Stock Assessment and Fisheries Monitoring Activities in the Little Colorado River within Grand Canyon During 2001

Final Report

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By

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TABLE OF CONTENTS

TABLE OF CONTENTS **2**

EXECUTIVE SUMMARY **8**

INTRODUCTION **9**

Objectives 10

METHODS **11**

Trips 11

Study site 11

Gear 12

Fish 13

Water quality 14

Mark-Recapture Analysis and Assumptions 14

SPRING RESULTS **19**

Physical Parameters 19

Effort and Catch Composition 20

Species Composition 21

Length frequencies 22

Sexual Condition 24

Predation 26

Parasites 27

Population Estimation 27

FALL TRIP RESULTS **31**

Physical Parameters 31

Effort and Catch Composition 32

Species Composition 33

Length frequencies 33

Sexual Condition 34

Predation 35

Parasites 36

Population Estimation 36

DISCUSSION 39

Objectives 39

Spring Abundance Estimate 39

Fall Abundance Estimate 40

2001 Abundance Estimates and Comparison with Historic Abundance Estimates 41

Recruitment 44

Sexual Condition 46

Parasites 47

RECOMMENDATIONS 49

DATA ARCHIVING 50

LITERATURE CITED 51

TABLE OF TABLES

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, 2001....53

Table 2. Habitat characteristics recorded for hoopnets set in Little Colorado River, 2001....54

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 2001. 55

Table 4. Summary of fish captured by trip, reach, gear type, and species; Little Colorado River, spring 2001. 56

Table 5. Number of humpback chub marked and unmarked during the recapture event by total length strata; Little Colorado River, spring 2001. 57

Table 6. Number of humpback chub marked and unmarked during the recapture event by reach; Little Colorado River, spring 2001....58

Table 7. Estimates of humpback chub abundance using Darroch estimator for fish < 240 mm and Chapman-Petersen estimator for fish ≥ 240 mm. Top portion of table gives estimates for fish ≥ 100 mm while bottom portion of table provides estimates for fish ≥ 150 mm; Little Colorado River, spring 2001....59

Table 8. Abundance estimates of humpback chub in lower 14.2 km of Little Colorado River using length stratified Chapman-Petersen estimator. Top portion of table gives estimates for fish ≥ 100 mm; mid portion of table gives estimates for fish ≥ 150 mm; while bottom portion of table gives estimates of fish ≥ 200 mm; Little Colorado River, spring 2001. 60

Table 9. Population estimates for humpback chub ≥ 150 mm by date. 1992 estimates are from Douglas and Marsh (1996); Little Colorado River, spring 2001. 61

Table 10. 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 2001. 62

Table 11. Summary of fish captured by trip, reach, gear type, and species; Little Colorado River, fall 2001. 63

Table 12. Number of humpback chub marked and not marked during the recapture event by reach and sub-reach in the Little Colorado River, fall 2001. 64

Table 13. Abundance estimates of humpback chub. Top portion of table gives the length stratified Chapman-Petersen abundance estimate of humpback chub 100 – 150 mm and humpback chub > 150 mm. Bottom portion of table gives proportion abundance estimate of humpback chub ≥ 200 mm; Little Colorado River, fall 2001. 65

Table 14. Abundance estimates of humpback chub ≥ 150 mm. 1991 & 1992 estimates are from Douglas and Marsh (1996); 2000 estimate is from Coggins and Van Haverbeke 2001.......................................66

Table 15. Population abundance estimates (N) for humpback chub ≥ 100 mm stratified by length and reach; Little Colorado River, fall 2001.......67

Table 16. Population Estimates for humpback chub ≥ 100 mm stratified by 10 mm length interval; Little Colorado River, fall 2001. 68

TABLE OF FIGURES

Figure 1. Map of the study site, showing Salt, Coyote and Boulders reaches in Little Colorado River. 69

Figure 2. Length frequency distributions of all humpback chub captured in hoop nets and in trammel nets; Little Colorado River, spring 2001. 70

Figure 3. Observed species compositions of all fish captured using hoopnets. Shaded portions are native fish; Little Colorado River, spring 2001. 71

Figure 4. Cumulative length frequency charts of all humpback chub captured in hoopnets at three different reaches (Salt, Coyote and Boulders); Little Colorado River, spring 2001. 72

Figure 5. Length frequency distribution of all flannelmouth sucker captured in hoopnets and trammel nets; Little Colorado River, spring 2001. ...73

Figure 6. Length frequency distributions of all bluehead suckers captured; Little Colorado River, spring 2001. 74

Figure 7. Length frequency distributions of all ictalurids captured; Little Colorado River, spring 2001. 75

Figure 8. Length frequency distributions (shown as percentage of total) of all humpback chub large enough to be PIT tagged captured during the marking and recapture events; Little Colorado River, spring 2001. 76

Figure 9. Cumulative length frequency distributions of humpback chub captured; Little Colorado River, spring 2001. 77

Figure 10. Observed species compositions of fish captured using hoopnets. Shaded portions are native fish; Little Colorado River, fall 2001. ..78

Figure 11. Length frequency distributions of all humpback chub captured in hoop nets and in trammel nets; Little Colorado River, fall 2001. ...79

Figure 12. Cumulative length frequency charts of all humpback chub captured in hoopnets at three different reaches (Salt, Coyote and Boulders); Little Colorado River, fall 2001. 80

Figure 13. Length frequency distribution of all flannelmouth sucker captured in hoopnets and trammel nets; Little Colorado River, fall 2001. 81

Figure 14. Length frequency distributions of all bluehead suckers captured; Little Colorado River, fall 2001. 82

Figure 15. Length frequency distributions of all humpback chub large enough to be PIT tagged captured during the marking and recapture events; Little Colorado River, fall 2001. 83

Figure 16. Cumulative length frequency distributions of humpback chub captured; Little Colorado River, fall 2001.......................................84

Figure 17. Estimated abundance of humpback chub by 10 mm total length interval; Little Colorado River, fall 2001. 85

Figure 18. 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). 86

Figure 19. Proportions of recaptured vs. not recaptured fish and mark vs. unmarked fish during the recapture event (October trip); Little Colorado River, fall 2001. 87

EXECUTIVE SUMMARY

The Grand Canyon Monitoring and Research Center (GCMRC) determined that a rigorous stock assessment program for the Little Colorado River (LCR) was a priority for 2001 (USFWS 2001). As a result, the U.S. Fish and Wildlife Service (USFWS) was contracted by the GCMRC to conduct stock assessment and monitoring activities in the LCR. A total of four monitoring trips were conducted during 2001: (1) 30 April to 11 May, (2) 4 to 15 June, (3) 1 to 12 October, and (4) 5 to 16 November. The primary goal of these trips was to obtain information for stock assessment of the humpback chub (*Gila cypha;* hereafter HBC). In addition, a secondary goal of these trips was to provide information for characterizing attributes of the natural history of the LCR fish community (e.g., species composition, sexual condition, parasites, etc.).

The four trips were 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 3,510 (SE = 282) HBC ≥ 100 mm total length (TL) residing in the lower LCR during the spring of 2001. Of these fish, it is estimated that there were 1,470 (SE = 240) HBC ≥ 200 mm (4+ year old adults). The results of the fall effort indicate that there were 2,424 (SE = 129) HBC ≥ 100 mm total length residing in the lower LCR during the fall of 2001. The fall 2001 estimate was not significantly different from the fall 2000 effort (Coggins and Van Haverbeke 2001).

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 resources downstream from Glen Canyon Dam and making recommendations for the development of a long-term monitoring program to assess those resources. The GCMRC is responsible for implementing the long-term monitoring program and assuring that it is fulfilling the needs of the AMWG. Of the suite of downstream resources, the HBC is particularly important due to its status as a federally listed endangered species.

A tremendous amount of research effort has been expended to gain a better understanding of HBC in Grand Canyon over the last 20 years (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 spent studying the life history and ecology of this species, rather than monitoring population trends. Therefore, the AMWG is unable to effectively assess the impacts of the operation of Glen Canyon Dam, or evaluate whether the fish management objectives associated in the Grand Canyon are being met. As a result, GCMRC has initiated long-term monitoring of Grand Canyon fishes to provide information on the dynamics of fish populations.

After testing various study designs (Coggins and Van Haverbeke 2001), in June 2000, the USFWS proposed a mark-recapture experiment to estimate HBC abundance in the LCR. A two-pass mark-recapture experiment was conducted to estimate the fall abundance of HBC. These trips occurred in October and November 2000 (Coggins and Van Haverbeke 2001). As a result of the success of this methodology, GCMRC contracted the USFWS to conduct two additional mark-recapture efforts in the LCR during 2001.

Objectives

The primary goal of the 2001 sampling trips was to obtain information for 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 2001 were:

1. Obtain spring and fall 2001 population estimates of HBC ≥ 100 mm in the lower 14.2 km of the Little Colorado River.
2. Estimate the over-winter survival/retention rate of juvenile HBC in the LCR between October 2000 and May 2001; and estimate the post-monsoon survival/retention rate of juvenile HBC in the LCR between May 2001 and October 2001.
3. Collect data in support of GCMRC planned stock assessment models. Specifically, our data and results will be used for models designed by GCMRC to estimate long-term population 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

Four fish monitoring trips were carried out in the LCR during 2001. The trip dates were: (1) 30 April to 11 May (hereafter referred to as the May trip), (2) 4 to 15 June, (3) 1 to 12 October, and (4) 5 to 16 November. 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 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

The principle gear type deployed was hoopnets. Hoopnets used were 0.5 - 0.6 m diameter, 1.0 m length, 6 mm (1/4”) mesh, and single 10 cm throat. Sixty hoopnets (45 during the May trip) 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, except for during May when 15 nets were fished evenly within each sub-reach). Each sub-reach within each reach was fished for four days (i.e., this included four nights). Hence, each hoopnet was fished four days (including four nights); however some minor exceptions to this rule were made to accommodate logistical concerns (i.e., difficult terrain in Salt reach and shorter day-length time during fall trips). 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 into the cod end of each net.

During the two spring trips, trammel nets were fished at the LCR confluence. Trammel nets were 75' long x 6' deep with 1" or 1.5" mesh. Trammel nets were checked and emptied of fish each 0.5 to 2 hours, and were fished in the LCR immediately above the mixing zone with the Colorado River. During the October trip, two fyke nets were used to test the feasibility of using an alternate gear type to hoopnets in the LCR. The nets were 1 m tall x 1.5 m wide, with ½" mesh and a 25' single wing.

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. 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 all 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. All fish lengths reported in this document refer to total lengths. All HBC ≥ 100 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 ≥ 125 mm (≥ 150 mm during October and November) were also scanned for a PIT tag; and if missing were injected with a new 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), pH, dissolved oxygen, and conductivity taken with a Hydrolab Surveyor 3 (programmed to record on an hourly basis). Additionally, turbidity readings (nephelometric turbidity units; NTUs) were taken daily with a Hach 2100P turbidimeter. All water quality data were gathered at Salt reach (~10.8 km).

Mark-Recapture Analysis and Assumptions

Two mark-recapture experiments (spring and fall) were conducted to estimate the abundance of HBC ≥ 100 mm in the lower 14.2 km of the LCR. Marking events occurred during the first spring trip (30 April to 11 May) and during the first fall trip (1 to 12 October). Fish ≥ 100 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 (4 to 15 June), and during the second fall trip (5 to 16 November).

As stated above, the target population was all HBC ≥ 100 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. 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 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 (through recruitment, immigration, mortality, or emigration).

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

3. All HBC ≥ 100 mm TL 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 marking and recapture events. However, this assumption was likely violated to an unknown degree 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 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, we do not believe the first assumption was violated. Again, we allowed for only a short time period (less than a month) between the marking 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). We 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 addresses whether 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 the notion of 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 data collected during both the capture and recapture events. The first test compared the length frequency distributions of fish captured during the marking event with those captured during the recapture event. The second test compared the length frequency distributions of fish marked during the marking event with those recaptured during the recapture event. 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, we used a contingency table analysis to test whether recapture rate differed among sampling reaches and sub-reaches (Seber 1982).

The results of these tests determined if modifications to the Chapman-Petersen estimator were necessary to minimize bias (Bernard and Hansen 1992).

The fourth assumption was not directly tested since an auxiliary mark (e.g., fin clip) was not applied to the fish. 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. We assumed that tag loss was probably negligible, but concluded that future investigation is warranted (i.e., secondary marking).

The fifth assumption relates to the ability of field personnel to detect the presence of a tag in a fish. We did not attempt to evaluate this assumption 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:

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

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

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 in the recapture event.

In order to characterize the size distribution of the estimated spring and fall populations, the overall estimate of abundance was stratified to different length intervals (i.e., size classes). The appropriate estimation formulae from Seber (1982) are:

$$N_x^* = \frac{M_x + C_x - R_x}{M + C - R} N^* = P\,(N^*), \tag{3}$$

$$V\left[N_x^*\right] = N_x^{*2}\left[\frac{1}{R_x} + \frac{2}{R_x^{\,2}} + \frac{6}{R_x^{\,3}}\right] + \frac{N_x^*\left(N^* - N_x^*\right)}{\left(M + C + 1\right)} \tag{4}$$

Where P indicates the proportion of fish within a particular size class and the subscript *x* indicates fish that belong to a particular size class (e.g., 100 to 125 mm). 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).

SPRING RESULTS

Physical Parameters

During the May trip, continuous interval hydrolab recordings failed, however, results were obtained from manual daily (morning and afternoon) readings from the Hydrolab and tubidimeter. The LCR was nearing base flow during the first two days of the trip, but was still slightly turbid (157 to 294 NTU). A small spate occurred on 2 May, which raised the river slightly. With this spate, turbidity increased to 998 NTU, and conductivity dropped from the previous day's high of 4,399 to 3,381 μS. Another slightly larger spate occurred on 5 May. This spate increased the turbidity to ~7,000 NTU. These two spates only raised the river level at one measured point ~13 cm, thus were minor events in terms of discharge increase. After the second spate, the LCR subsided again. By 10 May, turbidity had steadily decreased to 145 NTU, and conductivity increased to a high of 4753 μS. By 11 May, the LCR was approaching base flow again and was beginning to turn blue. Recorded water temperatures during this trip ranged from 18.6 to 22.3 ^{o}C (mean = 20 ^{o}C).

During the June trip, continuous hourly Hydrolab reading were obtained, as well as daily turbidimeter readings. The LCR ran at base flow the entire trip and was blue in color. Hence, turbidity remained low the entire trip, ranging from 8 to 14 NTU (mean = 11.3 NTU). Conductivity decreased steadily from a high of 4,464 μS on the first day to 3,212 μS on the last day of the trip. This observed steady decline is thought to be an error resulting from an equipment problem (i.e., precipitating salts may have been building up on the conductivity probe). Water temperatures during the trip ranged from 16.7 to 22.3 ^{o}C (mean = 21.3 ^{o}C).

Effort and Catch Composition

A total of 1,256 hoopnet sets were deployed during the May and June trips yielding 28,882 hours of fishing effort (Table 3). Catch per unit effort (i.e., total HBC captured/total net hours; CPUE) for HBC captured in hoopnets was higher in June (0.102 fish/net-hr) than in May (0.044 fish/net-hr). The June trip had more effort expended in an attempt to increase catches and increase the confidence of the population estimate. More HBC were captured in hoopnets during the June trip (1,658 fish) than during the May trip (551 fish), a result of higher catch rates associated with low turbidity conditions (USFWS 2000, Van Haverbeke 2000), and increased effort (i.e., more hoopnets were set in June; Table 3). The blue water in June may have made smaller HBC (85 to 200 mm) more vulnerable to catch than they were in May (Figure 2). CPUE for HBC varied little between reaches, staying relatively uniform on each given trip, and the distribution of effort (net hours) was similar among the three reaches on both trips (Table 3).

During the May and June sampling trips, a total of 5,311 fish were captured (Table 4). The predominant species were HBC (2,253 fish) and speckled dace (1,087 fish). Fathead minnow (*Pimephales promelas*) was the most predominant non-native species (897 fish). Distribution of HBC caught among reaches was fairly uniform, with the largest difference (85 fish; 15%) in June between Boulders and Salt reaches. Bluehead sucker and flannelmouth sucker were primarily captured in the Boulders and Coyote reaches on both trips (Table 4).

Species Composition

Observed species compositions during both the May and June trips were standardized by presenting hoopnet data only (Figure 3). The additional trammel net data can be found in Table 4. Species compositions during both spring trips were similar (Figure 3). A noticeable exception is that a greater proportion of fathead minnows were captured in June (20%) as compared to May (8%). HBC comprised the largest proportion of fish caught on both trips (52% and 41%). Exotic species collected were carp (*Cyprinus carpio*), red-shiner (*Cyprinella lutrensis*), fathead minnow, plains killifish (*Fundulus zebrinus*), black bullhead (*Ameiurus melas*), yellow bullhead (*A. natalis*), channel catfish (*Ictalurus punctatus*), rainbow trout (*Onchorhynchus mykiss*), and green sunfish (*Lepomis cyanellus*). Exotic species captured in hoopnets during the May and June trips comprised 18 and 25% of the catch, respectively. One adult (157 mm) green sunfish was captured in the Salt reach during the May 2001 trip. Green sunfish have been infrequently captured in the mainstem near LCR confluence (Maddux et al. 1987, Valdez & Ryel 1995). The fish was preserved as a voucher specimen, and is currently being kept at the USFWS Arizona Fishery Resources Office - Flagstaff.

Length frequencies

An abundance of HBC during both trips ranged between 75 to 225 mm, with no clear distinctions among cohorts (Figure 2). Clearly, a greater number of adult HBC > 300 mm were captured during May than in June. Figure 2 shows combined catches of hoopnets and trammel nets, but considering only hoopnet captures, in May, 165 HBC > 300 mm were captured, while in June, only 40 were captured, this despite increased effort in June. These patterns are consistent with post spawning adults moving out of LCR and back into the mainstem sometime previous, or during the June trip (Douglas and Marsh 1996). No young-of-the-year (YOY) HBC (< 50 mm) were captured during May, and only eleven YOY were captured in June (Figure 2).

The observed cumulative length frequencies changed dramatically between the May and June trips. During the May trip, a greater proportion of HBC > 240 mm were captured in all three reaches (Figure 4). This is also indicative of a larger number of spawning HBC being present in LCR during May. Although not explicitly shown in Figure 4, Salt reach captured more HBC > 240 mm on both trips than either Coyote or Boulders reaches. Hoopnets fished during May at Salt, Coyote and Boulders reaches captured 88, 71 and 47 HBC > 240 mm respectively. In June, Salt, Coyote and Boulder reach hoopnets captured 86, 12 and 7 HBC > 240 mm, respectively. Not only did Salt reach catch more fish > 240 mm on both trips, but Coyote and Boulders reaches showed declines in June for fish > 240 mm. Most of the fish that stayed at Salt reach were smaller adults (i.e., essentially all adults > 400 mm were gone by June).

