planktonic crustaceans, algae, and detritus (Valdez and Hoffnagle, 1999; Kennedy et al., 2013). A recent study suggests that production and distribution of HBC and other Grand Canyon fishes are limited by the availability of invertebrate food because almost all midges and blackflies are consumed annually (Kennedy et al., 2013). Rainbow trout consume copious amount of these invertebrates and are believed to predate on young native fishes, including the HBC (Yard et al., 2011).

Nonnative rainbow trout (*Oncorhynchus mykiss*) were introduced along the Colorado River in the 1920s for sport fishing. They prefer cold, clear, and swift moving water over gravel and cobble for spawning, hence they thrive under the GCD regulated flow regime. The 15 miles downstream of the GCD is a world-class, Blue Ribbon trout fishery.

In general, different species of fish tend to utilize different habitat at different life stages. Fish habitat can be characterized in terms of hydraulics, substrate size, temperature, water chemistry, etc. Valdez et al. (1990) developed a set of habitat suitability curves for four life stages of HBC in the Upper Colorado Basin using a large set of previously collected microhabitat data. Table 1 shows the summary statistics for distribution of substrate size and water depth and velocity utilized by adult HBC. Adults used average depth of 10.3 ft, average velocity of 0.6 fps, and preferred silt/sand substrate. Results for the other life stages were less significant and less conclusive compared to the adults due to issues such as: larvae samples were skewed because 89% of sampling was in backwater habitat, young-of-the-year life stage had a very small dataset due to confusion in distinguishing from roundtail chub (*Gila robusta*), and conflicting results between two distinct juvenile populations of HBC. A trend is that the fish utilize greater depth and venture in to swifter waters as they age. Other studies found that young HBC require low-velocity zones such as eddies and backwater and adult humpbacks require eddies and sheltered habitat along river banks (Kaeding and Zimmerman, 1983; Gerig et al., 2014). Eddies are areas of calm, recirculating flow, generally downstream of debris fans, bedrock outcrops, or protruding rocks. A basic understanding of river hydraulics is useful in discussing fish habitat.

Review of river hydraulics

Discharge and topography primarily influence river hydraulics (e.g. wetted width, depth, velocity, and shear stress). There is a complex interplay between water flow and the landscape because each directly affects the other, but on different time scales. In a natural river system, discharge depends heavily on climate and the contributing watershed area. Seasonal variations in precipitation and snow melt produce a characteristic hydrograph for a location on a river. The hydrograph may vary drastically year to year, but over time, a trend would develop in the timing, magnitude and frequency of flood events. These relatively large, rare disturbances tend to drive the geomorphology and influence what life forms can exist.

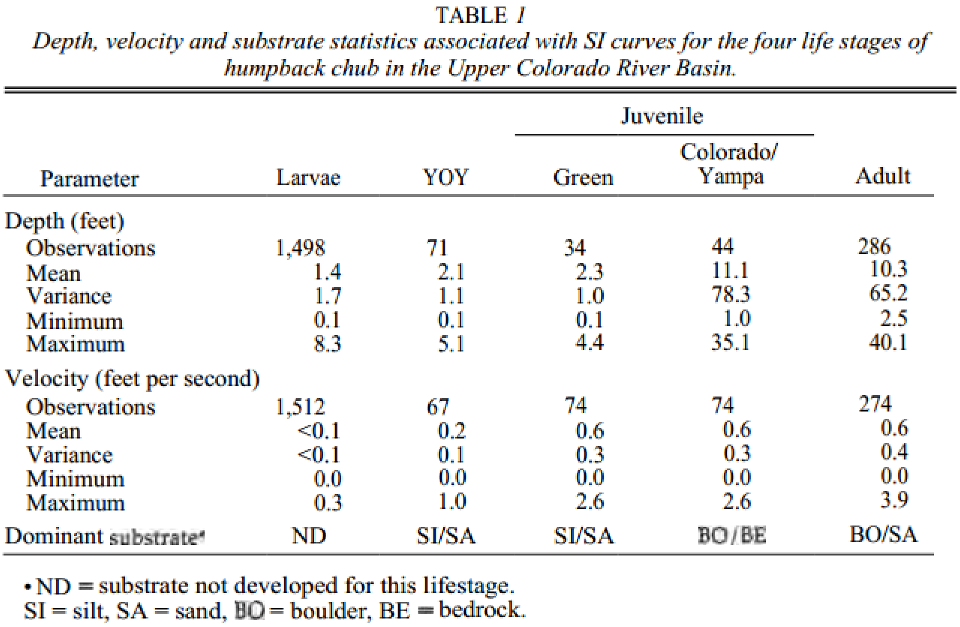


TABLE *1*

Depth, velocity and substrate statistics associated with SI curves for the four life stages of humpback chub in the Upper Colorado River Basin.

