Stock Assessment and Fisheries Monitoring Activities in the Little Colorado River within Grand Canyon During 2002

Final Report

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David R. Van Haverbeke

U. S. Fish and Wildlife Service

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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 for 2002 (USFWS 2001). As a result, the U.S. Fish and Wildlife Service (USFWS) was contracted by GCMRC to conduct stock assessment and monitoring activities in the LCR. A total of four monitoring trips were conducted during 2002: (1) 8 to19 April, (2) 13 to 24 May, (3) 16 to 27 September, and (4) 21 October to 1 November. 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 experiments 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 2,666 (SE = 463) HBC ≥ 150 mm total length residing in the lower LCR during the spring of 2002. Of these fish, it is estimated that there were 2,002 (SE = 463) HBC ≥ 200 mm (4+ year old adults). The results of the fall mark-recapture effort indicate that there were 2,774 (SE = 209) HBC ≥ 150 mm total length residing in the lower LCR during the fall of 2002. Of these fish, it is estimated that there were 839 (SE = 87) HBC ≥ 200 mm (4+ year old adults). In addition, it was estimated that there were 2,033 (SE = 284) HBC between 100 and 149 mm total length residing in the lower LCR during fall 2002 (this later estimate was not requested to be performed in the spring by GCMRC).

Introduction

With the passage of the Grand Canyon Protection Act in 1992, the Glen Canyon Dam Adaptive Management Program was initiated. The heart 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 HBC is particularly important due to its status as a federally listed endangered species (1967 (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 (e.g., Kaeding and Zimmerman 1983, Valdez and Ryel 1995, Douglas and Marsh 1996, Robinson et al. 1998, Gorman and Stone 1999, Clarkson and Childs 2000). However, the majority of this effort has been studying the life history and ecology of this species, rather than monitoring the population status. Therefore, the AMWG is unable to effectively assess the impacts of the operation of Glen Canyon Dam on HBC, or evaluate whether the fish management objectives in the Grand Canyon are being met. As a result, GCMRC has initiated a program that focuses on stock assessment for future long-term monitoring of Grand Canyon fishes.

After testing various study designs (Coggins and Van Haverbeke 2001), in June 2000, the USFWS undertook a mark-recapture experiment to estimate HBC abundance in the Little Colorado River (LCR). A two-pass mark-recapture experiment was conducted to estimate the fall abundance of HBC in the LCR. These trips occurred in October and November 2000 (Coggins and Van Haverbeke 2001). Two more mark-recapture experiments were carried out in 2001 (i.e., one spring estimate during May and June 2001, and another fall estimate during October and November 2001). As a result of the success of these mark-recapture experiments, GCMRC contracted the USFWS to conduct two additional mark-recapture efforts during 2002 in the LCR.

Objectives

The primary goal of the 2002 sampling trips was to obtain information for the stock assessment of HBC. A secondary goal of these trips was to provide information for characterizing the natural history of the LCR fish community. Therefore, all species of native and non-native fish were monitored. The specific objectives for 2002 were:

1. Obtain spring and fall 2002 population estimates of HBC $\geq$ 150 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 used for models designed by GCMRC to estimate long-term population and recruitment trends of HBC.

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 2002. The trip dates were: (1) 8 to 19 April, (2) 13 to 24 May, (3) 16 to 27 September, and (4) 21 October to 1 November. Participating field crew included personnel from USFWS, Arizona Game and Fish Department (AGFD), SWCA Inc., and volunteers (Table 1). A special thank-you is extended to all who participated on the trips.

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 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. The 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). The 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). The 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 effort was hoopnets. Hoopnets were 0.5 - 0.6 m diameter, 1.0 m length, 6 mm (1/4") mesh, with a single 0.1 m throat. Sixty hoopnets 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 four days (i.e., this included four nights); except during the November trip when each sub-reach was fished for three days (including three nights). Some very minor exceptions to this rule were made to accommodate logistical problems. A decision was made to fish each hoopnet for three days during November because calculations based on the previous two years of hoopnetting effort showed that the fourth day was only yielding an additional 8% catch of unique HBC (i.e., unique fish are fish that are captured only once within a trip, and do not include recaptures of the same fish within the same trip). In addition to evenly distributing the hoopnets throughout each reach and sub-reach, each hoopnet 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 hoopnets 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 hoopnet was checked and emptied of fish daily.

In an attempt to maximize catches, nets were baited with AquaMax carnivorous fish food (Purina Mills Inter. Inc., Brentwood, MO). Approximately 80 to 100 g of fish food was placed in a cloth container (socks or mesh bags) and tied at the cod end of each net.

All net locations were recorded as distance (rkm) above the confluence, side of the river (right, left, center), and were individually marked on topographic maps supplied by GCMRC. Each net location was also recorded using a Garmin GPS, unless a reading could not be obtained because of poor satellite coverage. At the request of GCMRC, general habitat characteristics were recorded for each net set, including shoreline habitat, hydraulic unit, substrate, and cover type (Table 2).

Fish

Data collected for native fish captured included: total and fork lengths (mm), 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; and if lacking a tag, were injected with a PIT tag. All other native fish ≥ 150 mm were also scanned for a PIT tag, and if not already tagged, were injected with a new PIT tag. Large bodied non-native fish (primarily ictalurids and salmonids) were sacrificed and their stomach contents were examined and recorded in the field.

Water quality

Measured water quality parameters included temperature (^{o}C) and turbidity (nephelometric turbidity units; NTUs). Turbidity readings were taken daily with a Hach 2100P turbidimeter. All water quality data was gathered at Salt reach (~10.8 km), except for during the October trip when it was collected at Boulders reach (~2.0 km).

Mark-Recapture Analysis and Assumptions

Two mark-recapture experiments (spring and fall) were conducted to estimate the abundance of HBC ≥ 150 mm in the lower 14.2 km of the LCR. Marking events occurred during the first spring trip (8 to 19 April) and during the first fall trip (16 to 27 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. Recapture events occurred during the second spring trip (13 to 24 May), and during the second fall trip (21 October to 1 November).

During the two fall trips, a population estimate was also conducted on HBC between 100 and 149 mm. This was performed by giving each HBC in this size class a left pelvic fin clip during September (to distinguish them as marked fish), and by giving each HBC in this size class a right pelvic fin clip during October (to distinguish them as unique recaptures during this trip).

The target population was all HBC ≥ 150 mm (however, as stated above, the target population during the fall trips also included HBC from 100 to 149 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 et al. 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 hoopnets 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 ≥ 150 mm in total length 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. However, this assumption was likely violated during the spring mark-recapture experiment. HBC movement and migration is known to occur during the spring of the year (Kaeding & Zimmerman 1983; Douglas & Marsh 1996). If HBC emigrate from the LCR or die between sampling events, it is assumed that both marked and unmarked fish are lost to the experiment 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) both occur between the events, there is no possible correction and the estimate will overestimate HBC abundance.

In contrast to the spring estimate, during the fall mark-recapture experiment, the first assumption was probably not violated. Again, we allowed for only a short time period (less than a month) between the mark and recapture events. Most importantly, HBC movement is thought to be at a minimum during this time of year (Douglas and Marsh 1996, Valdez and Ryel 1995). It was also assumed that growth related recruitment was minimized due to the short time span between marking and recapture events. Finally, all fish captured during both mark-recapture experiments 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., hoopnets) 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 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 was tested during the spring trips by applying a dorsal fin punch as an auxiliary mark to the newly PIT tagged fish ≥ 150 mm. 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. However, fish are routinely examined for evidence of an abdominal scar located near the pelvic fins associated with tagging. Though this scar is occasionally not visible on PIT tagged fish and is therefore a poor diagnostic tool for evaluating tag loss, very few fish displayed this scar that did not contain a PIT tag. It is assumed that tag loss was probably negligible, but conclude that future investigation is 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 (May and October trips), *C* is the number of fish captured during the recapture events (June and November trips), and *R* is the number of fish recaptured from the marked population in the recapture event. 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 in the experiments (Seber 1982).

APRIL/MAY TRIP RESULTS

Physical Parameters

Daily afternoon turbidity and temperature readings were taken during the April and May trips at Salt Camp. The LCR ran at base flow during (and between) both trips and was blue in color. Hence, turbidity remained low during the trips. During the 8 to 19 April trip, turbidity ranged from 4.2 to 14.1 NTUs (mean = 8.1 NTUs), while water temperatures ranged from 19 to 22 ^{o}C. During the 13 to 24

May trip, turbidity ranged from 3.3 to 17.6 NTUs (mean = 7.4 NTUs), while water temperatures ranged from 20 to 23 ^{o}C.

Effort and Catch Composition

During the April and May trips, a total of 1,421 hoop net sets were deployed, yielding 32,841 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 in May (0.237 fish/net-hr) than in April (0.127 fish/net-hr). More HBC were captured during the May trip (3,805 fish) than during the April trip (2,134 fish). Fishing effort during both trips combined produced a total catch of 10,764 fish, for all species (Table 4).

Species compositions during both spring trips were similar (Figure 2). The dominant species in the catch were HBC (5,939 fish; 55%) and speckled dace (2,128 fish; 20%). Fathead minnows comprised the most dominant non-native species (693 fish; 6%).

HBC comprised the largest proportion of fish caught on both trips (53 & 57%; Figure 2). One presumed razorback sucker (*Xyrauchen texanus*) x flannelmouth sucker hybrid was captured in May at 2.55 rkm (TL = 541). Exotic species collected were carp (*Cyprinus carpio*), red-shiner (*Cyprinella lutrensis*), fathead minnow (*Pimephales promelas*), plains killifish (*Fundulus zebrinus*), black bullhead (*Ameiurus melas*), yellow bullhead (*Ameiurus natalis*), and rainbow trout (*Oncorhynchus mykiss*). Exotic species captured in hoopnets during the April and May trips comprised 10% and 6% of the catch, respectively. Extremely under-represented by hoopnet catches were the high abundances of adult carp seen in the LCR during these sampling trips. Adult carp were consistently seen from the Confluence area to above Chute Falls, but are rarely captured in hoopnets.

Length frequencies

An abundance (80%) of HBC during both trips fell into the 80 to 175 mm size class, with no clear distinctions among cohorts (Figure 3). A greater proportion of adult HBC ≥ 300 mm was captured during April (13.4%; 286 fish) than in May (2.4%; 91 fish). This is an indication that large HBC were migrating out of the LCR in between the April and May trips, similar to the pattern observed during the spring sampling of 2001 (Van Haverbeke and Coggins 2002). Only one young-of-the-year (YOY) HBC (< 50 mm) was captured during April, and only eleven YOY were captured during May (Figure 3).

Cumulative length frequencies for HBC also show some patterns (Figure 4). First, a higher proportion of larger fish were captured during April than in May. For example, 22% of HBC captured were ≥ 240 mm TL during April, while this number declined to only 9% by May. This is further indication of a larger number of spawning HBC being present in LCR during April than during May. Second, Boulders reach captured the highest proportions of small HBC (< 100 mm; 50%), while Salt reach captured the least proportion of these fish (11.5%).

Flannelmouth sucker length frequency distributions show a pulse of YOY appearing during the May trip (Figure 5). This pulse primarily occurred in the Boulders reach.

Bluehead sucker length frequency distributions showed the presence of more adults in April (Figure 6). For example, during the April trip, Salt, Coyote and Boulders camps captured 4.5%, 16% and 46% (7, 37, and 91 fish respectively) bluehead sucker ≥ 175 mm. These respective numbers were only 1.6%, 3% and 14.9% (7, 7, and 30 fish respectively) in May. As with flannelmouth sucker, a pulse of YOY bluehead sucker was also detected in May (Figure 6).

Sexual Condition

Native fish were clearly spawning during the April trip. One hundred eleven ripe HBC were captured (5.2% of the total catch). Of these, ten were females. These ten females were found between 1.3 to 13 rkm in no obvious concentration, and ranged in length from 235 to 426 mm. Ripe male HBC were found scattered between 1.2 and 14 rkm, and ranged in length from 160 to 410 mm. Sixty-four males and twenty-four female HBC were reported as tuberculate, displaying breeding colors or both during April.

Only three (4.3% of the total catch) ripe flannelmouth sucker were captured during April, and all were male. All three were captured in the Boulders reach (between 2.2 and 3.1 rkm). These fish were all ≥ 390 mm.

Thirty-three (5.7% of the total catch) ripe bluehead sucker were captured in April. Of these, eleven were female. The ripe females were found between 1.6 and 10 rkm; however, four were captured at 4.2 rkm. The ripe males were captured between 0.2 and 6.5 rkm, with twelve concentrated at 4.2 rkm. In addition, twenty ripe fathead minnows, and ten ripe speckled dace were captured (with male and female representatives of each species).

In contrast to the April trip, the occurrence of ripe fish was diminished in May. Forty-five ripe HBC were captured (1.1 % of the total catch), seven which were females. The ripe females were captured between 5.07 and 11.8 rkm, while the ripe males were captured between 1.23 and 14.19 rkm. The females ranged in length from 185 to 423 mm, while the males ranged in length from 166 to 400 mm. Forty-four males and fourteen female HBC were reported as tuberculate, displaying breeding colors, or both.

No ripe flannelmouth sucker were caught in May, however, four males ≥ 450 mm were recorded as tuberculate. Seven (0.8% of the total catch) ripe bluehead sucker were captured between 3.8 and 5.2 rkm in May, one of which was female. One ripe speckled dace and one ripe yellow bullhead were recorded.

During April, 97 HBC ≥ 200 mm were ripe out of a total of 486 HBC ≥ 200 mm captured (i.e., 20% of the captured adult population in April was ripe). During May, 33 HBC ≥ 200 mm were ripe out of a total of 363 HBC ≥ 200 mm captured (i.e., 9% of the captured adult population was ripe).

Predation

Fourteen large bodied exotics were examined for stomach contents during both spring trips. These fish included two black bullhead, eleven yellow bullhead, and one rainbow trout. Eight of the bullhead (TL range = 177 to 270 mm) had fish remains in their stomachs. These included two speckled dace, two bluehead sucker, four fathead minnow and nine unidentified fish. Prey lengths (TL) ranged from 40 to 80 mm. Other food items found in the stomachs included carp scales, detritus, and fish food from the baited nets. The rainbow trout stomach was empty.

Parasites

Percent occurrence of the anchor worm (*Lernaea cyprinacea*) on HBC in April was very low, with only seven fish (0.7% of total fish captures) observed carrying the parasite, and with an average of 1.4 parasites per infected fish. In May, *Lernaea* was practically absent, as only one HBC was recorded with one anchor worm. Two HBC were seen with Asian tapeworm extruding from the vent, although the occurrence of this internal parasite was not monitored.

Population Abundance Estimation

The following criteria were used to define the sampled population during the spring mark-recapture experiment. During April, 566 unique HBC ≥ 150 mm were marked [*M*]. During May, 643 unique HBC ≥ 150 mm were captured [*C*], and 186 unique HBC ≥ 150 mm were recaptured [*R*]. The smallest HBC recaptured had a total length of 156 mm, and the largest recaptured HBC was 416 mm in TL. We chose to define our sampled population to include all HBC ≥ 150 mm.

As discussed in the length frequency section above, a greater number of adult HBC were captured during April than in May, suggesting that that there was movement of adult HBC out of LCR between the April marking and May recapture events (Figure 3). This pattern is further illustrated in Figure 7, which indicates a decline in the percentage of adult HBC captured during the May recapture event. Cumulative length frequency charts further illustrate the differences between the marking and recapture events (Figure 8). Using two-tailed Kolmogorov-Smirnov tests, the cumulative length distribution of marked [*M*] HBC was significantly different from captured [*C*] HBC (n_1 = 566, n_2 = 643, Z = 5.670, $p < 0.001$). Similarly, the cumulative length distribution of marked [*M*] HBC was significantly different than recaptured [*R*] HBC (n_1 = 566, n_2 = 186, Z = 4.591, $p < 0.001$; Figure 8). This was also confirmed by finding significant differences ($\chi^2 = 48.36$, df = 6, $p < 0.0001$) 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 emigration from the LCR for different sizes of fish (i.e., larger post-spawning fish left the LCR while smaller fish remained). Regardless, when mark rate differs as a function of length, it is appropriate to stratify the data into one or more length categories to obtain an unbiased estimate of the abundance (Seber 1982, Bernard and Hansen 1992).

In addition, we then searched for significant differences in mark rate among the three geographic strata. We found a significant difference ($\chi^2 = 40.73$, df = 2, $p < 0.0001$) 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 between Boulder and Coyote reaches ($\chi^2 = 0.11$, df = 1, $p = 0.74$; Table 6). These results indicated that pooling data across Coyote and Boulders reaches was appropriate, and that we could stratify the abundance estimate by length within Salt reach and within the pooled Coyote and Boulders reaches 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). This procedure was performed for Salt reach and for the pooled Coyote and Boulders reaches. The optimal length stratification for Salt reach occurred at 300 mm (χ^2 = 17.93). This means that, at Salt reach, independent estimates were produced for HBC from 150 to 300 mm and for HBC ≥ 301 mm. The optimal length stratification for the pooled Coyote and Boulders reaches occurred at 260 mm (χ^2 = 130.11). This means that, at the pooled Coyote and Boulders reaches, independent estimates were produced for HBC from 150 to 260 mm and for HBC ≥ 261 mm (Table 7). The resulting and **preferred** summed estimate (of all three reaches) for HBC ≥ 150 mm is 2,666 fish (SE = 463). Table 8 and Figure 9 show this estimate as compared against historical estimates.