In addition, Salt reach was different than both lower reaches with respect to small fish. During both trips, Salt reach caught noticeably fewer small HBC (particularly 50 to 125 mm; Figure 4). During the May trip, Salt, Coyote and Boulders captured 20, 47 and 27 HBC from 50 to 125 mm. During June, these numbers equaled 137, 263 and 314 fish at Salt, Coyote and Boulders reaches, respectively.

Flannelmouth sucker captured in hoopnets showed a similar trend to HBC, in that a greater number of adult flannelmouth sucker (> 300 mm) were captured in May than in June (Figure 5). During the May trip, Salt, Coyote and Boulders reaches captured 6, 1 and 36 flannelmouth sucker > 300 mm. During June, flannelmouth sucker captures numbered 2, 7 and 10 fish within the Salt, Coyote and Boulders reaches, respectively. Trammel nets fished at the confluence captured 64 (CPUE = 1.1 fish/hr) flannelmouth sucker > 300 mm in May and 34 (CPUE = 2.2 fish/hr) in June. Flannelmouth sucker < 300 mm showed distinct presumably cohort patterns during June, with peaks at 120 mm and ~225 mm (Figure 5). Only three flannelmouth sucker < 50 mm were captured in June, and none were captured during the May trip.

Bluehead sucker also showed the same trend of more adults in May than during June (Figure 6). During the May trip, Salt, Coyote and Boulders reaches captured 4, 7 and 56 bluehead sucker > 150 mm. Most of the bluehead sucker captured in May came from one net (36 fish). During June, bluehead sucker (> 150 mm) captures numbered 3, 1 and 6 within the Salt, Coyote and Boulders reaches, respectively. Only three bluehead sucker were captured in the trammel nets fished at the Confluence in May, and none in June.

All ictalurids (channel catfish, black and yellow bullheads) collected were combined in one length frequency histogram (Figure 7). Nearly all ictalurids captured were < 275 mm. This is assumed to be an artifact of gear selection (i.e., large catfish do not often go into our hoopnets). More ictalurids were captured, with fewer nets, during May (55 fish, CPUE = 0.004 fish/net-hr) than during June (33 fish; CPUE = 0.002 fish/net-hr).

Sexual Condition

Native fish were spawning during the May trip, and several localized spawning clusters were encountered. Seventy-seven ripe HBC were captured. Of these, six were females. The six ripe female HBC had a mean TL of 296 mm (SE =

44.5; 95% C.I. = 114). TL ranged from 140 to 386 mm, and median TL was 355 mm. Four ripe female HBC were captured between 2.5 and 3.0 rkm, another at 6.5 km, and one more at 10.6 km. Ripe male HBC were found scattered (generally 1 to 2 per rkm) between 1.1 and 13.7 rkm. Two obvious concentrations of ripe males appeared between 5.4 and 6.6 rkm (20 fish), and between 10.6 and 11 km (21 fish). Oddly, only three ripe males were captured between 2.5 and 3.0 km (where the most ripe females were captured). Thirty-eight male and eighteen female HBC were recorded as either tuberculate, displaying spawning colors, or both. Six female HBC were recorded as spent (i.e., post spawn condition). All six were > 363, and were captured below 5 km, giving some indication that the peak of the spawning event may have already passed (i.e., spent females already moving back toward the mainstem).

Twenty-six ripe flannelmouth sucker were captured in May. Of these, three were females, and all three were captured between 4.2 and 4.9 rkm (along the *Phragmites* banks). All ripe males were captured at 4.9 rkm, except one captured at the Confluence. All ripe females were > 490 mm and all ripe males were > 348 mm. One spent flannelmouth was recorded at the Confluence.

Fifty-one ripe bluehead sucker were captured in May. Of these, seven were females. These ripe females all occurred in one net at 4.1 rkm (along a *Phragmites* bank), except one at 4.9 rkm. Ripe males occurred sporadically between the Confluence and 9.6 rkm, however, one obvious concentration of 32 males occurred at 4.1 rkm (where the ripe females were captured), and another concentration of six males occurred at 4.6 rkm. All ripe females were > 220 mm, except one (146 mm). All ripe males were > 160 mm, except one (117 mm). In addition, two ripe speckled dace were recorded, and no ripe exotics were recorded.

In contrast to the May trip, the occurrence of ripe fish was greatly diminished in June. Only thirteen ripe male HBC were captured. Including the May trip, 84 ripe male HBC were captured, having a mean TL of 268 (SE = 9.3; 95% C.I. = 18.5; median TL = 247 mm; range in TL = 129 to 422 mm). All ripe HBC captured in June were scattered between 12 and 14.2 rkm, with an exception of one at 10.8 rkm. No obvious spawning concentrations were observed. No tuberculate HBC were recorded in June, however, eighty-four males and thirty-seven females were recorded with spawning coloration.

No ripe flannelmouth sucker were caught in June, however four males were recorded as tuberculate. All four were > 450 mm. In addition, no ripe bluehead sucker were captured, nor were any signs of tuberculation recorded. One ripe female channel catfish (400 mm) and four ripe fathead minnows were captured during June.

Predation

About 35 large bodied exotics were examined for stomach contents during both trips. These fish included black bullhead, yellow bullhead, channel catfish, carp, and rainbow trout. Three instances of direct predation on HBC were recorded. One yellow bullhead (255 mm) contained two HBC (105 & 80 mm). Another yellow bullhead (210 mm) contained one HBC, three red-shiner, and two fathead minnow (prey lengths not recorded). One black bullhead (185 mm) contained one HBC and two fathead minnow (prey lengths not recorded). One HBC (357 mm) was observed with an apparent catfish wound on the dorsum. In addition, three more ictalurids (including a 91 mm black bullhead) had preyed on red-shiner or fathead minnow. Finally, one rainbow trout (303 mm) contained a 95 mm speckled dace. All other stomachs were recorded as 'empty', or containing an assortment of algae, 'bugs', sticks, or fish food (used to bait the nets).

Parasites

Percent occurrence of the external parasite (*Lernaea cyprinacea*) on HBC in May was 4.3% (25 fish) with an average of 1.5 parasites per infected fish. No other fish were observed with *Lernaea*. In June, 6.3% (106 fish) of HBC carried the parasite, with an average of 1.3 parasites per infected fish. Seven flannelmouth sucker and one bluehead sucker also carried a total of fifteen *Lernaea.*

Population Estimation

During the spring mark-recapture experiment, 472 unique HBC ≥ 100 mm were marked [*M*], 1,068 were examined for marks [*C*] during recapture event, and 128 fish examined for marks were recaptures [*R*] from the marking event. To determine the upper and lower length boundaries of the sampled population, we noted the range in lengths observed among the recaptured fish. The smallest HBC recaptured had a total length of 103 mm and the largest recaptured HBC was 412 mm in TL. The estimate was not truncated at 103 mm (size of the smallest recapture), since this is within bounds of potential error in measurement, and marked fish could have grown this much between the marking and recapture events. Rather 100 mm was used as the lower bound. During the marking event, we captured 159 HBC ≥ 325 mm; and during the recapture event, we captured 14 HBC ≥ 300. We did not consider these numbers to be indicative of fishing gear selectivity, particularly when these types of hoopnets have been shown to effectively capture large HBC in previous studies (Gorman and Stone 1999). Therefore, we chose to define our sampled population to include all HBC ≥ 100 mm.

As discussed above, a greater number of adult HBC were captured during May than in June, suggesting that there was movement of adult HBC out of LCR between the marking (May) and recapture (June) events (Figure 2). This pattern is further illustrated in Figure 8, which shows a clear decline in the percentage of HBC > 240 mm captured during the June recapture event. Cumulative length frequency charts further illustrate the differences between the marking event and the recapture events (Figure 9). The cumulative length distribution of marked [*M*] HBC was significantly different from captured [*C*] HBC (n_1 = 471, n_2 = 1,068, Z = 6.669, p = 0.000). Similarly, the cumulative length distribution of marked [*M*] HBC was significantly different than recaptured [*R*] HBC (n_1 = 471, n_2 = 128, Z = 2.984, p = 0.000; Figure 9). 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). This was also confirmed by finding significant difference (χ^2 = 57.80, df = 6, p = 1.26^{-10}) in the mark rates of HBC within different length strata (Table 5). However, the more likely interpretation is that there was differential 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 significantly 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).

The optimal stratification is found by choosing length boundaries in a contingency table setting of unmarked and marked fish (e.g., Table 5) that maximize the χ^2 statistic (Seber 1982, Bernard and Hansen 1992). We performed this procedure and found that the optimal stratification occurred at 241 mm (χ^2 = 62.9), and therefore stratified our estimate at 241 mm (i.e., we produced independent estimates for HBC from 100 to 240 mm and HBC ≥ 241 mm).

We then searched for significant differences in mark rate among the three geographic strata. We found a significant difference (χ^2 = 24.10, df = 2, p = 5.82^{-6}) in the mark rate among the Salt, Coyote and Boulders reaches (Table 6). This result indicated that pooling data across the three reaches was not appropriate, and that we would need to stratify by length within each reach to obtain an unbiased estimate.

An important aspect of stratifying by reach is that fish do not move between the reaches between the marking and recapture events (i.e., each of the three reaches must be able to be treated independently). However, we found movement between the reaches occurring. 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 < 0.0000).

Given that incomplete mixing among geographic strata had occurred, the Darroch estimator should provide the least biased estimate of abundance (Darroch 1961, Seber 1982). Therefore, we attempted to use the Darroch model to estimate the abundance of fish < 241 mm and ≥ 241 mm. The Darroch model was successful for estimating abundance of HBC < 241 mm, but was unsuccessful at estimating abundance of HBC ≥ 241 mm (i.e., the model would not run because of too few recaptures of large fish).

Total abundance estimates for fish ≥ 100 mm and ≥ 150 mm were constructed by summing the estimated abundance from the Darroch model for fish < 241 mm and the estimated abundance from the Chapman-Petersen model for fish ≥ 241 mm (Table 7). However, we found no significant difference between doing this, and using a length stratified Chapman-Petersen estimate (Table 8). Given this, the preferred method is to use the most parsimonious estimator, which was the length stratified Chapman-Petersen. The summed Chapman-Petersen estimate for HBC ≥ 100 mm in the lower 14.2 km of the Little Colorado River was 3,510 (SE = 282) HBC (Table 8).

For comparative purposes with Douglas and Marsh (1996), we present an abundance estimate of HBC ≥ 150 mm. We found the optimal stratification for HBC ≥ 150 mm at 241 mm (χ^2 = 82.59). We did not multiply the length stratified Chapman-Petersen estimate of HBC ≥ 100 mm by the proportion of HBC ≥ 150 mm within each size category because we had concerns about PIT tag loss and mortality occurring in HBC between 100 to 150 mm (see discussion section below). Rather, we truncated the data set at 150 mm and provided a stratified estimate for HBC ≥ 150 mm. The summed Chapman-Petersen estimate for HBC ≥ 150 mm in the lower 14.2 km of the Little Colorado River was 2,082 fish (SE = 242; Table 8). This was significantly lower than the estimates provided by Douglas and Marsh (1996; Table 9).

Since the Recovery Goals for HBC (Valdez et. al. 2001) focus on abundance estimates of fish ≥ 200 mm (i.e., 4+ year old adults), we present estimates relating to their abundance. Using equations (3) and (4), we multiplied the above length stratified Chapman-Petersen estimates of HBC ≥ 150 mm by the proportion of fish ≥ 200 mm. The summed Chapman-Petersen estimate for HBC ≥ 200 mm in the lower 14.2 km of the Little Colorado River was 1,470 fish (SE = 240; Table 8).

FALL TRIP RESULTS

Physical Parameters

During the 1 to 12 October trip, Hydrolab data were collected continuously at one-hour intervals, after 4 October. Daily turbidity meter readings were taken beginning 5 October. The LCR was slightly turbid upon arrival, and was clearing from a previous spate. It continued clearing for the next few days, and was just turning blue when two small spates occurred on the 9 and 10 October. With these small spates, turbidity increased to 4,000 NTU. Conductivity dropped from a high of 4,473 μS on 8 October to 3,255 μS on 10 October. Turbidity steadily declined over the next few days as the river once again began to clear. By 12 October, turbidity had steadily decreased to 1,000 NTU, and conductivity had increased to 4,137 μS. Water temperatures during the trip ranged from 17.4 to 21.8 ^{o}C (mean = 19.8 ^{o}C).

During the 5 to 16 November trip, Hydrolab readings were not obtained. However, daily turbidimeter and manual temperature readings were taken. The LCR ran at base flow the entire trip and was blue in color. Hence, turbidity remained low the entire trip, ranging from 22.2 to 29.9 NTU (mean = 27.2 NTU). Water temperatures during the trip ranged from 17 to 19 ^{o}C (mean = 18 ^{o}C).

Effort and Catch Composition

A total of 1,393 hoopnet sets were deployed during the October and November trips yielding 32,449 hours of fishing effort (Table 10). The distribution of effort was similar among the three reaches with Salt reach receiving slightly less effort during each trip because of logistical constraints. Nets captured 8,235 fish (Table 11). The predominant species in the catch were HBC (5,246 fish) and speckled dace (1,337 fish). Fathead minnow again comprised the predominant non-native species (1,031 fish). Overall CPUE for HBC in October was 0.181 fish/net-hour, and in November was 0.142 fish/net-hour (Table 10). Overall CPUE for HBC in May 2001 was 0.044 fish/net-hour, and in June 2001 was only 0.102 fish/net-hour (Table 3). The higher CPUE during the fall efforts was largely a result of capturing the YOY size class (see Figures 2 and 11 for comparisons of

HBC captures < 100 mm). The distribution of HBC among reaches was somewhat skewed on each trip, with Coyote reach catching the most HBC in October, while Boulders reach caught noticeably fewer HBC in November (Table 10).

Species Composition

Species compositions were standardized during both the October and November trips by using hoopnet data only (i.e., fykenet data not included, but can be found in Table 11). Observed species compositions during both the October and November trips were similar, with some minor yet notable differences (Figure 10). HBC comprised the largest proportion of fish caught on both trips (70% and 59%). Captures of both speckled dace and fathead minnow increased in November; while captures of bluehead sucker and flannelmouth sucker both declined (Table 11, Figure 10). Exotic species included carp, fathead minnow, plains killifish, black bullhead, yellow bullhead, channel catfish and rainbow trout. Red shiner were absent during the fall sampling. Exotic species captured in hoopnets during the October and November trips comprised 10 and 16% of the catch, respectively.

Length frequencies

Length frequency distributions for HBC on both trips were similar (Figure 11). More HBC were captured during the October trip (2,915 fish) than during the November trip (2,331 fish), probably a result of the warmer water, and slightly increased effort in October (17 more hoopnets were set in October). Most HBC collected during both trips ranged between 50 to 100 mm, representing YOY (Figure 11).

Cumulative length frequencies for HBC were also similar for October and November (Figure 12). During both trips, Coyote and Boulders reaches show nearly identical cumulative length frequencies, while Salt reach is somewhat different, owing to a greater proportion of larger HBC (> 100 mm) being captured in Salt reach. For example, during October, 64% of the HBC captured in Salt reach were > 100 mm. In contrast, only 35 and 30% of the fish captured at Coyote and Boulders reaches, respectively, were > 100 mm.

Flannelmouth sucker length frequencies reflect the greater number of flannelmouth sucker captured in October (301 fish) compared to November (154 fish; Figure 13). However, in November more flannelmouth sucker > 300 mm (41 fish) were caught than in October (16 fish). Unlike HBC, flannelmouth suckers did not show strong peaks for YOY (i.e., fish < 100 mm). For example, only eight flannelmouth sucker < 100 mm were captured in October, and none in November.

More bluehead sucker were captured in October (107 fish), compared to November (14 fish; Figure 14). Similar to flannelmouth sucker, no strong YOY peaks are seen for bluehead sucker, with only 7 bluehead sucker < 100 mm captured in October, and none in November.

Sexual Condition

No ripe HBC were captured during the October trip, however three HBC were recorded with breeding coloration. All three were large fish > 320 mm. Fifty-two ripe bluehead sucker were captured in October. Of these, six were females. Spawning concentrations of bluehead sucker including ripe males and at least one ripe female occurred at 2.4, 2.5, 12.4 and 13.8 rkm. The largest of these concentrations occurred at 12.4 rkm, where three ripe females and 23 ripe males were captured in one net. The net was set in boulder habitat with current. Ripe females were > 175 mm, and ripe males were > 168 mm. No other ripe fish were recorded in October.

Two ripe HBC were observed during November in the Coyote reach. Both were males (396 and 405 mm). Fourteen ripe flannelmouth sucker were captured (13 males and 1 female). All except one male were captured in a single net at 4.2 rkm, along a vegetated bank in run current. Ripe males were tuberculate, and > 430 mm. The ripe female was 485 mm. Three ripe male bluehead sucker were captured in the Boulders and Coyote reaches. No other ripe fish were recorded.

Predation

Twenty-four large bodied exotics were examined for stomach contents during both trips. These fish included 11 black bullheads, 12 yellow bullheads, and one rainbow trout. Four instances of direct predation on HBC were recorded. One yellow bullhead (199 mm) contained two HBC (~70 mm each). Another yellow bullhead (234 mm) contained one HBC (58 mm) and one speckled dace (57 mm). One black bullhead (174 mm) contained three HBC (prey lengths not recorded). One HBC was regurgitated by a yellow bullhead (174 mm).

In addition, one yellow bullhead (249 mm) had four unidentified fish in its stomach (43 to 47 mm), and two yellow bullheads had carp scales or sticks and debris in their stomach. The remaining 18 exotics had empty stomachs.

Parasites

Percent occurrence of *Lernaea cyprinacea* on HBC in October was 4.4% (129 fish) with an average of 1.2 parasites per infected fish. In addition, five flannelmouth sucker had a total of six *Lernaea.* In November, 3.9% of HBC (90 fish) carried *Lernaea*, with an average of 1.5 parasites per fish. Also in November, three flannelmouth sucker, one speckled dace and one fathead minnow had a total of six *Lernaea*. Finally, two HBC were recorded with the Asian tapeworm (*Bothriocephalus acheilognathi*) protruding from their vent.

Population Estimation

During the fall mark-recapture experiment, 944 unique HBC ≥ 100 mm were marked [*M*], 730 were examined for marks [*C*] during the recapture event, and 325 fish examined for marks were recaptures [*R*] from the marking event.

The smallest HBC recaptured had a total length of 101 mm and the largest recaptured HBC was 414 mm in TL. We decided not to truncate the estimate at 101 mm (size of the smallest recapture), since error in measuring a fish can be greater than 1 mm. Rather, 100 mm was used as the lower bound. We captured seventeen HBC ≥ 300 mm that were tagged in the marking event, but only three HBC ≥ 300 mm in the recapture event. However, hoopnets have been shown to effectively capture large HBC in previous studies (Gorman and Stone 1999) and the literature suggests that most large individuals reside in the mainstem Colorado River during this time of year (Valdez and Ryel 1995). Therefore, it is likely that the observed low catches of large HBC are due to their absence in the system rather than fishing gear selectivity. Hence, we chose to define our sampled population to include all HBC ≥ 100 mm.

