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Mark-Recapture and Fish Monitoring Activities in the Little Colorado River in Grand Canyon from 2000 to 2019

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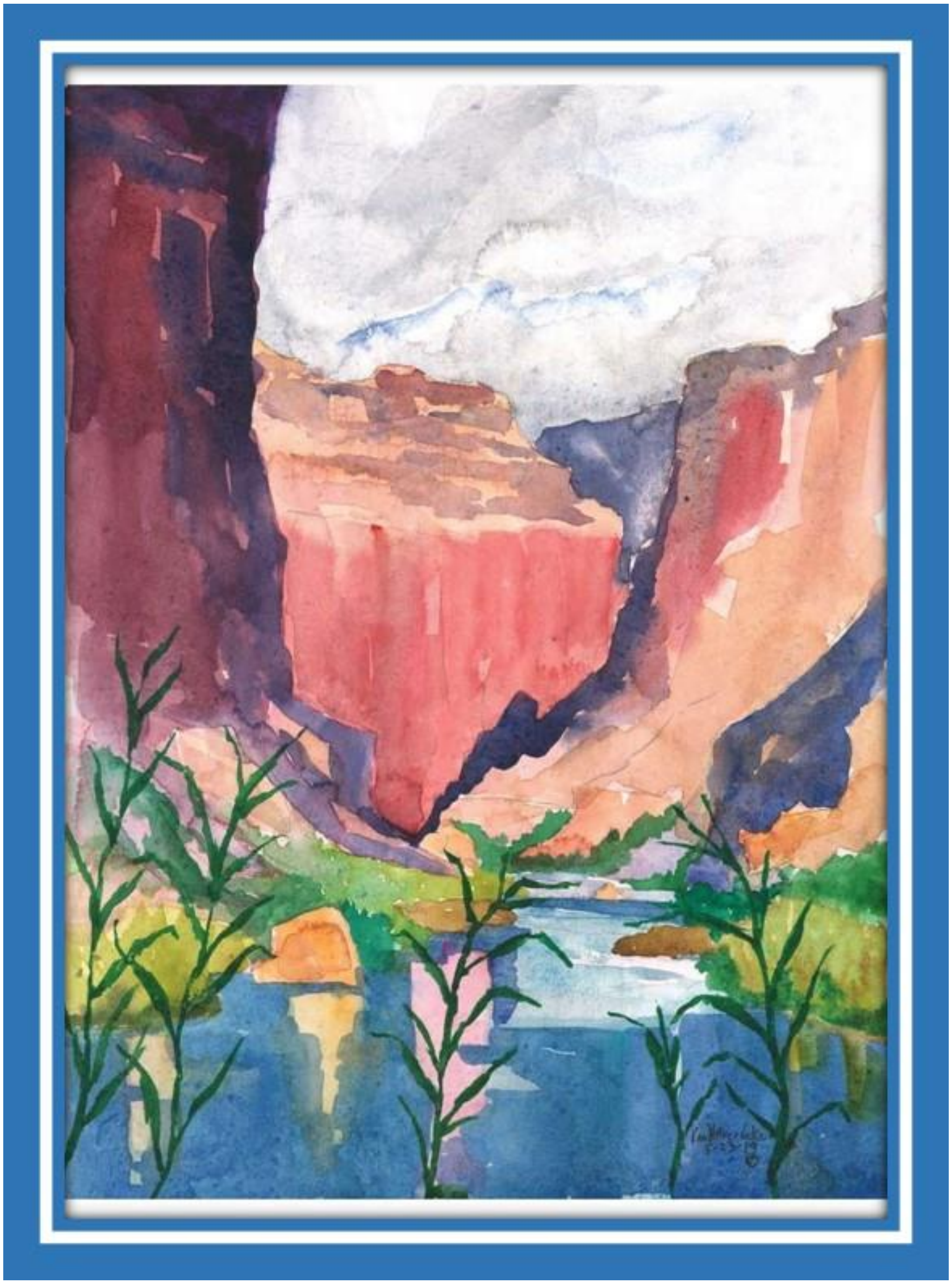

Coyote Reach, Little Colorado River. Watercolor by David R. Van Haverbeke, 23 May 2019.

