Stock Assessment and Fisheries Monitoring Activities in the Little Colorado River within Grand Canyon During 2003

Final Report

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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 GCMRC to conduct stock assessment and monitoring activities in the LCR. A total of four monitoring trips were conducted during 2003: (1) 31 March to 11 April, (2) 28 April to 9 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, length frequency, catch per unit effort (CPUE), sexual condition, predation, and parasites.

The four trips were primarily used to conduct two mark-recapture efforts to estimate the abundance of HBC in the lower 14.2 kilometers of the LCR. The results of the spring mark-recapture effort indicate that there were 3,419 (SE = 480) HBC ≥ 150 mm total length in the LCR during the spring of 2003. Of these fish, it is estimated that there were 1,421 (SE = 209) HBC ≥ 200 mm (4+ year old adults). The results of the fall mark-recapture effort indicate that there were 1,862 (SE = 206) HBC ≥ 150 mm total length in the LCR during the fall of 2002. Of these fish, it is estimated that there were 897 (SE = 105) HBC ≥ 200 mm (4+ year old adults). Finally, an attempt was made to estimate the abundance of HBC between 100 to 150 mm during fall of 2003; however no abundance estimate was obtained because of too few recaptures.

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 of the LCR HBC population is essentially a four pronged approach: 1) annual spring and fall HBC abundance assessments in the lower 14.2 km of the Little Colorado River (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); and 4) annual assessment of the overall LCR HBC population abundance and recruitment. This strategy provides a comprehensive view of the dynamics of the LCR HBC population whereby each of these programs are 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), and during the spring and fall of 2002 (Van Haverbeke 2003). In 2003, 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 14.2 km of the LCR with hoop nets deployed from three separate camp locations. However, largely because of funding restraints, our efforts only provide closed estimates during the spring and fall of each year, rather than on a year round monthly basis as was obtained by Douglas and Marsh. 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.

Another important aspect of these closed estimates is that the data facilitate incorporation into more inclusive open models (item 4 in the strategy listed above - to monitor the overall LCR HBC population abundance and recruitment. There has been misunderstanding that the closed estimates conducted in the LCR can not provide population parameters and trends for the entire LCR population, since there may be HBC residing in the mainstem Colorado River during the sampling periods. This same misunderstanding has at times been directed at the open Age Structured Mark-Recapture (ASMR) model being developed by Dr. Carl Walters. Thus some clarification is viewed as necessary in this report.

During any discrete year, the closed Chapman Peterson estimates may or may not provide an estimate of the overall abundance of the LCR population, since some HBC will likely be residing in the mainstem during each spring count. There may be a portion of adult HBC that are “skip spawners” (i.e., do not enter the LCR every year in order to spawn). Thus, the data, presented as discrete annual closed estimates, will not account for these fish. However, over a series of years, the data can be analyzed under open population models (such as Jolly-Seber or ASMR). Since adults from the mainstem enter the LCR to spawn (Douglas and Marsh 1996), and since the LCR is the only known spawning ground for HBC (Kaeding and Zimmerman 1983), presumably all adults in the mainstem that are going to contribute will eventually enter the LCR to spawn. This is precisely what the ASMR model attempts to estimate – the abundance of the overall LCR population. However, unlike our data set that is only inclusive from 2000 to 2003, the ASMR is inclusive of data since 1989. Thus, the ASMR model provides an estimate of the overall LCR population, inclusive of “skip spawners”. Such an approach (i.e., incorporating closed abundance estimates into open models) has been discussed in Pollack (1990).

OBJECTIVES

The primary goal of the 2003 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 2003 were:

1. Obtain spring and fall 2003 population estimates of HBC ≥ 150 mm in the lower 14.2 km of the LCR. Obtain a fall abundance estimate of HBC ≥ 100 mm in the lower 14.2 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 (Walters and Coggins 2003).

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 2003. The trip dates were: (1) 31 March to 11 April (referred to as the April trip henceforth), (2) 28 April to 9 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 14.2 km 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 10.7 rkm, 5.5 rkm, and 2.0 rkm, respectively (Figure 1). Each reach was broken down into three sub-reaches. Salt reach was broken down into three sub-reaches as follows: 14.2 to 12.9 rkm (Lower Atomizer Falls to Triple Drop), 12.9 to 11.6 rkm (Triple Drop to Hell Hole), and 11.6 to 10.0 rkm (Hell Hole to above House Rock). Coyote reach was broken down into three sub-reaches: 10.0 to 8.4 rkm (above House Rock to Redbud Canyon), 8.4 to 6.8 rkm (Redbud Canyon to above White Spot), and 6.8 to 5.0 rkm (above White Spot to 5.0 rkm). Boulders reach was broken down into three sub-reaches: 5.0 to 3.4 rkm (5.0 rkm to above Powell Canyon), 3.4 to 1.6 rkm (above Powell Canyon to above Jump Off Rock), and 1.6 to 0.0 rkm (above Jump Off Rock to Confluence).

Gear

Gear type deployed for fishing efforts was un-baited hoop nets. Hoop nets were 0.5 - 0.6 m diameter, 1.0 m length, 6 mm (1/4”) mesh, with a single 0.1 m throat. In comparison to 2001 and 2002 studies, hoop nets were not baited. Sixty hoop nets were fished throughout each of the three reaches during each trip. Nets were evenly distributed throughout each reach by fishing equal numbers of nets within each sub-reach (i.e., 20 nets were fished evenly within each sub-reach). Each sub-reach was fished for three days (i.e., this included three nights). Some very minor exceptions to this rule were made to accommodate logistical problems. In addition to evenly distributing the hoop nets throughout each reach and sub-reach, 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. 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 ArcMap. 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 lengths (mm; total and fork lengths for HBC), weight (g), sex (male, female, undetermined), sexual condition (ripe, spent), sexual characteristics (tuberculate, breeding colors), parasite types and number of parasites per fish. An exception was made for speckled dace, for which fork length, weight, 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, were injected with a PIT tag. All other native fish and carp ≥ 150 mm were also scanned for a PIT tag, and if not already tagged, were injected with a PIT tag. During the September and October trips, all HBC between 100 to 150 mm also received a PIT tag. Large bodied non-native fish (primarily ictalurids and salmonids) were sacrificed and their stomach contents were examined and recorded in the field. All bullhead were assumed to be black bullhead (*Ameiurus melas*) in this document based on anal ray counts (i.e., all bullhead checked had 16 to 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 (~10.8 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 14.2 km of the LCR. As mentioned above, the fall mark-recapture effort was inclusive of all HBC ≥ 100 mm. Marking events occurred during the first spring trip (31 March to 11 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 referred to in this document are fish that are captured only once within a trip, and do not include recaptures of the same fish within the same trip. Recapture events occurred during the second spring trip (28 April to 9 May), and during the second fall trip (20 October to 31 October).

The target population was all HBC ≥ 150 mm, but included all HBC ≥ 100 during the fall trips. 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 capture 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 14.2 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 recapture rate differed among sampling reaches and sub-reaches (Seber 1982). The results of these tests suggest if modifications to the Chapman-Petersen estimator are 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 be marked upon recapture were never in fact marked. Elastomer dye is logistically difficult to implement in the field, and fish secondarily marked in this manner have not had good tag retentions (Stone and Sponholtz 2003). However, fish are routinely examined for evidence of an abdominal scar located near the pelvic fins associated with PIT tagging. Though this scar is occasionally not visible on PIT tagged fish and is also a poor diagnostic tool for evaluating tag loss, very few fish displayed this scar that did not contain a PIT tag. It is assumed during these studies that tag loss was probably negligible, but conclude that future investigation might be warranted (i.e., other type of secondary marking).

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

Daily afternoon turbidity and temperature readings were taken during both spring trips at Salt Camp. The LCR was declining from spring run-off during the April trip (Figure 2). Generally, turbidity declined during the trip as flows subsided, decreasing from a high of 4,404 NTUs on 31 March to a low of 870 NTUs on 9 April (Figure 3). However, a small increase in flow occurred on 6 to 7 April, raising the turbidity slightly. Temperatures during this trip ranged from 18 to 22 ^{o}C (mean = 19 ^{o}C).

During the May trip, the LCR ran at base flow during this trip and was blue in color. Hence, turbidity remained low during the trip (Figure 3). Turbidity ranged from 3.0 to 6.1 NTUs (mean = 4.1 NTUs), while water temperatures ranged from 23 to 26 ^{o}C (mean = 24.5 ^{o}C).

Effort and Catch Composition

During both spring trips, a total of 1,091 hoop net sets were deployed, yielding 25,268 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 on the May trip (0.101 fish/net-hr) than on the April trip (0.026 fish/net-hr). More HBC were captured during the May trip (1,262 fish) than during the April trip (325 fish). Fishing effort during both trips combined produced a total catch of 3,156 fish, for all species (Table 4).

The dominant species captured on both spring trips were HBC (1,587 fish; 50%) and speckled dace (655 fish; 21%), however, species compositions between the two trips showed some differences. HBC comprised the largest proportion of fish caught on both trips (69% and 48%; Figure 4). Speckled dace increased in abundance from 7% (33 fish) in April to 23% (622 fish) in May. Red-shiners (*Cyprinella lutrensis*) comprised only 0.2% (1 fish) of the catch during April, but 5% (141 fish) during May. Exotic species collected (in order from most to least abundant captured) were red-shiner, fathead minnow (*Pimephales promelas*), carp (*Cyprinus carpio*), black bullhead (*Ameiurus natalis*), plains killifish (*Fundulus zebrinus*), and rainbow trout (*Oncorhynchus mykiss*). No channel catfish were captured. During each trip, 9% of the fish captured were exotic. Extremely under-represented by hoopnet catches were the high abundances of large (> 300 mm) carp observed in the LCR during these sampling trips (LCR crew members, pers. com.). Large carp were seen from the LCR confluence area to above Chute Falls, but none were captured in hoopnets.

Length frequencies

Overall, more HBC were captured during the May trip (1,262 fish) than during the April trip (325 fish; Figure 5). An abundance (40%, 510 fish) of HBC during both trips combined fell into the 150 to 200 mm size class, with no clear distinctions among cohorts (Figure 5). Excluding all HBC ≤ 99 mm), a greater number of adult HBC (≥ 200 mm) were captured during the May trip (230 fish; 33%) than during the April trip (110 fish; 35%). The discrepancies in numbers between the two trips suggest that fish became more vulnerable to capture during the blue water conditions prevailing in during May. In addition, a notable age-0 (≤ 85 mm) cohort of HBC was captured during the May trip (571 fish; 45% of the total HBC catch). Apparently missing in the histogram are the age-0 fish from 2002 (these should have formed a mode roughly centered around 93 mm according to the age at length key (GCMRC, unpublished data).

Cumulative length frequencies for HBC show that Salt reach captured a higher proportion of relatively larger fish on both trips (Figure 6). In addition, the higher proportion of age-0 fish captured during the May trip was primarily in Boulders and Coyote reaches.

Flannelmouth sucker length frequency distributions show a similar pattern to HBC in that a greater number of fish were captured during the May trip (175 fish; 7%) than during the April trip (33 fish; 7%), and that a small age-0 cohort was detected during the May trip (Figure 7). Most flannelmouth sucker were captured in the Boulders (72%) and Coyote (20%) 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 (383 fish; 14%) than during the April trip (40 fish; 8%) , and that an age-0 cohort was observed during the May trip (Figure 8).

Sexual Condition

During the April trip, twenty-nine ripe HBC were recorded (10% of HBC ≥ 150), all captured between 1.5 and 12.95 rkm. Only two of these were female (TLs = 188 and 305 mm). The ripe males ranged in TL from 151 to 413 mm. Twenty-four HBC were recorded as being tuberculate, displaying breeding colors, or both. Only one ripe flannelmouth sucker was recorded (TL = 475 mm; 11% of flannelmouth sucker ≥ 400 mm), a female captured at 2.5 rkm. Four ripe, male bluehead sucker were captured (range in TL = 202 to 268 mm, 14% of bluehead sucker ≥ 150 mm;) between 1.5 and 6.8 rkm. No other ripe fish were documented.

During the May trip, ninety ripe HBC were encountered (16% of HBC ≥ 150 mm). Of these, only two were females (206 and 312 mm TL). The remaining 88 males ranged in TL from 151 to 418 mm. The ripe HBC were captured between 2.04 to 13.53 rkm. Nine ripe flannelmouth sucker were captured (53% of flannelmouth sucker ≥ 400 mm). All were males captured at 2.95 rkm (range in TL = 445 to 531 mm). In addition, twenty ripe bluehead sucker were captured (TL range = 190 to 329 mm; 15% of the bluehead sucker ≥ 150 mm;). Nine of these ripe fish were captured at rkm 2.04 and another five at 8.59 rkm. Finally, three ripe fathead minnow, one ripe bullhead, and one ripe plains killifish were captured.

Presented here is the proportion of HBC ≥ 200 mm that were ripe during both trips. During April, 23 HBC ≥ 200 mm were ripe out of a total of 110 HBC ≥ 200 mm captured (i.e., 21% of the captured adult population in April was ripe). During May, 74 HBC ≥ 200 mm were ripe out of a total of 230 HBC ≥ 200 mm captured (i.e., 32% of the captured adult population was ripe).

Predation

Twenty large bodied exotics were examined for stomach contents during both spring trips. All were bullhead. Seven of the bullhead had fish, or fish remains in their stomach, including three HBC, two red shiners, one fathead minnow, one plains killifish, and the remains of ten other unidentified fish. The HBC prey was between 42 to 53 mm. Other food items found in the stomachs included eggs, insect parts, and detritus.

Parasites

Percent occurrence of the anchor worm (*Lernaea cyprinacea*) on HBC in April was very low, with only two fish (0.6% of total HBC captures) observed carrying the parasite, each with one parasite per infected fish. During May, six HBC were seen with *Lernaea* (0.5% of total HBC captures). These numbers represent low occurrence of the parasite. 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, 269 unique HBC ≥ 150 mm were marked [*M*]. During May, 493 unique HBC ≥ 150 mm were captured [*C*], and 38 unique HBC ≥ 150 mm were recaptured [*R*]. The smallest HBC recaptured had a total length of 152 mm, and the largest recaptured HBC was 439 mm in TL. We chose to define our sampled population to include all HBC ≥ 150 mm.

Length frequency distributions of HBC ≥ 150 mm did not suggest that there were severe violations in the assumption for no emigration or immigration occurring. Figures 9 and 10 illustrate relative uniformity in length frequencies of fish between the mark and recapture events. Using two-tailed Kolmogorov-Smirnov tests, the cumulative length distribution of marked [*M*] HBC was not significantly different from captured [*C*] HBC (n_1 = 269, n_2 = 493, Z = 0.881, p = 0.419). Similarly, the cumulative length distribution of marked [*M*] HBC was not significantly different than recaptured [*R*] HBC (n_1 = 269, n_2 = 38, Z = 0.970, p = 0.304; Figure 9). This was also confirmed by finding no significant differences (χ^2 = 8.26, df = 5, p = 0.143) 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 no 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 was not necessary.

In addition, we searched for significant differences in mark rate among the three geographic strata. We found no significant difference (χ^2 = 0.03, df = 2, p = 0.98) 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 = 4.85, df = 8, p = 0.77). The above tests suggest it was not necessary to stratify the data by geographic reach to obtain an estimate.

Since we found it was not necessary to stratify the data by length or by reach, we performed the Chapman modified Petersen estimate (Equations 1 and 2). The estimate for HBC ≥ 150 mm in the lower 14.2 km of the LCR is 3,419 fish (SE = 480). Table 7 and Figure 11 show this estimate as compared against previous historical estimates obtained by Douglas and Marsh (1996) 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; USFWS 2002), estimates are presented relating to their abundance. First, the data set was truncated to include only fish ≥ 200 mm. During April, 105 unique HBC ≥ 200 mm were marked [*M*]. During May, 210 unique HBC ≥ 200 mm were captured [*C*], and 14 unique HBC ≥ 200 mm were recaptured [*R*]. The smallest HBC recaptured [R] had a total length of 200 mm, and the largest recaptured was 439 mm in TL. Using two-tailed Kolmogorov-Smirnov tests, the cumulative length distribution of marked [*M*] HBC was not significantly different from captured [*C*] HBC (n_1 = 105, n_2 = 210, Z = 0.837, p = 0.486). However, the cumulative length distribution of marked [*M*] HBC was significantly different than recaptured [*R*] HBC (n_1 = 105, n_2 = 14, Z = 3.42, 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 was desirable. The optimal stratification occurred at 271 mm TL (i.e., independent estimates were produced for HBC <271 and for HBC > 270). The resulting pooled estimate was 1,543 fish (SE = 544). However, for fish > 270 there were only 4 recaptures.

As a result of the low number of recaptures in the estimate for fish > 270, the Chapman modified Petersen estimate of HBC ≥ 150 mm was multiplied by the proportion of fish ≥ 200 mm. The resulting, and **preferred** estimate for HBC > 200 mm was 1,421 fish (SE = 209). Table 8 and Figure 12 show this estimate as compared against the spring estimates for the past two years.