An important aspect of stratifying by reach is that fish do not move between the reaches between the mark and recapture events (i.e., each of the three reaches must be able to be treated independently). However, movement between the reaches did occur (Table 9). If movement occurs, it should be complete (i.e., all fish must be equally likely to remain within the reach they were tagged or move to any other reach). Following Seber (1982), we tested for complete mixing and rejected the null hypothesis (χ^2 = 146, $p < 0.0001$), suggesting that fish did not mix equally across reaches.

Given that incomplete mixing among geographic strata had occurred, the Darroch estimator should provide the least biased estimate of abundance (Darroch 1961, Seber 1982). The Darroch estimate is presented (Table 10); however, we caution that the Darroch estimator does not account for the significant length frequency complications discussed above. Nevertheless, the resulting pooled Darroch estimate for HBC ≥ 150 mm in the lower 14.2 km of the LCR is 1,907 fish (SE = 144; Table 10). The Darroch abundance estimates for each strata (Salt, Coyote and Boulders reaches) are 610, 869 and 428 fish, respectively (Table 10). We attempted to length stratify the Darroch model (as with the length stratified Chapman Petersen method above), however, the model was invalid because of too few recaptures.

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. We multiplied the above length stratified Chapman Petersen estimates of HBC ≥ 150 mm for Salt reach and for the pooled Coyote and Boulders reaches by the proportion of fish ≥ 200 mm within Salt and the pooled Boulders and Coyote reaches, respectively. The summed length stratified and geographic reach Chapman Petersen estimate for HBC ≥ 200 mm in the lower 14.2 km of the LCR is 2,002 fish (SE = 463; Table 11).

SEPTEMBER/OCTOBER TRIP RESULTS

Physical Parameters

During the September trip, daily afternoon turbidity and temperature readings were taken at Salt Camp. Turbidity readings (NTUs) were taken with a Hach 2100P turbidimeter. The LCR was declining from a major flood event prior to and during the first part of the trip (16 to 22 September). Hence the water was highly turbid during the entire trip. Turbidity declined from 38,336 NTUs on 16 September to 3,928 NTUs on 22 September (Figure 10). This decline corresponded with decreasing flow in the LCR, as the flood subsided. Another small spate arrived on 23 September, increasing the flow again. On 23 September, turbidity began increasing again as flow once again increased, reaching a high of 24,896 NTUs on 25 September (Figure 10). Temperatures during this trip ranged from 19 and 20 ^{o}C.

During the October trip, daily afternoon turbidity and temperature readings were taken at Boulders Camp. The LCR ran at base flow during this trip and was blue in color. Hence, turbidity remained low during the trip (Figure 10). Turbidity ranged from 2.9 to 7.1 NTUs (mean = 4.8 NTUs), while water temperatures ranged from 19 to 20 ^{o}C.

Effort and Catch Composition

A total of 1,073 hoopnet sets were completed during the September and October trips yielding 24,772 hours of fishing effort (Table 12). Total CPUE for HBC in September was 0.091 fish/net-hour, and in October was 0.132 fish/net-hour (Table 12). The distribution of effort was similar among the three reaches. Fishing effort during these trips produced a catch of 3,812 fish (Table 13). The dominant species in the catch were HBC (72%; 2,764 fish) and speckled dace (9%; 336 fish). The distribution of HBC among reaches was somewhat skewed on each trip, with Salt reach catching the most HBC (45%; 506 fish) in September, and Boulders reach catching the most HBC (37%; 612 fish) in October (Table 13). Carp comprised the dominant non-native fish in September (13%; 188 fish), while fathead minnow comprised the dominant non-native fish in October (6%; 142 fish).

Species Composition

Observed species composition during both the September and October trips were similar, with some notable differences (Figure 11). HBC comprised the largest proportion of fish caught on both trips (79 & 69%), compared to 53 to 57% in the spring. Speckled dace increased in proportion from 2% of the catch in September to 13% of the catch in October. Exotic species included carp, fathead minnow, plains killifish, black bullhead, yellow bullhead, channel catfish and rainbow trout. The proportion of carp declined from 13% in September to 3% in October. Red shiners were absent during the fall sampling. Exotic species captured in hoopnets during September and October comprised 15 and 10% of the catch, respectively.

Length frequencies

Length frequency distributions for HBC on both trips were similar (Figure 12). More HBC were captured during the October trip (1,637 fish) than during the September trip (1,127 fish), probably a result of blue water conditions in October. An abundance (77.3%) of HBC during both trips fell into the 100 to 200 mm size class, with no clear distinctions among cohorts (Figure 12). A greater number of large adult HBC (e.g., > 300 mm) were captured during October than during September (Figure 12). For example, 109 (6.7%) HBC ≥ 300 mm were captured on the October trip, while only 50 (4.4%) were captured during the September trip.

Cumulative length frequencies for HBC also show some patterns (Figure 13). First, the cumulative frequencies among camps were noticeably different between September and October. Second, Boulders reach captured the highest proportions of small fish during both trips (i.e., < 150 mm), while Salt reach captured the least proportion of these fish.

Flannelmouth sucker length frequency distributions show a bimodal peak (particularly in October; Figure 14), with peaks occurring at around 100 to 150 mm (presumed young of the year) and another peak of fish > 425 mm. This pulse of large fish primarily occurred in the Boulders reach, where flannelmouth sucker consistently spawn from year to year (D. Van Haverbeke, USFWS, pers. obs.).

Bluehead sucker length frequency distributions were much the same as HBC and flannelmouth sucker length frequencies with a greater showing of fish present during October (Figure 15).

Since we captured a large number of carp (260 fish for both trips combined) relative to other LCR trips, they are shown in Figure 16. The reason for their high abundance (particularly in September) is unknown. We did see many large adult carp (i.e., > 400 mm) during the April and May 2002 LCR sampling trips;

however, few of these were captured (Van Haverbeke 2002). Many of the carp captured in September and October were smaller (e.g., 80 to 200 mm TL). Explanations for their abundance may be: 1) the large adults seen in spring 2002 spawned, and 2) these fish came from upriver (above Chute Falls) with the floods. The second explanation begs the question whether there is a stable population of carp between Chute Falls and Blue Springs, or whether they came from a breached reservoir higher in the LCR drainage.

Sexual Condition

During September, only two ripe fish were captured. Both were male HBC (total lengths = 360 and 372 mm). Both fish displayed tuberculation and spawning colors and were captured at 11.96 rkm.

During the October trip, eleven (0.67% of the total captures) ripe HBC were encountered. Of these, 10 were males (TL range = 345 to 370 mm) and one was a female (TL = 420 mm). A small spawning aggregation of HBC occurred at 10.6 rkm, inclusive of the ripe female and six of the ripe males. A total of thirty-eight HBC displayed tuberculation, spawning coloration, or both. Forty-nine (33.8% of the total catch) ripe flannelmouth sucker were captured. Of these, only one was female (TL = 525 mm), while the males ranged in TL from 426 to 527 mm. All ripe flannelmouth sucker were captured in the Boulders reach. The ripe female and 22 of the ripe males were captured at 4.03 rkm, along a vegetated cut bank of *Phragmites* and cattails. In addition, five ripe bluehead sucker and one ripe female rainbow trout were captured.

Predation

Twenty-nine large bodied exotics were examined for stomach contents during both trips. These fish included ten black bullhead, eleven yellow bullhead, one carp, and seven rainbow trout. Four of the bullhead (TL range = 119 to 252 mm) had fish remains in their stomachs. These included one fathead minnow (50 mm TL) and other unidentified fish remains. Additionally, one net contained a yellow bullhead (TL = 200 mm) with several fathead minnows (TL = 49, 55 and 67 mm) and one speckled dace (TL = 83 mm) that appeared to have been regurgitated. Two of the rainbow trout had unidentified fish remains in their stomach. Other food items found in the stomachs included fish food from the baited nets, algae and insects.

Parasites

Percent occurrence of the external parasite (*Lernaea cyprinacea*) on HBC in September was very low, with only two fish (0.18% of total HBC captures) observed carrying the parasite, with one parasite per infected fish. During October, only four HBC were seen with *Lernaea* (0.24% of total HBC captures), with one parasite found per infected 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 experiment. During September, 629 unique HBC ≥ 150 mm were marked [*M*]. During October, 839 unique HBC ≥ 150 mm were captured [*C*], and 198 unique HBC ≥ 150 mm were recaptured [*R*]. The smallest HBC recaptured had a total length of 150 mm, and the largest HBC recaptured was 412 mm TL.

As presented above (length frequency sub-section), the length frequency distributions of HBC were somewhat different between the September and October trips (Figure 12). This pattern is further seen in Figure 17, which shows small differences 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 = 629, n_2 = 839, Z = 1.220, p = 0.102). However, the cumulative length distribution of marked [*M*] HBC was significantly different than recaptured [*R*] HBC (n_1 = 629, n_2 = 198, Z = 1.603, p = 0.012; Figure 18). We also found significant difference (χ^2 = 41.16, df = 6, p < 0.0001) in the mark rates of HBC within different length strata (Table 14). Although statistical significance was found in the Kolmogorov-Smirnov test between marked and recaptured fish, this result is probably not biological meaningful. At larger sample sizes, Kolmogorov-Smirnov tests will usually reject the null hypothesis (SPSS, 1995, p. 191). Nevertheless, 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 maximizes the homogeneity in mark rate among length groups (Seber 1982, Bernard and

Hansen 1992). We performed this procedure and found that the optimal stratification occurred at 160 mm (χ^2 = 17.93).

We also found significant difference (χ^2 = 15.98, df = 2, p < 0.001) in the mark rate among the 3 sampling reaches (Table 15). This test suggests that our abundance estimate should also be stratified by location (i.e., Salt, Coyote and Boulders reaches).

Based on the above tests, the abundance estimate should optimally be stratified by length (i.e., those fish from 150 mm to < 161 mm and those fish > 160 mm), and stratified by location (i.e., Salt, Coyote and Boulders reaches). However, we considered it not worthwhile to stratify by length, since the break (i.e., 160 mm) was nearly identical to the smallest recaptured HBC (150 mm). In addition, for a Chapman-Peterson estimate to be valid, there should be either complete or no mixing of fish between strata (i.e., between Salt, Coyote and Boulders reaches) between the mark [*M*] and capture [*C*] events (Seber 1982). We found movement (Table 16), but the mixing was judged incomplete, based on upon the consistency tests recommended by Seber (1982, p. 438).

Since our concerns were minimal concerning the significant (but probably not biologically meaningful) length frequency difference between the marked and recaptured populations, and to accommodate for incomplete mixing, the Darroch estimator is **preferred** (Seber 1982). The pooled Darroch estimate for HBC ≥ 150 mm in the lower 14.2 km of the LCR was 2,774 fish (SE = 209). The abundance estimates for each strata (Salt, Coyote and Boulders reaches) are

1,045, 1,263 and 466 fish, respectively (Table 17). Table 18 shows pooled Darroch estimate as compared against historical estimates for HBC ≥ 150 mm.

Since the Recovery Goals for HBC (USFWS 2002) focus on abundance estimates of fish ≥ 200 mm (i.e., 4+ year old adults), we present estimates relating to their abundance (Tables 19 and 20). First, we multiplied the above pooled Darroch estimates for fish ≥ 150 mm by the pooled proportion of fish ≥ 200 mm (Table 20). Second, we multiplied the above Darroch estimates for fish ≥ 150 mm within each reach by the proportion of fish ≥ 200 mm within each reach (Table 20). The resulting and **preferred** Darroch summed by reach estimate for HBC ≥ 200 mm in the lower 14.2 km of the LCR is 839 fish (SE = 87; Table 19). The Darroch abundance estimates of HBC ≥ 200 mm for each strata (Salt, Coyote and Boulders reaches) are 369, 346 and 125 fish, respectively (Table 19). For comparative purposes, we present the following estimates for HBC ≥ 200 mm, and for HBC < 200 mm (Table 20). First are the Darroch estimates summed by reach (as discussed above). Second, we multiplied the Chapman Petersen estimate for fish ≥ 150 mm by the proportion of fish ≥ 200 mm. Third, we multiplied the length stratified Chapman Petersen estimate for fish > 160 mm by the proportion of fish ≥ 200 mm (Table 20).

We also present estimates of HBC between 100 and 149 mm to assist GCMRC in population modeling efforts. During September, 267 unique HBC between 100 and 149 mm were marked [*M*]. During October, 455 unique HBC between 100 and 149 mm were captured [*C*], and 68 were recaptured [*R*]. Using two-tailed Kolmogorov-Smirnov tests, the cumulative length distribution of marked [M] HBC was not different from captured [*C*] HBC (n_1 = 267, n_2 = 455, Z = 1.293, p = 0.071). However, the cumulative length distribution of marked [*M*] HBC was significantly different than recaptured [*R*] HBC (n_1 = 267, n_2 = 88, Z = 1.403, p = 0.039). We conclude from these tests that that there was significant size selective bias within the sampled population, and that this difference may have been biologically meaningful (see Figure 19). As a result, we performed a Chapman Peterson abundance estimate stratified by length by procedures given in Seber (1982). We performed this procedure and found that the optimal stratification occurred at 130 mm (χ^2 = 7.57). The abundance estimate for HBC between 100 and 149 mm in the lower 14.2 km of the LCR was 2,033 fish (SE = 284; Table 21). Recall that HBC within this size class were fin clipped, rather than PIT tagged. As a result, investigating movement of individual fishes between reaches was impossible, precluding investigation of the Darroch model.

DISCUSSION

Spring Abundance Estimate

The length and geographic reach stratified Chapman Petersen estimates of 2,666 HBC ≥ 150 mm is offered as the **preferred** estimate for spring 2002. It attempts to account for the significant length frequency differences we found between the marked [*M*] and captured [*C*] populations, and marked [*M*] and recaptured [*R*] populations. It also reduces the potential bias that could have been present from differences in the mark rates between reaches. However, all of the spring length stratified and reach stratified Chapman Petersen estimates given for HBC could still be biased high. First, the length frequency analyses 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 possibly violated. Second, the mark rates were significantly different among the three geographic strata (Salt, Coyote and Boulders reaches). This finding suggests that there may have been differential emigration from the LCR among the three reaches. Third, the stratified Chapman Petersen estimates do not account for the movement of fish between reaches that was observed.

Since emigration evidently occurred, our estimate should ordinarily be germane to the abundance of fish during the mark event (Seber 1982). However, because movement of HBC occurred in both directions (i.e., upriver and downriver), this implies that both immigration and emigration of HBC within the LCR system may have been occurring. This would indicate that our length stratified and reach stratified Chapman Petersen estimates for HBC are biased high (Bernard and Hansen 1992).

Since the Darroch estimator accounts for the movement between reaches, it has been presented for comparative purposes. Note that the Darroch estimate is lower than the Chapman Petersen estimate. The Chapman Petersen estimate for HBC $\geq$ 150 mm is 2,666 fish (SE = 463; Table 7), while the Darroch estimate of HBC $\geq$ 150 mm is only 1,907 fish (SE = 144; Table 10). However, the Darroch estimates is not offered as the preferred estimate since it does not account for the significant (and biologically meaningful) length frequency differences between the marked and recaptured populations.

Despite the difficulties encountered in estimating the spring abundance of HBC in the LCR, the results do indicate that a decline has occurred in the population of HBC since the early 1990s. The April/May 2002 abundance estimate for HBC ≥ 150 mm (2,666 fish; SE = 463) is lower than the April 1992 estimate (5,555 fish; SE = 611) provided by Douglas and Marsh (1996). Recall also that our 2002 estimate is likely biased high for the reasons explained above. In addition, the April/May 2001 abundance estimate (Van Haverbeke and Coggins 2002) was lower than both the April and the May 1992 estimates; additional evidence that there has been a decline in HBC abundance since the early 1990s.

Also of concern are the abundance estimates for HBC ≥ 200 mm. In addition of a criteria for no significant decline occurring in the number of HBC within each wild population over an as yet undefined 5 to 8 year period, the Recovery Goals for HBC call for a minimum viable population of 2,100 HBC ≥ 200 mm in Grand Canyon (USFWS 2002). Our spring 2002 estimate of HBC ≥ 200 mm in the LCR falls at 2,002 fish (SE = 463), and may be biased high. Although this may suggest that there are an insufficient number of HBC ≥ 200 for recovery, it should be mentioned that our spring population estimate is germane to the number of fish in the LCR during April, and may not be inclusive of all spawning adults (i.e., there may be additional fish that were early spawners and had already left the LCR system prior to the marking event).

