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Population Estimates for Humpback Chub (*Gila cypha*) and Roundtail Chub (Gila robusta) in Westwater Canyon, Colorado River, Utah 2007-2008

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EXECUTIVE SUMMARY

Mark-recapture sampling was conducted in Westwater Canyon on the Colorado River to estimate the population size of humpback chub (*Gila cypha*) and roundtail chub (*G. robusta*). Three sampling passes were conducted during September and October of both 2007 and 2008. Profile likelihood intervals (PLIs) from closed population estimate models from 2007 and 2008 do not overlap with PLIs for the 1998 population estimate, suggesting a decline in the humpback chub population. Humpback chub population estimates in 2004 and 2005 also indicate a decline relative to the 1998 estimate. PLIs of humpback chub population estimates in 1999, 2000, 2003, 2004, and 2005 do overlap with PLIs from the 2007 and 2008 estimates. The upper boundary of the PLIs from the humpback chub population estimates in the 2005 and 2008 are also below the minimum viable population (2,100 adults) outlined in the 2002 humpback chub recovery goals. Population estimates for humpback chub were: 1,757 (CI, 1,097-3,173) in 2007 and 1,358 (CI, 997 to 1,957) in 2008. The roundtail chub population appears to be stable with confidence limits overlapping for all years from 1998 to 2008. Roundtail chub population estimates were: 5,696 (CI, 4,310-7,828) in 2007 and 3,987 (CI, 3,302-4,908) in 2008. Low numbers of juvenile humpback and roundtail chub 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 2007-2008 study period. Humpback chub catch rates were significantly lower in 2007 and 2008 than catch rates in 1998, but similar to catch rates from 2003-2005. The catch rate of roundtail chubs in 2007 was similar to the catch rate in 1998, and the 2008 roundtail catch rate was significantly higher than the 1998 value. The 2007 and 2008 trammel net catch rates for roundtail chub were similar to catch rates from 2003-2005 study. A comparison of humpback chub ISMP (interagency standardized monitoring program) data to a subset of data collected in 2007 and 2008 showed catch rates consistently lower than catch rates from 1988-1998. Roundtail chub ISMP catch rates varied among years but did not show the decline exhibited by the humpback chub data.

The mechanisms responsible for the decline of the humpback chub population estimates and catch rates are not easily identified. Analyses of length-frequency data suggest the population consists of older individuals with few younger recruits. These data suggest few humpback chub are recruiting into the adult population, while roundtail chub have continued to recruit well. Drought conditions prior to this study period may have played a 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 is a combined carrying capacity for these species, which occupy similar habitats, the decline in humpback chub may not be surprising when roundtail chub populations remain relatively high.

Continuation and refinement in population estimates for both humpback chub and roundtail chub is recommended for Westwater Canyon. Electofishing provides the majority of the juvenile humpback and juvenile roundtail chub mark/recapture data and should be continued. Though the majority of juvenile chub captures are greatest from electrofishing, current numbers of juvenile chub captures are still insufficient to estimate juvenile abundance or recruitment of first year adults. The long-term mark/recapture sampling in Westwater Canyon provides a valuable data set for analysis of survival rates that would further the understanding of the demographics of the two *Gila* species coexisting in the canyon.

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humpback chub, *Gila cypha*, roundtail chub, *Gila robusta*, Westwater Canyon, Colorado River, population estimate, movement

INTRODUCTION

Westwater Canyon contains one of five upper Colorado River Basin populations of endangered humpback chub. Other populations of humpback chub 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 largest population of humpback chub occurs in the Little Colorado River and Grand Canyon (Valdez and Clemmer 1982) on the mainstem Colorado River. The humpback chub was first described in 1946 (Miller 1946) and was included in the first list of endangered species in 1967 (32 FR 4001). It 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 by 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, including parasitism, hybridization, pesticides and pollutants are considered to have contributed to the decline as well (United States Fish and Wildlife Service (USFWS) 2002).

An amendment and supplement to the 1990 recovery goals for humpback chub (USFWS 1990) was finalized in 2002 that identified objective, measurable recovery criteria to downlist and delist humpback chub in both the upper and lower Colorado River Basin (USFWS 2002). Within the upper Colorado River Basin, one of the criteria to downlist humpback chub is the maintenance of one of the populations as a core population with a minimum viable population 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 is currently monitored two of every four years 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 (UDWR 2006b). Because these 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” finding. Roundtail chub are classified as sensitive species by the states of Colorado, Utah and Wyoming (Utah Division of Wildlife Resources (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 2006b).

Estimates were first conducted for humpback chub and roundtail chub in Westwater Canyon from 1998 to 2000 (Hudson and Jackson 2003). During that series of population estimates, point estimates for humpback chub indicated a non-significant downward trend, while point estimates for roundtail chub indicated a stable trend. In addition to point estimates conducted 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 significantly decreased over time, while roundtail chub long-term catch rates remained stable. Recommendations from that study: increasing the number of sample sites and the amount of sampling effort, were incorporated into the 2003–2005 sampling regime. In 2007 and 2008, the sampling effort and sampling locations remained consistent with the 2003–2005 efforts. This report documents the third series of population estimates conducted for 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 ($\geq$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 (Fig. 1). The length of the canyon extends 12 miles (RM 124.5–112.5). The canyon is characterized by the black Proterozoic gneiss and granite complex that comprise the inner gorge. The 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, 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) (Fig. 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 are sampled during each trip. In 2008, Big Hole (RM 116.0–116.3) was sampled during the third pass to determine if any chub inhabit the area below the rapids. Few fish of any species were collected at the Big Hole site, but the sampling did result in the capture of two roundtail chub. 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 2007 and 2008. Three 8-day sampling passes were conducted each year. Approximately 14 days elapsed between the end of one pass and the beginning of the subsequent pass in 2007, and approximately 9 days elapsed between passes in 2008. During each pass, Miners Cabin, Upper Cougar Bar, and Lower Cougar Bar (Fig. 1) were sampled for two nights and Hades Bar was sampled for one night. The Big Hole site was sampled for one night on the third sampling trip of 2008. Multi-filament trammel nets (23 m x 2 m; 2.5 cm mesh) and cataraft electrofishing (pulsed DC Smith-Root® electrofisher, 5.0 GPP) were used to collect fish. Hoop nets were utilized intermittently in 2003 and 2004, but were not used in 2007 and 2008. Total catch by gear type is presented in Appendix 1.

Trammel nets were set in mid-afternoon and checked every one and a half to two 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 chubs. Trammel nets were primarily set 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 2007 and 2008. In 2003 and 2004, electrofishing was conducted during only a single pass. Single pass electrofishing was previously established under ISMP protocol. Increased electrofishing was conducted beginning in 2005 to increase the catch of juvenile and early adult chubs and strengthen population estimates. The majority of electrofishing occurred at the three upper 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. Electrofishing catch rates of sub-adult *Gila* spp. is presented in Appendix 2.

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 (± 1mm) weight (± 1g), and dorsal and anal fin ray counts. Dorsal and anal fin ray counts are presented in Appendix 3. 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 and roundtail chub greater than 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.

Data Analysis

Population Estimate

Population estimates were determined for adult humpback chub and adult roundtail chub ($\geq$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 for each species. 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 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 humpback chub or juvenile roundtail chub (150–199 mm TL) 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.

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.

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 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 3.0 (SPSS Inc).

Catch rate data (CPUE) 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 to 1998.

Relative Condition

Relative condition, which accounts for allometric growth and is comparable between species, was calculated for humpback and roundtail chub. Data from Black Rocks and Westwater were combined from years 1991 to 2008 for the analysis. Relative condition (K_n) is observed mass (M_o) divided by expected mass (M_e) of a individual fish of its length:

$$K_n = (M_o / M_e) * 100$$

Expected mass is derived from weight-length regression:

$$Log_{10}M_e = ((Log_{10}length)\ slope) + y\ intercept)$$

All measurements were form captures of humpback and roundtail chub from the last week of August through the first week of November. Mean relative condition was

compared among years by Analysis of Variance: pairwise comparisons with Bonferroni adjustment ($p<0.05$; XSTAT 2009).

RESULTS

Population Estimates

Humpback chub

Due to the variability in capture probabilities in 2007, the Darroch M_t model was selected for the humpback chub population estimate. In 2008, the M_o model was selected. Population estimates of adult humpback chub in 2007 and 2008 remained similar to estimates calculated during the previous sampling period (2003–2005). Population estimates from 2007 and 2008 were: 1,757 (SE = 470) and 1,358 (SE = 232), respectively (Table 1, Figure 2). Coefficients of variation were 27% in 2007 to 17% in 2008 (Table 1). Point estimates from the 2003 to 2005 sampling period were: 2,973 (SE = 941), 1,729 (SE = 424), and 1,210 (SE = 213) (Jackson 2010) (Table 1, Figure 2). While no differences exist between population estimates from the 2007–2008 sampling period versus the 2003–2005 sampling period, the 2007–2008 population estimates are significantly lower than the population estimate from 1998. Population estimates from 1998 to 2000 were: 4,744 (SE = 1,089), 2,215 (SE = 624), and 2,201 (SE = 626) (Hudson and Jackson 2003) (Table 1, Figure 2). While the population estimates from 2007 and 2008 are significantly different than the 1998 estimate, the profile likelihood intervals associated with the 1999 and 2000 population estimates overlap with profile likelihood interval for the 2007 and 2008 population estimates, indicating no difference. Additionally, the upper end of the profile likelihood interval for the 2005 and 2008 estimates are below the minimum viable population identified in the 2002 recovery goals. Model output for all models calculated for humpback chub with Program CAPTURE are presented in Appendix 4.