FALL RESULTS

Physical Parameters

During the September trip, the LCR was declining from a flood that peaked four days before the trip on 11 September at a mean daily flow of 1,520 cubic feet per second (cfs). Flows decreased from 454 cfs on 15 September to 223 cfs on 24 September (Figure 13). Turbidity decreased from a high of 61,696 NTUs on 15 September to a low of 749 NTUs on 24 September (Figure 14). Temperatures ranged from 19 to 21 ^{o}C (mean = 20.3 ^{o}C).

During the October trip, the LCR was just at the tail end of another flood that peaked 16 days before the trip on 4 October at 1,910 cfs. Flows decreased from 224 on 20 October to 217 cfs on 29 October (Figure 13). Turbidity declined from a high of 2,152 NTUs on the 20 October to a low of 48 NTUs on 29 October (Figure 14). Water temperatures ranged from 18 to 19.5 ^{o}C (mean = 18.8 ^{o}C).

Effort and Catch Composition

A total of 1,090 hoop net sets were completed during the September and October trips yielding 25,002 hours of fishing effort. Total CPUE for HBC in September was 0.042 fish/net-hour, and in October was 0.132 fish/net-hour (Table 9). The distribution of effort was similar among the three reaches. Fishing effort during these trips produced a catch of 2,943 fish (Table 10). The dominant species in the catch were HBC (2,205 fish; 75%) and speckled dace (163 fish; 5%). Carp comprised the dominant non-native fish 157 fish; 5%).

Species Composition

Observed species composition during both the September and October trips were similar, with some small differences (Figure 15). HBC comprised the largest proportion of fish caught on both trips (73% and 75%), compared to 69% and 48% on the spring trips. Speckled dace increased in proportion from 2% of the catch in September to 7% of the catch in October. The proportion of carp declined from 10% in September to 4% in October. Exotic species in order of decreasing abundance included carp, fathead minnow, black bullhead, channel catfish, and plains killifish. Red shiners and rainbow trout were absent during the fall sampling. Exotic species captured in hoop nets during September and October comprised 16 and 11% of the catch, respectively.

Length frequencies

Length frequency distributions for HBC on both trips were similar (Figure 16), however, more HBC were captured during the October trip (1,692 fish) than during the September trip (513 fish), likely a result of decreased turbidity in October. An abundance (1,258 fish; 57%) of HBC combining both trips fell into the 50 to 100 mm size class. These are presumed age-0 fish. Similar to the spring histograms, apparently missing is the age-0 cohort from 2002 (fish roughly in the 100 to 140 mm range. Another group of fish appear between 150 to 250 mm (711 fish; 32%), but there are no clear distinctions among annual cohorts (Figure 16). Focusing on HBC ≥ 200 mm, a greater number were captured during the October trip (250 fish; 15%) than during the September trip (130 fish; 25%). Cumulative length frequencies for HBC (Figure 17) show that Salt reach captured a higher proportion of larger fish 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 October trip (101 fish; 4.5%) than during the September trip (9 fish; 1.3%), and that an age-0 cohort was detected during the October trip (Figure 18). Most flannelmouth sucker were captured in the Boulders reach (Table 10).

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 October trip (85 fish; 4%) than during the September trip (51 fish; 7%; Figure 19). Missing is the age-0 cohort of bluehead sucker detected during the spring trips (see Figure 8).

As in fall 2002 (Van Haverbeke 2002), a large number (157 fish; 5%) of carp were captured. Most of these are presumed age-0 or age-1 fish (Figure 20).

All except one channel catfish captured were presumed age-0 fish (Figure 21). The presence of age-0 catfish is not new in the LCR, but catches were much higher this year (30 age-0 fish) than during the past two years, for an unknown reason. Only one age-0 channel catfish was captured during spring and fall LCR monitoring activities in 2002 and only four age-0 catfish were captured during the same activities in 2001.

Finally, only two bullhead captured during September and October were presumed age-0 fish (< 100 mm; Figure 22).

Sexual Condition

During the September trip, twenty-three ripe bluehead sucker were captured (45% of captured bluehead ≥ 150 mm). All were male (TL range = 164 to 274 mm), and were captured between 1.1 and 4.25 rkm. Seventeen of these fish were captured at 2.03 rkm in riffle habitat. No other ripe fish were captured during September.

During the October trip, two (0.3% of HBC ≥ 150 mm) ripe HBC were captured. One was male (221 mm) captured at 12.12 rkm, and one was female (363 mm) captured at 2.04 rkm. Five ripe flannelmouth sucker were captured (TL range = 435 to 502 mm; 71% of flannelmouth sucker ≥ 400 mm). All were males captured from 3.04 to 3.09 rkm along vegetated shoreline (e.g., *Phragmites*) in slower moving water (i.e., glide habitat). In addition, fifty (62% of bluehead sucker ≥ 150 mm) ripe bluehead sucker (TL range = 154 to 265 mm) were captured between 0.92 and 10.65 rkm. All but one of these were male, and all but two were captured in faster moving water (i.e., run habitat).

Predation

Thirty-three large bodied exotics were examined for stomach contents during both trips. These fish included 32 bullhead, and one channel catfish. Three of the bullhead (TLs = 196, 222 and 240 mm) each had one HBC in their stomach (HBC TLs = 76, 67 and 140 mm, respectively). One additional bullhead (TL = 186 mm) had three HBC (TLs = 50, 55 and 57 mm) and one unidentified fish in its stomach. One other bullhead had unidentifiable fish remains in its stomach, and one bullhead stomach contained snails. The remaining fish had empty stomachs or detritus in their stomachs.

Parasites

Percent occurrence of the external parasite (*Lernaea cyprinacea*) on HBC in September was low, with only six fish (1.2% of total HBC captures) observed carrying the parasite, generally carrying only one parasite per infected fish. During October, 14 HBC were seen with *Lernaea* (0.8% of total HBC captures), each carrying from one to three parasites per fish. No Asian tapeworm was observed, but these internal parasites were not monitored.

Population Abundance Estimation

We used the following criteria to define our sampled population during the fall mark-recapture effort. During September, 234 unique HBC ≥ 150 mm were marked [*M*]. During October, 519 unique HBC ≥ 150 mm were captured [*C*], and 68 unique HBC ≥ 150 mm were recaptured [*R*]. The smallest HBC recaptured had a total length of 160 mm, and the largest HBC recaptured was 276 mm TL.

Figures 23 and 24, show uniformity in the length frequencies of marked, captured and recaptured fish. Using two-tailed Kolmogorov-Smirnov tests, the cumulative length distribution of marked [*M*] HBC was not significantly different from captured [*C*] HBC ($n_1 = 234$, $n_2 = 519$, $Z = 1.170$, $p = 0.129$). Likewise, the cumulative length distribution of marked [*M*] HBC was not significantly different than recaptured [*R*] HBC ($n_1 = 234$, $n_2 = 68$, $Z = 0.776$, $p = 0.583$; Figure 23). However, we did find significant difference ($\chi^2 = 13.85$, df = 5, $p = 0.017$) in the mark rates of HBC within different length strata (Table 11). Although this may be the result of no recaptures above 276 mm, we conclude from these tests that that there may have been significant size selective bias within the sampled population. As a result, we investigated stratifying our abundance estimate based on length (i.e., TL) by procedures given in 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 180 mm ($\chi^2 = 4.85$).

There was no significant difference ($\chi^2 = 4.79$, df = 2, $p = 0.091$) in the mark rate among the three sampling reaches (Table 12). 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 < 181 mm and those fish > 180 mm), but did not also need to be stratified by location. The length stratified Chapman Petersen abundance estimate for HBC ≥ 150 in the lower 14.2 rkm of the LCR was 1,862 fish (SE = 206; Table 13). Table 14 and Figure 25 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 ≥ 150 mm was multiplied by the proportion of fish ≥ 200 mm. The resulting abundance estimate of HBC ≥ 200 was 897 fish (SE = 105).

Concerning HBC between 100 and 149 mm, during September, 26 unique HBC between 100 and 149 mm were marked [*M*]. During October, 120 unique HBC between 100 and 149 mm were captured [*C*]. However, only one HBC was recaptured [R] during October. Because of too few recaptures, no population estimate was performed.

DISCUSSION

Spring Abundance Estimate

The non-stratified Chapman Petersen estimate of 3,419 (SE = 480) HBC ≥ 150 mm is given as the estimate for spring 2002. Because no significant differences were found in lengths between the marked [*M*] and captured [*C*] populations, and marked [*M*] and recaptured [*R*] populations, it was not necessary to stratify the data by length. The length frequency analyses did not provide evidence that larger HBC moved out of the LCR between the mark and recapture events. This means that the assumption of population closure was less likely violated. In addition, because no significant differences were found in the mark rate between reaches, it was not necessary to stratify the estimate by reach.

Our spring estimate for HBC ≥ 150 is higher than it has been for the past two years. This is encouraging; however, it is premature to assume that this indicates an increasing population trend. Even this 2003 estimate is still lower than the spring 1992 estimates provided by Douglas and Marsh (1996).

Also of concern are the abundance estimates for 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 2003 estimate of HBC ≥ 200 mm in the LCR falls at 1,421 (SE = 209). In addition, the spring 2002 abundance estimate for HBC ≥ 200 mm of 2,002 fish (SE = 463) was thought to be biased high (Van Haverbeke 2003). It is noteworthy that the spring 2003 abundance estimate for HBC ≥ 200 falls is nearly identical as the estimate for spring 2001 (1,470 fish; SE = 240), and that all three estimates provided from 2001 to 2003 fall below 2,100 fish.

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 proportion of HBC will be in the mainstem during our activities and will not be captured in the estimate. However, these estimates are being incorporated into open population models (i.e., Jolly-Seber in Program Mark, and ASMR) in order to estimate the entire LCR population.

As in previous years, there was a low percentage of ripe female HBC compared to ripe male HBC during the spring sampling of 2003 (i.e., 4 ripe females/115 ripe males in 2003, spring 2002 = 14/123, spring 2001 = 6/84). Gorman and Stone (1999) found a similar ratio 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 as a whole. Gorman and Stone also found that ripe females appeared to move into aggregations of ripe males to spawn, and also 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 humpback chub (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 suggests 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 Ne, and indeed is part of the basic equation in estimating Ne (e.g., Lande and Barrowclough 1987).

Fall Abundance Estimate

Like the spring abundance estimate provided for this year, the fall abundance estimate had few complications associated with violations of assumptions. The length frequency distributions of HBC ≥ 150 mm did not suggest that there were problems with emigration or immigration occurring. There was not a significant difference in length frequencies between the marked [*M*] and captured [*C*] fish, or between the marked [M] and recaptured [R] fish. There was a significant difference in the mark rates within the length strata, but not within the geographic reaches. For these reasons, the estimate was stratified by length. This year's fall estimate of 1,862 (SE = 206) HBC ≥ 150 mm was lower than the fall 2002 estimate of 2,774 fish (SE = 209), however, is similar to previous estimates obtained during the fall since the early 1990s. As discussed in Van Haverbeke (2003), the higher fall 2002 abundance estimate was thought to be an anomaly, possibly related to unusual hydrologic events.

To generate the estimate of 897 (SE = 105) HBC ≥ 200 mm, the length stratified Chapman-Petersen estimate for fish ≥ 150 mm was multiplied by the proportion of 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 was truncated and a length stratified estimate was obtained that was similar (although lower by 118 fish). It should be made clear that the low fall estimates for HBC ≥ 200 obtained over the past three years are expected to be lower than the spring estimates, since a proportion of HBC migrate out of the LCR after the spring spawning event (Gorman and Stone 1999). Nevertheless, they do provide trend data indicating that the numbers of these larger fish are low.

Last year, 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 estimate was not possible to make this year because only one fish was recaptured out of 26 marked.

CONCLUSIONS

Evidence has been presented for the past three years that the Grand Canyon population of HBC appears to have undergone a decline since the early 1990s. All three spring point abundance estimates for HBC ≥ 150 mm from the years 2001 through 2003 have been less than those provided by Douglas and Marsh (1996) during spring 1992 (although not all have been significantly less).

However, since 2001, the abundance estimate of HBC ≥ 150 has increased from 2,082 in spring of 2001 to 2,666 in spring 2002, and to 3,419 in spring of 2003. The reason for this is unknown with certainty at this time, but may be because of recruitment from the 2000 age-0 cohorts.

Some evidence for survivorship of the 2000 age-0 cohort is portrayed in Figure 26. The length at age key for the ASMR model (GCMRC, unpublished data), places age-1 HBC at 93 mm, age-2 HBC at 134 mm, and age-3 HBC at 174 mm. Note in Figure 26 that there is nearly a threefold increase in the abundance estimate of HBC between 150 to 200 mm in fall of 2002 (when the 2000 cohort should have been expected to be entering into the > 150 mm category). This increase carried into spring 2003 when these same fish would be estimated at 173 mm.

While the apparent survival of the 2000 cohort does seem to be a positive sign, this apparent increase in abundance of HBC ≥ 150 mm should be tempered with three additional observations. First, the spring abundance of HBC ≥ 200 mm since 2001 has remained low (i.e., < 2,100 fish). Second, the fall abundance of HBC ≥ 200 mm since 2001 has also remained low (i.e., < 900 fish). Third, survivorship and recruitment from the 2002 age-0 cohorts appears to have minimal. Very few age-0 fish were detected during the sampling of spring and fall of 2002 (Van Haverbeke 2003). In addition, catches of age-0 and age-1 HBC were found in standardized hoop netting locations in the mainstem Colorado River immediately below the LCR confluence during an unusually large flood (peak discharge measuring 11,500 cubic feet/second) during September 2002 (Paukert and Popoff 2002), indicating that a portion these fish were transported out of the LCR by the flood. Figure 27 gives some indication that the size class of HBC transported out of LCR by floods may be primarily age-0 and age-1 fish.

RECOMMENDATIONS

Since results for the past three years have important implications concerning the conservation and recovery of HBC in Grand Canyon, 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, population dynamics governing 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 trend abundance 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 problems 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 not viewed by some as 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 this data into open models.

Third, we recommend that continued efforts should be made to estimate the abundance of HBC between 100 to 150 mm via mark-recapture methodologies. Because only one fish was recaptured out of 26 fish marked (recapture rate = 3.8%), this may indicate either high PIT tag loss or mortality occurred in this size class of fish. However, obtaining information on this size class is of value, as it functions as the earliest signal for success of a given year's cohort, and could potentially someday link population dynamics of the HBC to events in the LCR (e.g., linking risk of extinction to environmental stochasticity). .

Fourth, 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 is 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 five MS Access files entitled:
LCR_2003_April_Boulders.mdb, LCR_2003_April_Coyote&Salt.mbd,
LCR_2003_May_Salt.mbd, LCR_2003_May_Coyote.mbd, and
LCR_2003_May_Boulders.mdb, LCR_2003_May_Coyote.mdb, and
LCR_2003_May_Salt.mdb.

The data for the two fall trips was delivered to GCMRC in six MS Access files entitled:
LCR_2003_September_Boulders.mdb, LCR_2003_September_Coyote.mdb,
LCR_2003_September_Salt.mdb, LCR_2003_Boulders.mdb,
LCR_2003_October_Coyote.mdb, and LCR_2003_October_Salt.mdb.

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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 2003.

	USFWS	AGFD	SWCA	Volunteer
31 March - 11 April	Dennis Stone [S] Pamela Sponholtz [C] Dewey Wesley [B]	Andy Makinster [C]	Matt Laurretta [B]	Nathan Taylor [S] Josh David [S] David O'Brien [C] Salvador Wilson (B)
28 April - 9 May	Dennis Stone [S] Mark Gard [S] Pam Sponholtz [C] Dewey Wesley [B]			Gail Harder [S] Bob Mankowski [C] Craig Ellsworth [C] Josh David [B] Mike Beaks [B]
15 - 26 September	Dennis Stone [S] Pam Sponholtz [S] Mitch Thorsen [S] Glen Knowles [C] Dewey Wesley [B]	Andy Makinster [C] Scott Rogers [B]		Tyler Rychener [C]
20 - 31 October	Dennis Stone [S] Josh David [C] Dewey Wesley [B] David Van Haverbeke [B]		Matt Lauretta [C]	Mike Melynchuck [S] Ami Pate [S] Beth Boivert [C] Melanie Caron [B]

Table 2. Habitat characteristics for hoop nets set in Little Colorado River, 2003.

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 2003.

		Effort		HBC	HBC
Trip	Reach	Sets	Hours	Catch	CPUE
April					
	Salt	186	4,492	136	0.030
	Coyote	179	4,073	129	0.032
	Boulders	180	4,163	60	0.014
	Total	545	12,728	325	0.026
May					
	Salt	186	4,365	396	0.091
	Coyote	180	4,074	428	0.105
	Boulders	180	4,101	438	0.107
	Total	546	12,540	1,262	0.101
Grand Total		1,091	25,268	1,587	0.063

Table 4. Summary of fish captured by trip, reach, gear type, and species; Little Colorado River, spring 2003.