Fall Abundance Estimate

Unlike the fall population estimate provided for the past two years (Coggins and Van Haverbeke 2001, Van Haverbeke and Coggins 2002), the fall estimate for HBC ≥ 150 mm in 2002 had some complications. For the following reasons and rationale, we opted to present a Darroch estimate as the **preferred** estimate, rather than a length stratified Chapman Petersen. There was not a significant difference in length frequencies between the marked [*M*] and captured [*C*] fish, but there was a significant difference in the length frequencies between the marked [*M*] and recaptured [*R*] fish. However, this difference was probably not biologically meaningful (i.e., the cumulative length frequency charts for marked and recaptured fish are much more closely aligned for the fall trips than for the spring trips). In addition, the optimal length stratification for a length stratified Chapman Petersen estimate would have been at 160 mm (i.e., only 10 mm larger than the smallest recaptured fish). Hence, it would have been of little value to stratify based on length. Finally, since HBC are presumably not migrating during this time of year (Douglas and Marsh 1996, Valdez and Ryel 1995), this means that the violation of closure assumption was much less of a concern for the fall estimate than for during the spring estimate.

Considering factors pertinent for a Darroch estimate, we did find a significant difference in mark rate of fish between the three reaches, and we identified that incomplete movement between the reaches was occurring. As a result of all of the above, we considered movement between camps to be potentially more of a biasing influence than the differences between the marked and recaptured length frequencies. Hence, the Darroch estimate is provided as potentially the least biased and **preferred** estimate.

The fall abundance estimate for HBC ≥ 150 mm is of interest for the following reasons. First, it is a relatively high estimate compared to other historical estimates (Douglas and Marsh 1996, Coggins and Van Haverbeke 2001, Van Haverbeke and Coggins 2002). For example, the fall 2002 estimate was 2,777 fish (SE = 209), while the nearest estimate this high was in October 1991 (2,038 fish; SE = 518; Douglas and Marsh 1996). Second, the fall 2002 abundance is nearly the same as the spring 2002 estimate of 2,666 fish. The reason for this is unknown, however, it does suggest that a portion of the population that ordinarily migrates out of LCR after spring spawning may not have done so. Alternatively, it could suggest that there was a secondary spawn during fall of 2002. We did capture eleven ripe HBC during the November trip. Finally, prior to the October trip, there was a very large flood event in the LCR (i.e., on the order of 20,000 cfs; USGS unpublished data). It is stressed here that the relatively high abundance estimate for HBC ≥ 150 mm for fall of 2002 does not indicate an increase in population since the early 1990s (see Figure 20). Rather, this higher fall estimate is viewed as an anomaly related to the retention of a larger portion of the population of HBC in the LCR during fall 2002, perhaps related to the large flood events seen this year.

To accommodate interest in the Recovery Goals for HBC, an estimate of HBC ≥ 200 mm is provided. The Darroch estimate for fall abundance of HBC ≥ 200 mm was 839 fish (SE = 87). This is lower than the target of 2,100 fish in the

Recovery Goals (USFWS 2002). However, this number is much less relevant than the higher spring abundance estimate for HBC ≥ 200 mm (i.e., a larger proportion of adult HBC are residing in the LCR during the spring months, compared to fall).

A length stratified Chapman Petersen estimate of 2,003 fish (SE = 284) is provided for the fall abundance of HBC from 100 to 149 mm. Since HBC within this size class were not tagged with a unique identifier (i.e., fin clips were used rather than PIT tags), there was no way to investigate for potential bias resulting from movement between reaches (as was done for HBC ≥ 150 mm TL). The fall abundance estimate for this size class of HBC does suggest that there was some recruitment from 2000 and 2001. However, there is some indication that a substantial portion of this size class was lost this year. First, the catches of HBC between 100 and 149 mm were much higher in the spring (3,871 fish; CPUE = 0.12 fish/net-hr) than during the fall (1,354 fish; CPUE = 0.05 fish/net-hr). Second, the LCR sustained a major flood event (~20,000 cfs, USGS provisional data) between the spring and fall trips. Floods in the LCR are known to transport YOY and juvenile HBC out of the system and into the mainstem Colorado River (Valdez and Ryel 1995). Evidence that this happened comes from high catches of YOY and juvenile HBC (during early September in standardized hoopnetting locations on the mainstem Colorado River immediately below the LCR confluence (Paukert and Popoff 2002). Nevertheless, our finding does suggest that there was still some recruitment from 2000 and 2001.

Conclusions

Evidence has been presented that the Grand Canyon population of HBC appears to have undergone a decline since the early 1990s. This decline is most readily seen in the spring abundance estimates for 2001 and 2002, when compared to the spring estimates provided during the early 1990's. Continued spring point population estimates will more accurately portray the true trend in HBC abundance. Nevertheless, the two studies combined (spring 2001 and spring 2002) supply fairly convincing evidence that the observed decline in HBC abundance since the early 1990s is real, and that it should be cause for concern by management.

RECOMMENDATIONS

Since results for the past two 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). Additionally, pursuing other options for the conservation of HBC may be prudent, including performing a feasibility study for supplemental stocking (USFWS 1990), and continuing involvement with and commitment to Humpback Chub ad hoc Committee for the Glen Canyon Dam Adaptive Management Workgroup: Comprehensive Management Plan.

Based on the analyses of 2002 spring and fall estimates, the following recommendations are made in order to improve the abundance estimates for 2003:

First, extend the recommendations from Van Haverbeke and Coggins (2001) that newly tagged fish during 2002 be given a secondary mark. It is recommended to use a long-term secondary marking device to accomplish this objective. A continued long-standing uncertainty in estimating Grand Canyon fish populations (even with larger fish) has been the issue of potential tag loss. This is currently not believed by researchers to be a severe problem, however, further investigation is warranted to preclude any uncertainty. It is suggested that continued experiments be carried out in a hatchery in order to identify an optimal method as a secondary mark.

Second, form an independent scientific panel to review stock assessment activities in Grand Canyon. There has been considerable debate concerning the most appropriate stock assessment methodologies to use. The formation of an independent review panel consisting of recognized stock assessment experts holding no financial or political interests would be in the best interest of the resource.

DATA ARCHIVING

The data for the two spring trips were delivered to Grand Canyon Monitoring and Research Center in five MS Access files entitled: LCR_2002_April_Boulders & Salt.mbd, LCR_2002_April_Coyote.mbd, LCR_2002_May_Salt.mbd, LCR_2002_May_Coyote.mbd, and LCR_2002_May_Boulders.mbd. The data for the two fall trips was delivered to Grand Canyon Monitoring and Research Center in six MS Access files entitled LCR_2002_September_Salt.mdb, LCR_2002_September_Coyote.mdb, LCR_2002_September_Boulders.mdb, LCR_2002_October_Salt.mdb, LCR_2002_October_Coyote.mdb, and LCR_2002_October_Boulders.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 2002.

	USFWS	AGFD	SWCA	Volunteer
8-19 April	David Van Haverbeke [S] Dennis Stone [S] Dewey Wesley [B]	David Ward [C] Pam Sponholtz [C}	Melissa Trammell [C]	Emily Thompson [S] Sean Grimes [B] Mike Bassett [B]
13-24 May	Dennis Stone [S] Tracey Scheffler [S] David Van Haverbeke [C] Dewey Wesley [B]		Matt Lauretta [S]	Kirsten Tinning [C] Katrina Lund [C] Corwin Grimes [B]
16-27 Sept.	Dennis Stone [S] Dewey Wesley [S] Chris Cantrell [S] Pam Sponholtz [C] Marshal Steven [B]	Andy Makinster [C] Dave Ward [B]	Matt Lauretta [C]	
21 Oct. - 1 Nov.	Dewey Wesley [S] Pam Sponholtz [C] David Van Haverbeke [B] Dennis Stone [B]	Clay Nelson [S] Eric Kohagen [C]	Lainie Johnstone [S]	Courtney Giauque [C] *Alysin Martinez [B]

Table 2. Habitat characteristics for hoopnets set in Little Colorado River, 2002.

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 hoopnet sets, hours of effort, humpback chub (HBC) catch, and HBC catch per unit effort (CPUE; fish/net-hr); Little Colorado River, spring 2002.

		Effort		HBC	HBC
Trip	Reach	Sets	Hours	Catch	CPUE
April					
	Salt	240	5,618	616	0.110
	Coyote	240	5,578	1,001	0.179
	Boulders	240	5,592	517	0.092
	Total	720	16,788	2,134	0.127
May					
	Salt	240	5,591	1,321	0.236
	Coyote	221	4,980	1,353	0.272
	Boulders	240	5,482	1,131	0.206
	Total	701	16,053	3,805	0.237
Grand Total		1,421	32,841	5,939	0.181

Table 4. Summary of fish captured by trip, reach, gear type, and species; Little Colorado River, spring 2002.

		Species*														
Trip	Reach - gear	BBH	BHS	CCF	CRP	FHM	FMS	GSF	HBC	PKF	RBS	RBT	RSH	SPD	YBH	Total
April																
	Salt - hoopnets		154			194	10		616				6	209	5	1,194
	Coyote - hoopnets	1	231			109	16		1,001				2	149		1,509
	Boulders - hoopnets		198		1	57	44		517	2			8	485		1,312
	Total	1	583	0	1	360	70	0	2,134	2	0		16	843	5	4,015
May																
	Salt - hoopnets		429		1	235	15		1,321	1			7	481	2	2,492
	Coyote - hoopnets	1	230		3	60	96		1,353			1	1	105	4	1,854
	Boulders - hoopnets		201		10	38	315		1,131		1		7	699	1	2,403
	Total	1	860	0	14	333	426		3,805	1	1	1	15	1,285	7	6,749
Grand Total		2	1,443	0	15	693	496	0	5,939	3	1	1	31	2,128	12	10,764

* 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*); RBS = assumed razorback sucker (*Xyrauchen texanus*) x flannelmouth sucker hybrid; RBT = rainbow trout (*Oncorhynchus mykiss*); RSH = red shiner (*Cyprinella lutrensis*); SPD = speckled dace (*Rhinichthys osculus*), YBH = yellow bullhead (*A. natalis*).

Table 5. Number of humpback chub marked and unmarked during the recapture event by total length strata; Little Colorado River, spring 2002.

Length strata	Unmarked	Marked	Mark rate
150-199	294	86	22.63%
200-249	69	71	50.71%
250-299	26	15	36.59%
300-349	15	6	28.57%
350-399	35	5	12.50%
400-449	17	3	15.00%
450-499	1	0	0.00%
Totals	457	186	28.93%

Ho: Mark rate among length strata is the same.
Reject null hypothesis ($\chi^2 = 48.36$, df = 6, $p < 0.0001$)

Table 6. Number of humpback chub marked and unmarked during the recapture event by reach; Little Colorado River, spring 2002.

Reach	Marked	Unmarked	Mark Rate
Salt	94	90	51%
Coyote	63	204	24%
Boulder	29	86	25%
Total	186	380	33%

Ho: Mark rate among reaches is the same.
Reject null hypothesis (χ^2 = 40.74, df = 2, p < 0.0001)

Ho: Mark rate among Coyote and Boulders reach is the same.
Accept null hypothesis (χ^2 = 0.11, df = 1, p = 0.74)

Table 7. Length stratified Chapman Petersen abundance estimates for humpback chub ≥ 150 mm by two geographic strata (i.e., Salt reach and pooled Coyote and Boulders reaches) in Little Colorado River; spring 2002.

Abundance of HBC >=150 mm TL in Salt reach

						95% Confidence Interval	
Length (mm)	Marked	Captured	Recaptured	N	SE	Lower	Upper
150 - 300	148	305	87	517	30	459	575
>=301	36	36	7	170	45	82	258
Sum Strata				687	54	582	792

Abundance of HBC >=150 mm TL in pooled Coyote and Boulders reaches

						95% Confidence Interval	
Length (mm)	Marked	Captured	Recaptured	N	SE	Lower	Upper
150 - 260	158	249	85	461	27	408	515
>=261	224	53	7	1,518	459	618	2,417
Sum Strata				1,979	460	1,078	2,880

Summed abundance of HBC >=150 mm TL in all reaches

						95% Confidence Interval	
	Marked	Captured	Recaptured	N	SE	Lower	Upper
Total sum	566	643	186	2,666	463	1,759	3,573

Table 8. 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); 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
Average April and May 92	4,959					
April/May 2001	2,090	244	1,611	2,569	0 - 14.2	147
April/May 2002	2,666	463	1,759	3,573	0 - 14.2	188
Average April and May 01-02	2,378					

Table 9. Numbers of humpback chub ≥ 150 mm that were marked during April and recaptured during May in three reaches (Salt, Coyote and Boulders) in Little Colorado River; spring 2002.

	Salt (recaptured)	Coyote (recaptured)	Boulders (recaptured)	% of recaps that moved
Salt (marked)	83	7	1	8.8%
Coyote (marked)	9	52	4	20%
Boulders (marked)	2	4	24	20%

Table 10. Darroch abundance estimates for humpback chub $\geq$ 150 mm in Little Colorado River; spring 2002.

Abundance estimates of HBC >=150 mm

					95% Confidence Interval	
Estimator	Total length (mm)	N	var(N)	SE(N)	Lower	Upper
pooled Darroch	>=150	1,907	20,719	144	1,625	2,189

Abundance estimates of HBC >=150 mm by reach (strata)

					95% Confidence Interval	
Strata	Total length (mm)	N	var(N)	SE(N)	Lower	Upper
Salt	>=150	610	4,930	70	472	748
Coyote	>=150	869	15,997	126	621	1,117
Boulders	>=150	428	8,595	93	246	610
Sum strata	>=150	1,907	29,522	172	1,570	2,244

Table 11. Length stratified and reach stratified Chapman Petersen abundance estimates of humpback chub ≥ 200 mm in Little Colorado River; spring 2002.

Abundance of HBC >=200 mm total length in Salt reach

							95% Confidence Interval	
Length stratification (mm)	Marked	Captured	Recaptured	P	N (>=200)	SE	Lower	Upper
150 - 300	148	305	87	0.36	185	16	127	243
>=301	36	36	7	1	170	45	82	258
Sum Strata					355	47	250	460

Abundance of HBC >=200 mm total length in pooled Coyote and Boulders reaches

							95% Confidence Interval	
Length stratification (mm)	Marked	Captured	Recaptured	P*	N (>=200)	SE	Lower	Upper
150 - 260	158	249	85	0.28	129	13	76	182
>=261	224	53	7	1	1,518	459	618	2,417
Sum Strata					1,647	460	746	2,548

Summed abundance of HBC >=200 mm total length in all reaches

			95% Confidence Interval	
	N (>=200)	SE	Lower	Upper
Total sum	2,002	463	1,095	2,909

P* = (marked fish >=200 + captured fish >=200 - recaptured fish >=200)/(marked fish >=150 + captured fish >=150 - recaptured fish >=150)

Table 12. Summary of fishing effort by trip, reach, number of hoopnet sets, hours of effort, humpback chub (HBC) catch, and HBC catch per unit effort (CPUE; fish/net-hr); Little Colorado River, fall 2002.

		Effort		HBC	HBC
Trip	Reach	Sets	Hours	Captured	CPUE
September					
	Salt	177	4,274	506	0.118
	Coyote	179	4,018	391	0.097
	Boulders	179	4,045	230	0.057
	Total	535	12,337	1,127	0.091
October					
	Salt	178	4,107	527	0.128
	Coyote	180	4,090	498	0.122
	Boulders	180	4,188	612	0.146
	Total	538	12,385	1,637	0.132
Grand Total		1,073	24,722	2,764	0.112

Table 13. Summary of fish captured by trip, reach, gear type, and species; Little Colorado River, fall 2002.

		Species[*]												
Trip	Reach - gear	BBH	BHS	CCF	CRP	FHM	FMS	HBC	PKF	RBT	RSH	SPD	YBH	Total
September														
	Salt - hoopnets		2		146	10	2	506				14	10	690
	Coyote - hoopnets	2	3		32	5	10	391				9		452
	Boulders - hoopnets	5	21	1	10	2	12	230				9		290
	Total	7	26	1	188	17	24	1,127				32	10	1,432
October														
	Salt - hoopnets		30		15	65	9	527	1			67	6	720
	Coyote - hoopnets	9	9		31	20	26	498				39		632
	Boulders - hoopnets		12		26	57	110	612		7		198	6	1,028
	Total	9	51		72	142	145	1,637	1	7		304	12	2,380
Grand Total		16	77	1	260	159	169	2,764	1	7	0	336	22	3,812

[*] 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*), YBH = yellow bullhead (*A. natalis*).

Table 14. Number of humpback chub marked and unmarked during the recapture event by total length strata; Little Colorado River, fall 2002.

Length strata	Unmarked	Marked	Mark-rate
150-199	452	130	22.34%
200-249	77	46	37.40%
250-299	17	15	46.88%
300-349	10	3	23.08%
350-399	44	2	4.35%
400-449	39	2	4.88%
450-499	2	0	0.00%
Totals	641	198	23.60%

Ho: Mark rate among length strata is the same.
Reject null hypothesis (χ^2 = 41.16, df = 6, p = 2.69E-07)

Table 15. Number of humpback chub marked and not marked during the recapture event by reach in the Little Colorado River, fall 2001.