As presented above, the length distributions of HBC were similar between the October and November trips (Figure 11). This pattern is further seen in Figure 15, which shows a similarity in the length frequencies of marked, captured and recaptured fish. Despite these similarities, the cumulative length distribution of marked [*M*] HBC was significantly different from HBC captured [*C*] during the recapture event (n_1 = 944, n_2 = 730, Z = 1.883, p = 0.002). Likewise, the cumulative length distribution of marked [*M*] HBC was significantly different than recaptured [*R*] HBC (n_1 = 944, n_2 = 325, Z = 2.412, p = 0.000; Figure 16). We conclude from these tests that there was significant size selective gear bias within the sampled population. Although statistically significant, this result is probably not biological meaningful. At larger sample sizes, Kolmogorov-Smirnov tests will usually reject the null hypothesis (SPSS, 1995, p. 191). As a result, our length frequency tests showed statistical significance; even though the cumulative length frequency curves nearly match (Figure 16). Nevertheless, we chose to stratify our abundance estimate based on length by procedures given in Seber (1982) and found the optimal stratification at 150 mm (χ^2 = 45.20).

We found no significant difference (χ^2 = 3.09, df = 2, p = 0.214) in the mark rate among the 3 sampling reaches (Table 12). We conclude from these tests that our abundance estimator need not be stratified by location.

Based on the above tests, we chose a stratified Chapman-Petersen model to estimate the abundance of HBC ≥ 100 mm in the lower 14.2 km of the LCR. The estimated abundance was 2,424 (SE = 129) HBC (Table 13).

For comparative purposes with historical estimates, we present an estimate of HBC > 150 mm (Tables 13 & 14, Figure 18). The estimated abundance of HBC > 150 mm was 1,064 fish (SE = 33; Table 14).

Since the Recovery Goals for HBC (Valdez et. al. 2001) focus on abundance estimates of fish ≥ 200 mm (i.e., 4+ year old adults), we present estimates relating to their abundance. We multiplied the above length stratified Chapman-Petersen estimate of HBC > 150 mm by the proportion of fish ≥ 200 mm. The estimated abundance of HBC ≥ 200 mm was 483 fish (SE = 48; Table 13).

Although there was not a significant difference in the mark rate among sampling reaches, indicating that pooling data across reaches was appropriate, it is informative to know the spatial distribution of HBC within the system. Therefore, we also constructed area stratified abundance estimates (Table 15). The majority (82%) of the population is concentrated in the Salt and Coyote sampling reaches with the remaining 18% residing in the lower Boulders reach. This is in contrast to fall 2000, when the majority (81%) of the population was in the Salt and Boulders reaches, while Coyote reach contained only 19% of the population (Coggins & Van Haverbeke 2001).

Using equations (3) and (4), the total abundance estimate was also stratified by 10 mm total length intervals (Table 16, Figure 17). It is apparent that the majority

(81%) of the population is smaller than 200 mm and that only 3% of the population was larger than 290 mm. Again, this is similar to the fall 2000 estimates, when the majority (81%) of the population was smaller than 225 mm, and only 3% of the population was larger than 315 mm.

DISCUSSION

Objectives

We were successful at obtaining spring and fall 2001 population estimates of HBC ≥ 100 mm in the lower 14.2 km of the LCR (Objective 1). Our most successful estimate appears to be the fall 2001 estimate. We were unable to estimate the over-winter survival/retention rate of juvenile HBC in the LCR between October 2000 and May 2001, or the post-monsoon survival/retention rate of juvenile HBC in the LCR between May 2001 and October 2001 (Objective 2). This was because in order to determine these survivorship rates, specific size class abundance estimates must be quantified. We were unable to reach this level of resolution for the spring 2001 abundance estimate. We were successful with Objective 3, and did collect data in support of GCMRC planned stock assessment models.

Spring Abundance Estimate

Overall performance of the spring abundance estimate was rather poor. We present an estimate of HBC abundance for spring 2001, but caution that there are a number of reasons why it could be biased. First, our length frequency analyses provide evidence that larger HBC left the LCR in between the marking and recapture events. This means that the assumption of population closure was violated to an unknown degree. Second, the mark vs. unmarked 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. Our length frequency analyses suggest this was caused by more large fish moving out of the Coyote and Powell reaches than out of the Salt reach. This suggests that resident HBC ≥ 240 mm in the LCR tend to be concentrated in the Salt reach.

Since emigration evidently occurred, our estimate is germane to the abundance of fish during the marking event (Seber 1982). This implies that our abundance estimate may be accurate for the abundance of spawners in the LCR during May.

Fall Abundance Estimate

Much like the fall population estimate provided in 2000 (Coggins & Van Haverbeke 2001), the fall estimate in 2001 had few complications. This is primarily because HBC are not migrating during this time of year (Douglas and Marsh 1996, Valdez and Ryel 1995), and violation of closure assumptions is less of a concern. We chose to stratify our estimate at 150 mm for technical reasons only (i.e., biologically we did not consider it necessary), and pooled our estimate across the three reaches.

One issue that has been of concern with population abundance estimates in Grand Canyon has been the question of tag loss and mortality. This is particularly relevant for the 2001 estimates, since we decided to tag fish as small as 100 mm. We found that the recapture rate (i.e., the proportion of recaptured fish during the recapture event) rate for HBC from 100 to 150 mm was about half that for fish from 150 to 200 mm (Figure 19). An almost identical trend was seen in mark rates (i.e., the proportion of marked fish during the recapture event; Figure 19). This provided some evidence that either: 1) mortality of smaller PIT tagged fish was occurring or 2) tag loss was occurring at a higher rate in smaller fish. We believe this to be a partial result of both. If animals lose their tags, the recapture rate will be smaller than expected, resulting in an overestimate of abundance (Seber 1982). Hence, our estimate for HBC in the 100 to 150 mm length range could be overestimated during both the spring and fall estimates.

2001 Abundance Estimates and Comparison with Historic Abundance Estimates

The LCR population of HBC consists of two primary components. There is a portion of fish that remain year-round in the LCR (Douglas and Marsh 1996); and there is a portion of fish that migrate from the mainstem to spawn in LCR (Keading and Zimmerman 1983, Valdez and Ryel 1995, Douglas and Marsh 1996). As a result of this life history characteristic, there are two possible strategies to estimate the LCR population of HBC. First, one could make the presumption that a spring abundance estimate obtained in LCR will represent the abundance of HBC that reside in the LCR, plus those that migrate from the mainstem into the LCR to spawn. This strategy was performed in our spring abundance estimate, which yielded an estimate of 3,510 HBC $\geq$ 100 mm. Second, one could add an estimate of HBC residing in the LCR (our fall estimate) to those HBC that have emigrated out of the LCR post-spawning season. This strategy involves the addition of two independent estimates (i.e., an LCR abundance estimate obtained during non-spawning season, and a mainstem estimate obtained during non-spawning season). During August and September 2001, SWCA obtained a mainstem abundance estimate for HBC ≥ 200 mm of 1,044 fish (SWCA, Inc. 2002). This estimate was inclusive of HBC from river mile 56 to 69 (or where about 90% of the mainstem portion of adult HBC reside; Valdez & Ryel 1995). Adding this estimate (1,044 fish) to our fall 2001 estimate for fish ≥ 100 mm (2,424 fish) gives 3,468 fish. This is very close to our spring abundance estimate of 3,510 fish. One can also restrict this same line of reason to fish ≥ 200 mm. Adding the SWCA Inc. (2002) estimate of 1,044 fish ≥ 200 mm to our fall estimate of fish ≥ 200 mm (483 fish) gives 1,527 fish. This is nearly identical from our spring estimate for HBC ≥ 200 mm of 1,470 fish.

Of further interest is that the mainstem abundance estimate obtained by SWCA for 2001 is a significant decrease from a similar mainstem abundance estimate obtained during the early 1990's (Valdez & Ryel 1995). SWCA estimated 1,044 (SE = 300) HBC ≥ 200 mm between river mile 56 to 69 during July/August and September 2001 (SWCA 2002), while Valdez & Ryel's (1995) estimate for HBC ≥ 200 mm during 1990 to 1993 was 3,482 (SE = 408) between river miles 57 to 65.4. This would appear to indicate that there has been a significant decline in the portion of HBC that reside in the mainstem since the early 1990's (SWCA, Inc. 2002). Furthermore, since mainstem HBC originate from the LCR (Keading and Zimmerman 1983), this suggests that there has been a decline in recruitment (or survivorship) from the LCR from over this time period. Alternatively (and more likely), the decline could be due to factors operating in the mainstem, such as poor survivorship of YOY and juvenile HBC displaced out of LCR (Valdez and Ryel 1995; Clarkson and Childs 2000).

In addition, we examine the following rational as further information as to why our spring estimate suggests a decrease in abundance of HBC. Because Douglas and Marsh (1996) abundance estimates only included HBC ≥ 150 mm, we can only compare this size group. Our spring estimate for HBC ≥ 150 (2,082 fish) is lower than the average estimate (4,959 fish) provided by Douglas and Marsh for April and May 1992 (Table 9). Additionally, the 95% confidence interval for our spring 2001 estimate does not overlap the confidence intervals for the estimates constructed in 1992. Finally, Douglas and Marsh's monthly abundance estimates did not drop below 4,300 fish until July in 1992 (Douglas & Marsh 1996), whereas our estimate was down to 2,082 fish by early May (assuming our estimate is germane to the marking event).

Our abundance estimate for HBC > 150 mm in fall 2001 (1,064 fish) is not significantly different than the estimate generated in fall 2000 (1,590 fish; Table 14). Neither of these estimates is significantly different than the October and November estimates obtained by Douglas and Marsh in 1992 (Table 14, Figure 18). The average of the four 1991/92 fall estimates was 1,636 while the average for the 2000 and 2001 estimates is 1,327 fish (Table 14). The 1992 estimates included a broader reach of river (0 – 14.9 rkm), while our 2001 estimate extends from the confluence the 14.2 rkm. Therefore, although our estimates may not be directly comparable to Douglas and Marsh's estimates, they are robust enough to provide a good comparison for trend.

With the data in hand, and with consideration of the above lines of rationale, it does appear that there has been a decline in the Grand Canyon HBC population since the early 1990's. The data and rationale also suggest that the main decline in HBC abundance has occurred in the portion of the population residing in the mainstem (i.e., recruitment or survivorship of HBC into the mainstem has declined).

Recruitment

As explained above, we were unable to quantify survivorship rates (Objective 2), because of a lack of resolution in size class abundances for the spring 2001 estimate. However, we do offer the following discussion concerning recruitment of native fish in the LCR.

Only eleven HBC < 50 mm were captured during the June 2001 trip, showing up as a very small proportion of the fish on the length frequency chart (Figure 2). Even though strong peaks of YOY HBC have been detected in the past as early as June (Van Haverbeke 2001b), June sampling is apparently still too early to reliably detect YOY production in any given year (i.e., timing of spawning can be different from year to year, or fish can still be too small to be captured in 1/4" mesh hoopnets).

In June 2001, there was an abundance of HBC in the 85 to 130 mm size class range, indicating recruitment from 2000 (Figure 2). This peak intergrades with even larger fish (i.e., 2 year old fish), suggesting that recruitment from 1999 also occurred. An interesting phenomenon seen in June 2001 is the small peak of fish between 50 to ~85 mm (Figure 2). This phenomenon was also seen (although less dramatically) in 1992, 1994 and 1995 (Van Haverbeke 2001). These fish are thought to be too large to be YOY fish, yet don't conform very well into the 'one-year old' size class (i.e., 85 to 130 mm). Possible explanations are variable growth rates of HBC, or late season spawning by some individuals. This could also explain why size classes of HBC greater than one year old tend to become 'blurred' in length frequency analyses.

As with HBC, very few YOY flannelmouth or bluehead sucker were captured (i.e., fish < 50 mm; Figures 5 & 6). Again, June may be too early to reliably detect YOY fish with ¼" mesh gear type. However, the length frequency charts do suggest that LCR production for flannelmouth sucker did occur in 1999 and 2000. In June, there is a peak of flannelmouth sucker centered on 120 mm, and another peak centers on 225 mm (Figure 5). These are supposed one and two year old fish. For bluehead sucker, a peak centered on 70 mm can be seen in June (Figure 6). These are presumed one year olds.

Strong peaks of YOY HBC were captured in both October and November (Figure 11). This YOY cohort of HBC was not detected in June 2001, and evidently, June is too early to consistently detect YOY HBC production. Additional sampling during spring 2002 will provide further information on the strength of recruitment from the 2001 YOY cohort.

Production of YOY flannelmouth for 2001 was less certain, as very few YOY were captured during the spring efforts (Figure 5), and only eleven fish < 100 mm were seen during the fall efforts (Figure 13). Bluehead sucker YOY were essentially absent in the October and November sampling efforts (Figure 14).

This is in contrast to the June 2001 effort, when a peak of YOY bluehead suckers centered ~70 mm was observed (Figure 6).

Sexual Condition

Our data concerning the mean total lengths of ripe female (296 mm) and male (268 mm) HBC hold some implications. Calculations of effective population size (N_e) for animals include the portion of the population that actively contributes gametes to the next generation (Franklin 1980, Lande 1995). Our data suggest that calculations of N_e for HBC may need to be based on size classes larger than 200 mm. If we consider that SWCA's estimate of HBC ≥ 200 mm was 1,044 fish (SWCA Inc., 2002); and that our fall LCR estimate of HBC ≥ 200 mm was 483 fish (see Table 16), this suggests a population of 1,527 HBC ≥ 200 mm. This nearly matches our spring estimate of 1,470 HBC ≥ 200 mm (when the migrating portion of population is in the LCR; Douglas and Marsh 1996). If this is indeed the case, this estimate (~1,500 HBC ≥ 200 mm) is already less than the proposed minimum viable population goal of 2,100 HBC ≥ 200 mm suggested by Valdez et al. (2001). Given the mean lengths of ripe HBC are greater than 200 mm, the genetic viability of the Grand Canyon population may be jeopardized.

Data collected from both the October and November trips provided additional evidence for late season spawning of Catostomids (see Douglas & Douglas 2000). This was particularly evident during the October trip, when several spawning concentrations of bluehead sucker were captured.

Parasites

We collected data on the presence of the external parasite, *Lernaea cyprinacea,* as this parasite is easily visible when handling fish in the field. Percent of the population infected with this parasite during our studies in 2001 ranged from 3.8 to 6.3, with only 1.2 to 1.5 parasites being observed per infected fish. In contrast, no *Lernaea* were recorded on HBC during the April and June 2000 LCR trips. Occurrence for November 2000 was 28% (2.5 parasites per fish), while for October 2000 it was 10% (1.7 parasites per infected fish). These data portray the cyclical nature of this parasite, but do not appear to be outside of the numeric norm for the LCR. The occurrence of this parasite appears to coincide with flows in the LCR (i.e., the parasite seems to become worse with long periods of blue water). Other than being a minor nuisance on a small percentage of the population, *Lernaea* does not appear to represent much of a threat to HBC at present.

A far worse parasite infecting HBC is the Asian tapeworm, *Bothriocephalus acheilognathi* (Clarkson et al. 1997). However, the extent and magnitude of this internal parasite is not reflected with our sampling regime (i.e., we only visually inspect the outside of the fish).

Conclusions

We have presented some evidence that the Grand Canyon population of HBC appears to have undergone a decline since the early 1990's. Specifically, our spring abundance estimate for HBC ≥ 150 mm is significantly less than those given by Douglas and Marsh (1996). Combined with the work of SWCA, this prognosis appears to be even more credible. We do caution, however, that our spring estimate may be subject to some bias, and that SWCA's mainstem estimate had a coefficient of variation wider than was desired (SWCA, Inc. 2002). We furthermore caution that our effort this year is the first attempt to estimate the abundance of spring HBC spawners in the LCR since 1992. Hence, it only represents one point population estimate after nine years of lapse. Additional spring point population estimates will add strength to the true trend in HBC abundance. Nevertheless, the two studies combined (ours and SWCA's) supply fairly convincing evidence that the observed decline in HBC abundance since the early 1990's is real, that it is significant, and that it should be cause for concern by management.

One could argue that since our 2001 fall abundance estimate for HBC > 150 mm is not significantly lower than the 1992 fall estimates provided by Douglas and Marsh (1996; Figure 18), this would indicate a stable LCR population. However, this argument fails to recognize that our spring 2001 estimate is significantly lower than the spring estimates provided in the 1990's. This is important because it suggests that the decline appears to have occurred in the portion of the population that migrates between the mainstem and the LCR to spawn. Additionally, the migratory portion of the population contains a large portion of adult fish (i.e., ≥ 200 mm), or those fish that are actively contributing to the production of gametes for future generations.

RECOMMENDATIONS

Based on the analyses of 2001 spring and fall estimates, we make the following recommendations in order to improve the abundance estimates for 2002.

First, we recommend that the spring 2002 estimate be carried out earlier than was the spring 2001 effort. This may help ensure that the peak abundance of spawning fish is included in the abundance estimate. Gorman and Stone (1999) reported that spawning activity of HBC in the LCR commenced in late March, peaked in mid-April, and waned in mid-May. Douglas and Marsh (1996) reported that population estimates peaked in early March, extended into April and then decreased into June. We know that the LCR hydrograph is highly variable from year to year, and assume that peak abundance of spawning fish is variable from year to year. We do not advise moving this trip too early, as this could result in difficulties associated with simultaneous immigration and emigration occurring (Bernard and Hansen 1992).

Second, we recommend that in the future that only fish ≥ 150 mm are PIT tagged. This is primarily to avoid PIT tag loss or mortality complications that we perceive to be occurring. As an alternative to PIT tagging fish in the 100 to 150 mm range, we suggest using fin clip methods.

Third, we recommend that newly tagged fish during 2002 be given a secondary mark. A long-standing uncertainty in estimating Grand Canyon fish populations (even with larger fish) has been the issue of potential tag loss. We do not currently feel it is a severe problem, however, we believe some investigation is warranted to preclude any uncertainty.

Fourth, there has been discussion as to the best gear to deploy in endeavoring to obtain abundance estimates in LCR. Douglas and Marsh (1996) used larger hoopnets, while we are using smaller hoopnets. Both large and small hoopnets have proven to be effective in other studies in the LCR (Douglas and Marsh 1996; Gorman & Stone 1999). They are both effective at capturing HBC. We attempted using fykenets as an alternative gear type during fall 2001. Although they did catch fish (Table 11), they are large, unwieldy, and would be susceptible to damage by a flood event. We do not recommend them as an alternative gear type to hoopnets.

