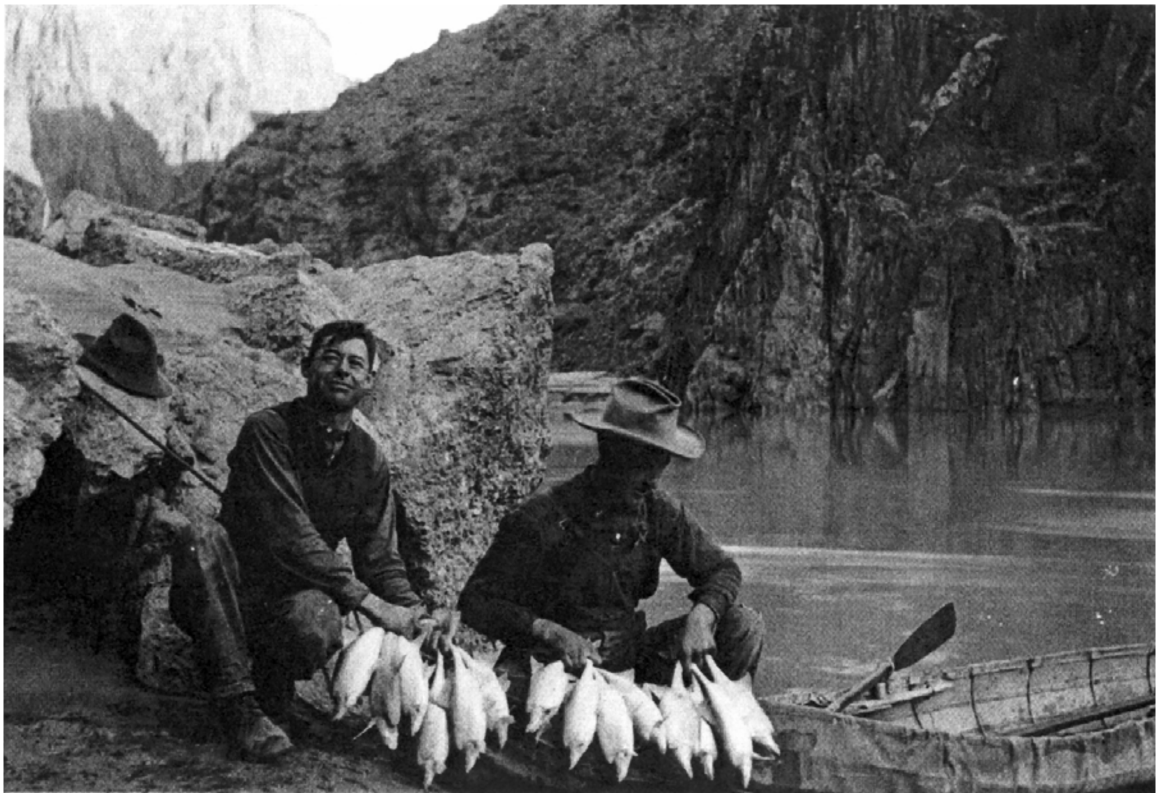
Stock Assessment and Fisheries Monitoring Activities in the Little Colorado River within Grand Canyon During 2004



Final Report

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by

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Cover: Early photograph of humpback chub taken on the mainstem Colorado River a short distance upriver from Bright Angel Creek. Photograph from Grand Canyon Archive.

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EXECUTIVE SUMMARY

The Grand Canyon Monitoring and Research Center (GCMRC) determined that a rigorous stock assessment program for fishes in the Little Colorado River (LCR) was a priority in 2000. As a result, since 2000, the U.S. Fish and Wildlife Service (USFWS) has been contracted by the GCMRC to conduct stock assessment and monitoring activities in the LCR. A total of four monitoring trips were conducted during 2004: (1) 29 March to 9 April, (2) 26 April to 7 May, (3) 15 to 26 September, and (4) 20 October to 31 October. The primary goal of these trips was to obtain stock assessment information of the humpback chub (*Gila cypha;* [HBC]). Also presented are summary data gathered during these trips relating to physical parameters, fish captures, species composition, length frequency, catch per unit effort (CPUE), sexual condition, predation, and external parasite occurrence.

The four trips were primarily used to conduct two mark-recapture efforts to estimate the abundance of HBC ≥ 150 mm total length (TL) in the lower 13.6 kilometers of the LCR. The results of the spring mark-recapture efforts indicate that there were 2,334 (SE = 411) HBC ≥ 150 mm in the LCR during the spring of 2004. Of these fish, it was estimated that there were 1,816 (SE = 397) HBC ≥ 200 mm (4+ year old adults). The results of the fall mark-recapture effort indicate that there were 2,565 (SE = 519) HBC ≥ 150 mm TL in the LCR during the fall of 2004. Of these fish, it is estimated that there were 796 (SE = 184) HBC ≥ 200 mm (4+ year old adults).

During the first spring trip, the LCR was declining from spring runoff. Turbidity declined from 1,936 nephelometric turbidity units (NTUs) to 55 NTUs, and daily afternoon water temperature remained a steady 19 ^{o}C. During the second spring trip, the LCR ran at base flows and was blue in color. Turbidities ranged between 9.1 and 12 NTUs and daily afternoon water temperatures averaged 20.8 ^{o}C.

Combining both spring trips, a total of 1,085 hoop net sets were deployed, yielding 25,218 hours of fishing effort. A total of 6,840 fish were captured, of which 3,871 were HBC. Catch per unit effort (CPUE) for HBC was 0.154 fish/net-hour. Nonnative fishes comprised 10% of the catch. One hundred and twenty-nine ripe HBC were captured of which six were female. Eleven ripe flannelmouth sucker (*Catostomus latipinnis*) and 120 ripe bluehead sucker (*C. discobolus*) were captured. Two HBC (one TL = 104 mm, the other prey length unrecorded) were found in the stomachs of 34 black bullhead (*Ameiurus melas*) examined. Percent occurrence of the external anchorworm (*Lernaea cyprinacea*) on HBC was only 0.05%.

During the first fall trip, the LCR was undergoing flooding. Turbidities ranged from 16,280 to 124,416 NTUs, and daily afternoon water temperatures averaged 17.4 ^{o}C. During the second fall trip, the LCR ran at base flow and was blue in color. Turbidities ranged from 23.8 to 61.4 NTUs and daily afternoon water temperatures averaged 17.9 ^{o}C.

Combining both fall trips, a total of 1,080 hoop net sets were deployed, yielding 25,396 hours of fishing effort. A total of 3,821 fish were captured, of which 2,778 were HBC. CPUE for HBC was 0.110 fish/net-hour. Nonnative fishes comprised 3.6% of the catch. Four ripe HBC were captured. All were male. In addition, three ripe flannelmouth sucker and 89 ripe bluehead sucker were captured. Six HBC (TL range 44-62 mm) were found in the stomachs of 21 black bullhead examined. Percent occurrence of the external anchorworm (*Lernaea cyprinacea*) on HBC increased from the low occurrence during spring (0.05%) to 15.3%.

INTRODUCTION

With the passage of the Grand Canyon Protection Act in 1992, the Glen Canyon Dam Adaptive Management Program was initiated. The center of the program is the Adaptive Management Work Group (AMWG). The AMWG has the responsibility of defining management objectives associated with the resources downstream of Glen Canyon Dam, and making recommendations for the development of a long-term monitoring program to assess those resources. The Grand Canyon Monitoring and Research Center (GCMRC) is responsible for implementing the long-term monitoring program and assuring that it is fulfilling the needs of the AMWG. The humpback chub (*Gila cypha*; HBC) is particularly important due to its status as a federally listed endangered species (U.S. Office of the Federal Register 32:48 [1967]:4001).

A tremendous amount of research has been conducted to gain a better understanding of HBC in Grand Canyon over the last 20 years. Some of this work has reported on population status (Kaeding and Zimmerman 1983, Valdez and Ryel 1995, Douglas and Marsh 1996), while other studies have focused on natural history and ecology (e.g., Robinson et al. 1998, Gorman and Stone 1999, Clarkson and Childs 2000). Because the AMWG has a need to effectively assess the impacts of the operation of Glen Canyon Dam on HBC and to evaluate whether fish management objectives in Grand Canyon are being met, GCMRC initiated a program in 2000 that focused on stock assessment and long-term monitoring of Grand Canyon fishes.

GCMRC's long-term monitoring strategy for the Little Colorado River (LCR) HBC population is essentially a four pronged approach:

1. Annual spring and fall HBC abundance assessments in the lower 13.6 km of the LCR.

2. Annual spring HBC relative abundance assessment in the lower 1200 m of the LCR.

3. Annual spring/summer HBC relative abundance assessment in the LCR Inflow (mainstem Colorado River mile 57 to 65.4).

4. Annual assessment of the overall LCR HBC population abundance and recruitment utilizing the age structured mark-recapture model (ASMR) developed by GCMRC (Coggins et al., *In prep.*).

This strategy provides a comprehensive view of the dynamics of the LCR HBC population whereby each of these programs is designed to complement each other.

In order to address item 1 above, in October and November 2000 the USFWS undertook an effort to estimate the fall abundance of HBC in the LCR (Coggins and Van Haverbeke 2001). Briefly, the strategy was to obtain a closed population estimate of HBC in the LCR via a two pass mark-recapture effort.

Because of the success of this initial effort, this strategy was expanded into mark-recapture efforts during the spring and fall of 2001 (Van Haverbeke and Coggins 2002), 2002 (Van Haverbeke 2003), and 2003 (Van Haverbeke 2004). In 2004, GCMRC again contracted the USFWS to conduct two additional mark-recapture efforts in the LCR.

One important element of these efforts is that they were designed to be comparable to the closed historical abundance estimates of HBC in the LCR provided by Douglas and Marsh (1996). Like Douglas and Marsh (1996), our approach is to obtain closed abundance estimates in the LCR via fishing the entire lower 13.6 km of the LCR with hoop nets deployed from three separate camp locations. However, largely because of funding constraints, our efforts only provide closed estimates during the spring and fall of each year, rather than on a monthly basis year round as was obtained by Douglas and Marsh (1996). Nevertheless, within a given set of spring and fall months, and within a given size class of fish (≥ 150 mm), our estimates are considered comparable to the estimates of Douglas and Marsh (1996). Our spring estimate is timed to coincide with the peak of HBC spawning within the LCR and therefore provides GCMRC with a reliable measure of the annual spawning magnitude. Our fall estimate is aimed primarily at providing an estimate of the abundance of sub-adult fishes rearing in the LCR.

OBJECTIVES

The primary goal of the 2004 sampling trips was to obtain information for the stock assessment of HBC. In addition, these trips provide information for characterizing the natural history and ecology of the LCR fish community. Therefore, all species of native and non-native fish were monitored. The specific objectives for 2004 were:

1. Obtain spring and fall 2004 population estimates of HBC ≥ 150 mm in the lower 13.6 km of the LCR.

2. Collect data in support of GCMRC stock assessment models. Specifically, our data and results will be incorporated into Age-Structured Mark-Recapture (ASMR) models that make full use of the historical database to estimate long-term population and recruitment trends of HBC (Coggins et al., *In prep.*).

In addition to the above stated objectives, information is also presented on physical parameters of the LCR, effort and catch compositions, species compositions, length frequencies, sexual conditions, predation, and parasites.

METHODS

Trips and Participating Personnel

Four fish monitoring trips were carried out in the LCR during 2004. The trip dates were: (1) 29 March to 9 April (referred to as the April trip henceforth), (2) 26 April to 7 May (referred to as the May trip henceforth), (3) 15 to 26 September, and (4) 20 October to 31 October. Participating field crew included personnel from USFWS, Arizona Game and Fish Department (AGFD), SWCA Inc., and volunteers (Table 1).

Study Site

All work was conducted in the lower 13.6 km of the LCR, below a large travertine structure known as “Atomizer Falls”. Note this year an updated photographic map provided by GCMRC was used which slightly modifies river kilometers. For example, previous USFWS reports since 2001 have defined the sampling reach for mark recapture studies as occurring in the lower 14.2 rkm of the LCR (e.g., Coggins and Van Haverbeke 2001, Van Haverbeke and Coggins 2002, Van Haverbeke 2003). The new maps define the sampling reach as occurring in the lower 13.6 rkm of the LCR.

During the course of each trip, the LCR was divided into three reaches by river kilometer (rkm) with base camps located within each reach. Rkm within the LCR began with zero at the confluence with the Colorado River. Base camps were established for the Salt reach, Coyote reach and Boulders reach at 10.4 rkm, 5.0 rkm, and 1.9 rkm, respectively (Figure 1). Each reach was divided into three sub-reaches. Salt reach was divided into three sub-reaches as follows: 13.6 to 12.3 rkm (Lower Atomizer Falls to Triple Drop), 12.3 to 11.2 rkm (Triple Drop to Hell Hole), and 11.2 to 9.6 rkm (Hell Hole to above House Rock). Coyote reach was divided into three sub-reaches: 9.6 to 8.0 rkm (above House Rock to Redbud Canyon), 8.0 to 6.5 rkm (Redbud Canyon to above White Spot), and 6.5 to 5.0 rkm (above White Spot to 5.0 rkm). Boulders reach was divided into three sub-reaches: 5.0 to 3.0 rkm (5.0 rkm to above Powell Canyon), 3.0 to 1.8 rkm (above Powell Canyon to above Jump Off Rock), and 1.8 to 0.0 rkm (above Jump Off Rock to Confluence).

Gear

Unbaited hoopnets were deployed to sample fishes (0.5 - 0.6 m diameter, 1.0 m length, 6 mm [1/4”] mesh, with a single 0.1 m throat). Sixty hoop nets were fished throughout each of the three reaches during each trip. Nets were distributed throughout each reach by fishing equal numbers of nets within each sub-reach (i.e., 20 nets were fished within each sub-reach). Each sub-reach was fished for three consecutive 24 hour periods (i.e., three days each). Some very minor exceptions to this rule were made to accommodate logistics. In addition, each hoop net was positioned in favorable habitat suspected of yielding catches of HBC. Nets were often repositioned following net checks if the catch was poor, or if an alternative site was available. Shoreline distance between nets varied due to many logistical considerations; however, most nets were placed between 80 to 150 m apart, and an effort is made to roughly space nets evenly. Most nets were tied from the shorelines and set along shore or within a few meters from shore. Some nets were tied from mid-channel boulders and fished further from shore. Each net was checked and emptied of fish daily.

All net locations were recorded as distance (rkm) above the confluence, side of the river (right, left, center), and nets were individually marked on photographic maps supplied by GCMRC. Net locations were entered into a field computer using Arc Map. General habitat characteristics were recorded for the nets, including shoreline habitat, hydraulic unit, substrate, and cover type (Table 2).

Fish

Data collected for native fish captured included: total length (mm; total and fork lengths for HBC), sex (male, female, undetermined), sexual condition (ripe, spent), sexual characteristics (tuberculate, breeding colors), external parasite types and number of external parasites per fish. An exception was made for speckled dace, for which fork length, sex and sexual characteristics were usually not recorded. All fish lengths reported in this document refer to total lengths (TL). All HBC ≥ 150 mm were scanned for a Passive Integrated Transponder (PIT) tag (Biomark, Inc.); and if lacking a tag or containing an older 400 kHz PIT tag, were injected with a new 134.2 kHz PIT tag. The two native suckers and carp ≥ 150 mm were also scanned for a PIT tag, and if not already tagged, were injected with a PIT tag. Stomach contents of large bodied non-native fish (primarily ictalurids and salmonids) were examined and recorded in the field. All bullhead were identified to be black bullhead (*Ameiurus melas*) in this document based on anal ray counts (i.e., all bullhead checked had 15-19 anal fin rays).

Water Quality

Measured water quality parameters included temperature (^{o}C) and turbidity (nephelometric turbidity units; NTUs), and were collected daily at Salt reach (~10.4 rkm). Turbidity readings were taken daily during the afternoon with a Hach 2100P turbidimeter. Provisional discharge (cubic feet per second; cfs) data were obtained from USGS gage station 09402300 located at approximately 1.0 rkm above the confluence in the LCR, and from USGS gage station 0940200 located on the LCR near Cameron, AZ.

Mark-Recapture Analysis and Assumptions

Two mark-recapture efforts (spring and fall) were conducted to estimate the abundance of HBC ≥ 150 mm in the lower 13.6 km of the LCR. Marking events occurred during the first spring trip (29 March to 9 April) and during the first fall trip (15 to 26 September). Fish ≥ 150 mm that had not previously been tagged were injected with an individually numbered and recorded PIT tag. At the end of each marking trip, all unique HBC that had been either tagged or recaptured from previous trips were considered the marked portion of the population. Unique fish are individuals that are captured within a trip, but do not include subsequent captures of that same fish during the same trip. Recapture events occurred during the second spring trip (26 April to 7 May), and during the second fall trip (20 October to 31 October).

The target population was all HBC ≥ 150 mm. However, frequently the target and sampled population (i.e., the size specific component of the population that is effectively sampled) differ, and it is only possible to estimate the abundance of the sampled population. Therefore, we first examined our data to define our sampled population. Bernard and Hansen (1992) suggest setting the lower boundary of the sampled population equal to the length of the smallest fish recaptured. However, we allowed for growth and measurement error that could have occurred between the marking and recapture events (10 mm). Provided that the smallest recaptured fish was within the expected growth rate curve for HBC in the LCR (Robinson and Childs 2001), we did not truncate our lower boundary for the estimate. We also did not truncate the upper end of our estimates, since the types of hoop nets used in our study have been shown to effectively capture large HBC in previous studies (Gorman and Stone 1999).

The Chapman modified Petersen two-sample mark-recapture model (Seber 1982) was used to estimate the abundance of the sampled population. Assumptions associated with this estimator are:

1. The population is closed, with no additions or losses between marking and recapture events either through recruitment, immigration, mortality, or emigration.

2. Marking does not affect capture probability during the recapture event.

3. All HBC in the target population have an equal probability of capture during the marking event or the recapture event; or marked fish mix completely with unmarked fish prior to the recapture event.

4. Marks (tags) are not lost between the marking and recapture events.

5. All marked fish captured can be recognized from unmarked fish.

The first assumption, addressing population closure, could potentially be violated in this system since HBC in the LCR have free access to the mainstem Colorado River. We attempted to minimize potential for violation of this assumption by only allowing a short time span (less than a month) to elapse between our mark and recapture events. It was also assumed that growth related recruitment was minimized due to the short time span between marking and recapture events.

The first assumption has a higher probability of being violated during spring than during fall mark-recapture events. HBC movement and migration is known to occur during the spring of the year (Kaeding and Zimmerman 1983; Douglas and Marsh 1996), but is thought to be at a minimum during the fall and winter months (Douglas and Marsh 1996, Valdez and Ryel 1995). If HBC emigrate from the LCR or die between sampling events, it is assumed that both marked and unmarked fish are lost at the same rate. The Chapman-Petersen estimator can still be used in this circumstance, but the population estimate will be germane for the population during the marking event. Additionally, if HBC immigrate into the LCR between the two events, then the population estimate will be germane for the population during the recapture event. If both additions and losses (i.e., such as immigration and emigration) occur between the events, there is no possible correction and the estimate will overestimate HBC abundance. Finally, all fish captured during both mark-recapture efforts were handled with utmost care to avoid injury or stress related mortality.

It was not possible to directly test the second assumption that capture and handling during the first event affected the recapture probability in the second event. However, results of the tests examining violation of the third assumption provided indirect evidence of whether the second assumption was violated. Again, careful handling of the fish throughout the study should have minimized problems of violating this assumption.