		Species*											
Trip	Reach	BBH	BHS	CCF	CRP	FHM	FMS	HBC	PKF	RBT	RSH	SPD	Total
April													
	Salt	11	5		5	10	2	136		2		9	180
	Coyote	1	7		3	2	7	129				10	159
	Boulders		28		5	2	24	60			1	14	134
	Total	12	40	0	13	14	33	325	0	2	1	33	473
May													
	Salt	7	73		3	58	15	396	2		88	244	886
	Coyote	2	132			15	35	428	1		12	155	780
	Boulders		178		6	5	125	438	1		41	223	1,017
	Total	9	383	0	9	78	175	1,262	4	0	141	622	2,683
Grand Total		21	423	0	22	92	208	1,587	4	2	142	655	3,156

* 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 (*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 2003.

Length strata	Unmarked	Marked	Mark rate
150-199	259	24	8.48%
200-249	73	10	12.05%
250-299	35	0	0.00%
300-349	12	1	7.69%
350-399	56	1	1.75%
400-449	20	2	9.09%
Totals	455	38	7.71%

Ho: Mark rate among length strata is the same.

Accept null hypothesis (χ^2 = 8.26, df = 5, p = 0.143)

Table 6. Number of humpback chub marked and unmarked during the recapture event by reach; Little Colorado River, spring 2003.

Reach	Unmarked	Marked	Mark rate
Salt	210	17	7.49%
Coyote	139	12	7.95%
Boulder	106	9	7.83%
Total	455	38	7.71%

Ho: Mark rate among the reaches is the same.

Accept null hypothesis ($\chi^2 = 0.03$, df = 2, p = 0.98)

Table 7. Population estimates for humpback chub ≥ 150 mm by date. 1992 estimates are from Douglas and Marsh (1996), 2001 estimate is from Van Haverbeke and Coggins (2002), 2002 estimate is from Van Haverbeke (2003); Little Colorado River.

			95 % Confidence Interval			
Date	Abundance Estimate	SE	Lower	Upper	Reach (rkm)	# per km
Apr-92	5,555	671	4,416	7,067	0 - 14.9	373
May-92	4,363	1,216	2,594	7,523	0 - 14.9	293
Jun-92	4,384	458	3,573	5,381	0 - 14.9	294
May-01	2,082	242	1,607	2,557	0 - 14.2	147
April/May 2002	2,666	463	1,759	3,573	0 - 14.2	188
April/May 2003	3,419	480	2,478	4,360	0 - 14.2	242

Table 8. Population estimates for humpback chub ≥ 200 mm by date. 2001 estimate is from Van Haverbeke and Coggins (2002), 2002 estimate is from Van Haverbeke (2003); Little Colorado River.

			95 % Confidence Interval			
Date	Abundance Estimate	SE	Lower	Upper	Reach (rkm)	# per km
May-01	1,470	240	1,000	1,940	0 - 14.2	104
April/May 2002	2,002	463	1,095	2,909	0 - 14.2	141
April/May 2003	1,421	209	1,011	1,831	0 - 14.2	100

Table 9. 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 2003.

		Effort		HBC	HBC
Trip	Reach	Sets	Hours	Catch	CPUE
September					
	Salt	184	4,040	185	0.046
	Coyote	180	4,073	147	0.036
	Boulders	180	4,088	181	0.044
	Total	544	12,201	513	0.042
October					
	Salt	186	4,504	609	0.135
	Coyote	180	4,146	440	0.106
	Boulders	180	4,151	643	0.155
	Total	546	12,801	1,692	0.132
Grand Total		1,090	25,002	2,205	0.088

Table 10. Summary of fish captured by trip, reach, gear type, and species; Little Colorado River, fall 2003.

		Species*											
Trip	Reach	BBH	BHS	CCF	CRP	FHM	FMS	HBC	PKF	RBT	RSH	SPD	Total
September													
	Salt	6	1		49	2	1	185				1	245
	Coyote	5	2	9	17	5	4	147				6	195
	Boulders	1	48	11	2	6	4	181				9	262
	Total	12	51	20	68	13	9	513	0	0	0	16	702
October													
	Salt	10	12		36	14	10	609	8			69	768
	Coyote	6	40		49	48	17	440	1			23	624
	Boulders	4	33	11	4	25	74	643				55	849
	Total	20	85	11	89	87	101	1,692	9	0	0	147	2,241
Grand Total		32	136	31	157	100	110	2,205	9	0	0	163	2,943

* 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 kiilifish (*Fundulus zebrinus*); RBT = rainbow trout (*Oncorhynchus mykiss*); RSH = red shiner (*Cyprinella lutrensis*); SPD = speckled dace (*Rhinichthys osculus*).

Table 11. Number of humpback chub marked and unmarked during the recapture event by total length strata; Little Colorado River, fall 2003.

Length strata	Unmarked	Marked	Mark rate
150-199	250	27	9.75%
200-249	156	37	19.17%
250-299	17	4	19.05%
300-349	5	0	0.00%
350-399	13	0	0.00%
400-449	10	0	0.00%
Totals	451	68	13.10%

Ho: Mark rates among length strata is the same.

Reject null hypothesis ($\chi^2 = 13.85$, df = 5, p = 0.017)

Table 12. Number of humpback chub marked and not marked during the recapture event by reach; Little Colorado River, fall 2003.

Reach	Unmarked	Marked	Mark rate
Salt	221	41	15.65%
Coyote	118	11	8.53%
Boulder	112	16	12.50%
Total	451	68	13.10%

Ho: Mark rate among the reaches is the same.
Reject null hypothesis (χ^2 = 4.79, df = 2, p = 0.091)

Table 13. Length stratified Chapman Petersen abundance estimates of humpback chub $\geq$ 150 mm; Little Colorado River; fall 2003.

Abundance of HBC >=150 mm TL

						95% Confidence Interval	
Length (mm)	Marked	Examined	Recaptured	N	SE	Lower	Upper
150 - 180	53	119	9	647	169	316	978
>180	181	400	59	1,215	118	985	1,446
Sum Strata				1,862	206	1,459	2,266

Table 14. Abundance estimates of humpback chub ≥ 150 mm by date. 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).

			95% Confidence Interval				
Date	Abundance Estimate	SE	Lower	Upper	Reach (rkm)	Size (mm)	# per km
October 1991	2,038	518	1,276	3,368	0 - 14.9	≥ 150 mm	137
November 1991	1,989	489	1,264	3,235	0 - 14.9	≥ 150 mm	133
October 1992	1,099	60	990	1,224	0 - 14.9	≥ 150 mm	74
November 1992	1,417	408	839	2,500	0 - 14.9	≥ 150 mm	95
October/November 2000	1,590	297	992	2,552	0 - 14.2	≥ 135 mm	107
October/November 2001	1,064	33	999	1,129	0 - 14.2	> 150 mm	71
October/November 2002	2,774	209	2,364	3,184	0 - 14.2	≥ 150 mm	186
September/October 2003	1,862	206	1,459	2,265	0 - 14.2	≥ 150 mm	125

Table 15. Abundance estimates of humpback chub ≥ 200 mm by date. 2001 estimate is from Van Haverbeke and Coggins (2002). 2002 estimate is from Van Haverbeke (2003).

			95% Confidence Interval			
Date	Abundance Estimate	SE	Lower	Upper	Reach (rkm)	# per km
October/November 2001	483	48	389	577	0 - 14.2	34
October/November 2002	839	87	668	1,010	0 - 14.2	59
September/October 2003	897	105	691	1,103	0 - 14.2	63

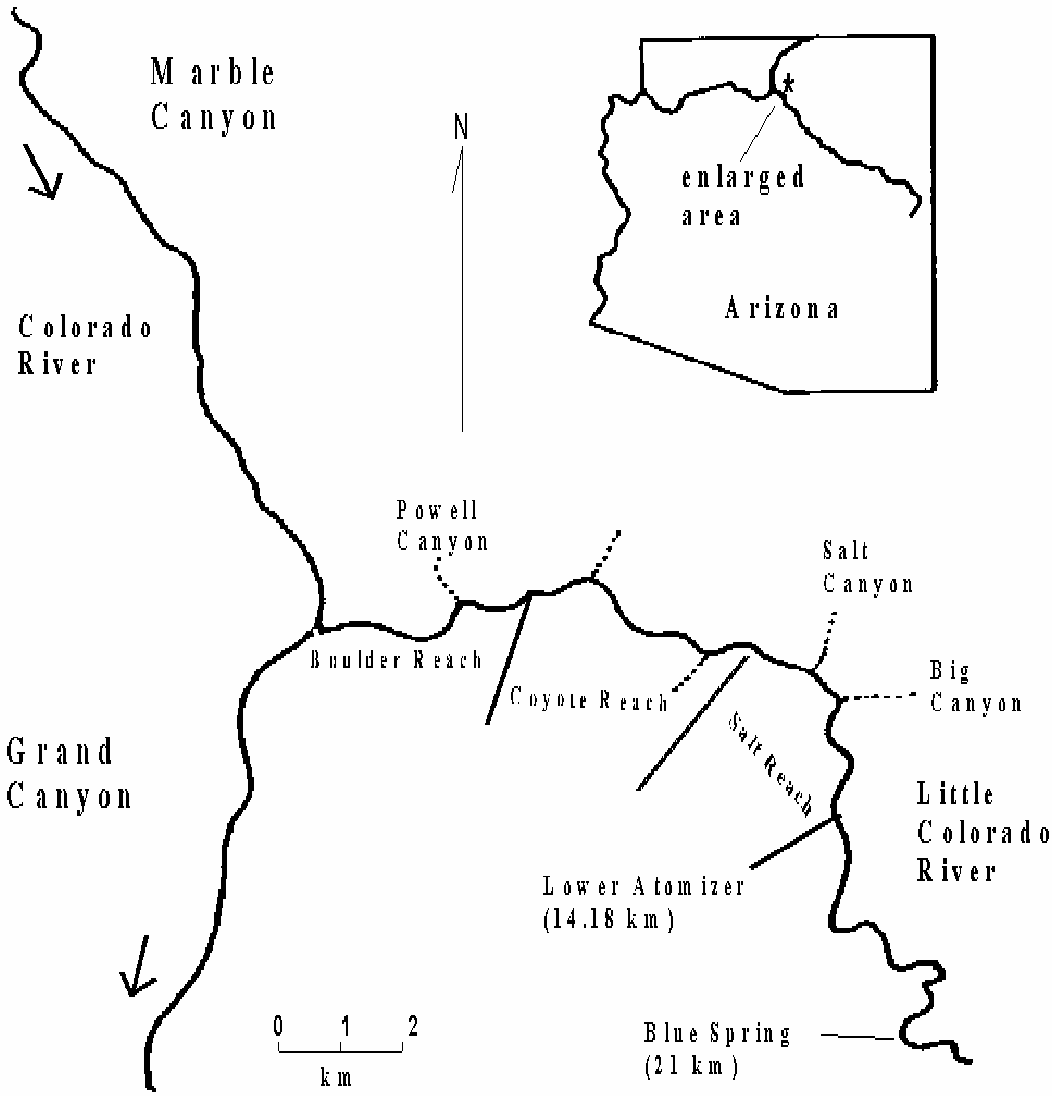


Figure 1. Map of the study site, showing Salt, Coyote and Boulders reaches in Little Colorado River.

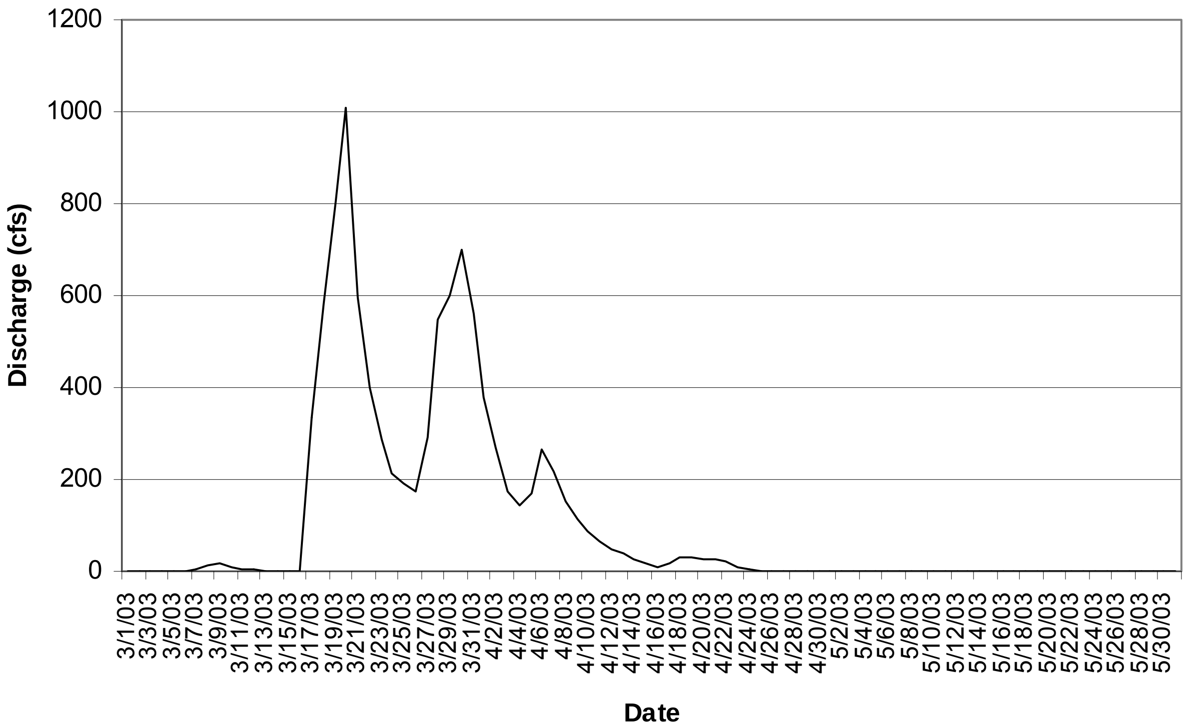


Figure 2. Provisional discharge (cubic feet/second) data from USGS gage station located in Little Colorado River approximately 1.0 rkm above the confluence.

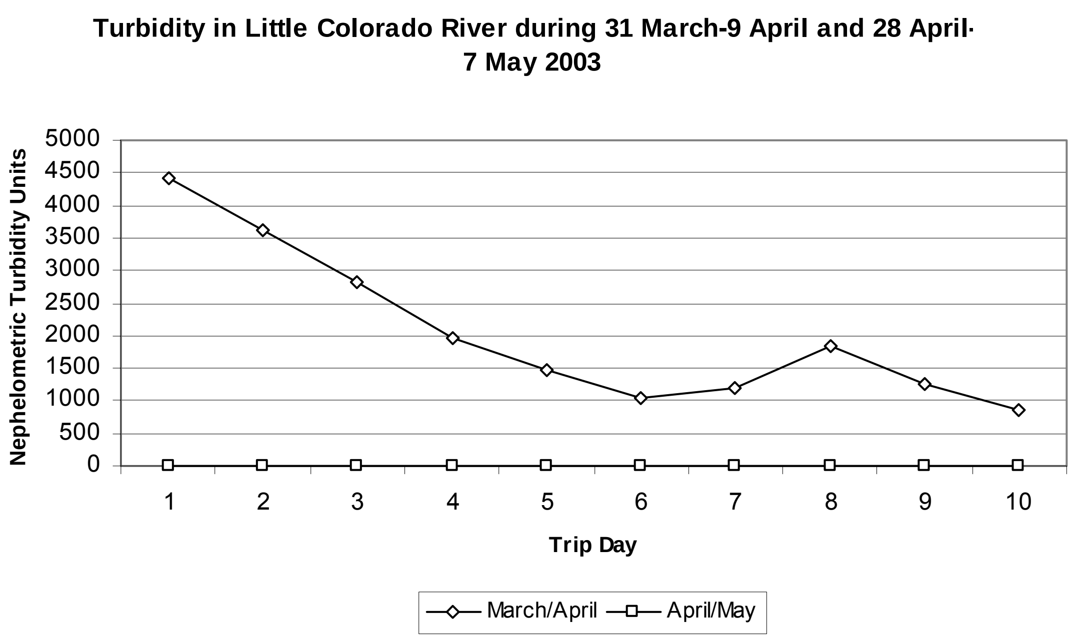
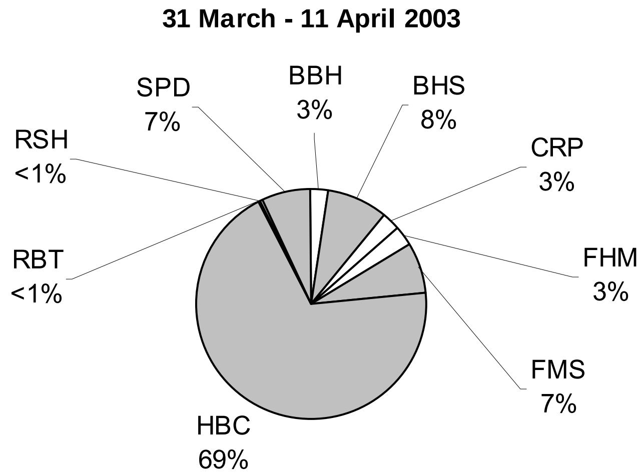


Figure 3. Turbidity readings taken in Little Colorado River during spring 2003.