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Contents

Figures

Tables

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Abstract

Since 2000, monitoring using hoop nets has been conducted in the lower 13.57 river kilometers (rkm) of the Little Colorado River (LCR) to estimate abundance and track trends in abundance of the endangered Humpback Chub (*Gila cypha*), and to monitor other fishes. These monitoring activities occurred during the spring and fall seasons. Native fish species continue to dominate the LCR, comprising 92 percent of fish captures since 2000. We used closed Chapman Petersen mark-recapture methods and catch per unit effort data to estimate either absolute or relative abundances of Humpback Chub of various size classes. Between 2000 and 2006, adult Humpback Chub (≥200 mm) maintained stable but low abundances of <3,000 individuals during the spring and fall seasons. From 2007 to 2014, the spring abundance of adult Humpback Chub significantly increased, and remained at elevated levels (~4,000 to 7,000 individuals). Fall abundances of adult Humpback Chub were also generally elevated during 2007-2014, but to a lesser extent. In 2015 and 2016, both the spring and fall abundances of adult chub in the LCR were depressed compared to the 2007-2014 timeframe. The reason why is uncertain, but it is thought that a large portion of the population remained in the mainstem during those two years. From 2017 to 2019, the spring adult Humpback Chub abundance in the LCR returned to levels equal to or exceeding those during 2007-2014.

Spring abundance estimates of sub-adult Humpback Chub (150-199 mm) were more variable than adults, but have also increased since 2006, with annual abundances ≥1,000 fish from 2007-2014, after which they declined to <1,000 fish during 2015-2016. Like adult Humpback Chub, from 2017-2019 sub-adults in the 150-199 mm size class returned to the elevated levels seen during the 2007-2014 period. Smaller size classes of Humpback Chub (<150 mm) displayed significant annual variation in abundance and catch per unit effort, which is thought to be related to the LCR hydrograph.

Bluehead Sucker (*Catostomus discobolus*) and Flannelmouth Sucker (*C. latipinnis*) were primarily monitored using catch per unit effort, but population estimates were also obtained using mark recapture and

simulation. Relative catches of both native sucker species have generally significantly increased in the post-2006 timeframe.

Reasons for the post-2006 increases of Humpback Chub, Bluehead Sucker, and Flannelmouth Sucker are thought to be related to several factors, including warmer mainstem Colorado River water temperatures since 2003, and possibly mechanical removal of nonnative fish in the mainstem Colorado River during 2003-2006.

Finally, annual monitoring has been conducted since 2006 to monitor Humpback Chub translocated to above Chute Falls in the LCR. Annual estimates of adult Humpback Chub above Chute Falls (>14.1 rkm) have ranged from 1-263, and annual estimates of adult chub in the Atomizer reach immediately below Chute Falls (13.57-14 rkm) have ranged from 16-435.

Introduction

With completion of the EIS on Operations of Glen Canyon Dam (USBR 1996), the Glen Canyon Dam Adaptive Management Program (GCDAMP) was initiated. Within GCDAMP, the Adaptive Management Work Group (AMWG) is responsible for defining management objectives associated with resources downstream from Glen Canyon Dam, and provides recommendations about development of long-term monitoring programs to assess those resources. The U.S. Geological Survey Grand Canyon Monitoring and Research Center (GCMRC) is responsible for developing and coordinating long-term monitoring programs and fulfilling the needs of the AMWG. Assessing the status of the Humpback Chub (*Gila cypha*) is particularly important because it is listed as a federally endangered species (U.S. Office of the Federal Register 32:48 [1967]:4001).