The third assumption addresses equal capture probability of all fish. This assumption can be violated if the capture gear (i.e., hoop nets) is highly size selective. To determine if the probability of capture varied due to fish size, Kolmogorov-Smirnov tests were applied to the length frequency data collected during both the mark and recapture events. The first test compared the length frequency distributions of marked fish [*M*] with those captured during the recapture event [*C*]. The second test compared the length frequency distributions of fish marked during the marking event [*M*] with those recaptured during the recapture event [*R*]. Capture probability can also differ by location (i.e., along the LCR river corridor). During marking and recapture events, sampling was equally distributed throughout the entire 13.6 km study area. To validate whether all fish had an equal probability of capture during the marking event regardless of their location, a contingency table analysis was used to test whether the “mark rate” differed among sampling reaches and sub-reaches (Seber 1982). This was performed by dividing the number of recaptured fish [R] by the number of fish captured [C] within each geographic reach, and comparing the results in the contingency table analysis. Similarly, a “recapture rate” can be used to validate whether all fish had an equal probability of capture during the recapture event. This was performed by dividing the number of recaptured fish [R] by the number of fish marked [M] within each geographic reach, and comparing the results in the contingency table analysis. The results the above tests suggested if modifications to the Chapman-Petersen estimator were necessary to minimize bias (Bernard and Hansen 1992). These modifications included stratifying the abundance estimates by length, by geographic reach, or both, if necessary.

The fourth assumption (potential tag loss) has proven to be more problematic to address. During the spring trips of 2001, a dorsal fin punch was used as an auxiliary mark to the newly PIT tagged fish ≥ 150 mm (Van Haverbeke and Coggins 2002). Unfortunately, this type of auxiliary mark was found to be unreliable as a diagnostic tool, because some marked fins regenerated and were unidentifiable, and some fins thought to have been marked (punched) were never in fact marked. Our experience with elastomer dye tags thus far has shown that they are too unreliable to use as a long term secondary mark (Stone and Sponholtz 2003). However, there may be potential for using elastomer dye to test for short term loss of PIT tags (i.e., tags that are lost before the wound heals). It was assumed during these studies that tag loss was probably negligible, but concluded that future investigation might be warranted (i.e., other type of secondary marking might be investigated).

The fifth assumption relates to the ability of field personnel to detect the presence of a tag in a fish. This assumption was not evaluated directly; however, our staff is trained in the proper operation of the PIT scanners and is exceedingly careful to ensure that PIT scanners are in good working order.

Abundance estimates were calculated with the formulae presented by Seber (1982) as:

$$N^* = \frac{(M+1)(C+1)}{R+1} - 1, \tag{1}$$

$$V[N^*] = \frac{(M+1)(C+1)(M-R)(C-R)}{(R+1)^2(R+2)}, \tag{2}$$

Where N^* is the estimated number of fish in the population, $V[N^*]$ is the estimated variance of the number of fish in the population, *M* is the number of fish marked during the marking events (April and September trips), *C* is the number of fish captured during the recapture events (May and October trips), and *R* is the number of fish recaptured from the marked population during the recapture events. The 95% confidence limits on our abundance estimates assume a normal distribution and are appropriate given the ratios of *R*/*C* and *R*/*M* observed (Seber 1982).

SPRING RESULTS

Physical Parameters

The LCR was declining from spring run-off during the April trip (Figure 2). This spring runoff began on 16 March, peaked at 363 cubic feet per second (cfs) on 17 March, and thereafter declined (as measured at Cameron Gage station, Figure 2). During the trip, above base flows decreased from 107 cfs on 29 March to 6.4 cfs on 7 April (Figure 2). Turbidity decreased from a high of 1,936 NTUs on 29 March to a low of 55 NTUs on 7 April (Figure 3). Daily afternoon water temperatures remained a steady 19 ^{o}C.

During the May trip, the LCR ran at base flows and was blue. Turbidity ranged between 9.1 and 12 NTUs (mean = 10.3 NTUs; Figure 3). Daily afternoon water temperatures ranged from 19 to 22 ^{o}C (mean = 20.8 ^{o}C).

Effort and Catch

During both spring trips, a total of 1,085 hoop net sets were deployed, yielding 25,218 hours of fishing effort (Table 3). Catch per unit effort (i.e., total HBC captured/total net hours; CPUE) for HBC captured in hoop nets was higher during the May trip (2,616 fish captured, 0.209 fish/net-hr) than during the April trip (1,255 fish captured, 0.099 fish/net-hr). Fishing effort during both trips combined produced a total catch of 6,840 fish, for all species (Table 4).

Species Composition

The dominant species captured during both spring trips were HBC (3,871 fish; 57%) and speckled dace (1,482 fish; 21%), however, species compositions between the two trips showed some differences. HBC comprised the largest proportion of fish caught on both trips (70% and 52%; Figure 4). Speckled dace increased from 10% (188 fish) in April to 26% (1,294 fish) in May. Exotic species collected (in order from most to least abundant captured) were fathead minnow (*Pimephales promelas*), red shiner (*Cyprinella lutrensis*), plains killifish (*Fundulus zebrinus*), black bullhead (*Ameiurus natalis*), carp (*Cyprinus carpio*), channel catfish (*Ictalurus punctatus*), rainbow trout (*Oncorhynchus mykiss*), and green sunfish (*Lepomis cyanellus*). During April, 10.7% of the fish captured were nonnative; while during May 9.1% of the fish captured were nonnative. Under-represented by hoop net catches were large carp (> 300 mm) observed in the LCR during these sampling trips (LCR crew members, pers. obs.). Large carp were seen from the LCR confluence area to above Chute Falls, but none were captured in hoop nets.

Length Frequencies and Catch

Overall, more HBC were captured during the May trip (2,616 fish) than during the April trip (1,255 fish; Figure 5). A large proportion (77%, 2,987 fish) of HBC during both trips combined fell into the 75 to 150 mm size class (Figure 5).

Excluding all HBC ≤ 150 mm, a nearly equal proportion of adult HBC (≥ 200 mm) were captured during the May trip (273 fish; 65%) compared to the April trip (206 fish; 66%). A small cohort of HBC ≤ 75 mm was detected during the April trip (82 fish, 6.5% of the total catch), and during the May trip (96 fish; 3.7% of the total catch).

Cumulative length frequencies for HBC (Figure 6) show relative uniformity in length distribution between camps, with Boulders and Coyote capturing a slightly higher proportion of fish < 100 mm on both trips.

Flannelmouth sucker length frequency distributions show a similar pattern to HBC in that a greater number of fish were captured during the May trip (166 fish; 3% of total May fish captures) than during the April trip (88 fish; 5% of total April fish captures), and that a small age-0 cohort was detected during the May trip (Figure 7). Most flannelmouth sucker were captured in the Boulders (79%) and Coyote (14%) reaches (Table 4).

Bluehead sucker length frequency distributions were much the same as HBC and flannelmouth sucker length frequencies in that a greater number of fish were captured during the May trip (481 fish; 10% of total May fish captures) than during the April trip (98 fish; 5% of total April fish captures), and that a clearly visible age-0 cohort was observed during the May trip (Figure 8).

Sexual Condition

During the April trip, 36 ripe HBC were captured. Thirty-one of these fish were male (TL range = 105 to 386 mm) and were captured between 0.9 and 12.07 rkm. The remaining five females (TL range = 148 to 364 mm TL) were captured between 1.5 and 6.57 rkm. One ripe male flannelmouth sucker (TL = 327 mm) was captured at 1.25 rkm. Forty ripe bluehead sucker were captured. Thirty-four of these were male (TL range = 176 to 282 mm) and were captured between 0.9 and 9.34 rkm. Six were female (TL range = 168 to 270 mm) and were captured between 2.02 and 9.34 rkm.

During the May trip, 83 ripe HBC were captured. Only one of these was female (TL = 404 mm), captured at 1.25 rkm. The other 82 males (TL range = 147 to 427 mm) were captured between 1.25 and 13.54 rkm. Ten ripe flannelmouth sucker were captured (TL range = 460 to 525 mm). All were captured between 2.0 and 4.1 rkm, except one female captured at 10.4 rkm. In addition, eighty ripe bluehead sucker (TL range = 127 to 316 mm) were captured between 0.1 and 11.7 rkm. Sixty-two of these fish were males.

During April, 22 HBC ≥ 200 mm were ripe out of a total of 206 HBC ≥ 200 mm captured (i.e., 11% of the captured adult population in April was ripe). During May, 63 HBC ≥ 200 mm were ripe out of a total of 273 HBC ≥ 200 mm captured (i.e., 23% of the captured adult population was ripe).

Predation

Thirty four bullheads and three rainbow trout were examined for stomach contents during both spring trips. Ten of the bullhead (TL range 154 to 264 mm) possessed fish remains in their stomach; including two HBC (one HBC measured 104 mm; the other was not measured for length), four flannelmouth suckers, one fathead minnow, one plains killifish, and the remains of several other unidentified fish. The remaining bullheads had either empty stomachs, or had consumed aquatic insects. One rainbow trout (TL = 293 mm) had a 95 mm HBC in its stomach. Another rainbow trout had a killifish and a hellgrammite in its stomach.

Parasites

Percent occurrence of the external parasite (*Lernaea cyprinacea*) on HBC in April was low, with only five fish (0.4% of total HBC captures) observed carrying the parasite, generally carrying only one parasite per infected fish. One flannelmouth sucker was captured carrying one of the parasites. During May, only 2 HBC were seen with *Lernaea* (0.08% of total HBC captures), each carrying one parasite per fish. Occurrence of the Asian tapeworm (*Bothriocephalus acheilognathi*) was not monitored during these trips.

Population Abundance Estimation

The following criteria were used to define the sampled population during the spring mark-recapture effort. During April, 273 unique HBC ≥ 150 mm were marked [*M*]. During May, 352 unique HBC ≥ 150 mm were captured [*C*], and 47 unique HBC ≥ 150 mm were recaptured [*R*]. The smallest HBC recaptured had a total length of 164 mm, and the largest recaptured HBC was 385 mm in TL. We defined our sampled population to include all HBC ≥ 150 mm in order to provide an estimate comparable to past efforts, and since there is no indication from past efforts that our gear is not efficient at capturing fish between 150 to 164 mm.

Length frequency distributions of HBC ≥ 150 mm suggested that there may have been violations in the assumption for no emigration or immigration occurring. Figure 10 illustrates some discrepancy in the cumulative length frequencies of HBC between marked [M] fish and captured [C] fish. This discrepancy is interpreted as movement of fish, either into or out of the LCR, or both. Using two-tailed Kolmogorov-Smirnov tests, the cumulative length distribution of marked [*M*] HBC was significantly different from captured [*C*] HBC (n_1 = 273, n_2 = 352, Z = 2.141, p < 0.001). Similarly, the cumulative length distribution of marked [*M*] HBC was significantly different from recaptured [*R*] HBC (n_1 = 273, n_2 = 47, Z = 1.980, p = 0.001; Figure 10). However, we found no significant difference (χ^2 = 7.72, df = 5, p = 0.172) in the mark rates of HBC within different length strata (Table 5). The typical conclusion drawn from test results as above is that there was significant size selective sampling during both the marking and recapture events (Bernard and Hansen 1992). However, the more likely interpretation is that there was some movement of spawning sized fish either to or from the LCR between the mark and recapture events. Regardless, since the Kolmogorov-Smirnov tests revealed significant differences in length distributions between the marked and captured portions of the population, it is appropriate to stratify the data into one or more length categories to reduce bias in the abundance estimate (Bernard and Hansen 1992).

In addition, we searched for significant differences in mark rate among the three geographic strata. We found no significant difference (χ^2 = 2.53, df = 2, p = 0.28) in the mark rate among the Salt, Coyote and Boulders reaches (Table 6). Upon further testing, we found that there was not a significant difference in the mark rates among the three sub-reaches within each reach (χ^2 = 13.43, df = 8, p = 0.098). The above tests suggest it was not necessary to stratify the data by geographic reach to obtain an estimate.

The optimal length stratification is found by choosing length boundaries in a contingency table of unmarked and marked fish (e.g., Table 5) that maximizes the homogeneity in mark rate among length groups (Seber 1982, Bernard and Hansen 1992). When this procedure was performed, it was found that the optimal stratification occurred at 250 mm (χ^2 = 15.47). This means that independent estimates were produced for HBC from 150 to 250 mm and for HBC > 250 mm (Table 7). The resulting and **preferred** summed estimate for HBC ≥ 150 mm is 2,334 fish (SE = 411). Table 8 and Figure 11 show this estimate as compared against historical estimates.

Since the Recovery Goals for HBC (USFWS 2002) focus on abundance estimates of fish ≥ 200 mm (i.e., 4+ year old adults; USFWS 2002), estimates are presented relating to their abundance. First, the data set was truncated to include only fish ≥ 200 mm. During April, 184 unique HBC ≥ 200 mm were marked [*M*]. During May, 229 unique HBC ≥ 200 mm were captured [*C*], and 28 unique HBC ≥ 200 mm were recaptured [*R*]. The smallest HBC recaptured [R] had a total length of 200 mm, and the largest recaptured was 385 mm in TL. Using two-tailed Kolmogorov-Smirnov tests, the cumulative length distribution of marked [*M*] HBC was significantly different from captured [*C*] HBC (n_1 = 184, n_2 = 229, Z = 2.491, p < 0.001). Likewise, the cumulative length distribution of marked [*M*] HBC was significantly different than recaptured [*R*] HBC (n_1 = 184, n_2 = 28, Z = 2.247, p < 0.001). The typical conclusion drawn from these test results is that there was significant size selective sampling during both the marking and recapture events (Bernard and Hansen 1992), or that stratifying the data by length to obtain an estimate is desirable. The optimal stratification occurred at 250 mm TL (i.e., independent estimates were produced for HBC <251 and for HBC > 250). The resulting pooled estimate was 1,763 fish (SE = 398). However, because it should result in less bias to use the entire data base rather than truncating it (Seber 1982), the Chapman modified Petersen estimate of HBC ≥ 150 to 250 mm (984 fish; see Table 7) was multiplied by the proportion of fish from 200 to 250 mm, providing an estimate of 467 fish in the 200-250 mm category. This abundance estimate was then summed with the Chapman modified Petersen length stratified abundance estimate of 1,349 fish >250 (see Table 7). The resulting, and **preferred** estimate for HBC > 200 mm was 1,816 fish (SE = 397). Table 9 and Figure 12 show this estimate as compared against the spring estimates for the past three years.

FALL RESULTS

Physical Parameters

During the fall of 2004, the LCR experienced several discrete monsoonal flooding events (Figure 13). In September, floods began on 19 September, peaked on 21 September at 2,160 cubic feet per second (cfs), and thereafter declined until 30 September, when another flood arrived. At Salt Camp, turbidity reached a high of 124,416 NTUs on 22 September, and thereafter decreased to a low of 16,280 NTUs on 29 September. Turbidity increased again on 30 September (fly-out day) to 67,584 NTUs with the arrival of another flood (Figure 14). Daily afternoon water temperatures ranged between 15.3 and 19.1 ^{o}C (mean = 17.4 ^{o}C).

During the October trip, the LCR ran at base flow and was blue. Although blue in color, turbidity was still declining from the sequence of flooding events experienced this fall and decreased from 61.4 NTUs on 19 October to 23.8 NTUs on 28 October (Figure 14). Daily afternoon water temperatures ranged from 17.1 to 18.3 ^{o}C (mean = 17.9 ^{o}C).

Effort and Catch

A total of 1,080 hoop net sets were completed during the September and October trips yielding 25,396 hours of fishing effort. Total CPUE for HBC in September was 0.036 fish/net-hour, and in October was 0.181 fish/net-hour (Table 10). The distribution of effort was similar among the three reaches. Fishing effort during these trips produced a catch of 3,821 fish (Table 11). The dominant species in the catch were HBC (2,778 fish; 73%) and speckled dace (644 fish; 17%). Fathead minnow comprised the dominant nonnative species (74 fish; 2%).

Species Composition

Observed species composition during both the September and October trips was similar, with some small differences (Figure 15). HBC comprised the largest proportion of fish caught on both trips (79% and 72%), compared to 70% and 52% on the spring trips. Speckled dace increased in proportion from 6% of the catch in September to 19% of the catch in October. The proportions of black bullhead and carp declined from 3% in September to <1% in October. Nonnative species in order of decreasing catch included fathead minnow, black bullhead, carp, channel catfish, red shiner, plains killifish and rainbow trout. Nonnative species captured in hoop nets during September and October comprised 11.4% and 2.1% of the catch, respectively.

Length Frequencies and Catch

More HBC were captured during the October trip (2,322 fish) than during the September trip (456 fish; Figure 16), likely a result of decreased turbidity in October (Figure 14). A spike of age-0 fish (<100 mm) was detected in October

(1,292 fish; 57% of total HBC captured in October; Figure 16). Another group of HBC on both trips fell into the 100 to 200 mm size class (1,121 fish; 40% of total HBC captures; modes ~130 mm), with no clear distinctions between cohorts. A greater number of HBC ≥ 200 mm were captured during the October trip (149 fish; 6% of total HBC captured in October) than during the September trip (74 fish; 3% of total HBC captured in September). Cumulative length frequencies for HBC (Figure 17) show capturing higher proportions of fish < 100 mm at Boulders and Coyote reaches on both trips compared to Salt reach.

Flannelmouth sucker length frequency distributions show that a greater number of fish were captured during the October trip (76 fish; 95% of total flannelmouth sucker captured on both trips) than during the September trip (4 fish; 5% of total flannelmouth sucker captured on both trips); Figure 18). Most flannelmouth sucker were captured in the Boulders reach (Table 11). Thirty-two presumed age-0 flannelmouth sucker (TL < 130 mm) were captured in October, and two in September.

Bluehead sucker length frequency distributions were similar to flannelmouth sucker length frequencies in that a greater number of fish were captured during the October trip (158 fish; 86% of total bluehead sucker captured during both trips) than during the September trip (25 fish; 14% of total bluehead sucker captured on both trips; Figure 19). Only 25 presumed age-0 bluehead sucker were captured during October and five during September.

Sexual Condition

During the September trip, only two ripe male bluehead suckers were captured (TL = 214 and 245 mm) in Boulders reach. During the October trip, four ripe male HBC (TL range = 200-385 mm) were captured; two in Boulders and two in Salt reach. Three ripe male flannelmouth sucker were captured (TL range = 320 to 490 mm), all in Boulders reach. In addition, 87 ripe bluehead sucker (TL range = 167 to 290 mm) were captured, all but five of them being captured in Boulders reach. Only six of these ripe bluehead were female. Finally, two ripe female speckled dace were captured in October.

Predation

Twenty-one black bullhead and 11 channel catfish were examined for stomach contents during the fall trips. Three of the bullhead (TL range 184 to 227 mm) had a total of six HBC in their stomachs (prey length range 44 to 62 mm). Five others had unidentified fish remains in their stomachs. The remaining bullhead had insects or detritus in their stomachs or had empty stomachs. Two of the channel catfish (TLs = 408 and 205 mm) had unidentified fish remains in their stomachs. The remainder had insects, detritus or empty stomachs.

Parasites

Percent occurrence of the external parasite (*Lernaea cyprinacea*) on HBC in September was moderate, with 100 fish (22% of total HBC captures) observed carrying the parasite, carrying 1-7 parasites per infected fish. Only one flannelmouth sucker was captured carrying one of the parasites. During October, 324 HBC were seen with *Lernaea* (14% of total HBC captures), each carrying 1-7 parasites per fish.

Population Abundance Estimation

We used the following criteria to define our sampled population during the fall mark-recapture effort. During September, 135 unique HBC ≥ 150 mm were marked [*M*]. During October, 416 unique HBC ≥ 150 mm were captured [*C*], and 21 unique HBC ≥ 150 mm were recaptured [*R*]. The smallest HBC recaptured had a total length of 151 mm, and the largest HBC recaptured was 342 mm TL.