Population estimates for juvenile humpback chub (150-199 mm TL) 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. Numbers of humpback chub juveniles collected by all methods were: six in 2003, 24 in 2004, eight in 2005, five in 2007 and seven in 2008. Numbers of first year adult humpback chub 200–220 mm captured were: 24 in 2003, 17 in 2004, 21 in 2005, 10 in 2007 and 16 in 2008.

Roundtail chub

Due to the variability in capture probabilities in 2007, the Darroch M_t model was selected for the roundtail chub population estimate. In 2008, the M_o model was selected. Population estimates of adult roundtail chub in 2007 and 2008 remained similar to estimates calculated during the previous sampling periods (1998–2000 and 2003–2005). Population estimates from 2007 and 2008 were: 5,696 (SE = 863) and 3,987 (SE = 402), respectively (Table 2, Figure 3). Coefficients of variation were 15% in 2007 and 10% in 2008 (Table 2). Population estimates from 1998 to 2000 were: 5,005 (SE = 1,500), 4,234

(SE = 973), and 4,971 (SE = 1,249) (Hudson and Jackson 2003) (Table 2, Figure 3). Population estimates from 2003 to 2005 were: 3,288 (SE = 507), 3,867 (SE = 444), and

4,317 (SE = 565) (Jackson 2010) (Table 2, Figure 3). Unlike the humpback chub population estimate, the data suggest the roundtail chub population within Westwater Canyon is stable. Model output for all models calculated for roundtail chub with Program CAPTURE are presented in Appendix 5.

Population estimates for juvenile roundtail chub (150–199 mm TL) were not attempted by mark/recapture data in 2007 or 2008 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 population (Jackson, 2010). Recruitment of first year adult roundtail chub was also not estimated in 2007 or 2008. Concerns related to the size class used for first year adults exist for roundtail chub similar to humpback chub. Numbers of roundtail chub juveniles collected by all methods were: 23 in 2003, 101 in 2004, 144 in 2005, 78 in 2007, and 27 in 2008. Numbers of individuals 200–220 mm were: 68 in 2003, 35 in 2004, 119 in 2005, 45 in 2007, and 48 in 2008.

Catch Rates

Humpback chub

2007—Trammel net catch rates of humpback chub varied among sampling passes in 2007 (Figure 4). Two hundred thirty-four adult humpback chub were captured during a total of 1,749 net hours. No juvenile humpback chub were captured with trammel nets in 2007. Highest mean catch rate of humpback chub occurred during the first sampling trip. Fifty-one additional adult humpback chub were captured during 18.3 hours of electrofishing effort (Figure 6). Five juvenile humpback chub were also captured by electrofishing. Forty-nine juvenile chub identified only as *Gila* spp. were also captured with electrofishing in 2007.

2008—Trammel net catch rates of humpback chub varied among sampling passes in 2008 (Figure 4). Three hundred twenty-two adult humpback chub were captured during a total of 1,616 net hours. No juvenile humpback chub were captured with trammel nets in 2008. Highest mean catch rate of humpback chub occurred during the first sampling trip. Twenty-seven additional adult humpback chub were captured during 16.0 hours of electrofishing effort (Figure 6). Six juvenile humpback chub were also captured by electrofishing. One hundred nine juvenile chub identified only as *Gila* spp. were also captured with electrofishing in 2008.

Roundtail chub

2007—Trammel net catch rates of roundtail chub varied among sampling passes in 2007 (Figure 5). Six hundred sixty-four adult roundtail chub were captured during a total of 1,749 net hours. One juvenile roundtail chub was captured with trammel nets in 2007. Highest mean catch rate of roundtail chub occurred during the last sampling trip. Two

hundred twenty additional adult roundtail chub were captured during 18.3 hours of electrofishing effort (Figure 6). Seventy-seven juvenile humpback chub were also captured by electrofishing. Forty-nine juvenile chub identified only as *Gila* spp. were also captured with electrofishing.

2008—Trammel net catch rates of roundtail chub varied among sampling passes in 2008 (Figure 5). Eight hundred seventy-three adult roundtail chub were captured during a total of 1,616 net hours. One juvenile roundtail chub was captured with trammel nets in 2008. Highest mean catch rate of humpback chub occurred during the last sampling trip. One hundred fifty-two additional adult roundtail chub were captured during 16.0 hours of electrofishing effort (Figure 6). Twenty-six juvenile roundtail chub were also captured by electrofishing. One hundred nine juvenile chub identified only as *Gila* spp. were also captured with electrofishing.

Catch Rate Comparisons

Catch rates of humpback chub during 2007 and 2008 sampling were significantly lower than in 1998 ($p < 0.05$, Figure 7). Catch rates of humpback chub in 2007 and 2008 were not different from previous sampling years 1999–2005. Catch rates of roundtail chub from 2007 and 2008 sampling are significantly higher than in 2000 ($p < 0.05$, Figure 7). The 2007 and 2008 catch rates of roundtail chub are not significantly different from catch rates in other sampling years. Catch rate of all *Gila* spp. combined in 2000 is significantly lower than combined catch rates in 2007 and 2008 ($p < 0.05$, Figure 7).

Single pass catch rate data from the 1998–2000, 2003–2005, and 2007–2008 study periods were also compared to ISMP data (1988–1997). As sampling from 1998–2008 includes multiple passes per year, catch rate data from only a single pass from years 1998–2008 are included for comparison with ISMP data (Figure 8). Single pass catch rate data of humpback chub has remained similar since 1999, but is lower than most years prior to 1999. Single pass catch rates of roundtail chub over the same period of time have remained similar and even increased during some recent years.

Movement

Humpback chub

Movement of humpback between Black Rocks and Westwater Canyon (separated by approximately 12 river miles) was documented during the 2007–2008 sampling period. Six total humpback chub were noted moving from Westwater Canyon to other locations within the Upper Colorado River Basin. One humpback chub captured in Westwater Canyon in 2007 was captured in Black Rocks in 1998. Three humpback chub captured in Westwater Canyon in 2007 were captured in Black Rocks during 2008. One humpback chub captured in Westwater in 2008 was also captured in Black Rocks in 2008, 19 days prior to being caught in Westwater Canyon. An additional humpback chub tagged in Westwater Canyon in October 2008 was captured approximately 50 river miles upstream

in August, 2010 at the Redlands fish passage on the Gunnison River (Bob Burdick, personal communication).

Roundtail chub

Movement of roundtail chub between Black Rocks and Westwater Canyon was also documented during the 2007–2008 sampling period. Eleven total roundtail chub were noted moving from Westwater Canyon to other locations within the Upper Colorado River Basin. Three roundtail chub captured in Westwater in 2007 were captured in Black Rocks in 2008. One roundtail chub captured in Westwater in 2008 was initially captured in Black Rocks in 2007. Two roundtail chub were captured in both Westwater and Black Rocks in 2007. Two roundtail chub were also captured in both Westwater and Black Rocks in 2008. Three additional roundtail chub captured in Westwater in 2007 and 2008 were also later captured in Black Rocks in 2008.

Length-Frequency

Length frequency histograms suggested the size of adult humpback chub and adult roundtail chub remained relatively consistent during the study period (Figures 9 and 10). The mean TL of adult humpback chub was 275 mm TL in 2007 (SD=39.2) and 279 mm TL in 2008 (SD=43.6) (Table 3.) The mean TL of the adult roundtail population was 259 mm in 2007 (SD=38.2) and 261 mm in 2008 (SD=31) (Table 3.) The mean TL of both adult humpback and roundtail chub from 2007-2008 are also similar to mean TLs from 1998 to 2005 (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. In the 2007 length-frequency histograms, young-of-year (YOY) *Gila* spp. are present, but this age class was uncommon in the 2008 histograms with only one individual being captured. The 2008 histograms indicate an increase in the number of age-1 *Gila* spp. (YOY in 2007 histograms) relative to the 2007 histograms. 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.

Size and Relative Condition

Humpback chub

The mean TLs of humpback chub remain stable in Westwater Canyon. From 1998 to 2008, humpback chub mean TL ranged from 267 mm TL in 2004 to 293 mm TL in 1999, but confident intervals overlap during all years indicating no significant differences.

Condition (K_n) of humpback chub was assessed using mass-length regression from historic humpback chub data from Black Rocks and Westwater Canyon combined (n = 4,543). The M_e (mass-length regression) equation was;

$$Log_{10}M_e = ((Log_{10}length)\ 2.839) + (-4.732)$$

Mean K_n of humpback chub in Westwater Canyon in 2008 was significantly higher than any previous year (Figure 11). Mean K_n in 2007 was significantly higher than in years prior to 1999, but was similar to most years after 1999.

Roundtail chub

The mean TLs of roundtail chub remain stable in Westwater Canyon. Roundtail chub mean TL ranged from 254 mm TL in 2005 to 279 mm TL in 1999. Similar to humpback chub, the mean TL of roundtail chub was not significantly different between years.