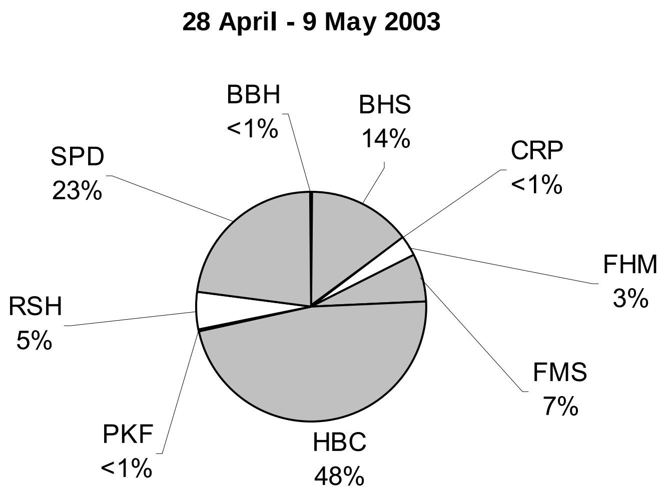
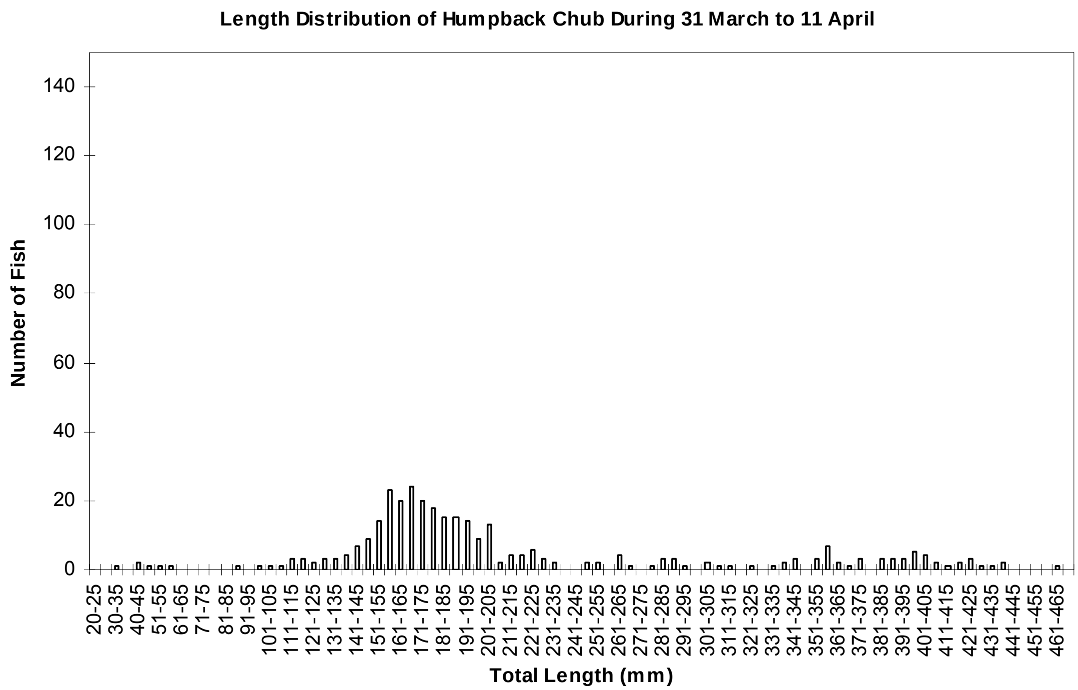


Figure 4. Observed species compositions of all fish captured. Shaded portions are native fish; Little Colorado River, spring 2003.

BBH = black bullhead (*Ameiurus melas*); BHS = bluehead sucker (*Catostomus discobolus*); 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*); RSH = red shiner (*Cyprinella lutrensis*); SPD = speckled dace (*Rhinichthys osculus*).



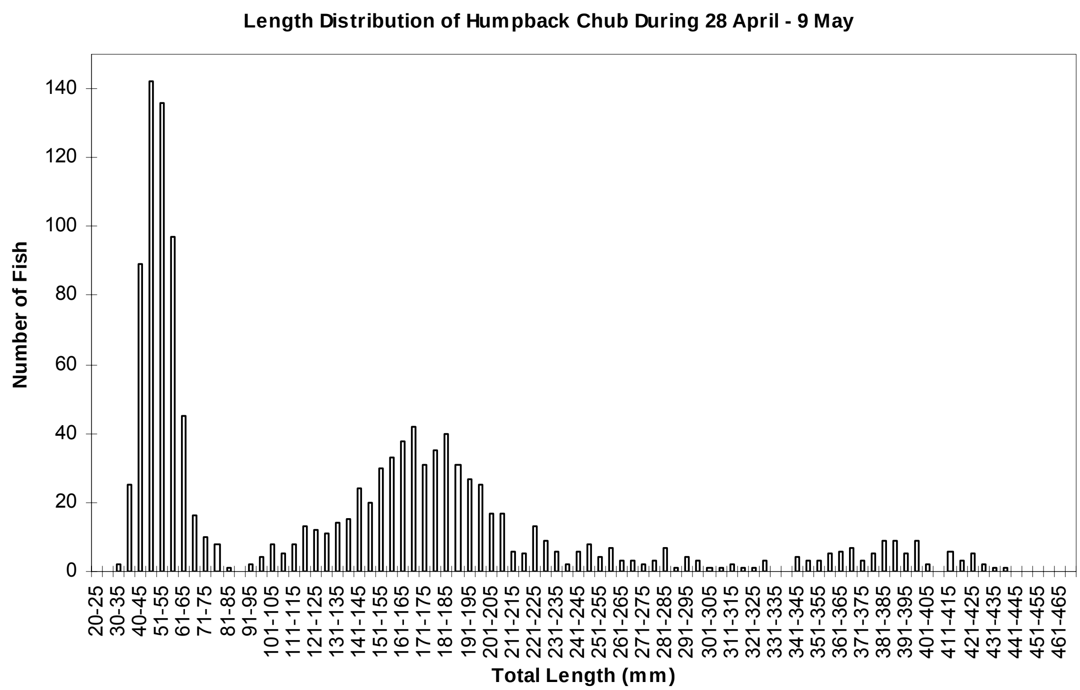
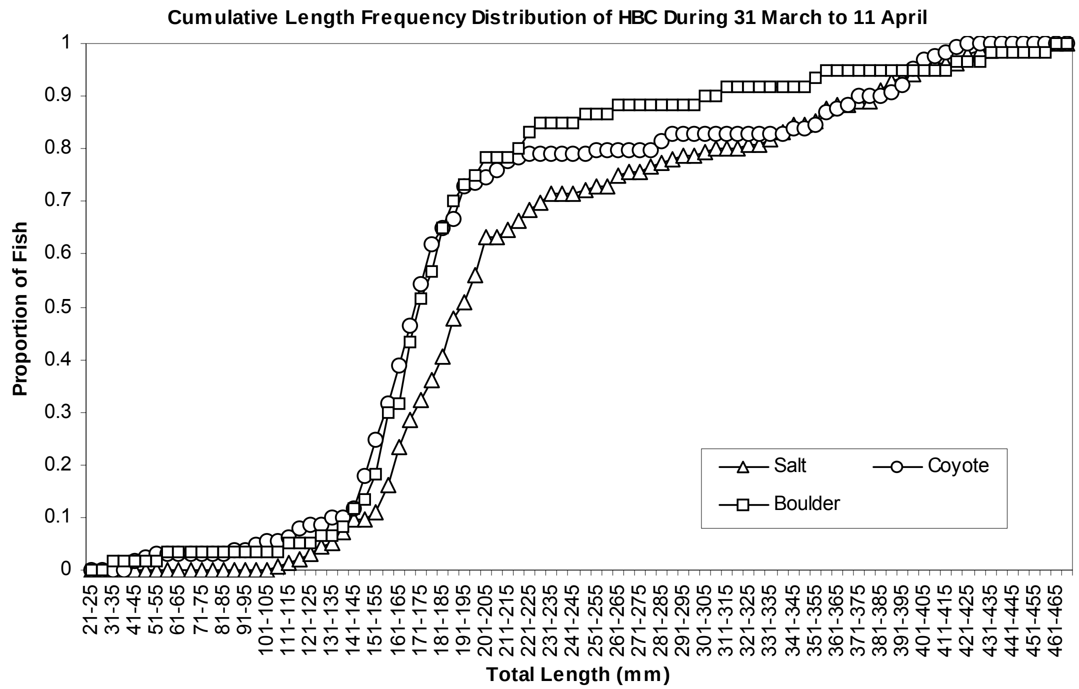


Figure 5. Total length frequency distributions of all humpback chub captured; Little Colorado River, spring 2003.



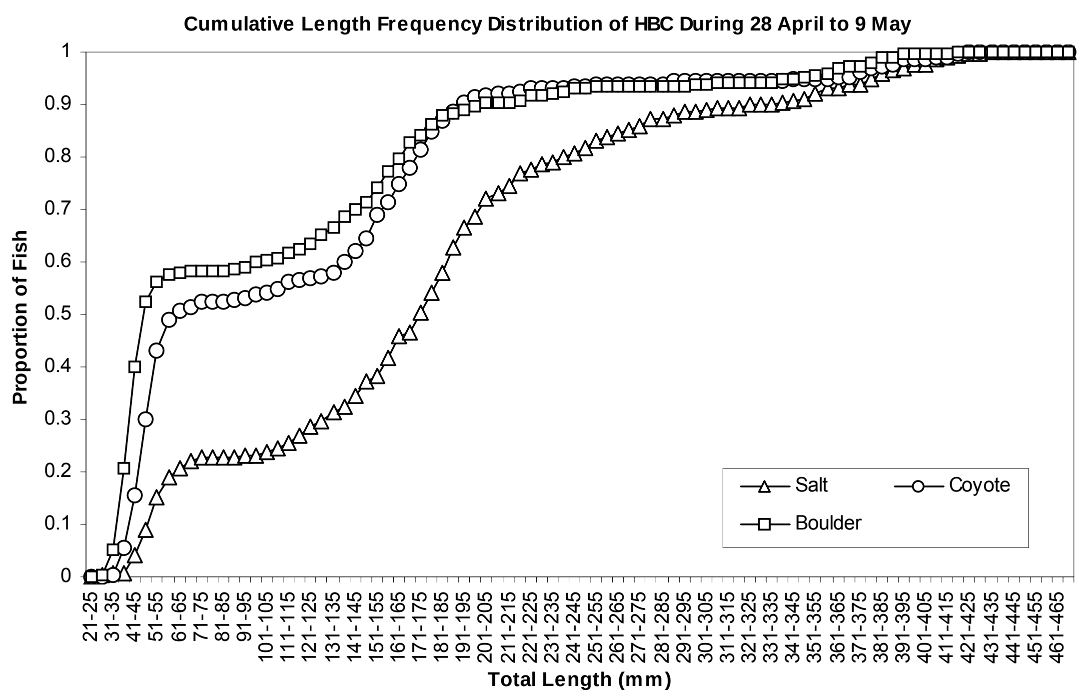
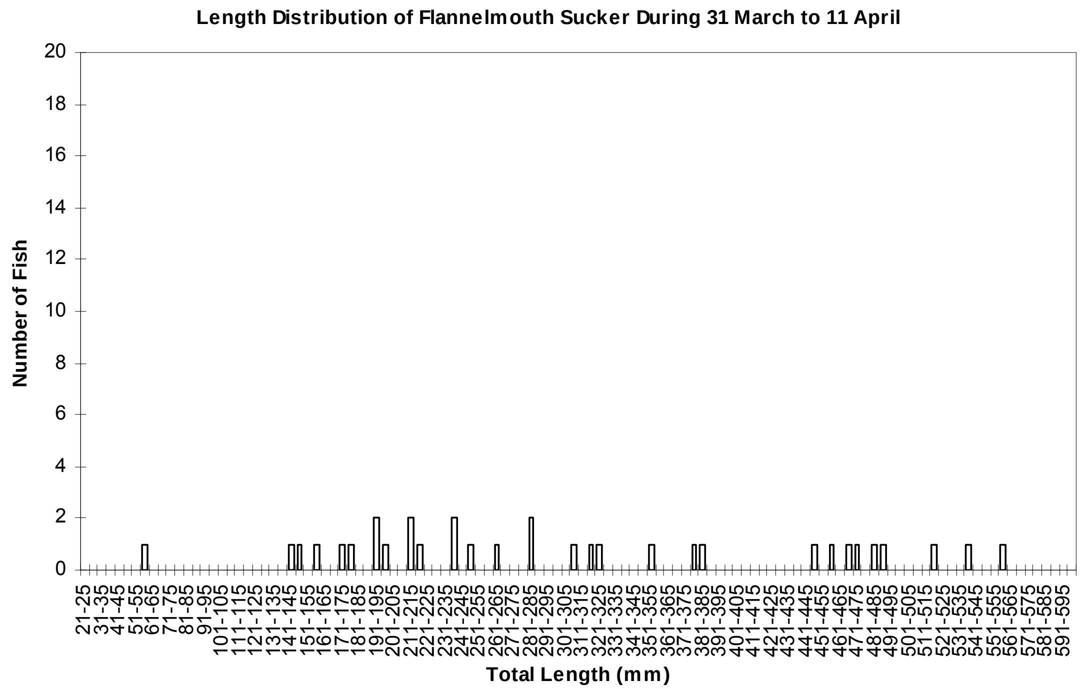


Figure 6. Cumulative length frequency charts of all HBC captured at three different reaches (Salt, Coyote and Boulders); Little Colorado River, spring 2003.



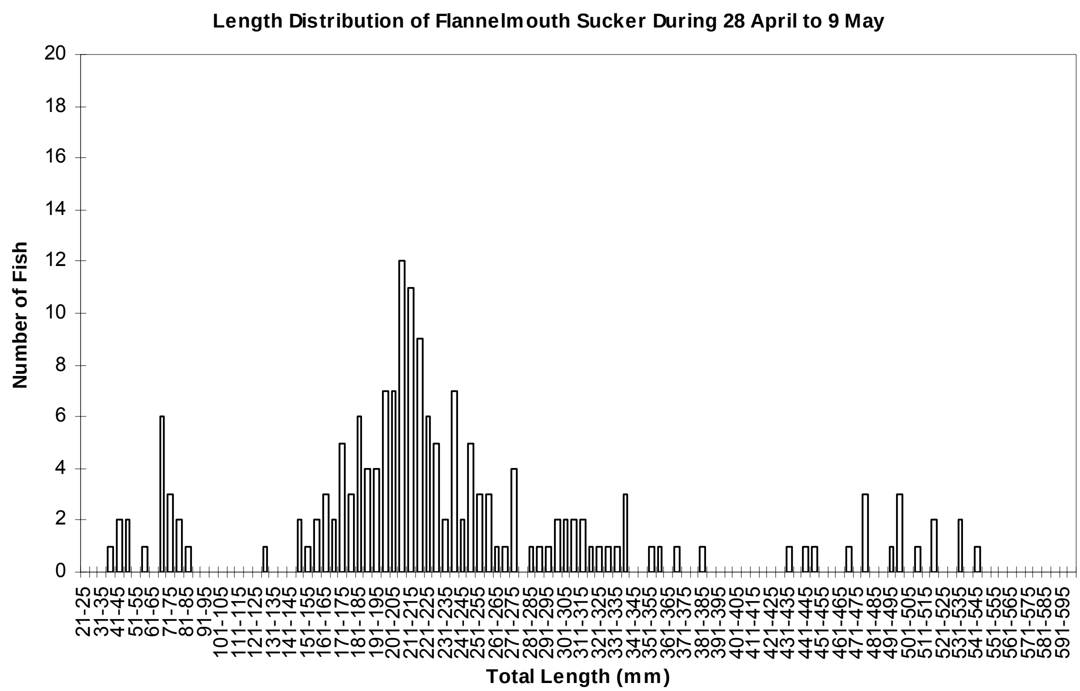
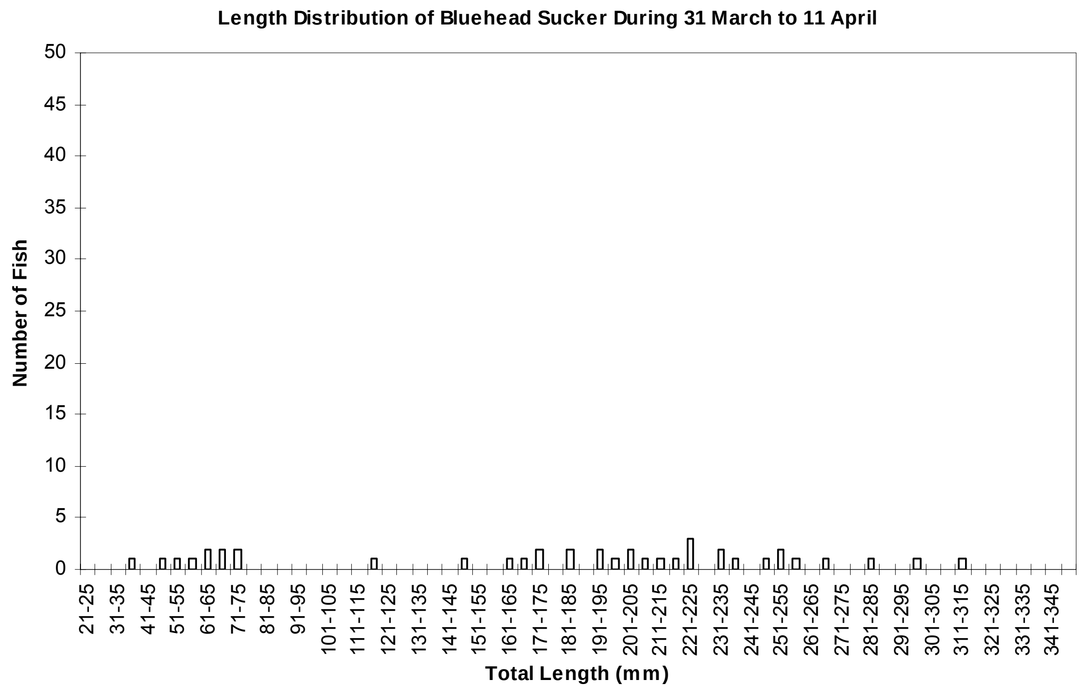


Figure 7 . Length frequency distribution of all flannelmouth sucker captured; Little Colorado River, spring 2003.