Reach	Marked	Unmarked	Mark Rate
Salt	266	110	29%
Coyote	221	49	18%
Boulder	185	39	17%
Total	672	198	77%

Ho: Mark rate among reaches is the same.
Reject null hypothesis ($\chi^2 = 15.99$, df = 2, $p < 0.001$)

Table 16. Numbers of humpback chub $\geq$ 150 mm that were marked during September and recaptured during October in three reaches (Salt, Coyote and Boulders) in Little Colorado River; fall 2002.

	Salt (recaptured)	Coyote (recaptured)	Boulders (recaptured)	% recaps that moved
Salt (marked)	97	6	1	6.7%
Coyote (marked)	12	35	7	35%
Boulders (marked)	1	8	31	23%

Table 17. Darroch abundance estimates of humpback chub $\geq$ 150 mm; Little Colorado River; fall 2002.

Abundance estimates of HBC >=150 mm in LCR for fall 2002

					95% Confidence Interval	
Estimator	Total length (mm)	N	var(N)	SE(N)	Lower	Upper
pooled Darroch	>=150	2,774	43,828	209	2,364	3,184

Abundance estimates of HBC >=150 mm TL by reach (strata) for fall 2002

					95% Confidence Interval	
Strata	Total length (mm)	N	var(N)	SE(N)	Lower	Upper
Salt	>=150	1,045	11,373	107	835	1,255
Coyote	>=150	1,263	53,424	231	810	1,716
Boulders	>=150	466	12,956	114	243	689
Sum strata	>=150	2,774	77,753	279	2,227	3,321

Table 18. Abundance estimates of humpback chub ≥ 150 mm by date. 1991 & 1992 estimates are from Douglas and Marsh (1996); 2000 estimate is from Coggins and Van Haverbeke (2001); 2001 estimate is from Van Haverbeke & Coggins (2002).

			95% Confidence Interval			
Date	Abundance Estimate	SE	Lower	Upper	Reach (rkm)	# per km
October 1991	2,038	518	1,276	3,368	0 - 14.9	137
November 1991	1,989	489	1,264	3,235	0 - 14.9	133
October 1992	1,099	60	990	1,224	0 - 14.9	74
November 1992	1,417	408	839	2,500	0 - 14.9	95
Average Oct. & Nov. 91-92	1,636					110
October/November 2000	1,590	297	992	2,552	0 - 14.2	112
October/November 2001	1,106	172	934	1,179	0 - 14.2	78
October/November 2002	2,774	209	2,364	3,184	0 - 14.2	195
Average Oct. & Nov. 00-02	1,823					128

Table 19. Abundance estimates of humpback chub ≥ 200 mm; Little Colorado River; fall 2002.

Abundance estimates of HBC >=200 mm in LCR for fall 2002

Estimator	Total length (mm)	N	var(N)	SE(N)	95% Confidence Interval	
					Lower	Upper
pooled Darroch	>=200	854	5,278	73	712	996

Abundance estimates of HBC >=200 mm TL by reach (strata) for fall 2002

Strata	Total length (mm)	N	var(N)	SE(N)	95% Confidence Interval	
					Lower	Upper
Salt	>=200	369	1,794	42	286	452
Coyote	>=200	346	4,676	68	211	480
Boulders	>=200	125	1,075	33	60	189
sum of reaches*	>=200	839	7,545	87	669	1010

*The preferred estimate, since it best accounts for movement of fish between reaches

Table 20. Estimates for humpback chub $\geq$ 200 mm, humpback chub < 200 mm, and sums of both using three different estimators in Little Colorado River; fall 2002.

Abundance estimates of HBC in LCR for fall 2002

					95% Confidence Interval	
Estimator	Total length (mm)	N	var(N)	SE(N)	Lower	Upper
Darroch	>=200	839	7,545	87	669	1,010
Darroch	<200	1,935	41,095	203	1,537	2,332
summed Darroch	>=150	2,774	48,640	221	2,342	3,206
Chapman Petersen	>=200	818	2,779	53	715	922
Chapman Petersen	<200	1,840	9,872	99	1,645	2,035
summed Chapman Petersen	>=150	2,658	12,651	112	2,438	2,879
length stratified Chapman Petersen	>=200	609	1,609	40	531	688
length stratified Chapman Petersen	<200	2,329	40,982	202	1,932	2,726
summed length stratified Chapman Petersen	>=160	2,939	42,591	206	2,534	3,343

Table 21. Length stratified Chapman Petersen abundance estimate for HBC 100 to 149 mm; Little Colorado River, fall 2002.

Abundance of HBC 100 - 149 mm TL

						95% Confidence Interval	
Length	Marked	Captured	Recaptured	N	SE	Lower	Upper
100 - 130	69	140	9	986	266	465	1,507
131 - 149	198	315	59	1,047	101	849	1,245
Sum Strata				2,033	284	1,477	2,589

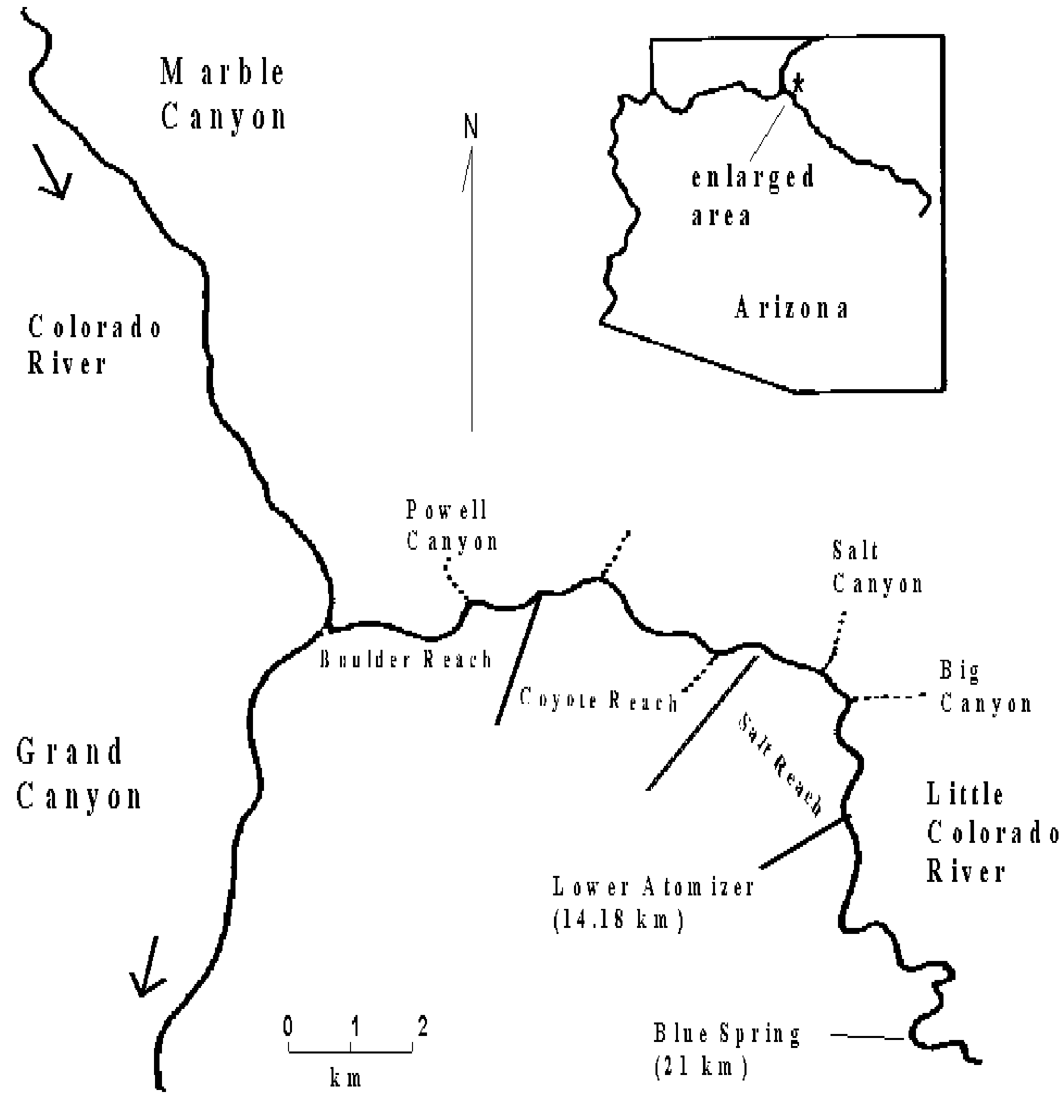


Figure 1. Map of the study site, showing Salt, Coyote and Boulders reaches in Little Colorado River.

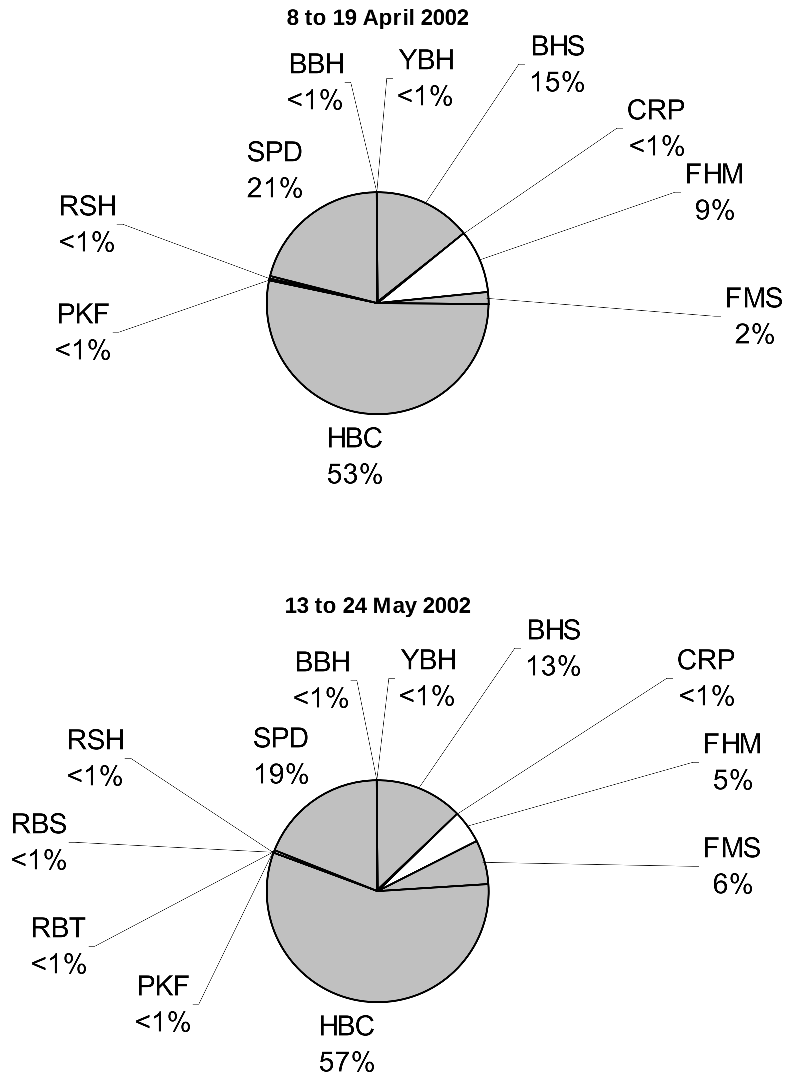
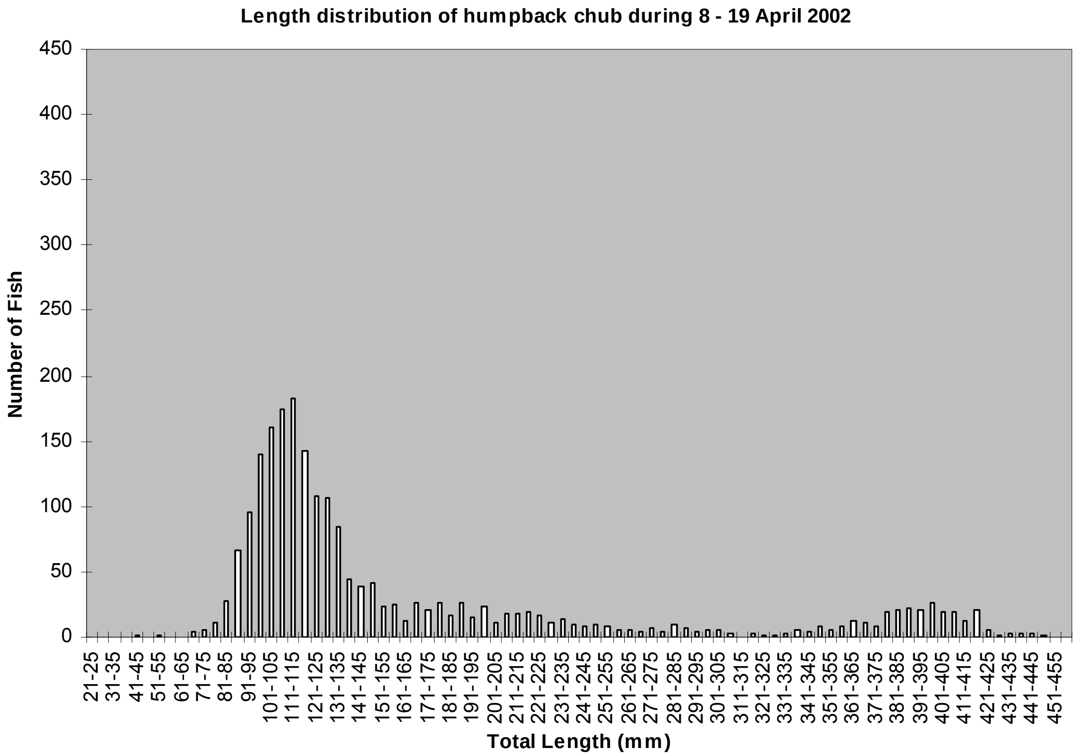


Figure 2. Observed species compositions of all fish captured using hoopnets. Shaded portions are native fish; Little Colorado River, spring 2002.

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*); RBS = assumed razorback sucker (*Xyrauchen texanus*) x flannelmouth sucker hybrid; RBT = rainbow trout (*Onchorynchus mykiss*); RSH = red shiner (*Cyprinella lutrensis*); SPD = speckeled dace (*Rhinichthys osculus*); YBH = yellow bullhead (*A. natalis*).



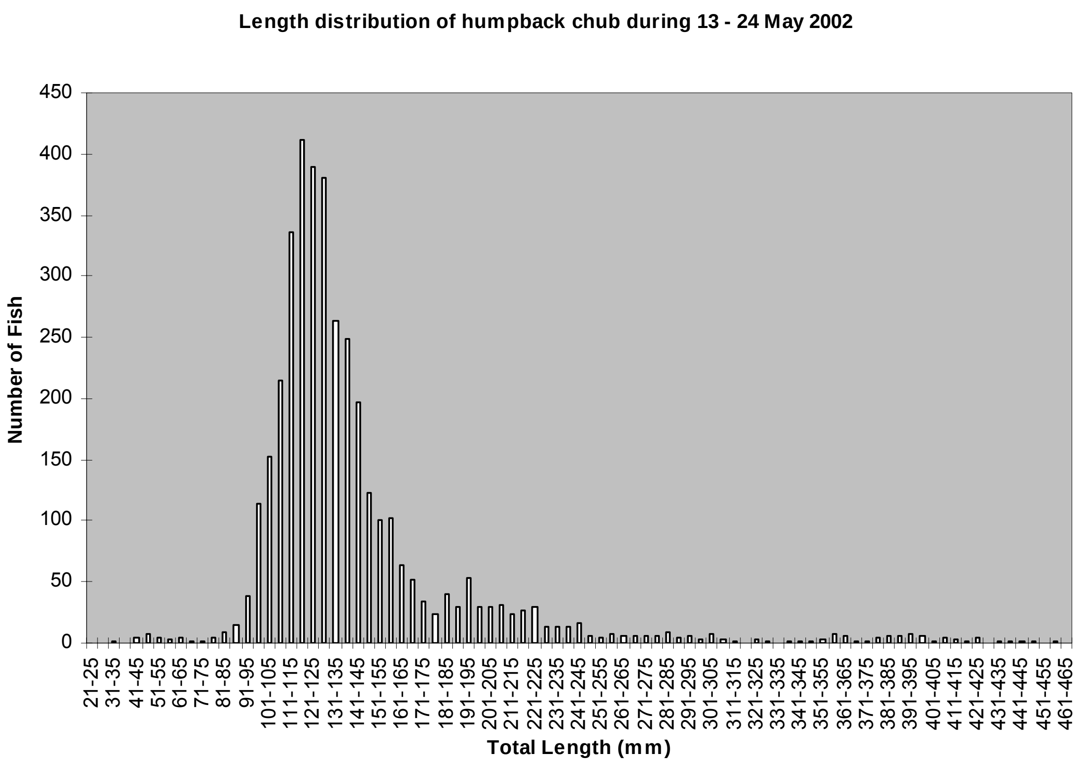


Figure 3. Total length frequency distributions of all humpback chub captured in hoop nets; Little Colorado River, spring 2002.