Condition of roundtail chub was assessed using mass-length regression from historic roundtail chub data from Black Rocks and Westwater Canyon combined (n = 8,444). The M_e (mass-length regression) equation was;

$$Log_{10}M_e = ((Log_{10}length)\ 2.928) + (-4.935)$$

Mean K_n of roundtail chub in Westwater Canyon in 2008 was significantly higher than any previous year (Figure 11). Mean K_n in 2007 was significantly higher than in all years prior to 1999.

DISCUSSION

Model Selection

Due to the variability in capture probabilities in 2007, the Darroch M_t model was chosen for both humpback chub and roundtail chub population estimates. In 2008, the M_o model was selected for both species. In both years, models including behavioral (M_b) and individual heterogeneity (M_h) components ranked higher than the null model M_o and models only including variability in capture probability (M_t). While M_b and M_h models often ranked higher, they were not considered because sampling within Westwater Canyon consists of only three sampling occasions (trips) per year. M_h and M_b components are difficult to model when only three sampling trips are completed and the number of animals captured is low. Variable capture probability among trips within a year may be due to environmental factors and not necessarily animal behavior such as net shyness. Jackson (2010) assessed the relationship of CPUE relative to discharge (cfs) and temperature (°C) using linear regression and found no significant relationships for either humpback chub or roundtail chub CPUE. While discharge and temperature did not explain differences in CPUE, turbidity, phase of the moon or other unknown environmental factors maybe affecting capture probability. Model output for models not selected or considered for humpback are presented in Appendix 4 and in Appendix 5 for roundtail chub.

Assumptions of Models

Some closed population model assumptions were likely violated to a small degree during the study period. Due to the presence of riffles and rapids that are impassible to upstream boat travel in Westwater Canyon, it is probable that some proportion of the population is

less likely to be captured. It is likely, based on previous data (Valdez et al. 1982), that a portion of the humpback chub population resides in the rapids section of the canyon that is not accessible for sampling. Sampling sites encompass the largest areas that can be effectively sampled, but small sections of suitable habitat exist in areas we are unable to sample. Within-year recaptures of both humpback chub and roundtail chub primarily occur at the same location as the first capture. While most recaptures occur in the same location as the initial capture, each year a small percentage (< 2%) of recaptures occur at different sampling locations. In 2008, one humpback chub and two roundtail chub were captured in both Black Rocks and Westwater Canyon. This was the second recorded case of humpback chub movement between Black Rocks and Westwater within a year. Shed PIT tags, identified by the presence of a PIT tag scar on a fish without being able to detect a tag with the PIT tag reader, and PIT tag numbers being recorded incorrectly was rarely observed during the study. Appendices 6 and 7 summarize long-term recaptures of humpback and roundtail chub within Westwater Canyon.

Population Estimates and Catch Rates

In 2007 and 2008, the population estimates of humpback chub in Westwater Canyon remained similar to years after 1998, but were significantly lower than the 1998 population estimate. The precision of estimates has increased since 1998 and is likely the result of increased sampling effort (addition of Upper Cougar Bar sampling site and electrofishing occurring during every sampling trip). The lowest CVs (0.17) occurred during 2005 and 2008. While precision of population estimates has been increasing, wide confidence limits still make detecting small changes in the population difficult. Additionally, the upper limits of the PLIs for the 2005 and 2008 Westwater Canyon estimates are below the minimum viable population of 2,100 individuals identified in the recovery goals.

Electrofishing was effective in collecting humpback chub and roundtail chub and was particularly effective in collecting 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 2007 and 2008, 19% and 9% of the total humpback chub catch were collected by electrofishing. All juvenile humpback chub, all juvenile chub identified as *Gila* spp. and > 99% of juvenile roundtail chub were captured by electrofishing.

Humpback chub trammel net catch rates declined similarly to adult population estimates, while roundtail chub trammel net catch rates remained stable. 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 2008, but appear stable since 1999 to 2008. Roundtail chub catch rates have remained more stable with the lowest catch rate occurring in 2000. While no significant relationship was found between humpback chub or roundtail chub CPUE and discharge by Jackson (2010) it is possible that drought conditions prior to this sampling period decreased spawning success of 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), 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 2007 and 2008 were 14,700 cfs and 39,600 cfs. Length-frequency histograms from 2007 and 2008 indicate higher number of captures of YOY chub during 2007 with 17 YOY chub captures in 2007 and only one YOY chub capture in 2008. While more YOY chub were captured in 2007 than in 2008, 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). Additionally, from 1999–2002 the Colorado River never peaked above 18,000 cfs. This period of peak spring flows well below 30,000 cfs could be responsible for the low numbers of juveniles and small adult humpback chub captured in 2007 and 2008.

Movement

Data from 2007 and 2008 indicate some movement of both humpback chub and roundtail chub is occurring between the Black Rocks and Westwater sampling areas. As sampling occurs during September and October in both Black Rocks and Westwater, the full extent of movement of individual fish between differing periods of the year and among years may not be fully understood. The total number of fish documented to be moving between the two sample areas is low, but a larger proportion of the populations may be moving during other seasons within the year. This amount of exchange of individuals between Westwater Canyon and Black Rocks allows the two populations to serve as a core population according to the recovery goals (USFWS 2002). Continuing to sample both Black Rocks and Westwater at similar times will decrease the chances of model assumption violations. Combining data from Black Rocks and Westwater for a single population estimate would eliminate concern over within-year movement between the two sampling areas and allow for combining the data for a single population estimate.

Size and Relative Condition

The mean TLs of humpback chub and roundtail chub remain stable in Westwater Canyon. Confidence intervals for humpback chub mean TL overlap during all years indicating no significant differences. Length-frequency data also indicate the majority of the adult population is composed of larger individuals with few adults being recruited into the population. 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.

Relative condition of humpback chub and roundtail chub varies among years in Westwater Canyon. Both humpback and roundtail chub condition was highest in 2008. While relative condition of both species was highest in 2008, confidence limits overlap for each species in many years. Significant differences also exist between the species during some years while confidence limits overlap in other years. No trends in condition related to river discharge are apparent.

Recruitment

No estimate of first-year adult recruitment or abundance of juvenile humpback chub or roundtail chub was calculated for the 2007 and 2008 study period. Jackson (2010) estimated first year adult recruitment by using the proportion of the first year adults in the total catch of a species and applying the same proportion to the abundance estimate for each species. Analysis of the Upper Colorado River Recovery Program humpback chub database indicate some individual humpback chub are persisting in the first year adult size class (200–220 mm TL) for multiple years. This suggests the method previously used to determine first year adult recruitment would overestimate recruitment and abundance of first year adults. Since mark recapture population estimates began in Westwater Canyon in 1998, the catch was only sufficient in 2005 to estimate abundance of juvenile roundtail chub.

Estimating abundance of juvenile and first year adult humpback chub and roundtail chub within Westwater Canyon would greatly aid in the understanding of the demographics of the two populations. Currently, our study design and sampling gear largely focus on monitoring adult chub. It is quite likely the catch of juvenile chub will continue to be below what is needed to estimate the juvenile proportion of the population as one-inch inner mesh trammel nets rarely capture chubs less than 200mm TL. Electrofishing captures chubs less than 200 mm TL, but the electrofishing catch alone is insufficient for conducting population estimates of juvenile chubs. Baited hoop nets are used effectively to capture juvenile humpback in the in Grand Canyon. In Westwater Canyon, hoop nets and cast nets were utilized from 2003 to 2005 in an attempt to increase the catch of juvenile and first year adult humpback chub and roundtail chub but were discontinued after 2005 because of low catch rates.

Several possible reasons for the insufficient catch of juvenile chubs exist. The possibility exists that juvenile chubs are not present in sufficient numbers because of poor spawning success related to the several years of low peak flows. Another potential reason for the low catch of juvenile chub is that chubs from 150–200 mm TL may be using similar habitat (deep eddies) as adult chub. The trammel nets currently utilized are only effective at catching chubs greater than 200 mm TL, and electrofishing is not effective in deep water. Trammel nets with smaller inner mesh could be used but would likely negatively affect the catch of adult chubs, which is not acceptable. Further complicating the issue is

our sampling schedule of two years off between study periods. By sampling only two of four years, cohorts can not be tracked to adulthood and determining growth rate from year to year is only possible one of every four years which makes determining first year adults unreliable.

Handling Concerns

McAda (2002) expressed concern of handling mortality by researchers as a possible cause of the decline observed for humpback chub in Black Rocks just upstream of Westwater Canyon. This concern is shared among other Upper Colorado River Basin researchers. In 2007 and 2008, the immediate mortality rate of humpback chub from trammel net sampling was less than 0.2% and the immediate mortality rate of roundtail chub was less than 0.3%. These immediate mortality values are slightly lower than rates found by Jackson (2010). No humpback chub and only one roundtail chub mortality were found from fish collected by electrofishing. While immediate mortality rates are low, mortality rate following release is unknown.

CONCLUSIONS

- Population estimates of humpback chub in Westwater Canyon remained stable during the study period (2007–2008). The profile likelihood intervals for humpback chub population estimates conducted from 1998–2008 indicate a significant decline from 1998 to 2008. The upper limit of the profile likelihood intervals for the 2005 and 2008 estimates are below the minimum viable population estimate of 2,100 adults identified in the recovery goals for this species. Additionally, the point estimates from Black Rocks and Westwater Canyon combined (1,645 adults) in 2008 are below the minimum viable population (Francis and McAda 2011).

