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# **Abundance Estimates for Humpback Chub (*Gila cypha*) and Roundtail Chub (*Gila robusta*) in Westwater Canyon, Colorado River, Utah 2011–2012**


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## TABLE OF CONTENTS

LIST OF TABLES ..... V
LIST OF FIGURES ..... VI
LIST OF KEY WORDS ..... VIII
EXECUTIVE SUMMARY ..... IX
INTRODUCTION ..... 1
STUDY AREA ..... 2
METHODS ..... 3
- FIELD SAMPLING ..... 3
- DATA ANALYSIS ..... 4
  - *Robust design for Humpback Chub capture-recapture studies* ..... 4
  - *Statistical modeling for Movement, Survival, Population Estimates of Humpback Chub* ..... 4
  - *Survival* ..... 6
  - *Roundtail Chub Population Estimate* ..... 7
  - *Catch Rates* ..... 7
  - *Relative Weight* ..... 8

RESULTS ..... 8
- MODEL SELECTION ..... 8
- HUMPBACK CHUB ABUNDANCE ..... 9
- HUMPBACK CHUB SURVIVAL ..... 9
- MOVEMENT (TRANSITION RATES) ..... 9
- ROUNDTAIL CHUB ABUNDANCE ..... 10
- CATCH RATES ..... 10
  - *Humpback Chub* ..... 10
  - *Roundtail Chub* ..... 11
- CATCH RATE COMPARISON ..... 11
- LENGTH FREQUENCY ..... 11
- RELATIVE WEIGHT ..... 12

DISCUSSION ..... 12
- HUMPBACK CHUB ABUNDANCE ESTIMATES ..... 12
- HUMPBACK CHUB SURVIVAL ..... 13
- CATCH RATES ..... 14
- MOVEMENT ..... 14
- SIZE AND CONDITION ..... 15

CONCLUSIONS ..... 15
RECOMMENDATIONS ..... 16
LITERATURE CITED ..... 18
APPENDIX ..... 35

# LIST OF TABLES

Table 1. Ranking of *post hoc* hypothesized models for evaluating survival (S), transition rates (psi), and capture probability (p) of Humpback Chub in Westwater Canyon, UT and Black Rocks, CO from 1998–2012. Abundance estimates are derived estimates via the Huggins estimator using numbers of fish captured and *p**, which is calculated from probabilities of capture from the top model (see Methods). The TL is total length (mm) and state is the canyon sampled. ........ 23

Table 2. . Population estimate for adult Roundtail Chub (>200 mm) in Westwater Canyon, UT 1998– 2012. Standard error (SE), profile likelihood interval (PLI), coefficient of variation, (CV), and capture probability (p-hat) are included with each population estimate. .......... 24

Table 3. Mean total length (TL) and associated standard deviation (SD) of Humpback and Roundtail Chubs in Westwater Canyon, UT from 1998–2000, 2003–2005, 2007–2008, and 2011–2012. ........ 25

# LIST OF FIGURES

Figure 1. Map of the study area. .......... 26

Figure 2. Abundance of Humpback Chub in Westwater Canyon, UT from 1998–2012. Error bars represent 95% confidence intervals. .......... 27

Figure 3. Capture probability of Humpback Chub in Westwater Canyon, UT from 1998–2012. 27

Figure 4. Coefficients of variation for Humpback Chub abundance estimates from 1998 – 2012. .......... 28

Figure 5. Annual survival of Humpback Chub in Westwater Canyon, UT from 1998–2012. Error bars represent ± 1 SE. .......... 28

Figure 6. Size dependent survival of Humpback Chub in Westwater Canyon, UT. Solid line is survival and dashed lines are 95%confidence limits. .......... 29

Figure 7. Predictions of annual changes in length for Humpback Chub when starting length in 1998 was either 200, 250, 300, or 350 mm TL. Estimates of change in fish length were from the Von Bertalanfy growth curve for Humpback Chubs in Westwater Canyon, Utah and Black Rocks, Colorado, from the Colorado River, from 1998 – 2012 (K = 0.0666 [SE =0.00669], $L_{\infty}$= 376.4 [SE = 9.86]), and indicated faster growth of younger and smaller fish and slow growth of larger and older fish. .......... 29

Figure 8. Abundance (N-hat) of adult Roundtail Chubs in Westwater Canyon, UT from 1998–2012. Error bars represent profile likelihood interval. .......... 30

Figure 9. Trammel net catch rate (CPUE) of Humpback Chub (all size classes combined) during each sampling pass in Westwater Canyon from 2011 – 2012. Error bars represent ± 1 SE. .......... 30

Figure 10. Numbers and catch rate (CPUE) of adult Humpback and Roundtail Chubs collected in Westwater Canyon during electrofishing from 2003 – 2012 by trip. Electrofishing was only conducted during one trip in 2003 and 2004. .......... 31

Figure 11. Catch rate (CPUE, three passes combined) of Humpback and Roundtail Chubs and all *Gila spp.* combined (<200 mm) in Westwater Canyon, UT from 1998 – 2012. Error bars represent ± 1 SE. .......... 31

Figure 12. Long-term catch rate (CPUE) of Humpback Chub and Roundtail Chub in .......... 32

Figure 13. Length-frequency histograms for Humpback Chub and Chub identified as *Gila* .......... 32

Figure 14. Length-frequency histograms for Roundtail Chub and Chub identified as *Gila spp*. in Westwater Canyon from 2011. .......... 33

Figure 15. Length-frequency histograms for Humpback Chub and Chub identified as *Gila spp.* in Westwater Canyon from 2012. ........................................................................................ 33

Figure 16. Length-frequency histograms for Roundtail Chub and Chub identified as *Gila spp.* in Westwater Canyon from 2012. ........................................................................................ 34

Figure 17. Mean relative weight ($W_r$) for Humpback and Round tail Chub in Westwater Canyon from 1998 – 2012. Error bars represent 95% confidence intervals. ................................. 34

# LIST OF KEY WORDS

Humpback Chub, *Gila cypha*, Roundtail Chub, *Gila robusta*, Westwater Canyon, Colorado River, population estimate, multi-state robust design, survival estimate, movement, transition rate

# EXECUTIVE SUMMARY

Capture-recapture sampling was conducted in Westwater Canyon on the Colorado River, Utah to estimate the abundance of Humpback Chub (*Gila cypha*) and Roundtail Chub (*Gila robusta*). Three sampling passes were conducted during September and October of both 2011 and 2012. Multi-state robust design models were incorporated in the abundance estimates in 2011 and 2012. Robust design models capitalize on the strengths of open and closed population models and typically provide more precise abundance estimates because they use all data collected over the study period to estimate model parameters such as probabilities of capture (*p*). Abundance estimates from 2011 and 2012 were lower than estimates in 1998, 1999, and 2004, suggesting a decline in the Humpback Chub population. The upper bounds of the confidence limits from the Humpback Chub population estimates in the 2007, 2008, 2011, and 2012 are all below the minimum core population abundance (2,100 adults) outlined in the 2002 Humpback Chub recovery goals. The Roundtail Chub population appears to be relatively high and stable with confidence limits overlapping for all years from 1998 to 2011.The Roundtail Chub population in 2012 was substantially lower than 2011. Population estimates for Humpback Chub were: 1,467 (CI, 1,175–1,861) in 2011 and 1,315 (CI, 1,022–1,713) in 2012. Roundtail Chub population estimates were: 7,177 (CI, 5,708–9,298) in 2011and 3,672 (CI, 2,739 – 4,367) in 2012. Low numbers of juvenile chubs (150-199 mm) collected during the study period precluded a population estimate based on mark-recapture data for the juvenile size class.

Humpback Chub and Roundtail Chub trammel net catch rates varied among passes during the 2011–2012 study periods. Humpback Chub catch rates were significantly lower in 2011 and 2012 than catch rates in 1998, but are similar to catch rates from all previous sampling. The catch rates of Roundtail Chub in 2011 and 2012 were the highest and second highest catch rates in all years of sampling, respectively. A comparison of Humpback Chub Interagency Standardized Monitoring Program (ISMP) (USFWS 1987) data to a subset of data collected in 2012 also showed catch rates consistently lower than catch rates from 1988–1998. The catch rate of Humpback Chub in 2011 was higher than catch rates from 1999–2008, but lower than 1988–1998, except for 1992 and 1994. Roundtail Chub ISMP catch rates varied between years but did not show the decline exhibited by the Humpback Chub data.

Apparent adult survival was calculated for 1998–2012. Apparent survival is the joint probability of a fish surviving from one year to the next and remaining in the population so it is available for recapture. The survival estimates 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 and it cannot distinguish if a fish that was previously captured avoided subsequent recapture by some behavioral change mechanism. The mean apparent survival for 1998–2012 is 71% with a range of 69% to 75%.

Transition rate (psi, $\psi$, movement), which is the annual probability of a fish moving from one reach to another and vice versa, was calculated for Humpback Chub between Westwater Canyon and Black Rocks. The transition rate of fish to move from Black Rocks to Westwater Canyon was 1.4%, which means if Black Rocks has a population of 600 Humpback Chub, approximately eight fish would move to Westwater Canyon each year. The transition rate of fish to move from Westwater Canyon to Black Rocks was 1.8% and this means if Westwater Canyon had a

population of 2,000 Humpback Chub, approximately 36 fish would move to Black Rocks each year.

The mechanisms responsible for declining Humpback Chub population estimates and catch rates were not easily identified. Analyses of length-frequency data suggested the population consisted of older individuals with few younger recruits. The low number younger fish capture could be a result of low recruitment, but it could also be a result of ineffective gear types. Drought conditions prior to this study period may have played a significant role in the declining trend of Humpback Chub while providing more favorable conditions for Roundtail Chub in Westwater Canyon. Since it is likely that there was a combined carrying capacity for these species, which occupy similar habitats, the decline in Humpback Chub may not be surprising when Roundtail Chub abundance remained relatively high.

Multi-state robust design abundance estimates should be continued for Humpback Chub and should be used for Roundtail Chub in the future for Westwater Canyon. Electofishing sampling provided the majority of the juvenile Humpback Chub and juvenile Roundtail Chub capture/recapture data and should be continued. While electrofishing sampling increased the number of juvenile chub captures, current numbers of juvenile chub captures were insufficient to estimate juvenile abundance or recruitment of first year adults. To alleviate those shortcomings, hoop netting will be incorporated into sampling with a goal to increase the number of juvenile chub captures.

# INTRODUCTION

Westwater Canyon of the Colorado River supports one of five upper Colorado River Basin populations of endangered Humpback Chub. Other populations of Humpback Chub in the Upper Colorado River basin occur in Yampa Canyon (Finney 2006), Desolation/Gray Canyon (Jackson and Hudson 2005), Cataract Canyon (Badame 2008), and Black Rocks (Francis and McAda 2011). In the lower Colorado River Basin, the single and largest population of Humpback Chub remaining occurs in the Little Colorado River and the adjacent mainstem Colorado River in the Grand Canyon (Valdez and Clemmer 1982; Valdez and Ryel 1995; Douglas and Marsh 1996; Coggins 2006; Van Haverbeke 2013). Humpback Chub was first described in 1946 (Miller 1946) and was included in the first list of endangered species in 1967 (32 FR 4001). The species is currently protected under the Endangered Species Act (ESA) of 1973, as amended. Alterations in the physical and biological characteristics of the Colorado River system from water-development projects, introductions of nonnative fishes and other human activities are primarily responsible for the decline of the Humpback Chub (Miller 1961, Minckley 1973). Other factors responsible for declines may include parasitism, hybridization, pesticides, and pollutants [United States Fish and Wildlife Service (USFWS) 2002].

An amendment and supplement to the 1990 Recovery Plan for Humpback Chub was finalized in 2002 that identified objective, measurable recovery criteria to downlist and delist Humpback Chub in both the upper and lower Colorado River Basins (USFWS 2002). In the upper Colorado River Basin, one of the criteria to downlist Humpback Chub is the maintenance of one self-sustaining core population with a minimum abundance of 2,100 adults for five consecutive years (USFWS 2002). Humpback Chub in Westwater Canyon and Black Rocks are considered a core population. The adult Humpback Chub population in these areas is currently monitored on a rotating schedule where sampling occurs in two consecutive years followed by a two-year hiatus, to measure progress toward achieving and maintaining a minimum viable population. Prior to 2007, the Westwater Humpback Chub population was sampled three out of every five years.