Figures 20 and 21, suggest some differences in the length frequencies of marked, captured and recaptured fish. Using two-tailed Kolmogorov-Smirnov tests, the length distribution of marked [*M*] HBC was significantly different from captured [*C*] HBC ($n_1 = 135$, $n_2 = 416$, $Z = 2.060$, $p < 0.001$). However, the length distribution of marked [*M*] HBC was not significantly different than recaptured [*R*] HBC ($n_1 = 135$, $n_2 = 21$, $Z = 0.636$, $p = 0.813$; Figure 21). In addition, there was no significant difference ($\chi^2 = 10.60$, df = 5, $p = 0.06$) in the mark rates of HBC within different length strata (Table 12). However, since the population of marked fish was found to be significantly different from the population of captured fish, it was necessary to stratify our abundance estimate based on length (Seber 1982).

The optimal stratification is found by choosing length boundaries in a contingency table setting of unmarked and marked fish that maximize the homogeneity in mark rate among length groups (Seber 1982, Bernard and Hansen 1992). This procedure was performed and it was found that the optimal stratification occurred at 200 mm ($\chi^2 = 0.15$).

In addition, there was no significant difference ($\chi^2 = 1.78$, df = 2, $p = 0.41$) in the mark rate among the three sampling reaches (Table 13). This test suggests that the abundance estimate need not also be stratified by location (i.e., Salt, Coyote and Boulders reaches).

Based on the above tests, it was concluded that the abundance estimate should be stratified by length (i.e., those fish from 150 mm to < 201 mm and those fish > 200 mm), but did not also need to be stratified by reach. The resulting length stratified Chapman modified Petersen abundance estimate for HBC ≥ 150 in the lower 13.6 rkm of the LCR was 2,565 fish (SE = 519; Table 14). Table 15 and Figure 22 show this estimate as compared against the historical estimates obtained by Douglas and Marsh (1996) for HBC ≥ 150 mm during these months.

Since the Recovery Goals for HBC (USFWS 2002) focus on abundance estimates of fish ≥ 200 mm (i.e., 4+ year old adults), an estimate is presented relating to their abundance. The above length stratified Chapman-Petersen estimate for fish > 200 mm (from Table 14) was recalculated to include fish ≥ 200 mm (i.e., four additional captured [C] 200 mm fish were included in the equations). The resulting abundance estimate of HBC ≥ 200 was 796 fish (SE = 184). Table 16 and Figure 23 show this as against historical estimates.

DISCUSSION

Spring Abundance Estimate

A length stratified Chapman Petersen estimate of 2,334 (SE = 411) HBC ≥ 150 mm is given as the estimate for spring 2004. Because significant differences were found in the length frequency distributions between the marked [*M*] and captured [*C*] populations, and between the marked [*M*] and recaptured [*R*] populations, it was considered necessary to stratify the data by length. The length frequency analyses provides indication that there was potentially some migratory activity occurring in the LCR between the mark and recapture events. This means that the assumption of population closure was possibly violated.

Since 2001, the spring abundance estimates of HBC ≥ 150 have increased and again declined. Abundance estimates increased from 2,082 in spring of 2001 to 2,666 in spring 2002, and to 3,419 in spring of 2003. This apparent increase may have been because of survivorship and recruitment from the 2001 (and possibly the 2000) age-0 cohorts. For instance, the 2001 age-0 cohort (mode ~80 mm) can be strongly seen in fall 2001 (Figure 24). The cohort can then be tracked into spring 2002 (mode ~115 mm) and into fall 2002 (mode ~155 mm). By spring 2003 this cohort is well into the 150-200 mm size category and may reflect the high abundance of HBC ≥ 150 mm during spring 2003 (Figure 11). In spring of 2004, we detected a decrease in the abundance of HBC ≥ 150 mm relative to spring 2003 (Figure 11). This decrease may be the result of low recruitment from the 2002 age-0 cohort, thought to be poor. Very few age-0 fish were captured during fall 2002 (Figure 24). This void can be tracked through spring and fall 2003 and shows up as a low spot in the length frequency histogram for fish roughly in the 155-180 mm category during spring 2004. In other words, the passing through of a strong cohort or two may have caused the increase in abundance in spring 2002 and 2003, while the entering of a weak cohort may have caused the decline in spring 2004. Finally, all spring estimates obtained between 2001 through 2004 have been lower (although not all have been significantly lower) than the spring 1992 estimates provided by Douglas and Marsh (1996).

Also of interest are the abundance estimates of HBC ≥ 200 mm. In addition of a criterion for no significant decline, the Recovery Goals for HBC call for a minimum viable population of 2,100 HBC ≥ 200 mm in Grand Canyon (USFWS 2002). The spring 2004 estimate for HBC ≥ 200 mm in the LCR falls at 1,816 (SE = 397). It is noteworthy that all four spring estimates provided from 2001 to 2004 fall below 2,100 fish. However, as mentioned in the introduction section, our annual closed LCR estimates by themselves are not intended to provide an estimate of the overall LCR population, because some portion of HBC will be in the mainstem during our activities and will not be captured in the estimate. Our annual data are being incorporated into open population models (i.e., Jolly-Seber in Program Mark, and ASMR) in order to estimate the entire LCR population.

Spring Sexual Condition

As in previous years, there was a low percentage of ripe female HBC compared to ripe male HBC during the spring sampling of 2004 (i.e., 6 ripe females/113 ripe males in spring 2004; spring 2003 = 4/115; spring 2002 = 14/123, spring 2001 = 6/84). Gorman and Stone (1999) found similar results during the spawning seasons of 1993 to 1995 (i.e., 16/93). Hoop net catch data over the years in the LCR has consistently shown that one or two ripe females are typically accompanied by numerous ripe males (GCMRC, unpublished data). Thus, this trend does seem to hold true for the population. Gorman and Stone (1999) also found that ripe females appeared to move into aggregations of ripe males to spawn, and found that while males have a protracted time span for being in a ripe condition; females are ripe for a shorter time span.

The Recovery Goals make the assumption that there is a 1:1 effective sex ratio in terms of contributors to the next generation (USFWS 2002). Even though a 1:1 sex ratio may exist in the wild for HBC (Valdez and Ryel 1995), this may not necessarily equate into a 1:1 effective sex ratio during spawning activities. As Soulé (1980) stated, "breeding structure is absolutely critical." The data suggest that the breeding structure for HBC may be more complex than simply assuming a 1:1 effective sex ratio. This is important, since the effective sex ratio has an impact on the estimation of N_e, and indeed is part of the basic equation in estimating N_e (e.g., Lande and Barrowclough 1987).

Fall Abundance Estimate

Like the spring abundance estimates provided for this year, the fall abundance estimates had few complications (i.e., simple rather than complex stratification methods were adequate). There was no significant difference in the length frequency distributions between the marked [*M*] and captured [*C*] fish, but was significant difference between the marked [M] and recaptured [R] fish. There was also no significant difference in the mark rates within the length strata, nor within the geographic reaches. However, because there was significant difference between the length frequencies of marked [M] and recaptured [R] fish, the estimate was stratified by length. This year's fall estimate of 2,565 (SE = 519) HBC ≥ 150 mm was higher (although not significantly) than the fall 2003 estimate of 1,862 (SE = 206), and all three estimates since 2002 have been significantly higher than the abundance estimate obtained during the fall of 2001 (N= 1,064, SE = 65). Similar to the discussion above concerning the variation in spring abundance of HBC ≥ 150 mm since 2001, variations in abundance during the fall also appear to reflect annual cohort strength. For example, the strong 2001 age-0 cohort is well into the 150-200 mm size category by fall of 2002 (Figure 24), and might reflect the significantly higher abundance of fish ≥ 150 mm compared to fall 2001 (Figure 22). It appears that the poor age-0 cohort from 2002 may be reflected in the comparatively lower fall 2003 abundance of HBC ≥150 mm (Figures 22). Figure 24 partially hints at this as low spot in the numbers of HBC captured in the roughly 110-170 mm size category during fall 2003. Finally, the 2003 age-0 cohort can be seen entering the 150+ mm size category in fall of 2004 (Figure 24) and the higher fall 2004 abundance estimate for HBC ≥ 150 mm appears to verify this (Figure 22).

To generate the fall 2004 estimate of 796 (SE = 184) HBC ≥ 200 mm, the length stratified Chapman-Petersen estimate for fish > 200 mm was corrected to include fish ≥ 200 mm. This procedure was performed because it was preferable to truncating the data at 200 mm and obtaining an independent length stratified estimate (Seber 1982). It should be mentioned that for an additional exercise, the data were truncated and a length stratified estimate was obtained that was similar (although higher by 55 fish and containing only 3 recaptures within one of the strata). It should be made clear that the low fall estimates for HBC ≥ 200 mm obtained over the past four years (Table 16) are expected to be lower than the spring estimates (Table 9), since a portion of HBC migrate out of the LCR after the spring spawning event (Gorman and Stone 1999). Nevertheless, both the fall and spring abundance estimates do provide trend data indicating that the numbers of these larger fish are low.

No estimate was provided this year for the abundance of HBC between 100 to 149 mm. This is because PIT tagging of HBC <150 mm was discontinued in 2004 because of concerns about mortality and potential tag loss in this size class of small fish. This estimate was also not possible to make in fall 2003 because only one fish was recaptured out of only 26 marked (Van Haverbeke 2004). This complication in fall 2003 (i.e., lack of captures and failure to achieve an abundance estimate for this size class of fish) may have been largely caused by the poor 2002 age-0 cohort, as Figure 24 clearly shows a lack of fish in the 100-150 mm size category during fall 2003. In fall 2002, a length stratified Chapman Petersen estimate of 2,033 fish (SE = 284) was given for the fall abundance of HBC from 100 to 149 mm (Van Haverbeke 2003). This success in obtaining an abundance estimate in fall 2002 may have been a result of the large 2001 age-0 cohort (i.e., sufficient fish were available for marking and recapture in this size category during fall 2002; Figure 24).

CONCLUSIONS

Evidence has been presented for the past four years that the LCR population of HBC appears to have undergone a decline since the early 1990s. This is most apparent in the spring abundance estimates. All four spring point abundance estimates for HBC ≥ 150 mm from the years 2001 through 2004 have been less than those provided by Douglas and Marsh (1996) during spring 1992 (although not all have been significantly less).

Contrary to the spring abundance trends, the abundance estimates obtained during the fall since 2000 for HBC ≥ 150 have not shown a decline compared to estimates in the 1990s. The spring abundance estimates are presumably more inclusive of the portion of the population that migrates between the mainstem Colorado River and the LCR for spawning activities, whereas the fall abundance estimates are presumably more representative of fish that reside year round (or over-winter) in the LCR. Because of this, it could be hypothesized that the decline in HBC abundance since the early 1990s may be in the portion of fish that migrate for spawning activities, and that this decline is being manifested in the observed declines in the spring spawning abundance in the LCR. It might also be hypothesized that an abundance of roughly 1,000 to 3,000 HBC ≥ 150 mm may be representative of the year round carrying capacity for HBC in the LCR (see Figure 22). Finally, the fall abundance of HBC ≥ 200 mm since 2001 has remained low (i.e., < 1000 fish), providing evidence that the numbers of these fish residing year round in the LCR is low, and that carrying capacity in the LCR alone for these larger fish may be lower than is desired for recovery purposes. If, as Douglas and Marsh (1996) hypothesized may be occurring, HBC are undergoing an alteration of life history and becoming more of a resident LCR population (with an attendant decline in the migrating portion of the population), then strategies to ensure the survivorship of annual cohorts and for providing carrying capacity in the mainstem may become increasingly more important for maintaining this dwindling population, particularly since single cohort survivorship appears to already have the capacity to visibly influence the abundance of fish ≥ 150 mm.

RECOMMENDATIONS

Since our results for the past four years have important implications concerning the conservation and recovery of HBC, it is recommended that GCMRC continue to pursue options that may enhance native fish populations in Grand Canyon. Primary among these are the reasonable and prudent measures listed in the Final Biological Opinion for the Operation of Glen Canyon Dam (USFWS 1994, USBR 1995).

Second, obtaining annual point abundance estimates for HBC via-closed mark-recapture methodologies is useful and should be continued. However, factors governing population dynamics of trend and abundance are more complex. The use of an open model (e.g., ASMR), which makes use of more extensive data collected over a longer period of time, and provides estimates of recruitment, mortality rates, and abundance trend is preferred (Kitchell et al. 2003) and may resolve more difficult questions. In other words, it would be more statistically efficient and robust to incorporate the base data from our annual LCR efforts into open population models for estimating the true trend and abundance of HBC in Grand Canyon (Kitchell et al. 2003).

As an alternative to this approach, it has been advocated by the Upper Colorado River Endangered Fish Recovery Program to sample concurrently in the mainstem and in the LCR in order to obtain an overall closed abundance estimate for the LCR population. The issues with this approach have been spelled out in detail by a panel of mark-recapture experts (Kitchell et al. 2003). Essentially, it is considered more efficient, more precise, and more representative of abundance and trend to utilize a multi-year open model approach (e.g., ASMR) rather than a closed model approach. Second, in order to run a concurrent estimate, intensive trammel netting in the mainstem will be required. This raises concerns about undue stress and mortality upon the adult fish residing in the mainstem. Entanglement gear, such as trammel nets, is known to be more stressful than entrapment gear, such as hoop nets (Hopkins and Cech 1992). Third, a switch towards a concurrent sampling methodology is expected to be costly, and is viewed by some as not making use of the best available scientific information (USGS 2004). For all of the above reasons, it is suggested that GCMRC continue its current strategy of obtaining closed population estimates in the LCR, and incorporating these data into open models.

Third, it is recommended that sampling activities are continued in the LCR during spring months. At this time, it is unknown what the discrepancies in ratios of ripe males to females may imply biologically. In addition, data collected in spring are preferred for current ASMR modeling efforts because the large number of fish captured improves the accuracy and precision of many aspects of the model (Kitchell et al. 2003).

DATA ARCHIVING

The data for the two spring trips were delivered to GCMRC in six MS Access files entitled:
LCR_2004_April_Boulders.mdb, LCR_2004_April_Coyote.mdb, LCR_2004_April_Salt.mdb, LCR_2004_May_Boulders.mdb, LCR_2004_May_October_Coyote.mdb, and LCR_2004_May_Salt.mdb.

The data for the two fall trips was delivered to GCMRC in six MS Access files entitled:
LCR_2004_September_Boulders.mdb, LCR_2004_September_Coyote.mdb, LCR_2004_September_Salt.mdb, LCR_2004_Boulders.mdb, LCR_2004_October_Coyote.mdb, and LCR_2004_October_Salt.mdb.

LITERATURE CITED

Bernard, D.R. and P.A. Hansen. 1992. Mark-recapture experiments to estimate the abundance of fish. Alaska Department of Fish and Game, Special Publication No. 92-4. Anchorage, Alaska.

Clarkson, R.W. and M.R. Childs. 2000. Temperature effects of hypolimnial-release dams on early life stages of Colorado River Basin big-river fishes. Copeia 2000(2): 402-412.

Coggins, L.G. Jr. and D.R. Van Haverbeke. 2001. Fisheries Monitoring Activities in the Little Colorado River within Grand Canyon During 2000. Final Report submitted to the Grand Canyon Monitoring and Research Center. U.S. Fish and Wildlife Service, Arizona Fishery Resources Office, Flagstaff. Document Number: USFWS-AZFRO-FL-01-007. 87 pp.

Coggins, L.G., Jr., W.E. Pine, III, C.J. Walters, D.R. Van Haverbeke, D. Ward, and H. Johnstone. *In prep*. Abundance Trneds and Status of the Little Colorado River Population of Humpback Chub, *Gila cypha*.

Douglas, M.E. and P.C. Marsh. 1996. Population estimates/population movements of *Gila cypha*, an endangered Cyprinid fish in the Grand Canyon region of Arizona. Copeia 1996(1): 15-28.

Gorman, O.T. and D.M. Stone. 1999. Ecology of spawning humpback chub (*Gila cypha*), in the Little Colorado River near Grand Canyon, Arizona. Environmental Biology of Fishes 55: 115-133.

Hopkins,T.E. and J.J. Cech, Jr. 1992. Physiological Effects of Capturing Striped Bass in Gill Nets and Fyke Nets. Trans. Am. Fish. Soc. 121:819-822.

Kaeding L.R. and M.A. Zimmerman. 1983. Life history and ecology of the humpback chub in the Little Colorado and Colorado Rivers of the Grand Canyon. Transactions of the American Fisheries Society 112:577-594.

Kitchell, J.F., C. Grimes, S.T. Lindley, D. Otis, C. Schwartz. 2003. Report to the Adaptive Management Work Group, Glen Canyon Dam Management Program: An Independent Review of Ongoing and Proposed Scientific Methods to Assess the Status and Trends of the Grand Canyon Population of the Humpback Chub (Gila cypha). 16 pp.

Lande, R. and G.F. Barrowclough. 1987. Effective population size: genetic variation, and their use in population management. pp. 87--123. *In*: M.E. Soulé (ed.) Viable Populations for Conservation, Cambridge University Press, Cambridge, UK.

Robinson, A.T. and M.R. Childs. 2001. Juvenile growth of native fishes in the Little Colorado River and in a thermally modified portion of the Colorado River. North American Journal of Fisheries Management 21:809-815.

Robinson, A.T., R.W. Clarkson and R. E. Forrest. 1998. Dispersal of larval fishes in a regulated river tributary. Transactions of the American Fisheries Society 127:772-786.

Seber, G.A.F. 1982. The Estimation of Animal Abundance, 2nd edition. Griffin, London. 654 pp.

Soulé, M.E. 1980. Thresholds for survival: maintaining fitness and evolutionary potential. pp. 151--169. *In*: M.E. Soulé & B.A. Wilcox (eds.) Conservation Biology: An evolutionary-ecological approach, Sinauer Associates, Sunderland, Massachusetts.

Stone, D. and P. Sponholtz. 2003. Translocation of Young-of-the-year Humpback Chub above Chute Falls in the Little Colorado River, AZ: Interim Report. USFWS Document Number USFWS-AZFRO-FL-04-006. 20 pp.

USGS [US Geological Survey]. 2004. Humpback chub concurrent population estimates. Memo from Jeffrey Lovich, USGS Southwest Biological Center Grand Canyon Monitoring and Research to Michael Gabaldon, Glen Canyon Adaptive Management Program. May 17 2004. 2 pp.

USBR [U.S. Bureau of Reclamation]. 1995. Operation of Glen Canyon Dam: Final Environmental Impact Statement. U.S. Bureau of Reclamation. 337 pp. plus attachments.

USFWS [U.S. Fish and Wildlife Service]. 2002. Humpback Chub (*Gila cypha*) Recovery Goals: Amendment and Supplementation to the Humpback Chub Recovery Plan. Denver, CO: U.S. Fish and Wildlife Service Mountain-Prairie Region 6.

USFWS. 1994. Final Biological Opinion: Operation of Glen Canyon Dam as the modified low fluctuating flow alternative of the final environmental impact statement operation of Glen Canyon Dam. Ecological Services Arizona State Office, Phoenix. 56 pp.

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 Bureau of Reclamation, Salt Lake City, Utah. Contract No. 0-CS-40-09110. BIO/WEST Report No. TR-250-08. 286 pp.

Van Haverbeke, D.R. 2004. Stock Assessment and Fisheries Monitoring Activities in the Little Colorado River within Grand Canyon during 2003. Final Report submitted to the Grand Canyon Monitoring and Research Center. U.S. Fish and Wildlife Service, Flagstaff. Document Number: USFWS-AZFRO-FL-04-007. 74 pp.