Parameter	Larvae	YOY	Juvenile Green	Juvenile Colorado/ Yampa	Adult
Depth (feet)					
Observations	1,498	71	34	44	286
Mean	1.4	2.1	2.3	11.1	10.3
Variance	1.7	1.1	1.0	78.3	65.2
Minimum	0.1	0.1	0.1	1.0	2.5
Maximum	8.3	5.1	4.4	35.1	40.1
Velocity (feet per second)					
Observations	1,512	67	74	74	274
Mean	<0.1	0.2	0.6	0.6	0.6
Variance	<0.1	0.1	0.3	0.3	0.4
Minimum	0.0	0.0	0.0	0.0	0.0
Maximum	0.3	1.0	2.6	2.6	3.9
Dominant substrate•	ND	SI/SA	SI/SA	BO/BE	BO/SA

• ND = substrate not developed for this lifestage.
SI = silt, SA = sand, BO = boulder, BE = bedrock.

River topography can be broken down in several ways. Channel slope, constriction points, and meandering affect how water moves over the landscape. Steeper gradient and lateral or vertical constrictions of flow are associated with high velocities. The degree of meandering and riffle-pool spacing can influence hydraulics over larger river scales. As rivers meander, energy is dissipated as the outside of bends are scoured. Vertical undulations along the longitudinal profile of a river bed are often associated with riffle pool sequences. These bumps or high elevation points reduce cross sectional area to flow via vertical constriction, and thus increase velocity. Bed and bank roughness alter flow patterns at much smaller spatial scales. Localized roughness takes into account substrate size, vegetation, bank material, and presence of bedrock outcroppings. Manning's equation is a useful tool for considering hydraulics as they relate to channel roughness:

$$V = \frac{k}{n} R_h^{2/3} S^{1/2}$$

as it relates average cross section velocity V, to hydraulic radius R_h, and slope S. The Manning's n term is a unitless representation for roughness which ranges from 0.02 – 0.08 in streams and is often used to calibrate hydrodynamic simulations. Flow is typically described as laminar or turbulent. The Reynolds equation is the ratio of inertial to viscous forces:

$$R_e = \frac{VR_h}{\upsilon}$$

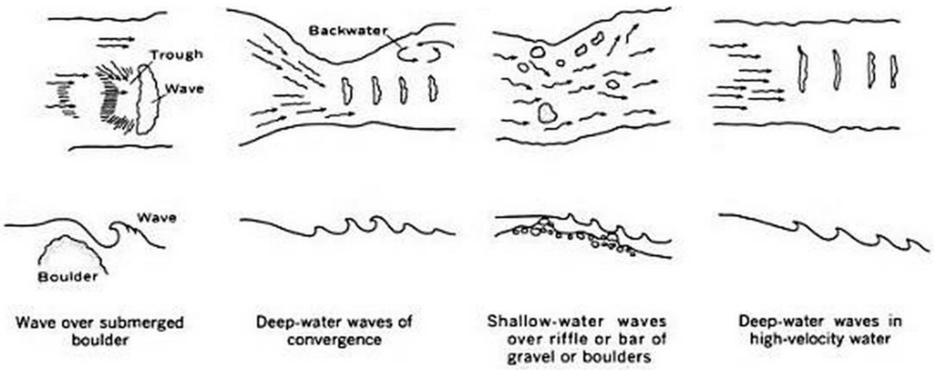
where R_e is the Reynolds number, and υ is the kinematic viscosity. Although there is no universal threshold, the transition between laminar and turbulent flow occurs at Reynolds number ~2,000. The higher the Reynolds number the more turbulent flow is.

