

**Population Estimates for Humpback Chub (*Gila cypha*)
In Cataract Canyon, Colorado River, Utah, 2003–2005**

Paul V. Badame

*Utah Division of Wildlife Resources-Moab Field Station
1165 S. Hwy 191-Suite 4
Moab, UT 84532*

***Final Report
May 2008***

Upper Colorado River
Endangered Fish
Recovery Program
Project #22L

Utah Division of Wildlife Resources
1594 W. North Temple
Salt Lake City, Utah

ACKNOWLEDGEMENTS

This study was funded by the Recovery Implementation Program for Endangered Fish Species in the Upper Colorado River Basin. The Recovery Program is a joint effort of the U.S. Fish and Wildlife Service, U.S. Bureau of Reclamation, Western Area Power Administration, state of Colorado, Utah, and Wyoming, Upper Basin water users, environmental organizations, the Colorado River Energy Distributors Association, and the National Park Service.

Mention of trade names or commercial products does not constitute endorsement of recommendation for use by the authors, the Fish and Wildlife Service, U.S. Department of the Interior, or members of the Recovery Implementation Program.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS	ii
TABLE OF CONTENTS	iii
LIST OF TABLES	v
LIST OF FIGURES	v
LIST OF KEY WORDS	vi
EXECUTIVE SUMMARY	vii
INTRODUCTION	1
METHODS	1
<i>Study Area</i>	1
<i>Sampling</i>	2
<i>Data Analysis</i>	3
<i>Population Estimate</i>	3
<i>CPUE</i>	3
<i>Length-Frequency</i>	3
<i>Growth</i>	4
RESULTS	4
<i>Humpback</i>	4
<i>Population Estimates</i>	4
<i>CPUE</i>	4
<i>Length-Frequency</i>	5
<i>Growth</i>	5
<i>Movement</i>	5
<i>Bonytail</i>	5
<i>Population Estimates</i>	5
<i>CPUE</i>	5
<i>Length-Frequency</i>	6
<i>Movement</i>	6
DISCUSSION	6
<i>Population Estimates</i>	6
<i>Growth</i>	7
<i>Movement</i>	7
<i>Summary</i>	7

TABLE OF CONTENTS (*continued*)

CONCLUSIONS	8
RECOMMENDATIONS	8
LITERATURE CITED	9
APPENDIX	17

LIST OF TABLES

Table 1. Humpback chub sectional estimates, density estimates, and whole population estimates and related statistics for Cataract Canyon 2003-2005. 11

Table 2. Trammel net effort and catch rates (CPUE) for humpback and bonytail for all sites combined, Cataract canyon 2003-2005. 11

LIST OF FIGURES

Figure 1. Map of the upper Colorado River Basin with present humpback chub population locations highlighted..... 12

Figure 2. Total catch per unit effort (CPUE) for humpback chubs in Cataract Canyon fall collections for all captures in between 1991 and 2005 13

Figure 3. Comparison or total CPUE for humpback chub in Cataract Canyon, Desolation Canyon and Westwater Canyon between 1991 and 2005..... 13

Figure 4. Annual total length frequency distributions for humpback chubs in Cataract Canyon fall collections for all captures in 2003, 2004, and 2005. 14

Figure 5. Length-weight relationship for adult humpback chubs in Cataract Canyon fall collections for all captures in 2003-2005 combined..... 15

Figure 6. Annual total length frequency distributions for bonytail chubs in Cataract Canyon fall collections for all captures in 2003, 2004, and 2005..... 16

LIST OF KEY WORDS

humpback chub, *Gila cypha*, bonytail chub, *Gila elegans*, Cataract Canyon, Colorado River, population estimate, growth, movement, trammel net, sectional estimates.

EXECUTIVE SUMMARY

Humpback chub (*Gila cypha*) are listed under the Endangered Species Act of 1973, as amended. In accordance with recovery goals finalized in 2002, population estimates were completed for adult humpback chub in Cataract Canyon on the Colorado River. The sampling was conducted from 2003 to 2005 with the objective of obtaining annual point estimates for humpback in the canyon. Sampling occurred between mid September and early November each of the three years of the study. Three sites were sampled for two nights on three occasions each year with approximately one week between sampling occasion. Approximately 28% (1.9 river miles) of the available habitat in Cataract Canyon was sampled on each occasion. The primary method of capture was trammel netting with supplemental electrofishing on one pass per year.

Population estimates were generated from mark-recapture data using closed population models calculated with program CAPTURE. Separate estimates were generated for each year of the study. Results indicated a non-significant decline in the adult humpback chub population during the 2003 – 2005 sampling period. The adult point estimates were 126 (2003), 91 (2004), and 70 (2005). The interpretation of these estimates relative to the amount of available habitat in Cataract Canyon depends on how movement, or lack thereof, effects the assumptions of the estimator. Every annual and intra-annual recapture of a humpback occurred in the individuals original capture site. No movement implies that mixing between the sample areas does not occur and that fall point estimates would relate only to the area sampled (2 river miles); therefore, the density estimates for the sampling period would be 63-35 fish/mile (no mixing model). If the density estimates are applied to the total available habitat in the canyon (approximately 7 river miles) the total population size would have varied between 468-262 adult humpbacks during the sampling period. Relative to other upper basin humpback chub populations; the density is similar to that of Desolation/Gray Canyons, and significantly less than found in Westwater Canyon.

Growth of humpback chub in Cataract Canyon was slow relative to other upper basin populations. In addition, the relative size structure of this population is small and is within a narrow range. In three years of sampling, the smallest humpback captured was 195 mm. Results from Desolation and Westwater trammel netting suggest our inability to capture smaller juveniles in Cataract is likely a limitation of net size used. Electrofishing has been the preferred method for finding juvenile chubs in other canyons; however, none were captured using this technique in Cataract Canyon. It is unclear if they are not present or if they are utilizing habitats which are unreachable with electrofishing.

Analysis of catch per unit effort (CPUE) totals for the period of 2003 to 2005 has shown no statistically significant changes for humpback chub. The average trammel net CPUE for humpback chubs in Cataract Canyon was lower than both Desolation Canyon and Westwater Canyon. Mean CPUE for bonytail chub declined quickly from 2003 to 2004 and 2005.

The small size of this population suggests a need to reassess how it is monitored. Although there are not enough adult individuals to consider this a core population, it is still considered an integral part of the overall upper basin population recovery. The persistence of stocked adult bonytail within Cataract Canyon also warrants continued monitoring.