Van Haverbeke, D.R. 2003. Stock Assessment and Fisheries Monitoring Activities in the Little Colorado River within Grand Canyon during 2002. Final Report submitted to the Grand Canyon Monitoring and Research

Center. U.S. Fish and Wildlife Service, Flagstaff. Document Number: USFWS-AZFRO-FL-04-002. 87 pp.

Van Haverbeke, D.R. and L.G. Coggins, Jr. 2002. Stock assessment and fisheries monitoring activities in the Little Colorado River within Grand Canyon during 2001. Draft final report submitted to the Grand Canyon Monitoring and Research Center. U.S. Fish and Wildlife Service, Flagstaff. Document # USFWS-AZFRO-FL-03-002.

Table 1. Personnel who participated on trips, listed by agency and trip. [S] = Salt Reach, [C] = Coyote Reach, and [B] = Boulders Reach. Little Colorado River 2004.

	USFWS	AGFD	SWCA	Volunteer
29 March - 9 April	Dennis Stone [S] Pamela Sponholtz [C] Josh David [C] Dewey Wesley [B] David Van Haverbeke [B]	Mike Figueroa [S]	Matt Laurretta [S]	Aaron Scrignar [C] Jim Walters [B]
26 April - 7 May	Dennis Stone [S] Josh David [S] Pam Sponholtz [C] Clay Ware [C] Dewey Wesley [B] David Van Haverbeke [B]		Suzanne Roades [C]	William Pine [S]
20 - 28 September	Dennis Stone [S] Josh David [C] Dewey Wesley [B] Cliff Tipton [B]			Christina Richards [S] Carla Beals [S] David O'Brien [C] Heather Keith [C] Andi Motney [B]
19 - 28 October	Dennis Stone [S] David Van Haverbeke [B] Josh David [C] Dewey Wesley [B]			Jeff Lantow [S] Melanie Caron [S] Erin Rechisky [C] Lisa Andersen [C] Stefan Pociask [C] Kelly Sheehan [B] Mike Melnychuk [B]

Table 2. Habitat characteristics for hoop nets set in Little Colorado River, 2004.

Shoreline habitat	Hydraulic Unit	Substrate	Cover type
cutbank	backwater	clay-silt-marle (< 0.06 mm)	boulders
debris fan boulders	eddy (counter current)	silt-sand (0.07-0.10 mm)	legde, or lateral cover
ledge	glide	sand (0.11-2.0 mm)	none
sand bar	pool (still)	gravel (2.1-15 mm)	undetermined
silt	rapid	pebble (16-31 mm)	vegetative cover
talus	return channel	rock (32-100 mm)	
traverntine dam	riffle	cobble (101-255 mm)	
vegetated shoreline	run	small boulder (256-999 mm)	
		boulder (1-3 m)	
		large boulder (> 3 m)	
		bedrock	

Table 3. Summary of fishing effort by trip, reach, number of hoop net sets, hours of effort, humpback chub (HBC) catch, and HBC catch per unit effort (CPUE; fish/net-hr); Little Colorado River, spring 2004.

		Effort		HBC	HBC
Trip	Reach	Sets	Hours	Catch	CPUE
April					
	Salt	180	4,304	469	0.109
	Coyote	181	4,129	242	0.059
	Boulders	180	4,249	544	0.128
	Total	541	12,682	1,255	0.099
May					
	Salt	184	4,384	1084	0.247
	Coyote	180	4,100	557	0.136
	Boulders	180	4,052	975	0.241
	Total	544	12,536	2,616	0.209
Grand Total		1,085	25,218	3,871	0.154

Table 4. Summary of fish captured by trip, reach, gear type, and species; Little Colorado River, spring 2004.

		Species*												
Trip	Reach	BBH	BHS	CCF	CRP	FHM	FMS	GSF	HBC	PKF	RBT	RSH	SPD	Total
April	Salt	9	13	1	6	48	2		469	1	2		35	586
	Coyote	4	21	1	1	43	7		242	1		11	16	347
	Boulders	3	64	5	1	50	79		544			10	137	893
	Total	16	98	7	8	141	88		1,255	2	2	21	188	1,826
May	Salt	12	185	1	1	220	15	1	1,084	22	1	41	156	1,739
	Coyote	4	138	2	1	51	28		557	16		18	92	907
	Boulders	2	158	3	3	33	123		975	6		19	1,046	2,368
	Total	18	481	6	5	304	166	1	2,616	44	1	78	1,294	5,014
Grand Total		34	579	13	13	445	254	1	3,871	46	3	99	1,482	6,840

* BBH = black bullhead (*Ameiurus melas*); BHS = bluehead sucker (*Catostomus discobolus*); CCF = channel catfish (*Ictalurus punctatus*); CRP = common carp (*Cyprinus carpio*); FHM = fathead minnow (*Pimephales promelas*); FMS = flannelmouth sucker (*Catostomus latipinnis*); GSF = green sunfish (*Lepomis cyanellus*); HBC = humpback chub (*Gila cypha*); PKF = plains killifish (*Fundulus zebrinus*); RBT = rainbow trout (*Oncorhynchus mykiss*); RSH = red shiner (*Cyprinella lutrensis*); SPD = speckled dace (*Rhinichthys osculus*).

Table 5. Number of humpback chub marked and unmarked during the recapture event by total length strata; Little Colorado River, spring 2004.

Length strata	Unmarked	Marked	Mark rate
150-199	104	19	15.45%
200-249	107	20	15.75%
250-299	31	6	16.22%
300-349	15	0	0.00%
350-399	34	2	5.56%
400-449	14	0	0.00%
Totals	305	47	13.35%

Ho: Mark rate among length strata is the same.

Accept null hypothesis (χ^2 = 7.72, df = 5, p = 0.172)

Table 6. Number of humpback chub marked and unmarked during the recapture event by reach; Little Colorado River, spring 2004.

Reach	Unmarked	Marked	Mark rate
Salt	143	25	14.88%
Coyote	73	7	8.75%
Boulder	89	15	14.42%
Total	305	47	13.35%

Ho: Mark rate among the reaches is the same.

Accept null hypothesis (χ^2 = 2.53, df = 2, p = 0.28)

Table 7. Length stratified Chapman Petersen abundance estimate for humpback chub ≥ 150 mm in the Little Colorado River, spring 2004.

						95% Confidence Interval	
Length (mm)	Marked	Captured	Recaptured	N	SE	Lower	Upper
150 to 250	156	250	39	984	122	745	1,223
>250	117	102	8	1,349	392	581	2,118
Sum strata				2,334	411	1,529	3,138

Table 8. Population estimates for humpback chub ≥ 150 mm by year and month; Little Colorado River.

			95 % Confidence Interval			
Date	N	SE	Lower	Upper	Reach (rkm)	# per km
Apr-92	5,555	671	4,416	7,067	0 - 13.6	408
May-92	4,363	1,216	2,594	7,523	0 - 13.6	321
Jun-92	4,384	458	3,573	5,381	0 - 13.6	322
May-01	2,082	242	1,607	2,557	0 - 13.6	153
April/May 2002	2,666	463	1,759	3,573	0 - 13.6	196
April/May 2003	3,419	480	2,478	4,360	0 - 13.6	251
April/May 2004	2,334	411	1,529	3,138	0 - 13.6	172

1992 estimates are from Douglas and Marsh (1996), 2001 estimate is from Van Haverbeke and Coggins (2002), 2002 estimate is from Van Haverbeke (2003); 2003 estimate is from Van Haverbeke (2004).

Table 9. Population estimates for humpback chub ≥ 200 mm by year and month; Little Colorado River.

Date	Abundance Estimate	SE	95 % Confidence Interval Lower	95 % Confidence Interval Upper	Reach (rkm)	# per km
May-01	1,470	240	1,000	1,940	0 - 13.6	108
April/May 2002	2,002	463	1,095	2,909	0 - 13.6	147
April/May 2003	1,421	209	1,011	1,831	0 - 13.6	104
April/May 2004	1,816	397	1,038	2,594	0 - 13.6	134

2001 estimate is from Van Haverbeke and Coggins (2002), 2002 estimate is from Van Haverbeke (2003), 2003 estimate is from Van Haverbeke (2004).

Table 10. Summary of fishing effort by trip, reach, number of hoop net sets, hours of effort, humpback chub (HBC) catch, and HBC catch per unit effort (CPUE; fish/net-hr); Little Colorado River, fall 2004.

		Effort		HBC	HBC
Trip	Reach	Sets	Hours	Catch	CPUE
September					
	Salt	180	4,274	105	0.025
	Coyote	180	4,221	199	0.047
	Boulders	180	4,100	155	0.038
	Total	540	12,595	459	0.036
October					
	Salt	180	4,372	741	0.169
	Coyote	180	4,139	556	0.134
	Boulders	180	4,291	1,025	0.239
	Total	540	12,801	2,322	0.181
Grand Total		1,080	25,396	2,781	0.110

Table 11. Summary of fish captured by trip, reach, gear type, and species; Little Colorado River, fall 2004.

		Species*												
Trip	Reach	BBH	BHS	CCF	CRP	FHM	FMS	GSF	HBC	PKF	RBT	RSH	SPD	Total
September														
	Salt	9		1	8	2	2		105				5	132
	Coyote	8	6	5	6	6			196	1			2	230
	Boulders		19	2	5	12	2		155	1		1	27	224
	Total	17	25	8	19	20	4	0	456	2	0	1	34	586
October														
	Salt	1	28		1	24			741	1			213	1,009
	Coyote	1	17	3		18	18		556				97	710
	Boulders	2	113			12	58		1,025		3	3	300	1,516
	Total	4	158	3	1	54	76	0	2,322	1	3	3	610	3,235
Grand Total		21	183	11	20	74	80	0	2,778	3	3	4	644	3,821

* BBH = black bullhead (*Ameiurus melas*); BHS = bluehead sucker (*Catostomus discobolus*); CCF = channel catfish (*Ictalurus punctatus*); CRP = common carp (*Cyprinus carpio*); FHM = fathead minnow (*Pimephales promelas*); FMS = flannelmouth sucker (*Catostomus latipinnis*); GSF = green sunfish (*Lepomis cyanellus);* HBC = humpback chub (*Gila cypha*); PKF = plains kiilifish (*Fundulus zebrinus*); RBT = rainbow trout (*Oncorhynchus mykiss*); RSH = red shiner (*Cyprinella lutrensis*); SPD = speckled dace (*Rhinichthys osculus*).

Table 12. Number of humpback chub marked and unmarked during the recapture event by total length strata; Little Colorado River, fall 2004.

Length strata	Unmarked	Marked	Mark rate
150-199	266	9	3.27%
200-249	81	10	10.99%
250-299	30	1	3.23%
300-349	6	1	14.29%
350-399	7	0	0.00%
400-449	5	0	0.00%
Totals	395	21	5.05%

Ho: Mark rates among length strata is the same.

Accept null hypothesis ($\chi^2 = 10.61$, df = 5, p = 0.060)

Table 13. Number of humpback chub marked and not marked during the recapture event by reach; Little Colorado River, fall 2004.

Reach	Unmarked	Marked	Mark rate
Salt	264	12	4.35%
Coyote	78	7	8.24%
Boulder	53	2	3.64%
Total	395	21	5.05%

Ho: Mark rates among length strata is the same.

Accept null hypothesis (χ^2 = 1.78, df = 2, p = 0.41)

Table 14. Length stratified Chapman Petersen abundance estimates of humpback chub ≥ 150 mm; Little Colorado River; fall 2004.

						95% Confidence Interval	
Length (mm)	Marked	Captured	Recaptured	N	SE	Lower	Upper
150 to 200	63	279	9	1,791	487	836	2,746
>200	72	137	12	774	179	424	1,124
Sum strata				2,565	519	1,548	3,582

Table 15. Abundance estimates of humpback chub ≥ 150 mm by year and month; Little Colorado River.

Date	Abundance Estimate	SE	95% Confidence Interval		Reach (rkm)	Size (mm)	# per km
			Lower	Upper			
Sep-91	1,771	300	1,296	2,492	0 - 13.6	>= 150 mm	130
October 1991	2,038	518	1,276	3,368	0 - 13.6	>= 150 mm	150
November 1991	1,989	489	1,264	3,235	0 - 13.6	>= 150 mm	146
Sep-92	1,950	1,381	598	6,908	0 - 13.6	>= 150 mm	143
October 1992	1,099	60	990	1,224	0 - 13.6	>= 150 mm	81
November 1992	1,417	408	839	2,500	0 - 13.6	>= 150 mm	104
October/November 2000	1,590	297	992	2,552	0 - 13.6	>= 135 mm	117
October/November 2001	1,064	33	999	1,129	0 - 13.6	>= 150 mm	78
October/November 2002	2,774	209	2,364	3,184	0 - 13.6	>= 150 mm	204
September/October 2003	1,862	206	1,459	2,265	0 - 13.6	>= 150 mm	137
September/October 2004	2,565	519	1,548	3,582	0 - 13.6	>= 150 mm	189

1991 and 1992 estimates are from Douglas and Marsh (1996); 2000 estimate is from Coggins and Van Haverbeke (2001); 2001 estimate is from Van Haverbeke and Coggins (2002); 2002 estimate is from Van Haverbeke (2003); 2003 estimate is from Van Haverbeke (2004).

Table 16. Abundance estimates of humpback chub ≥ 200 mm by year and month; Little Colorado River.

			95% Confidence Interval			
Date	Abundance Estimate	SE	Lower	Upper	Reach (rkm)	# per km
October/November 2001	483	48	389	577	0 - 13.6	36
October/November 2002	839	87	668	1,010	0 - 13.6	62
September/October 2003	897	105	691	1,103	0 - 13.6	66
September/October 2004	796	184	435	1,157	0 - 13.6	59

2001 estimate is from Van Haverbeke and Coggins (2002). 2002 estimate is from Van Haverbeke (2003), 2003 estimate is from Van Haverbeke (2004).

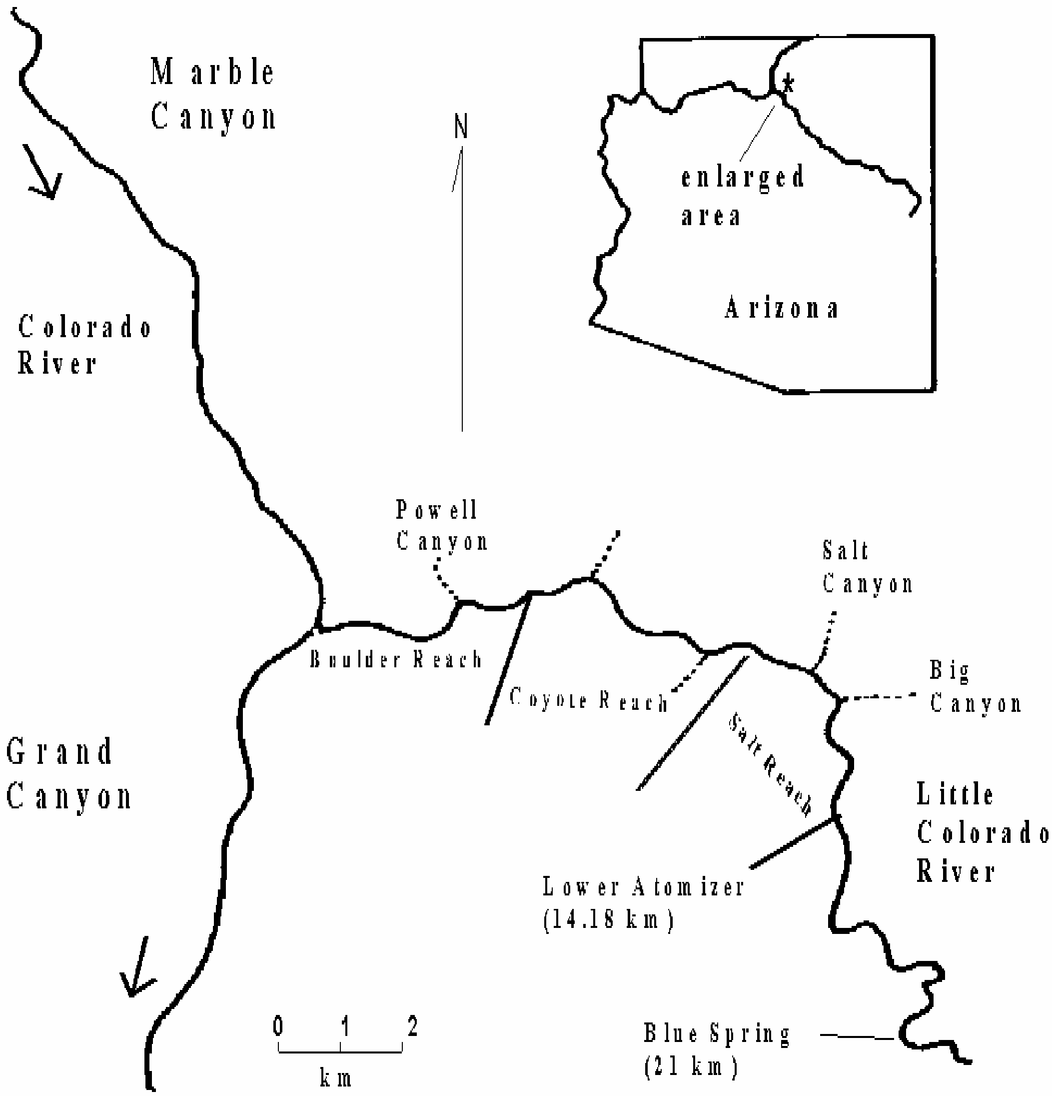


Figure 1. Map of the study site, showing Salt, Coyote and Boulders reaches in Little Colorado River.

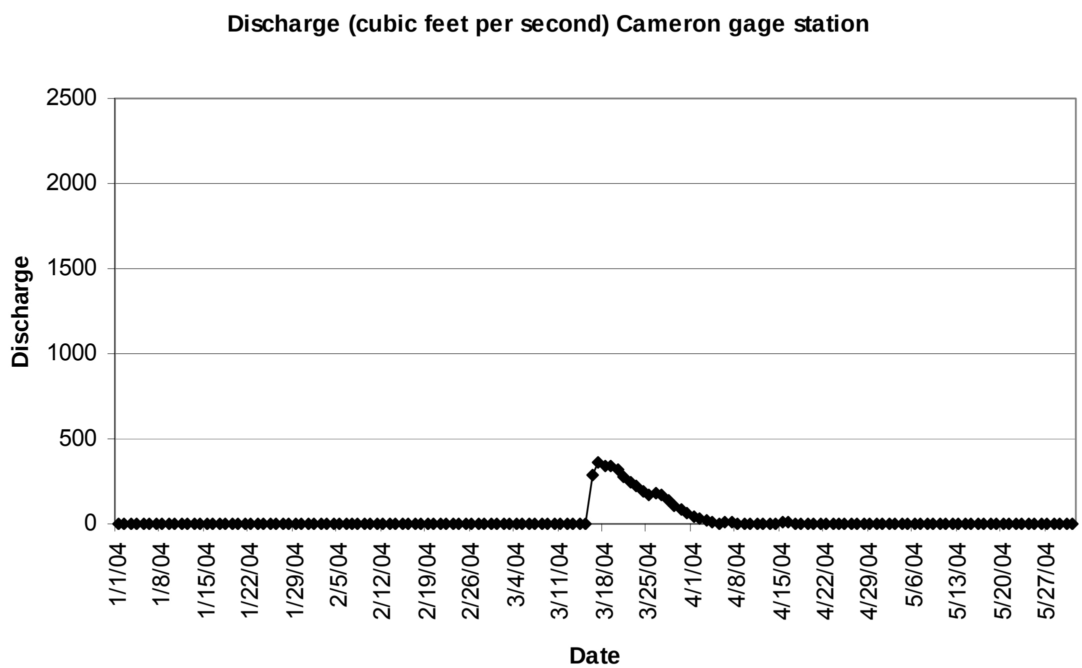


Figure 2. Provisional mean daily discharge (cubic feet/second) data from USGS gage station 0904200 located in Little Colorado River near Cameron, Arizona.

