Population Status of Humpback Chub, *Gila cypha*, and Catch Indices and Population Structure of Sympatric Roundtail Chub, *Gila robusta*, in Black Rocks, Colorado River, Colorado, 1998-2012

Picture 1. Humpback chub on grid board (2012). Photo credit: T. Francis, USFWS.

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Travis A. Francis
U.S. Fish and Wildlife Service
Colorado River Fishery Project
445 West Gunnison Avenue, Suite 140
Grand Junction, Colorado 81501

-and-

Dr. Kevin R. Bestgen
Dr. Gary C. White
Colorado State University
Larval Fish Laboratory
Fort Collins, Colorado 80523

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EXECUTIVE SUMMARY

The Colorado River in Black Rocks was sampled in 2011 and 2012 to estimate size and structure of the humpback chub *Gila cypha* population and relative abundance and size structure of sympatric roundtail chub *Gila robusta* occupying the study area during the sampling seasons. Sampling began in mid-September and continued through October. Four sampling passes were conducted in both years. The primary sampling technique was fishing multifilament trammel nets during both years. *Gila* captures were supplemented with baited hoop nets and PIT tag antenna in 2012.

Catch rates for humpback chub in 2011-2012 were comparable to those observed in 2007-2008 and 2003-2004. A total of 79 individual humpback chub were captured in 2011 and 119 were captured or sighted (detected by an antenna) in 2012. These numbers compare to 61 and 74 humpback chub captured in 2007-2008, and 69 and 74 in 2003-2004. Within-year recaptures were modest at six humpback chub recaptured in 2011. In 2012, the experimental sampling techniques increased our within-year recaptures or re-sightings to twelve humpback chub. In addition to within-year recaptures, six humpback chub were recaptured in 2011 and seventeen were either recaptured or re-sighted in 2012 that had been tagged in previous years. Twelve humpback chub recaptured or re-sighted in 2011-2012 were tagged in Westwater Canyon in prior years.

Total length of humpback chub captured in 2011 and 2012 ranged from 162 to 408 mm. Juvenile *Gila* (fish that couldn't be morphologically distinguished to species) total length ranged from 73 to 186 mm. Growth of humpback chub captured in multiple years averaged 12.2 mm/yr for fish <300 mm TL and 10.2 mm/yr for fish $\geq$ 300 mm TL. Mean relative condition of humpback chub improved significantly from 2007 to 2011.

In prior cycles of monitoring humpback chub, in both Black Rocks and Westwater Canyon, abundance estimates were calculated from data that were location specific and from only one sample cycle. However; for the 2011-2012 estimates, humpback chub data collected from both Black Rocks and Westwater Canyon from 1998-2012 were used in Program Mark to estimate survival, abundance, probabilities of capture, and transition rates between Black Rocks and Westwater Canyon. The new estimates of abundance were more precise and had reduced coefficients of variation. With the new model, estimated humpback chub abundance in Black Rocks was highest in 1998 (n=880, 95% CI 572-1,431) and 1999 (n=994, 95% CI 810-1,245). The first combined abundance estimate of humpback chub for Black Rocks (n=283, 95% CI 179-478) and Westwater Canyon (n=1,212, 95% CI 971-1,532) to fall below the minimum viable adult population (2,100 animals, humpback chub Recovery Goals documents; USFWS 2002) was in 2007 . Since 2007, estimated humpback chub abundance has remained stable. The 2011 estimate was 379 (95% CI 239-642) animals and the 2012 estimate was 404 (95% CI 298-571) animals. Survival was estimated as remaining fairly stable throughout all of the years ranging from 64-70%. Thus, annual humpback chub recruitment, in Black Rocks, must be offsetting annual adult mortality since 2007. Low estimates (1.4-1.8%) of humpback chub transition between Black Rocks and Westwater Canyon reflect high site fidelity, but still retain metapopulation dynamics between these two functionally distinct populations.

Long lived fishes occupying stochastic environments should be expected to have fluctuations in abundance; however, critically endangered species that have discreet populations living in very specific habitats require monitoring to insure populations are not lost to the gene pool and to help guide management decisions regarding the species status.

INTRODUCTION

The humpback chub (*Gila cypha*) is a long lived (up to 30 years) moderate-sized cyprinid endemic to the Colorado River Basin (Minckley 1973) that is currently listed endangered under the Endangered Species Act of 1973 (USFWS 2000). The species was not described until 1946 (Miller 1946) and little was known about its distribution until relatively recently. A pronounced hump behind its head gives this fish a striking, unusual appearance. It is thought that the hump is used as a hydrodynamic foil that helps it maintain its position in the deep, turbulent water it inhabits. It has an olive-colored back, silver sides, a white belly, small eyes and a long snout that overhangs its jaw (Miller 1946). Humpback chub are currently found in discrete populations within canyon-bound reaches of large rivers in the Colorado River basin (Valdez and Clemmer 1982). The largest population occurs in the Little Colorado and Colorado rivers in the Grand Canyon (Valdez and Ryel 1995; Douglas and Marsh 1996). All other populations occur in the upper Colorado River basin, including the Yampa and Green rivers within Dinosaur National Monument (Karp and Tyus 1990; Finney 2006), the Green River in Desolation and Gray canyons (Chart and Lentsch 1999a; Jackson and Hudson 2005; Badame 2012), and the Colorado River in Black Rocks (Kaeding et al. 1990; McAda 2007; Francis and McAda 2011), Westwater Canyon (Chart and Lentsch 1999b; Jackson 2010; Elverud 2012), and Cataract Canyon (Valdez 1990; Badame 2008).

Conflicts between water development interests in the upper basin and endangered fish began soon after the Endangered Species Act (as amended) was passed in 1973 (Wydoski and Hamill 1991). In an attempt to resolve those conflicts, the Upper Colorado River Endangered Fish Recovery Program (Recovery Program) was developed to recover humpback chub (and other listed fishes) and allow the states of the upper basin to continue to develop water to satisfy the needs of a growing population (Wydoski and Hamill 1991). During formation of the Recovery Program, an Interagency Standardized Monitoring Program (ISMP) was developed to monitor trends in the humpback chub populations in Black Rocks and Westwater Canyon (USFWS 1987; McAda et al. 1994). The ISMP sampling was limited to short periods of trammel netting at two or three year intervals. This sampling was sufficient to develop catch-per-effort indices indicating that humpback chub still occupied Black Rocks and Westwater Canyon and that young *Gila* continued to recruit to the adult population, but it was not sufficient to develop reliable estimates of population size.

During development of quantifiable Recovery Goals for humpback chub (USFWS 2002) it was determined that regular estimates of size and structure of the major populations were necessary to monitor recovery efforts. Studies designed to obtain the necessary data to produce population estimates have been completed in Yampa-Whirlpool, Westwater, Desolation-Gray, and Cataract canyons. The first three series of population estimates for Black Rocks humpback chub were completed in 1998-2000 (McAda 2002), 2003-2004 (McAda 2007) and 2007-2008 (Francis and McAda 2011). The Black Rocks population combined with the Westwater population is the largest core population found in the upper-basin. Among many other factors needed for recovery and downlisting, all populations of humpback chub must have self-sustaining populations over a five year period where the adult (Total Length [TL] > 200mm) abundance does not decline significantly and mean estimated recruitment of juveniles (TL 150-199mm) equals or exceeds annual adult mortality. In addition, one of the five upper-basin populations maintains a core population such that each point estimate exceeds 2,100 adults (USFWS 2002). Estimates of roundtail chub (*G. robusta)* population size were made in

2003-2004 and 2006-2007 for Desolation and Gray canyons (Jackson and Hudson 2005; Badame 2012) and 2003-2004 and 2007-2008 for Westwater Canyon (Jackson 2010; Elverud 2012) during humpback chub population studies. The Recovery Program recommended that population estimates for both species should be made concurrently during future work in Black Rocks and abundance of roundtail chub was estimated in Black Rocks in 2007-2008; however, too many assumptions in the model were violated (most noteworthy was the assumption of population closure) and future population estimation for roundtail chub in Black Rocks was determined to be unnecessary (Francis and McAda 2011).

The first objective of this report is to model humpback chub data collected from Black Rocks and Westwater Canyon from 1998-2012 and derive joint estimates of survival, abundance, probability of capture, relative condition, catch indices and population structure for Black Rocks humpback chub and transition rates of movement between Westwater and Black Rocks over a fourteen year period. The second objective of this report is to present catch indices and population structure of sympatric roundtail chub occupying Black Rocks, during 2011-2012.

METHODS

Study Area

Black Rocks is a 1.4 km section of deep-water habitat formed by erosion-resistant black metamorphic rocks (gneiss and schist) that were intruded by veins of molten rock (igneous materials), in the river channel (Picture 2). This unique area is about 6.4 km upstream from the Colorado-Utah state line and extends from river kilometer (RK, as measured for the Colorado River confluence with the Green River RK 0.0) 217 to RK 218.4 or river mile (RM) 135.5 to 136.5 (Figure 1) within Ruby Horsethief Canyon. Black Rocks and the upstream end of

Westwater Canyon are separated by about 16.8 RK (10.5 RM). The river channel is narrow and turbulent eddies, pools and runs are located throughout the short reach. Deep areas along the rock faces provide important habitat for humpback chub. Black Rocks is substantially deeper than other parts of the Colorado River, with an average depth of about 5 m and maximum depth of about 18 m (Valdez et al. 1982). Reaches up and downstream of Black Rocks are shallower and rarely exceed 2.5-3 m in depth (Pitlick and Cress 2000).

Picture 2. Black Rocks habitat. Photo credit: K. Hiam, USFWS.

Field Sampling

Sampling was conducted during base flows of mid-September through October, after water temperatures began to cool for the year as recommended by McAda (2002, 2007) to minimize handling stress experienced during warm weather. To develop reliable estimates, sampling passes were scheduled to correspond to a mark-recapture design. Sampling was conducted for four days (one pass), with at least one week separating passes. Four passes were conducted in both years (2011 and 2012) of the study.

The primary sampling technique utilized, from 1998-2012, was multi-filament trammel nets set along shoreline eddies or in other quiet habitats. Trammel nets were 22.86 m long and 1.83 m deep with 3.9 cm inner mesh and 30.5 cm outer mesh. Nets were attached to rock faces with pitons and straps. A sash weight was attached to the lead line and a floating buoy was attached to the float line of the free floating end of the net. Three to six trammel nets were set mornings and evenings during the crepuscular periods and checked at one to two hour intervals. Nets were left in the same location for 3-4 hours unless no fish were collected or excessive amounts of trash and debris required the nets to be moved sooner. As much of the Black Rocks reach as possible was sampled with this technique during each pass to ensure that all humpback chub had a possibility of being captured; however, a shallow riffle at about 218.1 RK (136.3 RM) and swift and laminar flow above the riffle limited the use of this technique above that point. Most locations were sampled more than once during each pass.

In an effort to collect more young-of-year and juvenile *Gila* (TL < 200 mm) a new technique for Black Rocks was employed (in 2012 only). Baited modified turtle hoop nets were set in similar locations as the trammel nets and in new locations where trammel nets were too large to sample with, such as attached to mid-channel boulders in faster moving water or in a smaller cove. The modified turtle hoop nets had three 61 cm diameter hoops set 43 cm apart with 6.4 mm mesh and a 10.2 cm opening. Nets were attached to rock faces by rope tied to pitons or were attached by rope tied to rebar driven into the shore. Bait canisters were built from 7.6 cm diameter PVC cut to 20.3 cm lengths with end caps, 0.64 cm holes were drilled throughout the canister to allow bait to escape slowly. Razorgrower, a fish food pellet (3 mm diameter) developed for rearing endangered razorback sucker (*Xyrauchen texanus*) in captivity was used as bait (USFWS Fish Technology Lab, Bozeman, MT). Seven to ten hoop nets were set and were checked three times a day, once in the morning, once in the afternoon and again in the late evening. This technique was not limited by the shallow riffle at 218.1 RK (136.3 RM) or by the swift and laminar flow above the riffle; thus, allowing for the entire reach to be sampled with all humpback chub having a possibility of being captured.

All *Gila* (*G. robusta; G. cypha; G. elegans* [bonytail]), razorback sucker (*Xyrauchen texanus*) and Colorado pikeminnow (*Ptychochelius lucius*) were removed from the nets, tentatively identified and immediately placed in a freshwater holding tank. Other native species were identified, counted, and released at the capture site. Non-native fish (with the exception of channel catfish and common carp) were removed. Net locations were identified to the nearest 0.16 RK (0.1 RM) and sampling time was recorded. After all nets were checked, all *Gila* and endangered fish captured were transferred to a central processing location (Figure 1). After processing, *Gila* and the other endangered fishes were released at the central processing location to expedite removing fish from multiple nets and to prevent immediate recapture of endangered fish.

In addition to nets, the entire Black Rocks reach was sampled with aluminum hulled motorboat-based electrofishing during most years (1998-2011) with 2012 being the exception. In 2012, low water levels restricted the electrofishing craft's ability to access the sampling reach. In 2011, the entire reach was sampled twice during all four passes. Both shorelines were electrofished on each occasion. Electrofishing was utilized to increase the probability of capturing small *Gila* and to capture fish that might be in areas that we could not sample with nets. Fish captured with electrofishing were also processed and released after each sample at the central processing site (Figure 1).

During processing, *Gila* were inspected and categorized as either humpback chub, roundtail chub, bonytail or an intergrade using criteria outlined by Douglas et al. (1989). Each fish (including razorback sucker and Colorado pikeminnow) was measured to total length (TL; ±1 mm), weighed with an Ohaus® electronic scale (± 1 gram), and scanned for a 134 kHz (new style) and 400 kHz (old style) passive integrated transponder (PIT) tag. Fish that had a 400 kHz PIT tag or were lacking a PIT tag were tagged with a 134 kHz PIT tag. After processing, all fish were placed into an oxygenated holding tank containing a mixture of salt (0.8% solution) and Stress Coat® (0.01% solution) for about one hour as a skin treatment and for us to assess their general post-capture health. Fish were then released at the central processing point.

In 2012, during the third pass only, three submersible PIT tag antennas were deployed at various locations, at different times, throughout the entire reach as part of a pilot study to collect additional data on PIT tagged fish. Two antennas were small submersible rings (ca. 25 cm in diameter), and the third was a modified turtle hoop net fitted with a square PIT antenna. Most deployments included baited. PIT equipment was typically deployed at approximately 1600-1700 and retrieved the following morning at 800-100 h, which mostly overlapped with the hoop netting schedules. Data collected from PIT devices were incorporated into population models along with data from conventional gear types.