Hydraulic geometry relations at-a-station and in the downstream direction were first described by Leopold and Maddock (1953). They showed that simple power functions could relate discharge to wetted channel width, mean flow depth, and mean velocity:

$$\mathrm{W} = \mathrm{a}Q^{b};\ \mathrm{D} = \mathrm{c}Q^{f};\ \mathrm{V} = \mathrm{k}Q^{m}$$

where a, c, k, b, f, and m are constants resulting from regression analyses. The exponents indicate the rate of increase in a hydraulic variable with changing discharge, whereas the coefficients represent the wetted channel dimensions at low flow. Hydraulic geometry has since proved useful in a variety of contexts including stream classification (Leopold and Wolman, 1957; Rosgen, 1994), river restoration (Shields et al., 2003), aquatic ecosystem evaluation (Jowett, 1998; Pitlick and Van Steeter, 1998). Unfortunately, it does not appear that any hydraulic geometry studies have been conducted on Grand Canyon stretch of the Colorado River.

Visually, rapids stand out as being regions of complex hydraulics. Leopold (1969) noted four types of waves in the Grand Canyon include those below large rocks or outcrops, deep-water waves caused by convergence, riffles in shallow water, and waves in deep high velocity water. Figure 4 shows a diagram of each wave type. The most common wave type, deep-water waves of convergence, forms a downstream backwater that may be preferred HBC habitat. Several have concluded that the dominant driver of hydraulics in the Grand Canyon is rock debris deposited by tributaries, which constrict the main stem, thereby ramping up localized velocity (Leopold, 1969; Schmidt and Grams, 2011; Wright and Kaplinski, 2011). Flooding on these unregulated tributaries can cause excessive amounts of unsorted rock to deposit in the Colorado River. A conceptual model of a typical eddy-fan complex is shown in Figure 5 (Schmidt and Grams, 2011). The diagram shows how flow is constricted and water begins to circulate over the downstream side of the debris fan.



Wave over submerged boulder

Deep-water waves of convergence

Shallow-water waves over riffle or bar of gravel or boulders

Deep-water waves in high-velocity water

Figure 4. Diagrams showing four types of water waves in rapids. Upper sketch shows a plan view of the river; lower sketch indicate the relation of waves to bed configuration (Leopold, 1969).

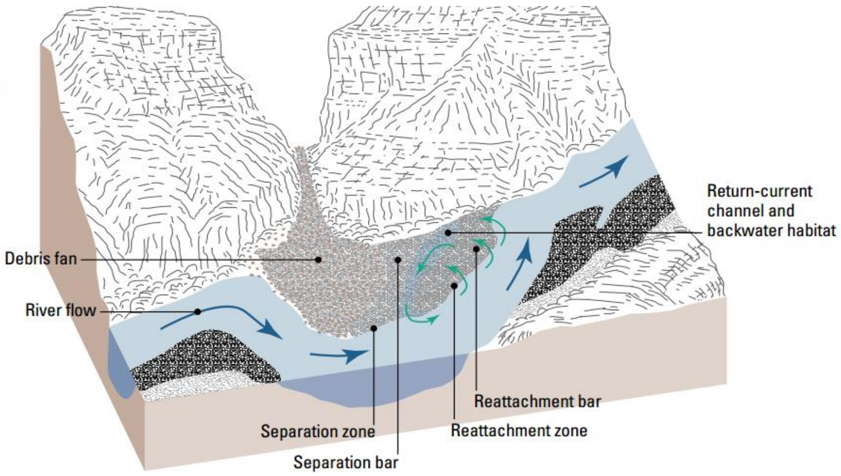


Figure 5. Diagram of a typical Grand Canyon eddy-fan complex (Schmidt and Grams, 2011).

High flow experiments

Experimental flows occurred in 1996, 2004, 2008, 2012, and 2013, and will continue given certain criteria through 2020. Valdez and Hoffnagle (1999) showed adult chub maintained normal movement behavior and were not swept downstream by the 1996 HFE of 44,900 cfs. Also, there were no adverse effects on habitat use or diet observed.

Conclusions

HBC have endured an altered flow regime, habitat degradation, and competition/predation from nonnative fishes. The colder waters of the modern Colorado River seem to limit spawning to warmer wild tributaries. With changing climate, drought and overall temperatures of the region are expected to increase, which may be beneficial to the native HBC. However, warmer water may benefit parasites or other competitive fishes as well. Furthermore, installation a selective withdrawal system may enable river temperature management. Flow regulation and debris fans from tributaries are the main drivers of hydraulics below GCD. Hydraulics are effectively managed by controlling discharge through GCD. While HFEs are believed to enhance chub habitat and population, it is unclear to what extent that has occurred. The next six years of HFE will surely shed more light on these complex interactions.

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