While Humpback Chub distribution is limited, current distribution of Roundtail Chub is much broader (Bezzerides and Bestgen 2002). Roundtail Chub occur in high numbers in areas where Humpback Chub exist in the upper Colorado River Basin such as in Westwater Canyon and Black Rocks, but Roundtail Chub are less abundant throughout the other portions of their range [Utah Division of Wildlife Resources (UDWR 2006a)]. Because the two species are closely related and overlap in habitat exists, an understanding of the status of these sympatric populations is valuable.

Roundtail Chub are not currently listed as threatened or endangered under the ESA in the Upper Colorado River Basin, but a 2009 status review of Roundtail Chub in the lower Colorado River Basin (below Glen Canyon Dam) resulted in a “warranted, but precluded” for listing finding. On Oct 7, 2015, the Service proposed a rule to list the Lower Colorado distinct population segment of Roundtail Chub as “threatened” under ESA (USFWS 2015). Roundtail Chub are classified as sensitive species by the states of Colorado, Utah and Wyoming (UDWR 2006a, 2006b), U.S. Forest Service (USFS) Rocky Mountain Region (USFS 2006), and is listed as a Species of Special Concern by the National Park Service (NPS), Southeast Utah Group (NPS 2006). A multi-state, multi-agency conservation agreement and strategy was developed and implemented to provide conservation measures for this sensitive species (UDWR 2006a).

Estimates of population abundance were first made for Humpback Chub and Roundtail Chub in Westwater Canyon from 1998 to 2000 (Hudson and Jackson 2003). During that timeframe, point estimates for Humpback Chub indicated a non-significant downward trend, while point estimates for Roundtail Chub indicated a stable trend. In addition to abundance estimates generated for both species, other parameters were assessed including catch rates, relative condition, and movement. Humpback Chub and Roundtail Chub populations have been monitored by the UDWR since 1988 through catch rate trends. Hudson and Jackson (2003) demonstrated that long-term catch rates for Humpback Chub had declined substantially over time, while Roundtail Chub long-term catch rates remained stable. Recommendations from that study to increase the number of sample sites and the amount of sampling effort were incorporated into the 2003–2005 sampling regime. In 2007, 2008, 2011, and 2012 the sampling effort and sampling locations remained consistent with the 2003–2005 efforts. This report documents the fourth series of population estimates based on field data collected in 2011 and 2012 on Humpback Chub and Roundtail Chub in Westwater Canyon.

The goal of this project was to estimate the population size of adult Humpback Chub in Westwater Canyon with the most precise confidence intervals possible. Specific objectives were: 1) to obtain a population estimate of adult Humpback Chub (≥200 mm) in Westwater Canyon and 2) to determine estimated recruitment of naturally produced subadult Humpback Chub (150-199 mm) in Westwater Canyon.

## STUDY AREA

Westwater Canyon is located on the Colorado River downstream of the Colorado-Utah border (Figure 1). The length of the canyon extends 12 river miles (RM 124.5–112.5). The canyon is characterized by black Proterozoic gneiss and granite complex that comprise the inner gorge. Habitat in the upper section of the canyon consists of runs, eddies, and pools interspersed between riffles and rapids. The steepest part of Westwater Canyon extends from RM 119.5 to RM 116.5. This portion of the canyon is not sampled due to the turbulent flows and Class III–IV rapids. However, United States Fish and Wildlife Sevice (USFWS) sampled the middle section of Westwater Canyon during 1979–1981 and found that Humpback Chub were present (Valdez et al. 1982). The lower section of Westwater Canyon is a confined canyon reach with a reduced gradient that is primarily composed of a homogenous run where chubs are scarce (Chart and Lentsch 1999, Jackson 2010).

Humpback Chub sampling occurred at four sites in the upper portion of Westwater Canyon. Three of the four sites were previously established through the Interagency Standardized Monitoring Program (ISMP; Figure 1): Miners Cabin (RM 123.4–124.0), Lower Cougar Bar/Little Hole (RM 120.8–122.6), and Hades Bar (RM 119.8–120.0). Sampling at the fourth site, Upper Cougar Bar (RM 121.8–122.6), began in 2003. A total of approximately 2.4 river miles is sampled during each trip. Depth measurements collected in 1994 for the ISMP sites showed maximum depths of 21.8 m at Miners Cabin, 19.5 m at Lower Cougar Bar/Little Hole, and 10.6 m at Hades Bar (Chart and Lentsch 1999). Each of these deep canyon habitats is bounded on the upstream and downstream by a riffle area.

# METHODS

## Field Sampling

Humpback Chub sampling in Westwater Canyon occurred in September and October of 2011 and 2012. Three eight-day sampling passes were conducted each year. Approximately six days elapsed between the end of one pass and the beginning of the subsequent pass in 2011, and approximately seven days elapsed between passes in 2012. During each pass, Miners Cabin, Upper Cougar Bar, and Lower Cougar Bar (Figure 1) were sampled for two nights and Hades Bar was sampled for one night. The Hades Bar site was not sampled on the third sampling trip of 2011 and 2012. This was due to motor issues and inclement weather. Multi-filament trammel nets (23 m x 2 m; 2.5 cm mesh) and a motorized/oar electrofishing (ETS Electrofishing) Cataraft were used to collect fish. Hoop nets were utilized intermittently in 2003 and 2004, but were not used during sampling in 2007–2012.

Trammel nets were set in mid-afternoon and checked every 1.5-2 hours until approximately midnight, at which time they were pulled. Nets were reset before sunrise and allowed to fish until approximately noon, while being checked at similar time intervals as evening sets. Trammel nets were set to target adult Humpback Chub in deep eddies off boulder or rock faces. Nets were occasionally also set in shallow riffle/run habitat. All chub were removed from the net, processed in camp, and released. Due to this protocol, a few chub were recaptured during the same 18-hour sampling period.

Electrofishing was conducted during each pass in 2011 and 2012. In 2003 and 2004, only a single electrofishing pass was conducted. Single pass electrofishing was previously established under the ISMP protocol. Increased electrofishing was conducted beginning in 2005 to increase the catch of juvenile and sub-adult chubs and strengthen population estimates. The majority of electrofishing occurred at the three upstream-most sites. Electrofishing effort was limited at Hades Bar because of the short sampling distance (0.2 river miles). Shoreline habitats were electrofished within each site. Electrofishing occurred prior to trammel nets being set and subsequent to nets being pulled. All adult Humpback Chub and Roundtail Chub collected during electrofishing were used in their respective population estimates. Electrofishing data were also used in determining catch rates, length-frequency analysis, and movement of chub in Westwater Canyon.

Chub were identified to species using a suite of diagnostic qualitative characters (i.e., degree of frontal depression, presence of scales on nuchal hump, the line of the angle of the anal fin base relative to the upper section of the caudal fin lobe, etc (Douglas et al. 1989, Douglas et al. 1998). Information collected from all chub captures included total length (mm), weight (g), and dorsal and anal fin ray counts. Fin ray counts are presented in appendices (Appendix Table1). Dorsal and anal fin ray counts are not a diagnostic characteristic of *Gila spp.* and are included for informational purposes only. In addition, Passive Integrated Transponder (PIT) tag numbers were recorded for recaptured chubs. Initial captures of Humpback Chub and Roundtail Chub

>150 mm received a PIT tag; the number was recorded before release of the fish. Information collected for other endangered species captured included total and standard length, weight, and PIT tag number. If no PIT tag was present, one would be inserted if chubs were > 150 mm.

**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). Sampling occasions completed at closely-spaced intervals (e.g. consecutive weeks within a year) were used to estimate 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 total length (TL) or greater (a few fish were tagged that were between 150-200 mm TL) and survival rates between years. In some reaches and years, data was available from four sampling passes, which was accommodated in the capture history matrix for the reach where only three passes were available by placing a "." in that column.

*Statistical modeling for Movement, Survival, Population Estimates of Humpback Chub*

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 $j$ ($\psi_{ij}$), capture-recapture probabilities within reach $i$ (reach is the state, here either Black Rocks 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 (Sananathan 1972; Huggins 1989, 1991; Alho 1990). 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 over all short-term sampling passes, and

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

where $p_{ji}$ 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 were included in the likelihood, individual covariates (here TL or polynomials for such) could be incorporated to estimate $p$, $\psi$, 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 capture probabilities (*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 between 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 coefficient of variation's (CV; which was calculated by standard error/mean) < 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 $L_\infty$ 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 estimated more realistic lengths (e.g., Bestgen et al. 2007). 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. We also incorporated recaptures of tagged Humpback Chubs made during the last pass of sampling in 2012 into the capture history matrix. This doubled the number recaptures made that year from 9 to 18, with resultant increased precision of estimates.

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 to resolve heterogeneity issues 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. There are few post-sampling approaches available that can make up for a lack of captures and recaptures to increase precision of estimates. To remedy heterogeneity effects as much as possible, we modeled probabilities of capture among years, states (Black Rocks or Westwater sites), and sampling passes for each possible combination. Because of those modeling efforts, and because heterogeneity was assumed low for different sizes of fish captured in trammel nets (preliminary models supported this), heterogeneity effects were presumed minimized in this modeling effort.

*Humpback Chub Survival*

The robust-design multi-state models in program MARK (White and Burnham 1999) were used to estimate reach-specific apparent survival for Humpback Chub captured in Westwater Canyon in the Colorado River. 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 $AIC_c$ was used as a guide in model selection. We were careful to guard against overfitting models with the sometimes sparse data available and focused on those that gave reasonable estimates of parameters that were critical to understanding the status of Humpback Chub in the Colorado River.

During the 2003 to 2005 study period, recruitment of first year adults (200-220 mm TL) was estimated (Jackson 2010). Subsequent analysis of Westwater Canyon mark/recapture data for Humpback Chub initially tagged at < 200 mm TL and recaptured in later years at > 200 mm TL indicate some individual Humpback Chub are persisting in the first year adult size class for multiple years. No aging of Humpback Chub from 200-220 mm TL from Westwater Canyon has occurred. Due to these findings and concerns over the accuracy of estimating the number of first year adults with the methods previously utilized, no estimate of Humpback Chub first year adults was calculated.

*Roundtail Chub Population Estimate*

Population estimates were determined for adult Roundtail Chub (>200 mm TL) in Westwater Canyon using closed population models within Program CAPTURE (Otis et al. 1978, White et al. 1982, Rexstad and Burnham 1991) imbedded in Program Mark (White and Burnham 1999). Data from electrofishing and trammel netting were combined. Program CAPTURE was used for model selection to help determine the most appropriate estimator. Models were ultimately determined by considering selection results generated in Program CAPTURE and other data available (i.e. capture probabilities, catch rate variability, and number of passes conducted). The null ($M_o$) and Darroch ($M_t$) models were selected and a separate adult population estimate was calculated for each year. Program CAPTURE was used to determine confidence intervals around each estimate, the coefficient of variation, and the probability of capture.

Profile likelihood intervals (PLI) were provided in lieu of 95% confidence intervals for the $M_t$ model. The profile likelihood interval helps to account for model selection uncertainty by providing more precise confidence intervals (David R. Anderson and Gary C. White, Colorado State University, Fort Collins, Colorado personal communication). In addition, these intervals tend to give more precise confidence intervals for small samples (Ross Moore, Mathematics Department, Macquarie University, Sydney, Australia personal communication).

Population estimates for juvenile chubs were not attempted due to low numbers of this size class being collected throughout all study years. In 2005, sufficient data was collected for mark-recapture population estimates for juvenile Roundtail Chub only (Jackson 2010). Population estimates for juvenile Roundtail Chub were not attempted in any other sample year because of insufficient data.

*Catch Rates*

Catch rates for chub collected by trammel net were determined by the number of a species caught per hour a net was fishing. Catch rates for chub collected by electrofishing were determined by the number of a species captured per electrofishing hour. Catch rate or catch per unit effort (CPUE) was compared between passes within and among years using nonparametric Kruskal-Wallis ANOVA along with pairwise multiple comparisons (Dunn's Method). Total annual CPUE comparisons were tested between years using the same analyses. All statistical tests were performed using SigmaStat 3.5 (SPSS Inc).