INTRODUCTION

The humpback chub (*Gila cypha*) was first described in 1945 (Miller 1946). Due to declines in distribution and abundance throughout its range, the humpback chub is currently protected under the Endangered Species Act of 1973, as amended (ESA, 16 U.S.C. 1531 *et. seq.*). The most recent recovery plan was finalized in 1990 (USFWS 1990), with an amendment and supplement to that plan approved in 2002 (USFWS 2002). The amendment and supplement to the 1990 recovery plan identifies objective and measurable recovery criteria to downlist and delist humpback chub in both the upper basin recovery unit and the lower basin recovery unit. Within the upper basin recovery unit, one of the criteria to downlist humpback chub is the maintenance of one of the five upper basin populations (Black Rocks, Westwater Canyon, Cataract Canyon, Yampa Canyon, Desolation/Gray Canyon) as a core population with a minimum viable population of 2,100 adults (≥ 200 mm) for five consecutive years. To delist humpback chub, the upper basin recovery unit will have to maintain this minimum viable population for an additional three years in two of the five upper basin humpback chub populations. The adult humpback chub population size will be determined via point estimates in two consecutive years out of every five. Within each core population, there must not be a significant decline of the trend in adult point estimates to downlist and delist humpback chub.

Population estimates for humpback chub in the upper basin were first conducted in Westwater Canyon from 1998 to 2000 (Hudson and Jackson 2003). The sampling in Westwater set the baseline standards for conducting mark-recapture estimates sampling in Cataract Canyon for humpback chub and followed the adult ISMP (Interagency Standardized Monitoring Protocol) methodology up until 2003. The adult ISMP sampling was a single trip utilizing trammel nets and electrofishing to measure presence, distribution, and relative catch rates for endangered species (USFWS 1987). The ISMP results for Cataract Canyon revealed a small, persistent population of humpbacks and very low catch rates (Valdez 1990). Cataract is also where one of the last known captures of a wild bonytail chub (*Gila elegans*) in the upper basin occurred (Valdez 1990). With low catch rates and likely a very small population, it was unclear if mark-recapture estimates would be a viable option for monitoring this population.

The abundance sampling design for Cataract Canyon was based on past efforts in Westwater and Desolation Canyons with the understanding that modifications would be made to the approach as more information was gained about the population of humpback chub in Cataract Canyon. The specific objectives of the project were 1) Estimate the Cataract Canyon adult humpback chub population size with confidence intervals as tight as possible and 2) Transport presumed wild bonytail to a hatchery.

METHODS

Study Area

Cataract Canyon is located on the Colorado River and begins 4 miles downstream of the confluence with the Green River (Figure 1). The length of the canyon extends approximately 37 miles (RM 212.5-175). The upper 10 miles of the canyon is within Canyonlands National Park and the lower 27 is within Glen Canyon National Recreation Area. The habitat in the upper section of the canyon consists of large eddy/pool complexes interspersed between large rapids. Some of the larger pools

have maximum depths over 75 feet. The substrates in the upper section consist mostly of large cobble to boulders. The steepest part of Cataract Canyon is the middle section (RM 205-201) containing 13 class III-IV rapids; the lowest set of rapids in this section is referred to as the “Big Drops” with a gradient of 30-35 ft/mile. The steepest portion of the canyon was not sampled due to turbulent flows, lack of camp access, and general lack of habitat. Lake Powell inundates the remaining 32 miles of the Cataract Canyon at full-pool.

A 5-year drought, beginning in 2001, dropped reservoir levels as much as 120 feet below full-pool. The result was an additional 32 miles of flowing river starting in 2002. By 2003 several rapids had reformed just below the “Big Drops” and by the fall of 2005 an additional 2.5 miles of whitewater was present, extending down to Waterhole Canyon (RM 198.5). Below Waterhole Canyon the river is generally a canyon bound run cutting through 50-150’ silt/clay deposits built up during higher lake levels.

Sampling

Sampling occurred in three primary sites which were previously identified as trend sites for long-term monitoring: Site 1 (RM 211.5-212), site 2 (RM 209.8-210.5), and Site 3 (RM 207-205) (Figure 1). Due to low flows, the trend site 3 was moved to RM 207.3-208.3. One additional site below the “Big Drops”, Waterhole Canyon (RM 198.5), was sampled in 2004 and 2005 to see if newly available river habitat was being utilized by endangered fish.

This project was initially scheduled to begin in 2002. However, due to record low flows that year, efforts were delayed until fall 2003. Each year three sampling trips were conducted within Cataract Canyon between late September and early November each year. Six to eight days lapsed between the end of one pass and the beginning of the subsequent pass. During each pass, sites were sampled for two nights. All unmarked endangered fish were marked on each pass. Gear included the use of trammel nets (23 m x 2 m; 2.5 cm and 1.25 cm mesh) and a pulsed DC Smith-Root[®] electrofishing unit mounted on a 14’ raft.

Trammel nets were set late-afternoon and checked every two hours until midnight, at which time they were pulled. Nets were reset before dawn and allowed to fish until late morning while being checked every two hours. Trammel nets were set to target juvenile and adult chubs. Trammel nets were primarily set in deep eddies off boulders or rock faces. Nets were occasionally set in relatively shallow riffle/run areas off in-channel boulders. All *Gila* spp. were removed from the net, processed, and released at the location of their capture.

Shoreline habitats were electrofished within each site on the first trip each year. Electrofishing efforts occurred prior to nets being set in late afternoon or after the final late net check was completed. Electrofishing was conducted to target smaller *Gila* spp. in addition to the late juvenile/adult component of the population.

Information collected from all *Gila* spp. captures included total length (mm), weight (g), and dorsal and anal fin ray counts. In addition, PIT tag numbers were recorded from recaptured chubs. Initial chub captures of fish greater than 150 mm received a PIT tag and the number was recorded. Information collected for all fish species caught included total length (mm) and weight (g).

Information collected for other endangered species captured included total length (mm), weight (g), and PIT tag number.

Data Analysis

Population Estimates

Mark-recapture population estimates were calculated for adult humpback chub in Cataract Canyon using closed population models in program CAPTURE (Otis et al. 1978, White et al. 1982, Rexstad and Burnham 1991). Chubs were marked on each pass each year. Only chubs which had been marked during a previous pass and recaptured within the same year were considered recaptures for the estimate model.

The specific estimator used by program CAPTURE for each years estimate was selected based on the programs model selection criterion and professional judgment, as to whether or not, the model fit the behavioral and biological observations in the field. Profile likelihood intervals are provided in lieu of 95% confidence intervals. The profile likelihood interval helps to account for model selection uncertainty and tend to give more correct confidence intervals for small samples (Bates and Watts 1980, Gimenez et al. 2005). However, the profile likelihood interval can only be determined for the null estimator (M_0) and the Darroch M_t estimators. The 95% confidence intervals are provided for all other estimators used (Table1; Appendix I).