Because of the above needs, GCMRC and U.S. Fish and Wildlife Service (USFWS) initiated a program in fall 2000 to conduct long-term monitoring of Humpback Chub in the Little Colorado River (LCR). Between 2000 and 2019, USFWS obtained closed mark-recapture population abundance estimates of Humpback Chub ≥150 mm in the lower 13.57 river kilometers (rkm) of the LCR during the spring spawning season and during the fall season (e.g., Van Haverbeke 2010, Van Haverbeke et al. 2013). The spring mark-recapture effort is aimed to coincide with the peak of Humpback Chub spawning in the LCR and provides an annual estimate of the spring spawning abundance. The fall mark-recapture efforts provide data about Humpback Chub overwintering in the LCR, particularly those in the juvenile and sub-adult life stages. Additionally, the fall mark-recapture efforts temporally expand marks and recaptures of Humpback Chub in the LCR, thereby providing a foundation for other open or multi-state models (e.g., Coggins et al. 2006, Coggins and Walters 2009, Yackulic et al. 2014).

In addition to estimating abundance and population trends of sub-adult and adult Humpback Chub ≥150 mm, there is interest in tracking abundance of smaller size classes of Humpback Chub <150 mm. This interest stems from a desire to further understand recruitment dynamics of Humpback Chub (e.g., Coggins and Walters 2009, Dzul et al. 2014). This information is also used to estimate the portion of age 0 chub that are annually removed for translocations to other tributaries in Grand Canyon (i.e., Bright Angel, Shinumo, or Havasu creeks; NPS 2013, Trammel et al. 2012) and for maintenance of a refuge population of Humpback Chub at the Southwest Native Aquatic Research and Recovery Center (SNARRC).

Finally, in addition to the ongoing monitoring in the lower 13.57 rkm of the LCR, Humpback Chub monitoring has occurred upstream of rkm 13.57 in the LCR between 2006 and 2019 (Van Haverbeke 2010, Van Haverbeke et al. 2013). The purpose for this monitoring has been two-fold. First, this portion of the LCR (rkm 13.57 to ~17.7) became of interest after a series of translocations initiated in 2003 moved juvenile Humpback Chub from the lower reaches of the LCR (~rkm 1.15 to 9.85) to upstream of a natural travertine structure called Chute Falls (rkm 14.1). Translocated chub were released at rkm 16.2. Monitoring efforts upstream of Chute Falls provide annual population estimates of these translocated chub as they grow into adulthood. Second, there is a small reach of river (Atomizer reach, rkm 13.57 to 14.1) that is not included during our mark-recapture efforts downstream of rkm 13.57. This is a section of river in which Humpback Chub naturally occur, and a section of river which many of the translocated chub occupy as they eventually disperse downstream. Monitoring in this short section of river helps to account for all Humpback Chub in the LCR system.

Previous Investigations

Early studies on Humpback Chub in Grand Canyon began in the 1970s and focused on morphology, life history, and ecology (Suttkus and Clemmer 1977, Kaeding and Zimmerman 1983, Minckley 1996). In Grand Canyon, Humpback Chub are potadromous, with adults typically migrating from nearby areas in the Colorado River to the LCR to spawn during spring (Douglas and Marsh 1996, Gorman and Stone 1999). Young Humpback Chub rear in the LCR and some remain in the LCR until early adulthood (Douglas and Marsh 1996, Gorman and Stone 1999) unless they emigrate or are transported out of the LCR by seasonal flood events (Valdez and Ryel 1995). In addition to the LCR population, there are several smaller “aggregations” of Humpback Chub inhabiting the mainstem Colorado River in Grand Canyon (Valdez and Ryel 1995). With few exceptions, post-dam mainstem reproduction in other aggregations has been absent (but see Valdez and Masslich 1999, Andersen et al. 2010) and exchange of individuals from these aggregations to the LCR is limited (Paukert et al. 2006). Recently, evidence has accumulated that a significant population of Humpback Chub has been developing in western Grand Canyon, likely sustained by mainstem spawning (Van Haverbeke et al. 2017, Rogowski et al. 2018).