DATA ARCHIVING

The data for the two spring trips were delivered to Grand Canyon Monitoring and Research Center in two MS Access files entitled: May_2001_LCR.mdb, and June_2001_LCR.mdb. The data for October was delivered to Grand Canyon Monitoring and Research Center in three MS Access files entitled LCR_2001_October_Boulder.mdb, LCR_2001_October_Coyote.mdb, and LCR_2001_October_Salt.mdb. The data for the November trip was delivered in three MS Access files entitled LCR_2001_Nov_Boulders.mdb, LCR_2001_Nov_Coyote.mdb, and LCR_2001_Nov_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, 2001.

	USFWS	AGFD	SWCA	volunteers
30 April - 11 May	Dennis Stone [S] Bem Galuardi [S] Lew Coggins [C] David Van Haverbeke [B] Dewey Wesley [B]	Scott Rogers [B]		Robin Longe [S] Carl Walters [C] David Ward [C] Dirk Zeller [B]
4 - 15 June	Ben Galuardi [S] Rob Simmonds [C] Dewey Wesley [B] David Van Haverbeke [B]	Schyuler Sampson [S] David Ward [C]		Carrie Carreno [S] Jeff Hinke [C] Isaac Kaplan [B] Scott Perry [B]
1 - 12 October	David Van Haverbeke [S] Mitch Thorson [S] Dewey Wesley [B]	David Ward [C] Jeff Falke [B]	Matt Lauretta [C]	Jennifer Ketterlin [S] Anne Widmer [C] Sean Grimes [B]
5 - 16 November	Dennis Stone [S] Dewey Wesley [B] Matt Campbell [B]	David Ward [C] Clay Nelson [C]	Jennifer Monks [S] Matt Lauretta [C]	Stuart Reeder [S]

Table 2. Habitat characteristics recorded for hoopnets set in Little Colorado River, 2001.

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 2001.

Trip	Reach	Effort Sets	Effort Hours	HBC Catch	HBC CPUE
May					
	Salt	180	4,319	211	0.049
	Coyote	180	4,152	198	0.048
	Boulders	180	4,183	142	0.034
	Total	540	12,654	551	0.044
June					
	Salt	240	5,436	501	0.092
	Coyote	240	5,626	571	0.102
	Boulders	236	5,166	586	0.113
	Total	716	16,228	1,658	0.102
Grand Total		1,256	28,882	2,209	0.076

Table 4. Summary of fish captured by trip, reach, gear type, and species; Little Colorado River, spring 2001.

Trip	Reach - gear	Species*													
		BBH	BHS	CCF	CRP	FHM	FMS	GSF	HBC	PKF	RBT	RSH	SPD	YBH	Total
May															
	Salt - hoopnets		5	5	7	27	6	1	211		2	1	15	16	296
	Coyote - hoopnets	1	7	3	4	31	9		198		2	21	97	12	385
	Boulders - hoopnets	1	59	11	8	23	60		142	1		5	61	6	377
	Boulders - trammel nets		3	2	4		62		25						96
	Total	2	74	21	23	81	137	1	576	1	4	27	173	34	1,154
June															
	Salt - hoopnets	2	18	1	3	342	4		501	2	1	14	57	4	949
	Coyote - hoopnets	9	64	3	47	346	84		571	1	2	20	190	2	1,339
	Boulders - hoopnets	2	57	6	7	128	275		586	4	2	70	667	4	1,808
	Boulders - trammel nets			1	6		34		19		1				61
	Total	13	139	11	63	816	397		1,677	7	6	104	914	10	4,157
Grand Total		15	213	32	86	897	534	1	2,253	8	10	131	1,087	44	5,311

* BBH = black bullhead (*Ameiurus melas*); BHS = bluehead sucker (*Catostomus discobolus*); CCF = channel catfish (*Ictalurus punctatus*); CRP = common carp (*Cyprinus carpio*); FHM = fathead minnow (*Pimephales promelas*); FMS = flannelmouth sucker (*Catostomus latipinnis*); GSF = green sunfish (*Lepomis cyanellus*); HBC = humpback chub (*Gila cypha*); PKF = plains killifish (*Fundulus zebrinus*); RBT = rainbow trout (*Oncorhynchus mykiss*); RSH = red shiner (*Cyprinella lutrensis*); SPD = speckled dace (*Rhinichthys osculus*), 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 2001.

Length strata	Unmarked	Marked	Mark-rate
100-149	491	26	5.03%
150-199	273	53	16.26%
200-249	92	30	24.59%
250-299	39	5	11.36%
300-349	12	3	20.00%
350-399	25	10	28.57%
400-449	8	1	11.11%
Totals	940	128	11.99%

Ho: Mark rate among length strata is the same.
Reject null hypothesis (χ^2 = 57.80, df = 6, p = 1.26E-10)

Table 6. Number of humpback chub marked and unmarked during the recapture event by reach; Little Colorado River, spring 2001.

Reach	Marked	Unmarked	Mark Rate
Salt	68	321	17%
Coyote	37	297	11%
Boulder	23	322	7%
Total	128	940	12%

Ho: Mark rate among reaches is the same.
Reject null hypothesis (χ^2 = 24.10, df = 2, p = 5.82 E-06)

Table 7. Estimates of humpback chub abundance using Darroch estimator for fish < 240 mm and Chapman-Petersen estimator for fish ≥ 240 mm. Top portion of table gives estimates for fish ≥ 100 mm while bottom portion of table provides estimates for fish ≥ 150 mm; Little Colorado River, spring 2001.

Abundance of humpback chub >=100 mm TL

Estimator	Total length (mm)	N	var(N)	SE(N)	95% Confidence Interval	
					Lower	Upper
Darroch	<241	2,626	88,299	297	2,044	3,208
Petersen	>=241	1,244	55,481	236	782	1,706
Sum	>=100 mm	3,870	143,780	379	3,127	4,613

Abundance of humpback chub >=150 mm TL

Estimator	Total length (mm)	N	var(N)	SE(N)	95% Confidence Interval	
					Lower	Upper
Darroch	<241	1,015	27,614	166	689	1,341
Petersen	>=241	1,244	55,481	236	782	1,706
Sum	>=150 mm	2,259	83,095	288	1,694	2,824

Table 8. Abundance estimates of humpback chub in lower 14.2 km of Little Colorado River using length stratified Chapman-Petersen estimator. Top portion of table gives estimates for fish ≥ 100 mm; mid portion of table gives estimates for fish ≥ 150 mm; while bottom portion of table gives estimates of fish ≥ 200 mm; Little Colorado River, spring 2001.

Abundance of humpback chub >=100 mm

Length (mm)	Marks	Captures	Recaptures	N	SE	95% Confidence Interval Lower	Upper
<241	261	951	109	2,266	154	1,964	2,569
>=241	210	117	19	1,244	236	782	1,706
Sum Strata				3,510	282	2,959	4,062

Abundance of humpback chub >=150 mm

Length (mm)	Marks	Captures	Recaptures	N	SE	95% Confidence Interval Lower	Upper
<241	161	434	83	838	57	727	949
>=241	210	117	19	1,244	236	782	1,706
Sum Strata				2,082	242	1,607	2,557

Abundance of humpback chub >=200 mm

Length (mm)	Marks	Captures	Recaptures	P*	N	SE	95% Confidence Interval Lower	Upper
<241	60	108	30	0.27	226	45	137	315
>=241	210	118	19	1	1,244	236	782	1,706
Sum Strata					1,470	240	1,000	1,940

P* = Proportion of fish using Equation 3.

Table 9. Population estimates for humpback chub ≥ 150 mm by date. 1992 estimates are from Douglas and Marsh (1996); Little Colorado River, spring 2001.

Date	Abundance Estimate	SE	95 % Confidence Interval		Reach (rkm)	Sampled Population
			Lower	Upper		
Apr-92	5,555	671	4,416	7,067	0 - 14.9	≥ 150 mm
May-92	4,363	1,216	2,594	7,523	0 - 14.9	≥ 150 mm
Jun-92	4,384	458	3,573	5,381	0 - 14.9	≥ 150 mm
May-01	2,082	242	1,607	2,557	0 - 14.2	≥ 150 mm

Table 10. 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 2001.

		Effort		HBC	HBC
Trip	Reach	Sets	Hours	Catch	CPUE
October					
	Salt	214	4,995	722	0.144
	Coyote	234	5,618	1,430	0.255
	Boulders	240	5,451	761	0.140
	Total	688	16,064	2,913	0.181
November					
	Salt	225	5,148	935	0.182
	Coyote	240	5,616	931	0.166
	Boulders	240	5,621	465	0.083
	Total	705	16,385	2,331	0.142
Grand Total		1,393	32,449	5,244	0.162

Table 11. Summary of fish captured by trip, reach, gear type, and species; Little Colorado River, fall 2001.

		Species*											
Trip	Reach - gear	BBH	BHS	CCF	CRP	FHM	FMS	HBC	PKF	RBT	SPD	YBH	Totals
October													
	Salt - hoops		6		4	89	33	721			61	8	922
	Coyote - hoops	7	9	1	3	209	132	1430	1		143		1,935
	Boulders - hoops		90		1	97	126	761			305	2	1,382
	Coyote - fykenets	1	2		2		10	3					18
	Totals	8	107	1	10	395	301	2,915	1		509	10	4,257
November													
	Salt - hoops		2		1	190	41	935			429	4	1,602
	Coyote - hoops	5	4		1	375	32	931		1	199		1,548
	Boulders - hoops		8			71	81	465	2	1	200		828
	Totals	5	14		2	636	154	2,331	2	2	828	4	3,978
Grand Total		13	121	1	12	1,031	455	5,246	3	2	1,337	14	8,235

* BBH = black bullhead (*Ameiurus melas*); BHS = bluehead sucker (*Catostomus discobolus*); CCF = channel catfish (*Ictalurus punctatus*); CRP = common carp (*Cyprinus linneaus*); 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*); SPD = speckled dace (*Rhinichthys osculus*), YBH = yellow bullhead (*A. natalis*).

Table 12. Number of humpback chub marked and not marked during the recapture event by reach and sub-reach in the Little Colorado River, fall 2001.

Reach	Marked	Unmarked	Mark Rate
Salt	170	237	42%
Coyote	112	117	49%
Boulder	43	51	46%
Total	325	405	45%

Ho: Mark rate among reaches is the same.
Fail to reject null hypothesis (χ^2 =3.09, df = 2, p = 0.213)

Table 13. Abundance estimates of humpback chub. Top portion of table gives the length stratified Chapman-Petersen abundance estimate of humpback chub 100 – 150 mm and humpback chub > 150 mm. Bottom portion of table gives proportion abundance estimate of humpback chub ≥ 200 mm; Little Colorado River, fall 2001.

Stratified abundance of humpback chub >=100 mm

Length (mm)	Marked	Examined	Recaptured	N	SE	95% Confidence Interval Lower	95% Confidence Interval Upper
100 - 150	337	281	69	1,361	125	1,116	1,605
>150	607	449	256	1,064	33	999	1,128
Sum Strata				2,424	129	2,171	2,677

Abundance estimate of humpback chub >=200 mm

Total length (mm)	Marked	Examined	Recaptured	P*	N	SE	95% Confidence Interval Lower	95% Confidence Interval Upper
>=200	272	208	117	0.45	483	48	389	576

P* = Proportion of fish > 200 mm using Equation 3.

Table 14. Abundance estimates of humpback chub ≥ 150 mm. 1991 & 1992 estimates are from Douglas and Marsh (1996); 2000 estimate is from Coggins and Van Haverbeke 2001.

			95% Confidence Interval			
Date	Abundance Estimate	SE	Lower	Upper	Reach (rkm)	Sampled population
October 1991	2,038	518	1,276	3,368	0 - 14.9	≥ 150 mm
November 1991	1,989	489	1,264	3,235	0 - 14.9	≥ 150 mm
October 1992	1,099	60	990	1,224	0 - 14.9	≥ 150 mm
November 1992	1,417	408	839	2,500	0 - 14.9	≥ 150 mm
Average Oct. & Nov. 91-92	1,636					
October/November 2000	1,590	297	992	2,552	0 - 14.2	≥ 150 mm
October/November 2001	1,064	33	999	1,128	0 - 14.2	> 150 mm
Average Oct. & Nov. 00-01	1,327					

Table 15. Population abundance estimates (N) for humpback chub ≥ 100 mm stratified by length and reach; Little Colorado River, fall 2001.

Humpback chub 100-150 mm							95% Confidence Interval	
Reach	Marked	Examined	Recaptured	N	V(N)	SE	Lower	Upper
Salt	85	133	22	588	5,224	72	446	730
Coyote	172	103	34	723	4,009	63	599	847
Boulders	80	45	13	336	2,430	49	239	433
Pooled	337	281	69	1,361	15,566	125	1,116	1,605

Humpback chub >150							95% Confidence Interval	
Reach	Marked	Examined	Recaptured	N	V(N)	SE	Lower	Upper
Salt	286	274	148	559	1,421	38	485	633
Coyote	225	126	78	370	887	30	312	429
Boulders	96	49	30	158	406	20	116	195
Pooled	607	449	256	1,064	1,088	33	999	1,128

Summed humpback chub >= 100 mm							95% Confidence Interval	
Reach	Marked	Examined	Recaptured	N	V(N)	SE	Lower	Upper
Salt	371	407	170	1,147	6,644	82	987	1,307
Coyote	397	229	112	1,093	4,895	70	956	1,230
Boulders	176	94	43	492	2,836	53	388	596
Total	944	730	325	2,732	16,654	129	2,479	2,985

Table 16. Population Estimates for humpback chub ≥ 100 mm stratified by 10 mm length interval; Little Colorado River, fall 2001.

				95% Confidence Interval	
Total Length interval (mm)	N	var(N)	SE(N)	Lower	Upper
100-109	435	62874	251	0	927
110-119	288	8199	91	111	466
120-129	237	9965	100	41	433
130-139	315	7772	88	142	488
140-149	146	1069	33	82	211
150-159	141	997	32	79	203
160-169	127	627	25	78	177
170-179	146	901	30	88	205
180-189	98	491	22	54	141
190-199	102	529	23	57	147
200-209	81	381	20	43	120
210-219	80	537	23	35	125
220-229	57	328	18	21	92
230-239	58	237	15	28	88
240-249	43	360	19	6	81
250-259	27	120	11	6	49
260-269	27	151	12	3	51
270-279	30	209	14	1	58
280-289	14	100	10	0	33
290-299	16	480	22	0	59
300-309	11	1070	33	0	75
>310	47	189	14	21	74

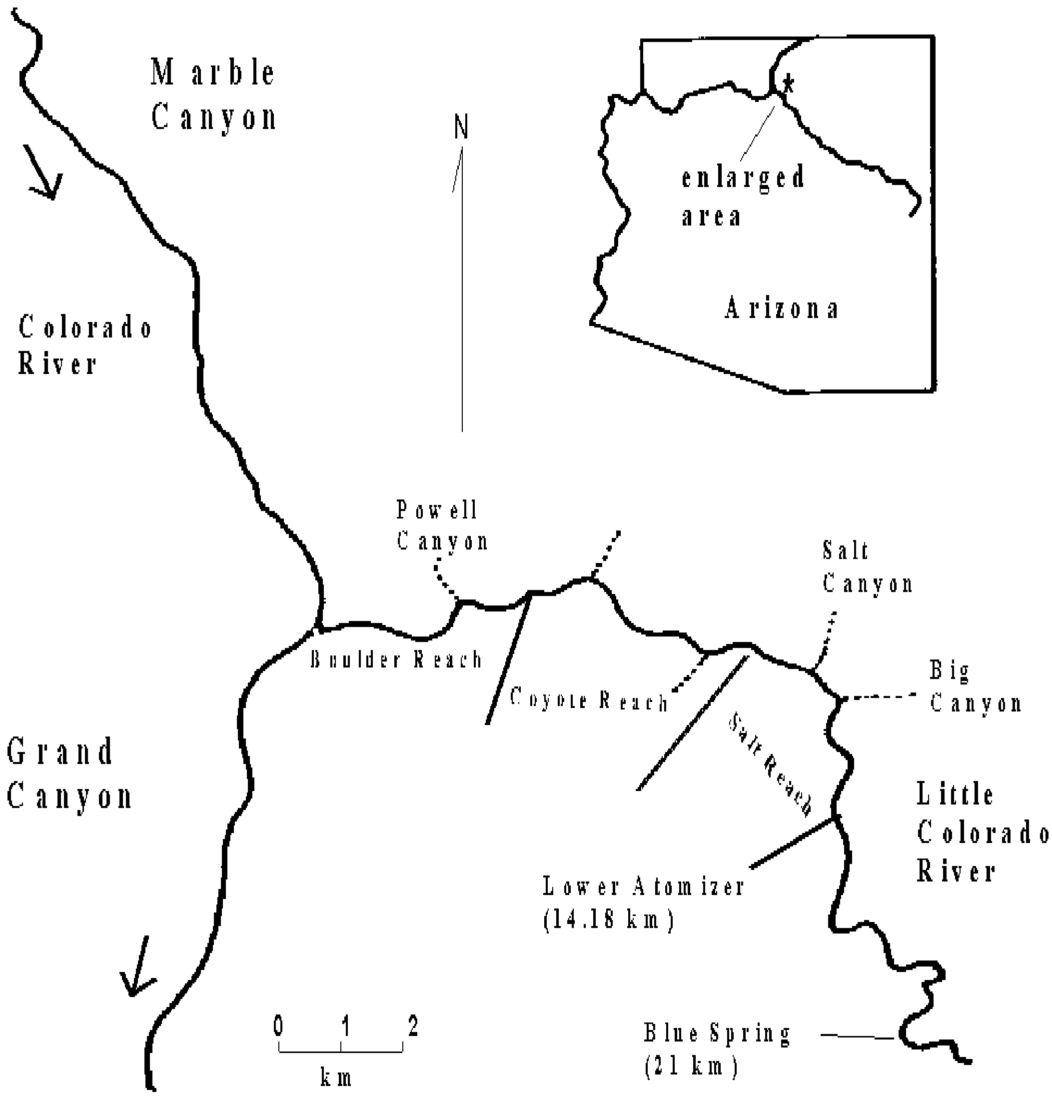
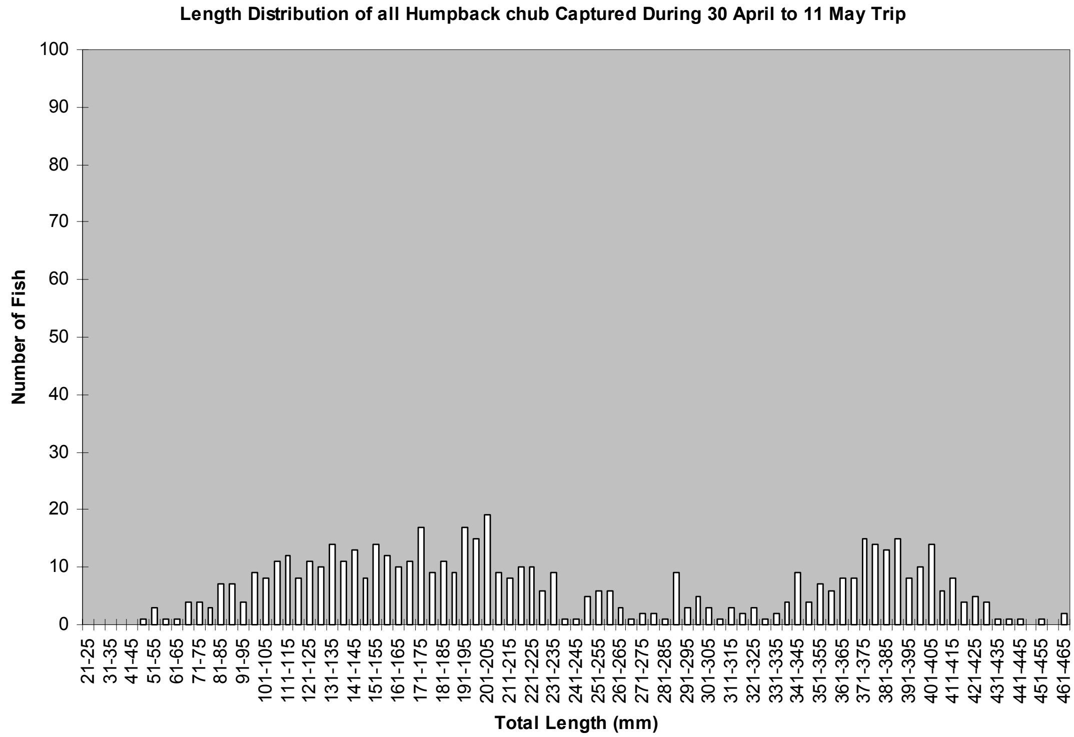


Figure 1. Map of the study site, showing Salt, Coyote and Boulders reaches in Little Colorado River.