In all years of sampling it was found that humpback movements were highly localized and that no mixing occurred between any sample sites; therefore, the estimates calculated are considered sectional estimates, relating only to the actual 1.9 river miles sampled. The sectional estimates were used to derive density estimates, which were extrapolated over the total available habitat within the canyon (7 RM).

CPUE

Catch per unit effort (CPUE) for trammel netting of humpback chub and bonytail chub was calculated as the total number of chubs captured within a sample location divided by the total hours for all nets fished in a sample area for each pass. CPUE was compared between passes within and among years using the Kruskal-Wallis nonparametric analysis of variance with Dunn's multiple comparisons test to examine the equality of samples and the two-sample Kolmogorov-Smirnov to compare the distribution of catch rates. In addition, total annual CPUE comparisons were tested between years using the same analyses. Data collected from electrofishing effort was not analyzed due to a limited amount of information.

Length-Frequency

Length-frequency distributions were determined for humpback chub and bonytail chub through the period of the study. Annual means, ranges, and modes were compared with simple descriptive statistics.

Growth

Mean annual growth rates were estimated from one year of growth on recaptured humpback chub from 2003 through 2005 and compared with respect to relative length class. The relationship of annual growth to length class was compared to other upper basin populations. Length to weight regression was used to calculate condition factors for adult chub and these results were also compared to other humpback populations.

RESULTS

Humpback

Population Estimates

In 2003 the annual sectional estimate for adult humpback chub was 127 individuals, which equates to a density of 66.8 fish/mile and an extrapolated estimate of 468 individuals within the available habitat in Cataract Canyon (Table 1). In 2004 the sectional estimate declined to 74 individuals, which equates to a density of 38.9 fish/mile, and an extrapolated estimate of 273 individuals within the available habitat in Cataract Canyon (Table 1). The 2005 sectional estimate remained near the same level at 80 individuals, which equates to a density of 42.1 fish/mile, and an extrapolated estimate of 295 individuals within the available habitat in Cataract Canyon (Table 1). The decline from 2003 to 2004 was 42%, however due to the large error bounds of the 2003 estimate the difference is not statistically significant ($p=0.39$).

CPUE

Total trammel net captures for humpback chub in 2003, 2004, and 2005 were 44, 43, and 31 and the mean CPUE was 0.032, 0.035, and 0.022 respectively (Table 2). Only two humpbacks were captured via electrofishing in 2003 and none were captured in 2004 or 2005.

Mean trammel net CPUE showed no significant change across all years. The Kruskal-Wallis test indicated there were no significant differences between passes within years, and there were no significant differences between passes among years.

A comparison of total CPUE by year between the data collected for this project (2003-2005) and data collected during ISMP sampling between 1991 and 1999 showed trammel net catch rates varying between 0.01 and 0.032 humpback/net-hour (Figure 2). Statistical significance was not examined due to vast differences in effort. Between 1991 and 2005, the range of annual CPUE for trammel net sampling in Cataract Canyon was 1/3 lower than observed in Desolation Canyon and 1/10 the rates observed in Westwater Canyon (Figure 3).

Length-Frequency

The length-frequency histograms for Cataract Canyon humpback chub showed a unimodal distribution for all years (Figure 4). The distribution mode declined from 240 mm in 2003-2004 to 230 mm in 2005. An ANOVA on ranks showed that the change was not significant ($p=0.16$). The difference between minimum and maximum total lengths declined from 95 mm and 98 mm during 2003-2004 to 60 mm in 2005. The smallest humpback collected in any year was 195 mm (2005) and the largest was 303 mm (2003).

Growth

The mean annual growth rate for humpback chub 210-225mm was 13.00 ± 1.52 mm. The mean annual growth rate for humpback chub 230-235 mm was 1.54 ± 2.87 mm. One individual with an initial capture length of 235 mm showed no growth after being at large for two years. The low number of annual recaptures precludes any statistical comparisons to other populations. For a general comparison, Westwater Canyon mean annual growth for humpbacks 190 - 260 mm was 10.15 ± 2.94 and for individuals 260 – 320 mm the mean annual growth was 7.70 ± 1.90 mm.

The length-weight regression coefficients for adult humpbacks in Cataract Canyon were:

$$\text{Log}_{10}(W) = -4.08 + 2.56 \log_{10}(L) (\text{Figure 5; } r^2=0.71).$$

Movement

Apparent site fidelity for humpbacks in Cataract Canyon was 100%. Examination of all 2003-2005 recapture data showed that for 13 individuals recaptured between trips, 4 individuals recaptured after 1 year, and 2 individuals recaptured after 2 years, the maximum movement was less than 300 meters and all recaptures occurred in their original habitat complex (i.e. the large eddy pool complex below rapid #2). No humpbacks from reaches outside of Cataract Canyon were captured during the study period.

Bonytail

Population Estimates

During the three years of monitoring, 2003 was the only year enough bonytail chub were marked and subsequently recaptured to calculate a population estimate. In 2003 the annual sectional estimate for adult bonytail chub was 66 individuals, which equates to a density of 34.7 fish/mile and an extrapolated estimate of 264 individuals within the available habitat in Cataract Canyon.

CPUE

Total trammel net captures for bonytail chub in 2003, 2004, and 2005 were 20, 1, and 5 with CPUE of 0.008, 0.001, and 0.003 respectively (Table 2). Although the decline in captures was numerically significant mean annual catch rates were not statistically different between years nor could they be distinguished from a CPUE of zero.

Length-Frequency

The initial (2003) length-frequency histograms for Cataract Canyon bonytail chub showed a skewed distribution with the majority of captured fish being adults over 300 mm (Figure 6). The annual distribution modes declined from 350 mm in 2003, to 278 mm in 2005; only one bonytail was captured in 2004 (340mm). The range of total lengths showed a shift from primarily large adults (200-380mm) in 2003 to a more unimodal narrow distribution of early adults in 2005 (250-300mm).

Movement

No net movement was observed for the bonytails marked and recaptured in 2003. No other within year recaptures occurred during the study period. All bonytails captured during the study period were stocked fish, most of which were stocked in the Green River at the town of Green River. It is unknown if the bonytail in Cataract Canyon are persistent residents or transients.