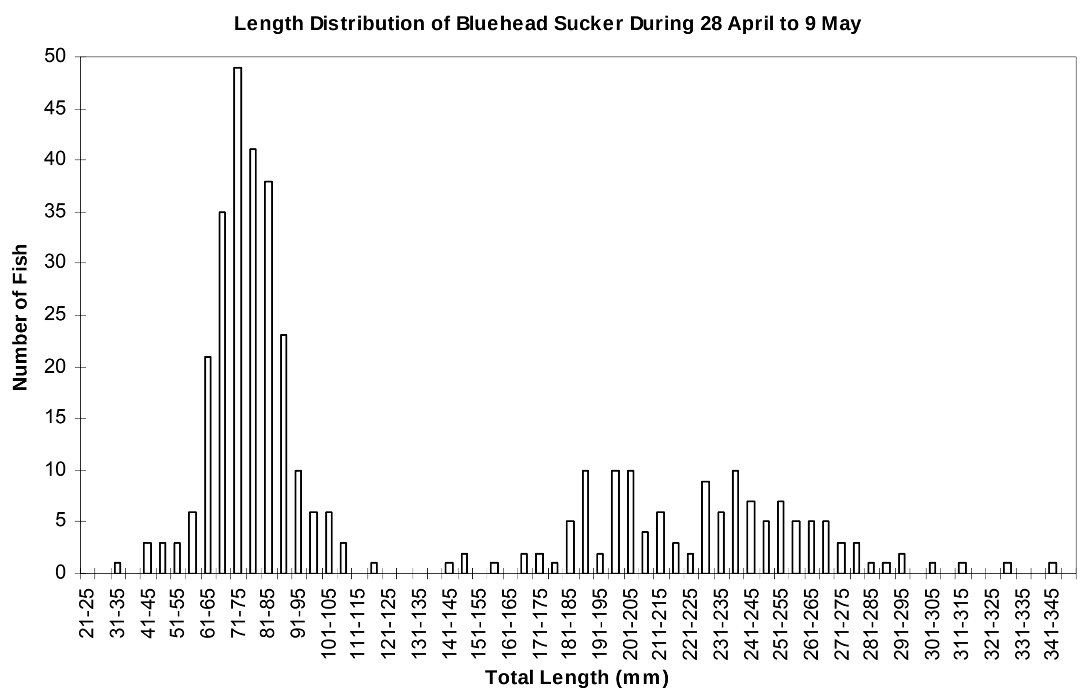


Figure 8 . Length frequency distributions of all bluehead sucker captured; Little Colorado River, spring 2003.

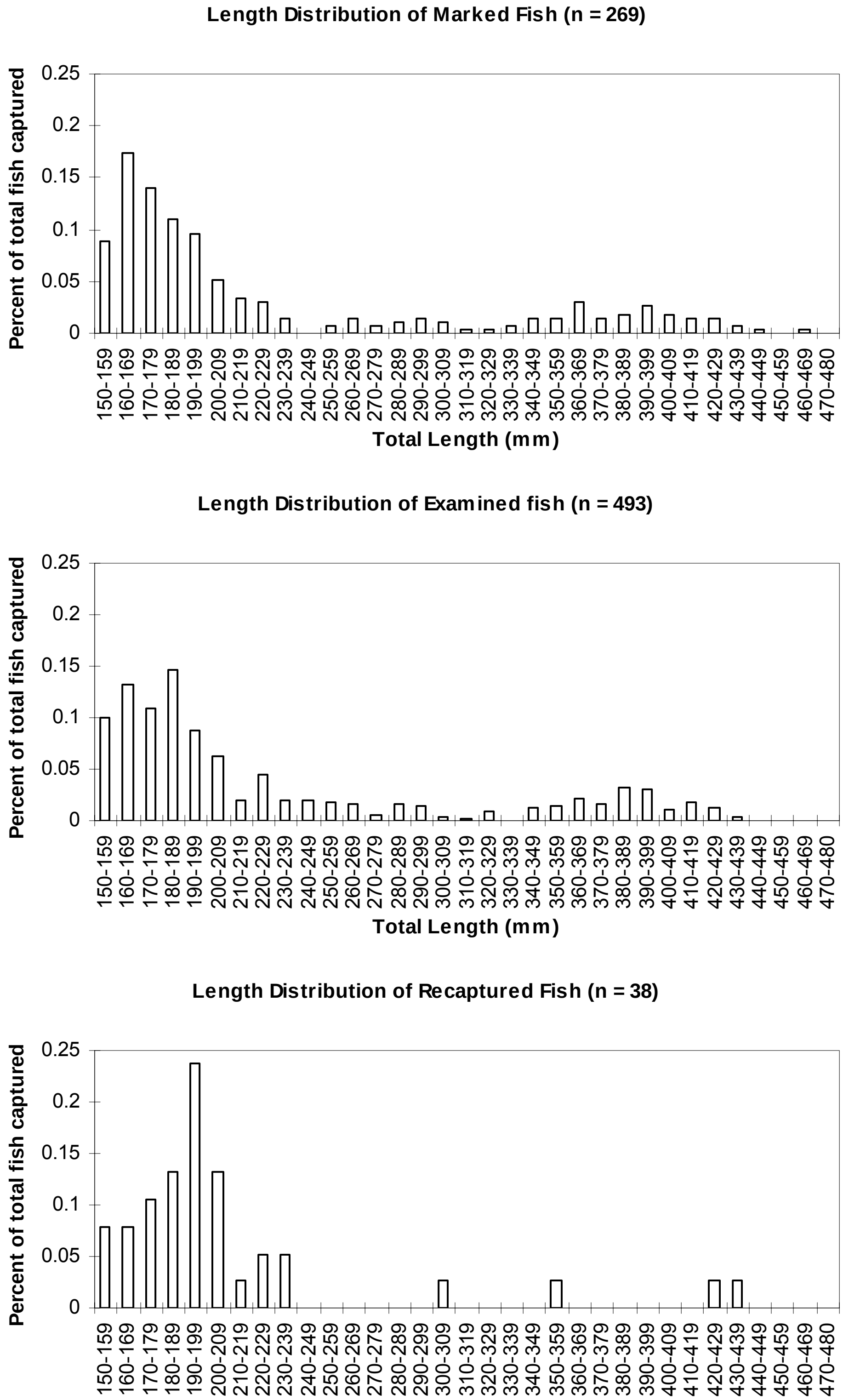
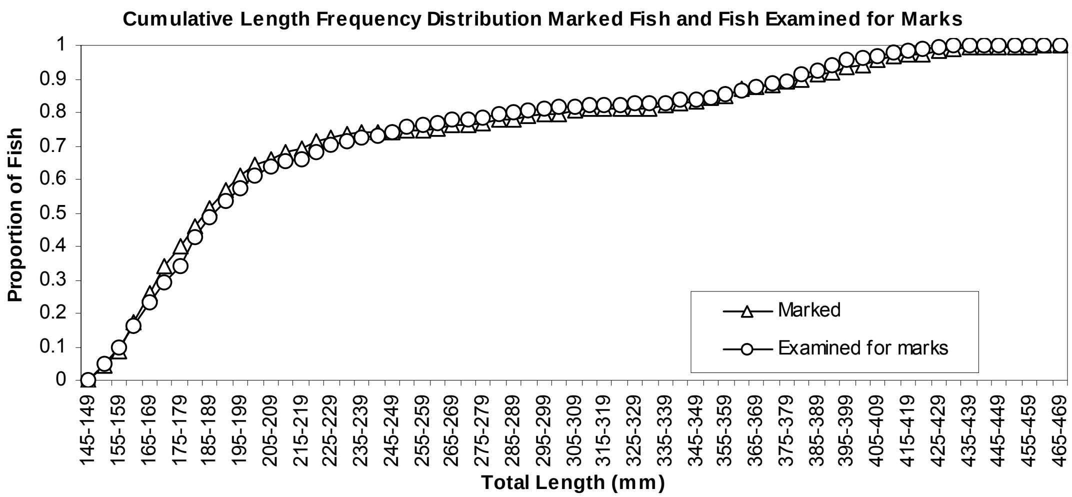


Figure 9. Length frequency distributions (shown as percentage of total) of all humpback chub ≥ 150 mm captured during the marking and recapture events; Little Colorado River, spring 2003.



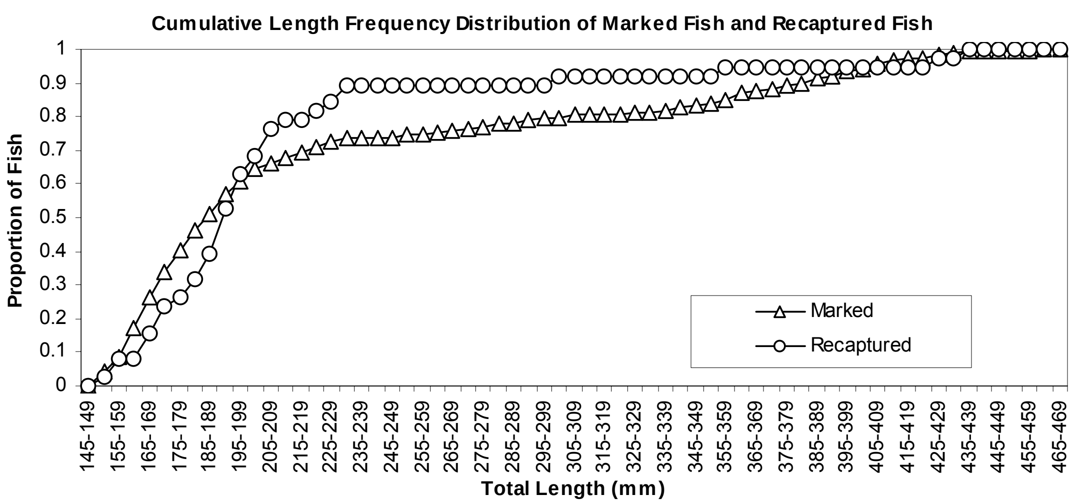


Figure 10. Cumulative length frequency distributions of humpback chub ≥ 150 mm captured; Little Colorado River, spring 2003.

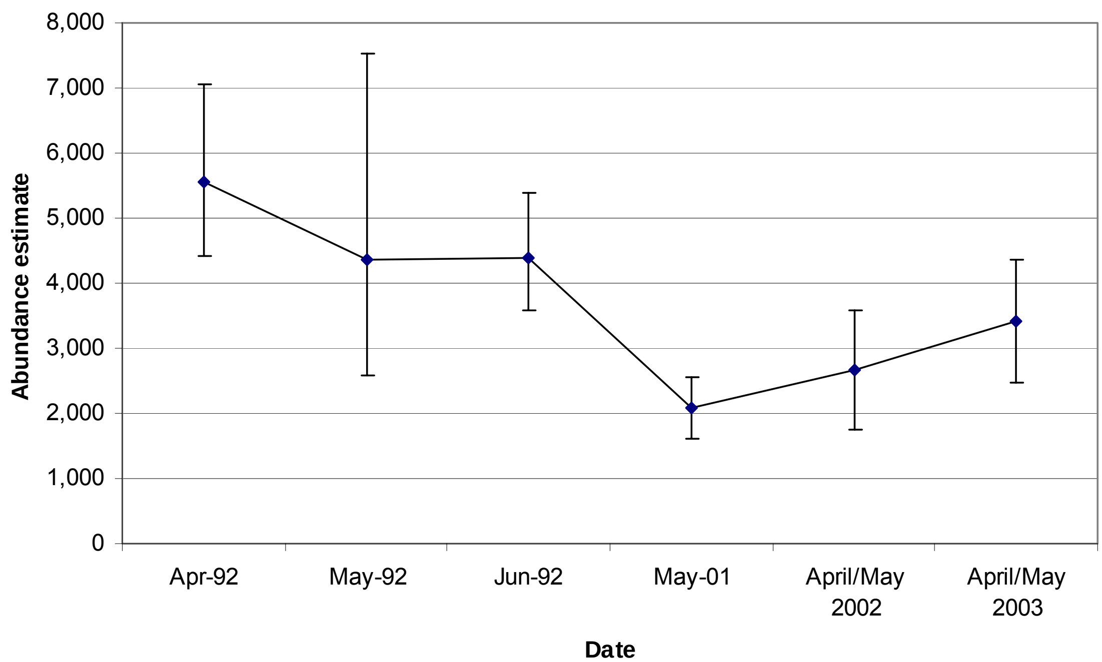


Figure 11. Spring abundance estimates of humpback chub ≥ 150 mm. 1992 estimates are from Douglas and Marsh (1996); 2001 estimate is from Van Haverbeke and Coggins (2002), 2002 estimate is from Van Haverbeke (2003).

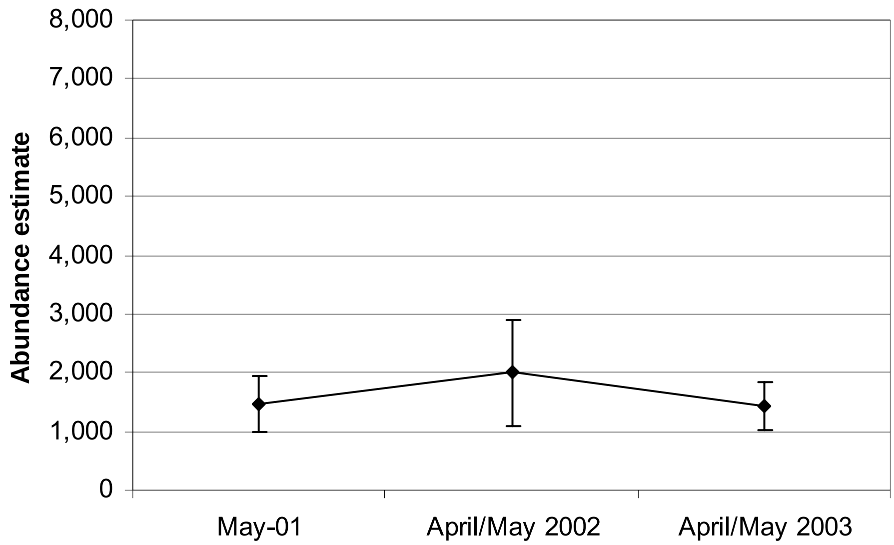


Figure 12. Spring abundance estimates of humpback chub ≥ 200 mm; 2001 estimate is from Van Haverbeke and Coggins (2002), 2002 estimate is from Van Haverbeke (2003).