Catch rate data for Humpback Chub and Roundtail Chub from 1998–2000, 2003–2005 and 2007–2008 was compared to ISMP data at the three previous ISMP sites (Miners Cabin, Little Hole, and Hades Bar). Data from the study period comparable in time of year to ISMP data collection dates were lifted out of the larger data set as ISMP data consists of only a single trip per year. Catch rates were calculated as number of a fish species caught per hour a net was fishing. Standardized net sizes have been utilized since 1998, but varied somewhat during years prior.

*Relative Weight*

Relative weight was calculated for Humpback Chub and Roundtail Chub in Westwater Canyon. Relative weight, which is a refinement of the relative condition factor ($K_n$), is a commonly used condition index for fish (Anderson and Neumann 1996; Bister et al 2000). The basic concept of the metric is the standard (score of 100) should describe the overall shape of the fish in good condition (Anderson and Neumann 1996). When the standard declines substantially below 100, problems may exist with food or feeding conditions and if values go well above 100 fish may not be using the surplus efficiently (Anderson and Neumann 1996). Data from years 1998 to 2012 was used for the analysis. Relative weight is calculated:

$$W_r = (W_0/W_s) * 100,$$

Where $W_o$ is the observed weight of each individual and $W_S$ is a length specific standard weight predicted by a weight-length regression constructed for each species. The equation for Humpback Chub is:

$$Log_{10}W_s = -5.278 + 3.096(Log_{10}TL),$$

and the equation for Roundtail Chub is:

$$Log_{10}W_s = -5.065 + 3.015(Log_{10}TL),$$

where *TL* is the total length of each individual fish (Didenko et al 2004).

# RESULTS

## 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 ($\psi$, probability of a fish moving from Black Rocks to Westwater, and vice versa), and *p*'s (Table 1). The modeling strategy was a typical one where best estimates of *p*'s for increasingly complex models were estimated and followed by addition of other parameters (see Zelasko et al. 2010 or more details). The top model in the set contained 45% of the $AIC_c$ weight and had 70 estimable parameters including survival rates for each reach and year and as a function of TL and $TL^2$, transition probabilities, and probabilities of capture 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 the same 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 (94 total parameters, model 11 in the set) received no weight and many survival parameters were not estimable.

## Humpback Chub Abundance

Annual abundance estimates for adult Humpback Chub (>200 mm TL) were calculated for 1998-2012 using the Huggins estimator in the robust design model in Program MARK. The annual abundance estimates for Humpback Chub ranged from 1,139 (2008) to 6,747 (1998; Figure 2). Point estimates 95% confidence intervals (CI) for 1998–2000 were: 6,747 (4,001–11,636), 3,520 (2,513–4,979), and 2,266 (1,742–2,975), respectively. Point estimates for 2003–2005 were: 2,520 (1,814–3,554), 2,724 (2,034–3,689), and 2,000 (1,596–2,530), respectively. Point estimates for 2007–2008 were: 1,212 (972–1,532) and 1,139 (954–1,379), respectively. Point estimates for 2011–2012 were: 1,467 (1,175–1,861) and 1,315 (1,022–1,713), respectively (Figure 2). Significance of differences in estimates was tested based on over lapping confidence intervals (Schenker and Gentleman 2001). The last four years (2007, 2008, 2011, and 2012) were significantly ($p<0.05$) lower than the previous six years sampled (1998, 1999, 2000, 2003, 2004, and 2005) except for 2000, 2003, and 2005.

Abundance estimates for juvenile Humpback Chub and first year adult Humpback Chub (200–220 mm TL) were not attempted due to the low numbers of these size classes collected throughout all study years.

Precision of Humpback Chub abundance estimates was assessed based upon probabilities of capture (Figure 3) and coefficients of variation (Figure 4). Temporal probability of capture has increased and coefficient of variation has decreased (Figures 3 and 4), which both means that the estimates are more precise. This increase in precision over time is likely the result of increased sampling efficiency and increased number of tagged individuals over time.

## Humpback Chub Survival

Apparent survival was calculated for Humpback Chub in Westwater Canyon, UT for 1998–2012 using robust design multi-state models in Program MARK (Figure 5). The top five models for survival included state and size as the covariates that had the greatest influence on survival (Table 1). Westwater Canyon had modestly higher survival rates than Black Rocks. However survival apparently declined with fish length for fish larger than 175 mm (Figure 6). Survival for Humpback Chub in Westwater Canyon was stable for all 14 years analyzed with a mean of 71% (Figure 5). There were no significant differences in survival among years for the Westwater Canyon population of Humpback Chub (Figure 5).

Total length was used as a covariate in the models for survival. The missing lengths of Humpback Chub during non-sampled years needed to be extrapolated, so a von Bertalanffy growth curve was fit to the data (Figure 7).

## Movement (Transition Rates)

Movement, or transition rates ($\psi$), was the annual probability of a fish moving from one reach to the other and vice versa. This was assessed using the robust design multi-state models in Program MARK to determine the extent of Humpback Chub movement between Black Rocks and Westwater canyons. Humpback Chub moved between Black Rocks and Westwater Canyon. The transition rate of fish to move from Black Rocks to Westwater Canyon was 1.4%. The transition rate of fish to move from Westwater Canyon to Black Rocks was 1.8%.

### Roundtail Chub Abundance

Due to the variability among passes in capture probabilities in 2011 and 2012 (i.e. heterogeneity), the Darroch $M_t$ model was selected for the Roundtail Chub abundance estimate. Abundance estimates of adult Roundtail Chub in 2012 remained similar to estimates calculated during the previous sampling periods (1998–2000, 2003–2005, 2007, and 2008). Abundance estimates of Roundtail Chub in 2011 and 2012 were 7,177 (PLI 5,670–9,298) and 3,672 (PLI 2,977–4,642), respectively (Table 2, Figure 8). Coefficients of variation were 12% in 2011 and 11% in 2012 (Table 2). The data suggest the Roundtail Chub population within Westwater Canyon is variable, but stable over time. Model output for all models and years calculated for Roundtail Chub with Program CAPTURE are presented in (Table 2).

Abundance estimates for juvenile Roundtail Chub (150–199 mm TL) were not attempted by capture/recapture data in 2011 or 2012 due to the low numbers of this size class in collections. In 2005, the catch of juvenile Roundtail Chub was sufficient to estimate the juvenile Roundtail Chub population (Jackson, 2010). Recruitment of first year adult Roundtail Chub was also not estimated in 2011 or 2012.

### Catch Rates

#### *Humpback Chub*

Trammel net catch rates of Humpback Chub varied among sampling passes in 2011 (Figure 9). A total of 369 adult Humpback Chub were captured in a total of 1,283 net hours of sampling. No juvenile Humpback Chub were captured with trammel nets in 2011. Highest mean catch rate of Humpback Chub occurred during the first sampling trip in 2011. Thirty additional adult Humpback Chub were captured during 11.6 hours of electrofishing effort (Figure 10). One juvenile Humpback Chub was also captured by electrofishing. One hundred and nineteen juvenile chub identified as *Gila spp*. were also captured with electrofishing in 2011.

Trammel net catch rates of Humpback Chub varied among sampling passes in 2012 (Figure 9). One hundred and eighty nine adult Humpback Chub were captured during a total of 1,091 net hours of sampling. One juvenile Humpback Chub was captured with trammel nets in 2012. Highest mean catch rate of Humpback Chub occurred during the second sampling trip. Thirteen additional adult Humpback Chub were captured during 13.0 hours of electrofishing effort (Figure 10). Three juvenile Humpback Chub were also captured by electrofishing. Two hundred and twenty two juvenile chub identified as *Gila spp*. were also captured with electrofishing in 2012.

*Roundtail Chub*

Trammel net catch rates of Roundtail Chub varied among sampling passes in 2011 (Figure 9). A total of 1,111adult Roundtail Chub were captured during 1,283 net hours. No juvenile Roundtail Chub were captured with trammel nets in 2011. Highest mean catch rate of Roundtail Chub occurred during the third sampling trip. One hundred and ten additional adult Roundtail Chub were captured during 11.6 hours of electrofishing effort (Figure 10). Seventy-seven juvenile Roundtail Chub were also captured by electrofishing.

Trammel net catch rates of Roundtail Chub varied among sampling passes in 2012 (Figure 9). Seven hundred forty five adult Roundtail Chub were captured during a total of 1,136 net hours. No juvenile Roundtail Chub were captured with trammel nets in 2012. Highest mean catch rate of Roundtail Chub occurred during the last sampling trip. Eighty three additional adult Roundtail Chub were captured during 13.0 hours of electrofishing effort (Figure 10). Twenty-six juvenile Roundtail Chub were also captured by electrofishing.

## Catch Rate Comparison

Catch rates of Humpback Chub during 2011 and 2012 sampling were significantly lower than in 1998 ($p < 0.05$, Figure 11). Catch rates of Humpback Chub in 2011 and 2012 were not significantly different from sampling years 1999–2008. Catch rates of Roundtail Chub from 2011 and 2012 sampling were significantly higher than all previous sampling years (p,0.05; Figure 11). Catch rates of all *Gila spp*. in 2011 and 2012 were significantly higher than all previous sampling years ($p < 0.05$, Figure 11).

Single pass catch rate data from the 1998–2000, 2003–2005, 2007–2008, and 2011–2012 study periods were also compared to ISMP data (1988–1997). As sampling from 1998–2012 includes multiple passes per year, catch rate data from only a single pass from years 1998–2012 are included for comparison with ISMP data (Figure 12). Single pass catch rate data of Humpback Chub has remained similar since 1999, with the exception 2011. Catch rates in 2011 were similar to catch rates from 1992–1998 and higher than the ones from 1999-2008 (Figure 12). Single pass catch rates of Roundtail Chub over the same period of time were relatively consistent, but have occasionally increased during recent years.

## Length Frequency

Length frequency histograms suggested the size of adult Humpback Chub and adult Roundtail Chub remained relatively consistent during the study period (Table 3, Figures 13–16). The mean TL of adult Humpback Chub was 269 mm in 2011 (SD=39) and 287 mm in 2012 (SD=42) (Table 3). The mean TL of the adult Roundtail population was 280 mm in 2011 (SD=33) and 282 mm in 2012 (SD=44) (Table 3.) The mean TL of both adult Humpback and Roundtail Chub from 2011–2012 are also similar to mean TLs from 1998 to 2008 (Table 3). While no changes in the mean size of adult Humpback Chub or Roundtail Chub were observed in the length data, the histograms do illustrate the presence of younger age classes (Figures 13, 14, 15, and 16). In the

2012 length-frequency histograms, young-of-year (YOY) *Gila spp*. are present (Figures 15 and 16), but this age class was not present in the 2011 (Figures 13 and 14). While the length-frequency histograms indicate the presence of YOY and age-1 chubs in some years, electrofishing is not likely effective enough at sampling YOY and age-1 chubs to monitor the abundance of these age classes.

### Relative Weight

Relative weight was calculated for Humpback Chub and Roundtail Chub in Westwater Canyon from 1998 to 2012. Statistically significant differences were identified based upon over non-lapping confidence intervals. Mean relative weight of Humpback Chub in 2011 and 2012 was significantly higher than 1998, 1999, 2000, 2003, 2004, and 2007 (Figure 17). There were no significant differences between 2011, 2012, 2005, and 2008.  Mean relative weight of Roundtail Chub in 2011 and 2012 was significantly higher than 1998, 2003, and 2004 (Figure 17). Mean relative weight of Roundtail Chub in 2011 and 2012 was also significantly lower than 2008 and no differences occurred among the remaining years.