DISCUSSION

Population Estimates and Catch Rates

The presumed product of our stratified, three pass mark-recapture sampling was a point population estimate for all adult humpback chubs within all available habitat in Cataract Canyon. The interpretation of the estimates relative to the area sampled in Cataract Canyon depends on how movement, or lack thereof, effects the assumptions of mixing for the estimator. Both annual and intra-annual recaptures of all humpbacks occurred in their original sampling sites. No movement would imply that mixing between the sample areas does not occur and that fall point estimates would relate only to the area sampled (2 river miles). To relate the fall point estimates to the entire Cataract Canyon reach; the estimate was converted to a density estimate and then applied to the total available habitat in the canyon (approximately 7 river miles); using this method it is estimated that the total population size would have varied between 468-262 adult humpbacks during the three year sampling period.

The M_0 model was selected for both 2003 and 2004 due to both model selection criterion and an observed lack of significant variation in capture rates and calculated probabilities of capture over the three sample sessions in each year. For the 2005 estimate, probabilities of capture varied enough among sample sessions that the CAPTURE selection criterion selected the Chao M_h model as the most appropriate for the data. Methodology, effort, and sampling locations did not vary from previous years; however, one potential source of heterogeneity in capture probability may have been the change in size structure of the sampled population.

From 2003 to 2005, humpback chub in Cataract Canyon appear to have undergone a decline in population size, however due to the low precision of the estimates no statistical differences can be reported. Consistent catch rates over the 3-year study period support the hypothesis that densities and overall population size did not measurably change between 2003 and 2005.

Catch rate trends between 1991 and 2005 showed a shallow cyclical pattern with average trip rates staying between 0.01 and 0.03 fish/hr. This general consistency of catch rates is interesting considering that effort during the 2003 to 2005 project was nearly 10 times greater than the effort expended in the 1990s. In comparison catch rates in Desolation/Gray Canyon have typically ranged between 0.1 and 0.25 fish/hr over the last 16 years of sampling (Jackson and Hudson 2005).

Growth

Apparent annual growth rates of humpback chub in Cataract Canyon are slower than those reported for all other upper basin populations (Meretsky et al. 2000; Jackson and Hudson 2005; Valdez 1995). Growth also appears to slow at smaller size classes than observed in other populations. The lack of later life stage growth creates a narrow unimodal size distribution for fish over 200 mm. This phenomenon intensified over the three year study period, with a final size range of only 60 mm for all fish captured with trammel nets. These comparisons of size and growth with other upper basin populations relate only to adult fish captured with similar methods.

Observers in the field have stated that humpbacks in Cataract appear smaller than those from other upper or lower basin populations. Meretsky et al. (2000) quantified this observation by comparing length-weight relationships for adult humpbacks in all of the primary populations in the lower and upper populations during the early to mid 90's; their findings showed that adult humpbacks in Cataract Canyon had the lowest condition factor of any of these populations. The length weight relationships for humpbacks captured during 2003-2005 were nearly identical to those reported by Meretsky et al. (2000). The lack of change in this relationship suggests that it may be an inherent trait of this population of chubs. However, the complete lack of humpbacks over 300 mm, suggests a significant loss of older adults. The larger adults over 300 mm were likely more productive individuals and this loss could result in a period of lower reproduction in Cataract Canyon.

Although the population appears to be very small in Cataract, it has continued to persist over the last 14 years and shown signs of continued recruitment. The current size structure however, suggests that there has been some loss of the older adults in the population.

Movement

The results determined from short-term and long-term recaptures were very straight forward, 100% apparent site fidelity during the study period. The trend of high site fidelity during fall monitoring has been observed in many humpback populations in the upper basin (Jackson and Hudson 2005; Jackson 2007; McAda 2003). Jackson and Hudson (2005) reported that only one within-year recapture moved out of its original capture location in Desolation Canyon during sampling in 2003 and 2004. Jackson (2006) reported that humpbacks in Westwater Canyon recaptured over periods between 4 and 13 years showed an 85% site fidelity and fidelity increased to over 90% when looking at within year recaptures. Radio telemetry studies in Black Rocks demonstrated a homing response in most tracked adult humpbacks and found that they typically made only localized diurnal movements (Valdez and Nilson 1982). Although high site fidelity may be a seasonal affect, it has a significant impact on our ability to measure the size of the entire population within these canyons.

With no perennial tributaries entering Cataract Canyon and over 120 river miles between this population and the Westwater or Desolation/Gray populations there may be little behavioral drive for upstream emigration for this population. Historical connections to other metapopulations in the lower portions of Cataract Canyon and Glen Canyon may have been similar to those now observed between Black Rocks and Westwater *Gila* spp.; but, in their current geographic island the humpbacks of Cataract Canyon remain very isolated from any other populations.

CONCLUSIONS

- The Cataract Canyon humpback chub population showed no statistical change during the sampling periods between 2003 and 2005.
- Humpback chub densities and catch rates in Cataract Canyon are similar to those observed in Desolation/Gray Canyon and substantially lower than found in Westwater/Black Rocks during the 2003-2005 sample periods.
- The Cataract Canyon bonytail chub population showed no statistical change during the sampling periods between 2003 and 2005.
- Humpbacks in Cataract Canyon showed 100% annual and intra-annual site fidelity during fall sampling between 2003 and 2005.
- High site fidelity resulted in population estimates which only relate to the areas sampled.
- Growth rates and condition factors of humpback chub are the lowest observed for any population in the upper Colorado River Basin.

RECOMMENDATIONS

- Humpback monitoring should continue to follow the schedule developed for sampling other upper basin chub populations, being conducted two of every four years. This would schedule sampling to restart in the fall of 2008.
- If the small size of the Cataract Canyon humpback population precludes the need for annual point estimates; then, future effort should be reduced to one intensive trip in which three or four separate habitat complexes are sampled for three days each. This will allow for continued tracking of distribution, growth, condition, relative catch rates. This type of sampling could also provide rough density estimates using recaptures between sampling days within each habitat complex sampled.
- Trammel nets should continue to be the primary sampling method, however, other methods such as baited traps should be utilized in an attempt to better sample the varied and deep habitats of Cataract Canyon.