- Population estimates for roundtail chub in Westwater Canyon remained stable during the study period (2007–2008). Profile likelihood intervals for roundtail chub population estimates conducted from 1998–2000, 2003–2005 and 2007–2008 overlap, indicating a stable population.

- The small number of captures of juvenile and first-year adult humpback chub precluded estimating the population of juvenile humpback chub or recruitment of first year adults 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 has shown considerable variation in catch rate of juvenile chub from year to year. This may indicate electrofishing may provide a relative measure of spawning success and subsequent year-class strength among years. Unfortunately, by sampling only two of every four years, cohorts cannot be tracked for more than one year.

- Catch rates of humpback chub declined significantly from 1998 to the 2007–2008 study period. Catch rates of roundtail chub remained relatively stable from 1998 to 2008.

- Humpback chub ISMP catch rates from 1988 to 2008 indicated a significant decline through time. Roundtail chub ISMP catch rates from 1998 to 2008 exhibit no significant change.

RECOMMENDATIONS

- Investigate other modeling tools to provide population estimates with increased precision.

- Consider implementing an additional project focused on estimating abundance of juvenile humpback chub, recruitment of first-year adult humback 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.

- Continue tagging and monitoring sympatric roundtail chub and consider tracking CPUE and explore open-abundance estimators.

- Sample both Westwater and Black Rocks concurrently so that data can be combined to develop a single population estimate which might eliminate concern over within-year movement between the two sampling areas.

- Continue to provide flow augmentation to coincide with spring peak flows

- Develop a captive refugia population of humpback chub originating form Black Rocks or Westwater Canyon.

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Table 1. Population estimate (N) for adult humpback chub (≥ 200 mm) in Westwater Canyon 1998–2008. Population estimates generated within program CAPTURE. Standard error (SE), profile likelihood interval (PLI), coefficient of variation (CV), probability of capture (p-hat), and model selection criteria are included with the respective population estimates.

Year	Model	Estimate	SE	PLI	CV	p-hat	Model Selection Criteria
1998	M_o	4,744	1,089	3,760–14,665	0.23	0.03	1.00
1999	M_o	2,215	624	1,608–7,508	0.28	0.04	0.24
2000	M_o	2,201	626	1,335–4,124	0.28	0.04	0.74
2003	M_t	2,973	941	1,710–6,042	0.31	0.03, 0.05, 0.02	1.00
2004	M_t	1,729	424	1,121–2,967	0.24	0.10, 0.03, 0.04	0.38
2005	M_t	1,210	213	880–1,769	0.17	0.06, 0.10, 0.10	0.75
2007	M_t	1,757	470	1,097–3,173	0.27	0.08, 0.05, 0.02	0.21
2008	M_o	1,358	232	997–1,957	0.17	0.08	0.21

Table 2. Population estimate (N) for adult roundtail chub (≥ 200 mm) in Westwater Canyon 1998–2008. Population estimates generated within program CAPTURE. Standard error (SE), profile likelihood interval (PLI), coefficient of variation (CV), probability of capture (p-hat), and model selection criteria are included with the respective population estimates.

Year	Model	Estimate	SE	PLI	CV	p-hat	Model Selection Criteria
1998	M_o	5,005	1,500	3,586–19,781	0.30	0.03	0.76
1999	M_o	4,234	973	3,349–12,917	0.23	0.04	0.13
2000	M_o	4,971	1,249	3,824–16,641	0.25	0.03	0.78
2003	M_t	3,288	507	2,458–4,469	0.15	0.06, 0.09	0.52
2004	M_t	3,867	444	3,124–4,912	0.11	0.09, 0.05, 0.08	1.00
2005	M_o	4,317	565	3,390–5,673	0.11	0.06	0.80
2007	M_t	5,696	863	4,310–7,828	0.15	0.05, 0.04, 0.10	0.92
2008	M_o	3,987	402	3,302–4,908	0.10	0.08	0.75

Table 3. Mean total length (TL) and associated standard deviation (SD) of humpback chub and roundtail chub in Westwater Canyon from 1998–2000, 2003–2005 and 2007–2008.

Year	Species	Mean TL of Adults	SD
1998	HB	278.6	40.2
	RT	266.0	33.5
1999	HB	292.6	43.3
	RT	279.0	34.3
2000	HB	290.0	46.6
	RT	274.6	35.0
2003	HB	269.5	43.0
	RT	263.1	32.5
2004	HB	265.8	35.1
	RT	265.8	30.1
2005	HB	269.5	40.3
	RT	254.3	34.1
2007	HB	274.9	39.2
	RT	259.0	38.2
2008	HB	279.3	43.6
	RT	261.0	31.0

Figure 1. Map of the study area

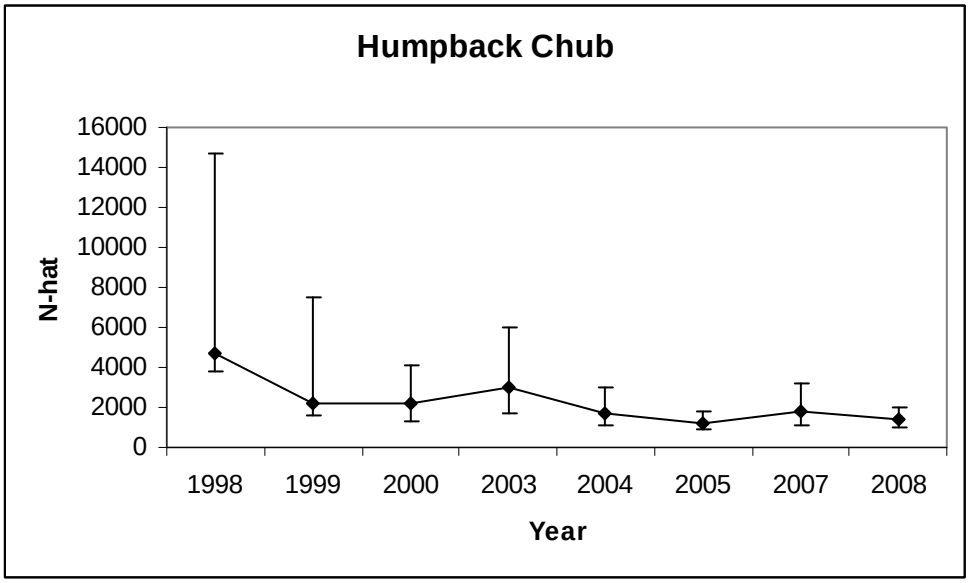


Figure 2. Abundance (N-hat) of adult humpback chub in Westwater Canyon, 1998 to 2008. Error bars represent profile likelihood intervals.

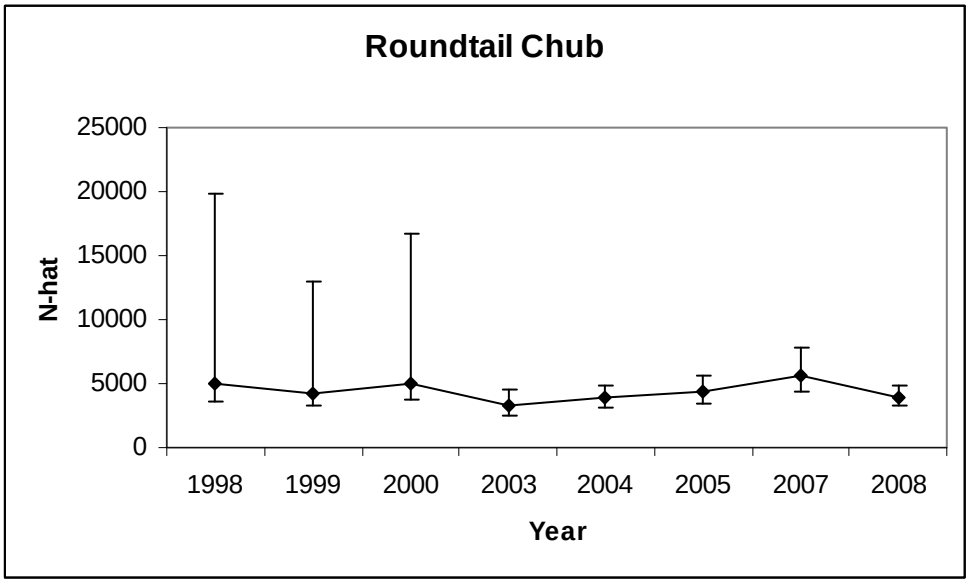


Figure 3. Abundance (N-hat) of adult roundtail chub in Westwater Canyon, 1998 to 2008. Error bars represent profile likelihood intervals.