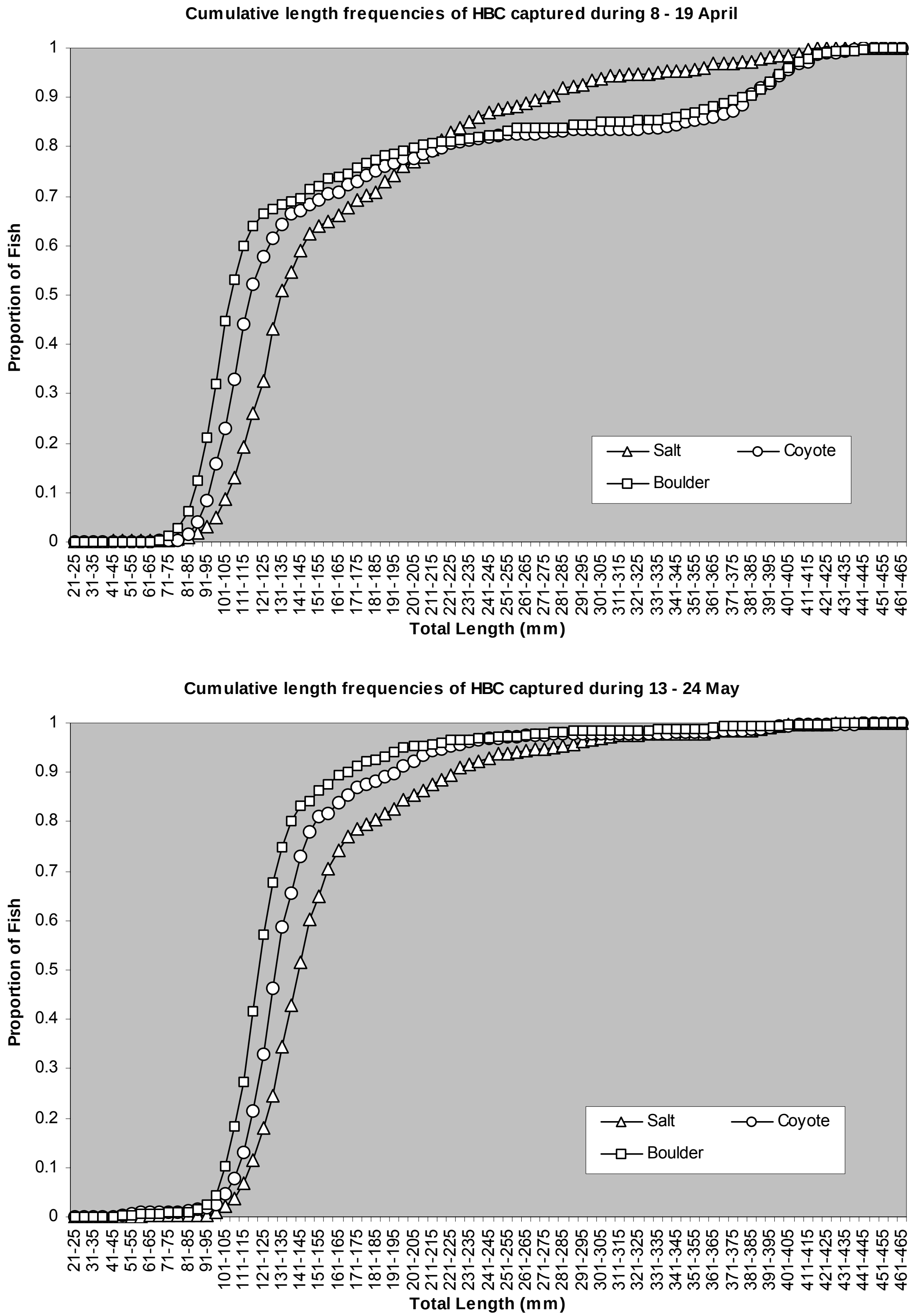
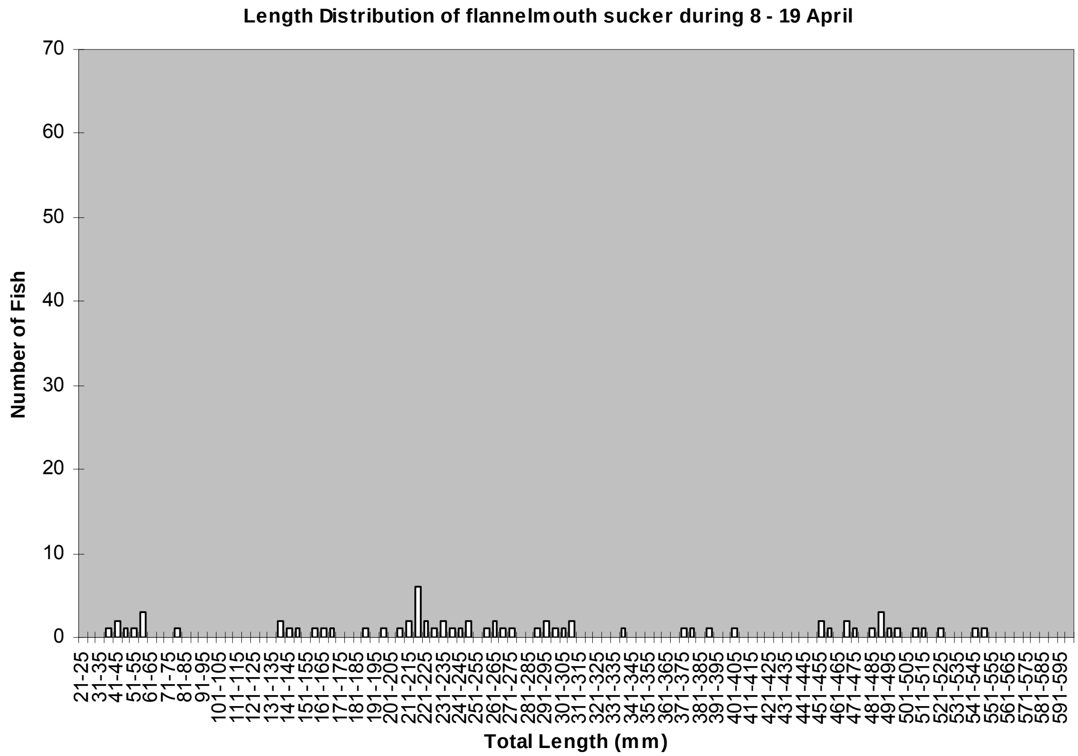


Figure 4. Cumulative length frequency charts of all HBC captured in hoopnets at three different reaches (Salt, Coyote and Boulders); Little Colorado River, spring 2002.



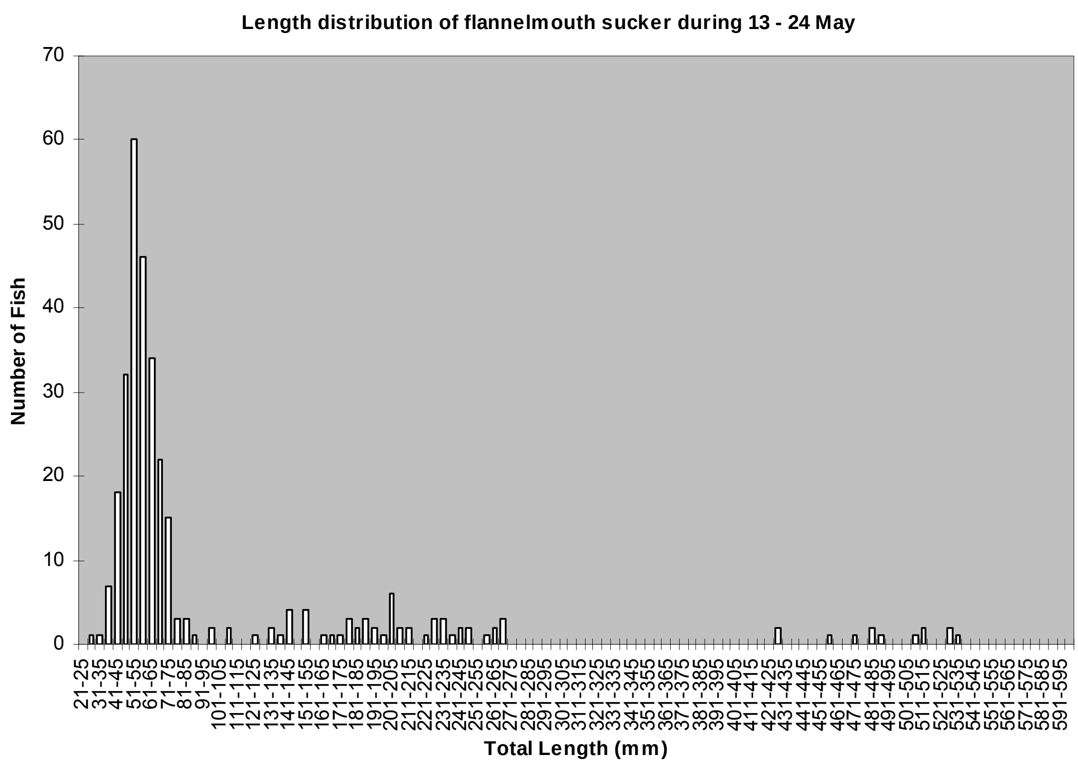
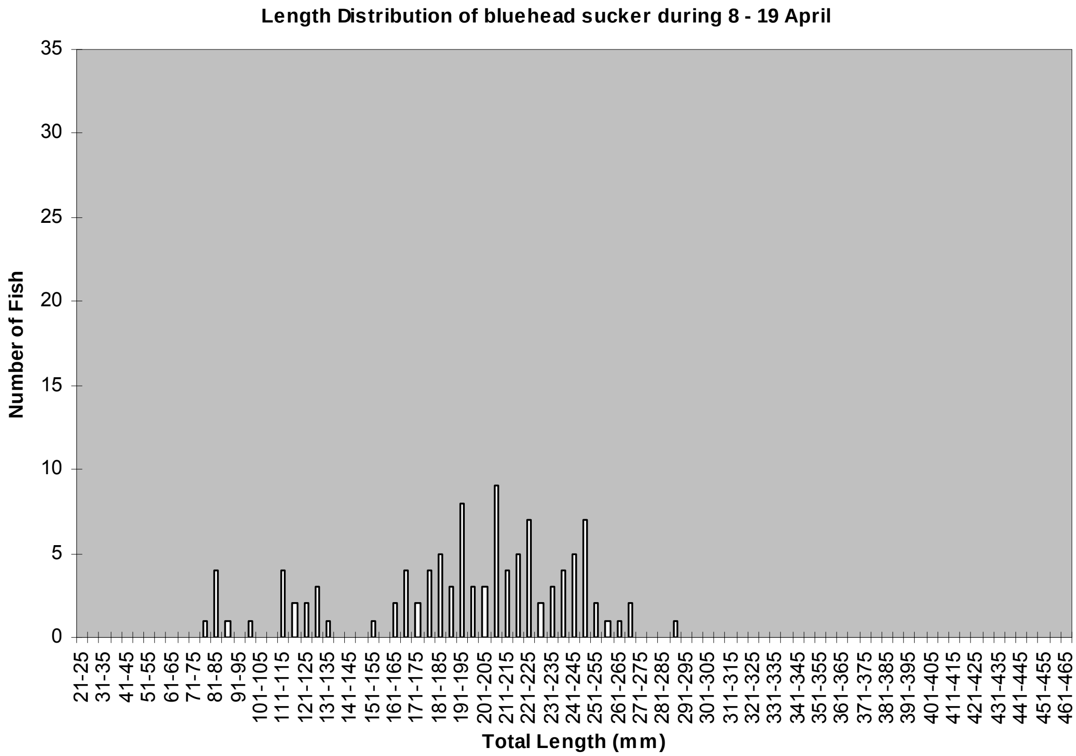


Figure 5. Length frequency distribution of all flannelmouth sucker captured in hoopnets and trammel nets; Little Colorado River, spring 2002.



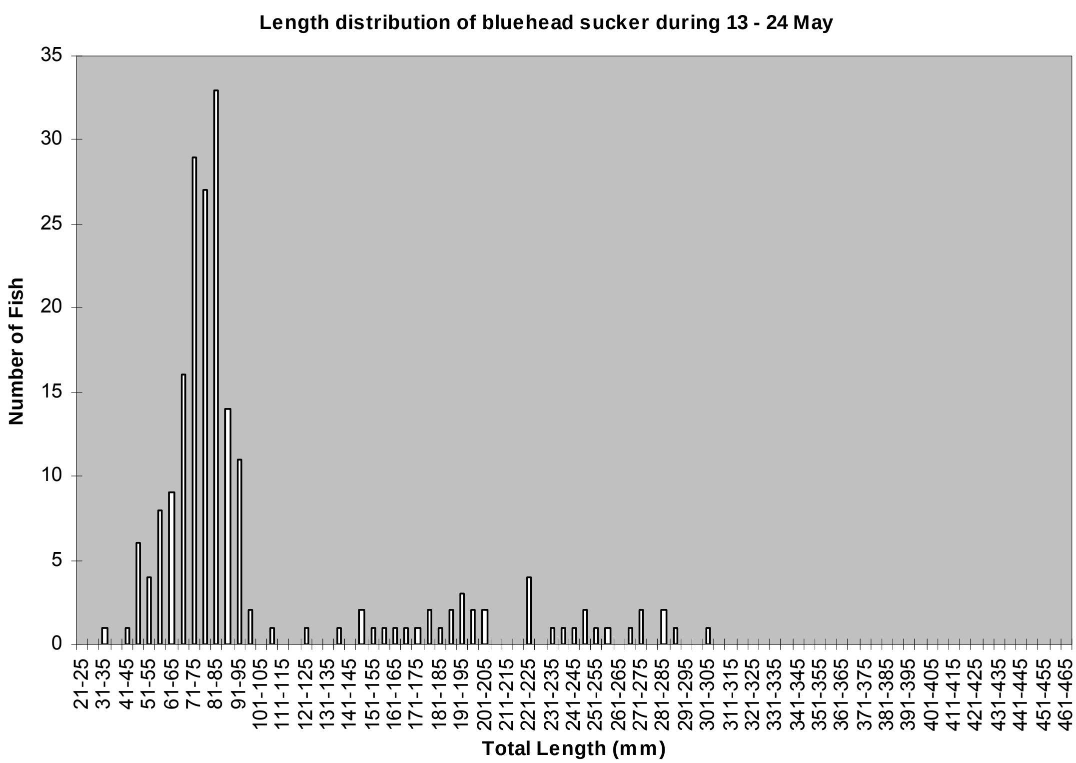


Figure 6. Length frequency distributions of all bluehead sucker captured; Little Colorado River, spring 2002.