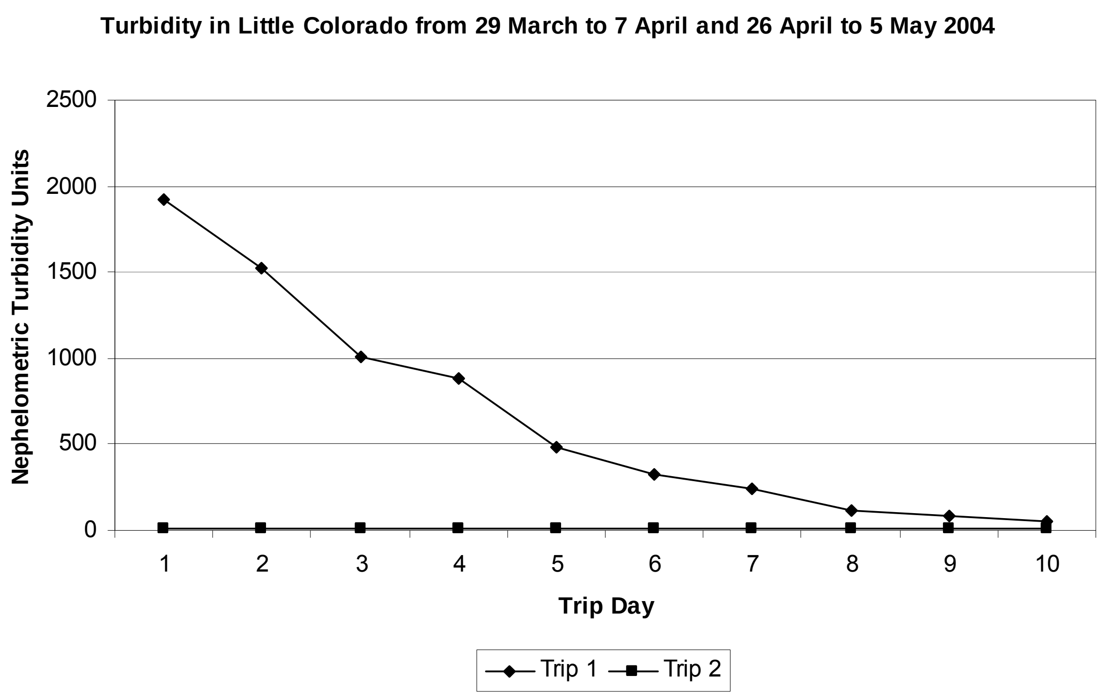


Figure 3. Turbidity readings taken in Little Colorado River during spring 2004.

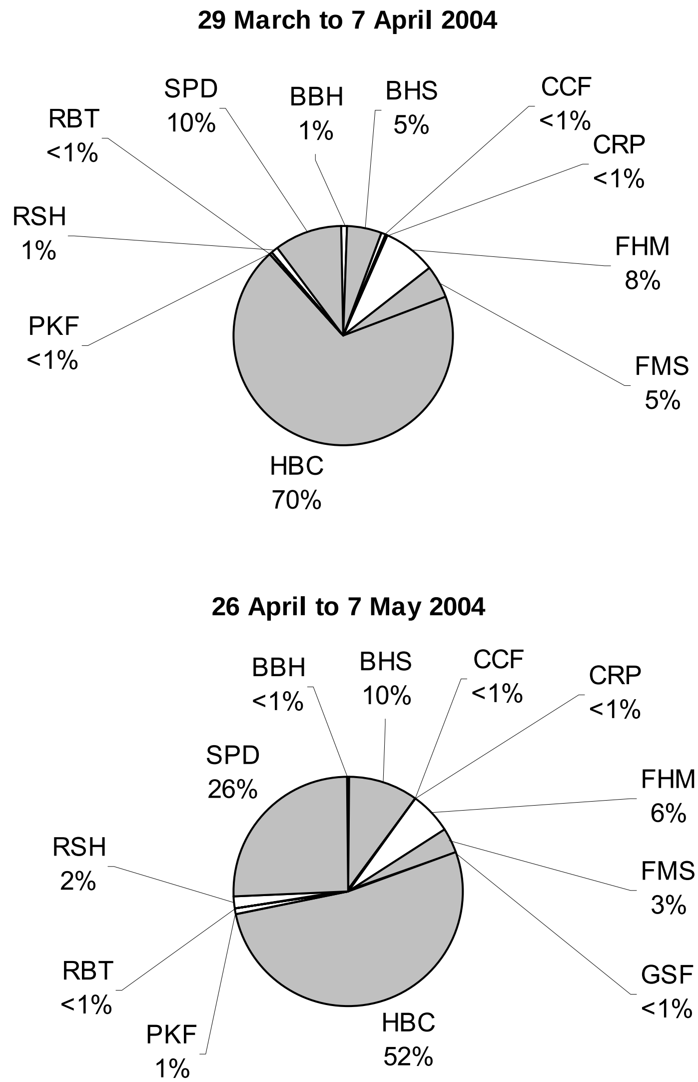


Figure 4. Observed species compositions of all fish captured. Shaded portions are native fish; Little Colorado River, spring 2004.

BBH = black bullhead (*Ameiurus melas*); BHS = bluehead sucker (*Catostomus discobolus*); CCF = channel catfish (*Ictalurus punctatus*); CRP = common carp (*Cyprinus carpio*); FHM = fathead minnow (*Pimephales promelas*); FMS = flannelmouth sucker (*Catostomus latipinnis*); GSF = green sunfish (*Lepomis cyanellus*), HBC = humpback chub (*Gila cypha*); PKF = plains killifish (*Fundulus zebrinus*); RBT = rainbow trout (*Onchorynchus mykiss*); RSH = red shiner (*Cyprinella lutrensis*); SPD = speckled dace (*Rhinichthys osculus*).

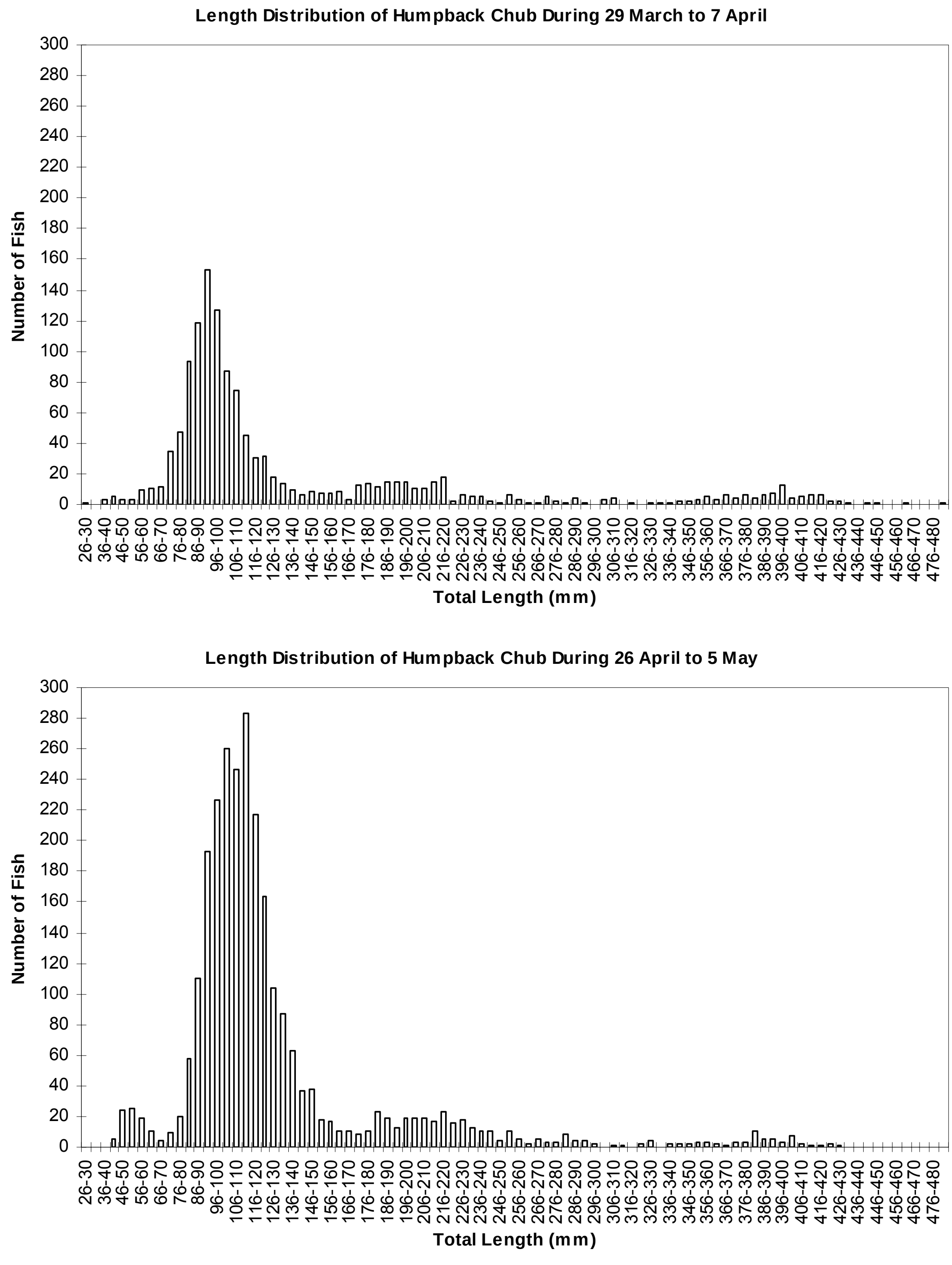
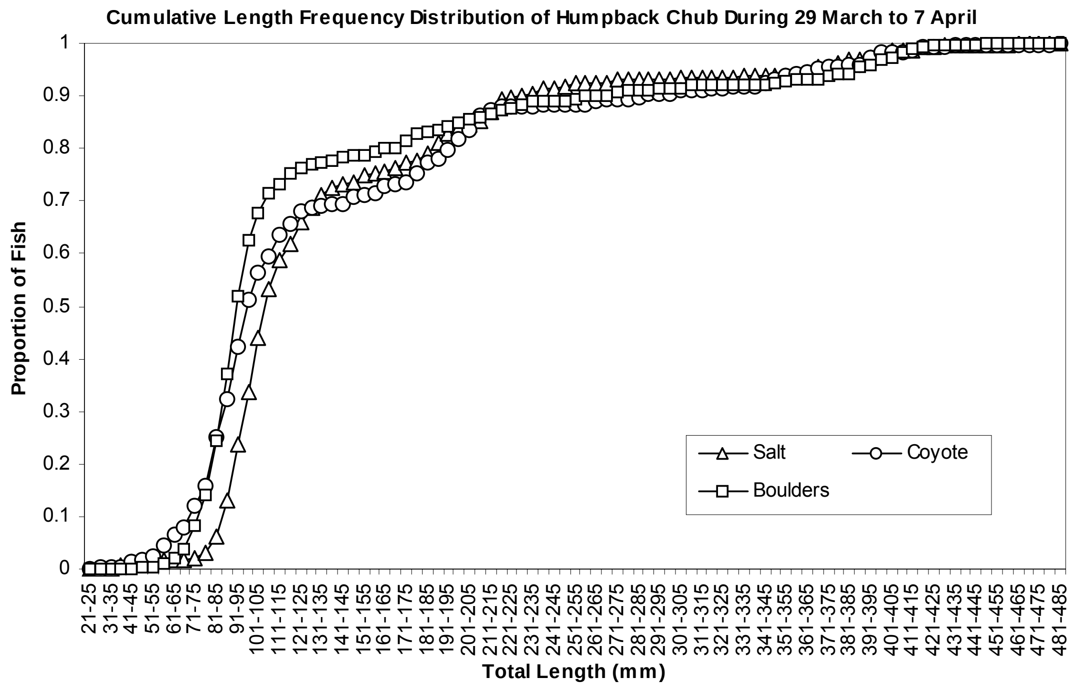


Figure 5. Total length frequency distributions of all humpback chub captured; Little Colorado River, spring 2004.



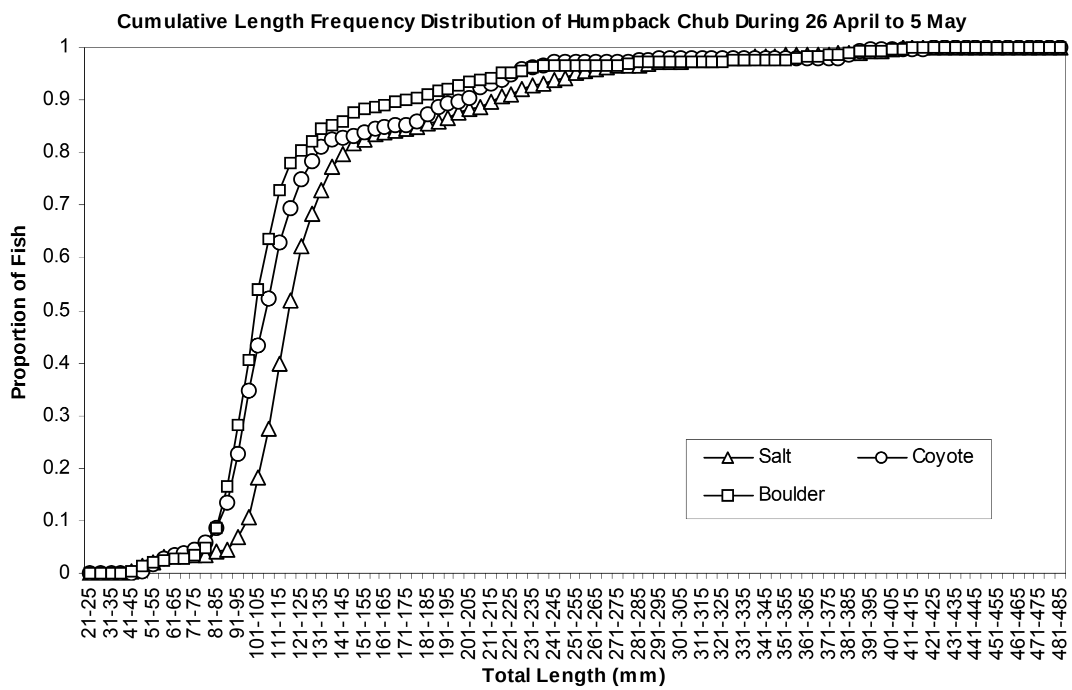
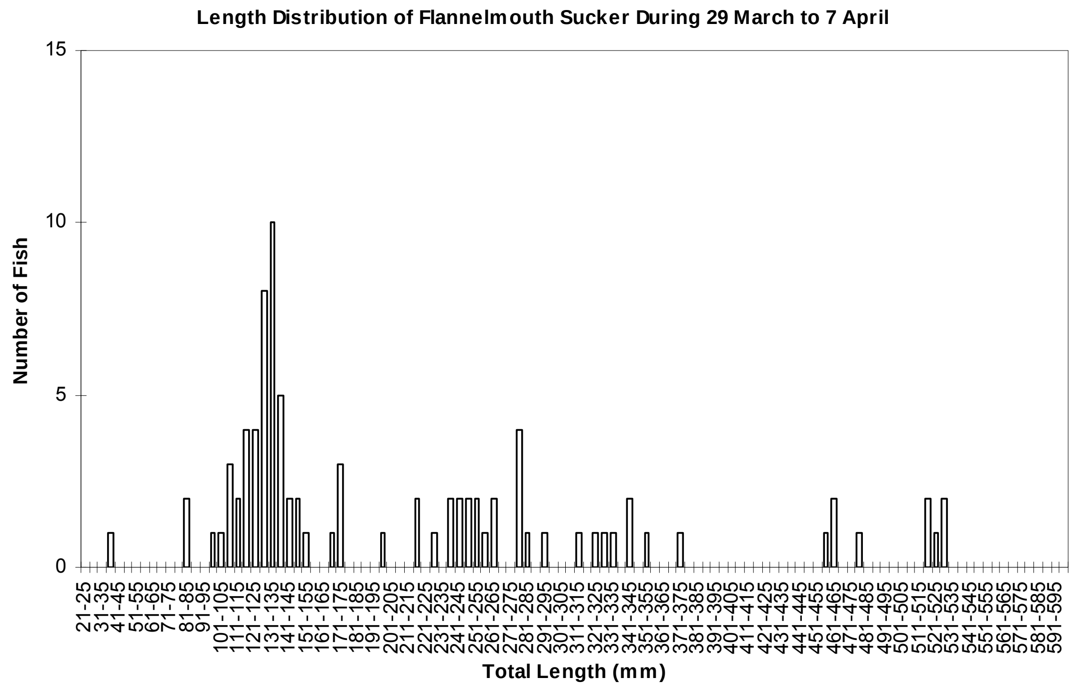


Figure 6. Cumulative length frequency charts of all HBC captured at three different reaches (Salt, Coyote and Boulders); Little Colorado River, spring 2004.