## DISCUSSION

### Humpback Chub Abundance Estimates

Formerly, program CAPTURE was used to estimate abundance of the Humpback Chub population in Westwater Canyon. Since the onset of the first abundance estimate, technologies have changed and more robust estimators are available. The data for Humpback Chub in Westwater Canyon is collected in such a way (two years on and two years off) that is well suited for the use of a robust design model, which allows closed population abundance estimates to be calculated for sampling years and estimates of survival to be estimated across years. Advantages of using robust design multi-state models over other capture-recapture models is they incorporate sampling data and capture probability information over all years to acquire more precise estimates, with the added benefit that estimates are less biased by heterogeneity in capture probabilities (Kendall 2001). All of those conditions were present in the 2011–2012 Humpback Chub abundance estimation period. The precision of the abundance estimates was increased, coefficient of variation was improved, capture probability was increased, and survival estimates were calculated for 1998–2012. By using the robust design model to estimate population abundance more precise estimates were obtained so smaller changes in abundance estimates can be detected.

The robust design model also might explain some discrepancies in abundances estimates calculated for earlier periods compared to these more recent estimates which use all data for estimation. . Although the confidence intervals for Humpback Chub abundance estimates conducted from 1998–2005 indicate a decline, the coefficient of variation for 1998 estimate was the highest on record. The high coefficient of variation in 1998 results in more uncertainty in the abundance estimate, so may be less reliable. The high coefficient of variation and low capture probability experienced in 1998 is likely due not as many tagged fish in the system and few recaptures of tagged fish.

To further increase the precision of the estimates, higher capture probabilities need to be obtained. One method to increase catch probabilities is to increase the number of recaptured Humpback Chub using submersible PIT tag antennas. The next sampling effort is scheduled for autumn 2016, during which we plan to incorporate submersible antennas in sampling.

**Humpback Chub Survival**

Apparent survival of Humpback Chub in Westwater Canyon was calculated using the robust design multi-state models in program MARK. The mean apparent survival for the average length Humpback Chub was 71% with a range between 69% and 75%.

Apparent survival rates for Humpback Chub in Westwater Canyon were size dependent with survival declining with fish size above 175 mm. 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 Westwater 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 6). 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 and 382 mm TL, respectively, in 2011 and 2012. Also a similar phenomenon was also documented for Colorado Pikeminnow in the Green (Bestgen et al 2007) and Colorado (Osmundson and White 2009) Rivers. Bestgen (2007) found that low numbers of recaptures of the largest individuals across years contributed to lower survival rates. Survival analysis uses recaptures across years to calculate annual survival rates. Thus, if low numbers of recaptures of a certain size are encountered then survival estimates will be lower. We examined the recapture histories of some of the larger individuals captured in Westwater Canyon and recaptures were very low.

Reasons for reduced recapture rates could include emigration, trap shyness, handling, and higher mortality of older fish. Reduced abundance may be the result of multiple factors including low recruitment, reduced available habitat from lower flows, predation, and reduced food availability. We suspect emigration is not a reason for reduced recapture rates because transition rates in and out of Westwater Canyon were relatively low 1.4% and 1.8%, respectively. High immigration rates to other reaches would not be expected because of lack of suitable habitat. The importance of the majority of these factors cannot be assessed here because those data are not available, but instead represent hypotheses that could be tested.

Stable survival rates for adult Humpback Chubs indicated that declining population abundances over time were likely due to reduced abundance, survival, and recruitment of younger life stages. A better understanding of abundance dynamics in early life stages (larvae to age-2 or so) may benefit efforts to manage for higher abundances of adult fish in the upper Colorado River basin.

## Catch Rates

Humpback Chub and Roundtail Chub trammel net catch rates both increased in 2011 and both decreased in 2012. Since abundance estimates began in Westwater Canyon in 1998, the Colorado River Basin has experienced an extended drought. Humpback Chub catch rates declined from 1998 to 2000, but appear stable from 2003 to 2012. Roundtail Chub catch rates have remained more stable with the lowest catch rate occurring in 2000. Jackson (2010) found no significant relationship between Humpback Chub or Roundtail Chub CPUE and discharge, but it is possible that drought conditions prior to this sampling period decreased spawning success or survival of Humpback Chub. Discharge in 2011 was the highest recorded for the Colorado River since 1983. It is also the highest trammel net CPUE for Roundtail Chub and the second highest trammel net CPUE for Humpback Chub. Chart and Lentsch (1999) hypothesized that periods of low river flow or drought may provide more favorable conditions for Roundtail Chub in areas that are normally dominated by Humpback Chub. Declines of other Upper Colorado Basin fish have been documented during recent years including: Humpback Chub in Desolation/Gray Canyon on the Green River (Jackson and Hudson 2005), Humpback Chub in Black Rocks on the Colorado River (McAda 2002, Francis and McAda 2011), and Colorado Pikeminnow in the Green River (Bestgen et al. 2005).

Chart and Lentsch (1999) found chub reproductive success was maximized when the Colorado River peaked near 30,000 cfs in 1996. Peak spring flows in 2011 and 2012 were 49,000 cfs and 5,960 cfs, respectively (USGS gage 09180500). Length-frequency histograms from 2011 and 2012 indicate higher number of captures of YOY chub with 202 in 2012 compared to only eight in 2011. While more YOY chub were captured in 2012 than in 2011, electrofishing is not likely effective enough to reliably monitor YOY chub abundance. Reliably identifying YOY chub to the species level is also impractical. Low flow conditions in Westwater Canyon would typically be more conducive to slow shallow and backwater habitats in which young Roundtail Chub are more likely to thrive. Opportunistic use of low velocity areas along shorelines more typical within Westwater Canyon during high flow years is likely a life history strategy more common of Humpback Chub than Roundtail Chub (Chart and Lentsch 1999). This was experienced in 2011 when peak spring flows were well above 30,000 cfs. This could be reason for the high numbers of juveniles and small adult Humpback Chub captured in 2012.

Electrofishing was an effective means to collect juvenile Humpback Chub and Roundtail Chub. Prior to 2005, electrofishing was only conducted during one pass in order to be consistent with ISMP sampling protocol. Beginning in 2005, electrofishing was conducted on every pass to increase captures and recaptures of fish. In 2011 and 2012, 8% and 4% of the total Humpback Chub catch were collected by electrofishing, respectively. All juvenile Humpback Chub, juvenile Chub identified as *Gila spp.*, and juvenile Roundtail Chub were captured by electrofishing. Although electrofishing was not that effective at capturing adult chubs that gear type should still be used because it is the most productive sampling for juvenile chubs.

## Movement

Humpback Chub movements were documented for several years via recapture of PIT tagged individuals, within years and between years, between Black Rocks and Westwater canyons(Francis 2011 and Elverud 2012). Although a handful of fish are observed each year moving between the canyons, the extent of the movements between these populations needed to be quantified. Transition rates (movement) were quantified in the multi-state robust design model in program MARK. The transition rate of Humpback Chub moving from Black Rocks to Westwater Canyon was 1.4%. This means if Black Rocks has a population of 600 Humpback Chub, approximately eight fish would move to Westwater Canyon each year. The transition rate of Humpback Chub to move from Westwater Canyon to Black Rocks was 1.8%. Similarly, if Westwater Canyon had a population of 2000 Humpback Chub, approximately 36 fish would move to Black Rocks each year. This type of movement between the two reaches would be expected considering the close proximity of the two canyons (12 miles), but the low transition rates would not be sufficient to quickly repopulate one or the other reach should a catastrophe occur with either population.

### Size and Condition

The mean TLs of Humpback Chub and Roundtail Chub remained stable in Westwater Canyon. Length-frequency data also indicated the majority of the adult population was composed of larger individuals with few adults being recruited into the population. This reduction of smaller size classes was likely a result of the gear type being used. The gear type used was not effective at capturing smaller size class Humpback Chub, or even what must be more abundant juvenile Roundtail Chub. Similar to Humpback Chub, the mean TL of Roundtail Chub was not significantly different among years. While the mean TL of each species has remained stable, the mean TL of Humpback Chub is typically 10 mm longer than Roundtail Chub in a given year, except for 2011 and 2012. In 2011, mean TL of Roundtail Chub was 10 mm longer than Humpback Chub and in 2012 mean TL of Humpback Chub was 5 mm longer than Roundtail Chub.

Relative weight of Humpback Chub and Roundtail Chub varied among years in Westwater Canyon. Both Humpback Chub and Roundtail Chub condition was highest in 2008. While condition of both species was highest in 2008, confidence limits overlap for each species in many years. Significant differences also existed between the species during some years while confidence limits overlapped in other years. In general, the relative weight of Humpback Chub and Roundtail Chub was below 100, which typically suggests either problems with food availability or feeding conditions (Anderson and Neumann 1996). However, this population of Humpback Chub was not likely experiencing the problem with available food because $W_r$ values were just slightly under 100 (Figure 17). Growth rates for all size classes, especially the largest adults were very low and on the order of a few mm/yr.

## CONCLUSIONS

- Abundance estimates of Humpback Chub in Westwater Canyon remained stable during the study period (2011–2012).

- The abundance estimates for Humpback Chub using the robust design model are more precise than previous closed capture model used in the past.

- Survival of adult Humpback Chub has remained stable at 71% since 1998. Stable survival values for adults indicated that declining population abundances were likely due to reduced abundance, survival, and recruitment of younger life stages.

- Abundance estimates for Roundtail Chub in Westwater Canyon remained stable during the study period (2011–2012). Profile likelihood intervals for Roundtail Chub abundance estimates conducted from 1998–2000, 2003–2005, 2007–2008, and 2011–2012 overlap, indicating a stable population.

- Low number of juvenile and first year adult Humpback Chub captures precluded estimating the abundance of those age groups in Westwater Canyon. It may be possible to conduct mark recapture estimates of juvenile or first year adult Humpback Chub, but doing so would require substantial increase in sampling effort, modification of sampling protocol or initiation of a separate study.

- Electrofishing resulted in low adult catch rate of chubs, but was the only method that was effective at capturing smaller (<200 mm) chubs.

- Humpback Chub ISMP catch rates from 1988 to 2008 indicated a significant decline through time, but significantly increased in 2011and then significantly decreased in 2012.

- Roundtail Chub ISMP catch rates from 1998 to 2012 exhibit no significant change.

## RECOMMENDATIONS

- Continue to use robust design multi-state models for Humpback Chub parameter estimation

- Continue to estimate survival of Humpback Chub

- Use robust design multi-state models to estimate abundance of Roundtail Chub for increased precision.

- Consider implementing an additional project focused on studying early stages and estimating abundance of juvenile Humpback Chub, recruitment of first year adult Humpback Chub and adult survival in Black Rocks and Westwater Canyon.

- Continue electrofishing during every pass to maximize the number of marked and recaptured fish and to collect the juvenile portion of the Humpback and Roundtail population.

- Use submersible PIT tag antenna arrays to increase the number of recaptures of chubs.