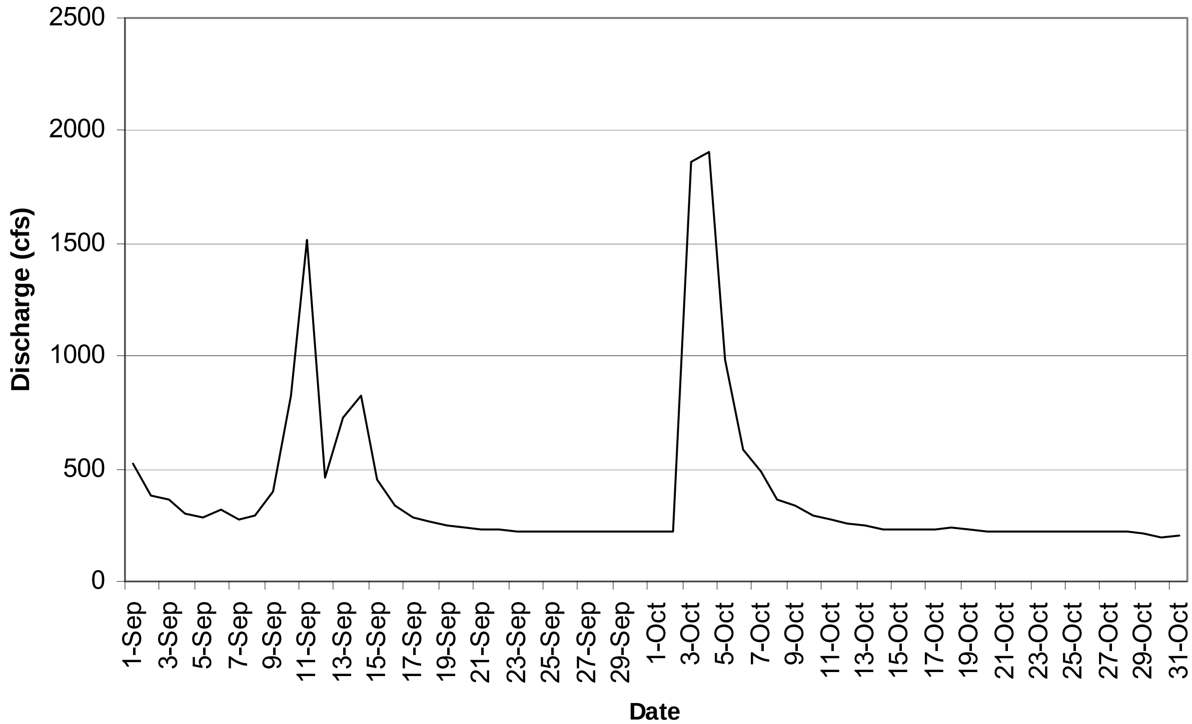


Figure 13. Mean daily dicharge (cubic feet/second; cfs) from Little Colorado River approximately 1.0 rkm above the confluence. Provisional data from USGS gage station 0940300.

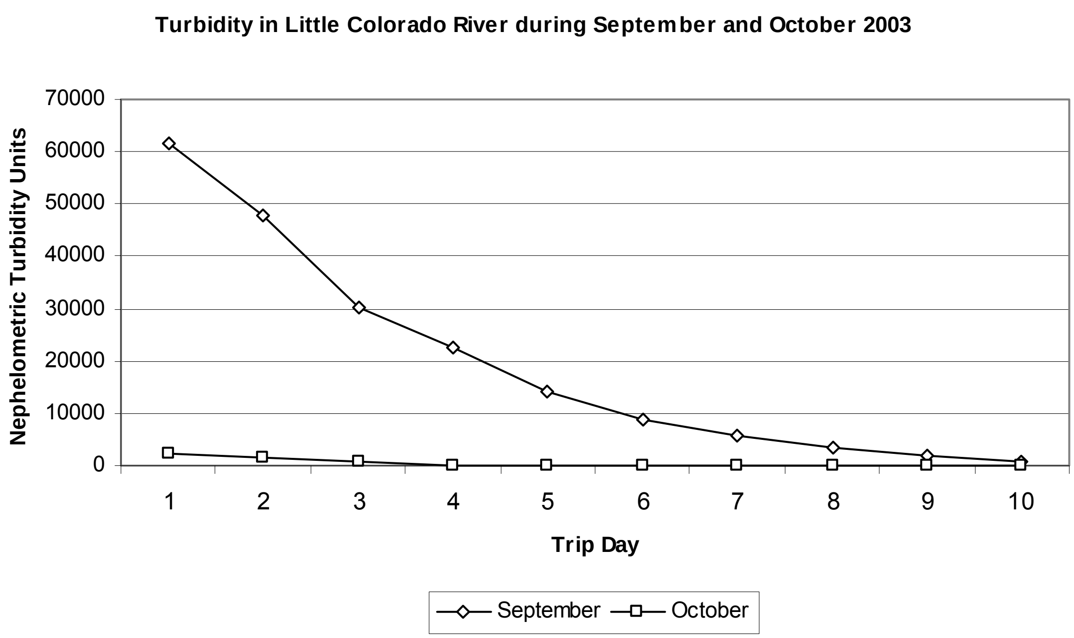
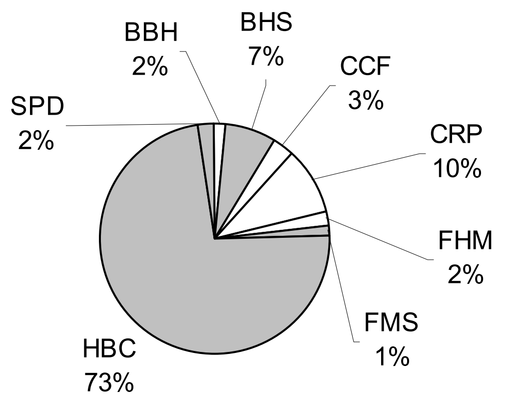


Figure 14. Turbidity readings taken during fall 2003; Little Colorado River.

15 - 24 September 2003



20 - 29 October

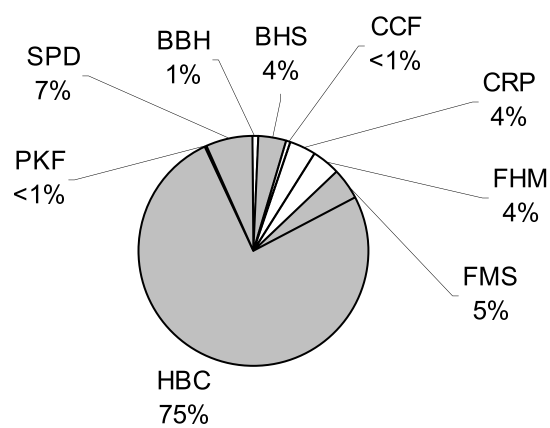
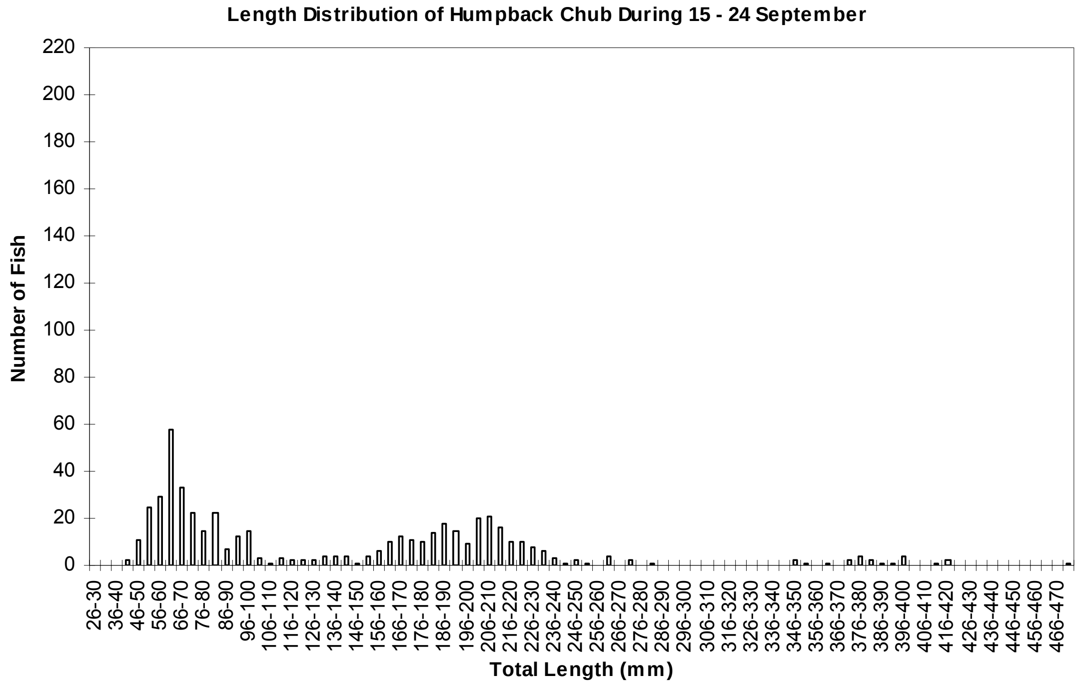


Figure 15. Observed species comparisons of fish captured. Shaded portions are native fish; Little Colorado River, fall 2003.

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*); SPD = speckled dace (*Rhinichthys osculus*).



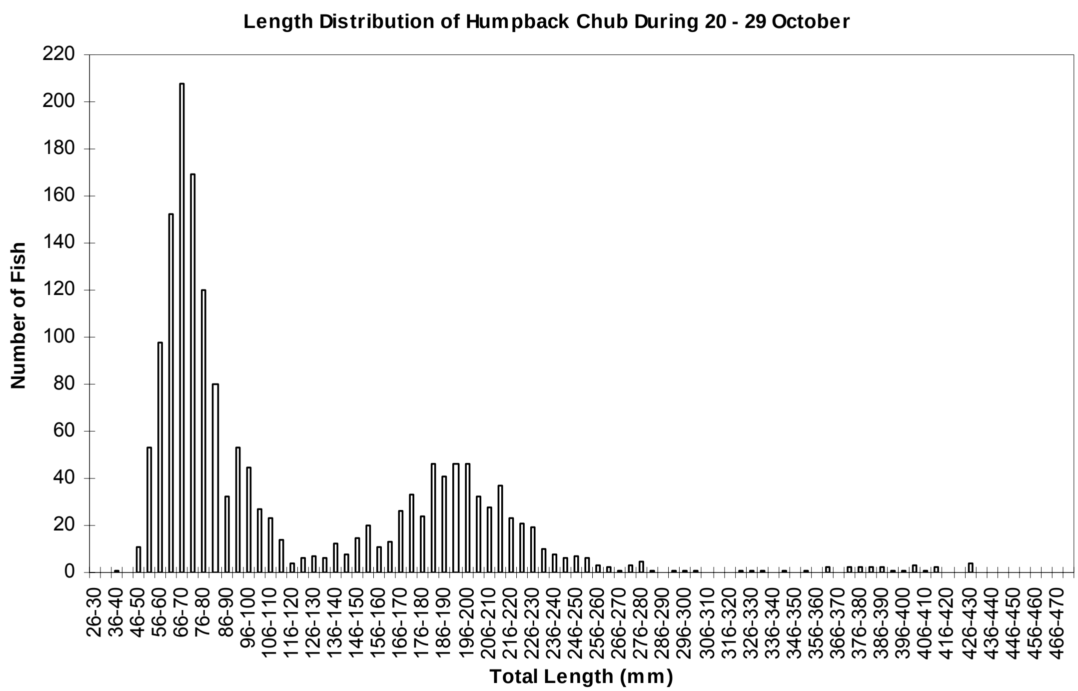
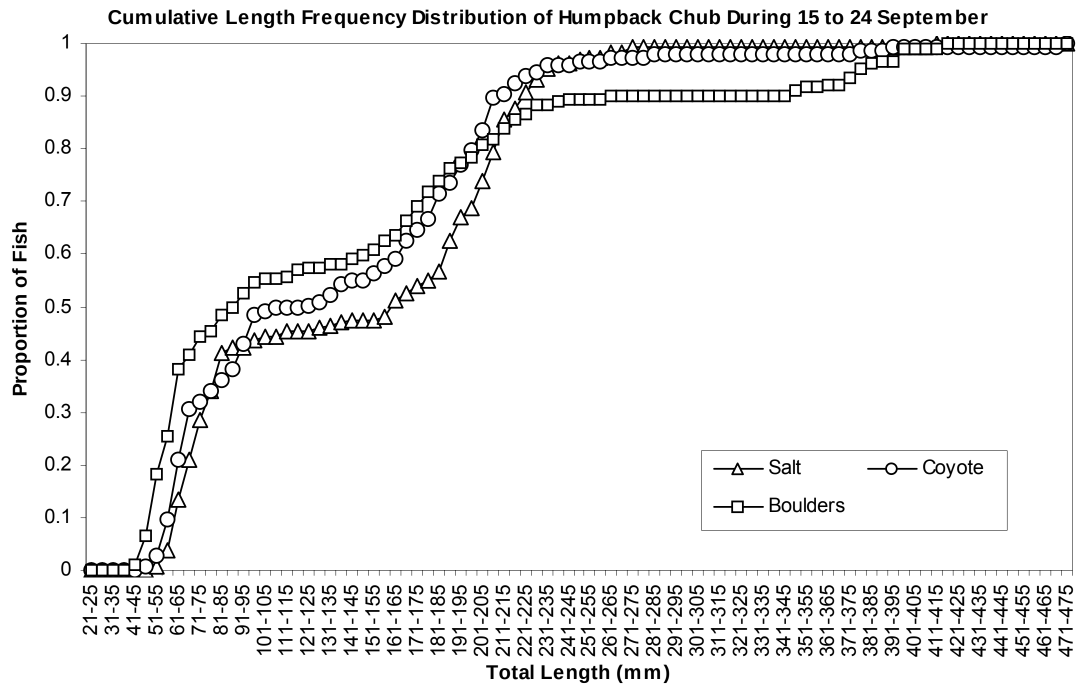


Figure 16 . Length frequency distributions of all humpback chub captured; Little Colorado River, fall 2003.



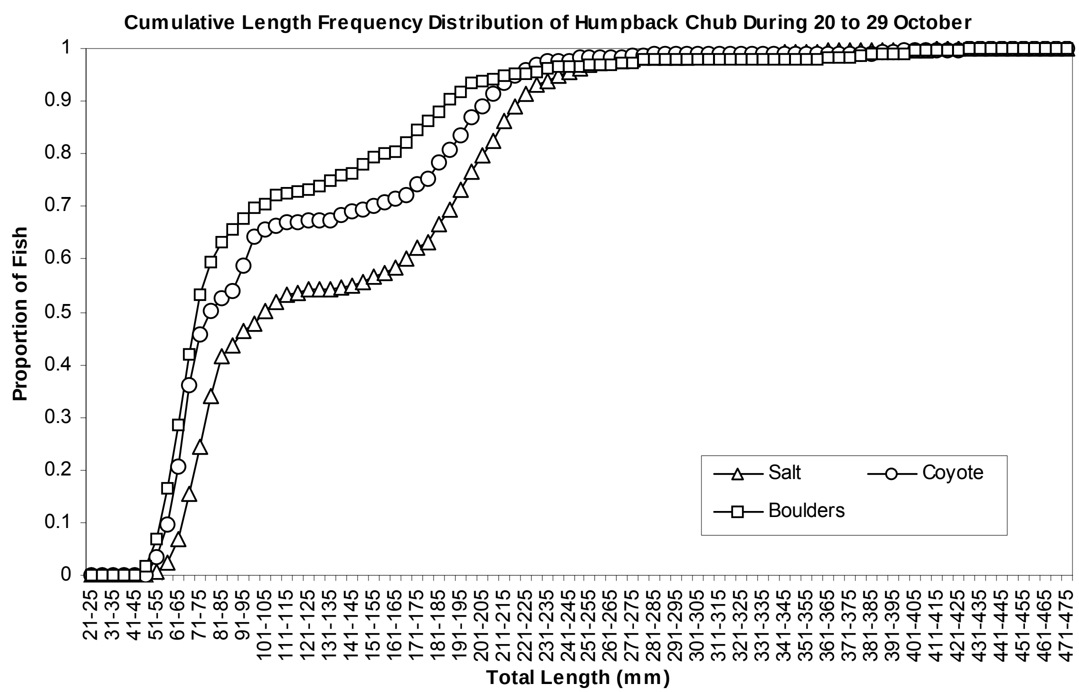
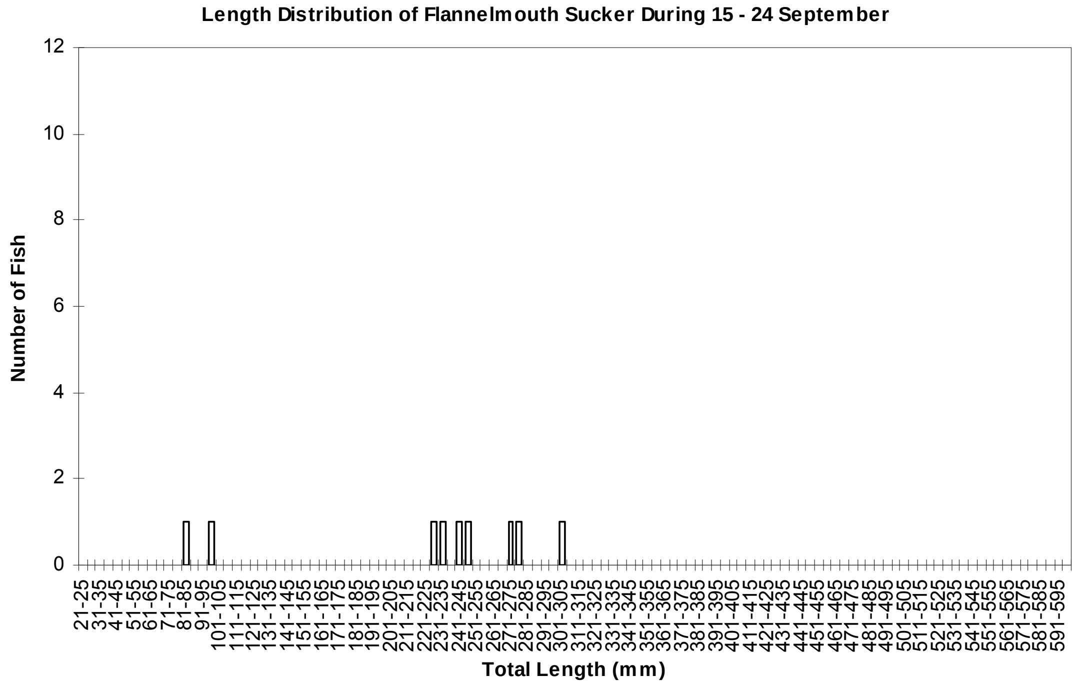


Figure 17. Cumulative length frequency charts of all humpback chub captured at three different reaches (Salt, Coyote and Boulders); Little Colorado River, fall 2003.