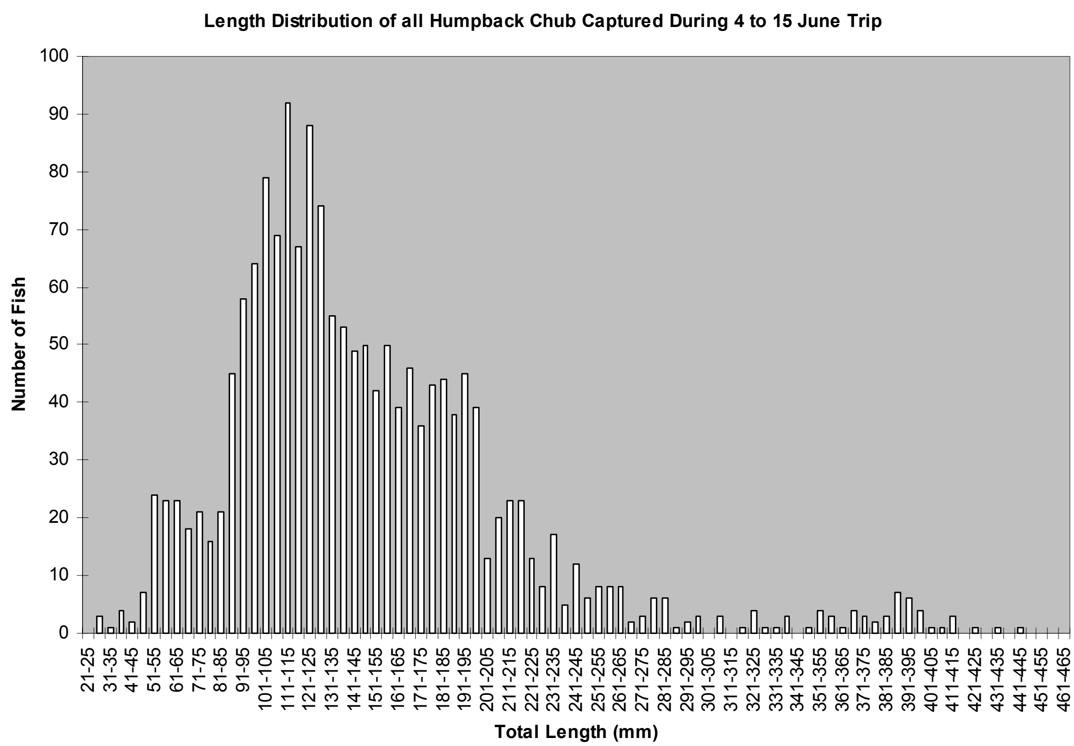
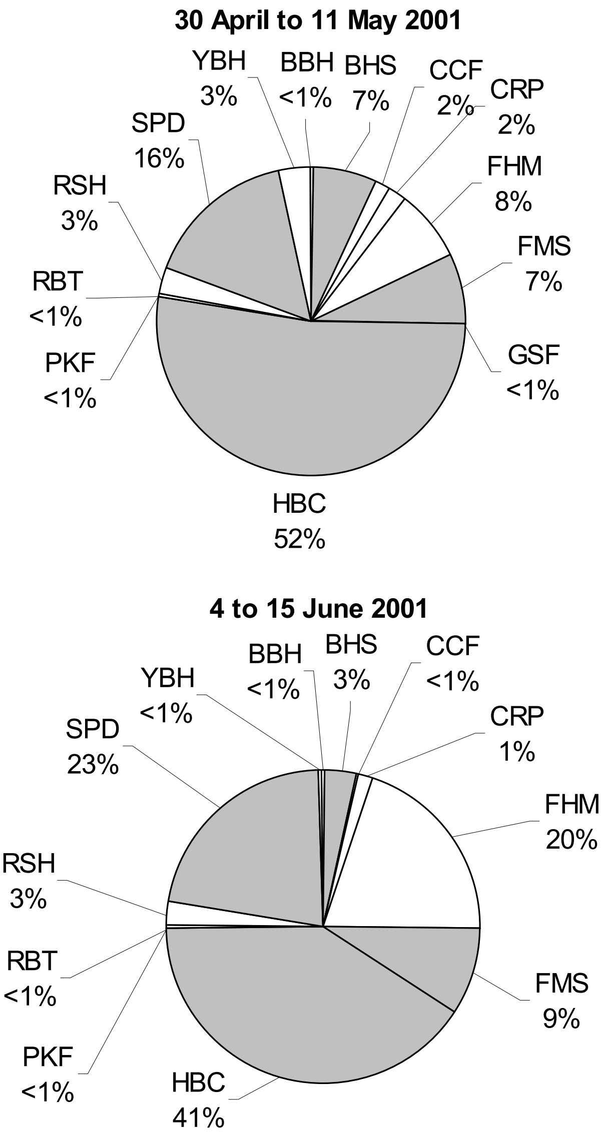
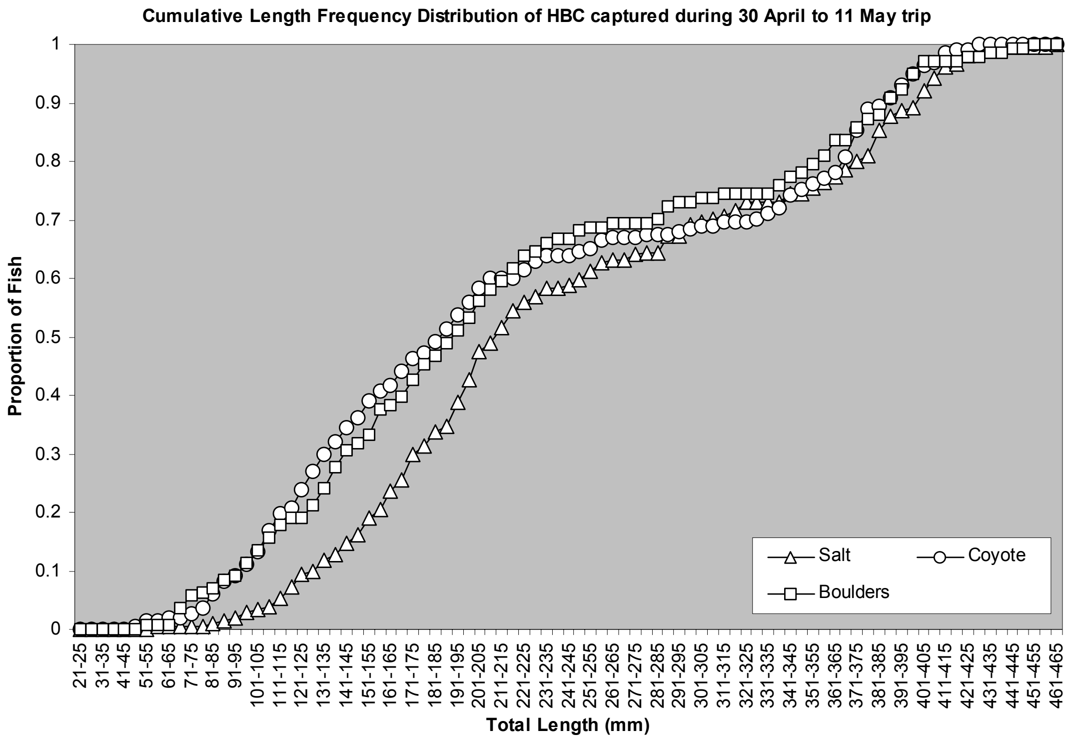


Figure 2. Length frequency distributions of all humpback chub captured in hoop nets and in trammel nets; Little Colorado River, spring 2001.



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*); GSF = green sunfish (*Lepomis cyanellus*); HBC = humpback chub (*Gila cypha*); PKF = plains killifish (Fundulus zebrinus); RBT = rainbow trout (*Onchorynchus mykiss*); RSH = red shiner (*Cyprinella lutrensis*); SPD = speckled dace (*Rhinichthys osculus*); YBH = yellow bullhead (*A. natalis*).

Figure 3. Observed species compositions of all fish captured using hoopnets. Shaded portions are native fish; Little Colorado River, spring 2001.



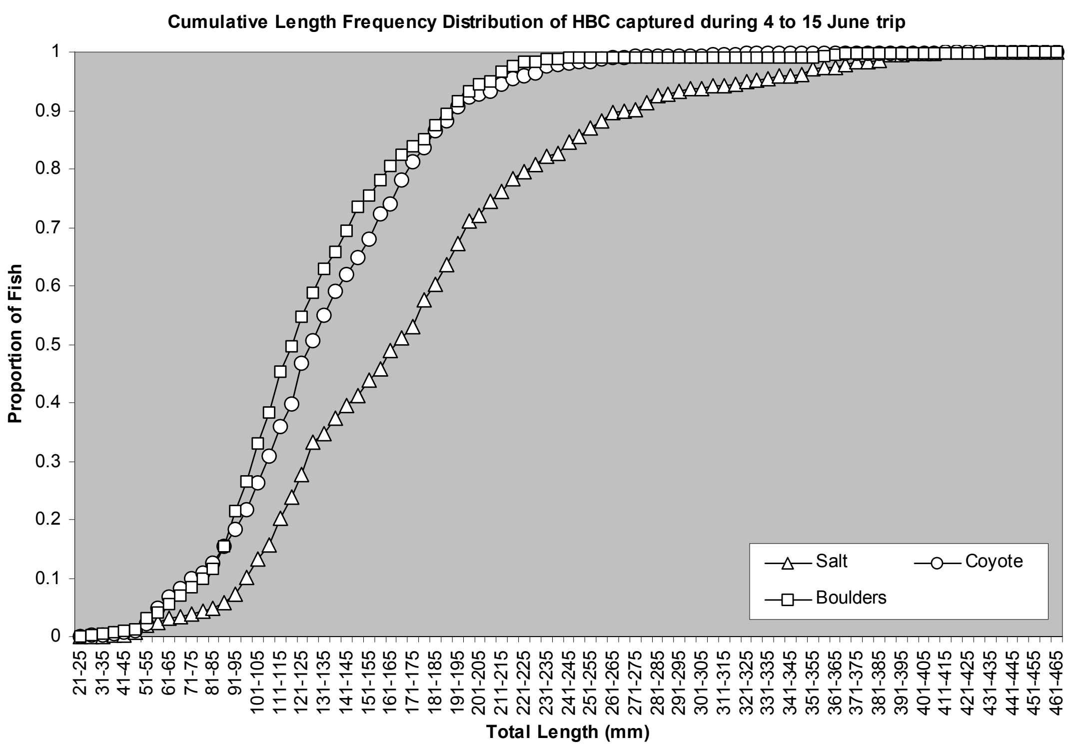
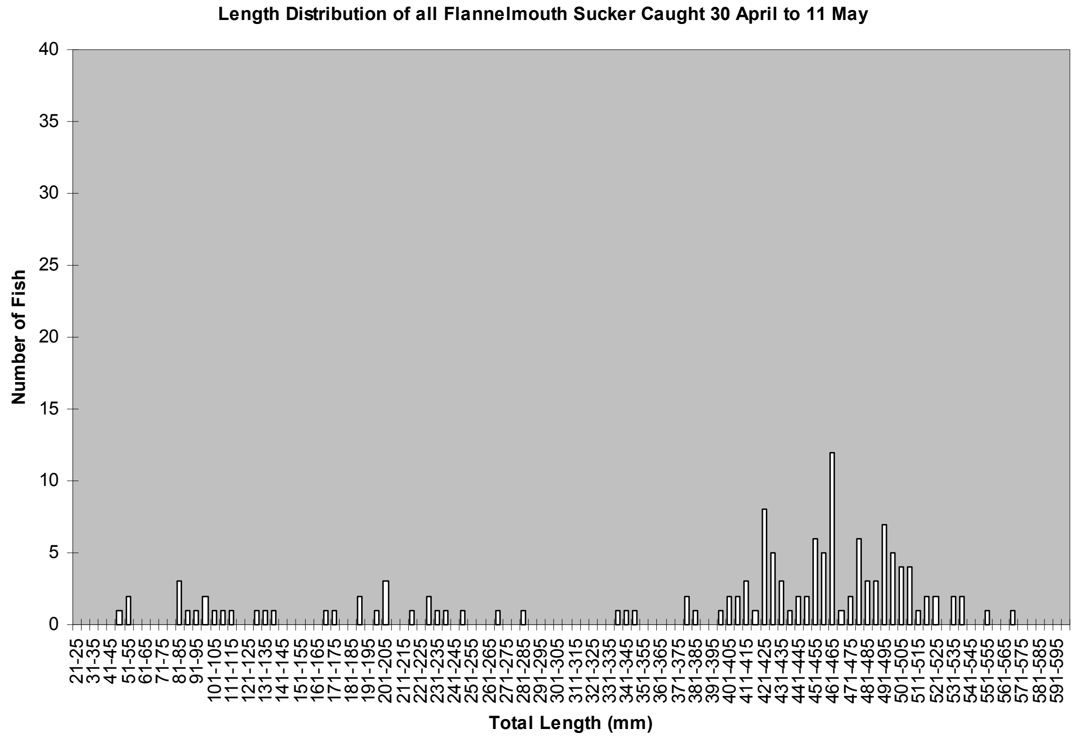


Figure 4. Cumulative length frequency charts of all humpback chub captured in hoopnets at three different reaches (Salt, Coyote and Boulders); Little Colorado River, spring 2001.



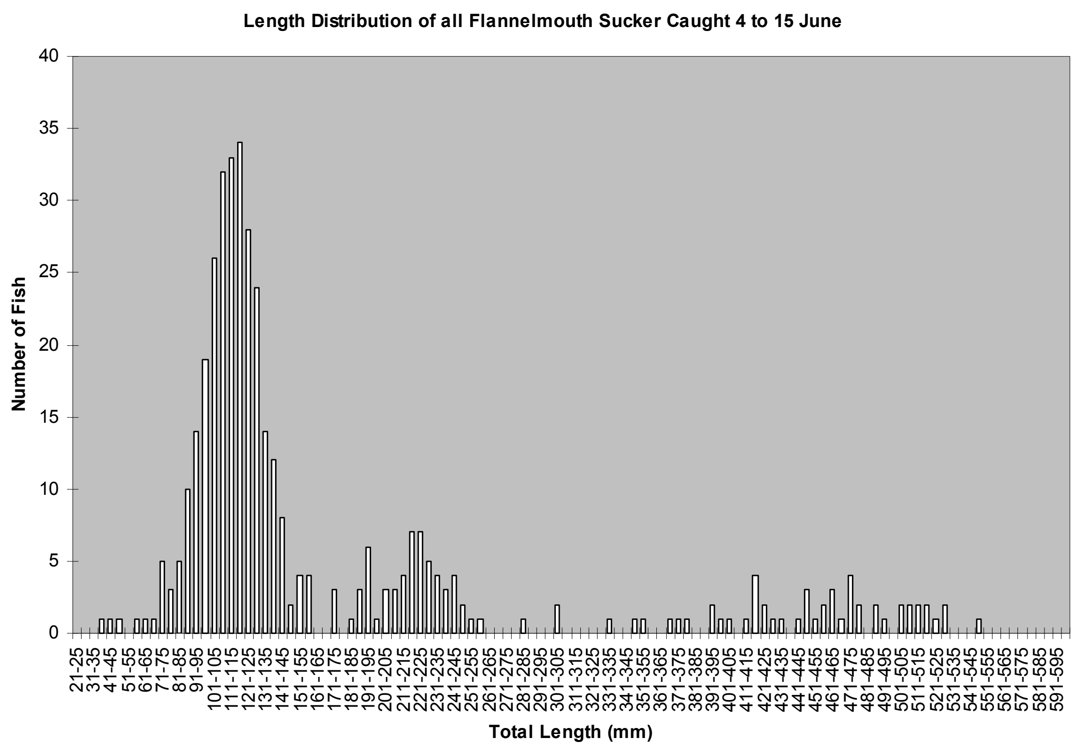
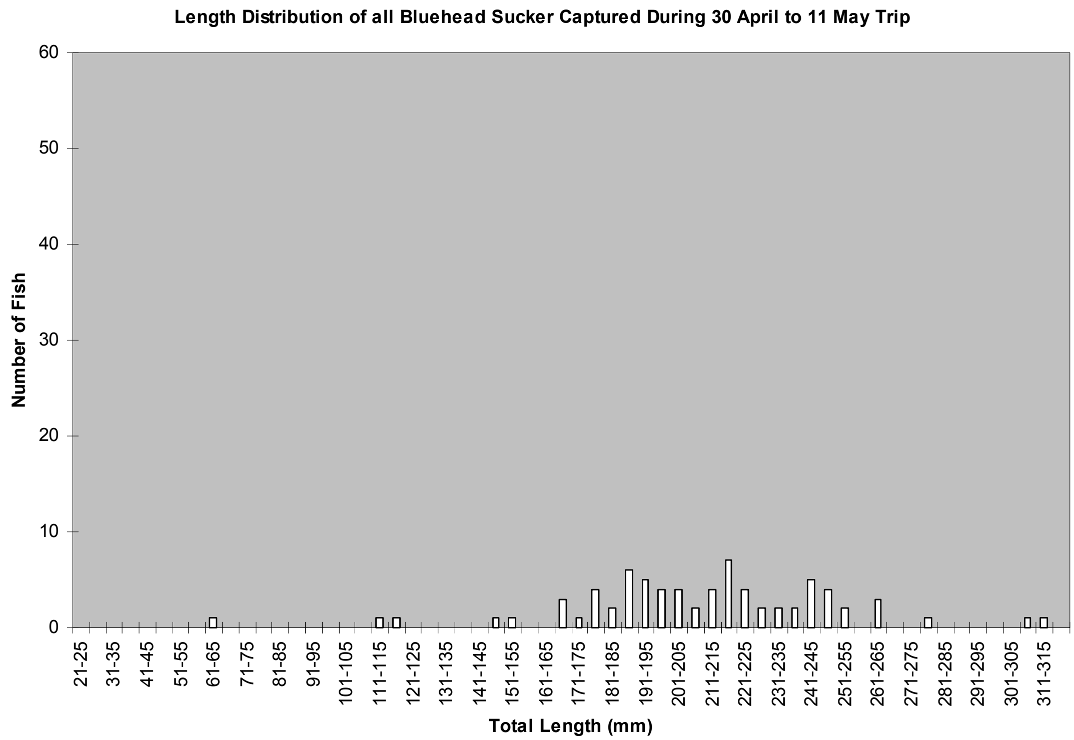


Figure 5. Length frequency distribution of all flannelmouth sucker captured in hoopnets and trammel nets; Little Colorado River, spring 2001.