LITERATURE CITED

- Bates, D. M., and Watts, D. G. (1980). Relative Curvature Measures of Nonlinearity. *Journal of the Royal Statistical Society. Ser. B*, 42, 1–25.
- Gimenez, O., R. Choquet, L. Amor, P. Scofield, D. LEBRETON, and R. PRADEL. 2005. Efficient Profile-Likelihood Confidence Intervals for Capture–Recapture Models. *Journal of Agricultural, Biological, and Environmental Statistics*, Volume 10, Number 2, Pages 1–13.
- Jackson, J.A., and J.M. Hudson. 2005. Population Estimate for humpback chub (*Gila cypha*) in Desolation and Gray Canyons, Green River, Utah 2001-2003. Utah Division of Wildlife Resources, Salt Lake City, Utah. Publication Number 05–25.
- Hudson, J.M. and J.A. Jackson. 2003. Population Estimates for Humpback Chub (*Gila cypha*) and Roundtail Chub (*Gila robusta*) in Westwater Canyon, Colorado River, Utah, 1998–2000. Utah Division of Wildlife Resources, Salt Lake City, Utah. Publication Number 05–25.
- McAda, C.W. 2003. Population size and structure of humpback chub in Black Rocks, 1998–2000. U.S. Fish and Wildlife Service, Colorado River Fisheries Project Office, Grand Junction, Colorado.
- Meretsky, V.J., R.A. Valdez, M.E. Douglas, M.J. Brouder, O.T. Gorman, and P.C. Marsh. 2000. Spatiotemporal variation in length-weight relationships of endangered humpback chub: Implications for conservation and management. *Transactions of the American Fisheries Society* 129:419-428.
- Miller, R.R. 1946. *Gila cypha*, a remarkable new species of cyprinid fish from the Colorado River in Grand Canyon, Arizona. *Journal of the Washington Academy of Sciences* 36:409–415.
- Nesler, T.P. 2000. Recovery of the Colorado River endangered fishes: biological recovery goals and criteria for Colorado pikeminnow, humpback chub, razorback sucker, and bonytail. Colorado Division of Wildlife, Fort Collins, Colorado.
- Otis, D.L., K.P. Burnham, G.C. White, and D.R. Anderson. 1978. Statistical inference from capture data on closed animal populations. *Wildlife Monographs*. 62:1–135.
- Rexstad, E. and K. Burnham. 1991. User’s guide for interactive program CAPTURE. Unpublished report, Colorado Cooperative Fish and Wildlife Research Unit, Colorado State University, Fort Collins, Colorado.
- USFWS. 1987. Interagency Standardized Monitoring Program Handbook. U.S. Fish and Wildlife Service, Colorado River Fisheries Project Office, Grand Junction, Colorado.
- USFWS. 1990. Humpback chub recovery plan, 2nd revision. Report of Colorado River Fishes Recovery Team to U.S. Fish and Wildlife Service, Region 6, Denver, Colorado.

- USFWS. 2002. Humpback chub (*Gila cypha*) recovery goals: an amendment and supplement to the humpback chub recovery plan. U.S. Fish and Wildlife Service, Mountain-Prairie Region 6, Denver, Colorado.
- Valdez, R.A. 1990. The Endangered fish of Cataract Canyon. Report of BIO/WEST, Inc. to Utah Division of Wildlife Resources, SLC, Utah.
- Valdez, R.A., and R.J. Ryel. 1995. Life history and ecology of the humpback chub (*Gila cypha*) in the Colorado River, Grand Canyon, Arizona. Final Report to the Bureau of Reclamation, Salt Lake City, Utah. Contract No. 0-CS-40-09110. BIO/WEST Report No. TR-250-08.
- Valdez, R.A., P. Mangan, R. Smith, and B. Nilson. 1982. Part 2 Colorado River Fishery Project Final Report Field Investigations. U.S. Fish and Wildlife Service and U.S. Bureau of Reclamation, Salt Lake City, Utah.
- White, G.C., D.R. Anderson, K.P. Burnham, and D.L. Otis. 1982. Capture-recapture and removal methods for sampling closed populations. Los Alamos National Laboratory, LA-8787-NERP, Los Alamos, New Mexico.

Table 1. Humpback chub sectional estimates, density estimates, and whole population estimates and related statistics for Cataract Canyon 2003-2005. All estimates represent the null model (M_0). Related statistics are: probability of capture (P-hat), coefficient of variation, and profile of likelihood intervals (P.L.I.), 95% confidence intervals (C.I.).

YEAR	Sect. Est	P-hat	C.V.	Sectional P.L.I. or C.I	Density (fish/mile)	Whole Pop Estimates	Whole Pop. P.L.I.or C.I.
2003 (M_0)	127	0.09	49%	59-463	66.8	468	217-1,705
2004 (M_0)	74	0.16	35%	39-160	38.9	273	144-589
2005 (M_h)	80	0.15	46%	42-208	42.1	295	155-652

Table 2. Trammel net effort and catch rates (CPUE) for humpback and bonytail for all sites combined, Cataract canyon 2003-2005.

Year	Effort (net hrs)	# HB Captures	HB CPUE (fish/net hr)	# BT Captures	BT CPUE (fish/net hr)
2003	1375	44	0.032	20	0.008
2004	1245	43	0.035	1	0.001
2005	1375	31	0.022	5	0.003