Since emplacement of Glen Canyon Dam, the Colorado River throughout Grand Canyon has been predominately characterized by cold hypolimnetic release waters (Wright et al. 2009) that negatively affect Humpback Chub by lengthening the egg incubation period, decreasing egg and larval survival, and slowing growth at all life stages (Hamman 1982, Clarkson and Childs 2000, Robinson and Childs 2001, Coggins and Pine 2010). These factors are considered to have caused range contraction and decreases in abundances of Humpback Chub in Grand Canyon (Kaeding and Zimmerman 1983, Douglas and Marsh 1996, USFWS 2002) and limited the spatial distribution of Humpback Chub to near the LCR. Likewise, warmer mainstem waters that have occurred more often since about 2003 have likely led to population and range expansion during the post 2006 timeframe (Van Haverbeke et al. 2013, Van Haverbeke et al. 2017). Because of the need to conserve and recover this relict species, several studies have focused on estimating population abundance of the LCR population (Douglas and Marsh 1996, Coggins et al. 2006, Coggins and Walters 2009, Van Haverbeke et al. 2013, Yackulic et al. 2014).

Purpose and Objectives

The purpose of this report is to summarize Humpback Chub mark-recapture studies in the LCR from 2000 through 2019 and evaluate the status and trends of Humpback Chub during those years. Population variables evaluated for the study include closed population estimates, length frequency distributions, and external parasites of Humpback Chub during the spring and fall seasons. In addition, data are presented on relative abundance (catch per unit effort) of smaller size classes of Humpback Chub (<150 mm), as well as Flannelmouth Sucker (*Catostomus latipinnis*) and Bluehead Sucker (*C. discobolus*) ≥150 mm. The specific objectives of this report are:

1. Present closed Chapman-modified Peterson (Chapman Petersen) abundance estimates of Humpback Chub ≥150 mm and ≥200 mm in the lower 13.57 rkm of the LCR during the spring and fall seasons.
2. Present Chapman Petersen abundance estimates of age 0 Humpback Chub (40-99 mm) in the lower 13.57 rkm of the LCR during the fall season.
3. Present Chapman Peterson abundance estimates of Humpback Chub in the LCR between rkm 13.57 and 14.1 and between rkm 14.1 to 17.7 (Atomizer and Chute Falls reaches).
4. Present additional information related to physical parameters of the LCR, length frequency distributions of native fishes, species composition, and parasites.
5. Present 2019 annual data alongside previous data to provide data continuity.

For additional detailed information about monitoring activities, readers should consult Pillow (2019) concerning the spring 2019 mark-recapture trips; Stone (2019) concerning the 2019 Chute Falls monitoring trip;

and Pillow and Williams (2020) concerning the fall 2019 monitoring trip and translocation of Humpback Chub to Chute Falls.

Methods

Trips and Participating Personnel

Between September 2000 and October 2019, 77 field trips were conducted to perform 38 mark-recapture efforts to estimate abundance of Humpback Chub ≥150 mm and ≥200 mm in the lower 13.57 rkm of the LCR. A mark-recapture event occurred each spring (generally during April and May), and each fall (generally during September and October). In addition, between 2006 and 2019, eighteen trips were conducted to estimate abundances of Humpback Chub upstream of rkm 13.57 in the LCR (Atomizer and Chute Falls reaches). These trips occurred during May or June. Personnel on the above mentioned trips included USFWS staff from the Arizona Fish and Wildlife Conservation Office, USFWS volunteers, collaborative staff from the Arizona Game and Fish Department, Navajo Nation Fish and Wildlife Department, Grand Canyon National Park, and GCMRC.

During 2019, four trips were conducted in the lower 13.57 rkm of the LCR: 16-26 April, 14-24 May, 17-27 September, and 15-25 October. The May trip included monitoring in the Atomizer and Chute Falls reaches.

Study Area

Work during the spring and fall trips in the lower 13.57 rkm of the LCR was conducted downstream of a large travertine structure called Lower Atomizer Falls, with the confluence of the LCR and the mainstem Colorado River designated as rkm 0 (Figure 1). During these trips, the LCR was divided into three contiguous reaches (Boulders, Coyote, and Salt). Each reach was divided into three subreaches (Table 1).