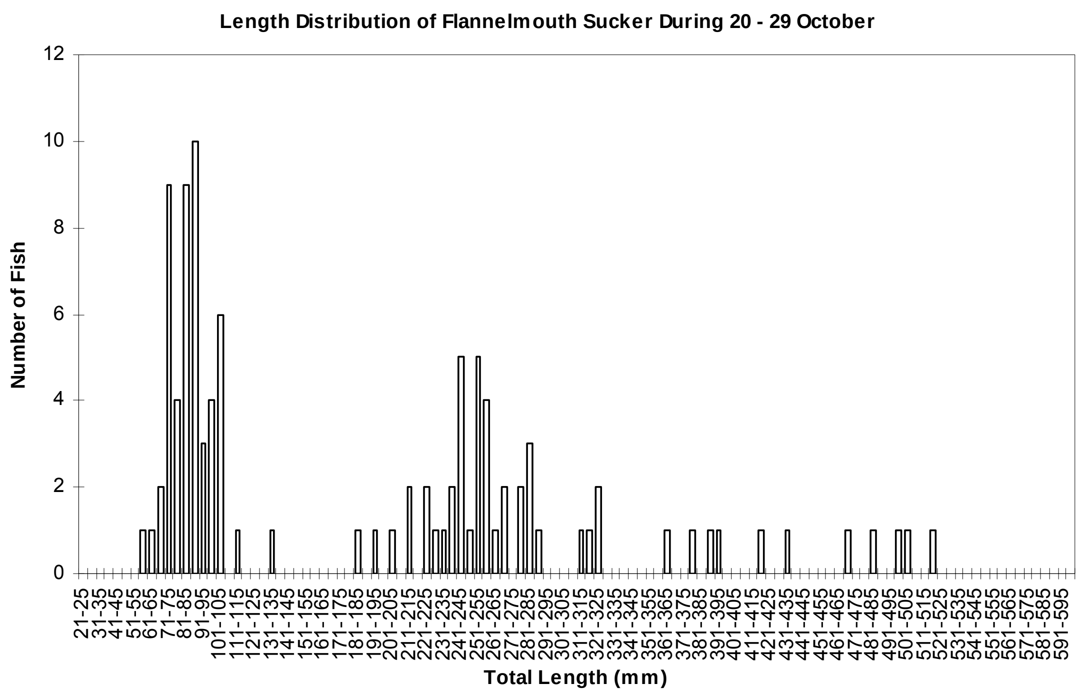
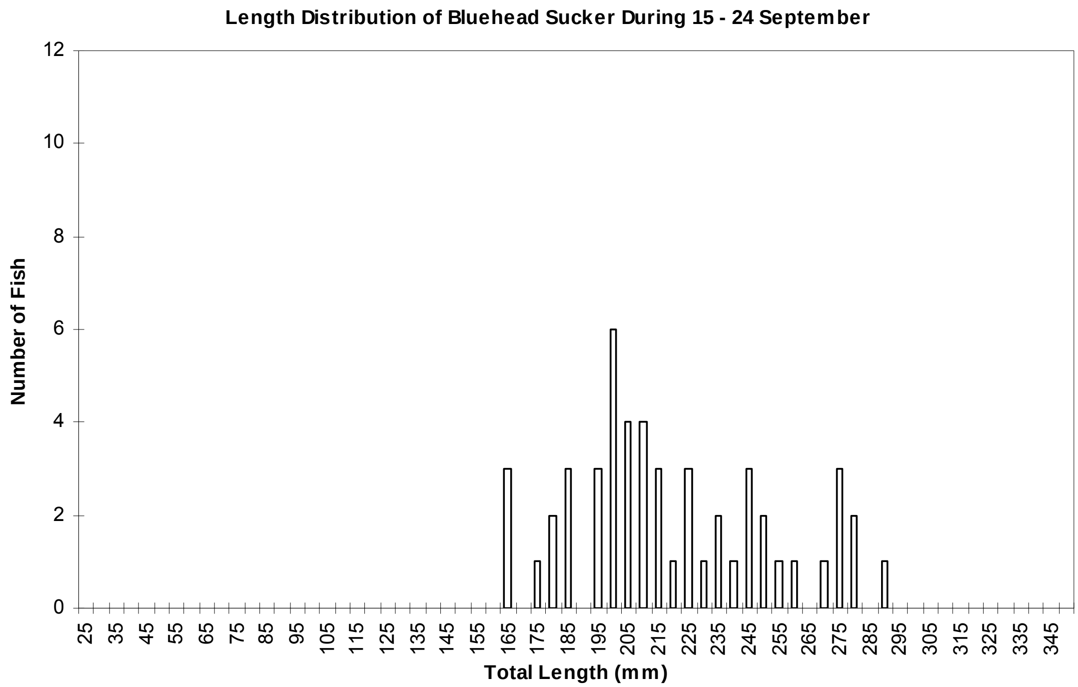


Figure 18 . Length frequency distribution of all flannelmouth sucker captured; Little Colorado River, fall 2003.



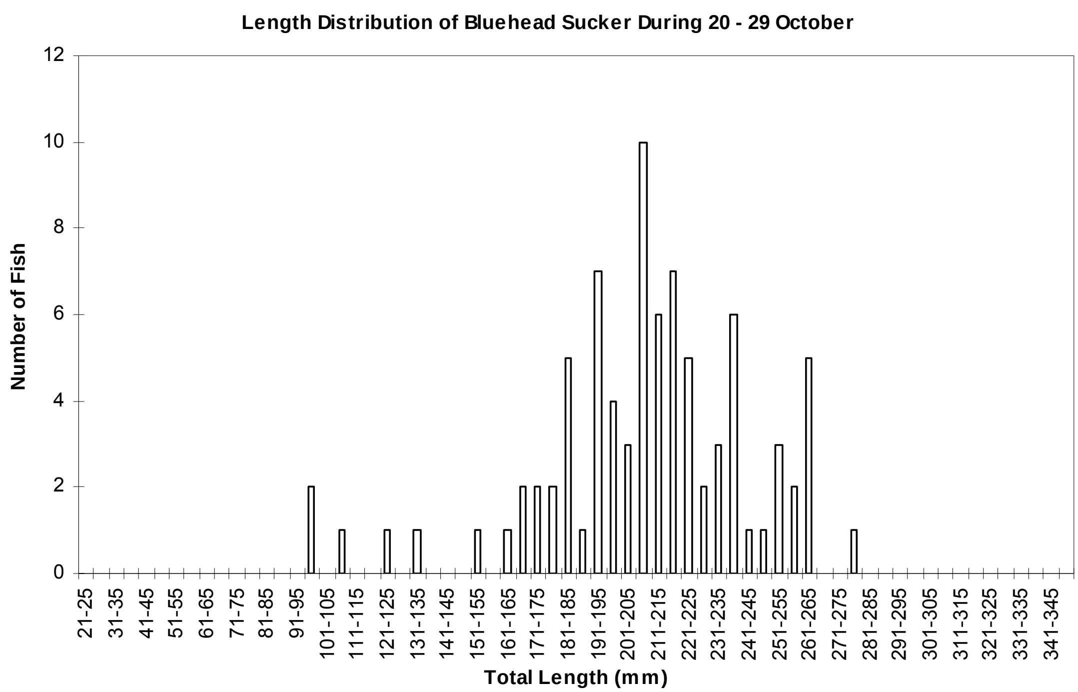


Figure 19 . Length frequency distributions of all bluehead sucker captured; Little Colorado River, fall 2003.

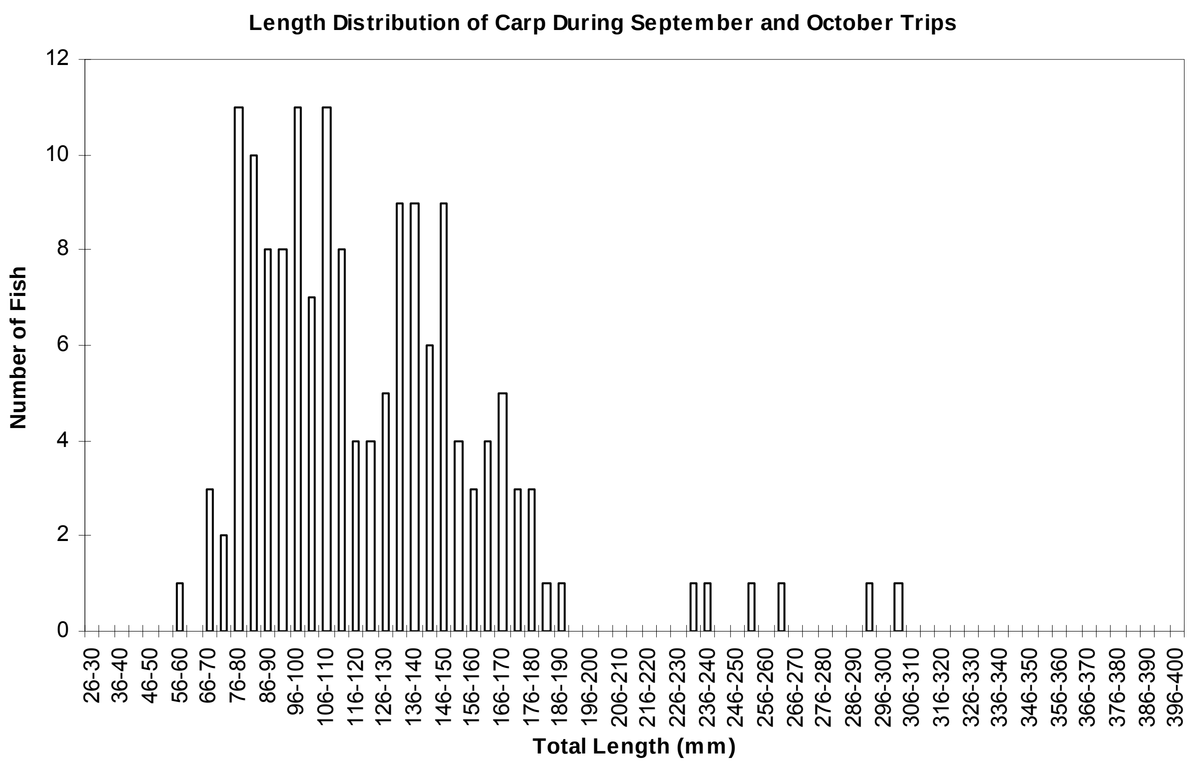


Figure 20. Length frequency distributions of all carp captured; Little Colorado River; fall 2003.

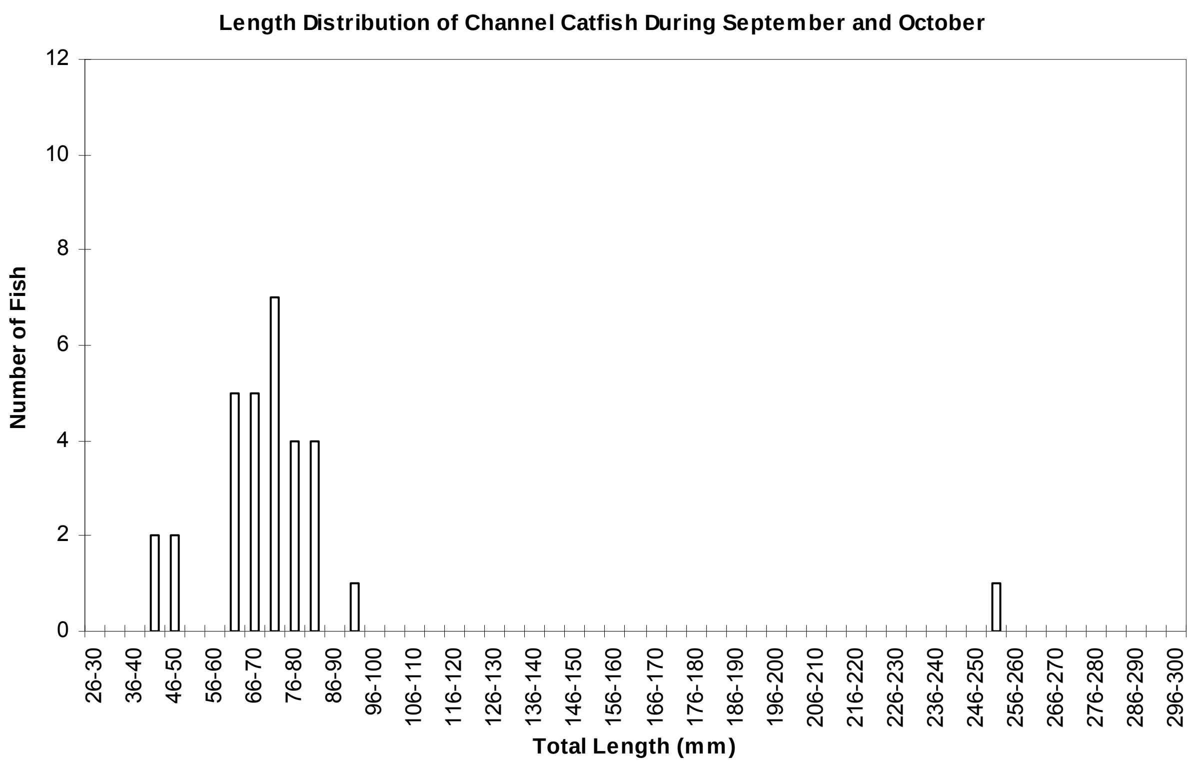


Figure 21. Length frequency distribution of all channel catfish captured; Little Colorado River; fall 2003.

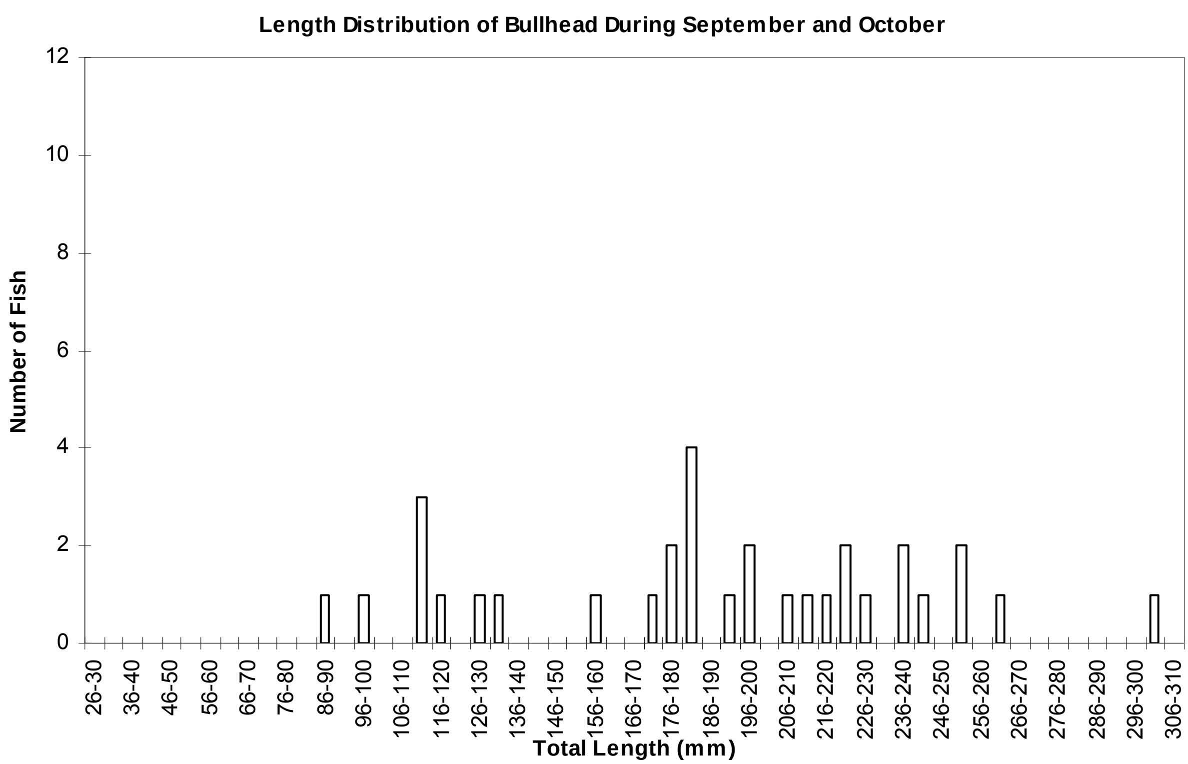


Figure 22. Length frequency distribution of all bullhead captured; Little Colorado River; fall 2003.