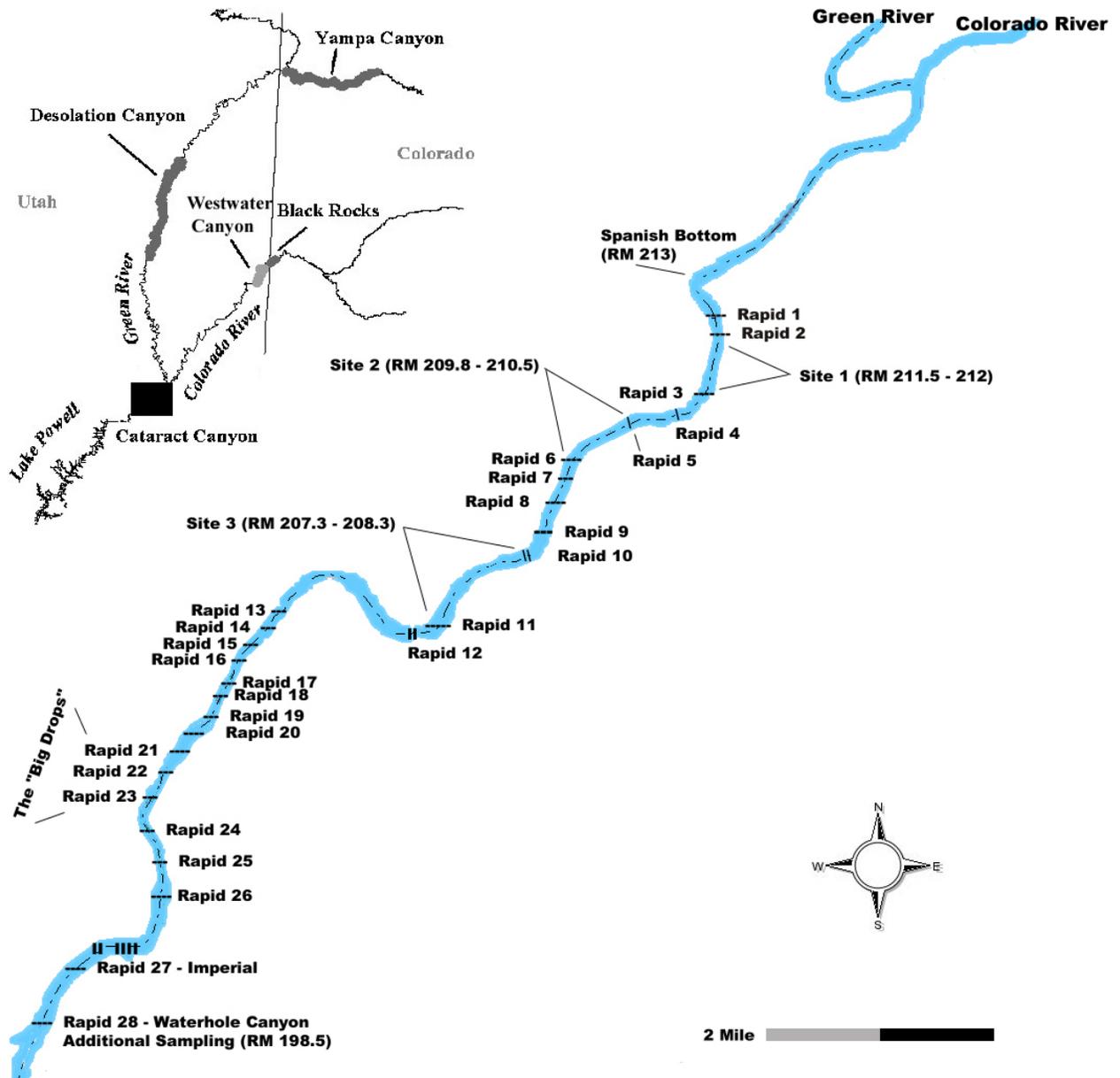


Figure 1. Map of the upper Colorado River Basin with present humpback chub population locations highlighted and Cataract Canyon detail depicting sampling locations and rapids.

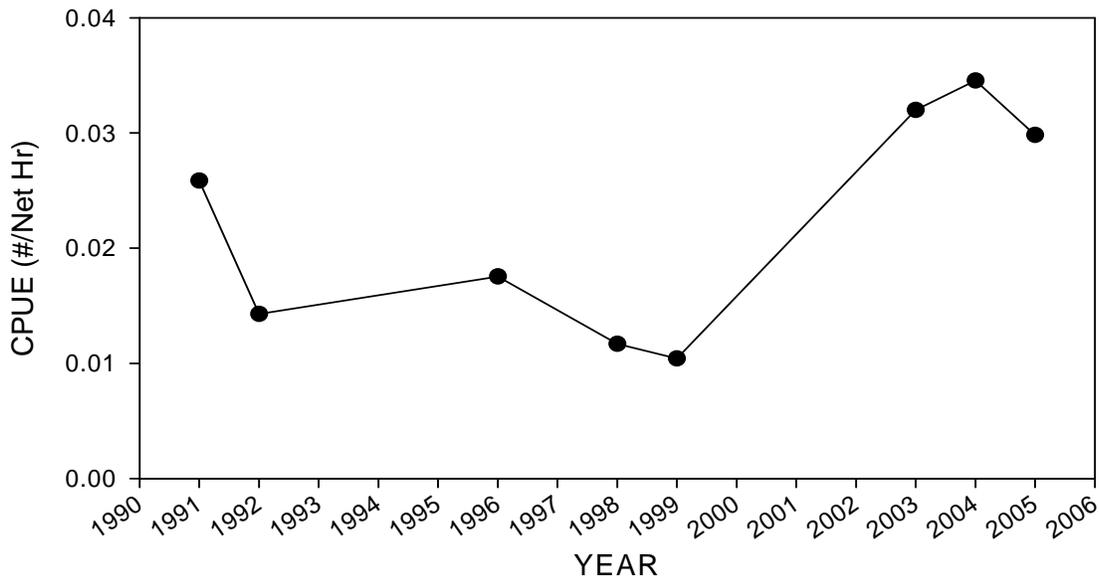


Figure 2. Total catch per unit effort (CPUE) for humpback chub in Cataract Canyon fall collections for all captures in between 1991 and 2005 (Top)

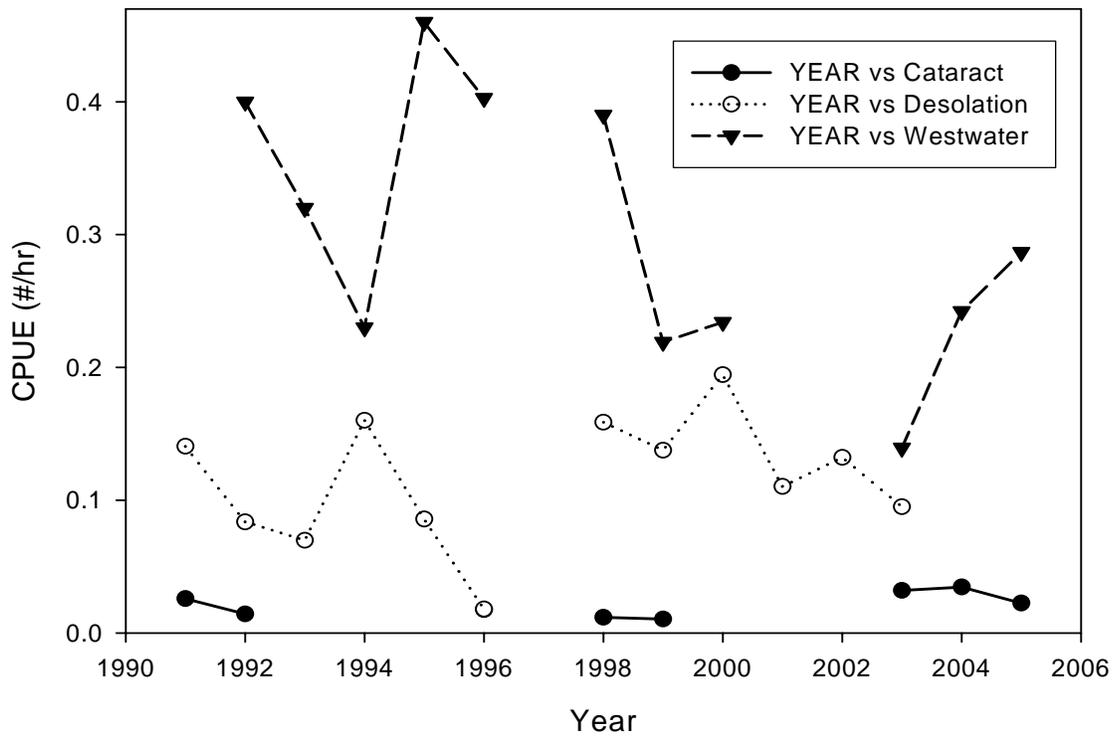


Figure 3. Comparison of total CPUE for humpback chub in Cataract Canyon, Desolation Canyon and Westwater Canyon between 1991 and 2005.