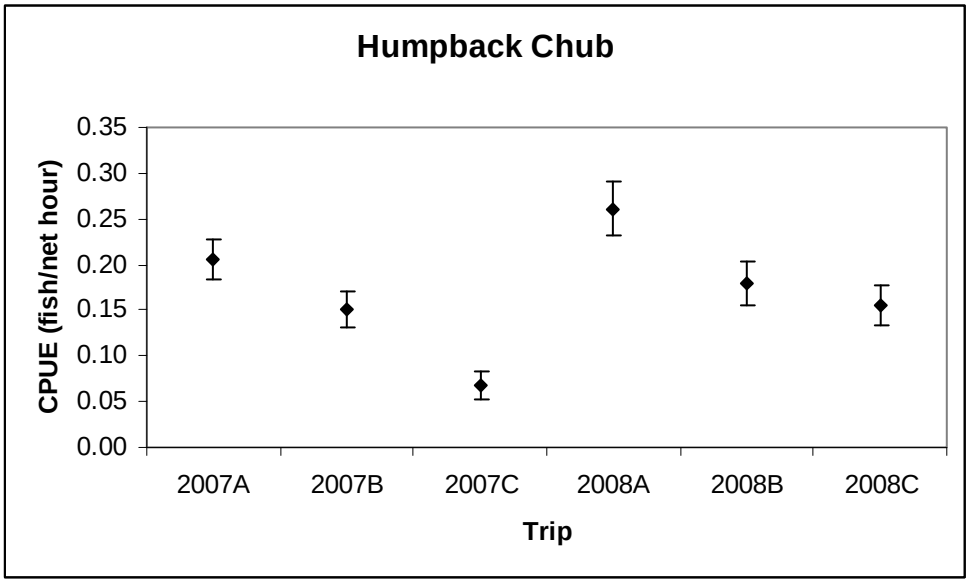


Figure 4. Trammel net catch rate (CPUE) of humpback chub (all size classes combined) during each sampling pass in Westwater Canyon from 2007 to 2008. Error bars represent standard error.

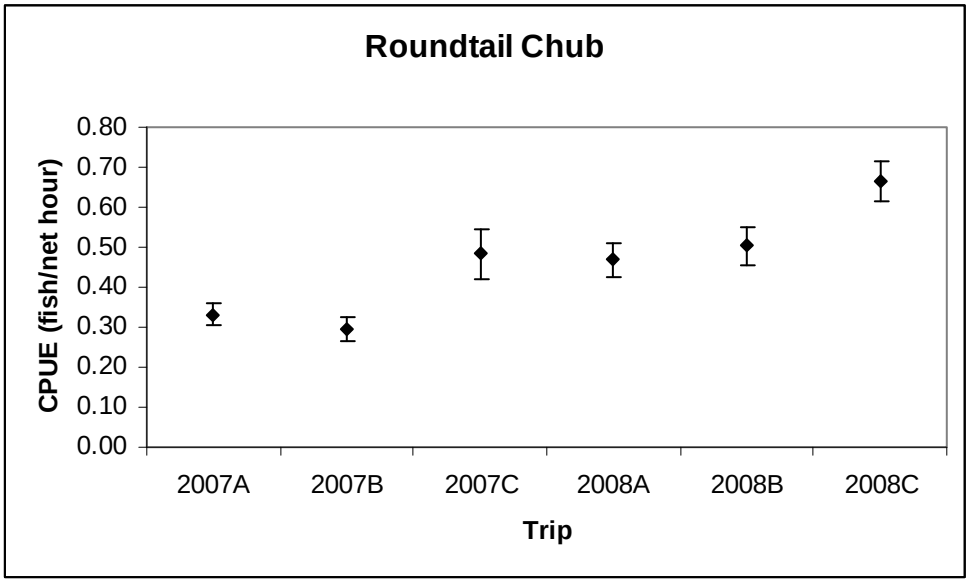


Figure 5. Trammel net catch rate (CPUE) of roundtail chub (all size classes combined) during each sampling pass in Westwater Canyon from 2007 to 2008. Error bars represent standard error.

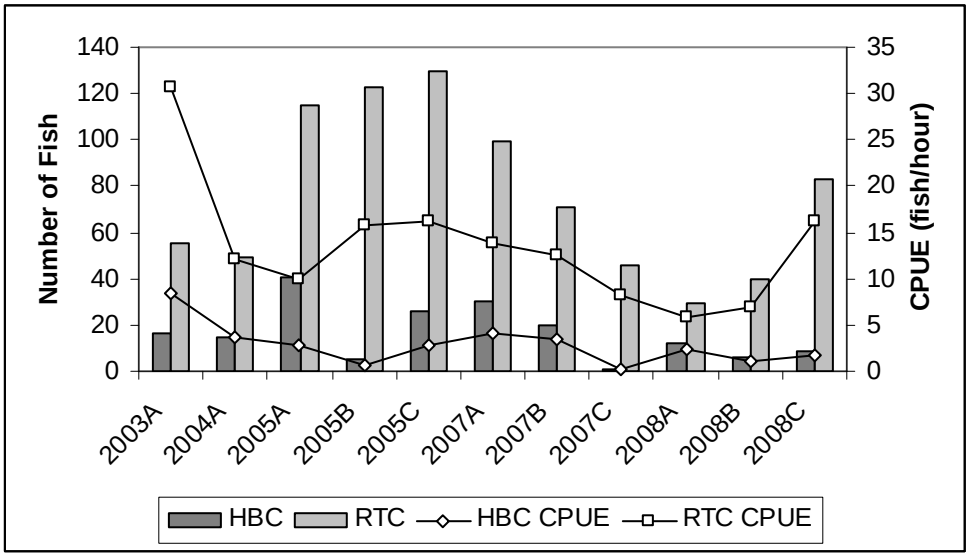


Figure 6. Numbers and electrofishing catch rate (CPUE) of adult humpback chub and adult roundtail chub collected in Westwater Canyon from 2003 to 2008 by trip. Electrofishing was only conducted during one trip in 2003 and 2004.

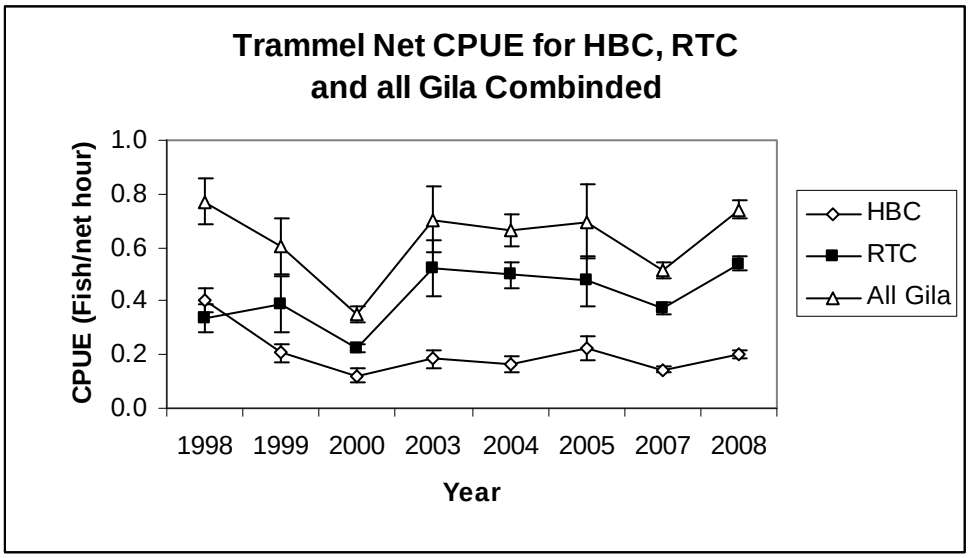


Figure 7. Catch rate (CPUE, three passes combined) of humpback chub, roundtail chub and all *Gila* spp. combined (all size classes combined) in Westwater Canyon from 1998 to 2008. Error bars represent standard error.

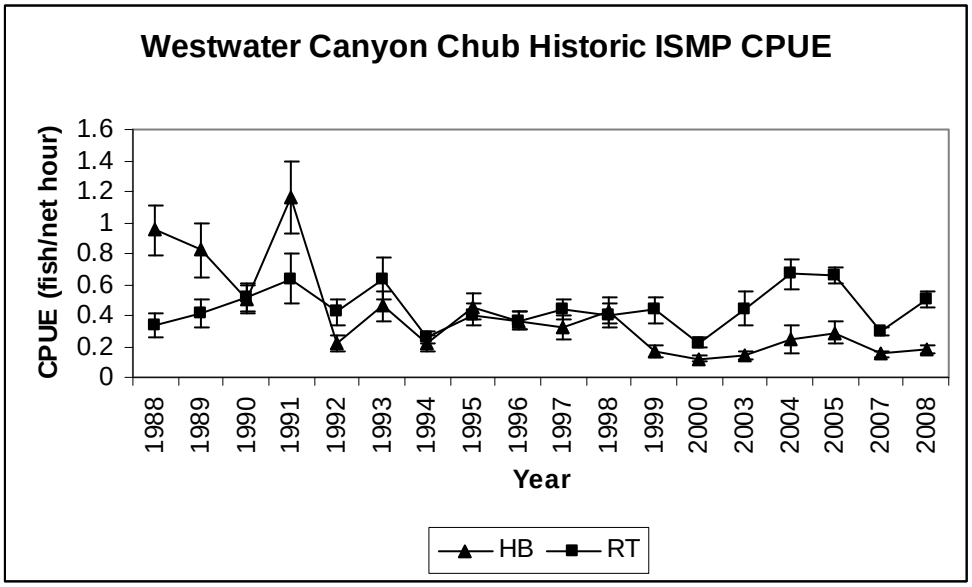
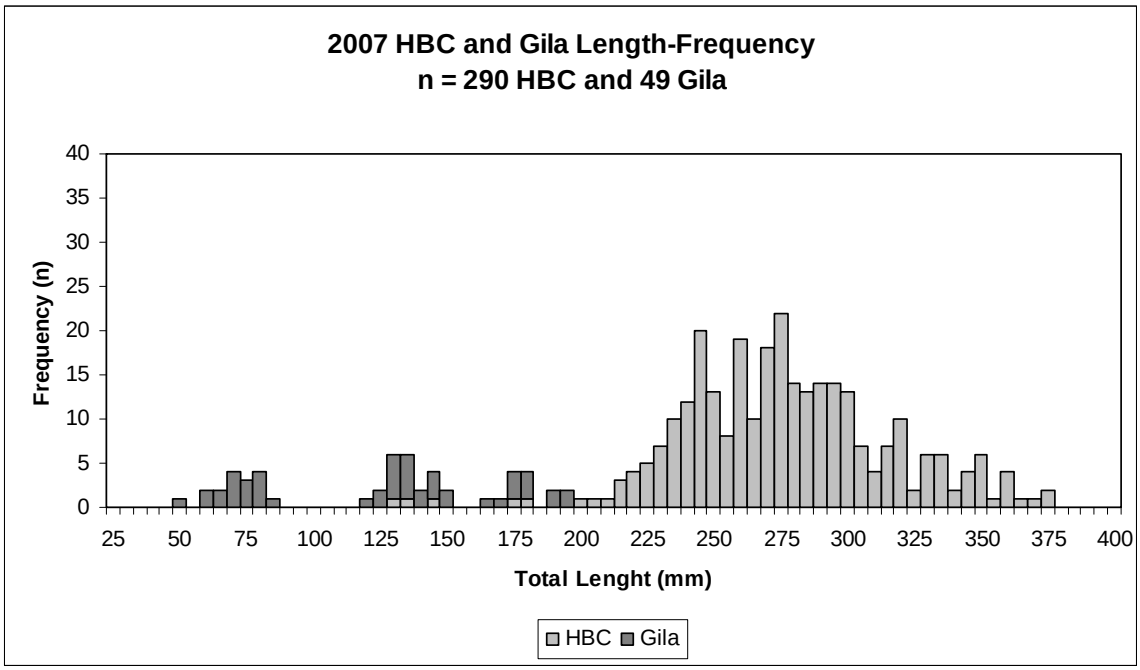