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Table 1. Ranking of *post hoc* hypothesized models for evaluating survival (S), transition rates (psi), and capture probability (p) of Humpback Chub in Westwater Canyon, UT and Black Rocks, CO from 1998–2012. Abundance estimates are derived estimates via the Huggins estimator using numbers of fish captured and *p**, which is calculated from probabilities of capture from the top model (see Methods). The TL is total length (mm) and state is the canyon sampled.

| **Model** | **AICc** | **Delta AICc** | **AICc Weights** | **Model Likelihood** | **Num. Par** |
|---|---|---|---|---|---|
| S(state+TL^2) psi(state) p(state*year*pass) | 15530.3811 | 0 | 0.44833 | 1 | 70 |
| S(state+TL) psi(state) p(state*year*pass) | 15530.8789 | 0.4978 | 0.34954 | 0.7797 | 69 |
| S(state+TL) psi(state) p(state*year*pass+TL) | 15532.9341 | 2.553 | 0.12509 | 0.279 | 70 |
| S(state+TL^2) psi(state*TL) p(state*year*pass) | 15533.9034 | 3.5223 | 0.07704 | 0.1718 | 72 |
| S(state) psi(state) p(state*year*pass+TL) | 15580.5519 | 50.1708 | 0 | 0 | 69 |
| S(state) psi(state) p(state*year*pass+TL^2) | 15582.6181 | 52.237 | 0 | 0 | 70 |
| S(state) psi(state) p(state*year*pass) | 15591.7247 | 61.3436 | 0 | 0 | 68 |
| S(.) psi(state) p(state*year*pass) | 15595.6105 | 65.2294 | 0 | 0 | 67 |
| S(year) psi(state) p(state*year*pass) | 15595.8164 | 65.4353 | 0 | 0 | 80 |
| S(state*year) psi(state) p(state*year*pass) | 15599.2478 | 68.8667 | 0 | 0 | 94 |
| S(state*year) psi(state) p(state*year*pass) | 15599.2498 | 68.8687 | 0 | 0 | 94 |
| S(state*year) psi(state) p(state+year+pass) | 16086.9868 | 556.6057 | 0 | 0 | 44 |
| S(.) psi(state) p(state+year+pass) | 16113.8829 | 583.5018 | 0 | 0 | 17 |

Table 2. . Population estimate for adult Roundtail Chub (>200 mm) in Westwater Canyon, UT 1998– 2012. Standard error (SE), profile likelihood interval (PLI), coefficient of variation, (CV), and capture probability (p-hat) are included with each population estimate.

| **Year** | **Model** | **Estimate** | **SE** | **PLI** | **CV** | **p-hat** |
|---|---|---|---|---|---|---|
| 1998 | $M_o$ | 5,005 | 1,500 | 3,586 -19,781 | 0.3 | 0.03 |
| 1999 | $M_o$ | 4,234 | 973 | 3,349 -12,917 | 0.23 | 0.04 |
| 2000 | $M_o$ | 4,971 | 1,249 | 3,824 -16,641 | 0.25 | 0.03 |
| 2003 | $M_t$ | 3,288 | 507 | 2,458 - 4,469 | 0.15 | |
| 2004 | $M_t$ | 3,867 | 444 | 3,124 - 4,912 | 0.11 | 0.09, 0.05, 0.08 |
| 2005 | $M_t$ | 4,317 | 565 | 3,390 - 5,673 | 0.11 | 0.05, 0.06, 0.07 |
| 2007 | $M_t$ | 5,696 | 863 | 4,310 - 7,828 | 0.15 | 0.05, 0.04, 0.06 |
| 2008 | $M_t$ | 3,940 | 397 | 3,266 - 4,851 | 0.10 | 0.07, 0.08, 0.10 |
| 2011 | $M_t$ | 7,177 | 888 | 5,670 - 9,298 | 0.12 | 0.05, 0.03, 0.07 |
| 2012 | $M_t$ | 3,672 | 415 | 2,977- 4,642 | 0.11 | 0.07, 0.09, 0.07 |

Table 3. Mean total length (TL) and associated standard deviation (SD) of Humpback and Roundtail Chubs in Westwater Canyon, UT from 1998–2000, 2003–2005, 2007–2008, and 2011–2012.

| Year | Species | Mean TL of Adults | SD | Minimum TL | Maximum TL |
|---|---|---|---|---|---|
| 1998 | HB | 279 | 40.2 | 190 | 380 |
| | RT | 266 | 33.5 | 197 | 385 |
| 1999 | HB | 293 | 43.3 | 194 | 388 |
| | RT | 279 | 34.3 | 182 | 371 |
| 2000 | HB | 290 | 46.6 | 160 | 402 |
| | RT | 275 | 35.0 | 126 | 388 |
| 2003 | HB | 270 | 43.0 | 190 | 392 |
| | RT | 263 | 32.5 | 111 | 399 |
| 2004 | HB | 266 | 35.1 | 124 | 394 |
| | RT | 266 | 30.1 | 112 | 374 |
| 2005 | HB | 270 | 40.3 | 130 | 394 |
| | RT | 254 | 34.1 | 151 | 416 |
| 2007 | HB | 275 | 39.2 | 126 | 375 |
| | RT | 259 | 38.2 | 125 | 396 |
| 2008 | HB | 279 | 43.6 | 149 | 385 |
| | RT | 261 | 31.0 | 148 | 380 |
| 2011 | HB | 269 | 39.0 | 118 | 375 |
| | RT | 280 | 33.0 | 125 | 389 |
| 2012 | HB | 287 | 42.0 | 170 | 382 |
| | RT | 282 | 44.0 | 165 | 434 |

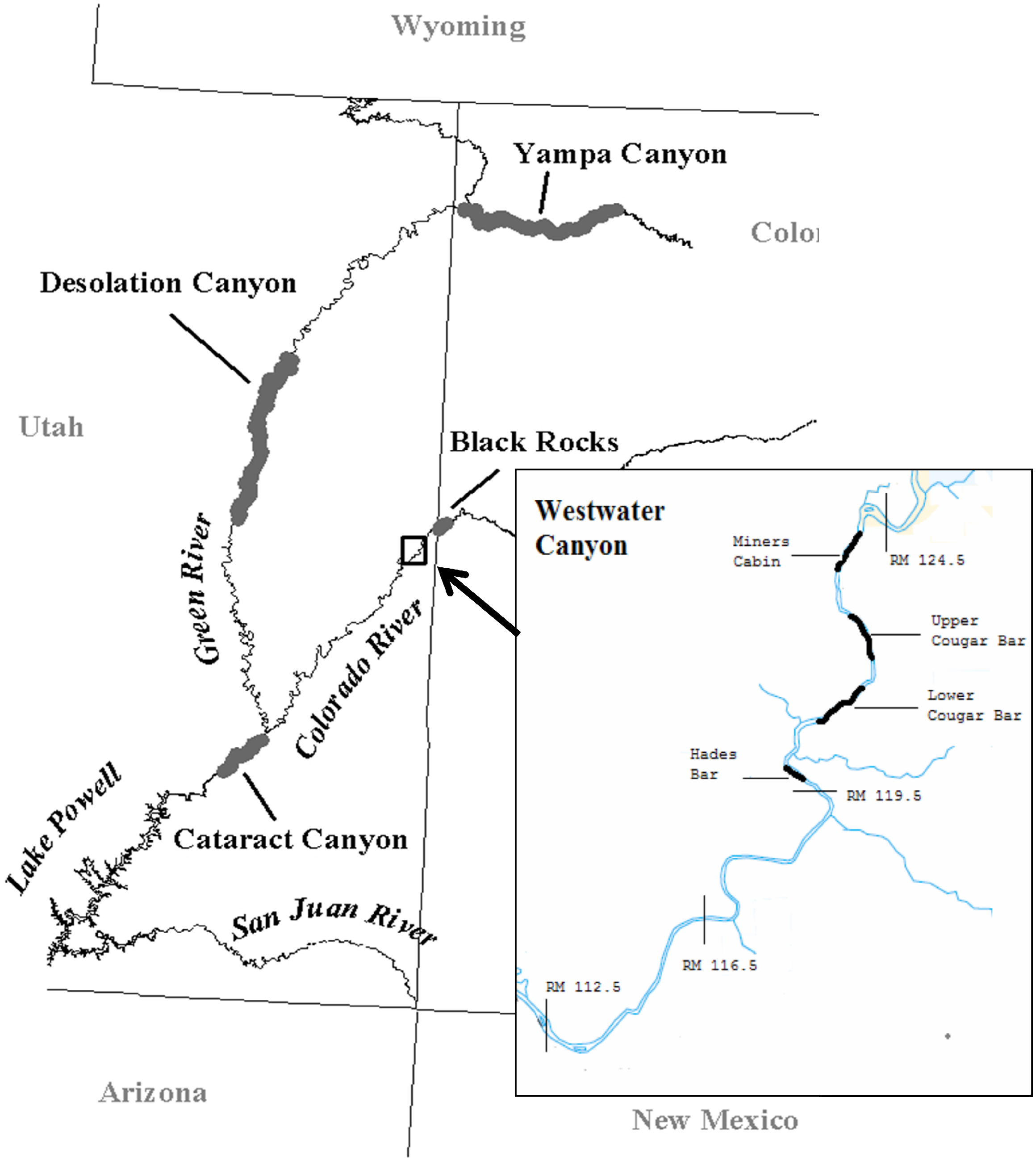


Figure 1. Map of the study area.

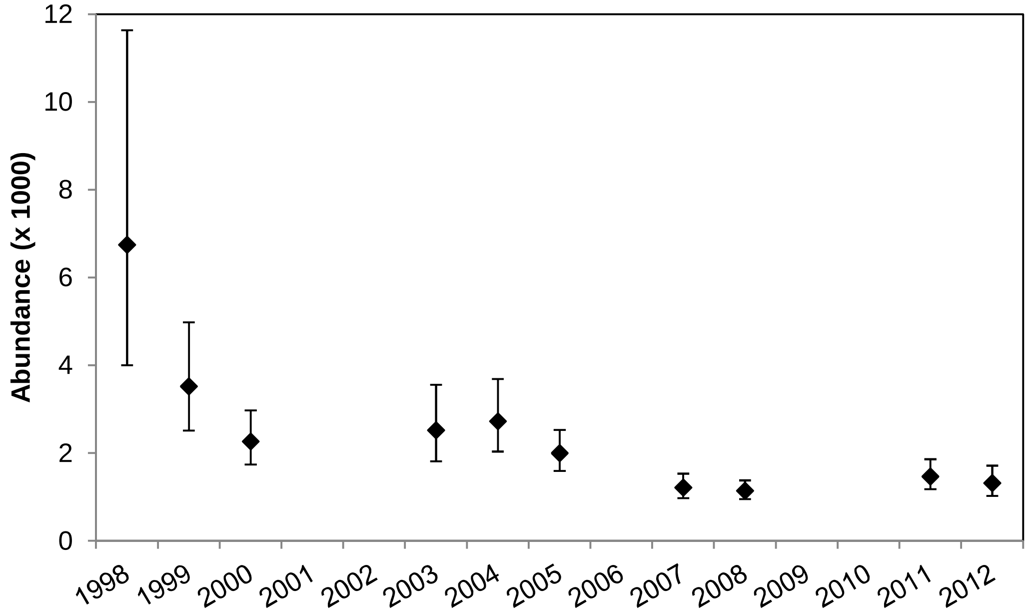


Figure 2. Abundance of Humpback Chub in Westwater Canyon, UT from 1998–2012. Error bars represent 95% confidence intervals.

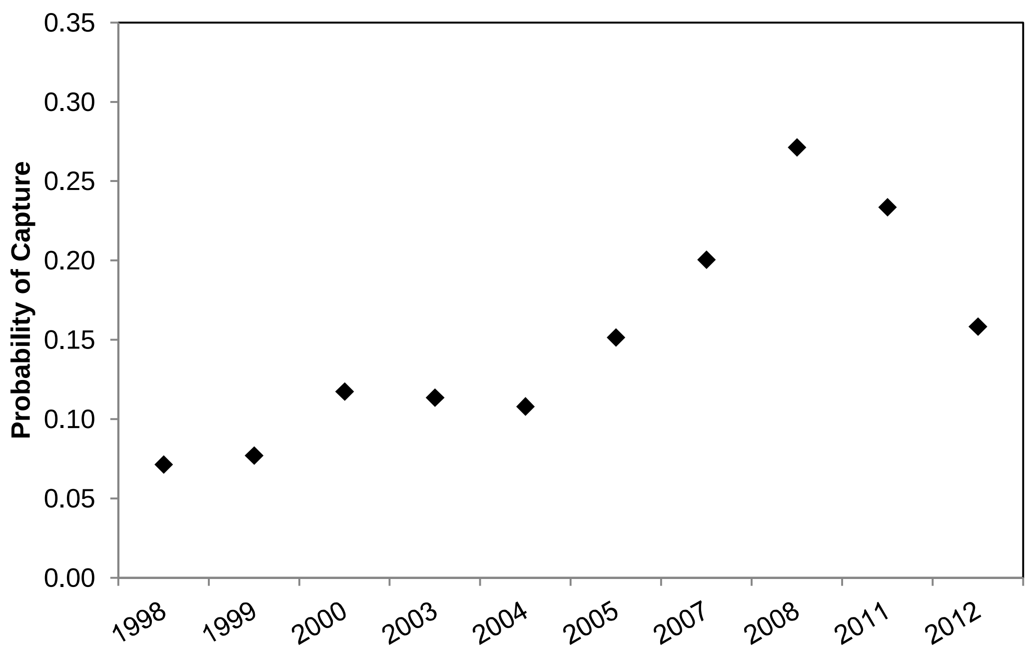


Figure 3. Capture probability of Humpback Chub in Westwater Canyon, UT from 1998–2012.