During the May Chute Falls trip, the LCR upstream of rkm 13.57 was divided into Atomizer reach from the top of Lower Atomizer Falls (rkm 13.57) to the base of Chute Falls (rkm 14.1), and Chute Falls reach from the top of Chute Falls (rkm 14.1) to ~rkm 17.7 (Figure 1, Table 1).

Gear and Effort

During the spring and fall trips in the lower 13.57 rkm of the LCR, unbaited hoop nets (0.5 - 0.6 m diameter, 1.0 m length, 6 mm [1/4”] mesh, with a single 0.1 m throat) were used to sample fishes. During 2001 and 2002, nets were baited with AquaMax Grower 600 for Carnivorous Species (Purina Mills, Inc., Brentwood, MO). Baiting in the lower 13.57 rkm was then discontinued because of uncertainty about PIT tagging mortality in fish with full stomachs. With few exceptions, ~540 net sets were deployed during each monitoring trip. Each "net set" consisted of a hoop net being deployed in the river for ~24 hours, after which it was checked for fish. This resulted in ~180 net sets being deployed per reach (i.e., Boulders, Coyote, and Salt reaches). Each reach was divided into three subreaches, and within each subreach, ~20 nets were set for three 24-hour periods. This design resulted in a stratified netting effort that was spatially and temporally uniform among sampling trips across years (Figures 1 and 2). Exceptions to the above were five trips during 2001 and 2002, when nets were set for four 24-hour periods rather than three. Minor variation also occurred because helicopter logistics occasionally resulted in slightly shortened trips (e.g., spring 2006, fall 2011, 2013, 2014 and 2017 mark trips). One trip was cancelled in fall 2018 because of inclement weather and flooding. With exclusion of the five higher effort trips in 2001 and 2002, average hoop netting effort among spring trips was 12,446 hrs per trip (SE = 907), and among fall trips was 12,282 hrs per trip (SE = 1,058). During spring 2019, 540 hoop net sets were deployed during the April trip and 541 hoop net sets were deployed during the May trip, yielding 12,612 and 12,649 hours of effort, respectively. During fall 2019, 493 hoop net sets were deployed during the September trip yielding 11,613 hours of effort, and 539 hoop net sets were deployed during the October trip yielding 12,435 hours of effort.

During the Chute Falls monitoring trips, hoop nets were baited near their cod ends by attaching nylon mesh bags (30 x 30 cm, 6 mm mesh) filled with ~160 g AquaMax Grower 600 for Carnivorous Species (Purina Mills Inc., Brentwood, MO). This was done to increase fish captures in order to more closely track translocated fish (Stone 2005). In addition, because our population estimation technique for these reaches involves using capture probability data collected while using baited nets between 2006 and 2009, we have continued to bait nets in the Atomizer and Chute Falls reaches. Typically, the Atomizer reach (rkm 13.57-14.1) was sampled with 17 hoop nets, and the Chute Falls reach (rkm 14.1 to ~rkm 17.7) was sampled with 33 hoop nets, all of which were run for three 24-hr periods. During 2006-2009, the Atomizer and Chute Falls reaches monitoring entailed two trips per year (a marking trip and a recapture trip), but years 2010-2019 included only annual marking trips. Sampling effort (hours of hoop netting) was uniform across trips, both in the Atomizer reach and in the Chute Falls reach (Figure 3). More effort than usual was spent in the Chute Falls reach during 2016 because of a small flood (i.e., three high turbid sampling days were repeated with sampling during three ensuing low turbidity days). Between 2006-2019, average trip hoop netting effort in the Atomizer reach was 1,143 hours (SE = 31), and average hoop netting effort in the Chute Falls reach was 2,440 hours (SE = 440). During 2019, 51 net sets were deployed in the Atomizer reach yielding 1,208 hours of effort, and 95 net sets were deployed in the Chute Falls reach yielding 2,253 hours of effort.