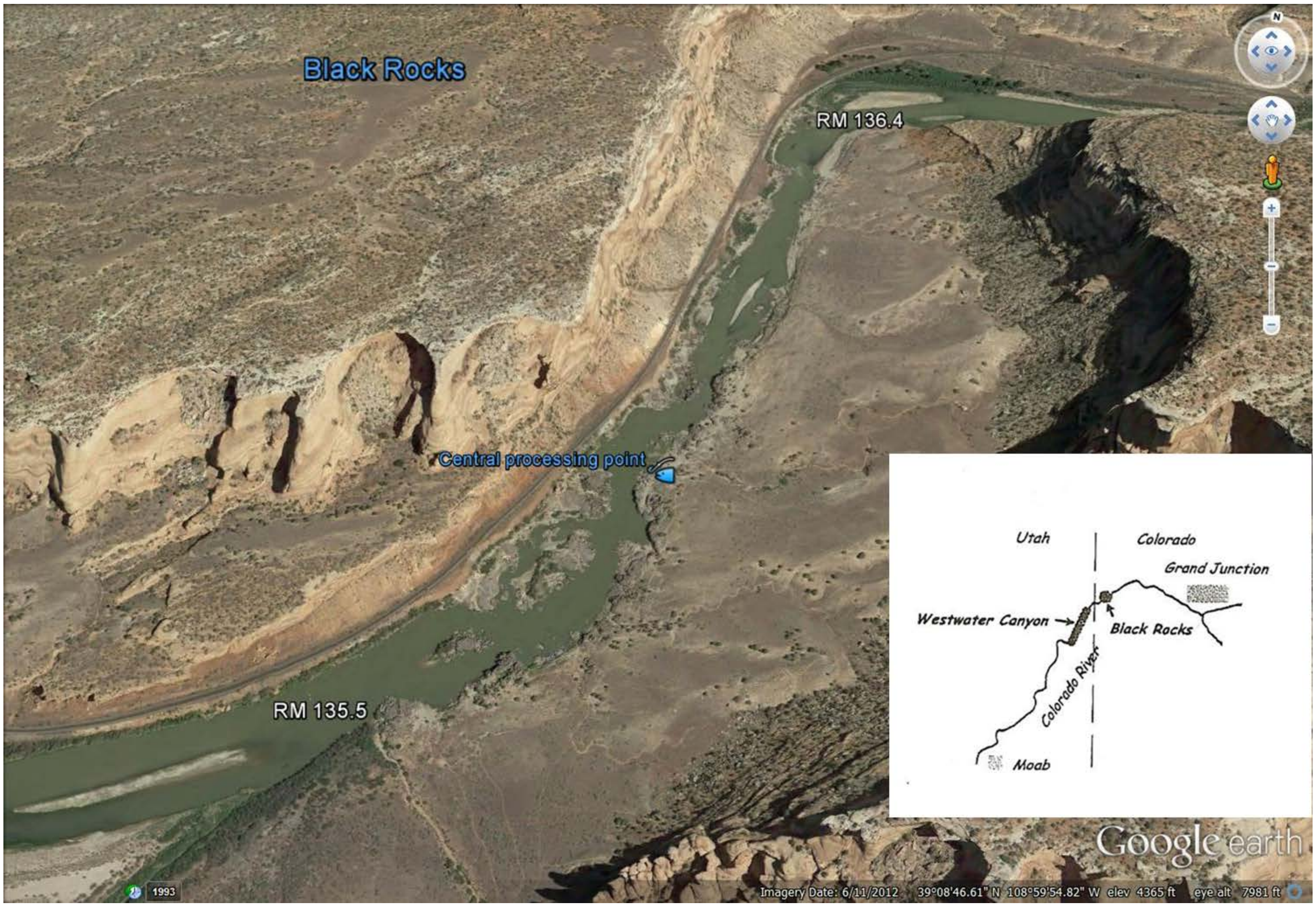


Figure 1. Google earth image (eye altitude 7981 ft.) of Black Rocks study area. Inset map illustrates Black Rocks proximity to Westwater Canyon (downstream 16.8 RK).

Data Analysis

Robust design for humpback chub capture-recapture studies

Robust-design sampling and analysis capitalizes on the strengths of closed and open population models used to estimate demographic parameters (Pollock 1982; Pollock et al. 1990). Capture-recapture data for all captured or sighted (i.e., detected by PIT antennas) humpback chub were placed into a matrix with a row for each individual fish and columns organized by year, location (i.e., Black Rocks or Westwater Canyon) and pass. The matrix indicated whether an individual was captured or not during each pass and the TL at the time of capture (± 1 mm TL). Within pass recaptures were not included in the matrix for demographic parameter estimation. Sampling occasions completed at closely-spaced intervals (e.g. consecutive weeks within a year) were used to estimate annual population abundance using closed population models. That level of sampling completed in two or more consecutive years allowed for estimation of population size of tagged fish, mainly adults 200 mm TL or greater (a few fish were tagged that were between 150-200 mm TL) and survival rates between years. In Black Rocks, data was available from 4 sampling passes, which was accommodated in the capture history matrix for Westwater Canyon where only three passes were available by placing a "." in that column.

Statistical modeling

The combined robust-design (Kendall 1999; Kendall et al. 1995; 1997) multi-state (Brownie et al. 1993; Hestbeck et al. 1991) model in Program MARK (White and Burnham 1999) was used to estimate survival in year *t* (S_t), probability of transition between reach *i* and *j* (ψ_{ij}), capture-recapture probabilities within reach *i* (reach is the state, here either Blackrocks or Westwater) for each year *t* and sampling pass *k* (p_{itk}), and humpback chub abundance in each reach *i* for each year *t* (N_{it}). Abundance of adult humpback chub in each reach was estimated with the Huggins estimator (Sanathanan 1972; Huggins 1989; Alho 1990; Huggins 1991). Abundance estimates from the Huggins model were derived by the equation:

$$\hat{N} = \sum_{i=1}^{M_{t+1}} (1/p_i^*),$$

where M_{t+1} was the number of unique animals captured or sighted over all short-term sampling passes, and

$$p_i^* = 1 - \prod_{j=1}^{t} (1 - p_{ji}),$$

and p_{ji} was the probability of initial capture within the sampling season. Animals in the population that were never captured have capture probability $(1 - p)$ but were removed from the likelihood. The new multinomial distribution still summed to one, and because only fish that were captured or sighted were included in the likelihood, individual covariates (here TL or polynomials for such) could be incorporated to estimate p, ψ, and S, where appropriate. Information for the p^* estimates are from both the closed-capture portion of the likelihood used for abundance estimation and the Cormack-Jolly-Seber (CJS) component of the model used to estimate annual survival rates if TL is included as a covariate. With the information provided about p^* from the CJS portion of the likelihood, the individual p's per pass within the annual sampling period are identifiable based on the numbers of fish initially captured during each sampling pass within a year. Recaptures of fish in reaches among passes within a single year provided estimates of abundance. We used confidence intervals and their overlap among pairs of estimates to assess significance; high precision estimates had coefficients of variation (CV's) < 10%, moderate precision estimates had CV's of 10-25%, and low precision estimates had CV's > 25%.

We used a von Bertalanffy function to estimate fish growth between years after first capture. The function was based on length data collected from 1998-2012. To use length as a covariate, lengths for each captured fish were needed for each year of the study. However, because individual fish were not captured in each sampling year, their lengths in years when not captured had to be estimated by interpolation or extrapolation. For fish that were captured more than once within a year, the mean of the measured lengths was used for that year. The von Bertalanffy model was used to estimate missing lengths following Osmundson and White

(2009). To fit the von Bertalanffy model, a difference equation was assumed, following generally the procedures of White and Brisbin (1980). For the von Bertalanffy model:

$$L_{i+1} = (t_{i+1} - t_i)k(L_\infty - L_i) + L_i ,$$

where L_i is the length at year i, t_i is the actual year of the observation, *k* is the von Bertalanffy growth coefficient, and L_∞ is the asymptotic length. To estimate the two parameters, the equation was implemented recursively, with $t_{i+1} - t_i = 1$. So, to predict a length for a fish not captured in 2008 from a length from the same fish in 2006, for example, the equation was first applied with the observed length from 2006 to predict a 2007 length. The predicted length in 2007 was then used to predict a length in 2008. The model was thus used to produce individual covariate values of length for each year. Using these lengths, an input file for Program MARK was created. Use of the more complicated von Bertalanffy growth estimation approach was justified because it was more realistic (e.g., Bestgen et al. 2010). It is typically important to test for the effect of the covariate TL in abundance or survival estimation modeling because of the potential effects of fish size during electrofishing on probabilities of capture. However, because most fish were captured in trammel nets where length was not assumed to be a factor, we did not allow for variation in probability of capture as a function of length. Abundance estimators such as those in program CAPTURE (White et al. 1982) do not have the capability to use individual covariates because the likelihood includes probabilities for animals that are never captured, so the covariates are unknown.

Selection between models was performed with information-theoretic procedures (Akaike's Information Criterion adjusted for small sample size [AIC_c], Burnham and Anderson 1998). We did not have sufficient recapture information to test the hypothesis that capture probabilities were equal to recapture probabilities among the short-term and annual sampling occasions (i.e., $p_k = c_k$), so no heterogeneity was assumed and p was set equal to c (Bestgen et al. 2007). It would be desirable to test for differences in rates of capture and recapture in various models to evaluate if behavior effects (e.g., fish avoidance of nets after first capture) were influencing recapture rates. This would involve fitting mixture models of Pledger (2000), which were designed to incorporate heterogeneity caused by differing probabilities of capture for different segments of the population. However, we could not consider these models further because higher numbers of recapture occasions (e.g., minimum of 5) and higher capture probabilities are needed to detect differences in capture probabilities among groups of animals in the same population. We also attempted to explain heterogeneity among years, states (Black Rocks or Westwater Canyon sites), and sampling passes by estimating capture probabilities for each possible combination, and because heterogeneity was assumed low for different sizes of fish captured in trammel nets (preliminary models supported this), heterogeneity effects were presumed minimized.

The robust-design multi-state models in program MARK (White and Burnham 1999) were used to estimate reach-specific apparent survival for humpback chub in Black Rocks and Westwater Canyon. Apparent survival rates (S) were the joint probability of a fish surviving from one year to the next and remaining in the population available for capture. In other words, estimates from these models do not distinguish a fish that died in the study area from one that survived and moved from the study reach to an unsampled reach. These models also could not distinguish if fish that were previously captured avoided subsequent recapture by some behavioral change mechanism. Such a behavioral change would result in reduced capture probability and lower apparent survival rates. Survival rates were from additive models, such that differences across years were estimated for each reach, but differences between reaches were held constant. Thus, survival rates vary by year but differences between reaches were the same across the sample period. A model that computed different survival rates for each year and reach were attempted but data were too sparse to obtain reasonable estimates in many years (many estimates close to 0 or 1). The AIC_c (AIC for small samples) was used as a guide in model selection (Table 2). We were careful to guard against over-fitting models with the sometimes sparse data available and focused on those models that gave reasonable estimates of parameters that were critical to understanding the status of humpback chub in the Colorado River.

Relative abundance

Mean log-transformed (LN, natural log; data were not normally distributed) catch per effort (CPE, fish per net-hour) for trammel netting and hoop netting was calculated for humpback chub and roundtail chub for each pass and year the technique was utilized. Mean LN CPE was compared among passes and years using Analysis of Variance; pairwise comparisons were made using Tukey's Honestly-Significant-Difference (HSD) Test ($P<0.05$; SYSTAT13). Mean CPE was not calculated for electrofishing.

Size Structure

Length-frequency distributions of *Gila* were calculated by year. Humpback chub recaptured within a year were only used once (last capture) in the analysis. Mean annual growth increments were calculated from differences in total length of fish that were captured in more than one year. Mean CPE and a length-frequency distributions were also calculated for roundtail chub.

Relative condition

Consistent with methods used to track body condition of Colorado pikeminnow in the upper Colorado River, relative condition was calculated for humpback chub and roundtail chub (Osmundson and White 2009, Francis and McAda, 2011). Relative condition accounts for allometric growth and makes the measurement comparable between species and between different units of measure (Le Cren 1951). The standard average body condition is represented by 100 (x 100). Relative body condition (K_n) is the observed mass (M_o) of a given fish divided by the expected mass for a fish of its length:

$$K_n = (M_o \div M_e) \times 100$$

The expected mass or standard weight (M_e) is calculated using constants derived from mass-length regressions:

$$\log_{10} Me = ((\log_{10} \text{length})\ \text{slope}) + \text{y intercept}$$

The constants for these time-of-year-specific mass-length regressions were derived from humpback chub or roundtail chub captured from the mainstem of the Colorado River (Black Rocks and Westwater Canyon) from 1991 through 2012. Wege and Anderson (1978) suggest using samples from the mid-to-late growing season when tissue accumulation is neither high nor low (pre-or-post spawning). Relative condition of each animal was calculated using the constant specific to animals captured from the last week of August through the end of the first week in November. Mean K_n was compared among passes and years using Analysis of Variance; pairwise comparisons were made using Tukey's Honestly-Significant-Difference (HSD) Test ($P<0.05$; SYSTAT13).

RESULTS

Sampling Dates, River Flow and Water Temperature in 2011 and 2012

Sampling began in mid-September and concluded in late October in both years (Table 1). Mean river flow varied greatly between years (mean, 4,986 cubic feet per second [cfs] in 2011; mean, 2,616 cfs in 2012), yet was more constant among passes within each year (Table 1). Fluctuations in flows within each year were generally gradual and not subject to dramatic, short-term pulses. Amplitude of fluctuation within passes ranged from 100 to 1,740 cfs (median, 560 cfs), but never resulted in dramatic changes in river elevation during the sampling period. Mean daily water temperature was typically 25°C (or greater) in most of July and August but declined to 18-19°C when sampling began in mid-September (Table 3). Cooling progressed rapidly in the fall and declined to 10-12°C when sampling ended in late October.

Table 1. Sampling dates, river flow and temperature during Black Rocks sampling, 2011-2012. Measurements were made at the USGS river gage at the Utah-Colorado state line (09163500).

Year	Dates	Pass	Mean River Flow[1] (CFS)	Mean Water Temperature[1] (ºC)
2011	9/13-9/16	1	5,128	18.21
	9/26-9/30	2	4,522	17.18
	10/11-10/14	3	5,248	12.79
	10/25-10/28	4	5,116	9.74
2012	9/11-9/14	1	2,651	19.82
	9/25-9/27	2	2,743	16.14
	10/9-10/11	3	2,277	12.92
	10/22-10/24	4	2,585	12.28

[1] Mean of Daily Means

General Fish Health

Most fish appeared to be in good health during and after treatment and swam away quickly after they were released. In 2011, two juvenile indeterminate *Gila* died after being captured for reasons unknown; one humpback chub collected had a recent otter bite, but no visible infection; and two humpback chub had severe spinal deformities (scoliosis and lordosis; Pictures 3 and 4), one of which swam upside down (and was recaptured in 2012). In 2012, one roundtail chub died after its gills were damaged by a trammel net. Also in 2012, a volunteer PIT tagged one humpback chub and one roundtail chub deeply and may have caused internal damage; however, both swam away after treatment. All other *Gila* appeared healthy upon release. No evidence of parasites or fungus was noted in captured or recaptured fish.

Picture 3. Humpback chub captured in Black Rocks (2011) with severe lordosis resulting in a deformed caudal peduncle. Photo credit: T. Francis, USFWS.

Picture 4. Humpback chub captured in Black Rocks (2011 and 2012) with severe scoliosis and lordosis resulting in a deformed caudal peduncle. Photo credit: T.Francis, USFWS.

Humpback chub

Relative Abundance

A total of 79 individual humpback chub were captured in 2011 (six were within-year recaptures) and 119 individual humpback chub were captured or sighted in 2012 (12 were within-year recaptures or re-sights). In 2011, 331.72 hours of trammel netting resulted in 87% of the humpback chub catch and 8.97 hours of electrofishing resulted in 13% of the humpback chub catch. In 2012, 405.32 hours of trammel netting resulted in 70% of the humpback chub catch, 1,770.27 hours of baited hoop netting resulted in 22% of the humpback chub catch, and antenna sightings resulted in 8% of the humpback chub catch.

The LN transformed mean catch rates of humpback chub captured in trammel nets ranged between about 0.06 to 0.25 fish per net hour in 2011-2012 (Figure 2). The LN transformed mean CPE in passes 3 and 4, of 2012, was significantly ($P<0.05$) higher than many passes in 2007, 2008 and 2011 (Figure 2). The LN transformed mean CPE for humpback chub was significantly higher in 1999 when compared to all years except for 1998 (Figure 3). Mean

CPE for humpback chub was significantly higher in 1998 when compared to all years except for 1999, 2011, and 2012 (Figure 3). During all other years mean CPE varied though not significantly.