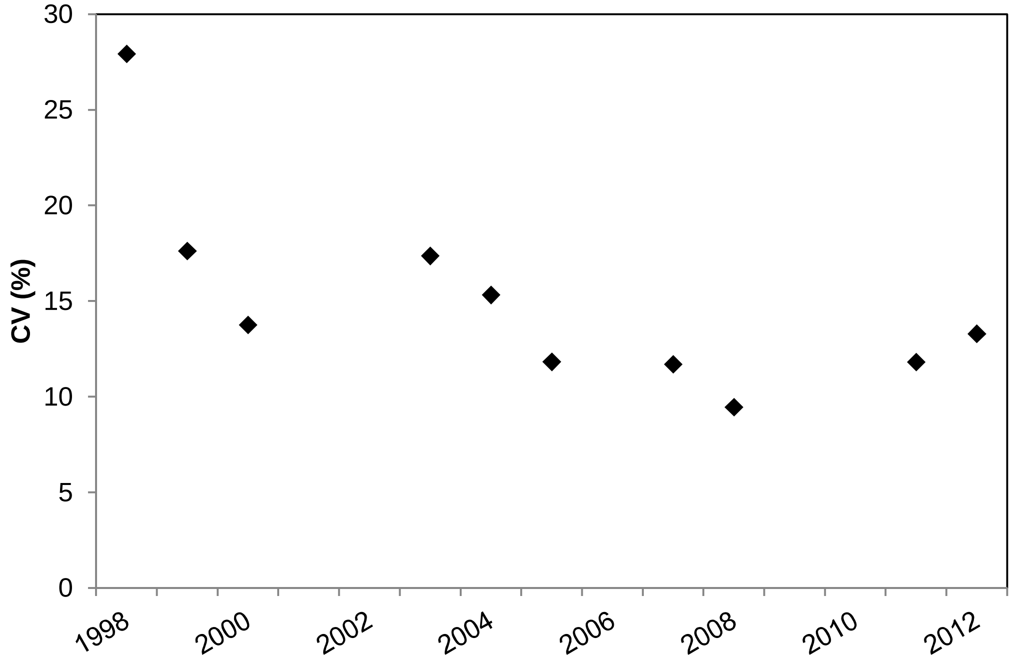


Figure 4. Coefficients of variation for Humpback Chub abundance estimates from 1998 – 2012.

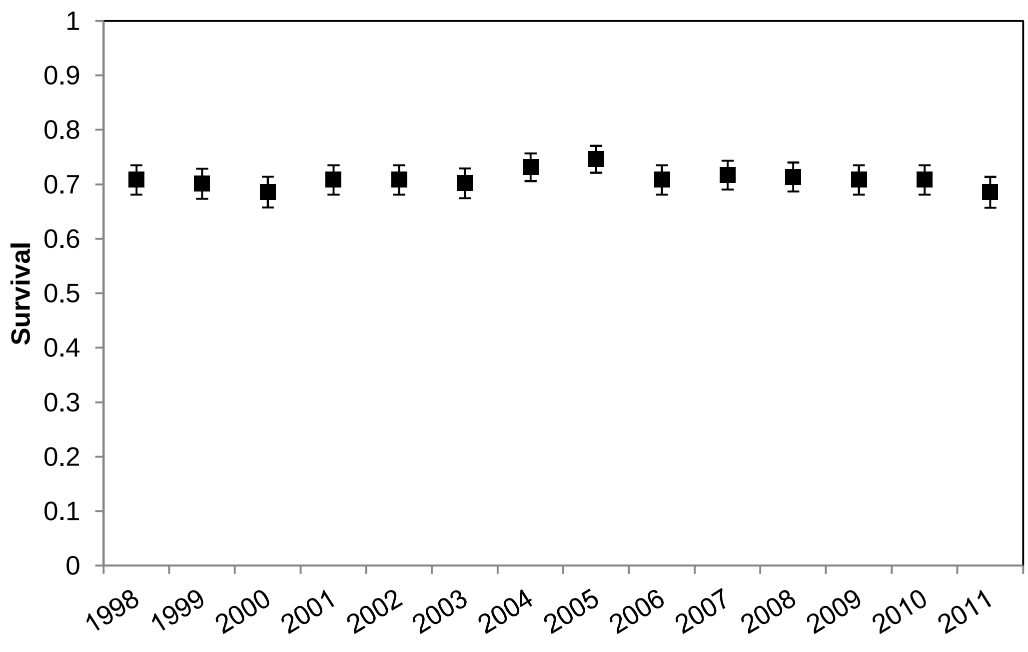


Figure 5. Annual survival of Humpback Chub in Westwater Canyon, UT from 1998–2012. Error bars represent ± 1 SE.

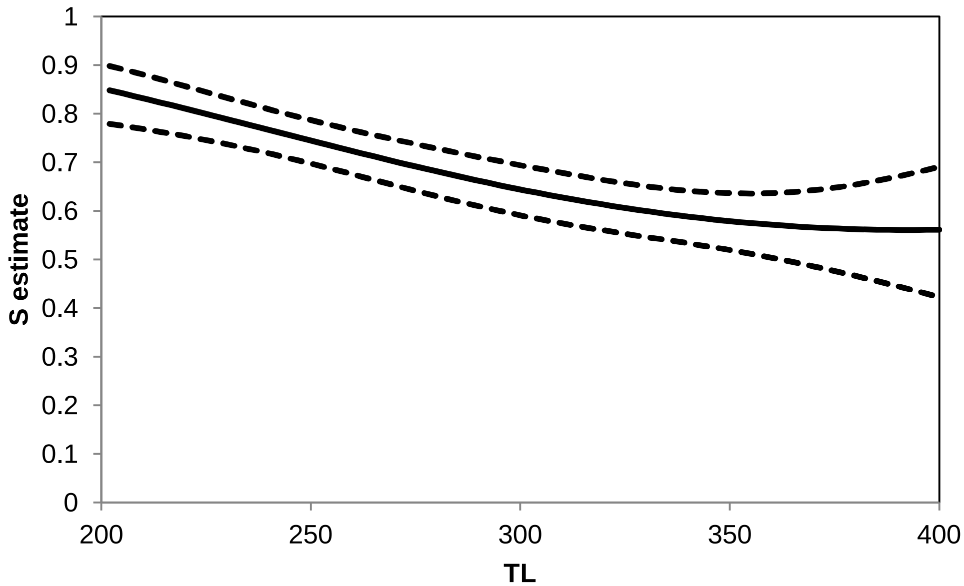


Figure 6. Size dependent survival of Humpback Chub in Westwater Canyon, UT. Solid line is survival and dashed lines are 95%confidence limits.

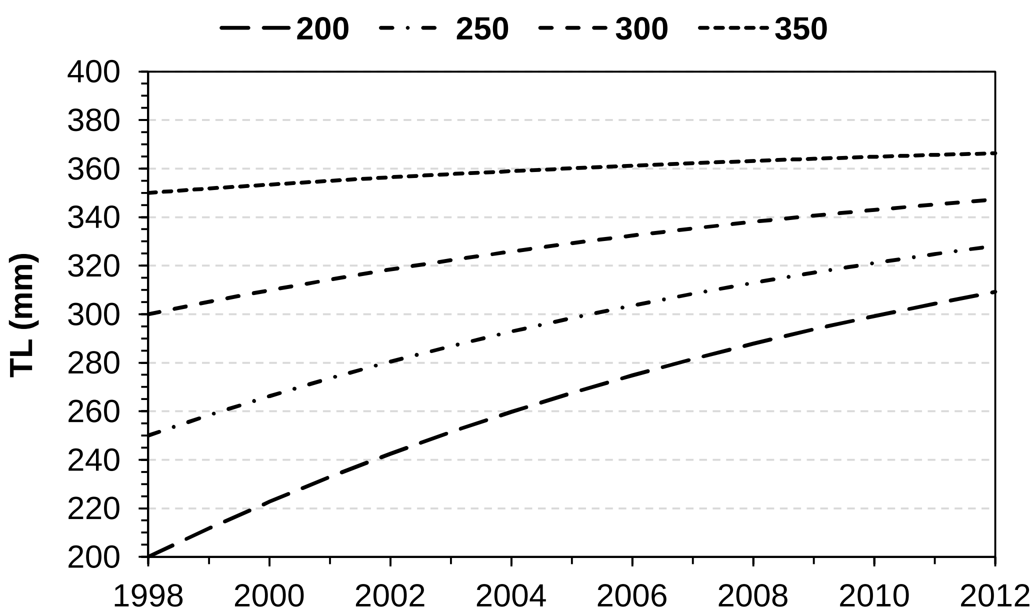


Figure 7. Predictions of annual changes in length for Humpback Chub when starting length in 1998 was either 200, 250, 300, or 350 mm TL. Estimates of change in fish length were from the Von Bertalanfy growth curve for Humpback Chubs in Westwater Canyon, Utah and Black Rocks, Colorado, from the Colorado River, from 1998 – 2012 (K = 0.0666 [SE =0.00669], $L_{\infty}$= 376.4 [SE = 9.86]), and indicated faster growth of younger and smaller fish and slow growth of larger and older fish.

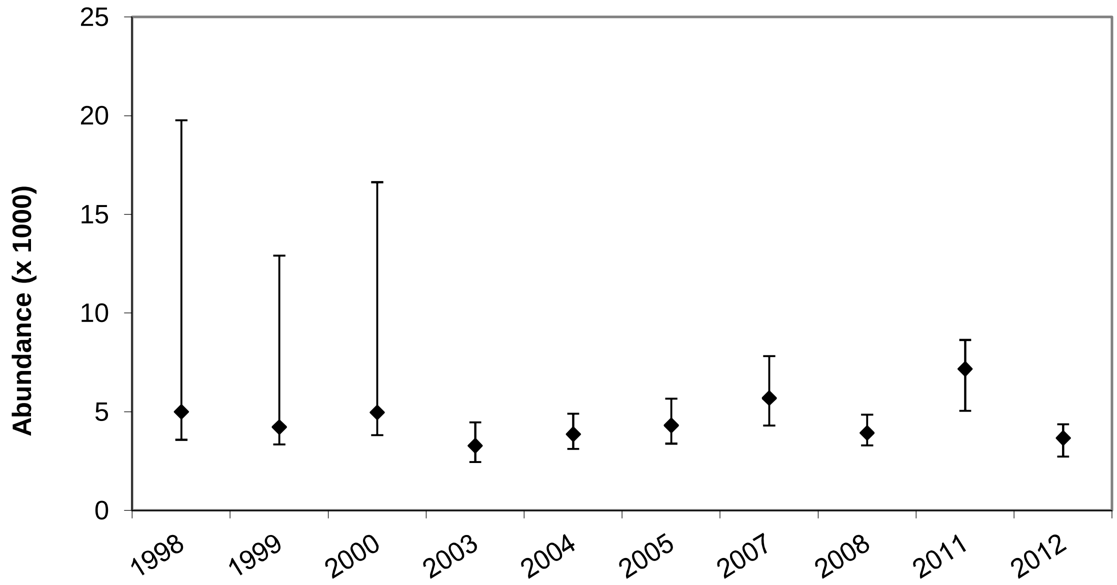


Figure 8. Abundance (N-hat) of adult Roundtail Chubs in Westwater Canyon, UT from 1998–2012. Error bars represent profile likelihood interval.