Figure 8. Long-term catch rate (CPUE) of humpback chub and roundtail chub in Westwater Canyon, 1988–2008. Note that data from 1998–2008 has been lifted from larger population estimate sampling data to be comparable to previous ISMP sampling data. Error bars represent standard error.



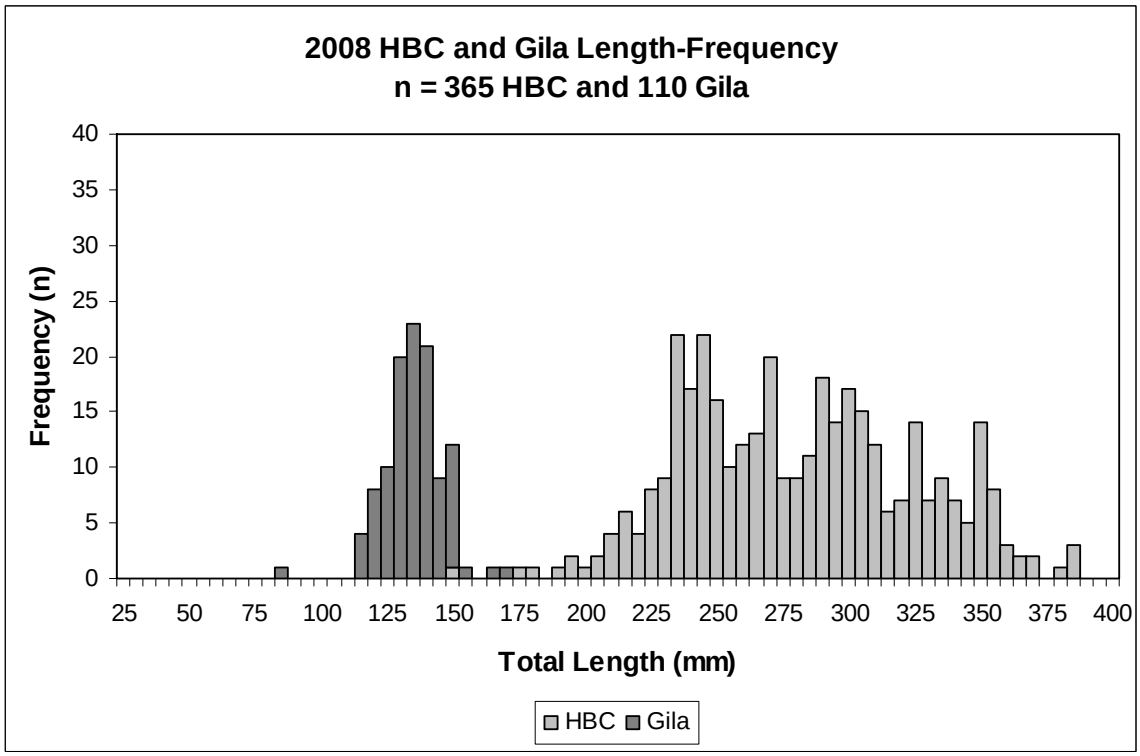
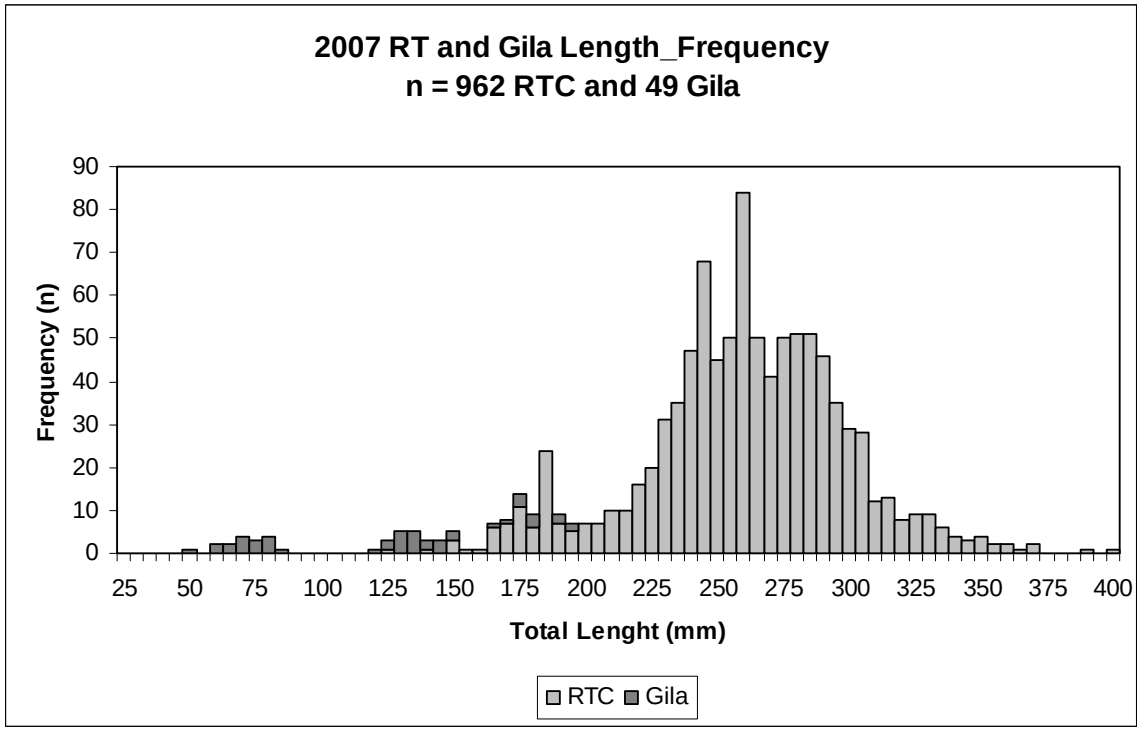


Figure 9. Length-frequency histograms for humpback chub and chub identified as *Gila* spp. in Westwater Canyon from 2007–2008.