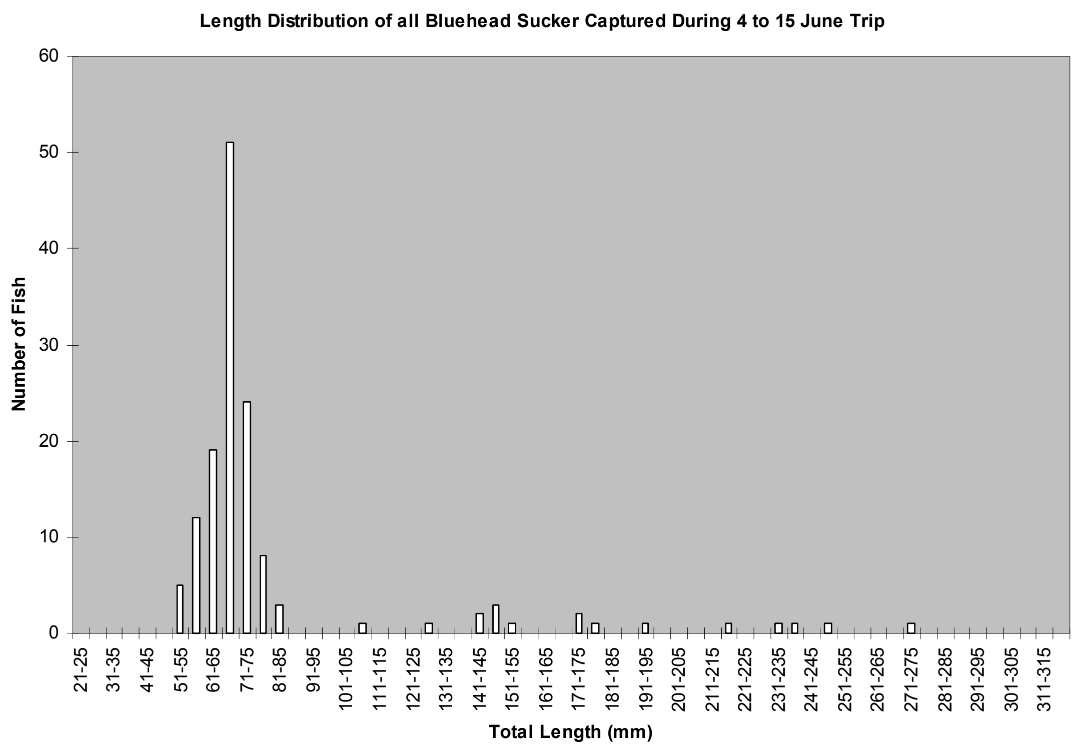


Figure 6. Length frequency distributions of all bluehead suckers captured; Little Colorado River, spring 2001.

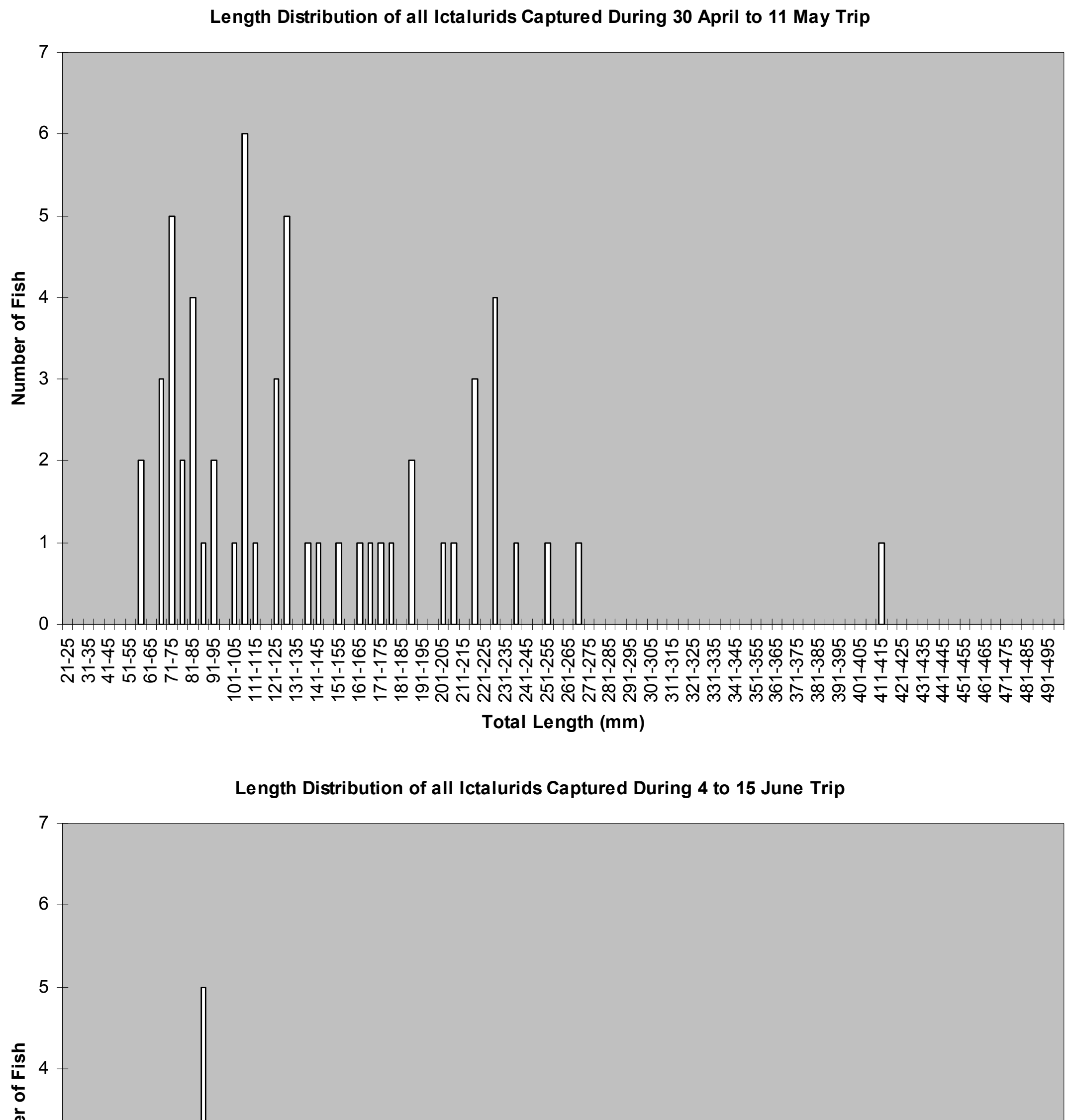


Figure 7. Length frequency distributions of all ictalurids captured; Little Colorado River, spring 2001.

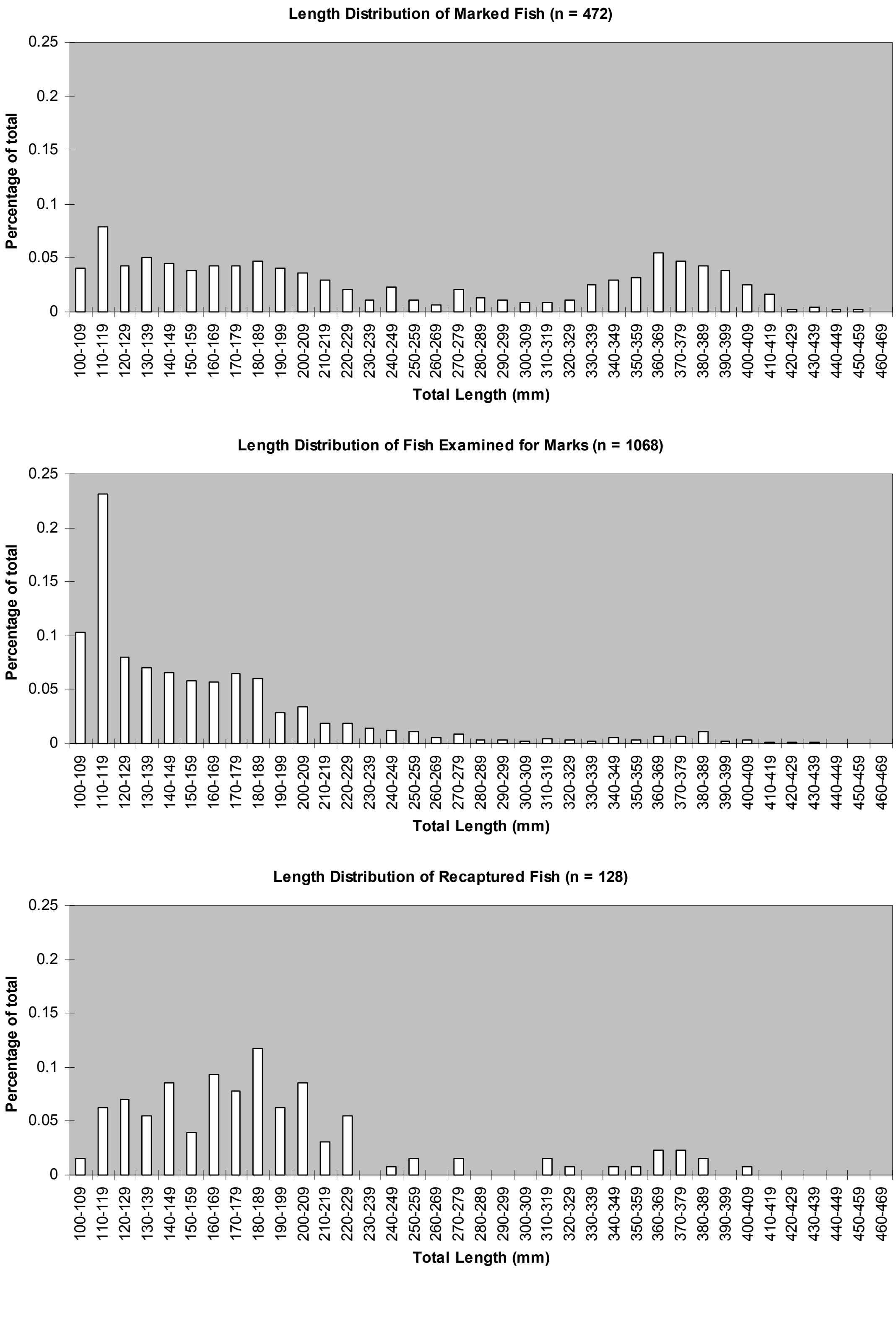
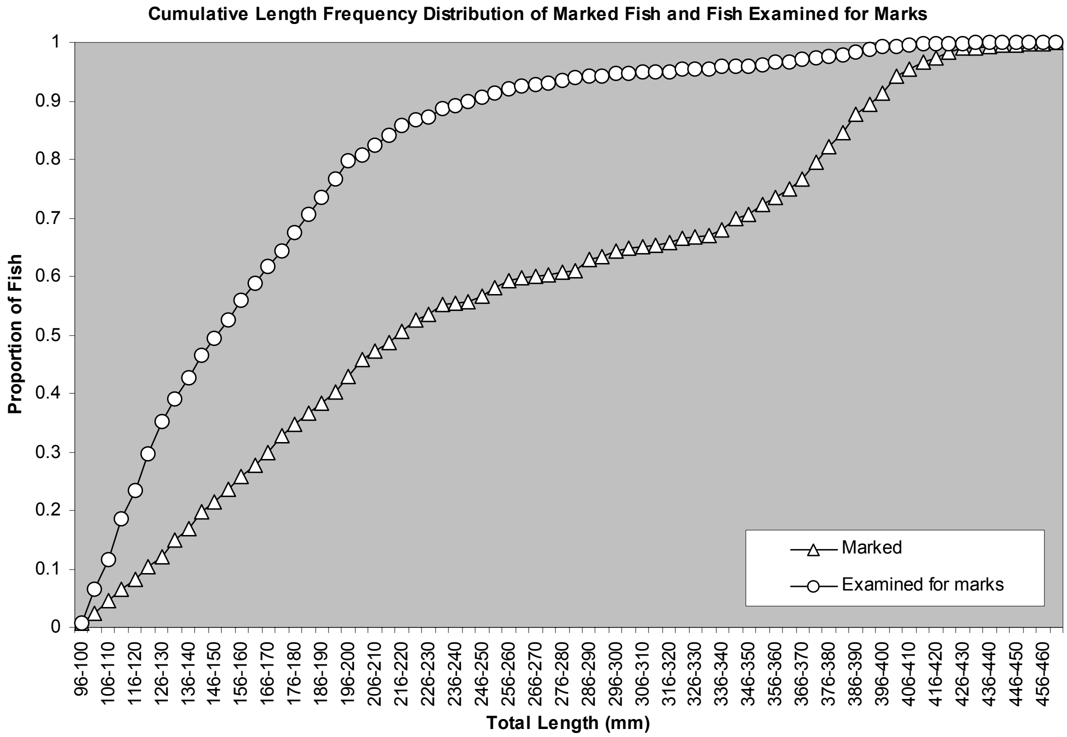


Figure 8. Length frequency distributions (shown as percentage of total) of all humpback chub large enough to be PIT tagged captured during the marking and recapture events; Little Colorado River, spring 2001.



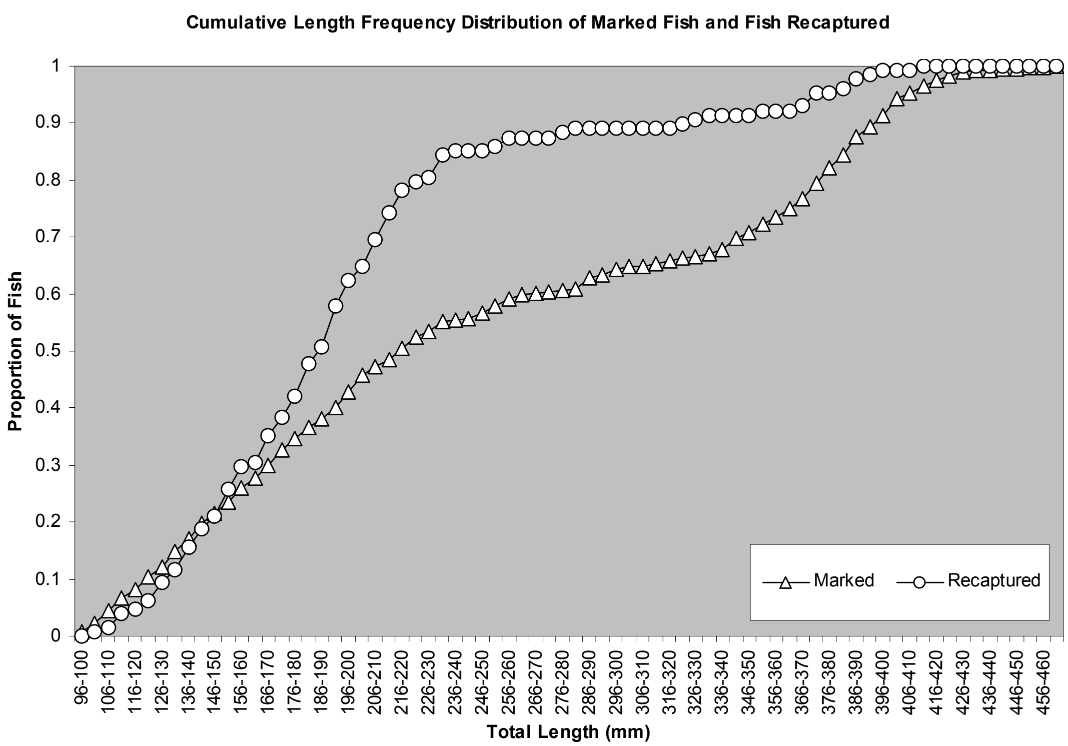
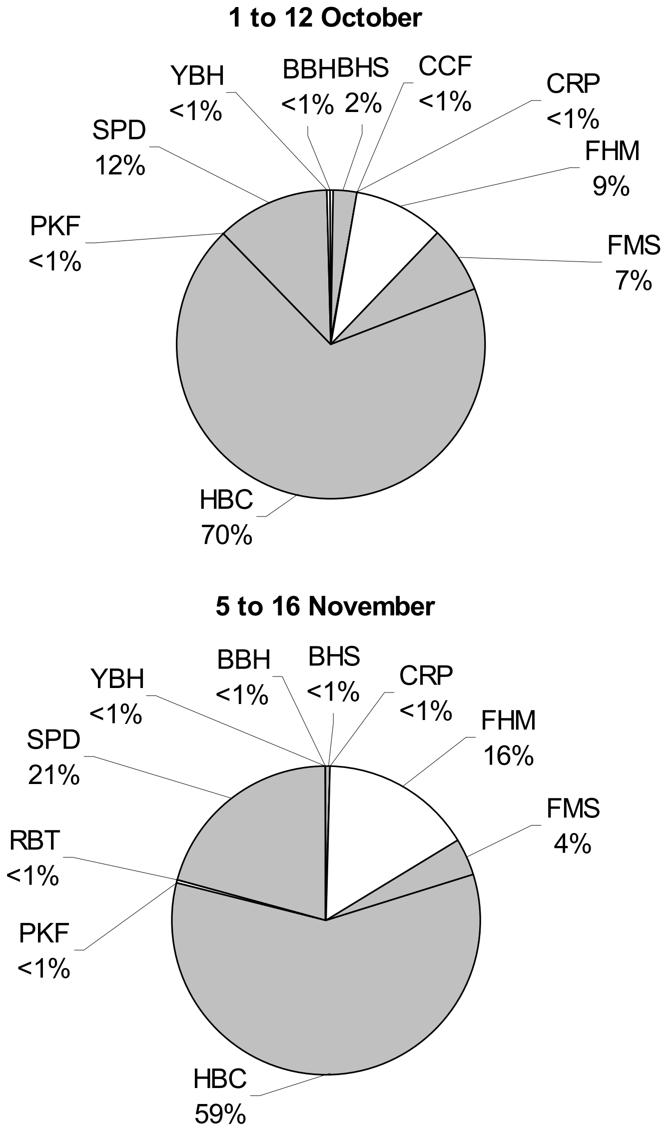
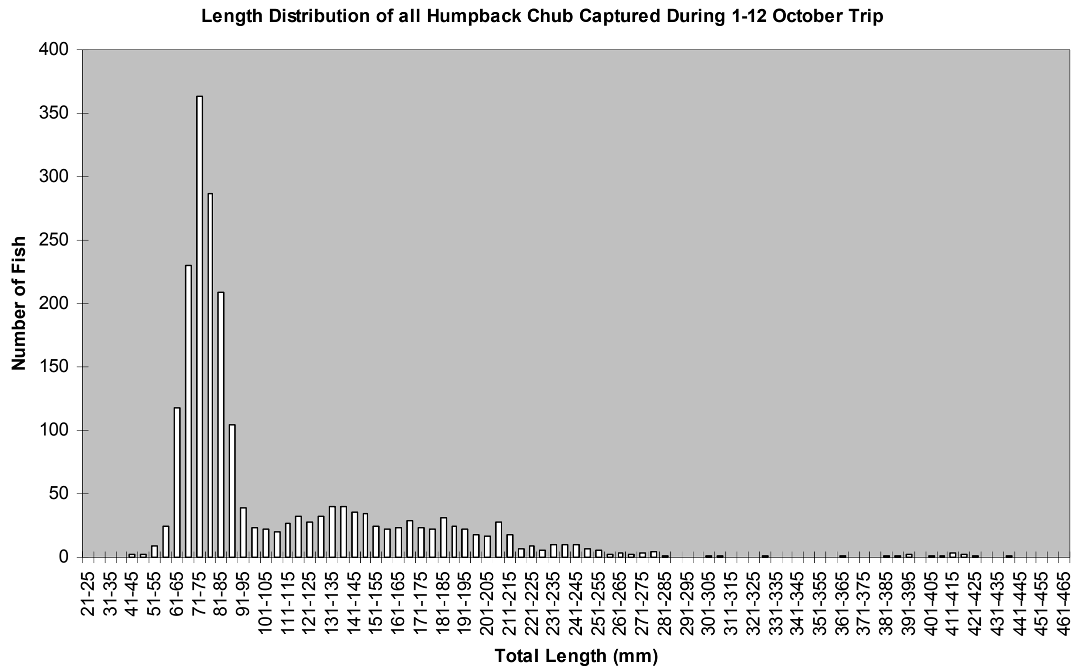


Figure 9. Cumulative length frequency distributions of humpback chub captured; Little Colorado River, spring 2001.