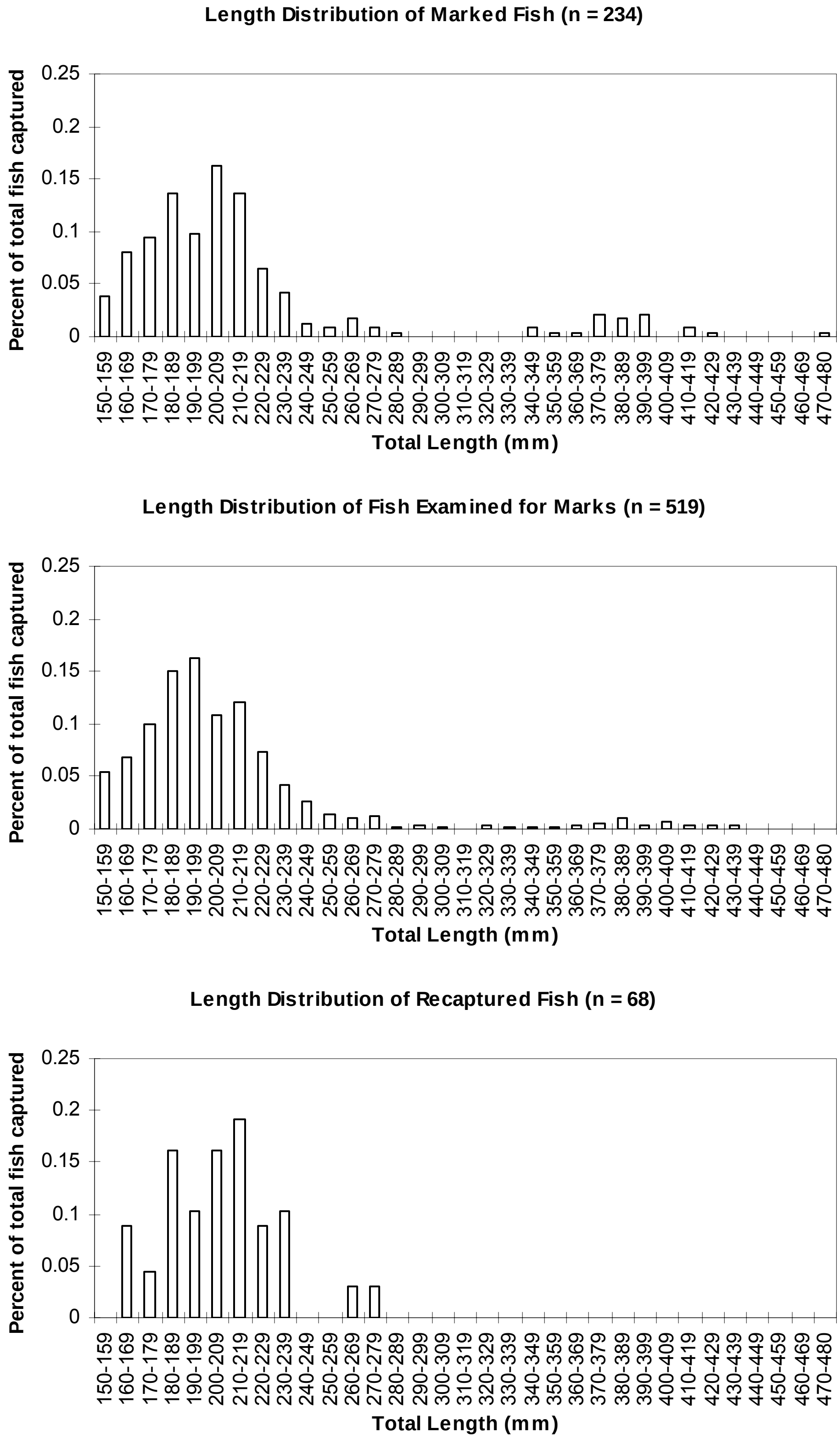


Figure 23 . Length frequency distributions (shown as percentage of total) of all humpback chub ≥ 150 mm captured during the marking and recapture events; Little Colorado River, fall 2003.

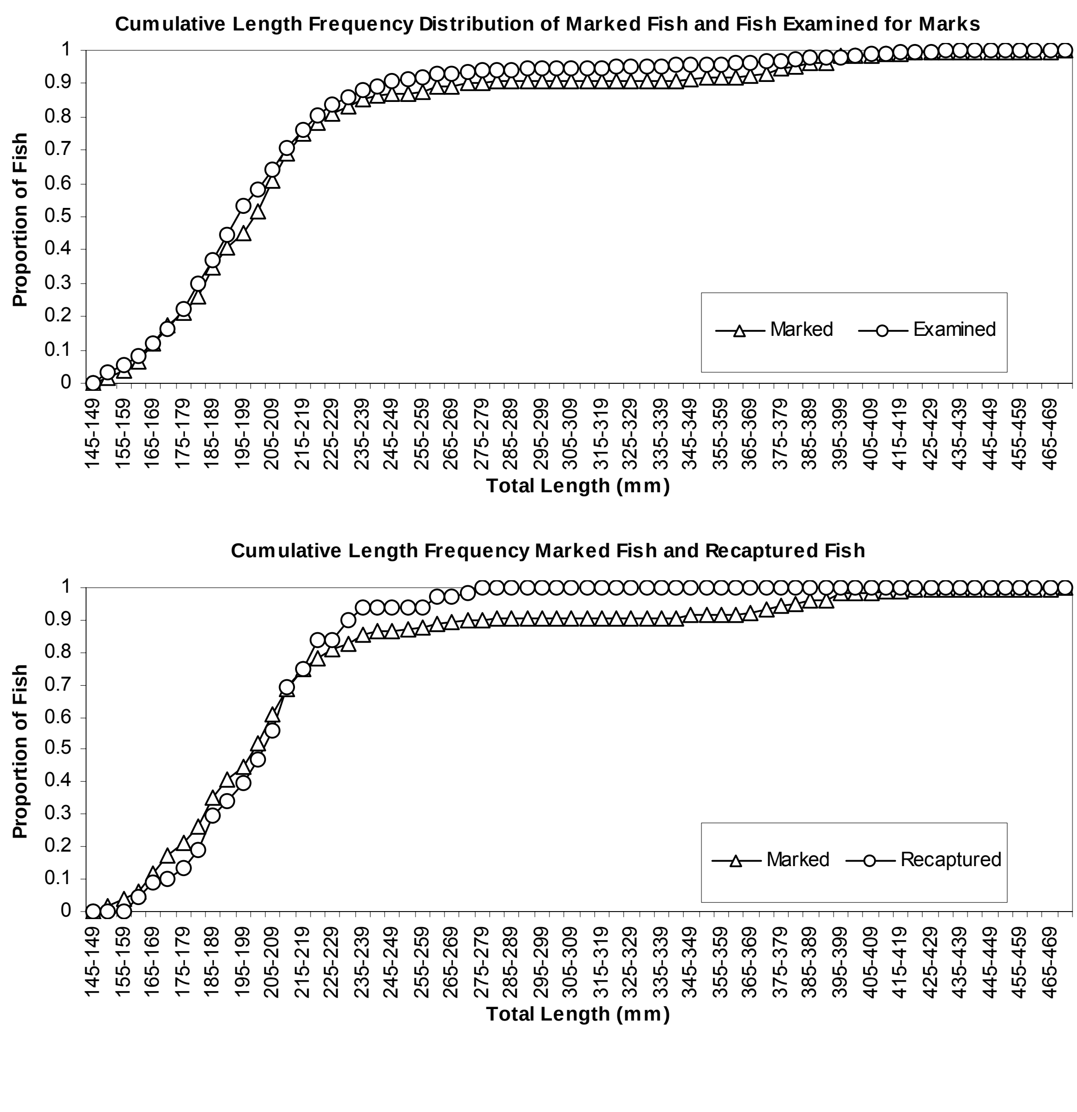


Figure 24. Cumulative length frequency distributions of humpback chub ≥ 150 mm; Little Colorado River, fall 2000.

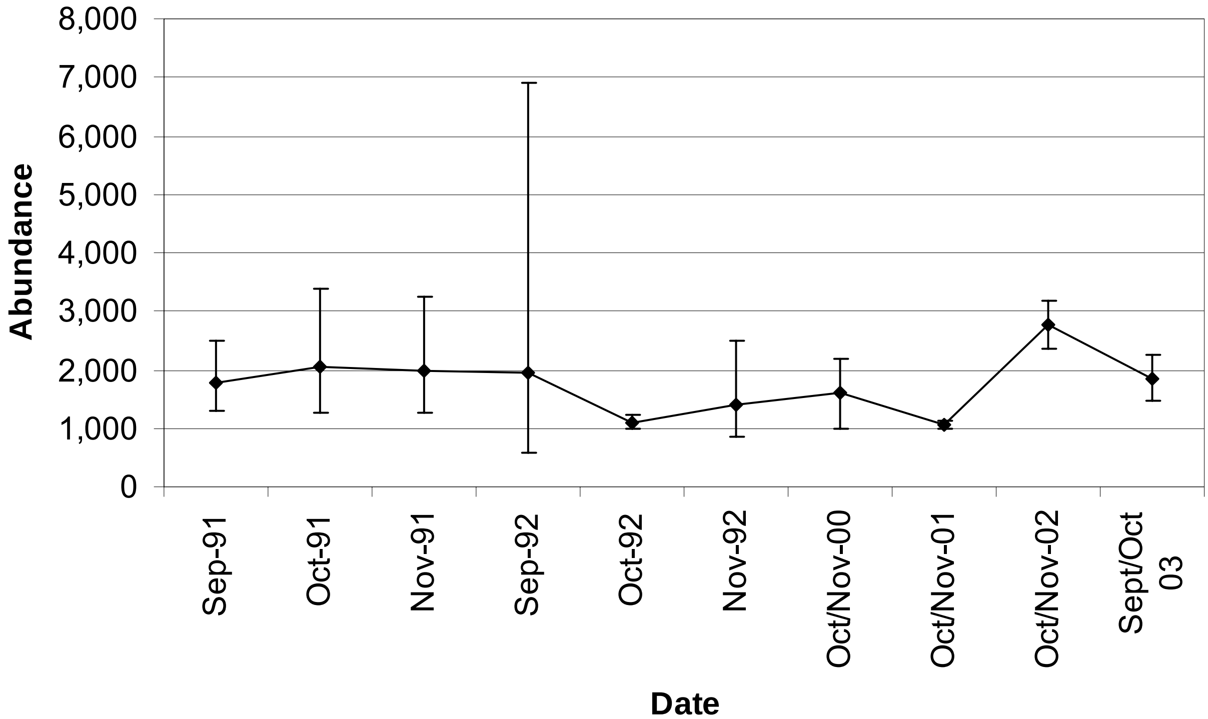


Figure 25. Fall abundance estimates of humpback chub ≥ 150 mm. 1991 and 1992 estimates are from Douglas and Marsh (1996); 2000 estimate is from Coggins and Van Haverbeke (2001), 2001 estimate is from Van Haverbeke and Coggins (2002).

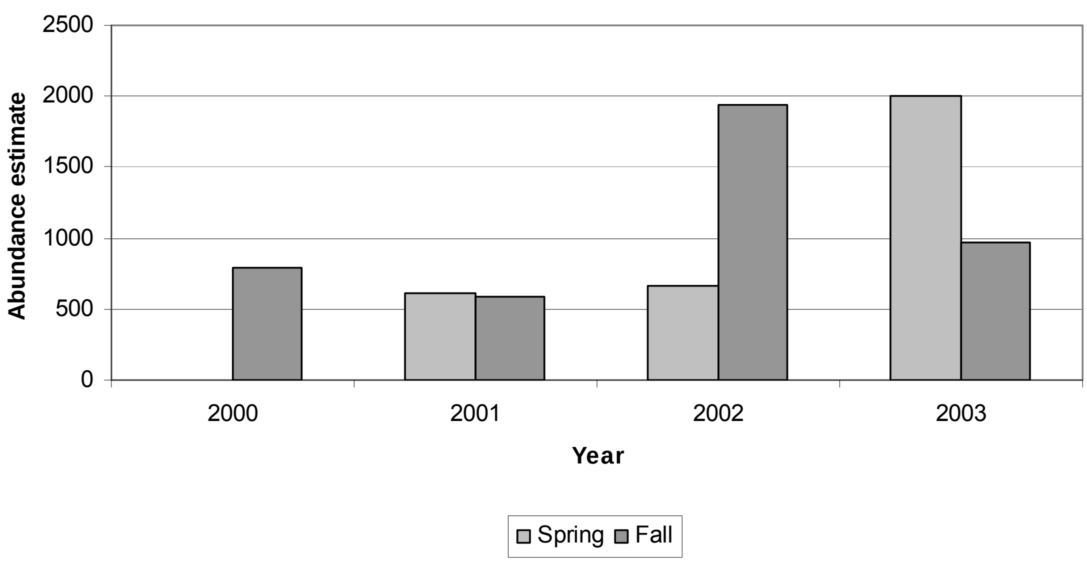


Figure 26. Provisional abundance estimates of humpback chub from 150 to 200 mm from fall 2000 to fall 2003 (error bars not provided).

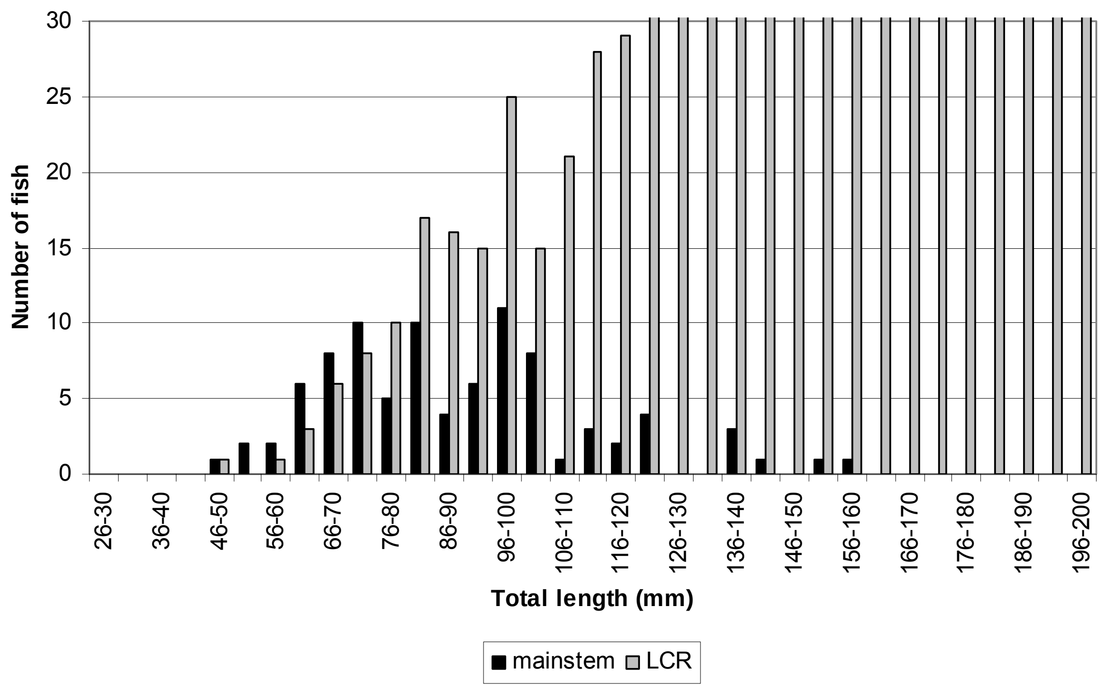


Figure 27. Length frequency distributions of humpback chub captured in hoopnets in the mainstem Colorado below the confluence with the Little Colorado River (LCR) and in hoopnets in the Little Colorado River during fall 2002.