On all LCR monitoring trips, nets were positioned in habitat suspected to catch Humpback Chub, and were frequently repositioned or moved if the catch was poor and if an alternative site was available. Nets were spread throughout each subreach within constraints of river hydrology and depth. Most nets were set near shore, but some were set further midstream if access allowed. Each net was checked and emptied of fish daily. Net locations on all sampling trips above were recorded as distance (rkm) upstream of the confluence.

Fish Handling and Data Collection

Data collected from fish included species, total and fork length (mm), sex, sexual condition (ripe, not ripe, gravid), and sexual characteristics (tuberculate, spawning colors). Speckled Dace and non-native fish were generally measured only for total length. Humpback Chub and other fish were visually checked for the presence of the external copepod parasite (*Lernaea cyprinacea*), but the internal Asian fish tapeworm *(Bothriocephalus acheilognathi*) was not monitored. All fish lengths reported refer to total length.

Humpback Chub, Flannelmouth Sucker, and Bluehead Sucker ≥150 mm were scanned for a Passive Integrated Transponder (PIT) tag (Biomark Inc., Boise, ID), and if lacking a tag were PIT tagged. From 2000 through 2002, 400 kHz PIT tags were used. Thereafter, 134 kHz PIT tags were used and fish containing a 400 kHz tags were retagged with a 134 kHz tag. From 2000 to 2003 and from 2009 onward Humpback Chub ≥100 mm were PIT tagged. From 2012 through 2019 some Humpback Chub as small as 65 mm TL were PIT tagged, but generally chub below 80 mm were not PIT tagged. From 2000 through spring 2003, most fish were weighed (g). Methods for collection of fish data followed the Standardized Methods for Grand Canyon Fisheries Research 2012 (Persons et al. 2013) with the following additions:

1. Humpback Chub ≥100 mm in the Chute Falls monitoring efforts were PIT tagged from 2006 onward.

2. From 2010 onward, Visible Implant Elastomer (VIE, Northwest Marine Technology, Shaw Island, WA) tags were used during the fall mark-recapture trips in the lower 13.57 rkm to mark Humpback Chub that were too small to PIT tag effectively. During the September marking trips chub 40-99 mm received a red or orange (depending on the year) VIE tag, and chub 40-99 mm during the October recapture trips received a blue or green (depending on the year) VIE tag. Tag placement was trip specific (e.g., below, anterior, or posterior to dorsal fins, and left or right side of dorsal fins). Secondary VIE tags were inserted (generally on opercles or on top of head) for size strata marks (e.g., 40-59 mm, 60-80 mm).

Water Quality

Measured water quality parameters for the spring and fall trips included turbidity readings (nephelometric turbidity units, NTUs) collected near Salt Camp (rkm 10.4), Coyote Camp (rkm 9.0), or Boulders Camp (rkm 1.9). Generally, three or more turbidity daily readings were taken with a Hach 2100P Turbidimeter (Loveland, CO) and averaged. During Chute Falls trips, these measurements were taken at Translocation Camp (rkm 16.2). Provisional data (mean daily discharges in cubic feet per second; cfs) were downloaded (http://waterdata.usgs.gov/az/nwis/uv?site_no=09402000) for USGS gage station 0940200 located on the LCR near Cameron, Arizona.

Closed Mark-Recapture

Between 2000 and 2019, closed Chapman Petersen mark-recapture efforts were conducted during the spring and fall to estimate abundance of Humpback Chub ≥150 mm in the lower 13.57 rkm of the LCR. During 2000, no spring mark-recapture effort occurred. Like Douglas and Marsh (1996), our approach was to obtain closed abundance estimates of Humpback Chub ≥150 mm via fishing the lower 13.57 rkm of the LCR with hoop nets. However, our efforts only provide abundance estimates during the spring and fall seasons of each year rather than on a monthly basis as in Douglas and Marsh (1996). This is because Douglas and Marsh (1996) conducted monthly sampling whereas this study only collected data four times per year. Nevertheless, within a given set of months, and within a given size class of fish (≥150 mm), our abundance estimates are comparable to Douglas and Marsh (1996).