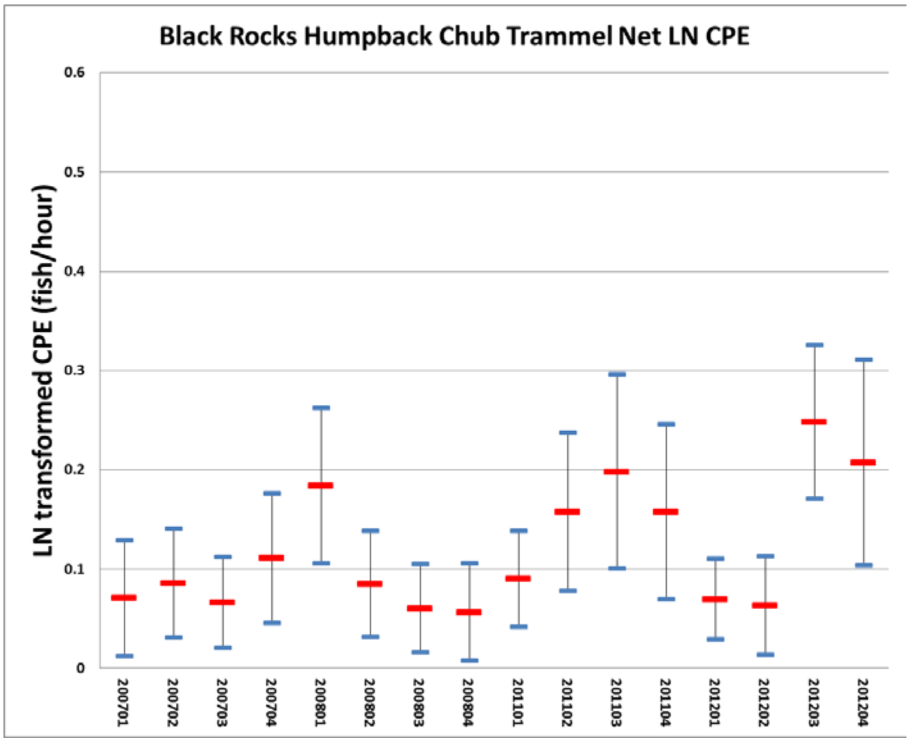


Figure 2. LN transformed mean CPE (fish/hr; 95% CI) for humpback chub captured using trammel nets in Black Rocks, 2007–2008 and 2011-2012. Dates of sampling trips (passes) are provided in Table 1.

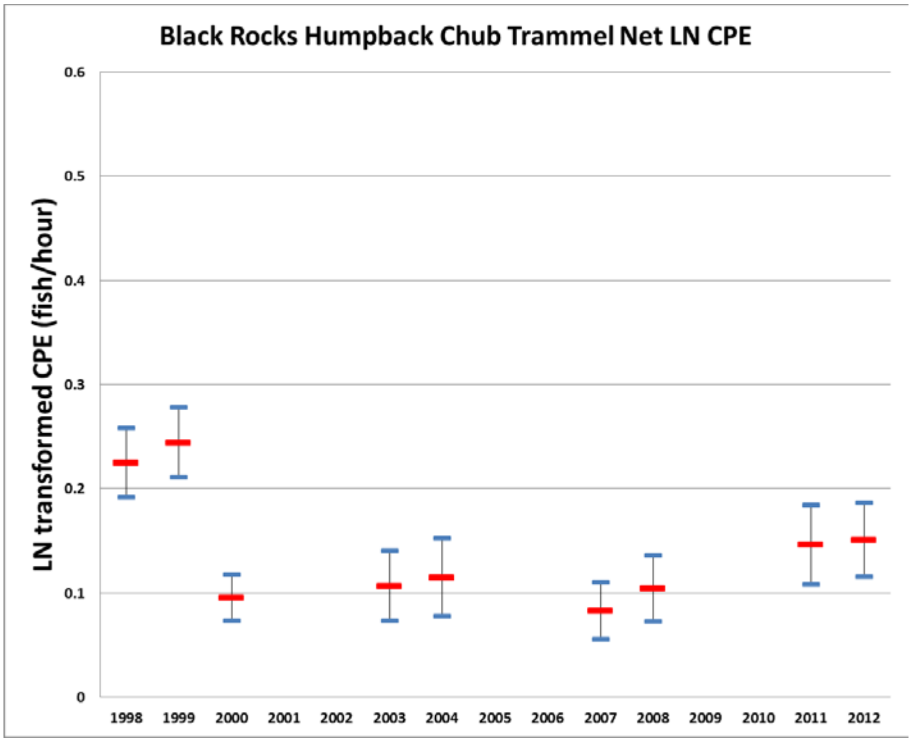


Figure 3. LN transformed mean CPE (fish/hr; 95% CI) for humpback chub captured using trammel nets; 1998–2000, 2003–2004, 2007–2008, and 2011-2012.

Electrofishing was only conducted in 2011, and mean catch rates of humpback chub was 1.22 (± 1.40, 95% CI) fish per hour. In 2012, flows inhibited our ability to bring a hard-bottom electrofishing craft to the study area.

The LN transformed mean catch rates of humpback chub captured in baited hoop nets ranged between about 0.00 to 0.03 fish per net hour in 2012 (Figure 4). During all passes mean CPE varied though not significantly with the exception of pass 2 when no humpback chub were caught with this method. Baited hoop netting was not utilized as a sampling technique until 2012; therefore, there is no effort in previous years to compare.

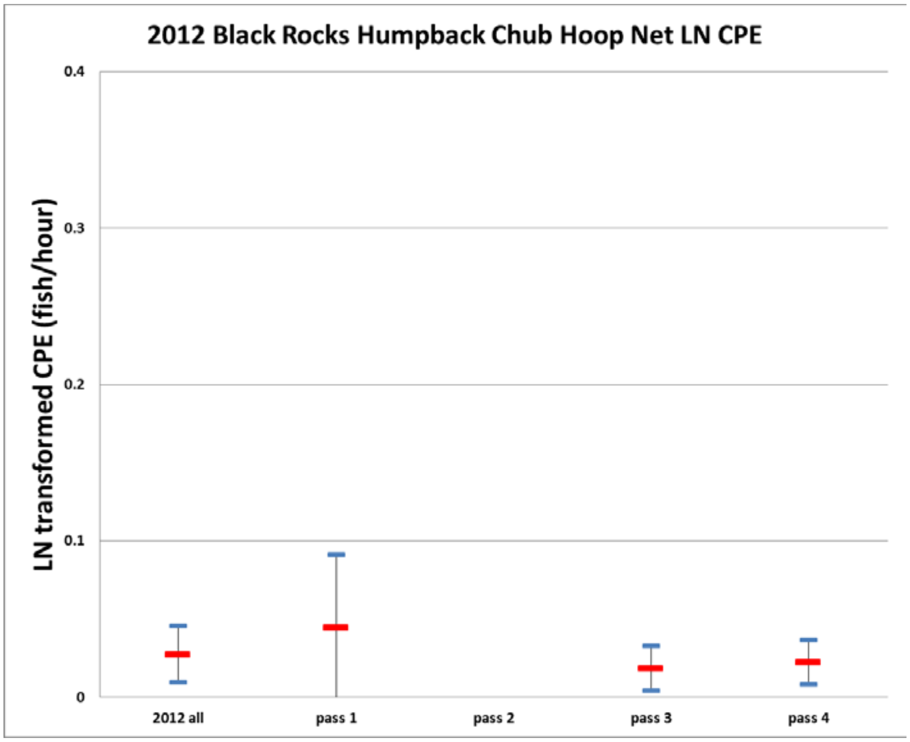


Figure 4. LN transformed mean CPE (fish/hr; 95% CI) for humpback chub captured using baited hoop nets in Black Rocks 2012. Dates of sampling trips (passes) are provided in Table 1.

Size Structure

Morphologically confirmed humpback chub captured in Black Rocks during 2011 and 2012 ranged from 162 to 408 mm TL (mean 263 mm; Figure 5). In 2011 and 2012, 174 juvenile *Gila* (roundtail chub, humpback chub or an intergrade that couldn't be morphologically distinguished) captured ranged from 73 to 186 mm TL (mean 117 mm; Figure 5). Size structure has shifted towards smaller adult humpback chub which had a unimodal (mode 250 mm; Figure 5) distribution when compared to most other years (which ranged from bimodal to unimodal distributions with modes from 230 to 340 mm TL with a mean of 290 mm TL; Figure 6).

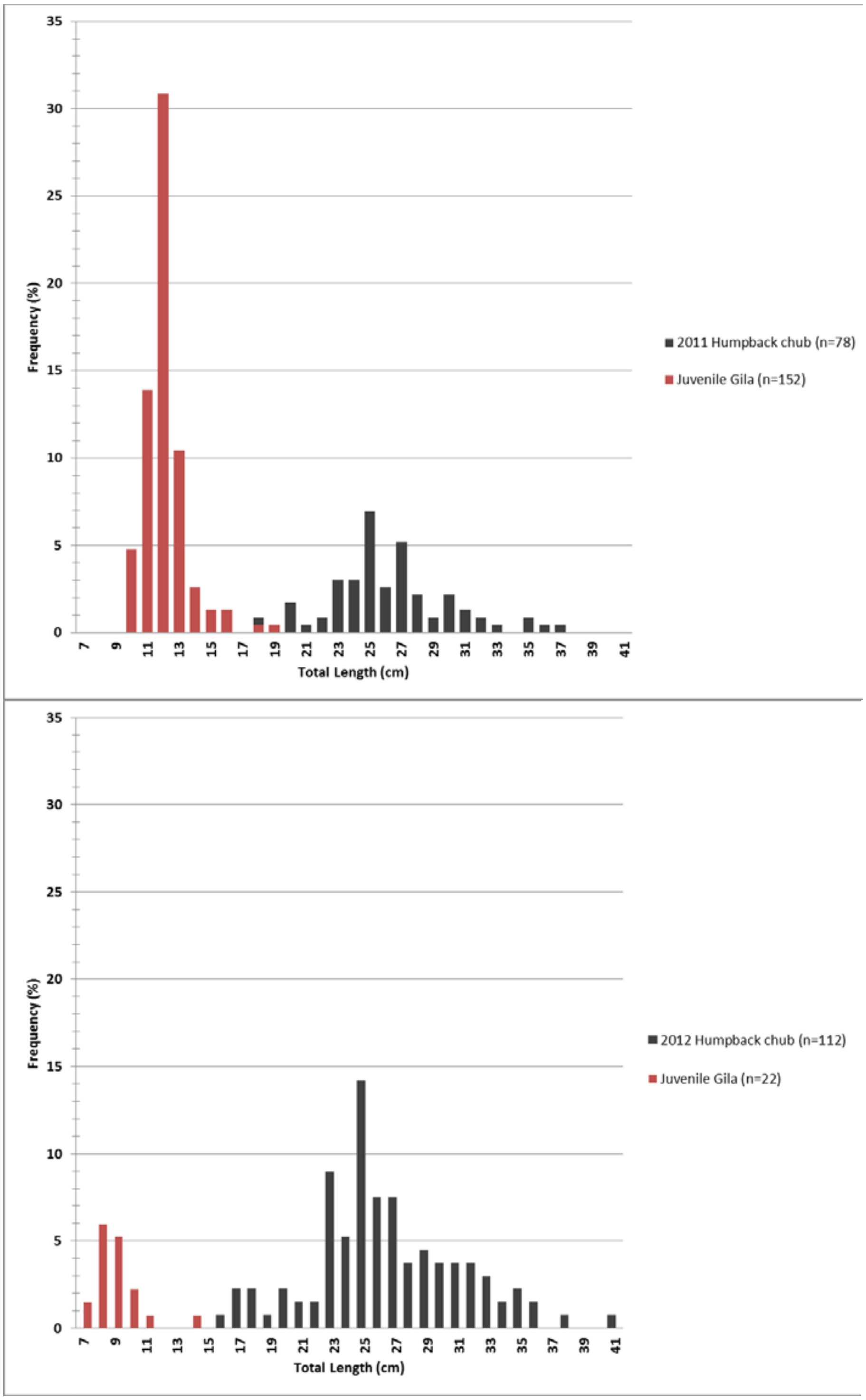
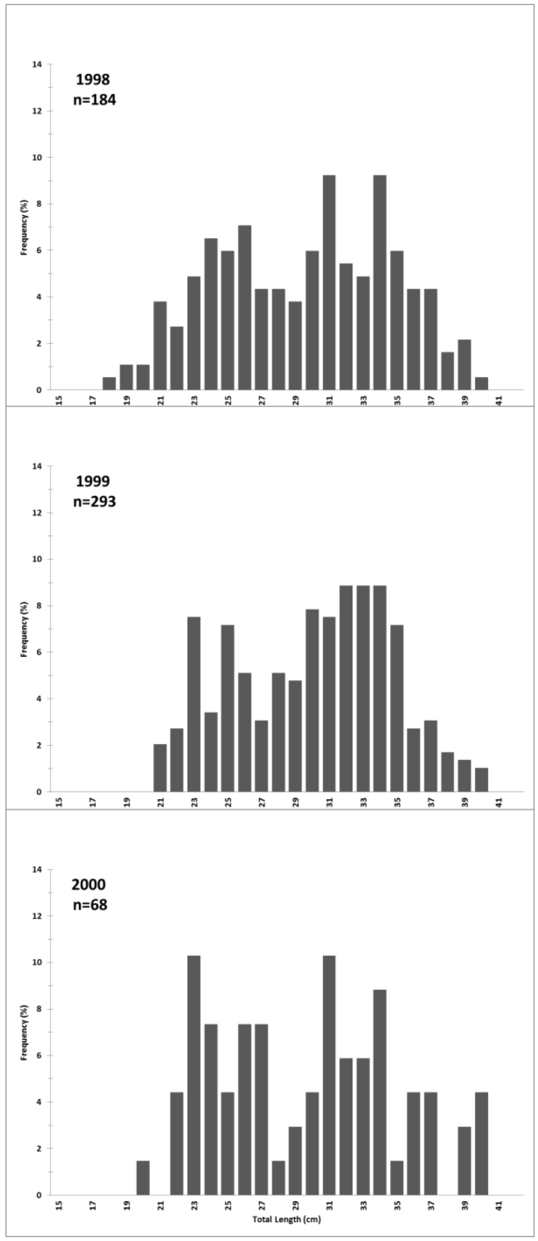


Figure 5. Size structure of humpback chub in Black Rocks, 2011-2012.



1998
n=184
1999
n=293
2000
n=68
Frequency (%)
Total Length (cm)

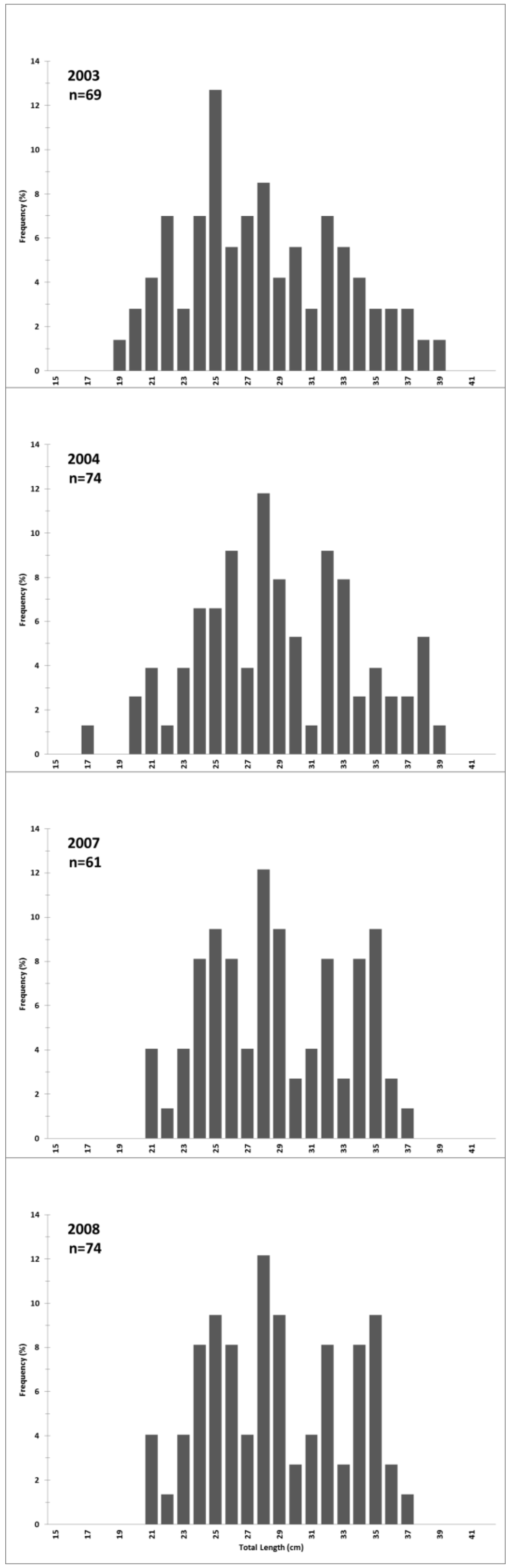


Figure 6. Size structure of humpback chub in Black Rocks, 1998–2000, 2003–2004 and 2007–2008.