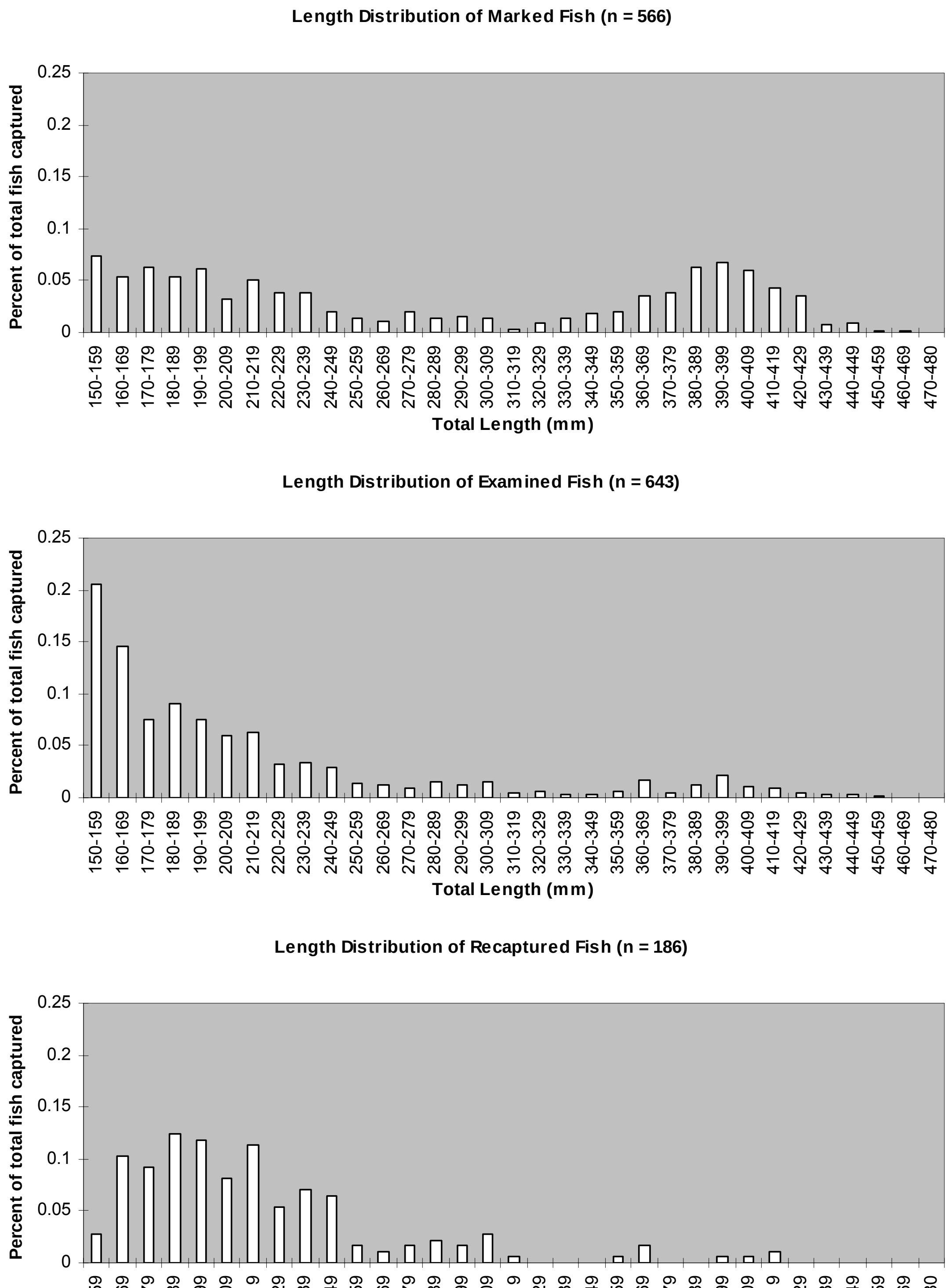
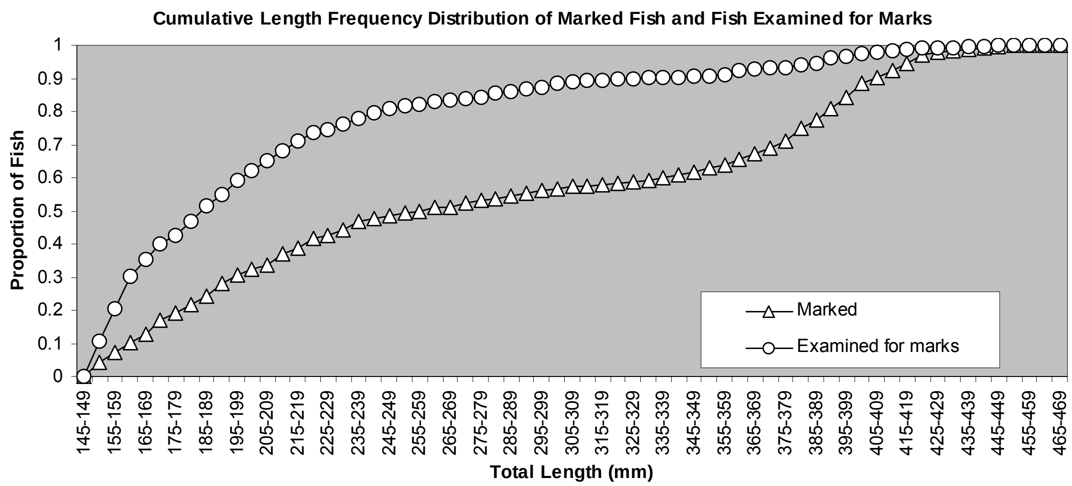


Figure 7 . Length frequency distributions (shown as percentage of total) of all humpback chub ≥ 150 mm captured during the marking and recapture events; Little Colorado River, spring 2002.



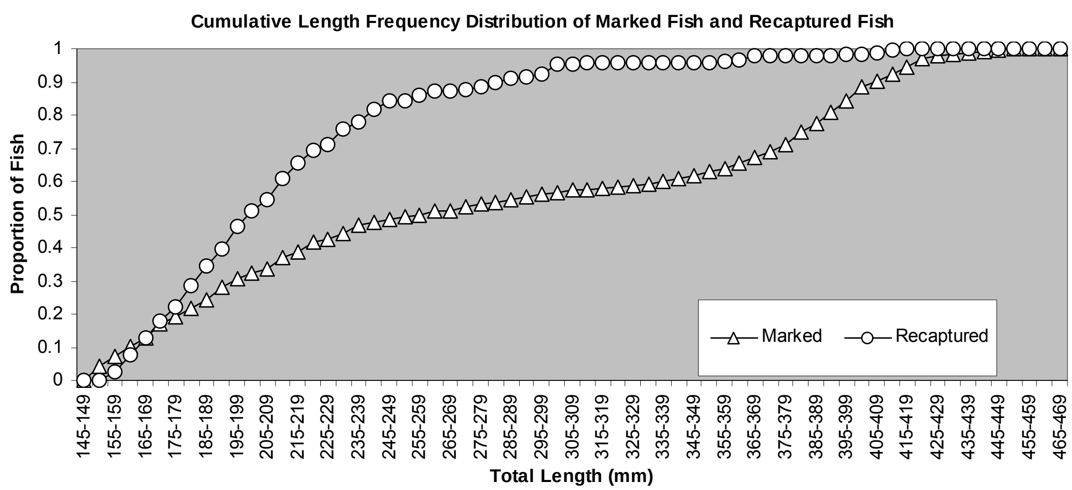


Figure 8. Cumulative length frequency distributions of humpback chub ≥ 150 mm captured; Little Colorado River, spring 2002.

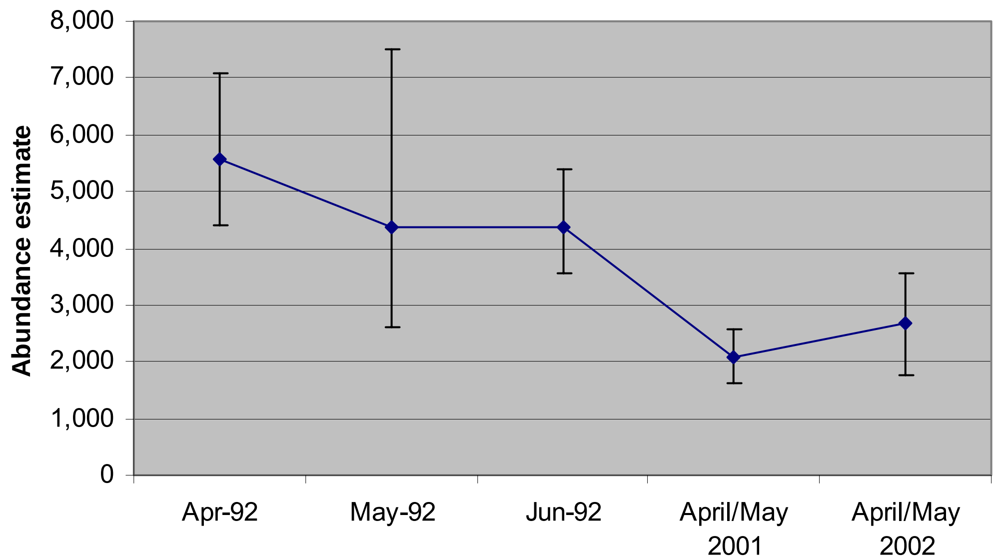


Figure 9. Spring abundance estimates of humpback chub ≥ 150 mm. 1992 estimates are from Douglas & Marsh (1996); 2001 estimate is from Van Haverbeke and Coggins (2002).

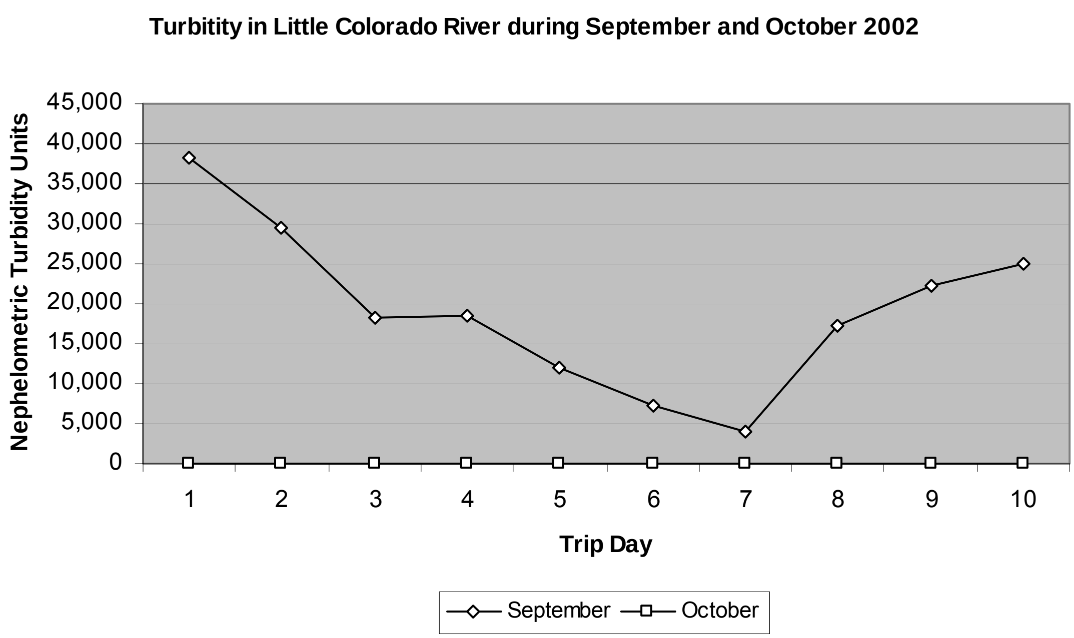
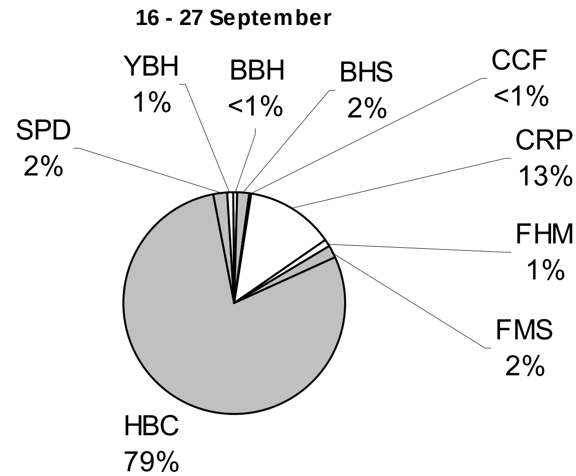


Figure 10. Turbidity readings taken during fall 2002; Little Colorado River.



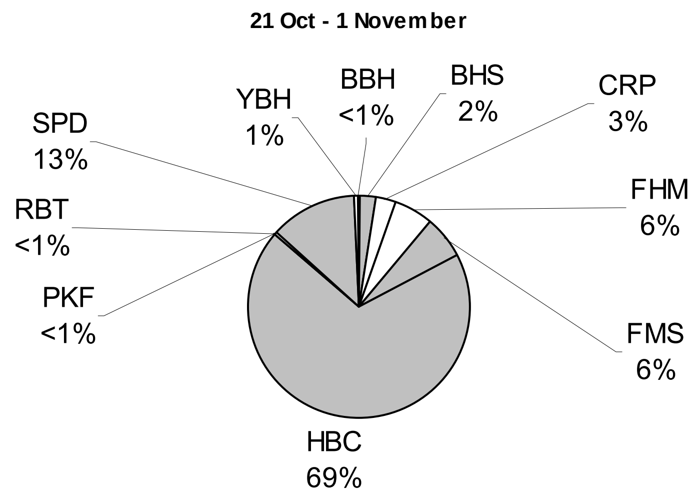
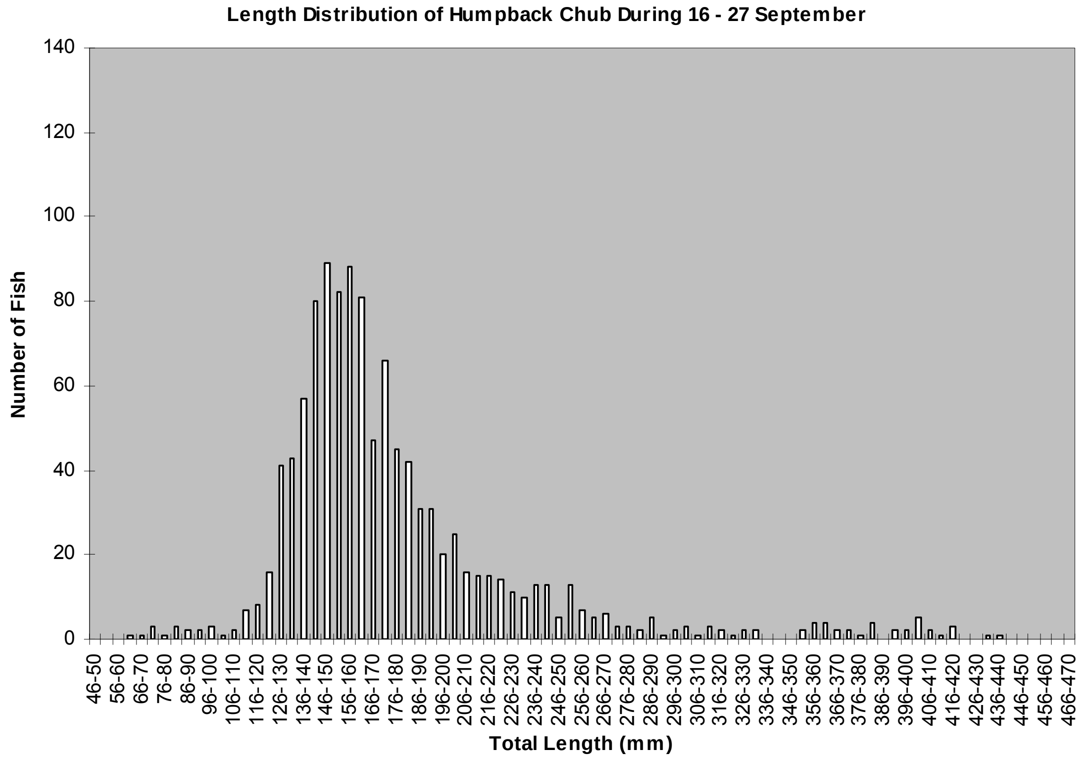


Figure 11. Observed species comparisons of fish captured using hoopnets. Shaded portions are native fish; Little Colorado River, fall 2001.

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*); YBH = yellow bullhead (*A. natalis*).



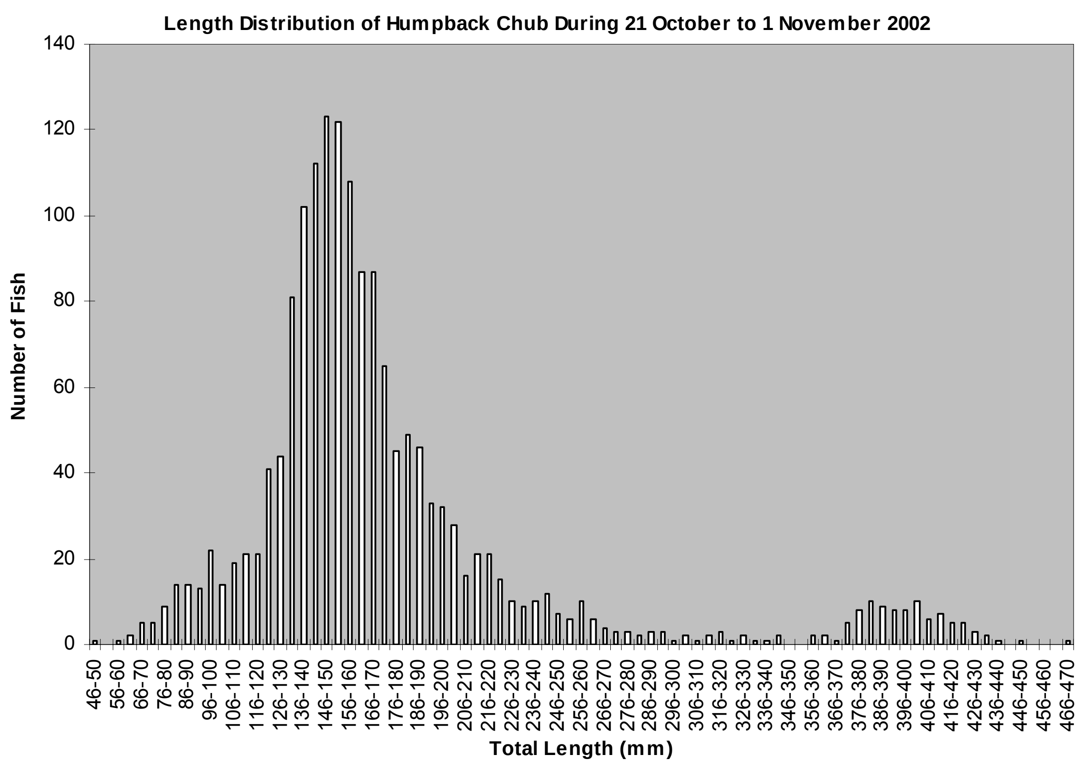


Figure 12. Length frequency distributions of all humpback chub captured in hoop nets; Little Colorado River, fall 2002.