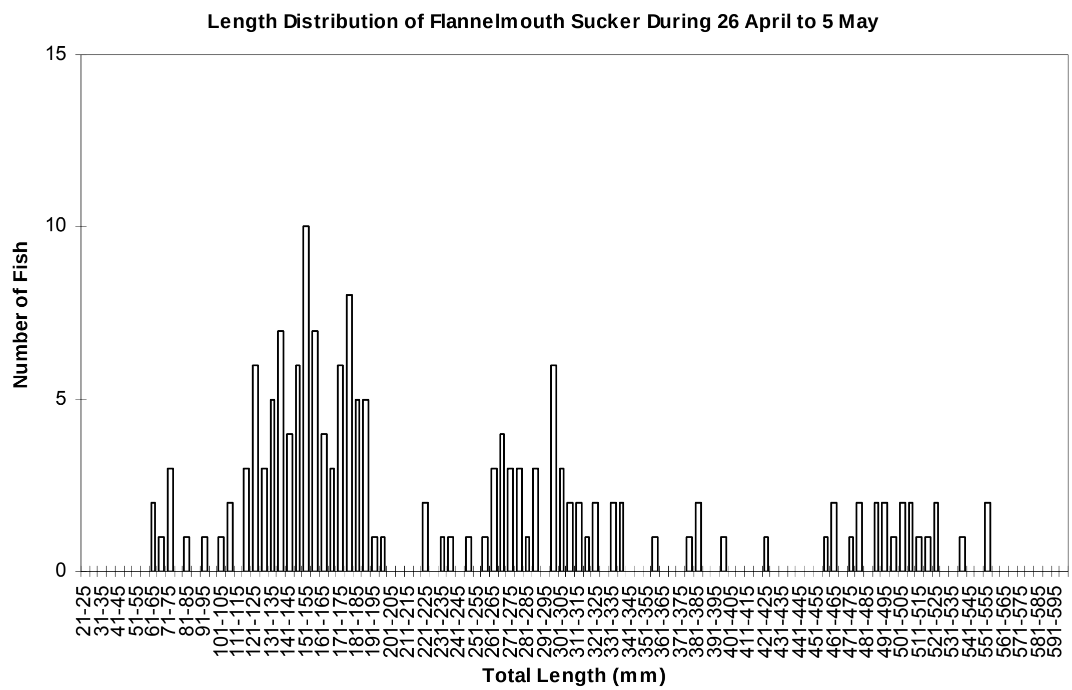
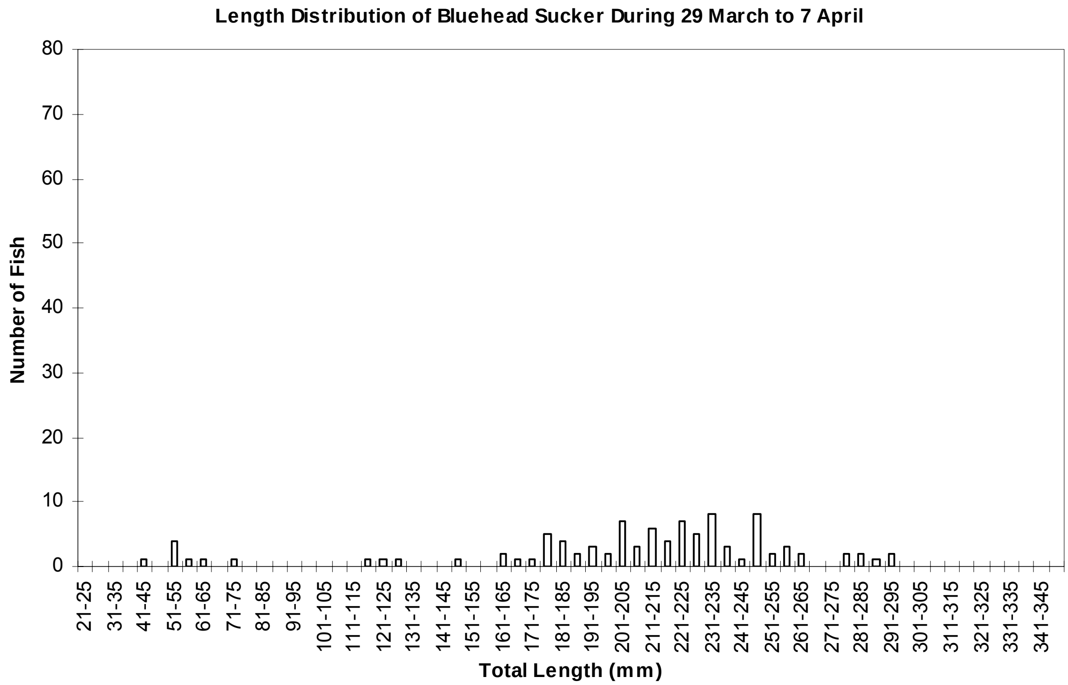


Figure 7 . Length frequency distribution of all flannelmouth sucker captured; Little Colorado River, spring 2004.



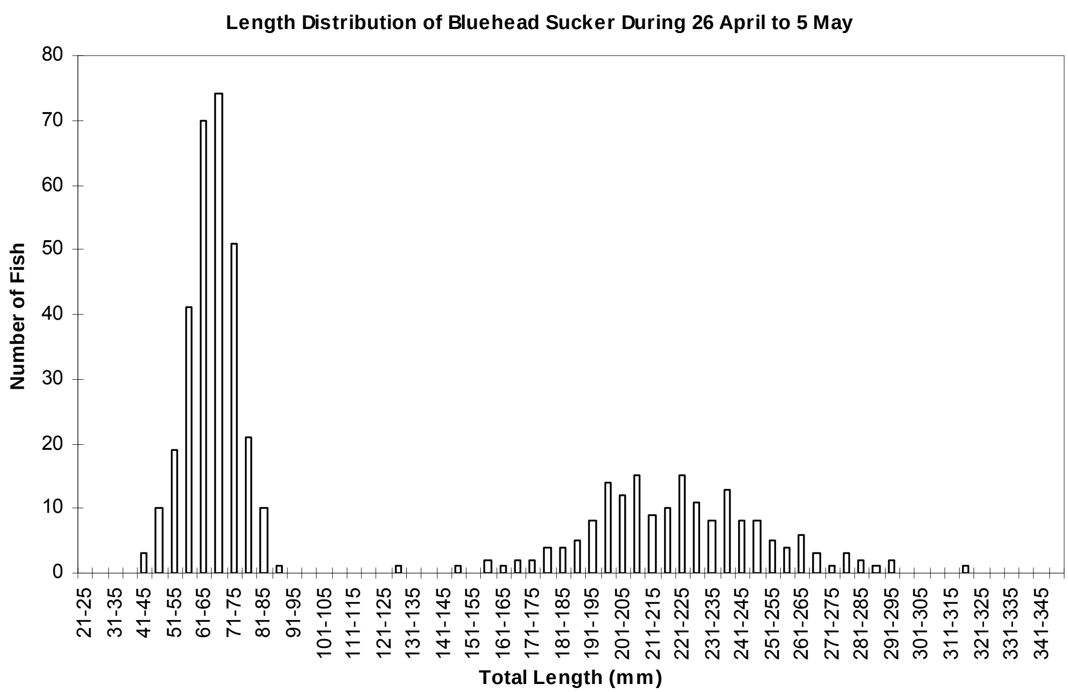
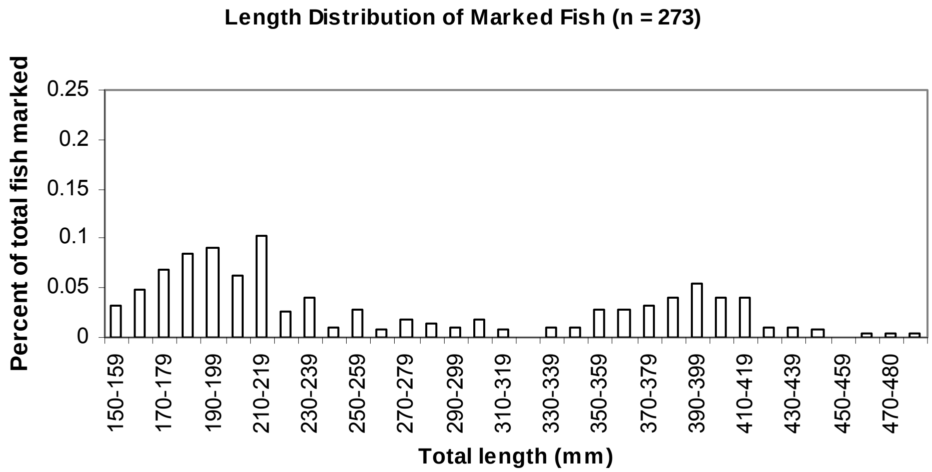
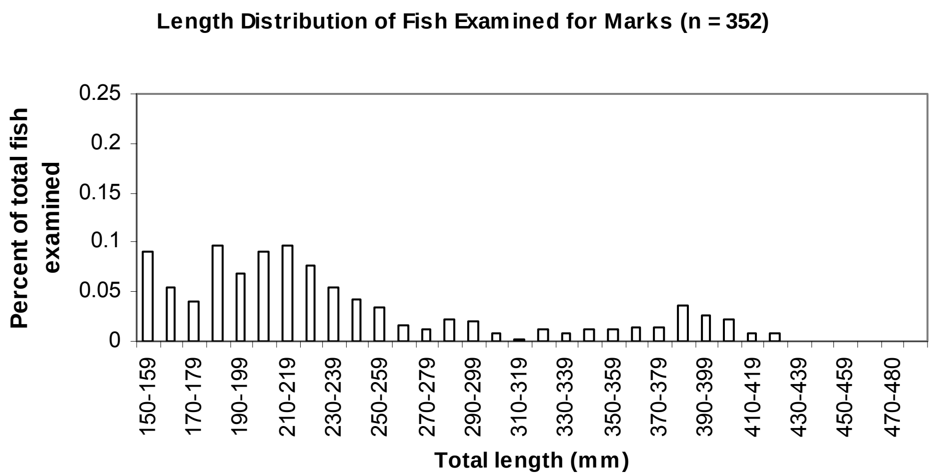


Figure 8. Length frequency distributions of all bluehead sucker captured; Little Colorado River, spring 2004.





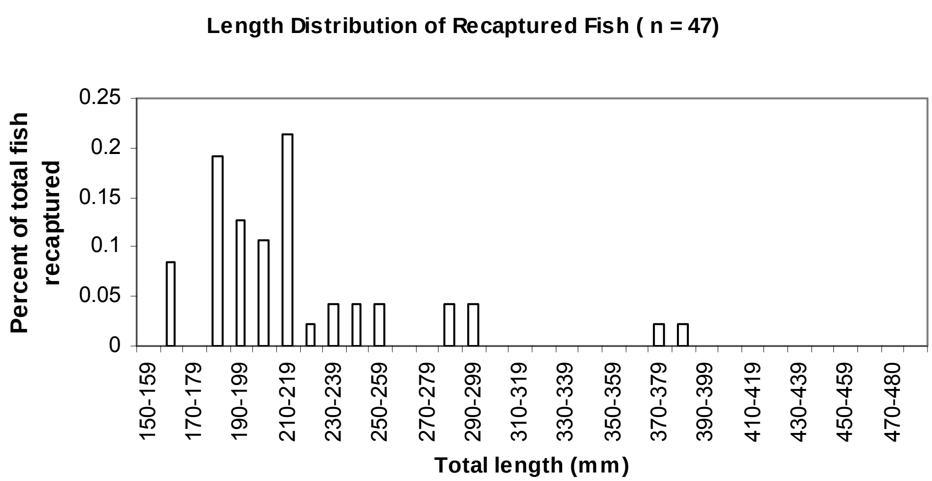
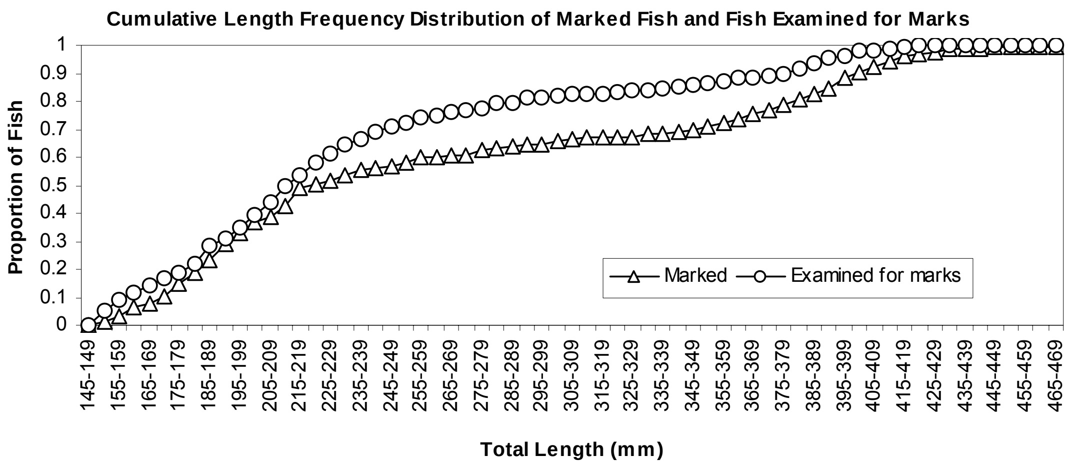


Figure 9. Length frequency distributions (shown as percentage of total) of all humpback chub ≥ 150 mm captured during the marking and recapture events; Little Colorado River, spring 2004.



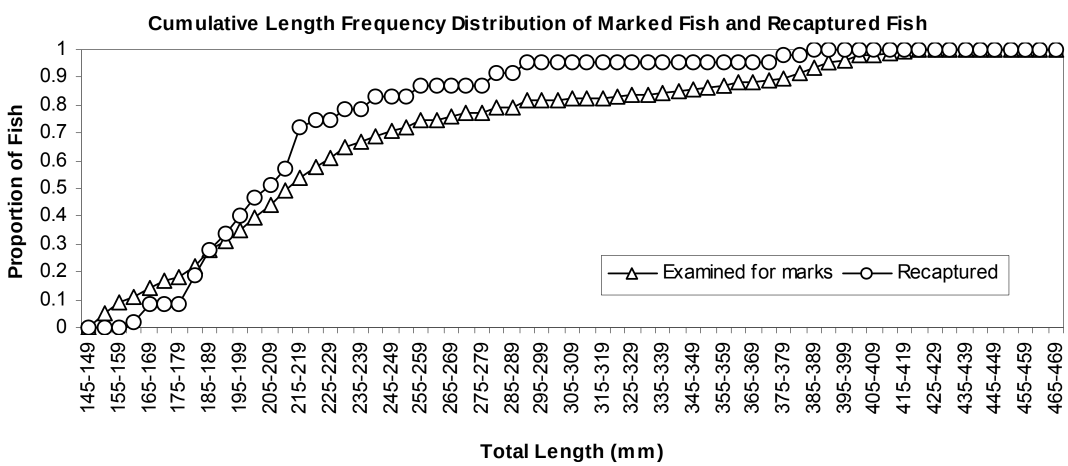


Figure 10. Cumulative length frequency distributions of humpback chub ≥ 150 mm captured; Little Colorado River, spring 2004.

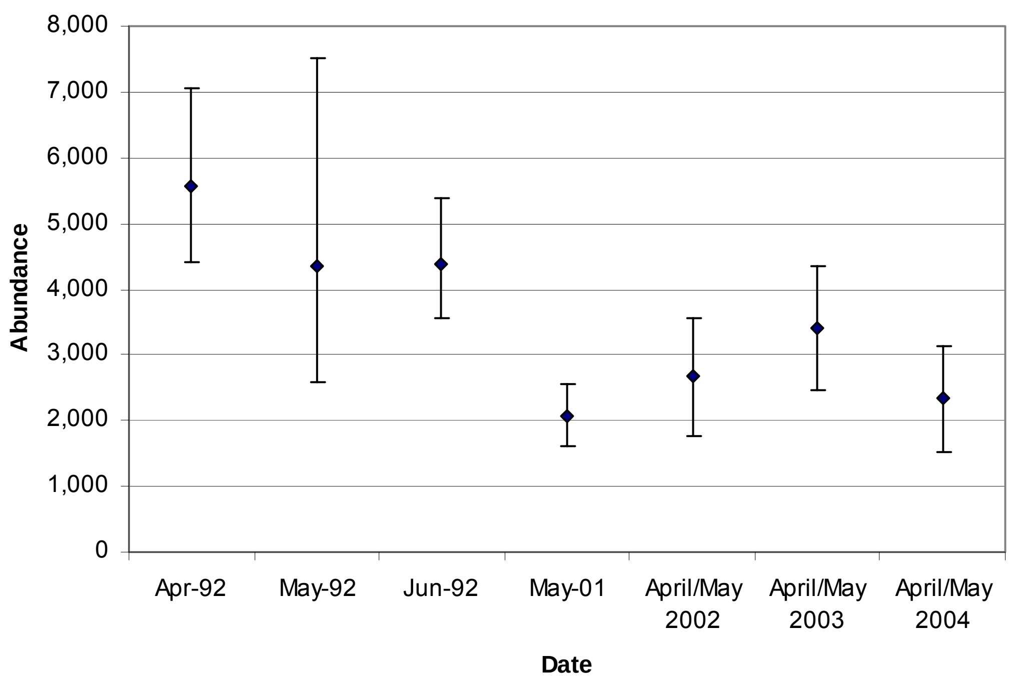


Figure 11. Spring abundance estimates of humpback chub ≥ 150 mm.

1992 estimates are from Douglas and Marsh (1996); 2001 estimate is from Van Haverbeke and Coggins (2002), 2002 estimate is from Van Haverbeke (2003), 2003 estimate is from Van Haverbeke (2004).

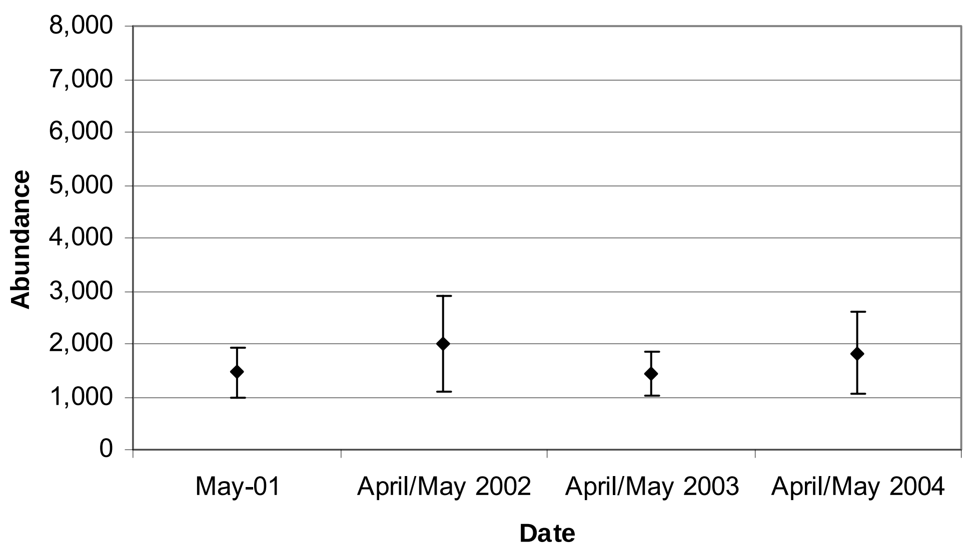


Figure 12. Spring abundance estimates of humpback chub ≥ 200 mm.

2001 estimate is from Van Haverbeke and Coggins (2002), 2002 estimate is from Van Haverbeke (2003), 2003 estimate is from Van Haverbeke (2004); Little Colorado River.

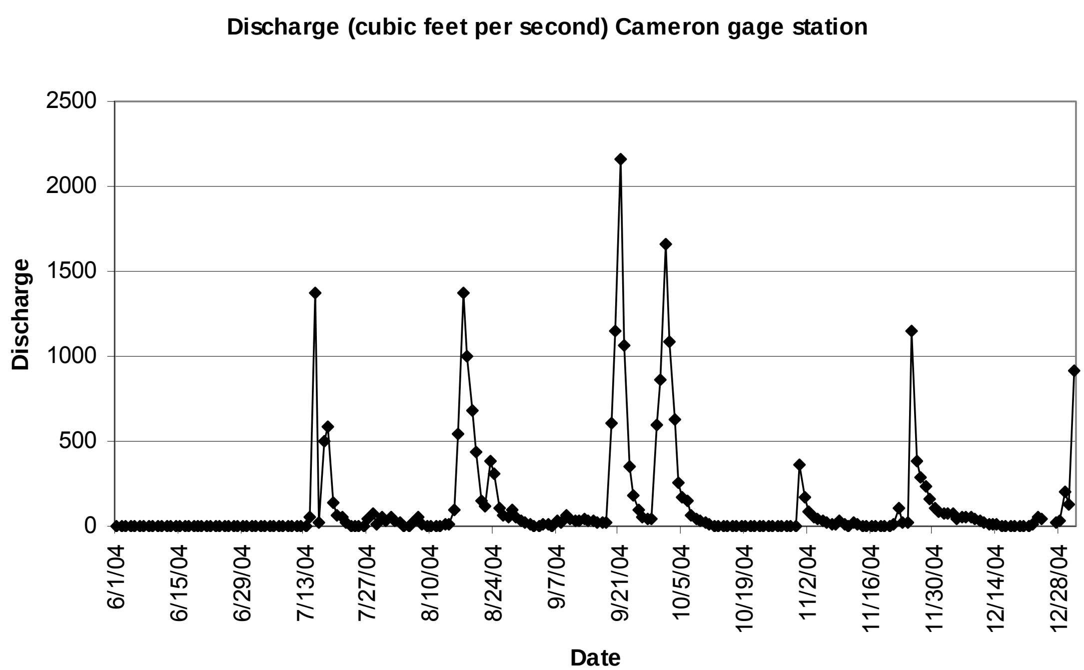


Figure 13. Provisional mean daily discharge (cubic feet/second; cfs) from USGS gage station 0904200 located in Little Colorado River near Cameron, Arizona.