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

Figure 10. Observed species compositions of fish captured using hoopnets. Shaded portions are native fish; Little Colorado River, fall 2001.



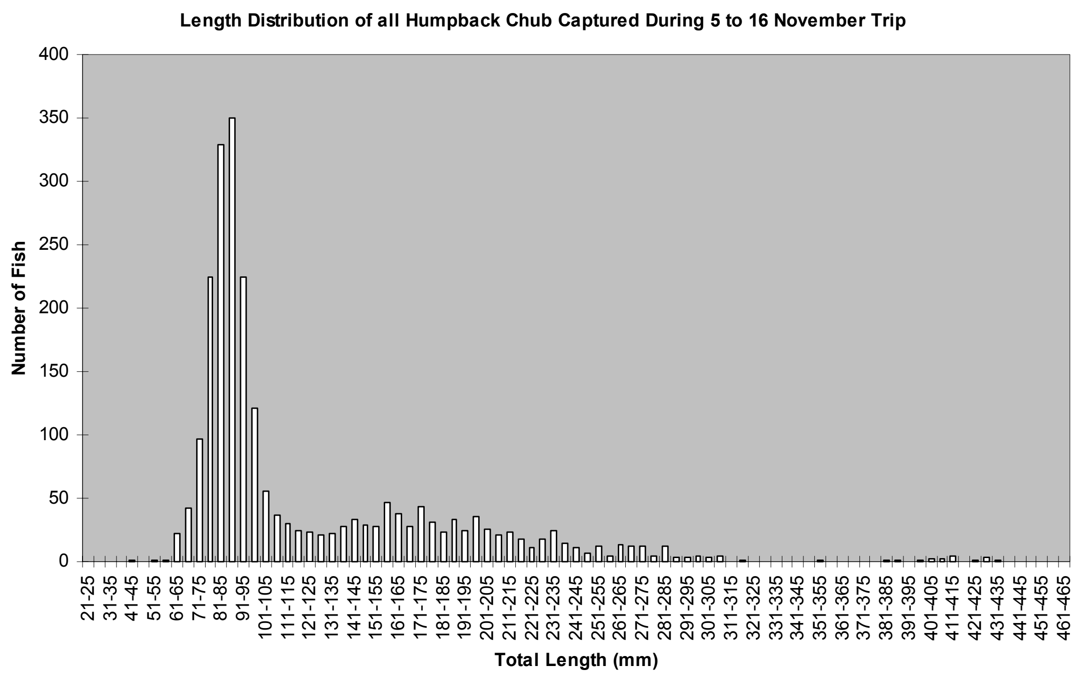
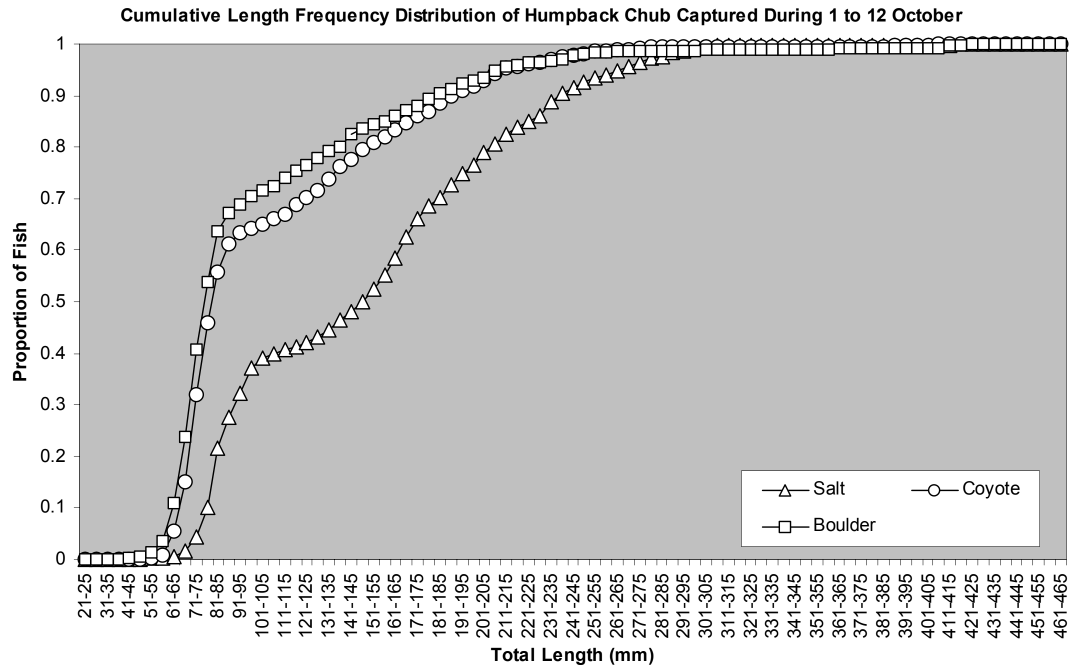


Figure 11. Length frequency distributions of all humpback chub captured in hoop nets and in trammel nets; Little Colorado River, fall 2001.



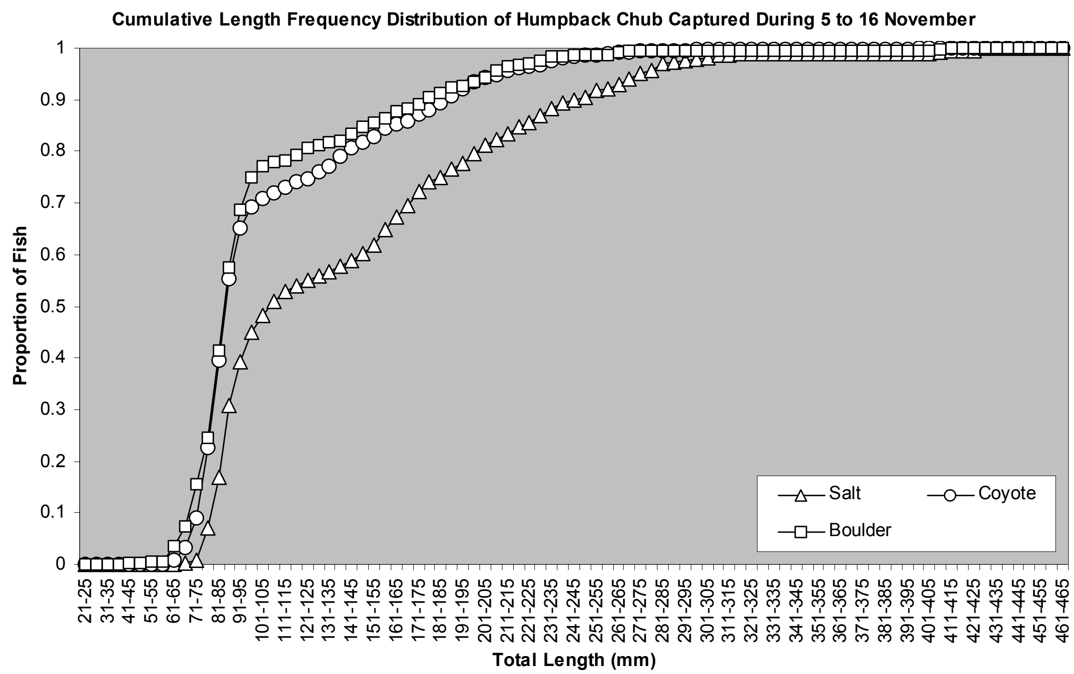


Figure 12. Cumulative length frequency charts of all humpback chub captured in hoopnets at three different reaches (Salt, Coyote and Boulders); Little Colorado River, fall 2001.

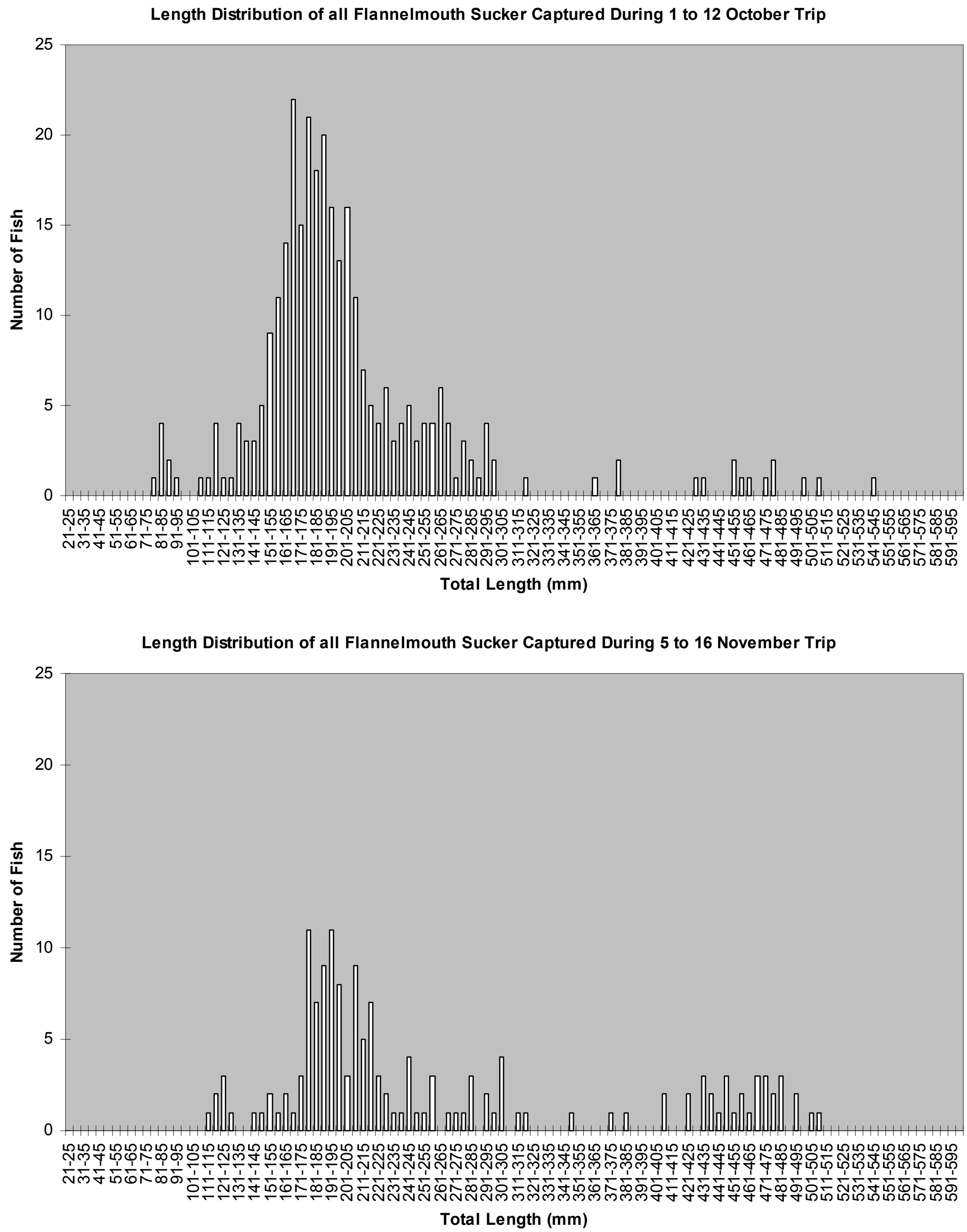
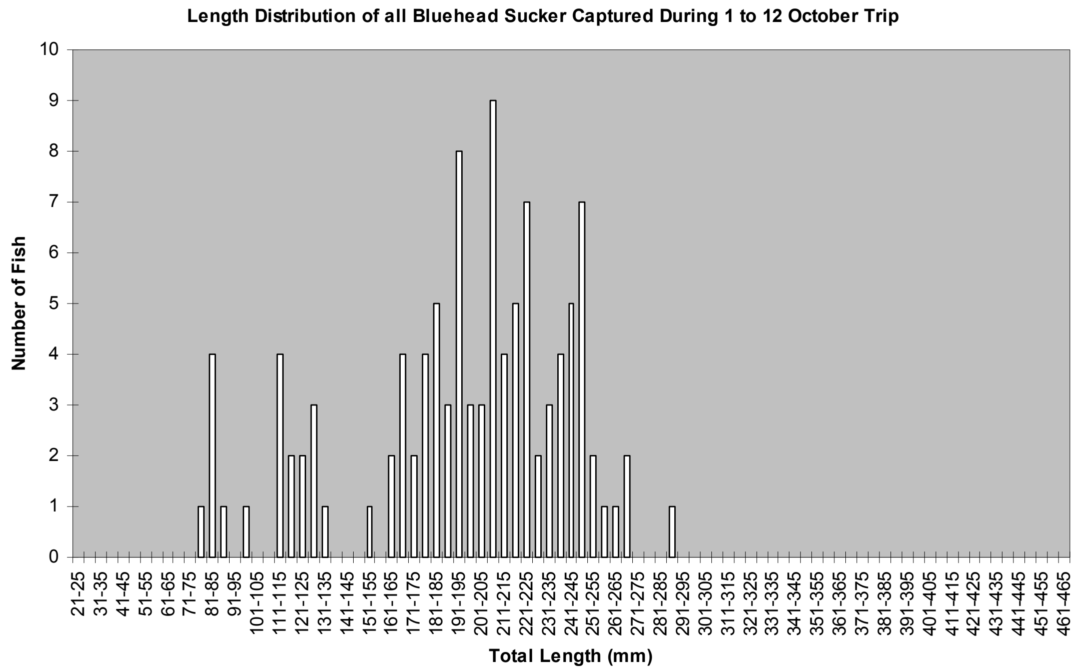


Figure 13. Length frequency distribution of all flannelmouth sucker captured in hoopnets and trammel nets; Little Colorado River, fall 2001.



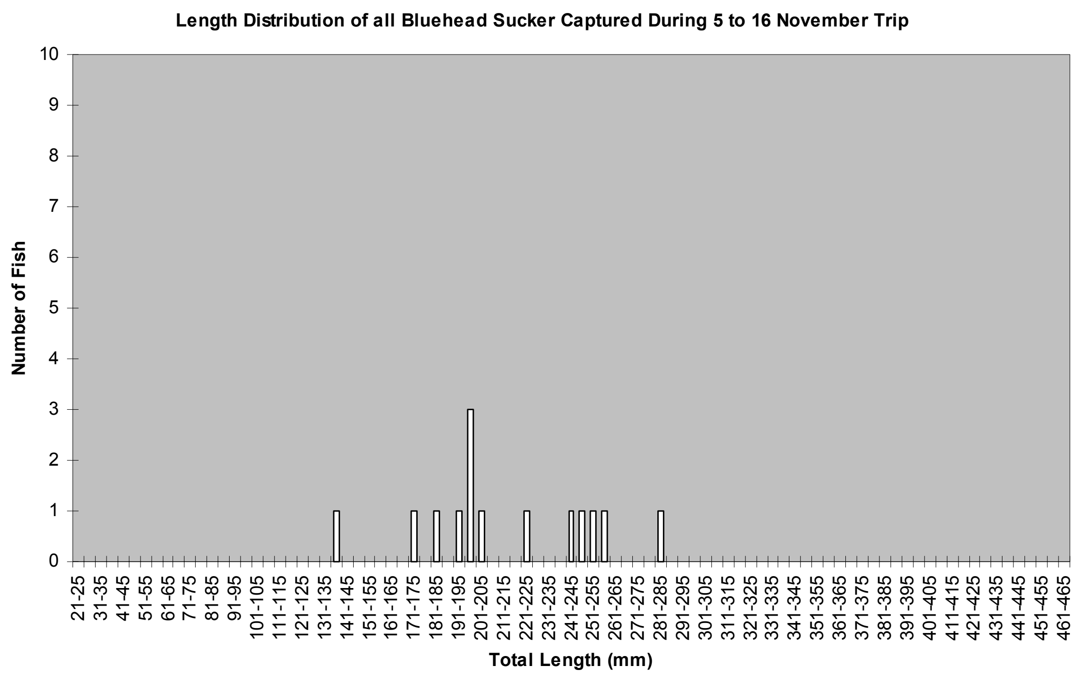


Figure 14. Length frequency distributions of all bluehead suckers captured; Little Colorado River, fall 2001.