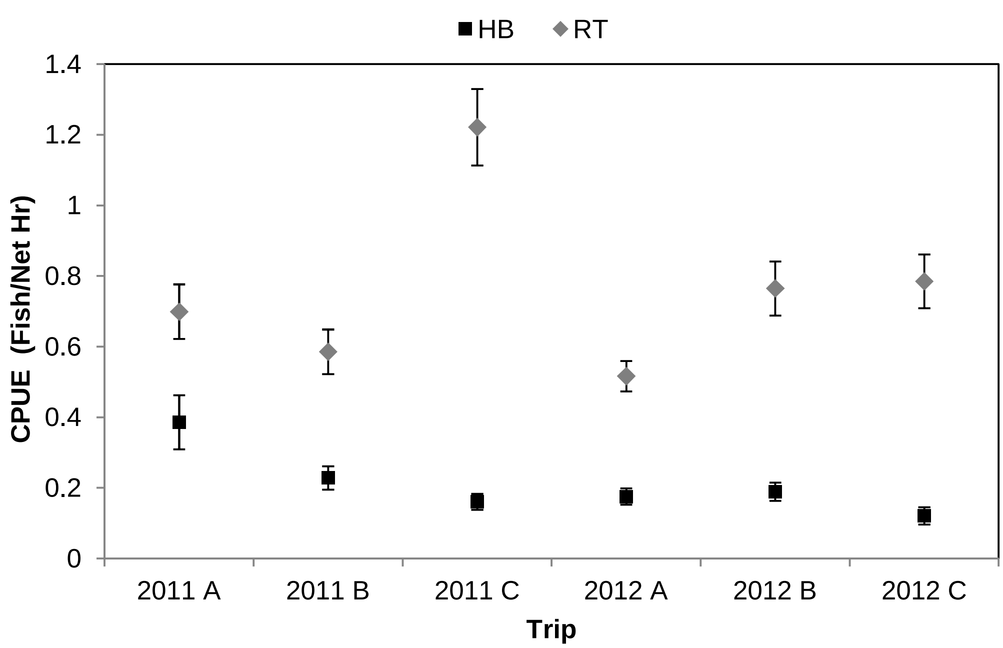


Figure 9. Trammel net catch rate (CPUE) of Humpback Chub (all size classes combined) during each sampling pass in Westwater Canyon from 2011 – 2012. Error bars represent ± 1 SE.

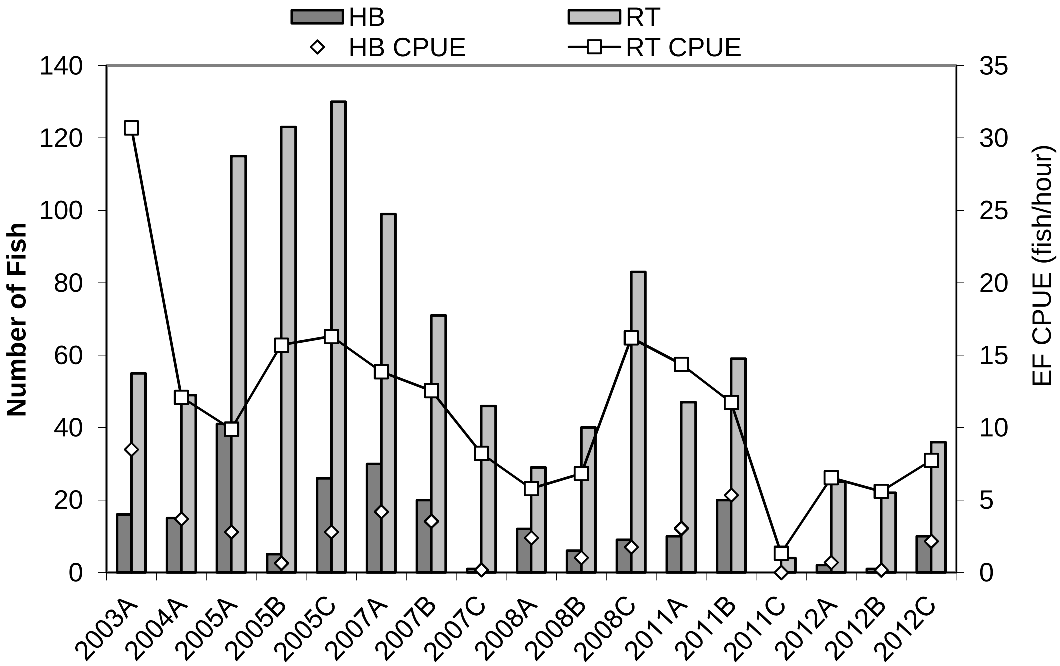


Figure 10. Numbers and catch rate (CPUE) of adult Humpback and Roundtail Chubs collected in Westwater Canyon during electrofishing from 2003 – 2012 by trip. Electrofishing was only conducted during one trip in 2003 and 2004.

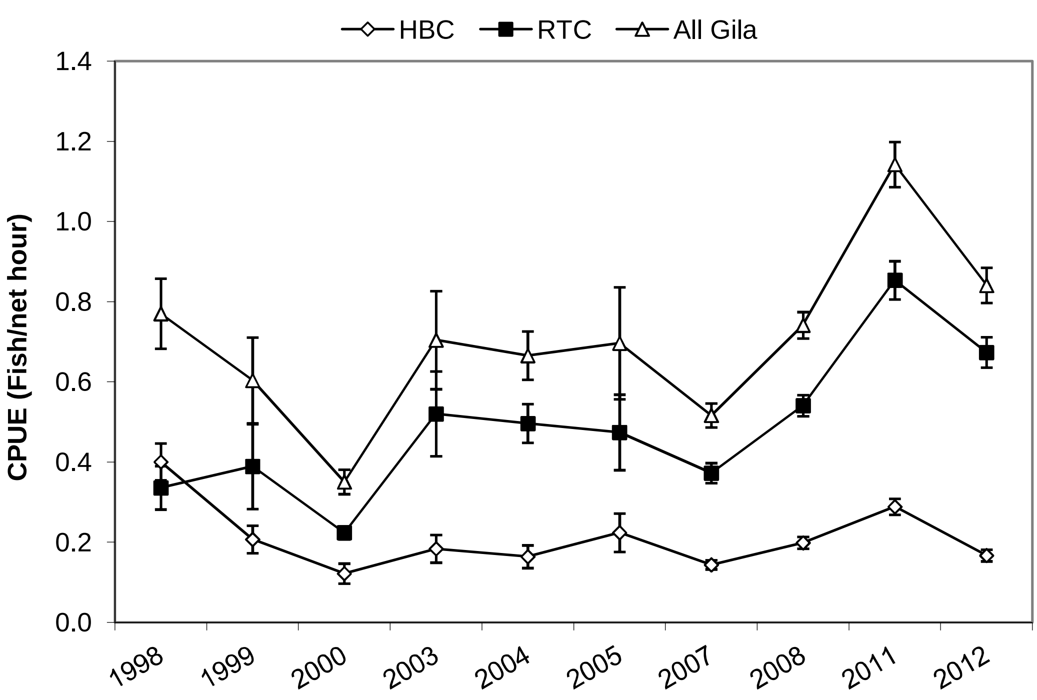


Figure 11. Catch rate (CPUE, three passes combined) of Humpback and Roundtail Chubs and all *Gila spp.* combined (<200 mm) in Westwater Canyon, UT from 1998 – 2012. Error bars represent ± 1 SE.

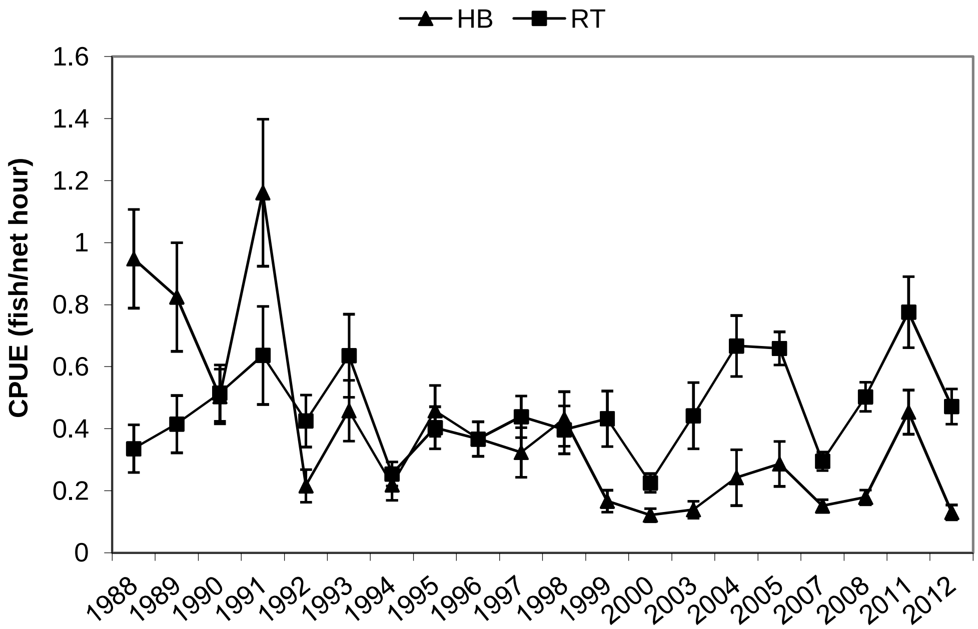


Figure 12. Long-term catch rate (CPUE) of Humpback Chub and Roundtail Chub in Westwater Canyon, UT from 1988–2012. Note that data from 1998–2012 has been lifted from larger population estimate sampling data to be comparable to previous ISMP sampling data. Error bars represent ± 1 SE.

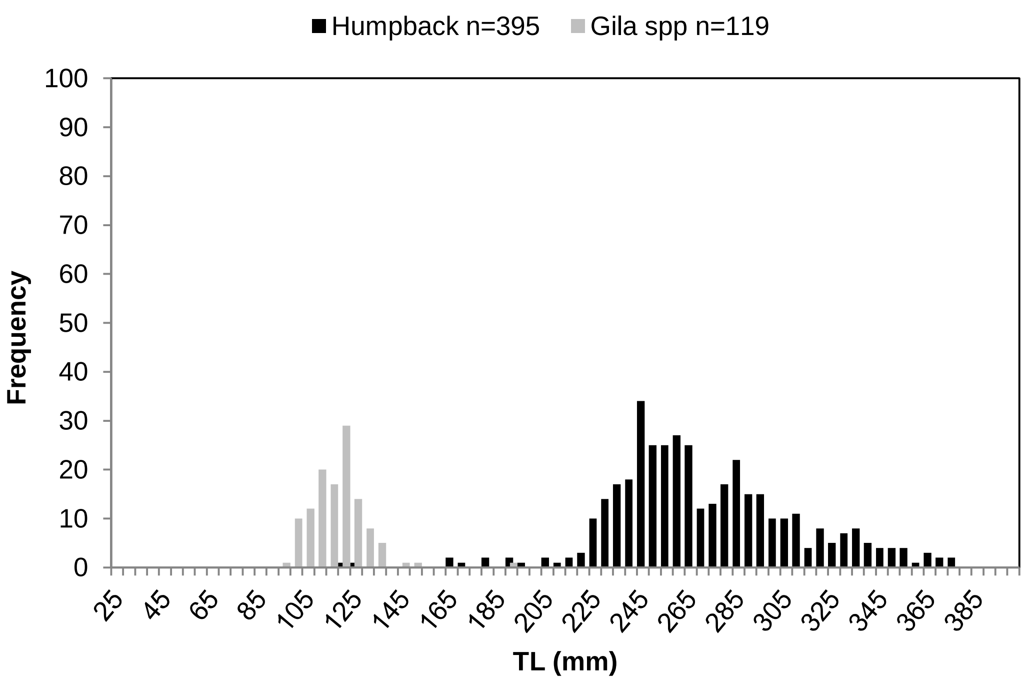


Figure 13. Length-frequency histograms for Humpback Chub and Chub identified as *Gila spp.* in Westwater Canyon from 2011.