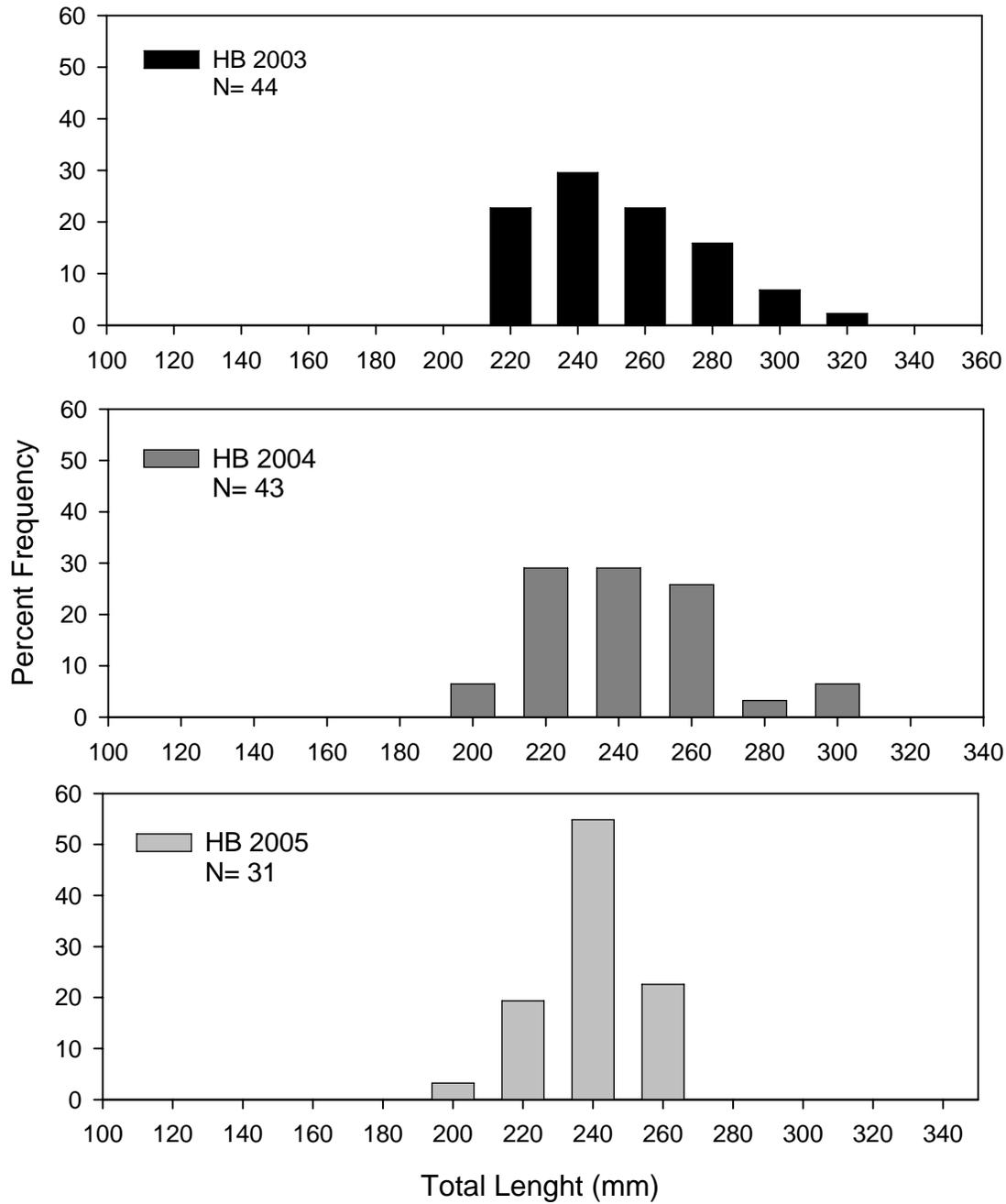


Figure 4. Annual total length frequency distributions for humpback chubs in Cataract Canyon fall collections for all captures in 2003, 2004, and 2005.