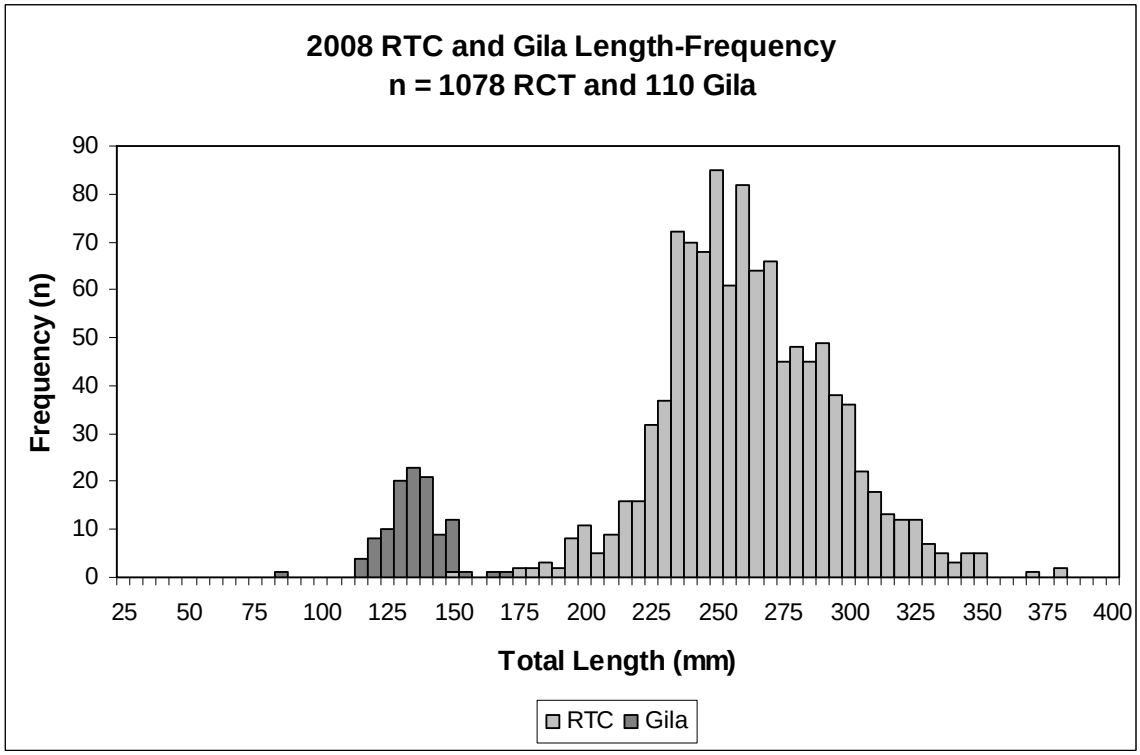


Figure 10. Length-frequency histograms for roundtail chub and chub identified as *Gila* spp. in Westwater Canyon from 2007–2008.

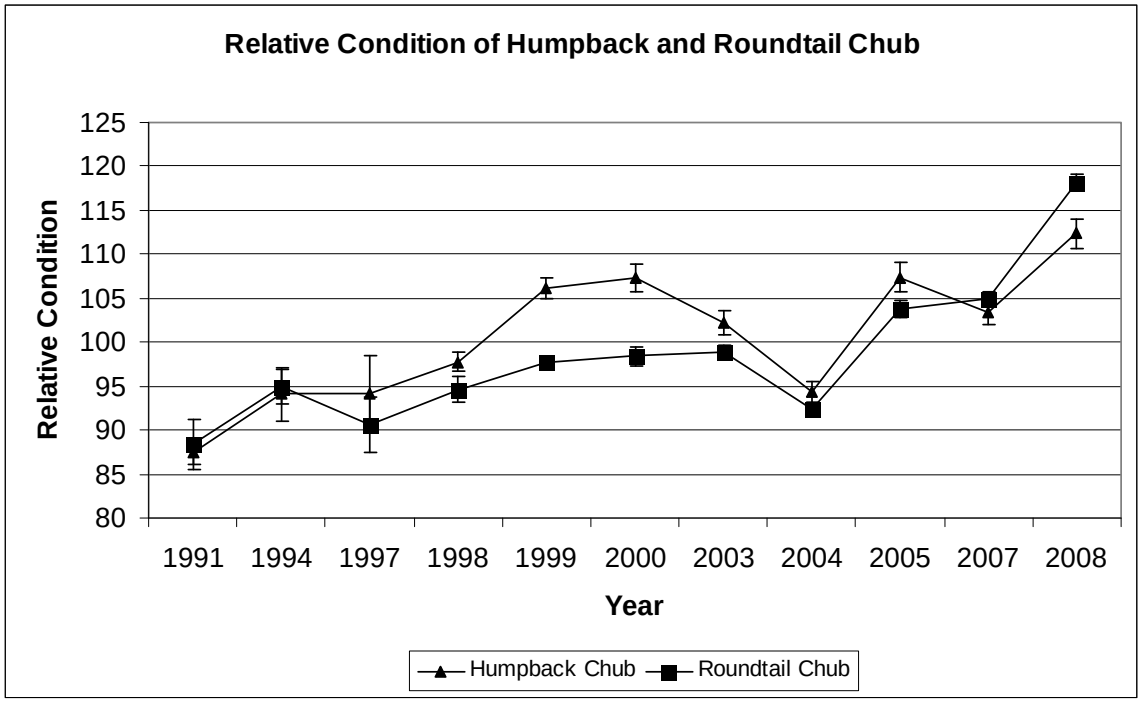


Figure 11. Mean relative condition (K_n) of humpback chub and roundtail chub in Westwater Canyon, 1991–2008.

-Appendix Table 1. Summary of adult humpback chub and adult roundtail chub captures by gear type. Methods of capture include: HN/CN = hoop or cast net, TR = trammel net and EL = electrofishing. *Total captures for roundtail chub in 2003 include fish from pass one and pass two only. Electrofishing was conducted during the second pass in 2003, the first pass in 2004 and all passes in 2005, 2007 and 2008. Cast netting and hoop netting were discontinued after 2005 because of low catch rates in 2003, 2004 and 2005.

	Total Captures	Number of Captures by Gear Type		
HBC		HN/CN	TR	EL
2003	284	1	267	16
2004	283	0	271	12
2005	295	1	185	109
2007	285	-	234	51
2008	349	-	322	27
RTC				
2003	501*	7	434	60
2004	806	7	756	43
2005	778	0	433	345
2007	884	-	664	220
2008	1025	-	873	152

-Appendix Table 2. Electrofishing CPUE (number of fish/hour) for all juvenile humpback chub (HBC), roundtail chub (RTC), and intermediate or unidentified chub (CH) captured from 2003 to 2008.

Year	Electrofishing Hours	HBC	RTC	CH
2003	1.8	1.14	7.95	17.61
2004	4.1	3.70	13.58	6.17
2005	29.8	0.20	4.73	8.05
2007	18.4	0.27	4.19	2.67
2008	16.0	0.38	1.63	6.82

-Appendix Table 3. Fin ray count (dorsal/anal) percentages for humpback chub (HBC), roundtail chub (RTC), and intermediate or unidentified chub (CH) captured from 2003 to 2008.

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

-Appendix Table 4. Summary of population estimates generated within Program CAPTURE for adult humpback chub in Westwater Canyon, 1998–2000, 2003–2005 and 2007–2008. Information for comparison within each year among estimators considered includes the abundance estimate, 95% confidence intervals, coefficient of variation (CV), and probability of capture (p-hat). *Values in parentheses in estimator column for years 2007 and 2008 are CAPTURE defined model selection criteria. **Values in parentheses are profile likelihood intervals for each point estimate. See Table 1 for selected model.

Year	Estimator	N	95% Confidence Interval*	CV	p-hat
1998	M_o	4,744	3,085–7,462 (3,760–14,665)	0.23	0.035
	Darroch M_t	3,190	2,427–4,251 (2,860–24,710)	0.14	0.05, 0.05, 0.05
	Chao M_t	6,243	3,770–10,579	0.27	0.03, 0.03, 0.03
1999	M_o	2,215	1,322–3,863 (1,608–7,508)	0.28	0.041
	Darroch M_t	2,670	1,551–4,766 (1,673–6,613)	0.30	0.04, 0.04, 0.02
	Chao M_t	2,699	1,502–5,057	0.32	0.04, 0.04, 0.02
2000	M_o	2,201	1,308–3,855 (1,335–4,124)	0.28	0.041
	Darroch M_t	1,713	1,116–2,728 (1,218–3,978)	0.23	0.04, 0.04, 0.08
	Chao M_t	1,862	1,134–3,199	0.27	0.03, 0.04, 0.07
2003	M_o	3,236	1,803–6,029 (1,857–6,598)	0.32	0.03
	M_h	567	525–617	0.04	0.18
	Chao M_h	4,645	2,504–8,837	0.33	0.02
	M_b	1,558	496–8,113 (578–31,160)	0.95	0.07
	M_{bh}	1,558	496–8,113 (578–31,160)	0.95	0.07
	M_{th}	3,365	1,822–6,463	0.34	0.02, 0.05, 0.02
	M_{tb}	353	305–544 (308–7,060)	0.15	0.22, 0.55, 0.48
	Darroch M_t	2,973	1,667–5,521 (1,710–6,042)	0.31	0.03, 0.05, 0.02
	Chao M_t	2,676	1,538–4,851	0.30	0.03, 0.06, 0.02

-Appendix Table 4. Cont.

Year	Estimator	N	95% Confidence Interval*	CV	p-hat
2004	M_o	2,016	1,276–3,309 (1,295–3,475)	0.25	0.04
	M_h	544	503–592	0.04	0.18
	Chao M_h	2,807	1,716–4,729	0.27	0.03
	M_b	328	306–369 (305–370)	0.05	0.47
	M_{bh}	328	306–369 (305–370)	0.00	0.47
	M_{th}	2,164	1,305–3,747	0.28	0.08, 0.02, 0.03
	M_{tb}	467	326–9,340	0.44	0.37, 0.17, 0.24
	Darroch M_t	1,729	1,108–2,821 (1,121–2,967)	0.24	0.10, 0.03, 0.04
	Chao M_t	1,578	1,023–2,548	0.24	0.11, 0.03, 0.04
2005	M_o	1,231	891–1,764 (895–1,803)	0.18	0.08
	M_h	540	500–588	0.04	0.19
	Chao M_h	1,754	1,202–2,638	0.20	0.06
	M_{th}	1,340	856–2,234	0.25	0.06, 0.09, 0.09
	M_{tb}	3,540	304–542,621 (438–70,800)	27.70	0.02, 0.03, 0.03
	Darroch M_t	1,210	877–1,730 (880–1,769)	0.17	0.06, 0.10, 0.10
	Chao M_t	1,202	860–1,747	0.18	0.06, 0.10, 0.10

-Appendix Table 4. Cont.