Growth

A total of 28 individual humpback chub were captured during 2011-2012 that had been captured and measured in previous years, in some cases, more than once. These fish were partitioned into two groups based on their length when initially tagged: those < 300 mm TL and those ≥ 300 mm TL. Mean annual growth for fish < 300 mm was 12.2 mm/yr (n = 24; SE = 1.8; range, 2–37). Mean annual growth of fish ≥ 300 mm was 10.2 mm/yr (n = 4; SE = 3.6; range, 3–20).

Relative Condition

The M_e (mass-length regression) equation derived from humpback chub captured in Black Rocks and Westwater Canyon (n = 5,265) is

$$\log_{10} M_e = ((\log_{10} \text{length})\ 2.7516) + (-4.5089)$$

Mean K_n (relative body condition) for humpback chub in Black Rocks increased significantly (P<0.05) between 1998 and 1999 and between 1998 and 2000. During all other years mean K_n varied though not significantly. There appeared to be an overall upward trend in mean K_n for humpback chub in Black Rocks from 1998 to 2003, and again from 2004 to 2011(Figure 7). In most years, mean K_n of humpback chub in Westwater Canyon and Black Rocks was similar, with trends tracking one another quite closely (Figures 7 and 8). Mean K_n was significantly (P<0.05) higher in Westwater Canyon than Black Rocks in 2008, 2011 and 2012.

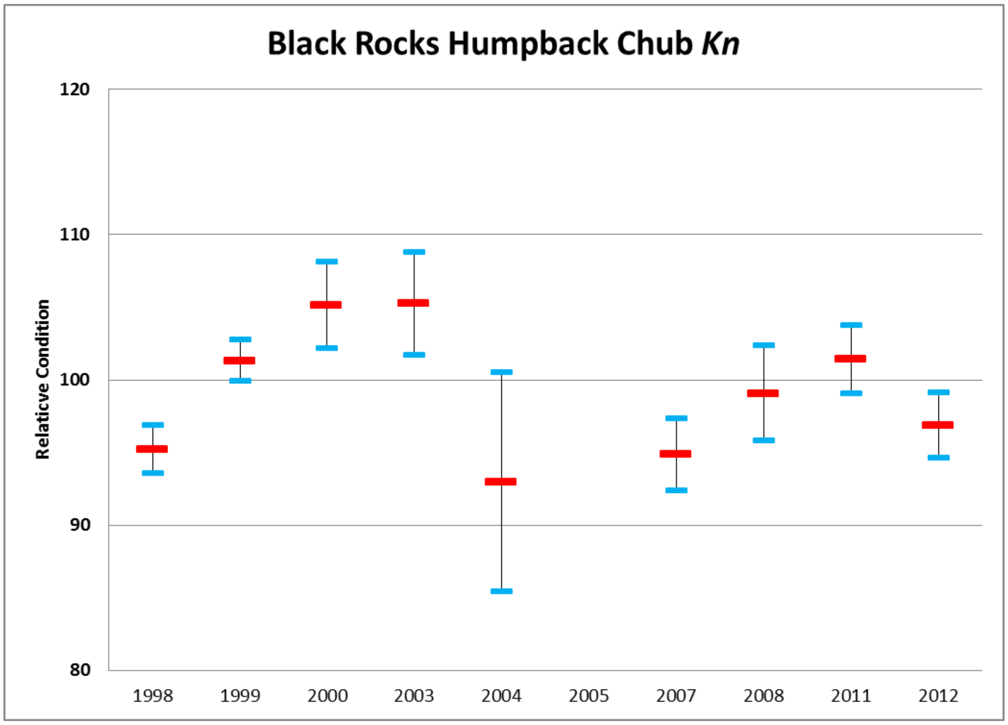


Figure 7. Mean relative body condition (Kn) of humpback chub captured in Black Rocks of the Colorado River (RK 217–218.4). Upper and lower bars represent 95% confidence intervals.

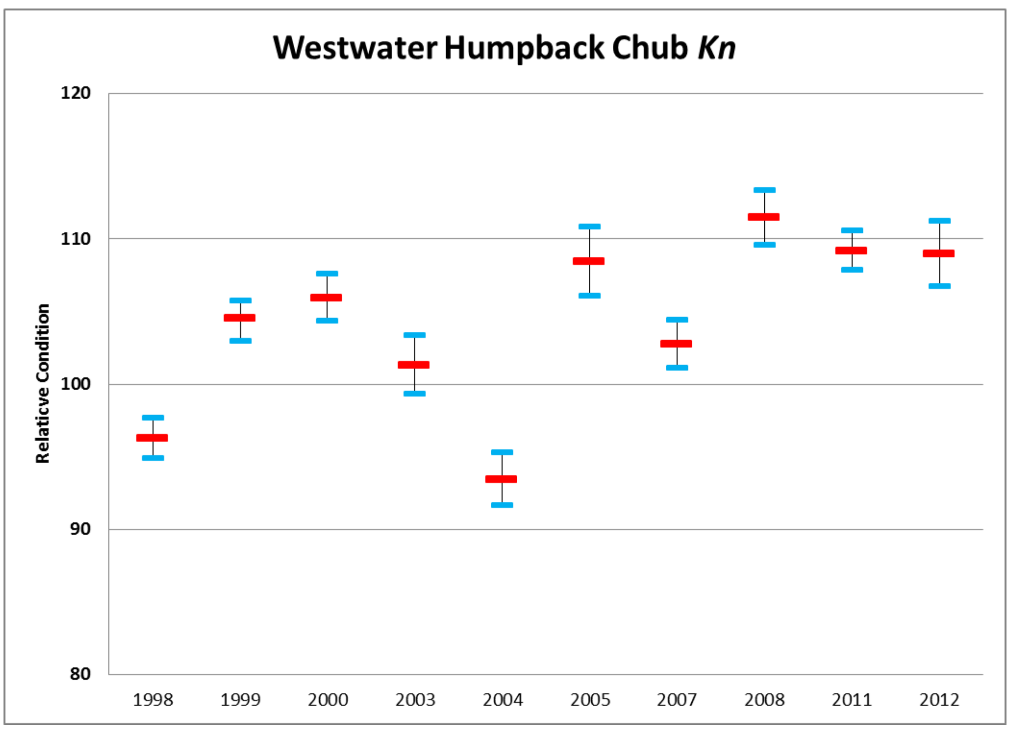


Figure 8. Mean relative body condition (Kn) of humpback chub captured in Westwater Canyon of the Colorado River (RK 205.3-180.7). Upper and lower bars represent 95% confidence intervals.

Model Selection

A set of 13 models was fit to the data to examine the importance of year-specific apparent survival (S), reach transition probabilities (ψ, probability of a fish moving from Blackrocks to Westwater, and vice versa), and capture probabilities (p's, Table 2). The top model in the set contained 45% of the AIC_c weight and had 70 estimable parameters including survival rates for each year within a reach (an additive model for reaches) and as a function of TL and TL^2, transition probabilities, and probabilities of captures for every year, reach, and state combination. The second-ranked model had 35% of total model weight and one fewer parameter (the TL^2 term), with all else being the same. Because the signs of the survival terms in the top and second-ranked models were all negative and those models contained the bulk of the total weight (80%), and presented essentially the same trends, only the top-ranked model was interpreted in this analysis. A model with year and reach specific survival rates (and interactive model such that survival rates for every year and reach; 94 total parameters, model 11 in the set) received no weight and many survival parameters were not estimable.

Table 2. Model Selection in Program Mark for Parameter Estimation of Humpback Chub Collected in Black Rocks and Westwater Canyon, 1998-2012.

Real Function Parameters of	AICc	Delta AICc	AICc Weights	Model Likelihood
{S(state+TL^2) psi(state) p(state*year*pass) DM ID}	15530.3811	0	0.44833	1
{S(state+TL) psi(state) p(state*year*pass) DM ID}	15530.8789	0.4978	0.34954	0.7797
{S(state+TL) psi(state) p(state*year*pass+TL) DM ID}	15532.9341	2.553	0.12509	0.279
{S(state+TL^2) psi(state*TL) p(state*year*pass) DM ID}	15533.9034	3.5223	0.07704	0.1718
{S(state) psi(state) p(state*year*pass+TL) DM ID}	15580.5519	50.1708	0	0
{S(state) psi(state) p(state*year*pass+TL^2) DM ID}	15582.6181	52.237	0	0
{S(state) psi(state) p(state*year*pass)}	15591.7247	61.3436	0	0
{S(.) psi(state) p(state*year*pass)}	15595.6105	65.2294	0	0
{S(year) psi(state) p(state*year*pass)}	15595.8164	65.4353	0	0
{S(state*year) psi(state) p(state*year*pass)}	15599.2478	68.8667	0	0
{S(state*year) psi(state) p(state*year*pass) DM}	15599.2498	68.8687	0	0
{S(state*year) psi(state) p(state+year+pass)}	16086.9868	556.6057	0	0
{S(.) psi(state) p(state+year+pass)}	16113.8829	583.5018	0	0

S=survival, state=location of capture (Black Rocks or Westwater Canyon), psi=transition rates, TL=total length, p=probability of capture (or sighting [antenna detection])

Estimated Abundance

In previous reports, estimated adult humpback chub (TL > 199 mm; USFWS 2002) abundance was derived in a closed model (Program CAPTURE) for each time interval (1998-2000, 2003-2004, 2007-2008), and was not informed by the captures of prior sessions in Black Rocks or captures in Westwater Canyon. For this report, a combined robust design multi-state model re-estimated abundance for all of these time periods and 2011-2012, and the abundance estimate was informed by estimated apparent survival and transition rates between Black Rocks and Westwater Canyon. Considering the potential temporal separation between captures and the possibility of a given fish to grow into an adult size class by their next capture, all fish that were identified as a humpback chub, regardless of TL, were used in the estimate. However, most of the captures utilized by the model were adults (98.6%); thus, the model functionally produced estimates of the adult population. The top models' (Table 2) estimates of abundance were averaged for better precision.

The new estimates of abundance had tighter confidence intervals (CI) when compared to those reported in earlier work (Figure 9). Achieving CV's less than 0.20 are considered necessary for robust estimates. Abundance estimate CV's reported by earlier work in Black Rocks only achieved this standard once in 1999 (0.13), while this standard was achieved twice with the new model's estimates in 1999 (0.11) and 2012 (0.17). However, all of the CV's were reduced with the new model (Figure 11), suggesting better estimates of abundance in all years. With the new model, estimated humpback chub abundance in Black Rocks were highest in 1998 (n=880, CI 572-1,431) and 1999 (n=994, CI 810-1,245; Figure 10). By 2007, the estimated abundance of humpback chub declined significantly to their lowest point of 283 (CI 179-478) animals. Since 2007, estimated humpback chub abundance has remained stable. The

2011 estimate was 379 (CI 239-642) animals and the 2012 estimate was 404 (CI 298-571) animals (Figure 10).

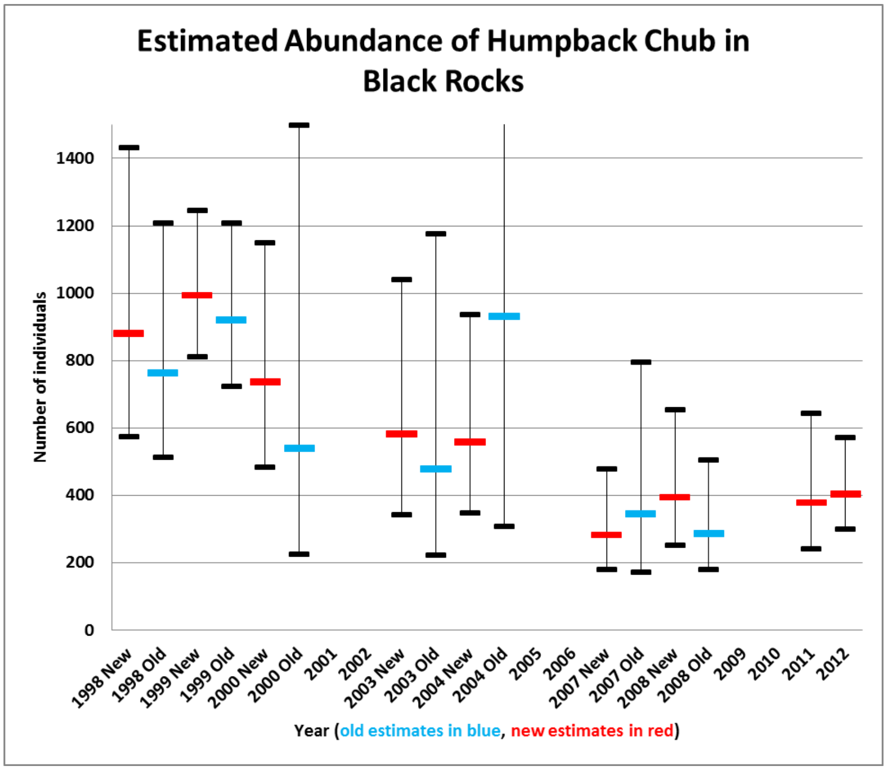


Figure 9. Old and new estimates of humpback chub abundance in Black Rocks, 1998-2012.

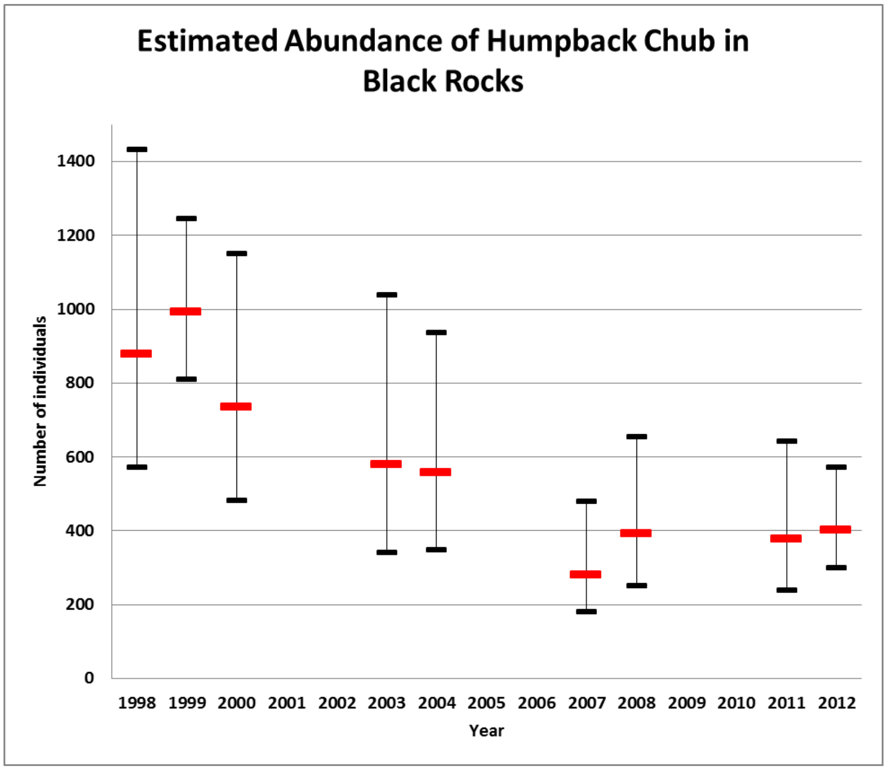


Figure 10. Model averaged estimates of humpback chub abundance in Black Rocks, 1998-2012.

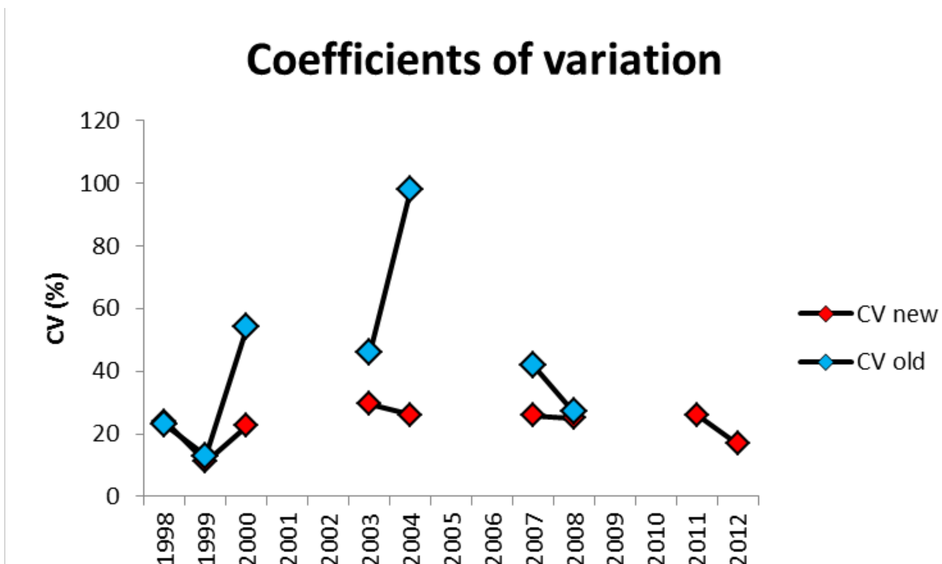


Figure 11. Coefficients of variations for new (red) and old (blue) estimates of humpback chub abundance.