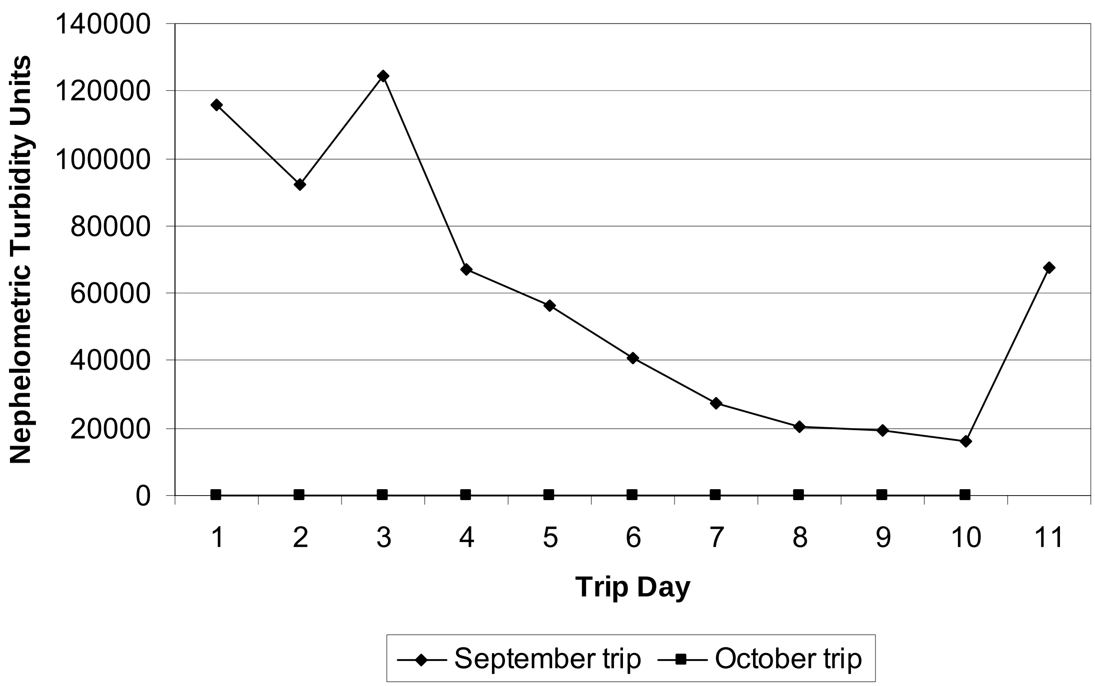


Figure 14. Turbidity readings taken during fall 2004; Little Colorado River.

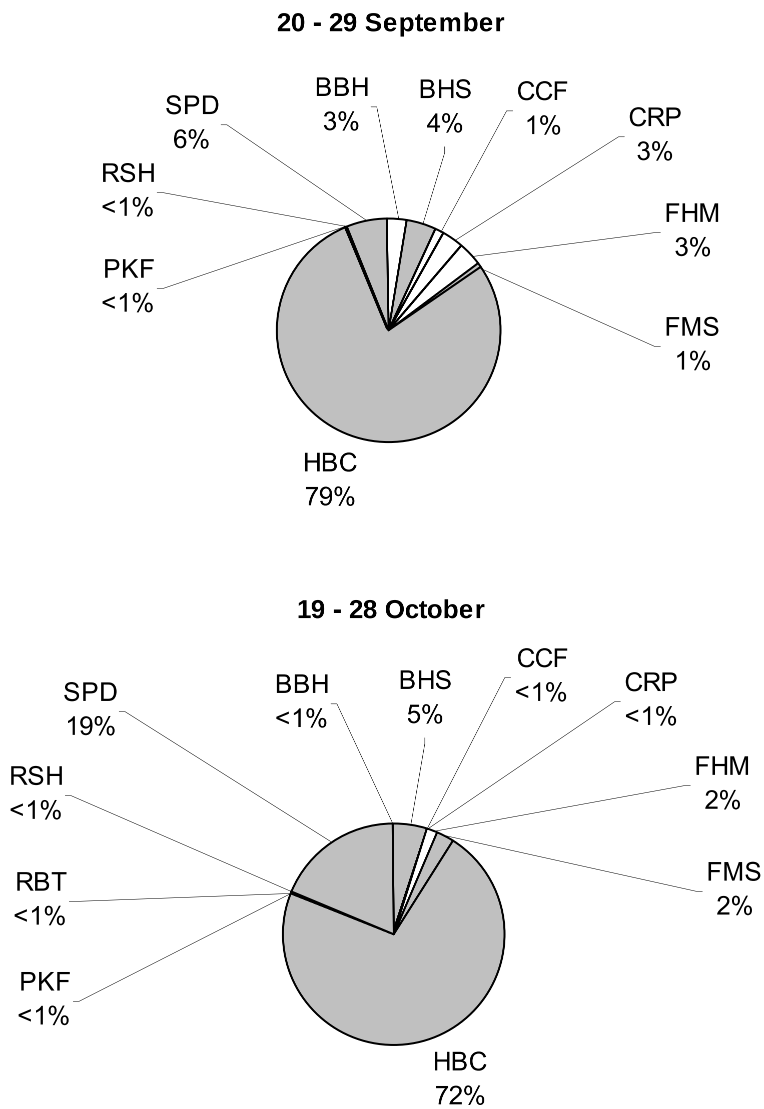


Figure 15. Observed species comparisons of fish captured. Shaded portions are native fish; Little Colorado River, fall 2004.

BBH = black bullhead (*Ameiurus melas*); BHS = bluehead sucker (*Catostomus discobolus*); CCF=channel catfish (*Ictalurus punctatus*); CRP = common carp (*Cyprinus carpio*); FHM = fathead minnow (*Pimephales promelas*); FMS = flannelmouth sucker (*Catostomus latipinnis*); HBC = humpback chub (*Gila cypha*); PKF = plains killifish (*Fundulus zebrinus*); RBT = rainbow trout (*Onchorynchus mykiss*); SPD = speckled dace (*Rhinichthys osculus*).

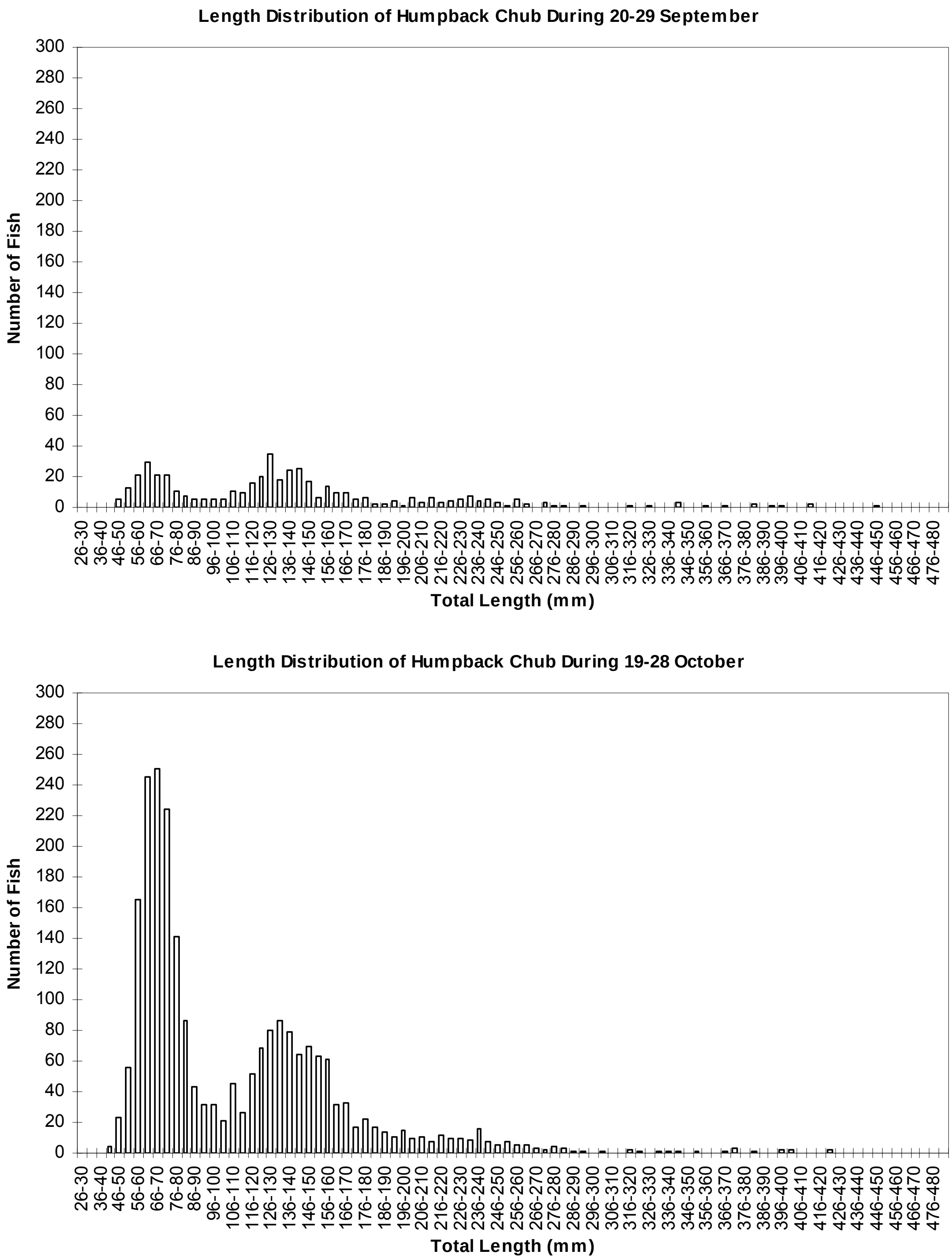
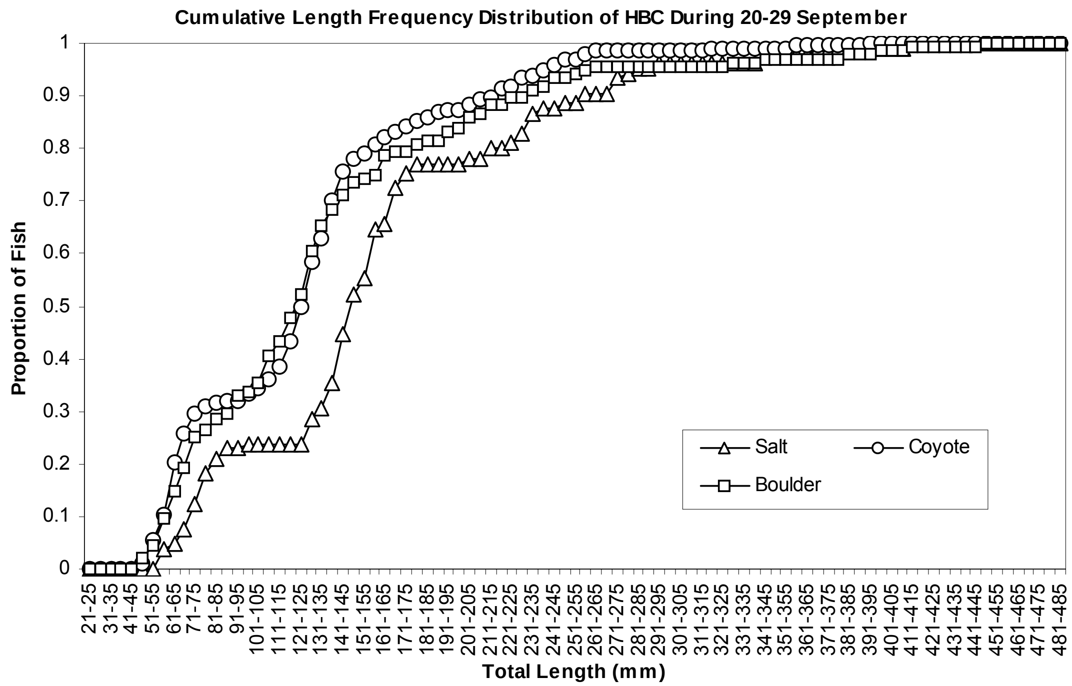


Figure 16. Length frequency distributions of all humpback chub captured; Little Colorado River, fall 2004.



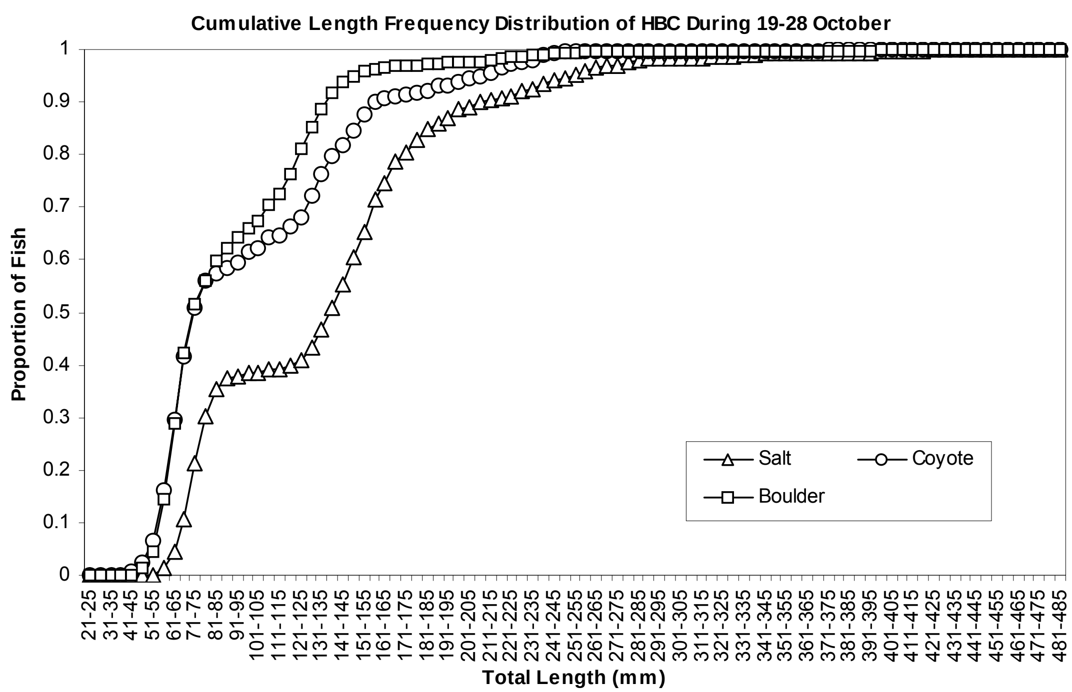


Figure 17. Cumulative length frequency charts of all humpback chub captured at three different reaches (Salt, Coyote and Boulders); Little Colorado River, fall 2004.

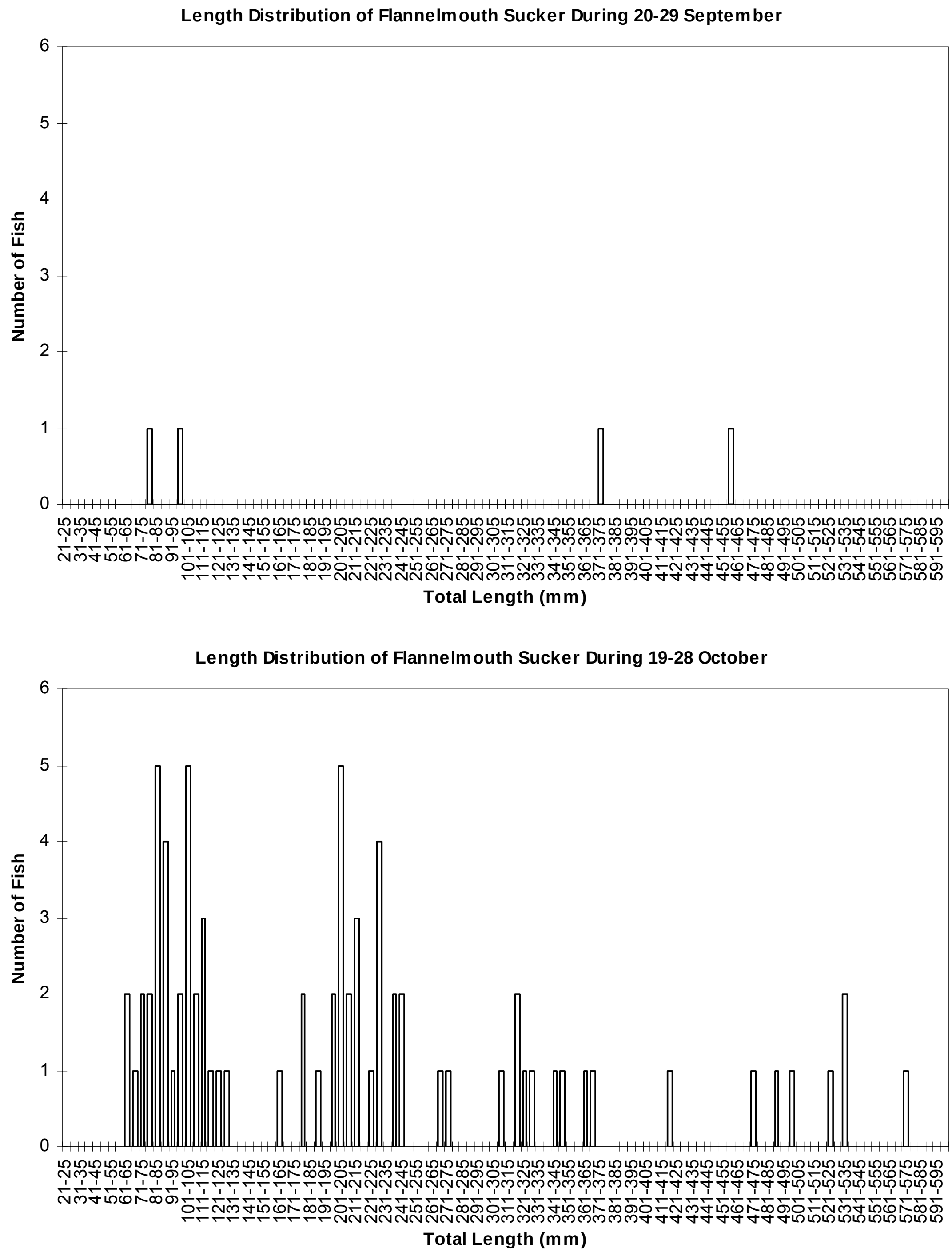
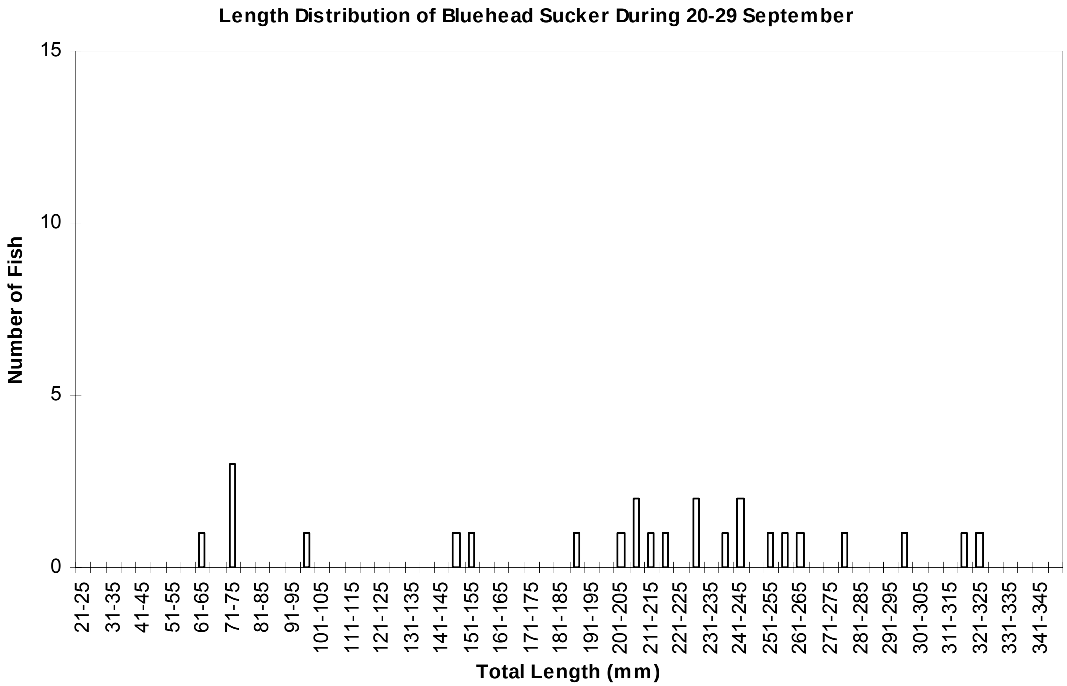


Figure 18 . Length frequency distribution of all flannelmouth sucker captured; Little Colorado River, fall 2004.