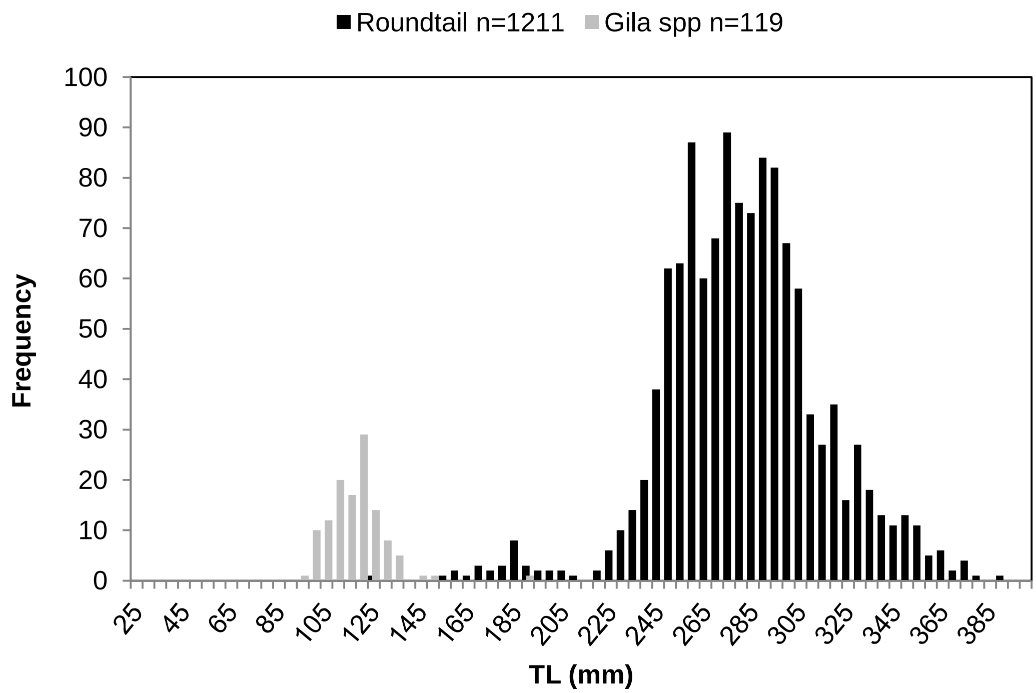


Figure 14. Length-frequency histograms for Roundtail Chub and Chub identified as *Gila spp*. in Westwater Canyon from 2011.

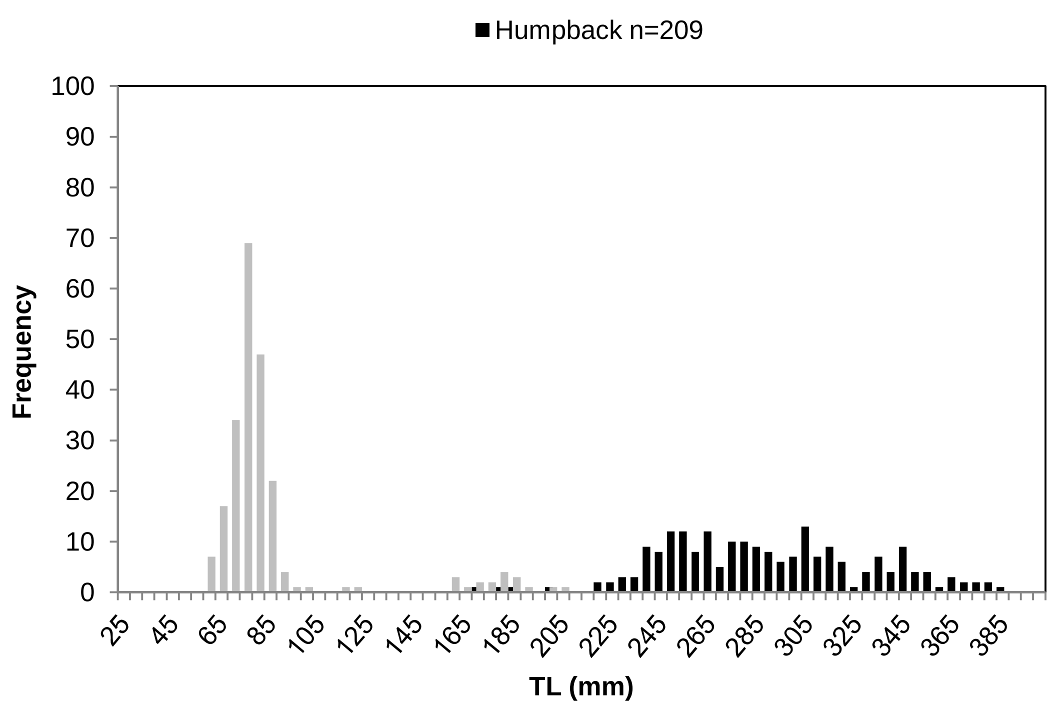


Figure 15. Length-frequency histograms for Humpback Chub and Chub identified as *Gila spp.* in Westwater Canyon from 2012.

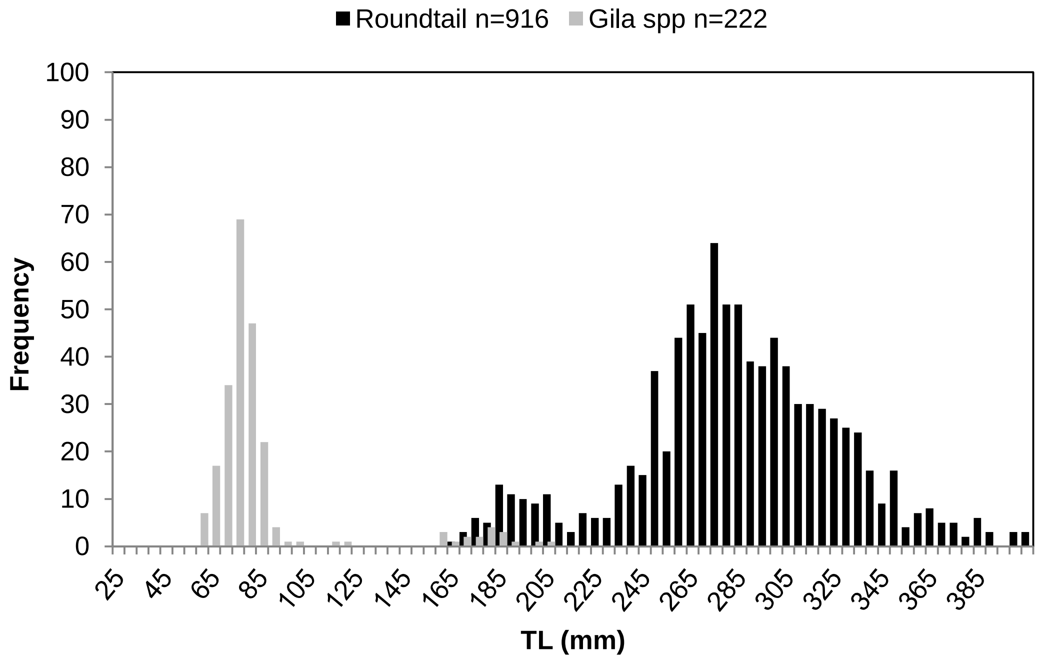


Figure 16. Length-frequency histograms for Roundtail Chub and Chub identified as *Gila spp.* in Westwater Canyon from 2012.

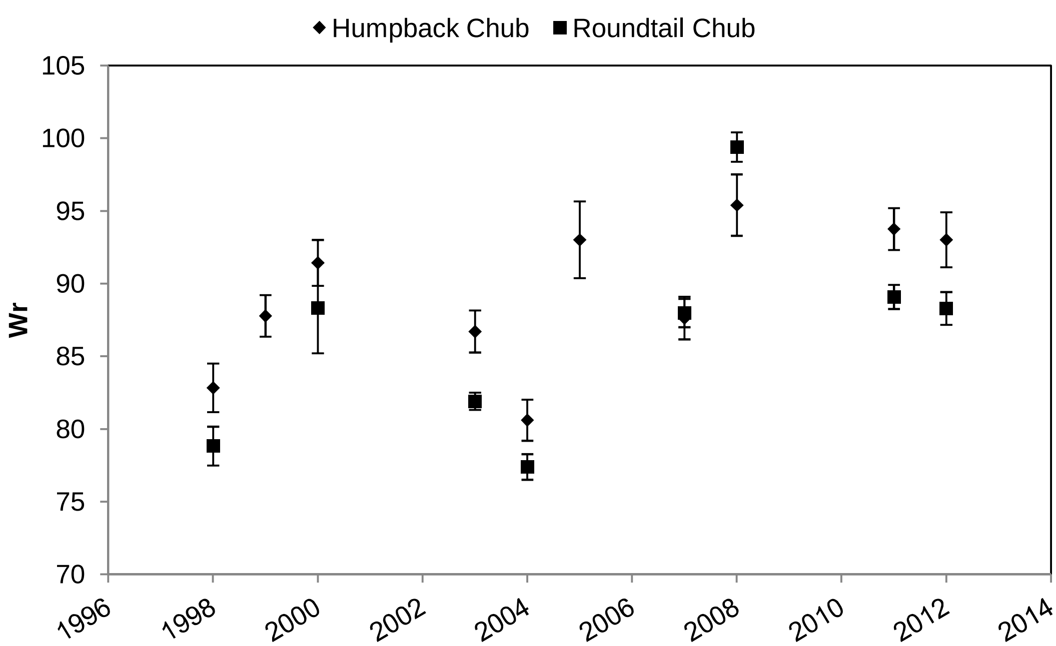


Figure 17. Mean relative weight ($W_r$) for Humpback and Round tail Chub in Westwater Canyon from 1998 – 2012. Error bars represent 95% confidence intervals.

# APPENDIX

Appendix Table 1. Fin ray count (dorsal/anal) percentages for Humpback Chub (HBC), Roundtail Chub (RTC), and intermediate or unidentified Chub (CH) captured from 2003 to 2011. Fin ray counts did not occur in 2012.

| Species | Dorsal/Anal | 2003 | 2004 | 2005 | 2007 | 2008 | 2011 |
|---|---|---|---|---|---|---|---|
| HBC | 9/9 | 35 | 49 | 38 | 24 | 23 | 126 |
| | 9/10 | 57 | 40 | 45 | 39 | 40 | 158 |
| | Other | 8 | 11 | 17 | 36 | 36 | 110 |
| RTC | 9/9 | 77 | 75 | 65 | 39 | 31 | 617 |
| | 9/10 | 18 | 14 | 16 | 30 | 38 | 320 |
| | Other | 5 | 11 | 19 | 30 | 31 | 270 |
| CH | 9/9 | 83 | 37 | 77 | 24 | 13 | 32 |
| | 9/10 | 17 | 25 | 11 | 52 | 43 | 17 |
| | Other | 0 | 38 | 12 | 24 | 45 | 22 |

Appendix Table 2. Presence and absence of species collected in Westwater Canyon, UT. Black text is native species and italicized text is nonnative species.

| Species | 1998 | 1999 | 2000 | 2001 | 2003 | 2004 | 2005 | 2007 | 2008 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Roundtail Chub | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| Humpback Chub | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| Colorado Pikeminnow | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| Flannelmouth Sucker | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| Bluehead Sucker | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| Razorback Sucker | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| Bonytail | N | N | N | N | N | Y | Y | Y | Y | Y | Y |
| Speckled Dace | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| Razorback Sucker x Flannelmouth Sucker | N | N | N | N | N | N | N | N | N | Y | Y |
| *Common Carp* | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| *Channel Catfish* | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| *White Sucker* | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| *Black Bullhead* | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| *Yellow Bullhead* | N | N | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| *Smallmouth Bass* | Y | N | N | N | Y | Y | Y | Y | Y | Y | Y |
| *Sand Shiner* | N | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| *Gizzard Shad* | N | N | N | N | N | N | N | N | Y | Y | Y |
| *Largemouth Bass* | N | N | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| *Rainbow Trout* | N | N | N | N | N | N | Y | Y | Y | Y | Y |
| *Brook Trout* | N | N | N | N | N | N | N | Y | Y | Y | Y |
| *Brown Trout* | N | N | N | N | N | N | N | N | N | Y | Y |
| *Green Sunfish* | N | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| *Bluegill* | N | N | N | N | N | N | N | N | Y | Y | Y |
| *Black Crappie* | N | N | N | N | N | N | N | N | Y | Y | Y |
| *Walleye* | N | N | N | N | N | N | N | N | N | N | Y |
| *Striped Bass* | N | N | N | N | N | N | N | N | N | N | Y |
| *Flannelmouth Sucker x White Sucker* | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Bluehead Sucker x White Sucker* | N | N | N | N | Y | Y | Y | Y | Y | Y | Y |