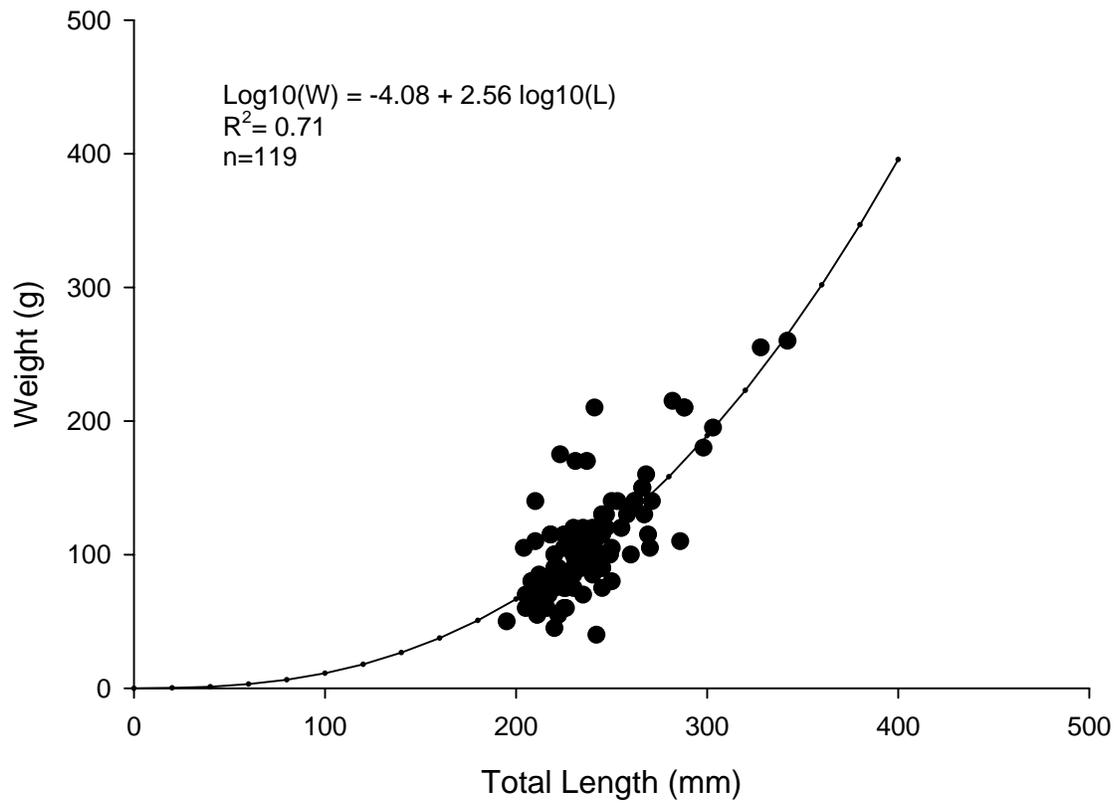


Figure 5. Length-weight relationship for adult humpback chubs (≥ 200 mm) in Cataract Canyon fall collections for all captures in 2003-2005 combined.

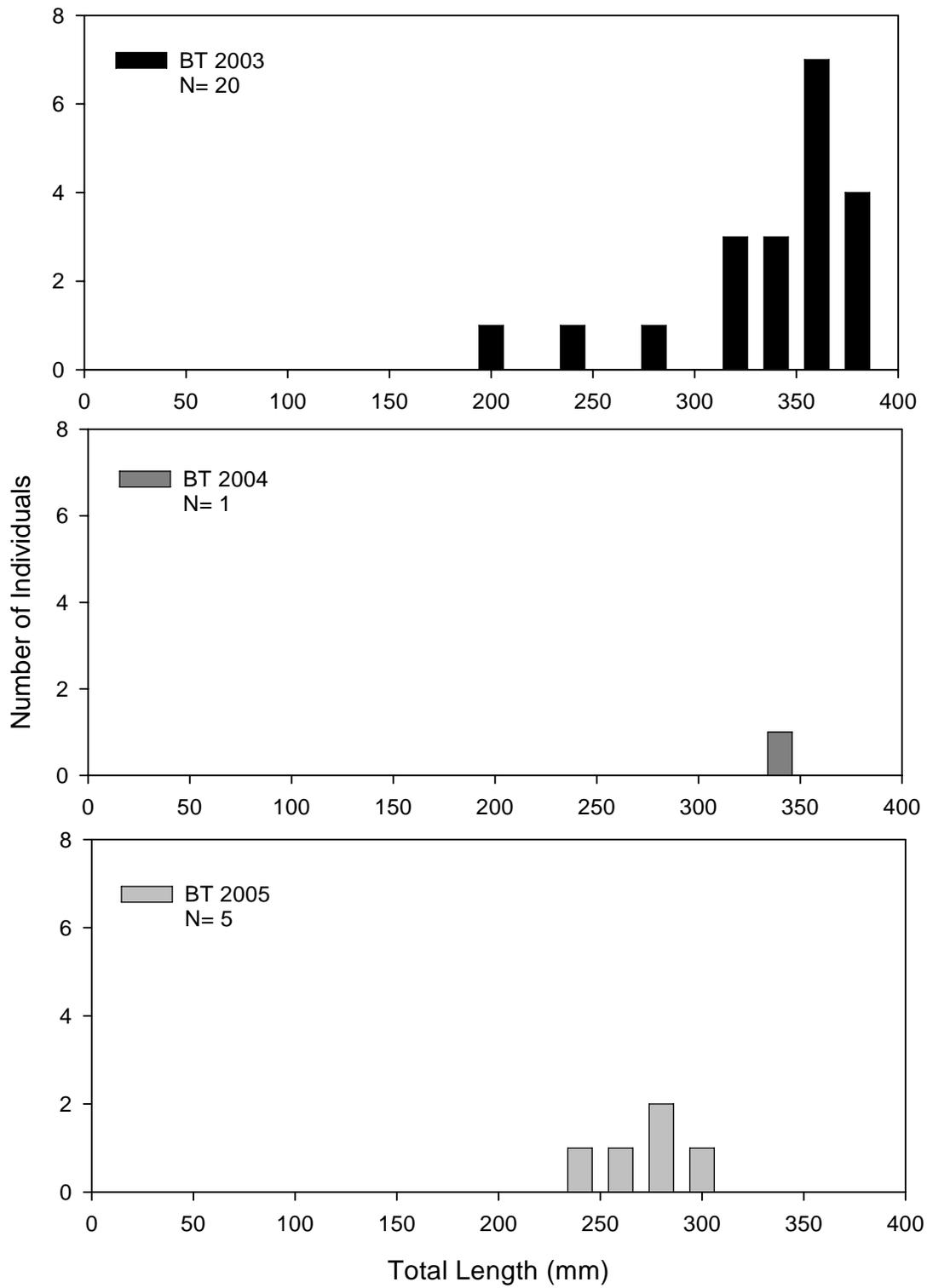


Figure 6. Annual total length frequency distributions for bonytail chubs in Cataract Canyon fall collections for all captures in 2003, 2004, and 2005.

Appendix I. Summary of appropriate population estimates generated within Program CAPTURE for adult humpback chub in Cataract Canyon, 2003-2005. Information for comparison within each year of the study among the six estimators used includes the population estimate for the sampled area (Sectional N), Profiles of Likelihood, coefficient of variation (CV), probability of capture (\hat{p}), and the model selection criteria.

<i>Year</i>	<i>Estimator</i>	<i>Sectional N</i>	<i>Profile of Likelihood</i>	<i>CV</i>	<i>p-hat</i>	<i>Model Selection Criteria</i>
2003	M ₀	127	59–463	0.50	0.092	1.00
	Chao M _h	172	74–509	0.56	0.068	0.82
	Darroch M _t	122	570–442	0.48	0.100	0.00
2004	M ₀	74	44–181	0.35	0.157	1.00
	Chao M _h	143	63–420	0.55	0.082	0.82
	Darroch M _t	74	43–180	0.33	0.160	0.00
2005	M ₀	63	35–177	0.39	0.152	0.42
	Chao M _h	80	42–208	0.30	0.121	0.76
	Darroch M _t	61	34–167	0.37	0.156	0.36