Estimated Survival

Estimates of survival were derived from the top robust design multi-state model selected in Program Mark (Table 2). Estimated mean survival rates for humpback chub occupying

Black Rocks, from 1998-2011, has remained stable ranging from 64-70% (Figure 12) and these estimates were derived from a fixed mean TL of all the fish observed during a given year (Table 3). However, survival apparently declined for larger and older fish Estimated survival ranged from 86% for a fish at 200 mm TL to 56% for a fish at 400 mm TL (Figure 13).

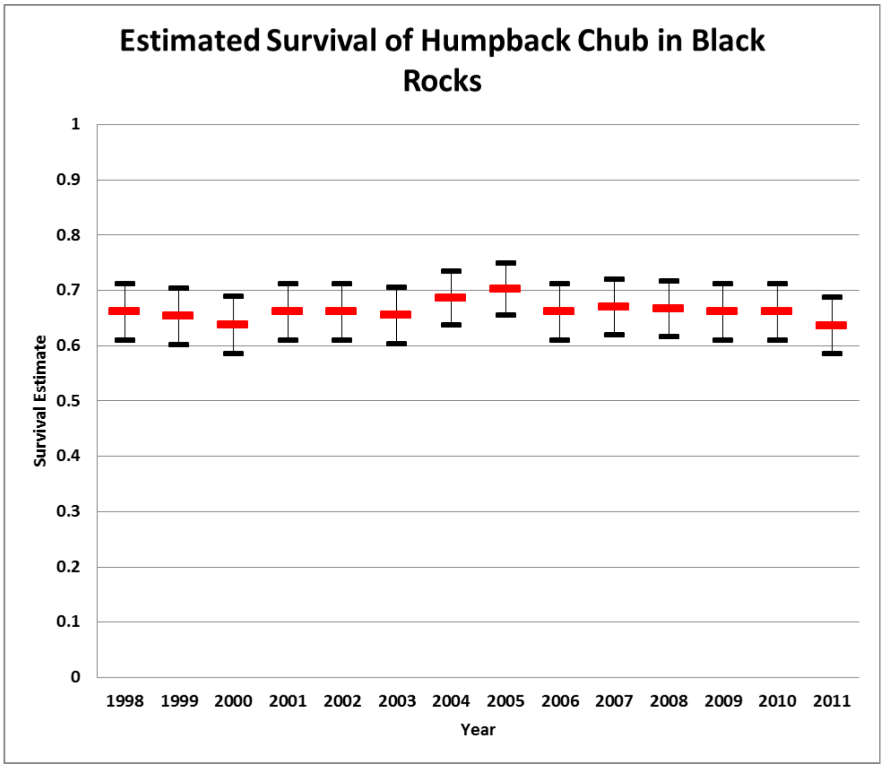


Figure 12. Estimated annual rates of survival for humpback chub in Black Rocks. Estimates are derived from a mean fixed TL of fish observed in a given year (range: 269-303 mm TL).

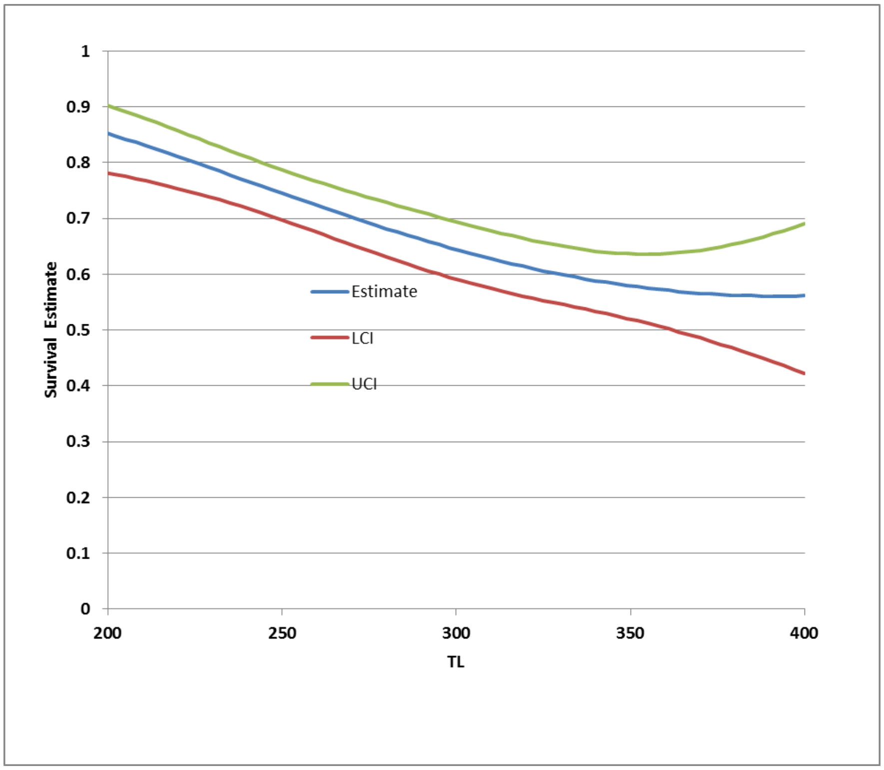


Figure 13. Estimated rates of survival for humpback chub (relationship derived from all fish collected in all years; 1998-2012) in Black Rocks at a given TL (mm).

Table 3. Mean annual total lengths (mm) of humpback chub captured in Black Rocks.

Year	N	Mean	Median	Std Dev	N	Minimum	Maximum
1999	52	294.2	291	47.3	52	208	395
2000	67	303.7	303	46.0	67	219	401
2001	0	290.0					
2002	0	290.0					
2003	32	293.6	286.5	47.7	32	226	392
2004	39	276.9	273	37.4	39	206	377
2005	42	269.1	260	43.9	42	183	386
2006	0	290.0					
2007	64	285.1	281.5	39.2	64	217	369
2008	103	286.9	285	37.4	103	225	368
2009	0	290.0					
2010	0	290.0					
2011	52	303.9	302	34.1	52	230	366
2012	82	296.7	295.5	38.0	82	209	377

Probabilities of Capture

The top model selection (Table 2) supported estimation of capture probabilities (*p*) for humpback chub that are specific to state (Black Rocks or Westwater Canyon), pass and year.

As was the case with survival estimation, *p* were calculated from a fixed mean TL of all the fish observed during a given year (range: 269-303 mm TL: Table 3) so that among-year *p* could be compared. Annual *p* ranged from 9% in 2000 to 30% in 2012 (Figure 14).

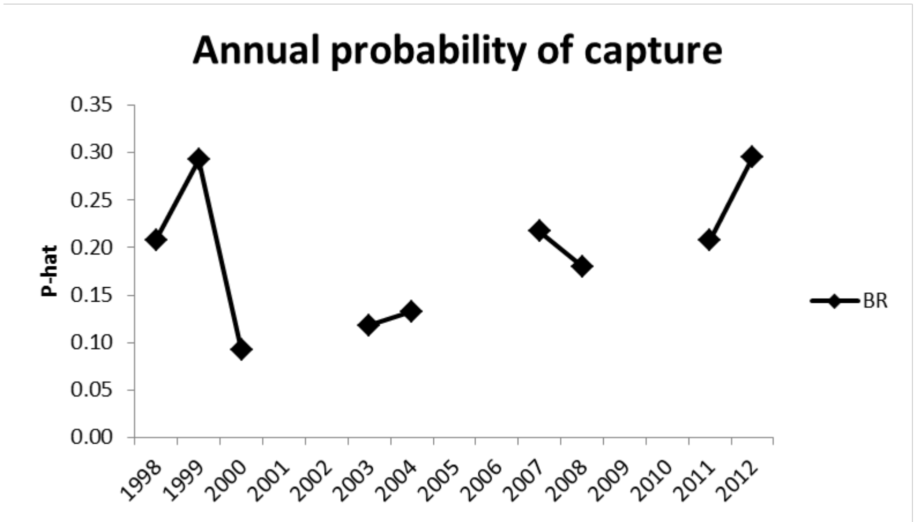


Figure 14. Annual probability of capturing humpback chub in Black Rocks. Estimates are derived from a mean fixed TL of fish observed in a given year.

Probabilities of Transition

Transition probabilities (psi) estimate the likelihood of a tagged humpback chub to move from one state (Black Rocks or Westwater Canyon) to another. The psi adjusts estimated p-hat because p-hat functions on the likelihood of a fish staying in the study area. From 1998-2011, estimated psi for fish moving from Black Rocks to Westwater Canyon was 1.4% (CI 0.5-3.7%) and the estimated psi for fish moving from Westwater Canyon to Black Rocks was 1.8% (CI 1.1-2.9%).

Movement and Recapture Histories

Although there were few within-year recaptures of fish (n=6 in 2011, n=12 in 2012), 35 humpback chub (n=6 in 2011, n=17 in 2012) were recaptured that had been handled in a previous year of this study or in earlier mark-recapture studies (McAda 2002, 2007; Francis and McAda, 2011: Table 4). Twenty three of these were recaptures of fish from Black Rocks, one was first collected in Westwater Canyon (2007) and was later recaptured in Black Rocks in two separate years (2008 and 2012). In addition, twelve humpback chub were recaptured that had been first captured in Westwater Canyon (n=3 in 2011, n=9 in 2012). There was only one movement of a humpback chub from Black Rocks to Westwater Canyon during 2011 and 2012. This fish was first captured in Westwater Canyon in 2011, and was subsequently recaptured in Black Rocks in 2011 only to return to Westwater Canyon and be recaptured again in 2012.

Table 4. Capture history of humpback chub captured in 2011–2012 that were handled in earlier years (BR = Black Rocks, WW = Westwater).

PIT TAG	1998	1999	2000	2003	2004	2005[1]	2007	2008	2011	2012
2011										
3D91C2D9AFE0C	BR								BR	
3D91C2D9AC355				BR					BR	
3D91BF1A04680					WW				BR	
3D9257C6B67AC							BR		BR	
3D9257C6B6EC8							BR		BR	
3D91C2C57A896								BR	BR	BR
3D91C2C57B080								BR	BR	BR
3D91C2C3EF6EF								WW	BR	
3D91C2D154097									WW + BR	WW
2012										
3D9257C6AC975		BR		BR			BR			BR
3D91BF1CD2755					WW			WW		BR
3D9257C6B9029							BR	BR		BR
3D9257C66CD4D							WW		WW	BR
3D9257C6A6D12							WW			BR
3D9257C6A1B43							WW	BR		BR
3D9257C66CE37							WW			BR
3D91C2C3A0CB0								BR		BR
3D91C2C3D2308								WW		BR
3D91C2C3F031A								WW		BR
3D91C2D9B033C									BR	BR
3D91C2D9A0A89									BR	BR
3D91C2D9990CB									BR	BR
3D91C2D9A26BE									BR	BR
3D91C2D9AA333									BR	BR
3D91C2D91770B									BR	BR
3D91C2D912B6C									BR	BR
3D91C2D999BB8									BR	BR
3D91C2D998B29									BR	BR
3D91C2DD648EA									BR	BR
3D91C2D99D830									BR	BR
3D91C2D9AA19F									BR	BR
3D91C2D9A16F8									BR	BR
3D91C2D164CEB									WW	BR
3D91C2D59C53E									WW	BR
3D91C2D5AB9FD									WW	BR

[1] Sampling only occurred in Westwater Canyon.

Submersible PIT tag antenna were only used during pass 3 in 2012

Roundtail chub

Relative Abundance

A total of 491 individual roundtail chub were captured in 2011 (21 were within-year recaptures) and 657 individual roundtail chub were captured or sighted in 2012 (18 were within-year recaptures or re-sights). In 2011, 331.72 hours of trammel netting resulted in 74% of the roundtail chub catch and 8.97 hours of electrofishing resulted in 26% of the roundtail chub catch. In 2012, 405.32 hours of trammel netting resulted in 57% of the roundtail chub catch, 1,770.27 hours of baited hoop netting resulted in 37% of the roundtail chub catch, and antenna sightings resulted in 6% of the roundtail chub catch.

The LN transformed mean catch rates of roundtail chub captured in trammel nets ranged between about 0.17 to 1.34 fish per net hour in 2011-2012 (Figure 15). Mean CPE in pass 3 and 4, of 2008, was significantly ($P<0.05$) higher than many passes in 2007, 2011 and 2012 (Figure 15). The LN transformed mean CPE for roundtail chub increased significantly in 2003 when compared to 1998-2000, and remained significantly higher through 2012 (Figure 16). The LN transformed mean CPE for roundtail chub was significantly higher in 2008 when compared to all other years (Figure 16).

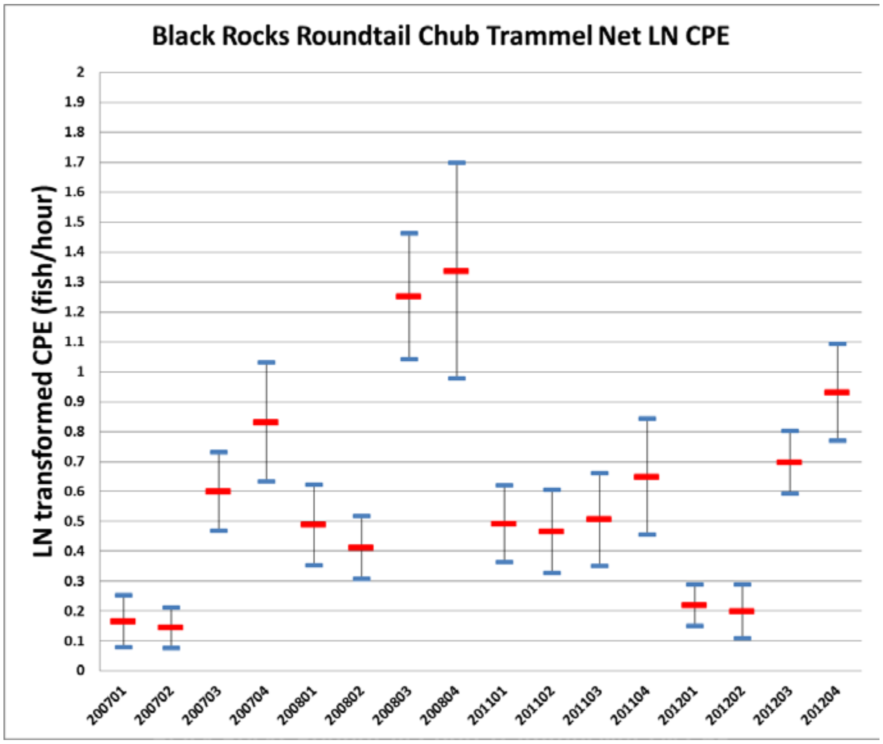


Figure 15. LN transformed mean CPE (fish/hr; 95% CI) per pass for roundtail chub captured using trammel nets in Black Rocks, 2007–2008 and 2011-2012. Dates of sampling trips (passes) are provided in Table 1.