Year	Estimator	N	95% Confidence Interval*	CV	p-hat
2007	M_o (0.14)	1,941	1,184–3,316 (1,205–3,519)	0.27	0.05
	M_h (0.00)	496	457–542	0.04	0.18
	M_b (0.74)	297	277–335 (276–335)	0.05	0.48
	Chao M_h	2,715	1,598–4,763	0.29	0.03
	M_{th} (0.50)	1,994	1,172–3,555	0.29	0.07, 0.05, 0.02
	M_{bh} (0.36)	297	277–335 (276–335)	0.05	0.478, 0.478, 0.478
	M_{tb} (1.00)	49,442	1,188–2,595,786 (257-988,840)	NA	0.003, 0.002, 0.001
	Darroch M_t (0.21)	1,757	1,081–2,987 (1,097–3,173)	0.27	0.08, 0.05, 0.02
	Chao M_t	1,600	1,001–2,681	0.26	0.08, 0.06, 0.02
2008	M_o (0.21)	1,358	993–1,920 (997–1,957)	0.17	0.08
	M_h (0.13)	590	547–640	0.04	0.19
	M_b (1.00)	435	378–541 (377–556)	0.09	0.34
	Chao M_h	1,923	1,337–2,845	0.20	0.06
	M_{th} (0.30)	1,473	960–2,393	0.24	0.10, 0.07, 0.05
	M_{bh} (0.47)	435	377–541 (377–556)	0.09	0.34, 0.34, 0.34
	M_{tb} (0.65)	544	330–3,058 (360 –>10,880)	0.84	0.27, 0.24, 0.21
	Darroch M_t (0.00)	1,315	965–1,854 (969–1,896)	0.17	0.11, 0.08, 0.06
	Chao M_t	1,306	947–1,870	0.18	0.11, 0.08, 0.06

-Appendix Table 5. Summary of population estimates generated within Program CAPTURE for adult roundtail chub in Westwater Canyon, 1998–2000, 2003–2005 and 2007–2008. Information for comparison within each year among estimators considered includes the abundance estimate, 95% confidence intervals, coefficient of variation (CV), and probability of capture (p-hat). *Values in parentheses in estimator column for years 2007 and 2008 are CAPTURE defined model selection criteria. **Values in parentheses are profile likelihood intervals for each point estimate. See Table 3 for selected model. Note: 2003 includes two passes only due to limited marking of fish.

Year	Estimator	N	95% Confidence Interval*	CV	p-hat
1998	M_o	5,005	2,869–8,980 (3,586–19,781)	0.30	0.03
	Darroch M_t	2,553	1,824–3,651 (2,180–27,386)	0.18	0.01, 0.06, 0.09
	Chao M_t	5,121	2,738–9,922	0.34	0, 0.03, 0.04
1999	M_o	4,234	2,754–6,665 (3,349–12,917)	0.23	0.04
	Darroch M_t	2,999	2,231–4,100 (2,662–16,739)	0.16	0.03, 0.05, 0.07
	Chao M_t	5,129	3,115–8,673	0.27	0.02, 0.03, 0.04
2000	M_o	4,971	3,107–8,144 (3,824–16,641)	0.25	0.03
	Darroch M_t	5,038	3,266–7,929 (3,718–14,667)	0.23	0.03, 0.02, 0.05
	Chao M_t	6,116	3,544–10,831	0.29	0.02, 0.02, 0.04
2003	M_o	-	-	-	-
	Darroch M_t	3,288	2,458–4,469 (2,963–65,760)	0.15	0.06, 0.09
	Chao M_t	-	-	-	-

-Appendix Table 5. Cont.

Year	Estimator	N	95% Confidence Interval*	CV	p-hat
2004	M_o	3,345	2,750–4,121 (3,041–5,490)	0.10	0.08
	M_h	1,542	1471–1621	0.02	0.19
	Chao M_h	5,522	4,327–7,124	0.13	0.05
	M_b	2,336	1,552–3,947 (1629–5205)	0.25	0.13
	M_{bh}	2,336	1,552–3,947 (1629–5205)	0.22	0.13
	M_{th}	3,058	3,058–5,311	0.19	0.09, 0.05, 0.08
	M_{tb}	2,384	1,213–6,946 (1,346–47,680)	0.52	0.15, 0.08, 0.15
	Darroch M_t	3,867	3,112–4,868 (3,124–4,912)	0.11	0.09, 0.05, 0.08
	Chao M_t	3,780	3,027–4,788	0.11	0.09, 0.05, 0.08
2005	M_o	4,317	3,371–5,608 (3,390–5,673)	0.13	0.06
	M_h	1,459	1,390–1,536	0.03	0.18
	M_{th}	4,841	3,441–6,974	0.18	0.05, 0.06, 0.07
	M_{tb}	33,733	1,070–3,482,086 (1,433–674,660)		0.01, 0.01, 0.01
	Darroch M_t	4,273	3,338–5,547 (3,356–5,613)	0.11	0.05, 0.06, 0.07
	Chao M_t	4,366	3,368–5,745	0.14	0.05, 0.06, 0.07

-Appendix Table 5. Cont.

Year	Estimator	N	95% Confidence Interval*	CV	p-hat
2007	M_o (0.72)	5,814	4,358–7,864 (4,391–7,982)	0.15	0.05
	M_h (0.68)	1,527	1,455–1,606	0.03	0.18
	Chao M_h	10,133	7,163–14,487	0.18	0.03
	M_{th} (0.81)	9,612	5,784–16,369	0.27	0.03, 0.02, 0.03
	M_{tb} (0.57)	4,296	1,179–32,030 (1,468–85,920)	1.28	0.07, 0.05, 0.08
	Darroch M_t (0.92)	5,696	4,275–7,696 (4,310–7,828)	0.15	0.05, 0.04, 0.06
	Chao M_t	6,684	4,829–9,392	0.17	0.04, 0.03, 0.05
2008	M_o (0.75)	3,987	3,294–4,882 (3,302–4,908)	0.10	0.08
	M_h (0.86)	1,717	1,642–1,800	0.02	0.19
	Chao M_h	5,652	4,534–7,114	0.11	0.06
	M_{th} (0.27)	4,271	3,277–5,682	0.14	0.07, 0.07, 0.09
	M_{tb} (0.39)	10,058	1,782–201,160	3.39	0.03, 0.03, 0.04
	Darroch M_t (0.01)	3,940	3,258–4,822 (3,266–4,851)	0.12	0.07, 0.08, 0.10
	Chao M_t	3,980	3,256–4,926	0.11	0.07, 0.08, 0.10

-Appendix Table 6. Persistence of humpback chub originally marked prior to the 2003–2005 and 2007–2008 study periods in Westwater Canyon. Note: 1993 and 1997 are not represented in the chart because no fish were recaptured from 1993 or 1997. Numbers of fish marked in 1993 and 1997 were 114 and 51 respectively. No fish were marked in 2001, 2002 and 2006.

Year	Number of Humpback Chub Marked	Number and Percentage of Humpback Chub Recaptured from Previsous Sampling Periods by Year									
		2003		2004		2005		2007		2008	
		n	%	n	%	n	%	n	%	n	%
2005	235	-	-	-	-	-	-	36	15.3%	31	13.2%
2004	261	-	-	-	-	-	-	24	9.2%	24	9.2%
2003	259	-	-	-	-	-	-	13	5.0%	13	5.0%
2000	277	10	3.6%	8	2.9%	5	1.8%	4	1.4%	2	0.7%
1999	278	3	1.1%	2	0.7%	0	0.0%	4	1.4%	3	1.1%
1998	501	5	1.0%	2	0.4%	1	0.2%	3	0.6%	4	0.8%
1996	160	1	0.6%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
1995	147	0	0.0%	1	0.7%	1	0.7%	0	0.0%	0	0.0%
1994	188	1	0.5%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
1992	132	6	4.5%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total		26	-	13	-	7	-	84	-	77	-

-Appendix Table 7. Persistence of roundtail chub originally marked prior to the 2003–2005 and 2007–2008 study periods in Westwater Canyon. Note: 1992, 1993, 1994, 1996, and 1997 are not represented in the chart because no fish were recaptured from those years. Number of fish marked in 1992, 1993, 1994, 1996, and 1997 were 271, 292, 127, 126, and 126 respectively. No fish were marked in 2001, 2002, and 2006.

Year	Number of Roundtail Chub Marked	Number and Percentage of Roundtail Chub Recaptured from Previsous Sampling Periods by Year									
		2003		2004		2005		2007		2008	
		n	%	n	%	n	%	n	%	n	%
2005	811	-	-	-	-	-	-	68	8.4%	40	4.9%
2004	648	-	-	-	-	-	-	27	4.2%	16	2.5%
2003	654	-	-	-	-	-	-	7	1.1%	9	1.4%
2000	521	8	1.5%	5	1.0%	2	0.4%	4	0.8%	1	0.2%
1999	481	1	0.2%	2	0.4%	1	0.2%	1	0.2%	0	0.0%
1998	397	2	0.5%	1	0.3%	3	0.8%	1	0.3%	0	0.0%
1995	193	1	0.5%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
1992	271	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total		12	-	8	-	6	-	108	-	66	-