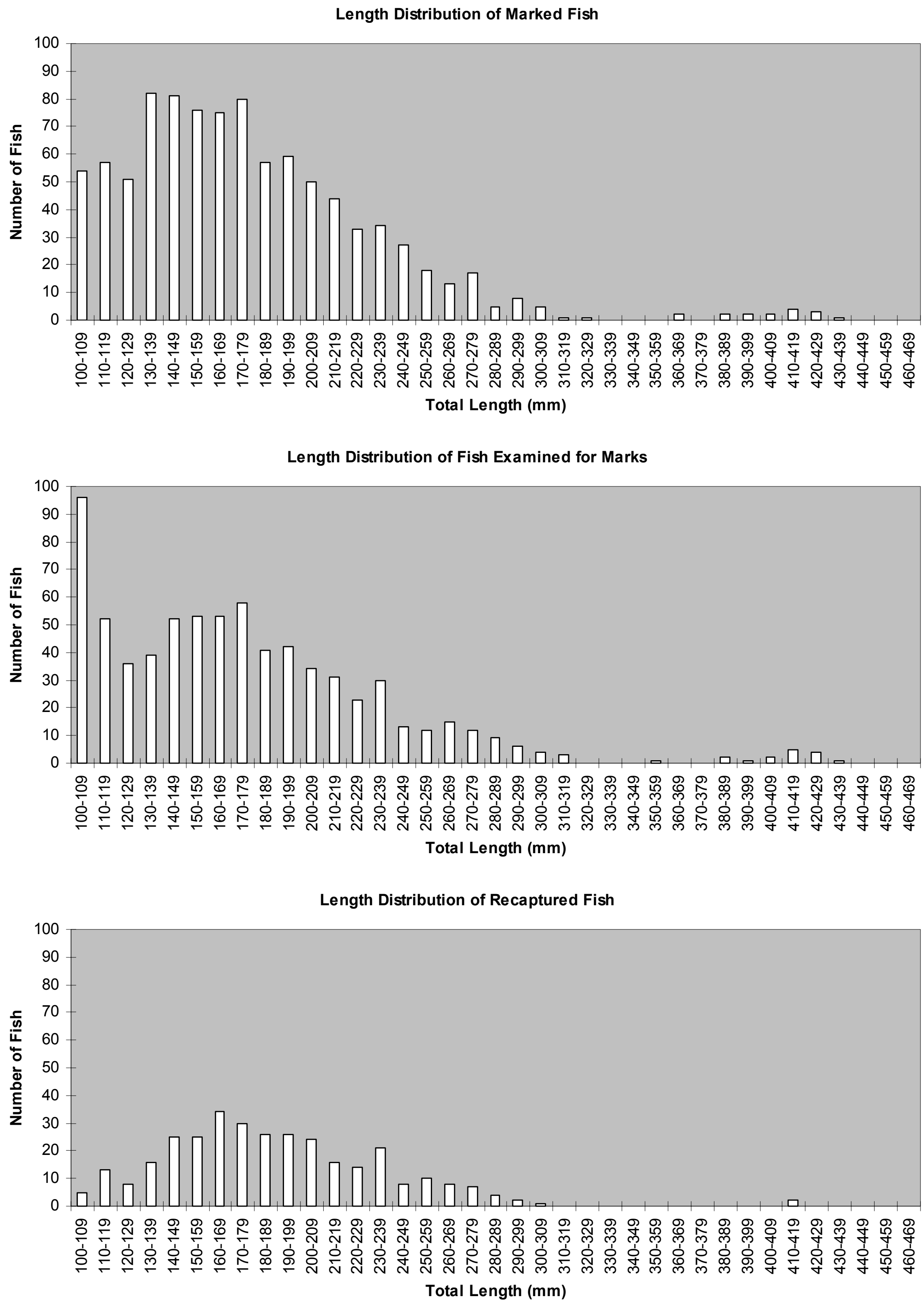


Figure 15. Length frequency distributions of all humpback chub large enough to be PIT tagged captured during the marking and recapture events; Little Colorado River, fall 2001.

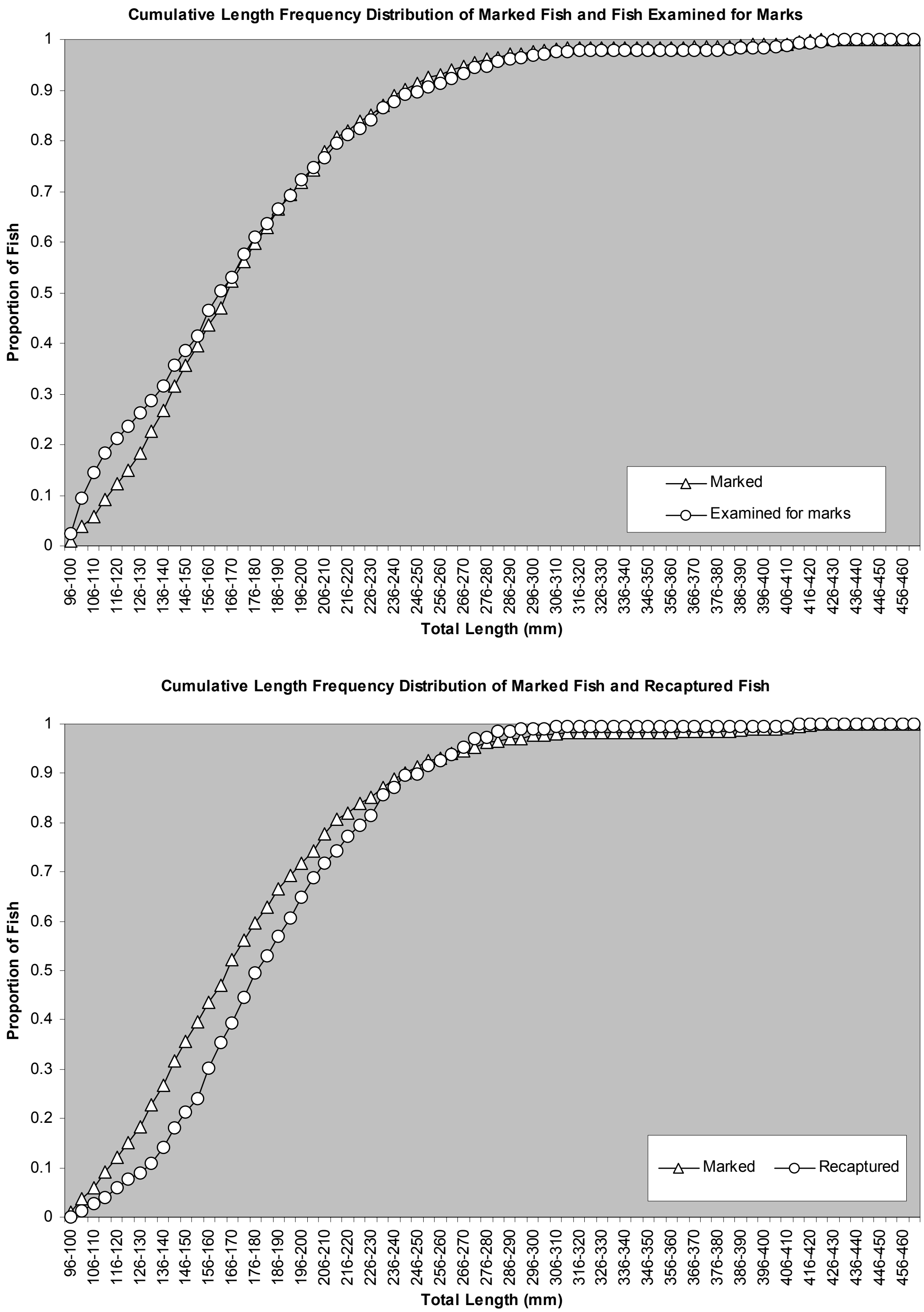
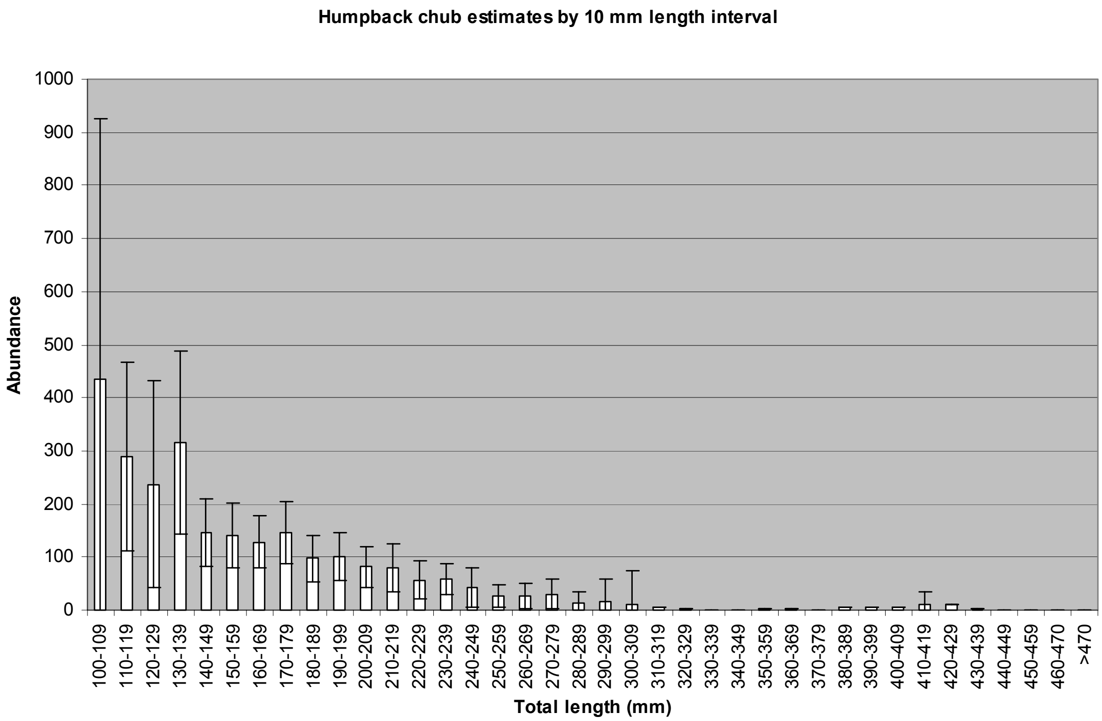


Figure 16. Cumulative length frequency distributions of humpback chub captured; Little Colorado River, fall 2001.



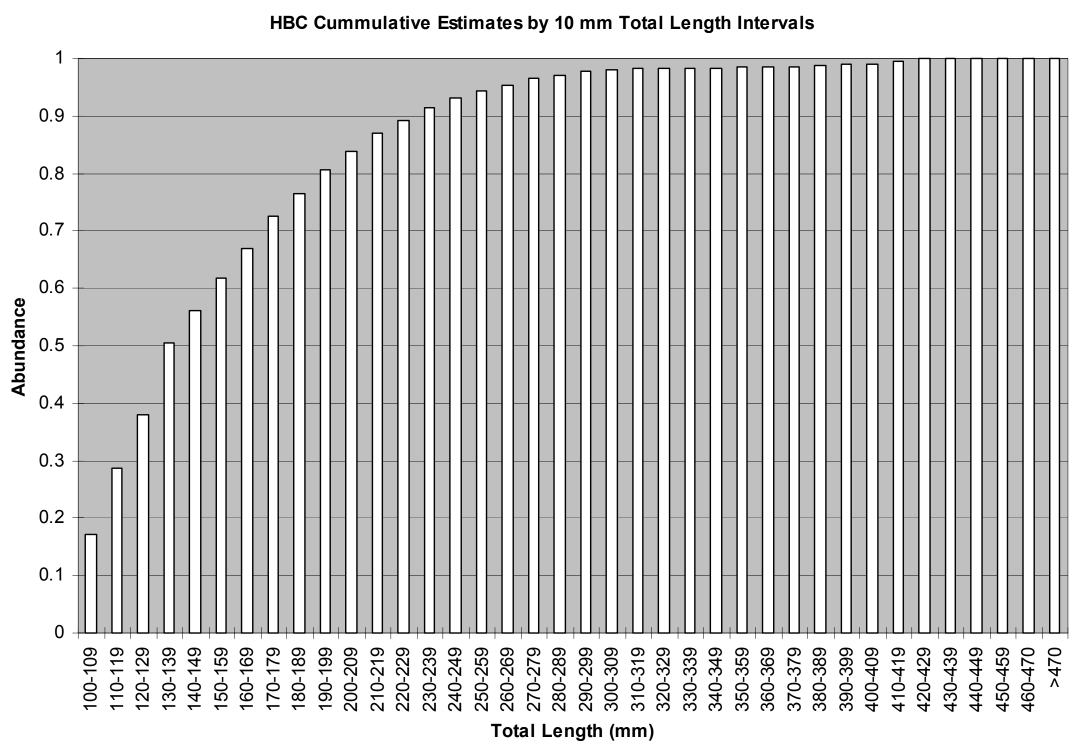


Figure 17. Estimated abundance of humpback chub by 10 mm total length interval; Little Colorado River, fall 2001.

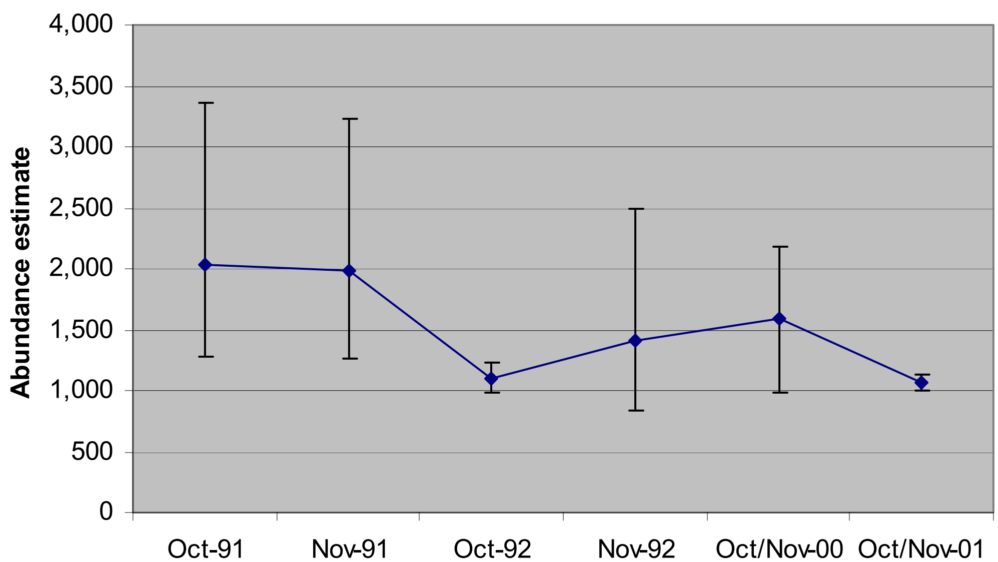


Figure 18. Fall abundance estimates of humpback chub ≥ 150 mm. 1991 and 1992 estimates are from Douglas & Marsh (1996); 2000 estimate is from Coggins and Van Haverbeke (2001).

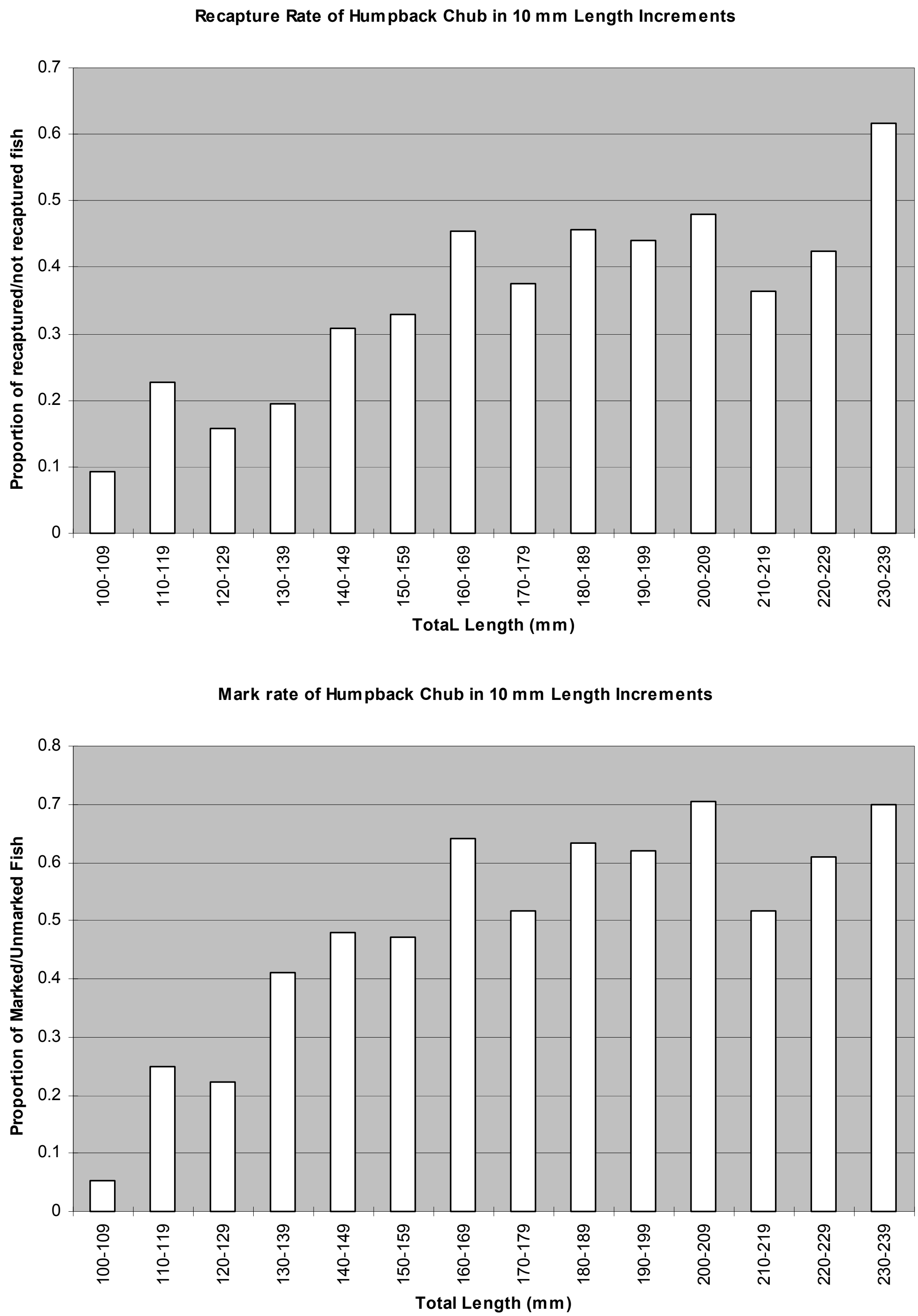


Figure 19. Proportions of recaptured vs. not recaptured fish and mark vs. unmarked fish during the recapture event (October trip); Little Colorado River, fall 2001.