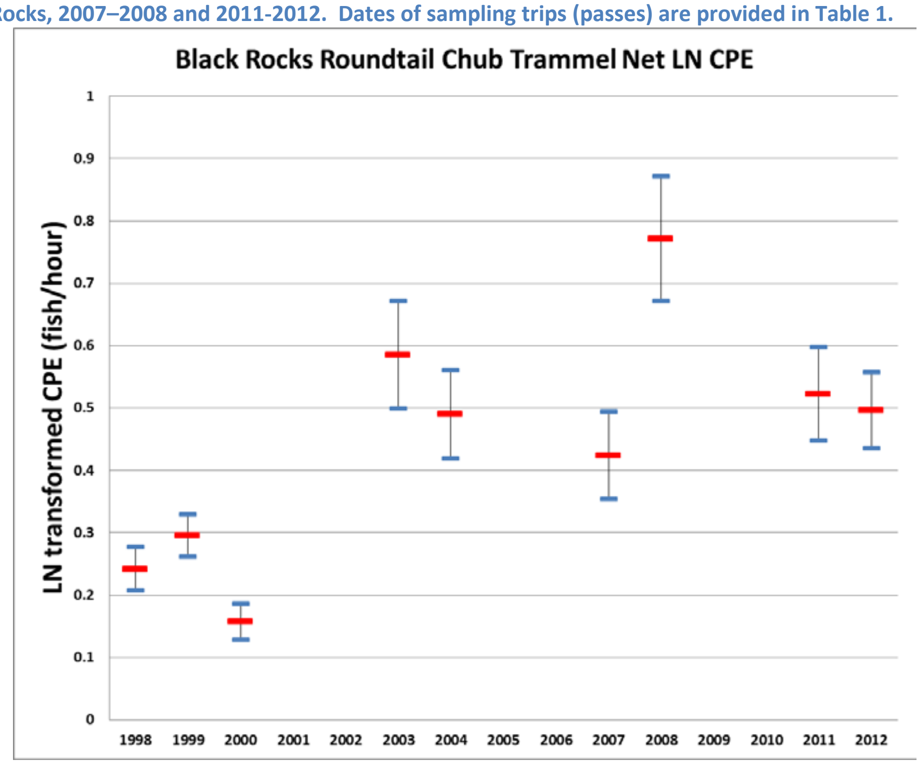


Figure 16. LN transformed mean CPE (fish/hr; 95% CI) per year for roundtail chub captured using trammel nets; 1998–2000, 2003–2004, 2007–2008, and 2011-2012.

Electrofishing was only conducted in 2011, and mean catch rates of roundtail chub was 14.54 (± 15.20, 95% CI) fish per hour. In 2012, flows inhibited our ability to bring a hard-bottom electrofishing craft to the study area.

The LN transformed mean catch rates of roundtail chub captured in baited hoop nets ranged between about 0.01 to 0.17 fish per net hour in 2012 (Figure 17). During pass 1 and pass 2 mean roundtail chub CPE was significantly ($P<0.05$) lower than pass 3 and pass 4. The LN transformed mean catch rates of juvenile *Gila* spp. (morphologically unidentifiable to species) in baited hoop nets ranged between about 0.01 to 0.04 fish per net hour in 2012 (Figure 18). There were no significant variations in juvenile *Gila* spp. baited hoop net CPE among passes in 2012. Baited hoop netting was not utilized as a sampling technique until 2012; therefore, there is no effort in previous years to compare.

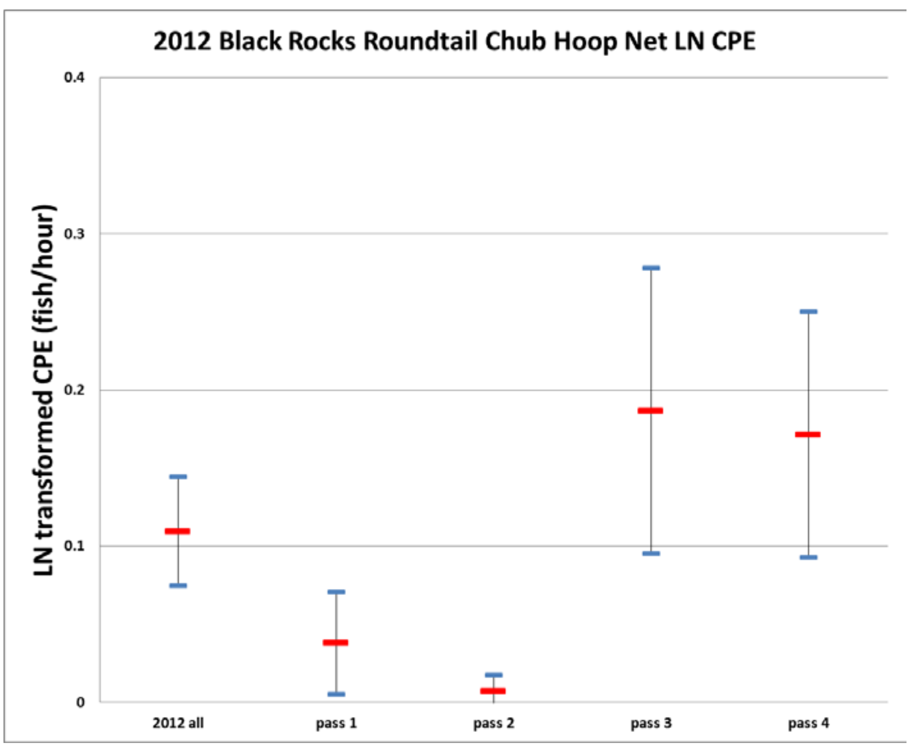


Figure 17. LN transformed mean CPE (fish/hr; 95% CI) for roundtail chub captured using baited hoop nets in Black Rocks 2012. Dates of sampling trips (passes) are provided in Table 1.

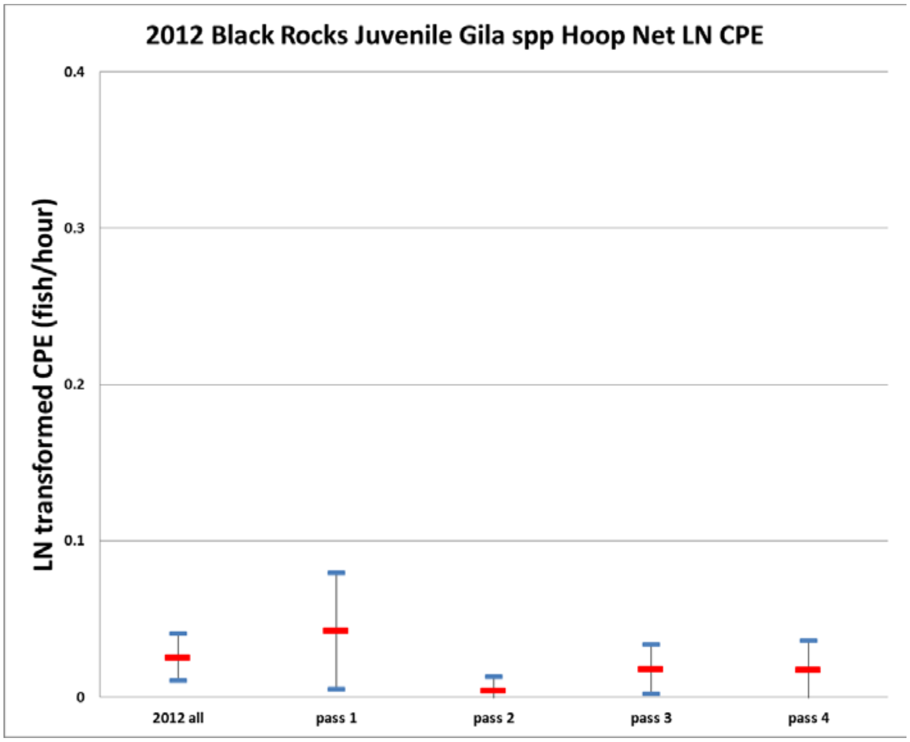


Figure 18. LN transformed mean CPE (fish/hr; 95% CI) for juvenile Gila spp. captured using baited hoop nets in Black Rocks 2012. Dates of sampling trips (passes) are provided in Table 1.

Size Structure

Roundtail chub captured in Black Rocks during 2011 and 2012 ranged from 166 to 471 mm TL (mean 268 mm; Figure 19). In 2011 and 2012, 174 juvenile *Gila* (roundtail chub, humpback chub or an intergrade that couldn't be morphologically distinguished) captured ranged from 73 to 186 mm TL (mean 117 mm; Figure 5). Size structure has shifted towards a larger proportion of smaller adult roundtail chub which had a bimodal distribution in 2012 (modes 200 and 280 mm; Figure 19) distribution when compared to most other years (unimodal distributions with modes from 240 to 280 mm TL with a mean of 260 mm TL; Figure 20).

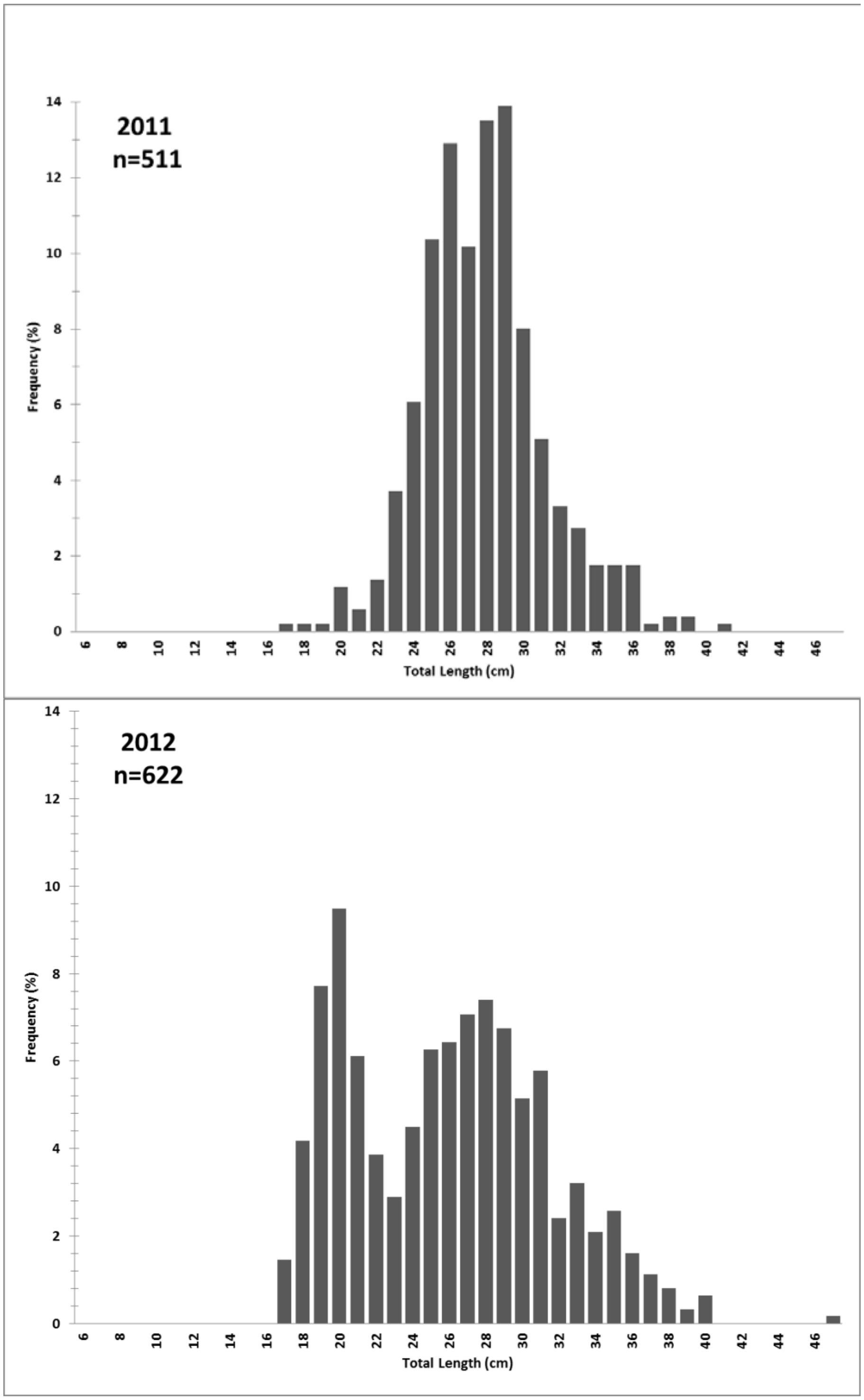


Figure 19. Size structure of roundtail chub in Black Rocks, 2011-2012.

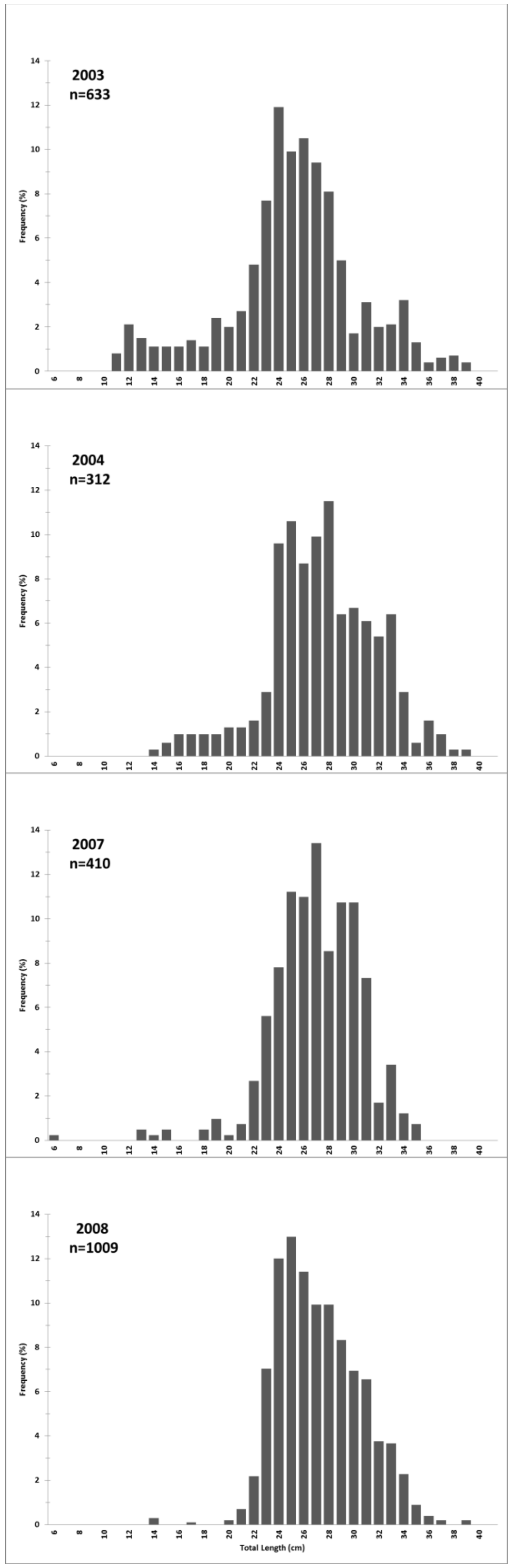


Figure 20. Size structure of roundtail chub in Black Rocks, 2003–2004 and 2007–2008.

Growth

A total of 58 individual roundtail chub were captured during 2011-2012 that had been captured and measured in previous years, in some cases, more than once. These fish were partitioned into two groups based on their length when initially tagged: those < 300 mm TL and those ≥ 300 mm TL. Mean annual growth for fish < 300 mm was 24.2 mm/yr (n = 47; SE = 3.0; range, 1–91). Mean annual growth of fish ≥ 300 mm was 17.8 mm/yr (n = 11; SE = 4.6; range, 3–43).

Relative Condition

The M_e (mass-length regression) equation derived from roundtail chub captured in Black Rocks and Westwater Canyon (n = 11,706) is

$$\log_{10} M_e = ((\log_{10} \text{length})\ 2.9855) + (-5.0713)$$

Roundtail chub weights were not recorded in 2003 and 2004; therefore, mean K_n (relative body condition) was not calculated for these years. Mean K_n for roundtail chub in Black Rocks increased significantly (P<0.05) from 1998 to 1999 and 2000, and again from 2007 to 2008 followed by a significant declining trend in 2011 and 2012. There was a significant difference in mean K_n for roundtail chub in Black Rocks during most years (Figure 21). In most years, mean K_n of roundtail chub in Westwater Canyon and Black Rocks was similar, with trends tracking one another quite closely (Figures 21 and 22). Mean K_n was significantly (P<0.05) higher in Westwater Canyon than Black Rocks in 2007, 2008, 2011 and 2012.