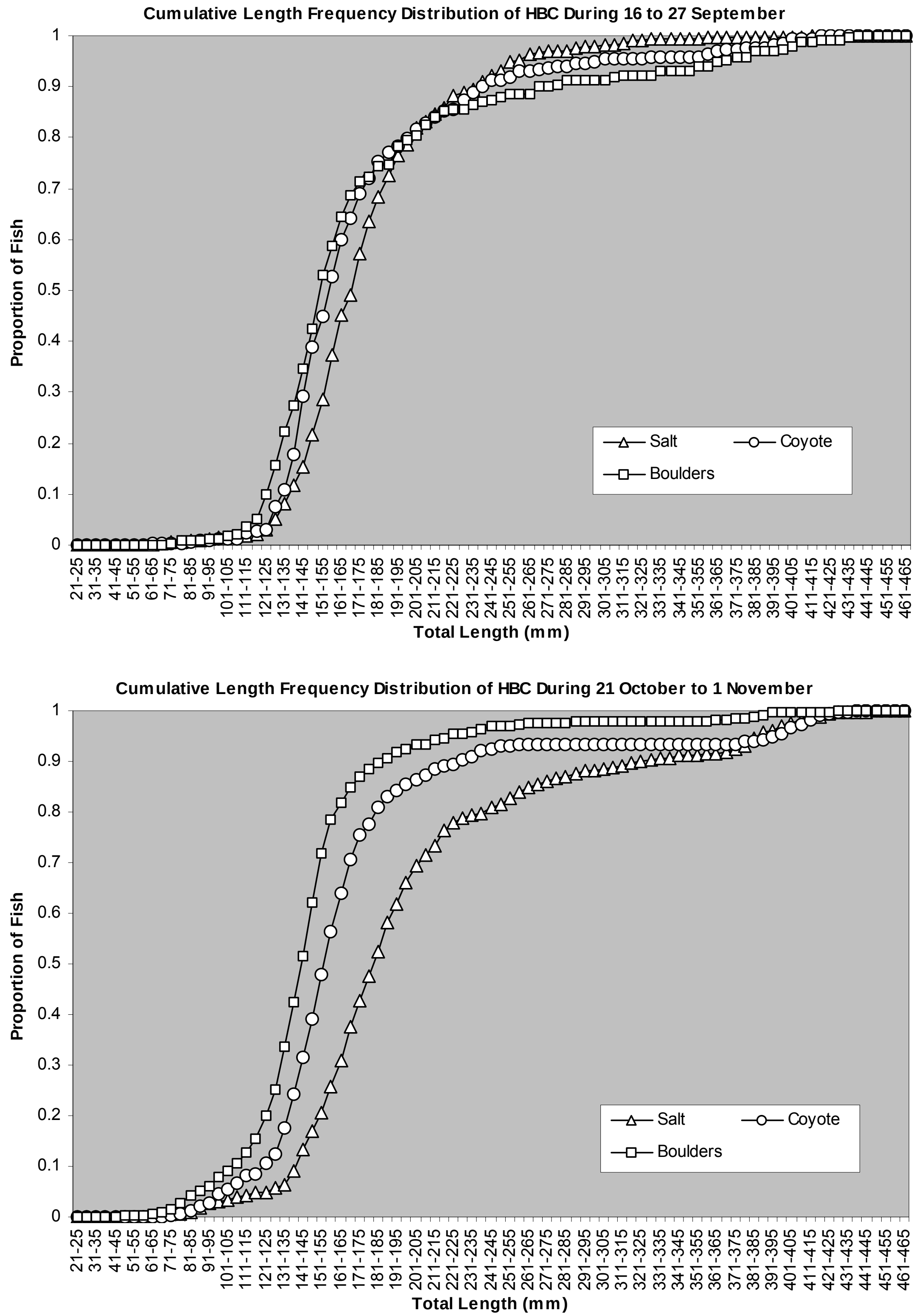


Figure 13. Cumulative length frequency charts of all humpback chub captured in hoopnets at three different reaches (Salt, Coyote and Boulders); Little Colorado River, fall 2002.

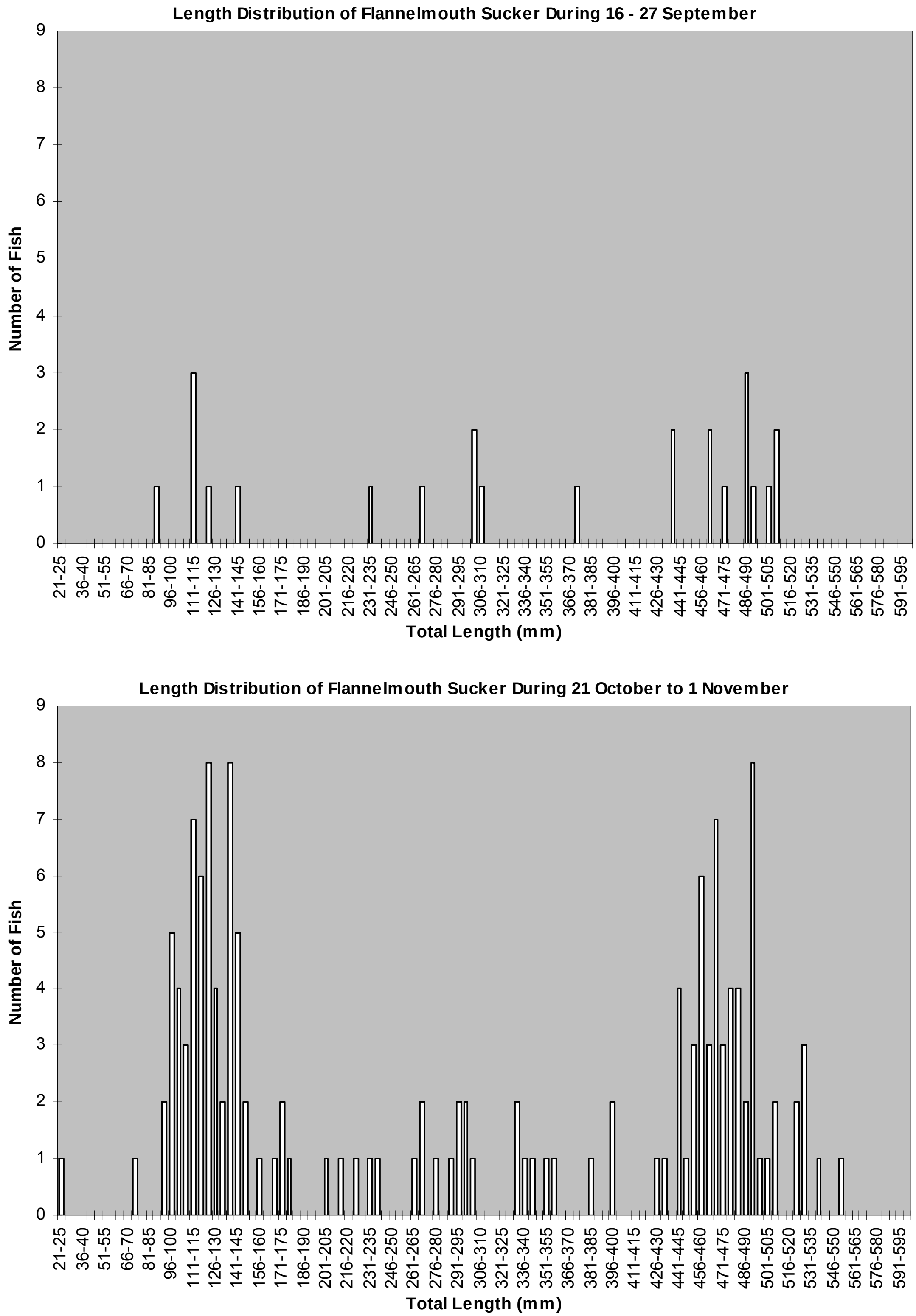
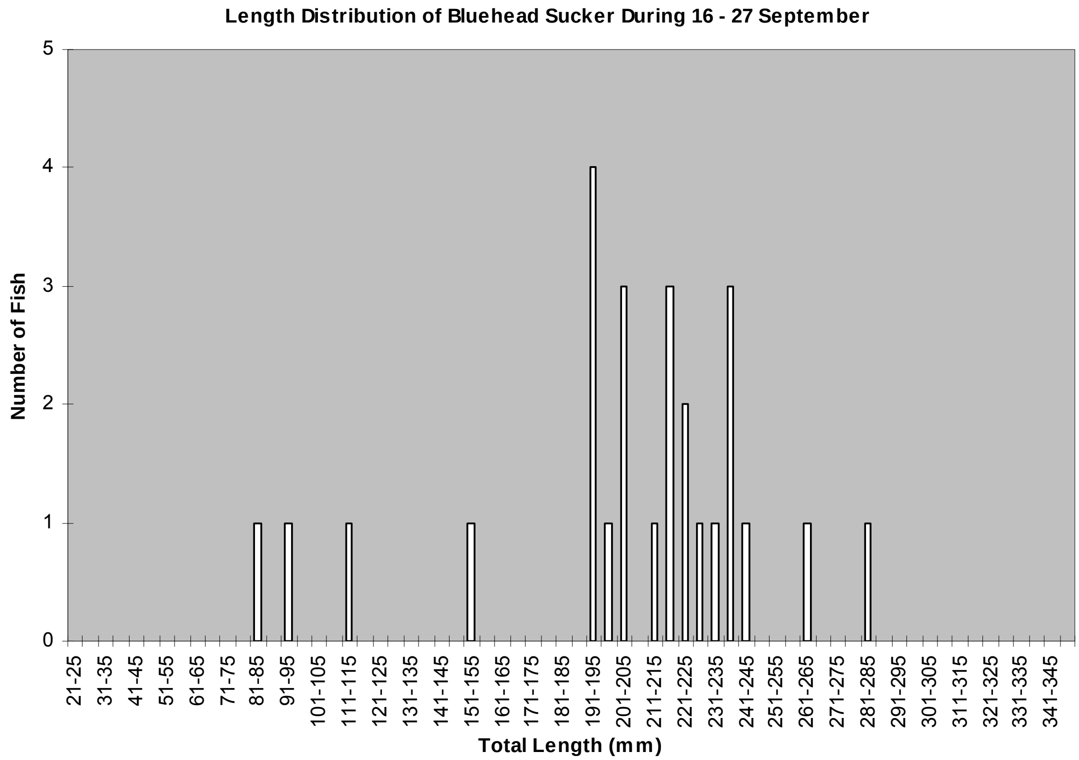


Figure 14. Length frequency distribution of all flannelmouth sucker captured in hoopnets; Little Colorado River, fall 2002.



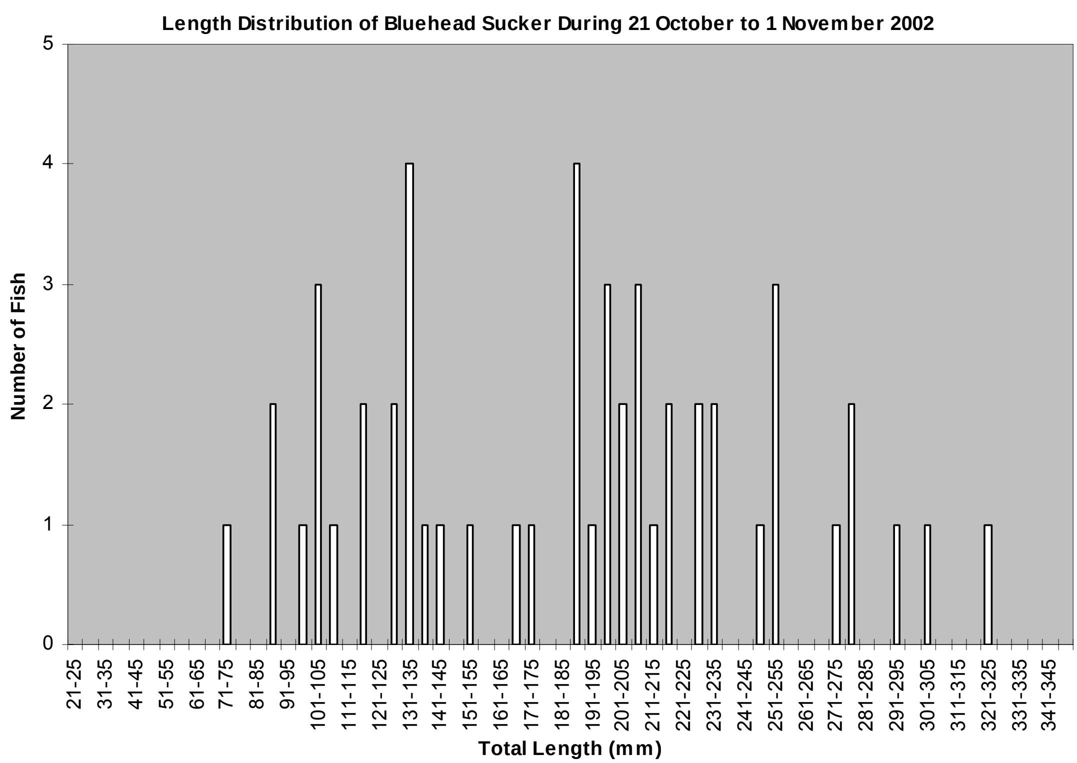
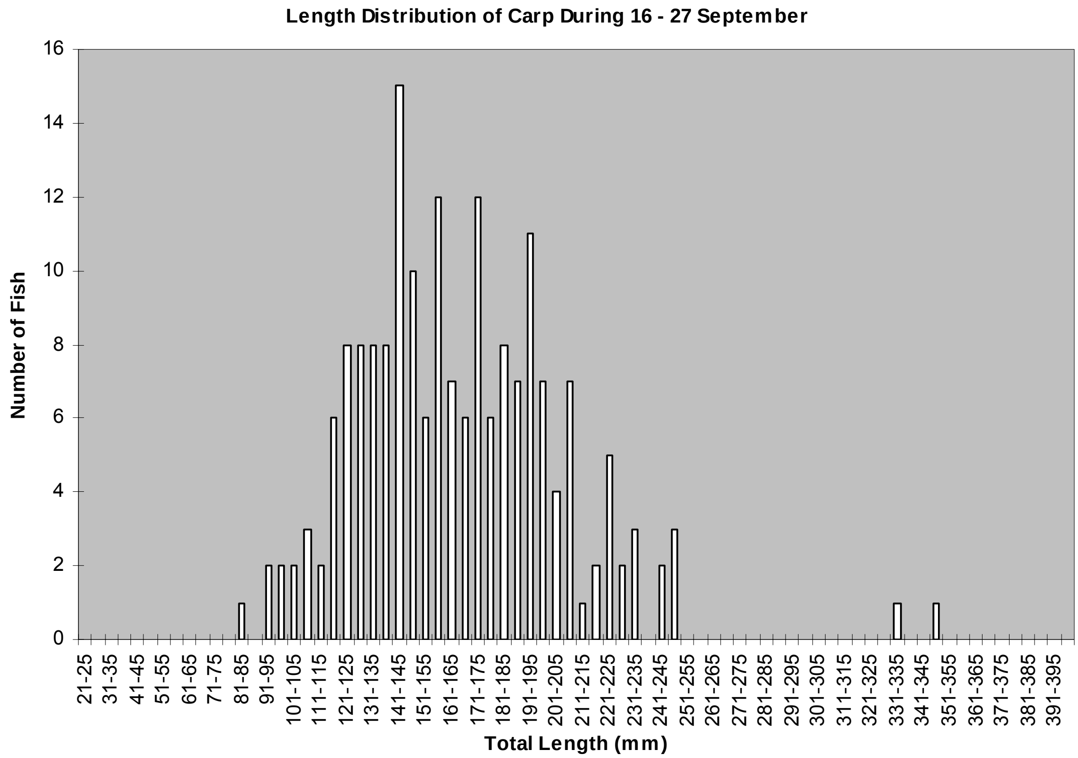


Figure 15. Length frequency distributions of all bluehead sucker captured; Little Colorado River, fall 2002.