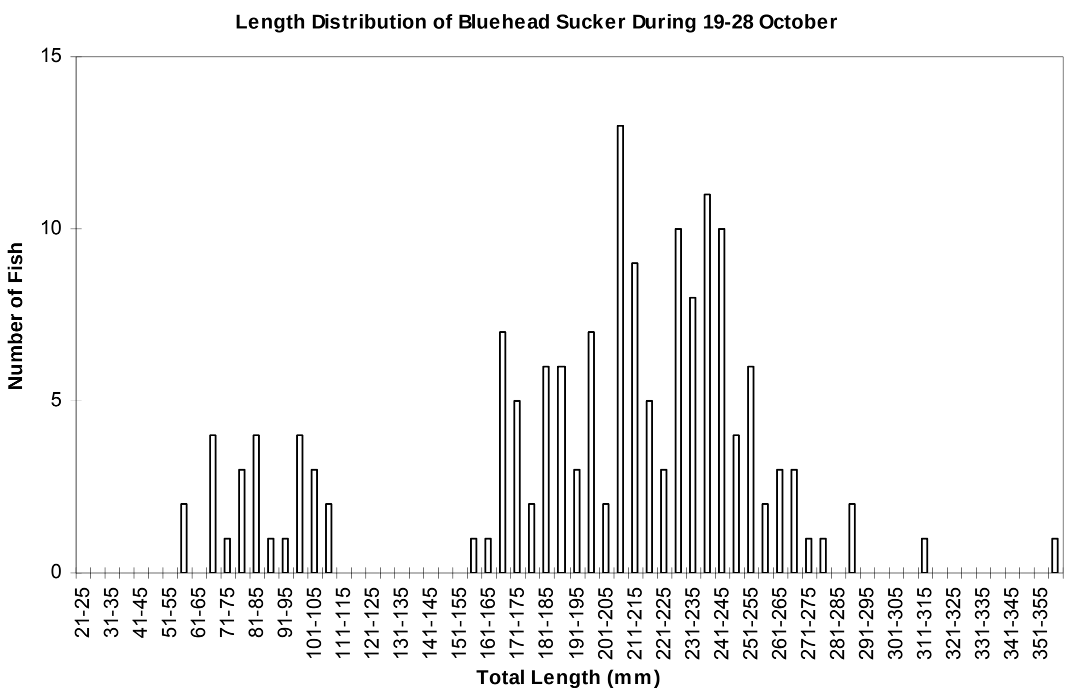


Figure 19 . Length frequency distributions of all bluehead sucker captured; Little Colorado River, fall 2004.

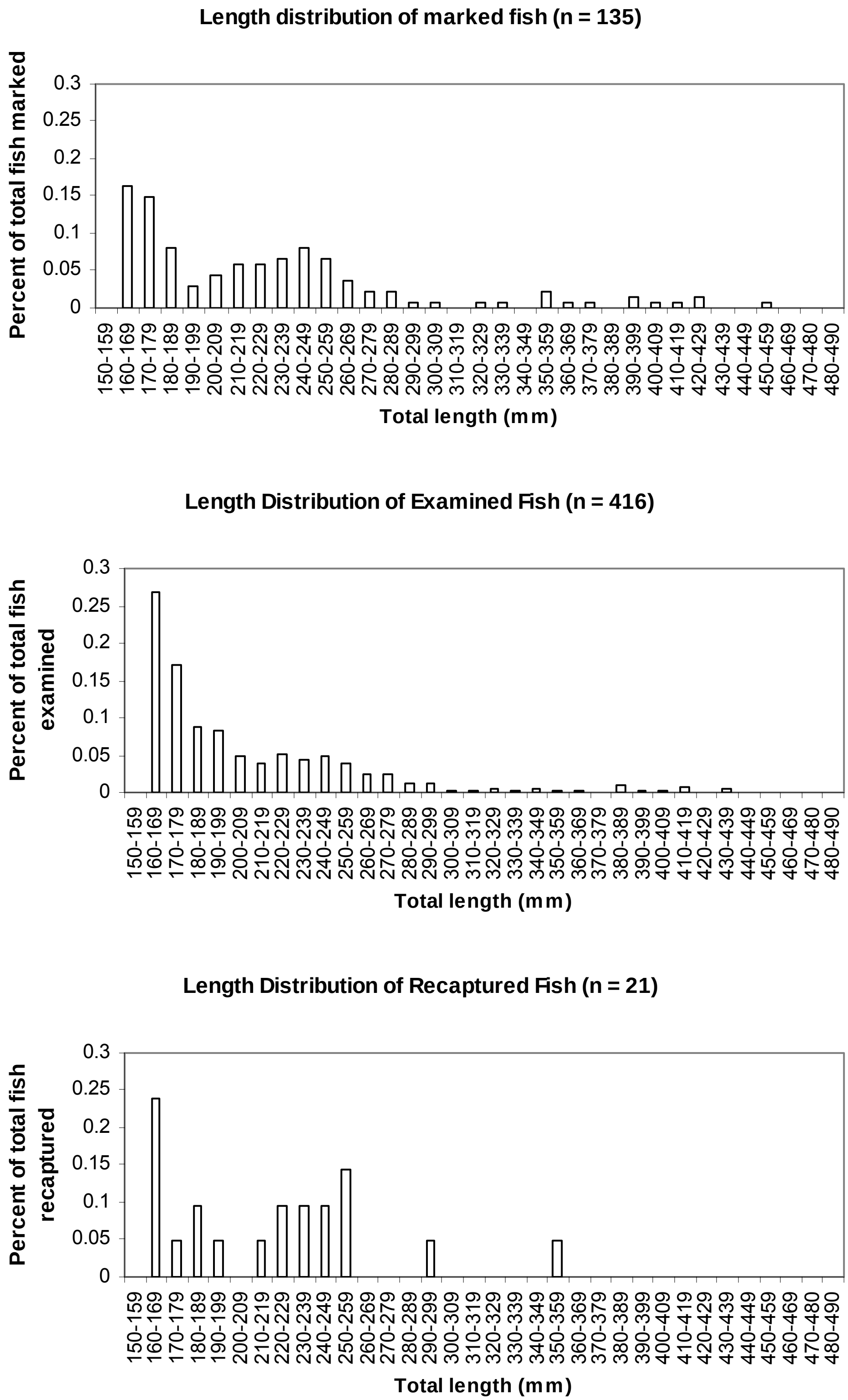
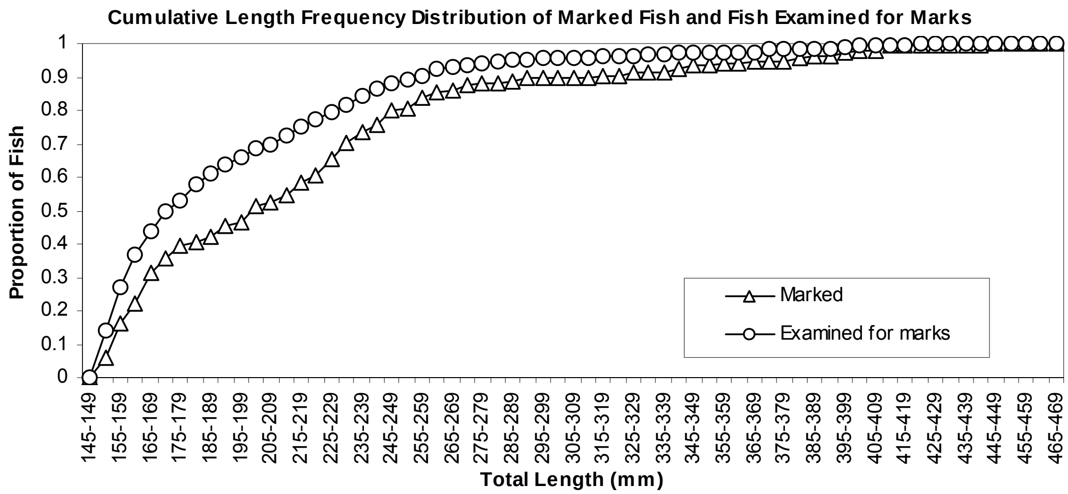


Figure 20. Length frequency distributions (shown as percentage of total) of all humpback chub ≥ 150 mm captured during the marking and recapture events; Little Colorado River, fall 2004.



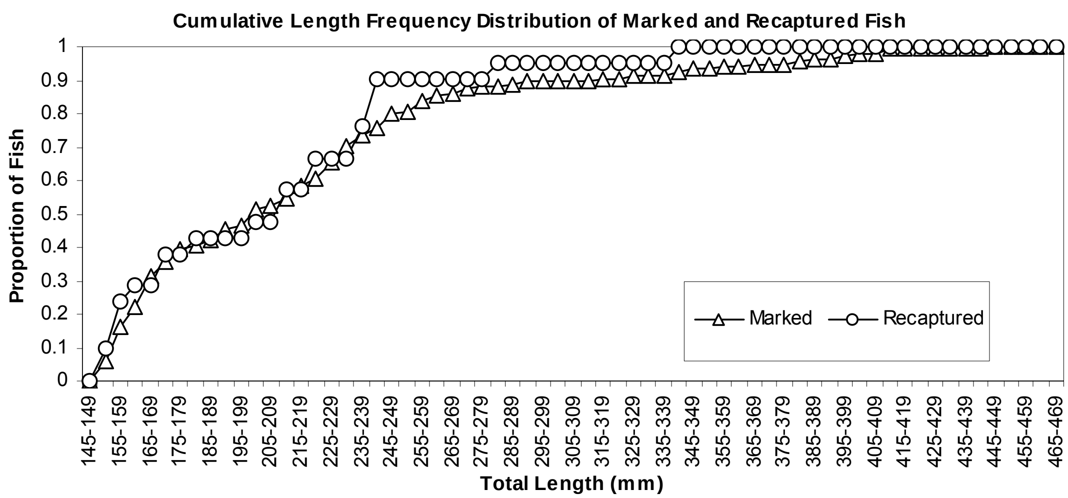


Figure 21. Cumulative length frequency distributions of humpback chub ≥ 150 mm; Little Colorado River, fall 2004.

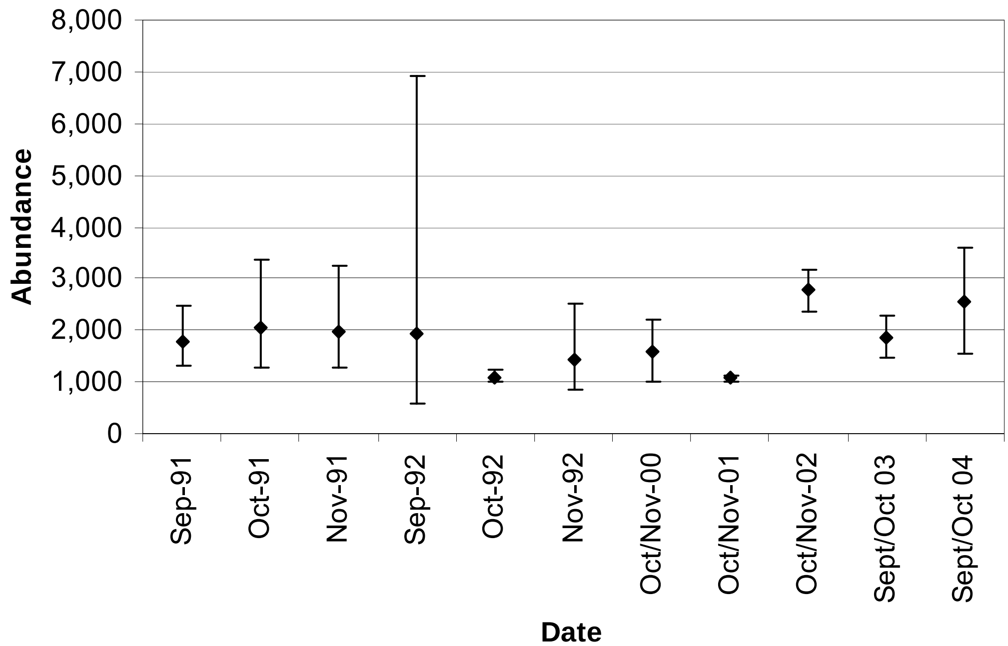


Figure 22. Fall abundance estimates of humpback chub ≥ 150 mm.

1991 and 1992 estimates are from Douglas and Marsh (1996); 2000 estimate is from Coggins and Van Haverbeke (2001), 2001 estimate is from Van Haverbeke and Coggins (2002), 2002 estimate is from (Van Haverbeke (2003), 2003 estimate from Van Haverbeke (2004).

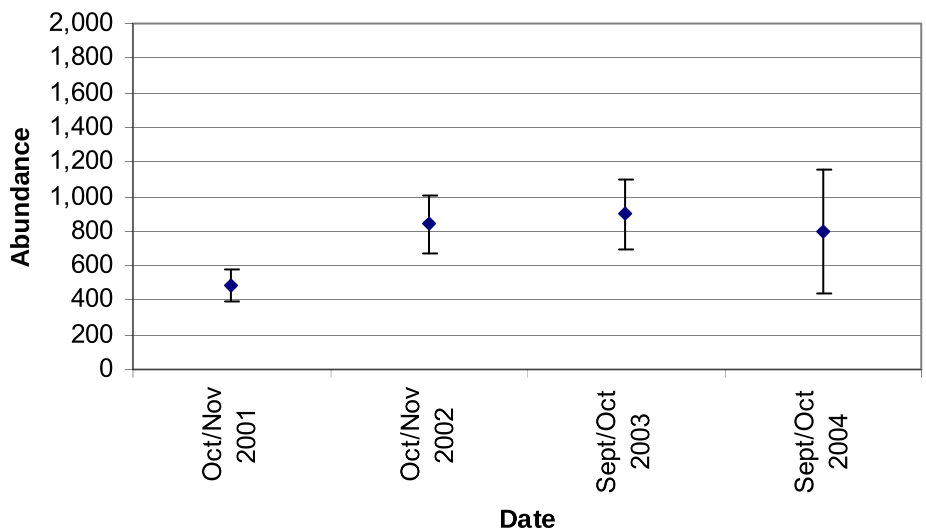


Figure 23. Fall abundance estimates of humpback chub ≥ 200 mm.

2001 estimate is from Van Haverbeke and Coggins (2002), 2002 estimate is from (Van Haverbeke (2003), 2003 estimate from Van Haverbeke (2004).

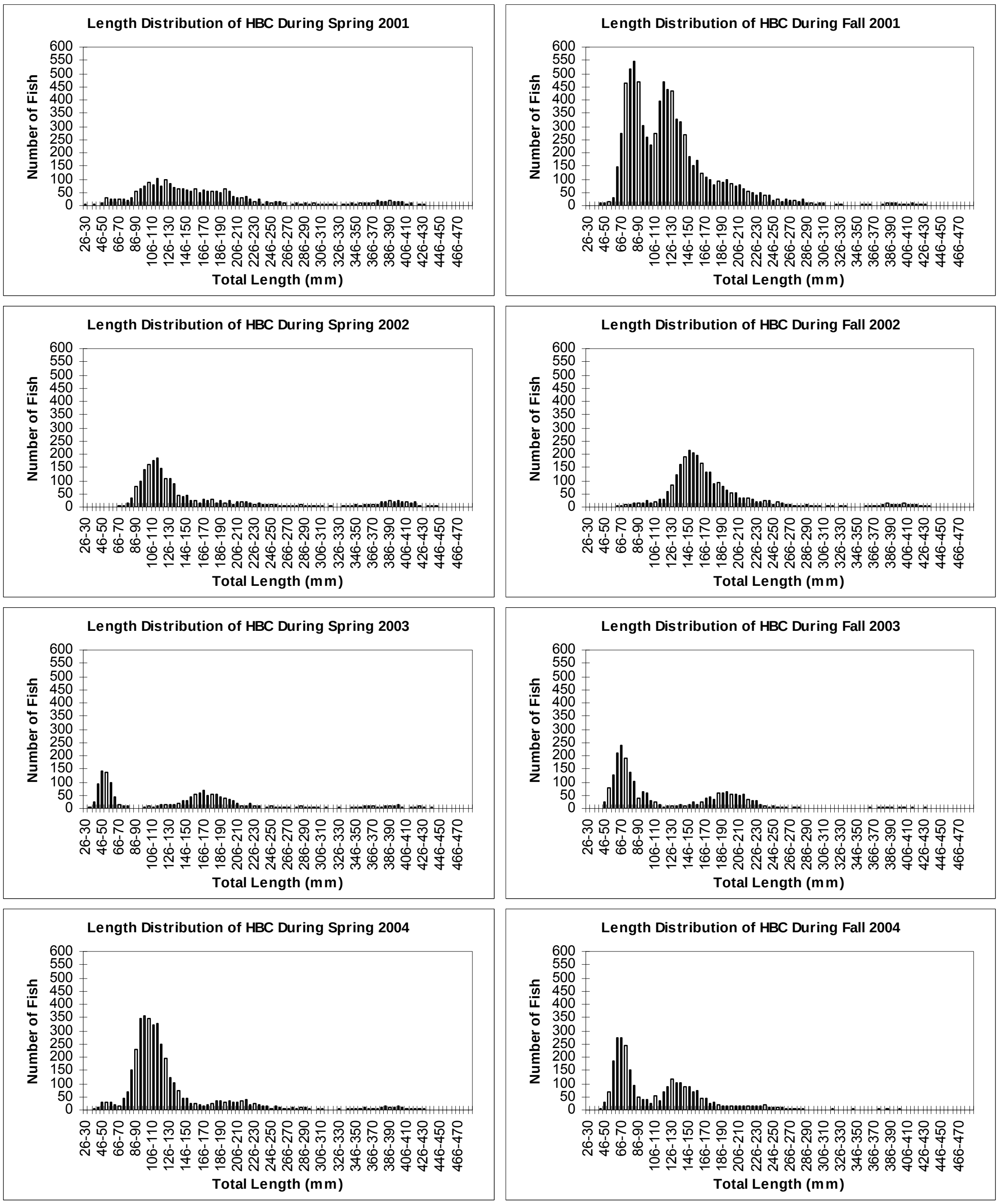


Figure 24. Length frequency distributions of humpback chub (HBC) from spring 2001 through fall 2004.