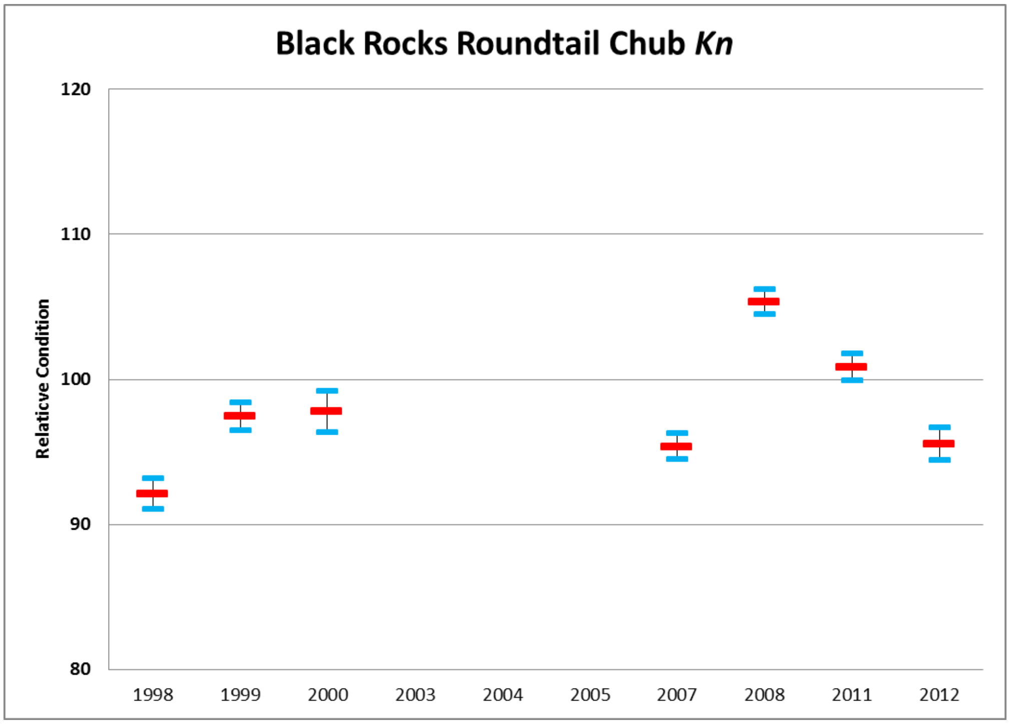


Figure 21. Mean relative body condition (Kn) of roundtail chub (RT) captured in Black Rocks of the Colorado River (RK 217–218.4). Upper and lower bars represent 95% confidence intervals.

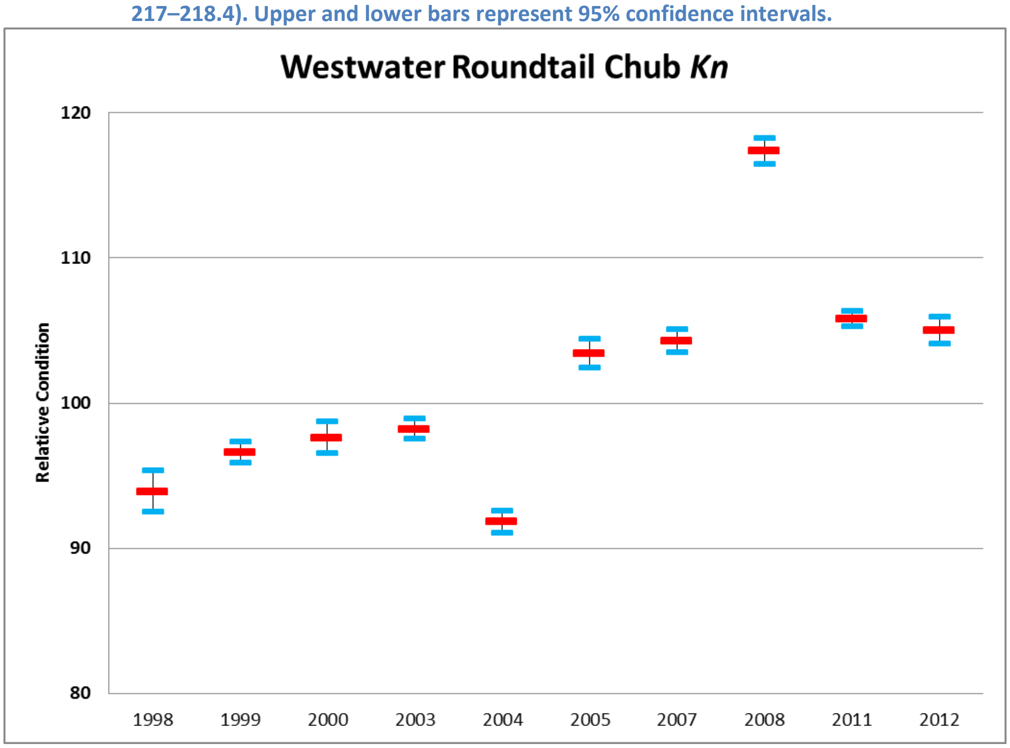


Figure 22. Mean relative body condition (Kn) of roundtail chub (RT) captured in Westwater Canyon of the Colorado River (RK 205.3-180.7). Upper and lower bars represent 95% confidence intervals.

Movement and Recapture Histories

Fifty seven roundtail chub (n=14 in 2011, n=43 in 2012) were recaptured that had been handled in a previous year of this study or in earlier mark-recapture studies (McAda 2002, 2007; Francis and McAda, 2011). Seven of these fish were first collected in Westwater Canyon (n=4 in 2005, n=2 in 2007, and n=1 in 2008) and were later recaptured in Black Rocks (2011 and 2012; Table 5).

Table 5. Capture history of roundtail chub captured in 2011–2012 that were handled in earlier years (BR = Black Rocks, WW = Westwater).

PIT TAG	2005[1]	2007	2008	2011	2012
2011					
3D91BF18C61D4	WW	WW		BR	
3D9257C695AA0		BR		BR	
3D9257C6A5816		BR	BR	BR	
3D9257C6B78E1		BR		BR	
3D9257C6B814D		BR	BR	BR	
3D9257C6B9166		BR		BR	
3D9257C6B9916		BR	BR	BR	
3D91C2C3E79FE			WW	BR	
3D91C2C3F2E09			BR	BR	
3D91C2C439A54			BR	BR	BR
3D91C2C579189			BR	BR	
3D91C2C579F17			BR	BR	
3D91C2C57AFD3			BR	BR	
3D91C2C57D10C			BR	BR	
2012					
3D91BF18C2414	WW				BR
3D91BF18C2B4F	WW	WW			BR
3D91BF1CD2FC9	WW				BR
3D9257C69E36B		BR			BR
3D9257C6A1B4A		WW			BR
3D9257C6B3921			BR		BR
3D9257C6B85C1		BR			BR
3D9257C6B9037		BR	BR		BR
3D9257C6B9AE5		WW	WW		BR
3D91C2C3D7C68			BR		BR
3D91C2C3E97C4				BR	BR
3D91C2C43F0EE			BR		BR
3D91C2C571757			BR		BR
3D91C2C5719D3			BR		BR
3D91C2C57AADD			BR		BR
3D91C2C57C972			BR		BR
3D91C2D77EE2E				BR	BR
3D91C2D908207				BR	BR
3D91C2D90B9CA				BR	BR
3D91C2D90C7B7				BR	BR
3D91C2D90E37D				BR	BR
3D91C2D994069				BR	BR
3D91C2D995B66				BR	BR
3D91C2D9966A7				BR	BR
3D91C2D9970F3				BR	BR
3D91C2D99900D				BR	BR
3D91C2D99A707				BR	BR
3D91C2D99AD18				BR	BR
3D91C2D99B8D2				BR	BR
3D91C2D99C111				BR	BR
3D91C2D99DD3A				BR	BR
3D91C2D9A16CC				BR	BR
3D91C2D9A16F8				BR	BR
3D91C2D9A2335				BR	BR
3D91C2D9AB514				BR	BR
3D91C2D9ADEC0				BR	BR
3D91C2D9AEE31				BR	BR
3D91C2D9AFE99				BR	BR
3D91C2DD5F27F				BR	BR
3D91C2DD64EDD				BR	BR
3D91C2DD655C9				BR	BR
3D91C2DD669AD				BR	BR
3D91C2DD68696				BR	BR

[1] Sampling only occurred in Westwater Canyon.

Incidental Catch

Species Composition

Humpback chub and *Gila* (a fish with both humpback chub and roundtail chub morphological characteristics) percent representation in trammel net captures combined have remained fairly stable in 2007 (8.32%), 2008 (5.42%), 2011 (9.05%) and 2012 (8.77%) in Black Rocks. Roundtail chub percent representation in our trammel net catch was stable in three of the four years (2007 {48.91%}, 2011 {44.6%}, and 2012 {33.31%}); however, in 2008, the trammel net catch was primarily roundtail chub at 72.26% (Figure 23).

In all four years the number of native species collected in Black Rocks by trammel nets has remained at six or seven (Table 6). The number of nonnative species represented in the trammel net catch has increased from seven in both 2007 and 2008, to ten in 2011 and 2012 (Table 6). Four of those additional species are piscivorous (bluegill, yellow bullhead, largemouth and smallmouth bass). In 2011, largemouth bass were first observed in the trammel net catch (.11%) and, in 2012, they increased to 6% of the total trammel net catch (Figure 23).

The three other endangered Colorado River fishes were all incidentally caught during this effort in 2011 and 2012. In 2011, one bonytail (*Gila elegans*), two Colorado pikeminnow (*Ptychochelius lucius*), and four razorback sucker (*Xyrauchen texanus*) were collected by either trammel netting or electrofishing. In 2012, five adult Colorado pikeminnow were collected by trammel netting (Table 7).

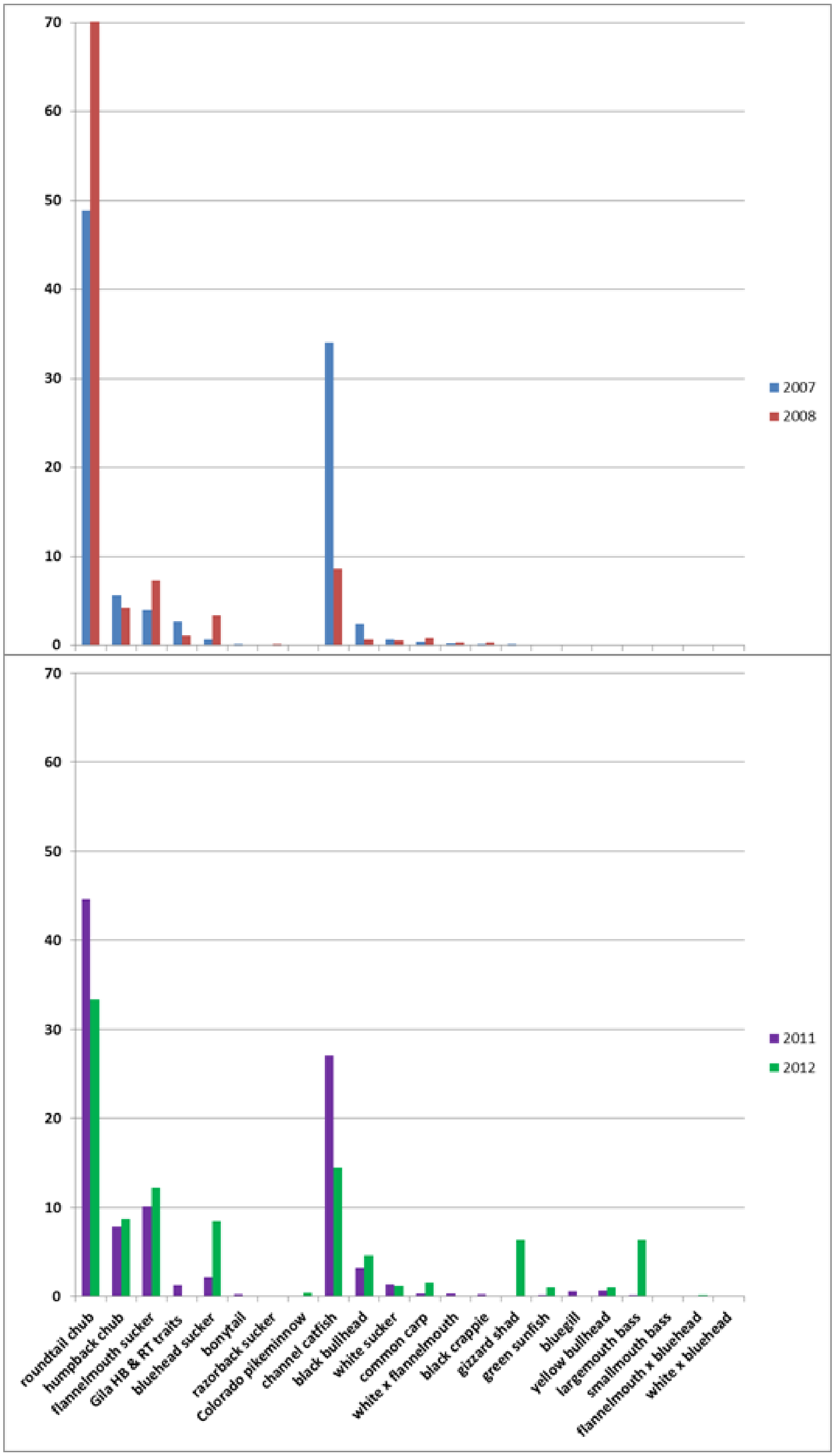


Figure 23. Percent species composition in trammel net catch: 2007 and 2008, 2011 and 2012.

Table 6. Species presence/absence in Black Rocks trammel net catch 2007-2012. Native species are labeled in black and non-native species are in red.

	2007	2008	2011	2012
roundtail chub	Yes	Yes	Yes	Yes
humpback chub	Yes	Yes	Yes	Yes
flannelmouth sucker	Yes	Yes	Yes	Yes
Gila HB & RT traits	Yes	Yes	Yes	Yes
bluehead sucker	Yes	Yes	Yes	Yes
bonytail	Yes	No	Yes	No
razorback sucker	No	Yes	No	No
Colorado pikeminnow	No	No	No	Yes
flannelmouth x bluehead	No	No	No	Yes
channel catfish	Yes	Yes	Yes	Yes
black bullhead	Yes	Yes	Yes	Yes
white sucker	Yes	Yes	Yes	Yes
common carp	Yes	Yes	Yes	Yes
white x flannelmouth	Yes	Yes	Yes	No
black crappie	Yes	Yes	Yes	No
gizzard shad	Yes	No	No	Yes
green sunfish	No	Yes	Yes	Yes
bluegill	No	No	Yes	No
yellow bullhead	No	No	Yes	Yes
largemouth bass	No	No	Yes	Yes
smallmouth bass	No	No	No	Yes
white x bluehead	No	No	No	Yes

Table 7. Incidental endangered fish PIT tag histories

Year	Species	PIT Tag Histories
2011	Bonytail (*Gila elegans*, abbreviation BT)	N=1 stocked in Debeque Canyon (RMI 194.0) in 2011
	Colorado pikeminnow (*Ptychochelius lucius, abbreviation* - CS)	N=1 male tagged in Canyonlands (RMI 16.5) in 1998 during CS estimate, captured again in Canyonlands (RMI 26.5) in 2000 during CS estimate, captured again just downstream of Loma CO (RMI 147.4) in 2010 during CS estimate N=1 tagged near UT/CO state line (RMI 131.1) in 2008 during CS estimate
2012	Razorback sucker (*Xyrauchen texanus* abbreviation - RZ)	N=1 stocked in the Gunnison River near Delta (RMI 57.1) in 2010 N=1 stocked in the Colorado River near Palisade CO (RMI 184.7) in 2008 N=1 stocked in the Colorado River near Clifton CO (RMI 177.4) in 2008 N=1 stocked in the Colorado River near Palisade CO (RMI 184.7) in 2011
	Colorado pikeminnow (*Ptychochelius lucius, abbreviation* - CS)	N=1 tagged just upstream (RMI 138.8) of Black Rocks in 2005 during CS estimate, captured again in 2007 during HB estimate in Black Rocks (RMI 136.0) N=1 male tagged just upstream (RMI 137.2) of Black Rocks in 2008 during CS estimate, captured again in 2010 during CS estimate near Palisade CO (RMI 181.4) N=1 tagged just downstream of Gunnison River confluence (RMI 167.2) in 2008 during CS estimate N=1 female tagged just downstream of Gunnison River confluence (RMI 167.6) in 2009 during CS estimate N=1 tagged on this capture occasion

Discussion

Robust design abundance estimates for populations of humpback chub in the Upper Colorado River Basin are necessary to evaluate current management efforts designed to lead to recovery of the species (USFWS 2002). In prior cycles of estimating humpback chub abundance in both Black Rocks and Westwater Canyon, only the data collected for that sample cycle (two or three year period) and individual local (Black Rocks or Westwater Canyon) would be used for model selection and then parameter estimation in either program CAPTURE or MARK. This left the number of estimable parameters low (didn't include S or psi) and didn't allow the models to be informed by the earlier datasets. As recommended by both Francis and McAda (2011) and Elverud (2012), the current study includes all of the data collected in both locations from 1998 through 2012 and re-estimates all prior years' parameters (*p* and abundance). The result included the ability to estimate some parameters, such as survival, during the years work wasn't performed and allowed for new parameters to be estimated such as transition rates between the two locations. The new estimates of humpback chub abundance, now informed with historical data, also achieved better precision with reduced coefficients of variation, suggesting better estimates in all years.