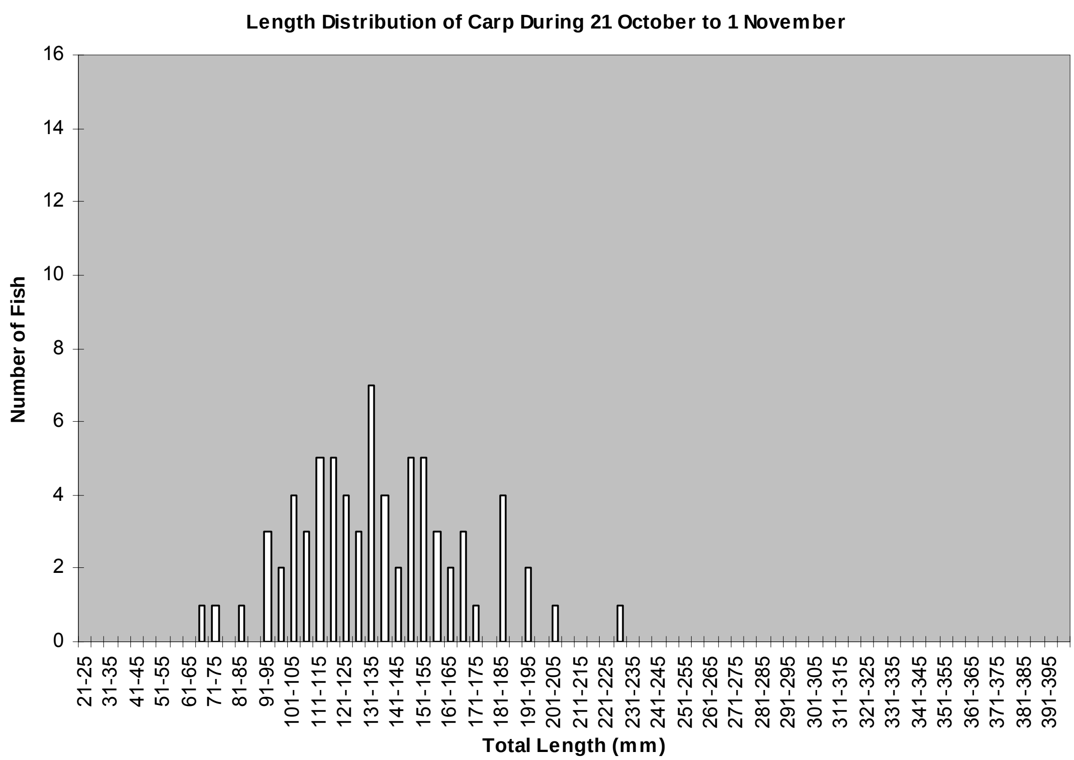


Figure 16. Length frequency distributions of all carp captured during fall 2002; Little Colorado River.

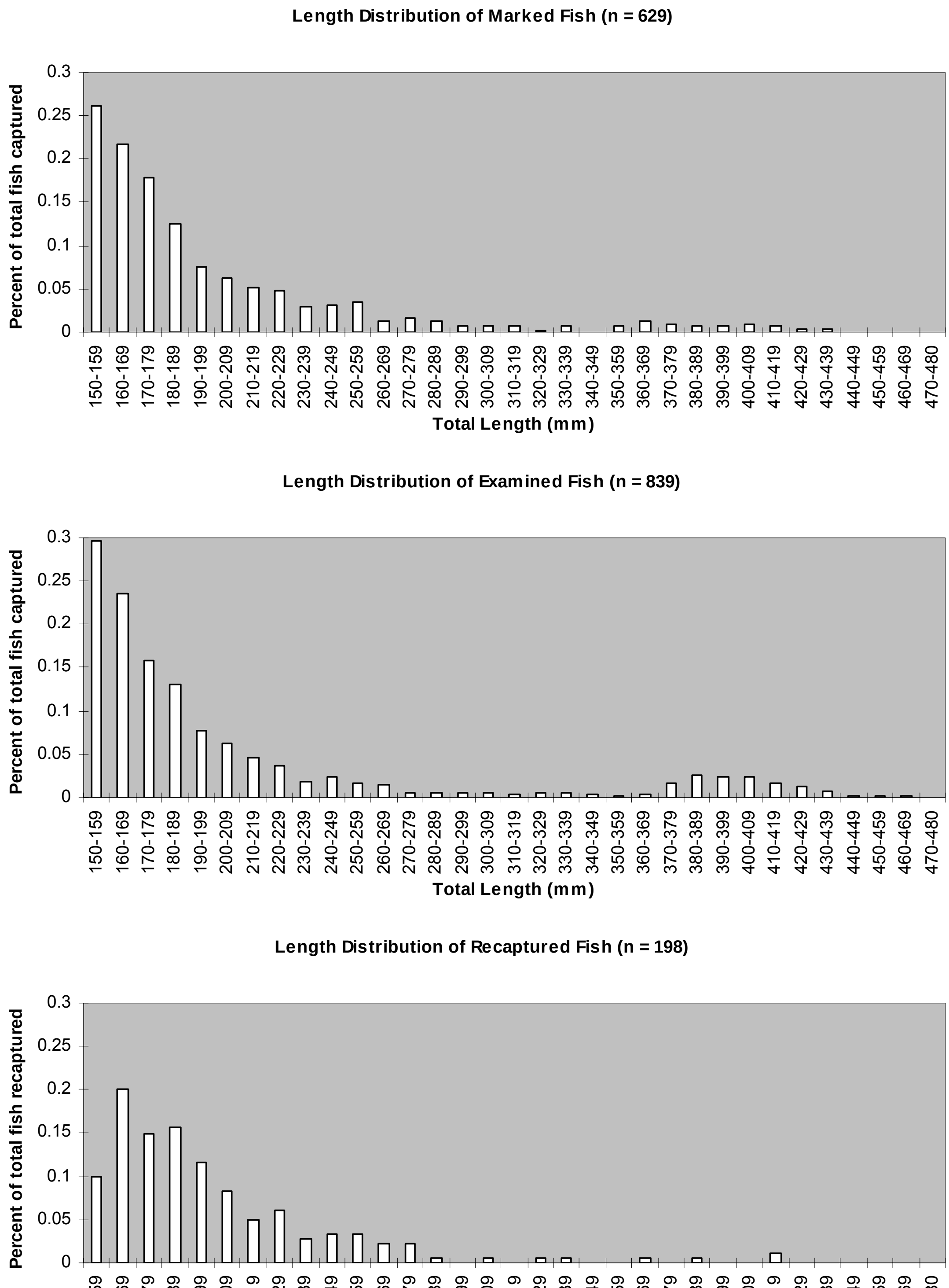


Figure 17 . Length frequency distributions (shown as percentage of total) of all humpback chub ≥ 150 mm captured during the marking and recapture events; Little Colorado River, fall 2002.

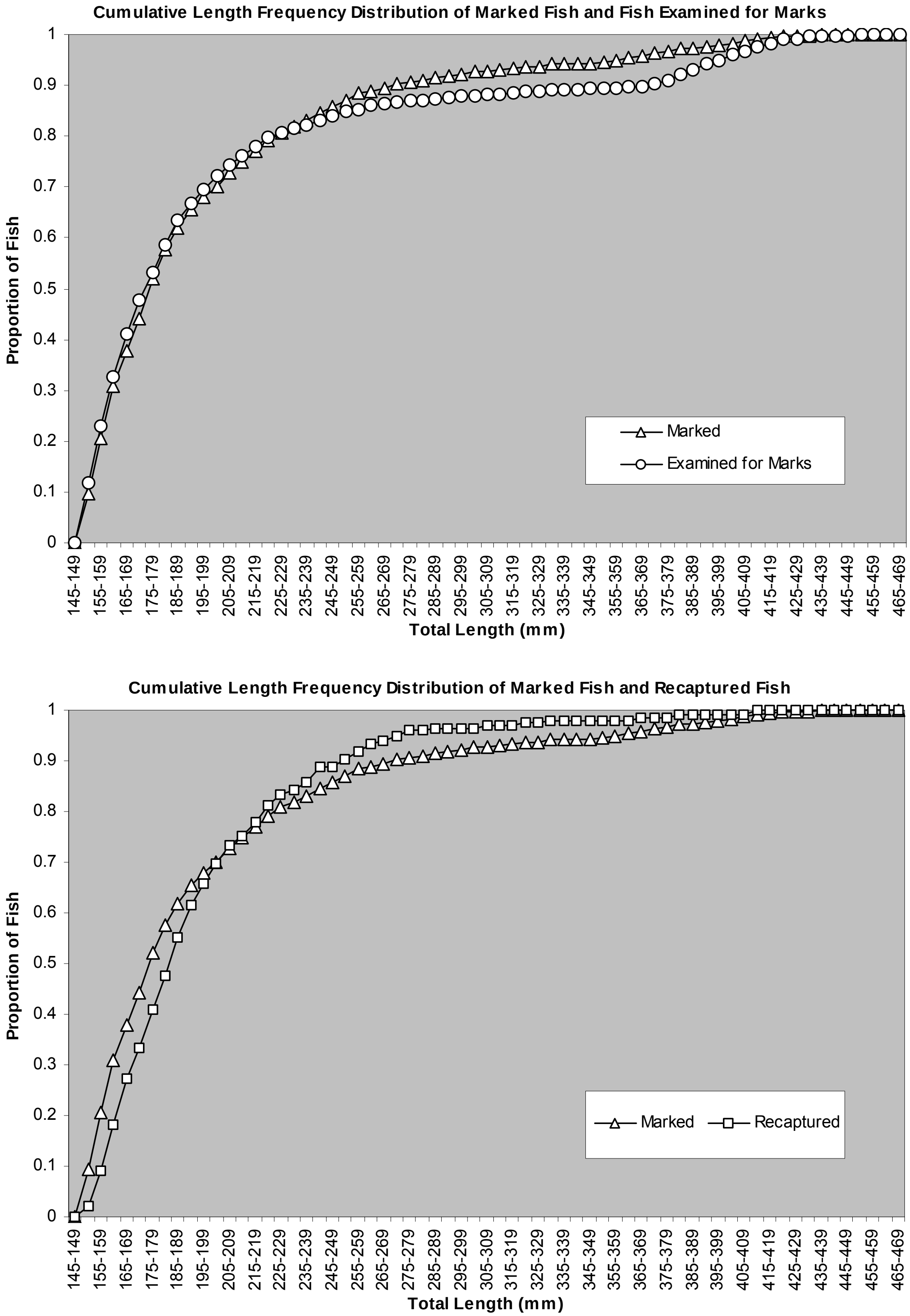
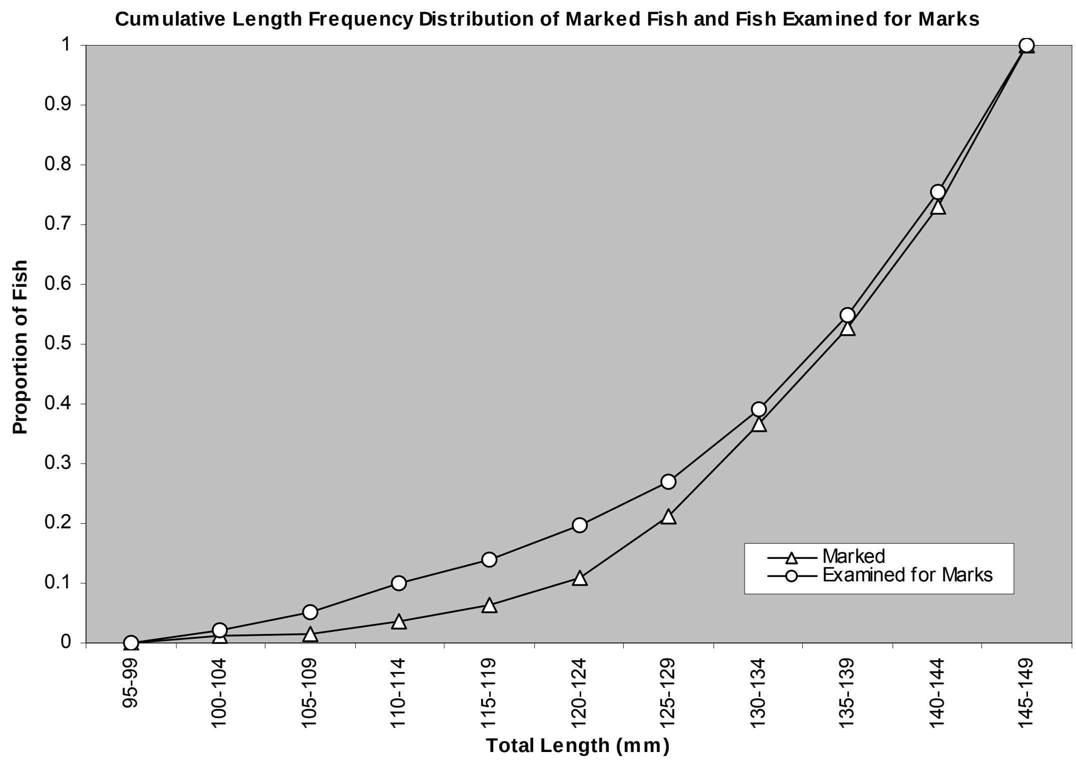


Figure 18. Cumulative length frequency distributions of humpback chub ≥ 150 mm; Little Colorado River, fall 2002.



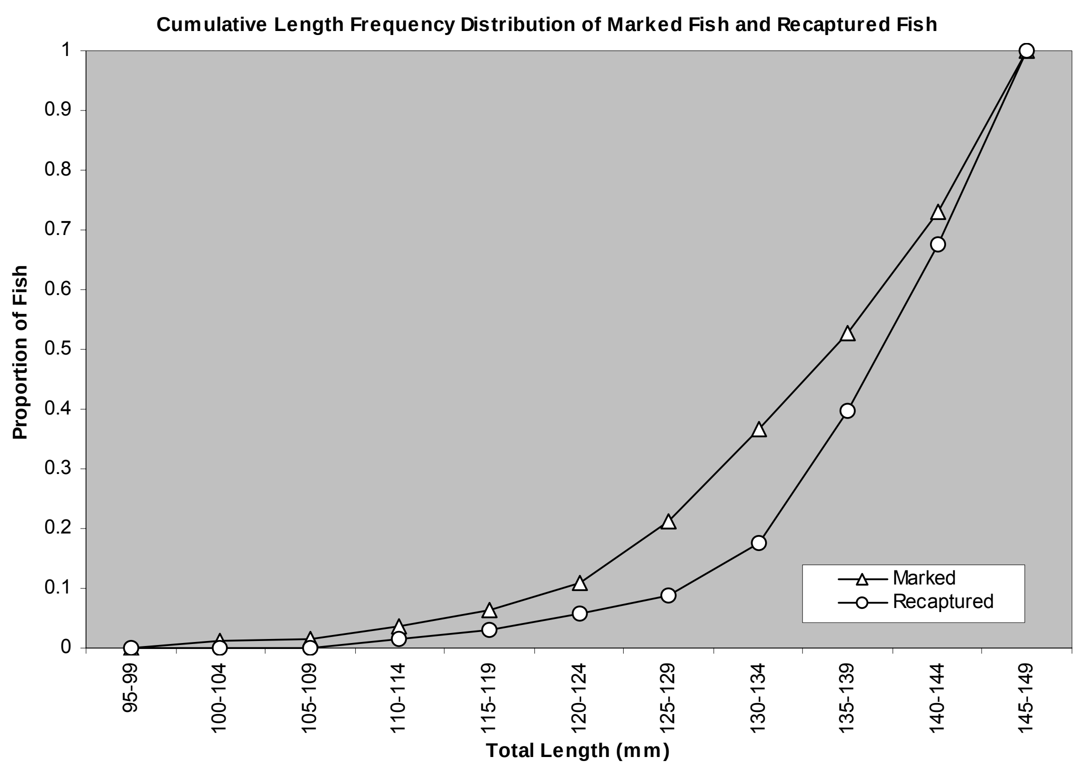


Figure 19. Cumulative length frequency distributions of humpback chub between 100 and 149 mm; Little Colorado River, fall 2002.

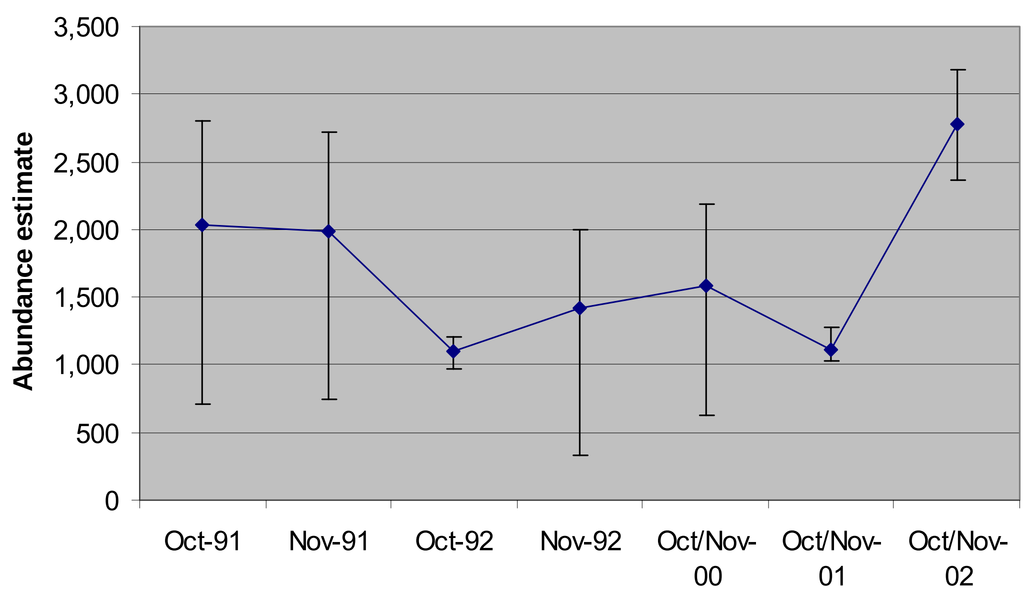


Figure 20. Fall abundance estimates of humpback chub ≥ 150 mm. 1991 and 1992 estimates are from Douglas & Marsh (1996); 2000 estimate is from Coggins and Van Haverbeke (2001), 2001 estimate is from Van Haverbeke and Coggins (2002).