In addition to the joint reach analysis, in 2012, two new sampling techniques were utilized in Black Rocks. The two new techniques included the use of baited modified turtle hoop nets in all four passes and the use of submersible PIT tag antenna during the third pass only. A total of four hoop net/PIT antenna and six ring antenna sets were completed during Oct 9 – 12, 2012, which resulted in detection of 53 unique tagged fish (38 roundtail chub, 12 humpback chub, 2 *Gila* sp., and one unidentified fish). Sixteen fish were collected in the PIT-equipped hoop net, although none of them were tagged. None of the fish detected by the hoop net PIT antenna were actually captured in the hoop net. The additional use of these new techniques yielded the highest estimated annual probability of capture (30%, Figure 14) and the second lowest coefficient of variation (0.17, Figure 11) for abundance estimation from 1998 through 2012. The use of baited hoop nets also increased our likelihood of catching juvenile *Gila* spp. and juvenile humpback chub when compared to the rest of the sampling years (Figures 5 and 6). This provides strong support for using these techniques in future years of sampling and supports continued research into novel sampling techniques.

Francis and McAda (2011) and Elverud (2012) reported that the first combined abundance estimate of humpback chub for Black Rocks and Westwater Canyon to fall below the minimum viable adult population (MVP; 2,100 animals, as stated in the humpback chub Recovery Goals; USFWS 2002) was in 2007. Hines et al (2016) and our new estimates provided by the joint reach analysis had the same result with the 2007 combined estimate falling below the MVP at 1,495 animals (95% CI: 1,151-2,010). The most recent joint estimates of 1,846 animals (2011, 95% CI: 1,414-2,503) and 1,719 animals (2012, 95% CI: 1,320-2,284) are higher than 2007 and 2008 joint estimates but are still below the minimum viable adult population. These estimates, coupled with the declining estimates of humpback chub in Desolation-Gray, Yampa and Cataract Canyons (Badame 2012; Finney 2006; Badame 2008) supported the recommendation from both Francis and McAda (2011) and Elverud (2012) to begin building a captive refuge population. The Recovery Program's biology committee approved this recommendation and in 2014 the U.S. Fish and Wildlife, Grand Junction Colorado River Fishery Project began collecting refuge fish from Black Rocks. As of August, 2015 this refuge consists of 25 wild fish and some of the adults from the 2014 collection spawned in the pond and produced over a thousand more. Fin clips will be collected for genetic analysis. Pending the genotype results, these fish would be available to repatriate or augment disappearing populations, such as that formally documented in the Yampa River, or for when other populations are subject to catastrophe.

Size structure of the Black Rocks humpback chub population did not change appreciably from 1998 to 2008 (Figure 6), but the size structure shifted towards smaller adult humpback chub in 2011 and 2012 (mode 250 mm; Figure 5). In 2010, Francis and Elverud completed a young-of-year *Gila* spp scouting trip on the Colorado River from Black Rocks to Cisco, UT to determine where to best collect young-of-year fish for the future refuge population. They sampled the Colorado River and found *Gila* spp in all but one of their samples. In total, they sampled 14 different sites ranging from backwaters to side channels and calm shoreline habitats. They handled over 1,400 young-of-year *Gila* spp with an average catch of 100 *Gila* spp per seine haul (Francis 2010). These large numbers have never been reported for Black Rocks or Westwater *Gila* spp from projects focused on young-of-year production such as Chart and Lentsch (1999b). This (2010) strong year class may have contributed to the shift of adult humpback chub size to smaller and younger animals in 2011 and 2012.

McAda (2002) expressed concern that delayed mortality played a role in the apparent decrease in the Black Rocks adult humpback chub population size during the 1998-2000 study period (Figure 9). The new joint reach robust design statistical analysis allowed for analyzing estimated survival of humpback chub by total length. Year-to-year survival comparisons could then be made by taking an average of all humpback chub total lengths for a given sampling year.

The apparent decline in survival rates of larger humpback chubs is not intuitive, given that larger and older fish typically show higher survival rates (e.g., Coggins et al. 2006). In this

Black Rocks Canyon data set, the few large fish captured in early years of the study were typically not seen again, and the logical outcome of this from an analytical perspective is a decline in survival rates of larger fish as indicated (Figure 13). The maximum lengths reported for adult humpback chubs (Table 3) has declined through time, with fish reported at or near 400 mm TL in 1998 and 1999, but maximum size of fish declined to about 375 mm TL in 2011 and 2012. Absence of large fish could be due to sampling bias against their capture, emigration, mortality, or other factors.

Similarly, in 1998 through 2000, the size structure of humpback chub collected in Black Rocks included a greater proportion of large fish from 350 to 410 mm when compared to the more recent years of sampling (Figures 5 and 6). Humpback chub of that size are most likely the oldest in the population and their estimated rates of survival are the lowest at 57-58% (Figure 13). In spite of apparent absence of larger and older humpback chub in recent sampling years, mean length of chubs has not declined over time (Table 3). Lack of decline in mean lengths of chubs despite fewer large fish is likely a result of fewer smaller fish, and also, the few older and larger fish that are unlikely to change population mean lengths.

Year-to-year survival rate comparisons remained fairly stable ranging from 64-70% (Figure 12) suggesting delayed sampling mortality was not an issue. It is more likely recruitment was not keeping up with adult mortality caused by natural attrition of those older year-classes of fish that were more represented in the 1998 through 2000 catch. The estimated annual abundance of adult humpback chub in Black Rocks has remained stable, since 2007, suggesting that recruitment is offsetting annual adult mortality (Figure 10). However, the decrease in adult humpback chub abundance through time suggests that recent recruitment may be insufficient to bolster populations sufficiently to achieve downlisting. A more focused effort investigating early life stages of *Gila* spp is warranted to determine recruitment limiting factors.

Metapopulations are networks of geographically separated populations that have some degree of intermittent or regular gene flow between them (Gilpin and Hanski 1991). Estimated rates of annual transition of adult humpback chub between Black Rocks and Westwater Canyon were low (1.4%; 1.8%). These estimates reflect high site fidelity, while still showing metapopulation dynamics between two functionally distinct populations of humpback chub in Black Rocks and Westwater Canyon. However, these transition rates are informative as to reflect the population level effects. For example, the annual transition of 1.4% of the adult humpback chub from Black Rocks to Westwater Canyon doesn't reflect a measureable abundance change for either population because it would only be a few individuals. However, the 1.8% annual transition from the larger population of humpback chub in Westwater Canyon to the smaller population in Black Rocks doesn't reflect a measureable adult abundance change in Westwater Canyon but it does in Black Rocks. Using the 2012 estimates of humpback chub abundance in Black Rocks (404 animals; Figure 9) and Westwater Canyon (1,315 animals) an estimated six humpback chub would transition from Black Rocks to Westwater Canyon (a net increase in abundance for Westwater Canyon of 0.5%) and an estimated 24 humpback chub would transition from Westwater Canyon to Black Rocks (a net increase in abundance in Black Rocks of 5.9%). Therefore, humpback chub recruitment in Black Rocks is driven by both reproduction in Black Rocks and immigration (or transitions of adults from Westwater Canyon).

The abundance of humpback chub in Black Rocks and Westwater Canyon declined significantly in 2007 when compared to the highest estimates of abundance in 1998 and 1999

(Figure 10). In 2004, humpback chub relative body condition was at its lowest during the 1998-2012 time period at 93% (95%CI: 85%-101%) in Black Rocks and 93% (95%CI: 92%-94%) in Westwater Canyon (Figures 7 and 8). Burdick (2003) reported a dramatic increase of non-native centrarchids, namely smallmouth bass (*Micropterus dolomieu*) and largemouth bass (*Micropterus salmoides*) in Ruby Horsethief Canyon which includes Black Rocks. Pilger et al. (2008) identified a disproportional abundance of native fishes in juvenile largemouth bass stomachs in the San Juan River. Marsh and Douglas (1997) found that a significant component of introduced nonnative fishes diets, in the Little Colorado River, were humpback chub and other native fishes. It is possible that the competitive and predatory pressures of these non-native fishes on humpback chub in Black Rocks had an effect on their overall body condition and subsequent abundance.

According to the National Oceanic and Atmospheric Administration (www.noaa.gov), the Upper Colorado River Basin is experiencing a protracted multi-year drought which began in October 1999. These drought conditions could negatively affect invertebrate production (a primary food source for humpback chub) and spawning habitat by a loss in submerged habitat and/or sedimentation in important cobble bed materials (Osmundson and Scheer 1998, Chart and Lentsch 1999b), reduce available humpback chub habitat, and change the hydrology (less turbulent river flows with lower velocities) in Black Rocks. These conditions may be more conducive to other native and non-native fishes species-specific life histories possibly contributing to the species composition change in Black Rocks from 2008 through 2012 (Figure 23). The new composition of fishes represented in Black Rocks could be negatively pressuring the humpback chub population through both competitive and predatory interactions.

Sympatric roundtail chub are especially abundant in Black Rocks and Westwater Canyon during low-water years (Francis and McAda 2011; Kaeding et al 1990; Chart and Lentsch 1999b). Roundtail chub catch rates, in Black Rocks, significantly increased in 2003-2012 when compared to 1998-2000 (Figure 16). Average catch ratios (humpback chub and integrades: roundtail chub) in Black Rocks have declined dramatically from 55:45 (an average ratio calculated from the years 1979-1981, 1983-1985, 1988, and 1991; USFWS 2002) to 9:91 in 2007-2008 and 20:115 in 2011-2012. If these ratios are reflective of the composition of *Gila* spp in Black Rocks during the spawning season, there might be a greater potential for hybridization. These ratios suggest potential competitive and predatory interactions with humpback chub in Black Rocks during the sampling season.

Recreational river use in this reach has drastically increased since 1998, and ten campsites were established in the very short Black Rocks reach, which are now so popular that they have to be permitted by the Bureau of Land Management (B.L.M.). Permitting began in 2013, and the B.L.M. has collected data on camp nights and number of users during the permitted period (May through the end of September). The number of users has increased from 8,343 (2013) to 9,961 (2015) and the number of camp nights has increased from 930 (2013) to 1,122 (2015) (Troy Schnurr, B.L.M. River Manager, *personal communication*). There have always been a small group of anglers that have targeted Black Rocks for channel catfish (*Ictalurus punctatus*). However, the increased recreational use by river rafters has increased the overall number of angling hours in Black Rocks (Troy Schnurr, B.L.M. River Manager, *personal communication*). Angling was historically used as a sampling technique to collect humpback chub in Black Rocks for research (McAda2002, McAda et al 1994). Typically, researchers would use small barbless hooks baited with various insects and worms found in Black Rocks and would float them down eddy lines near large rock walls with good success. The primary angling equipment being used currently by new campers in Black Rocks (as observed by Troy Schnurr and our field crews) is for trout fishing (i.e. fly/spin) which would be ideal for catching *Gila* spp. Additional research is necessary to determine if increased angling pressure could be another factor contributing to the adult Black Rocks humpback chub population not reaching historic abundances.

The drought, human influences, and fish community level interactions have all likely contributed to the decrease in abundance of humpback chub in Black Rocks. Fortunately, the multi-year joint reach analysis evidenced important life history parameters that suggest their abundance has remained stable since 2007. Recruitment from the large cohort produced in 2010 and transitions of fish from Westwater Canyon to Black Rocks have offset annual adult mortality. Continued monitoring of this population is warranted and is planned for 2016-2017.

Conclusions

- Multi-year joint statistical modeling of humpback chub collected in both Black Rocks and Westwater Canyon provided much more insight on important life history parameters such as survival, recruitment, probabilities of transition, and adult abundance. It also provided more precise estimates of abundance and probabilities of capture when compared to the earlier statistical modeling for Black Rocks and Westwater Canyon.
- Combined estimated abundance of humpback chub in Black Rocks and Westwater Canyon have remained below the Recovery Program's prescribed MVP (2,100 adults; USFWS 2002) since 2007. The combined 2011 estimate is 1,846 animals

(95% CI: 1,414-2,503) and the 2012 estimate is 1,719 animals (95% CI: 1,320-2,284).

- The use of baited hoop nets and submersible PIT tag antenna, in 2012, greatly increased the probability of capturing or sighting humpback chub in Black Rocks.
- Annual estimates of apparent survival of humpback chub in Black Rocks have remained stable (64-70%) since 1998; suggesting negligible sampling inflicted delayed mortality. These estimates also suggest insufficient recruitment to bolster adult populations.
- Abundance of humpback chub in Black Rocks has remained stable since 2007, providing evidence of recruitment offsetting annual adult mortality.
- The size structure of the humpback chub population, in Black Rocks, shifted towards smaller adults (mode 250 mm) in 2011 and 2012.
- Estimated rates of transition of humpback chub from Westwater Canyon to Black Rocks (1.8%) could be a net gain of nearly 6% to the 2012 Black Rocks adult population. Estimated rates of transition from Black Rocks to Westwater Canyon (1.4%) only nets a 0.5% gain to the 2012 Westwater Canyon adult population.
- The Upper Colorado River Basin's protracted multi-year drought appears to have negatively affected the Black Rocks humpback chub population. Possible causal agents include; reduced invertebrate production, reduction in available habitat, hydrological changes (lower velocities and turbulence), and a change in the composition of fishes occupying Black Rocks.
- The fish community change in Black Rocks has included a proportional shift away from *Gila* spp and an increased number of species from 13 (2007) to 17 (2012;

Figure 23 and Table 6). This shift in fish community structure could negatively pressure the humpback chub population through both competitive and predatory interactions.

- Average catch ratios of humpback chub to roundtail chub, in Black Rocks, has shifted from 55:45 (USFWS 2002) to 20:115 in 2011-2012. This could lead to an increased potential of hybridization in Black Rocks *Gila* spp.

Recommendations

- Continue mark-recapture sampling of humpback chub in Black Rocks and Westwater Canyon on the same time schedule (in the fall for two consecutive years followed by a two year rest period) and utilize the joint reach statistical modeling approach.
- Monitor (seine slack water habitats from Mee Canyon to Westwater Ranger Station) young-of-year *Gila* from July through August to better understand year-class strength and limiting factors affecting recruitment.
- Continue building a captive refuge population of humpback chub, currently maintained by the Ouray National Fish Hatchery, Grand Valley Unit.
- Continue using trammel netting, electrofishing, baited hoop netting, and submersible PIT tag antenna on all sampling trips for better precision in parameter estimation.
- Continue tagging and monitoring (they are caught by all the techniques described in the methods section) sympatric roundtail chub so we can better understand their interactions with humpback chub in Black Rocks.

- Work with the Colorado Parks and Wildlife and Bureau of Land Management to investigate potential occurrences of incidental humpback chub catch by recreational anglers, and remedy if needed. Hang informational and educational signs at all of the Black Rocks camp sites (10) explaining how to properly identify and handle a rare native fish and include a short narrative on native fish life histories.
- Confer with Principal Investigator tasked with mark recapture studies on humpback chub occupying Westwater Canyon and determine the most appropriate index for tracking body condition of both populations of humpback chub.

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Affiliation of Individuals Cited as Personal Communication

Schnurr, Troy. Bureau of Land Management, Grand Junction, Colorado.