Abundance estimates were obtained for all Humpback Chub ≥150 mm, and in some years was estimated for smaller size classes (e.g., Humpback Chub ≥100-149 mm from 2010 onward, and ≥40-99 mm during fall trips 2010 onward). We first examined our data to define the 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 (generally ~10 mm). We did not truncate the upper length end of our abundance estimates, because the types of hoop nets used in our study have been shown to capture large Humpback Chub (Gorman and Stone 1999, Stone and Gorman 2006).

The closed Chapman modified Petersen two-sample mark-recapture model (Seber 2002) was used to estimate abundance where:

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

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

Where:

N^{*} = the estimated number of fish in the population,

$V\left[N^*\right]$ = the estimated variance of the number of fish in the population,
M = the number of fish marked during the marking event,
C = the number of fish captured during the recapture event,
R = the number of fish recaptured from the marked population during the recapture event.

In order to estimate the abundance of Humpback Chub ≥200 mm, the Chapman Petersen estimates of Humpback Chub ≥100 mm were multiplied by the proportion of Humpback Chub ≥200 mm with the formulae presented in Seber (2002) as:

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

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

Where: P_x 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., ≥ 200 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 2002).

Using the Chapman Peterson model requires only two trips (i.e., a marking trip and a recapture trip) to generate abundance estimates, and therefore requires less handling of fish. In addition, data gathered to produce the Chapman Petersen estimates can be incorporated into open and multi-state models (e.g., Coggins et al. 2006, Coggins and Walters 2009, Yackulic et al. 2014, Dzul et al. 2014, Van Haverbeke et al. 2015). Assumptions necessary for unbiased estimates of abundance using the Chapman Petersen estimator are:

1. The population is closed with no additions (i.e., recruitment, immigration) or losses (i.e., mortality, emigration) between marking and recapture events
2. All individuals in the target population have an equal probability of capture. Specifically:
    a. Marked individuals mix completely with unmarked individuals prior to the recapture event.
    b. Marking does not affect capture probability during the recapture event (i.e., animals are not 'trap-happy' or 'trap-shy').
3. Marks (tags) are not lost between the mark and recapture events.
4. All marked individuals captured can be recognized from unmarked individuals.

The first assumption, addressing population closure, could potentially be violated in this system because Humpback Chub in the LCR have access to the mainstem Colorado River. This assumption has a higher probability of being violated during the spring than during the fall mark-recapture events. Humpback Chub movement and migration is known to occur during the springtime (Kaeding and Zimmerman 1983, Douglas and Marsh 1996), but is thought to be much lower during the fall and winter months (Douglas and Marsh 1996). We minimized potential for violating this assumption by allowing less than a month to elapse between mark and recapture events. It was also assumed that growth-related recruitment was minimal because of the short time span between the mark and recapture events. Finally, all fish captured during the mark-recapture efforts were handled with care according to protocols (Persons et al. 2013) to minimize injury or stress to fish.

If the Humpback Chub population experiences only losses between mark and recapture events, the Chapman Petersen estimator will be unbiased and pertain to population abundance during the marking event. Conversely, if the Humpback Chub population experiences only additions, population estimates will be unbiased and pertain to abundance during the recapture event. However, if both additions and losses occur, there is no possible correction and the estimator will overestimate abundance (Otis et al. 1978, Seber 1982). For further explanation about population estimation, and measures taken to minimize assumption violation during these studies, see Van Haverbeke et al. (2013).

Population Estimation using Capture Probability Data and Monte Carlo Simulation

In addition to the closed Chapman Petersen population estimator, we used capture probability (*p*) data and Monte Carlo simulation in some instances to estimate abundances of Humpback Chub. From 2010 onward, *p* data and Monte Carlo simulation rather than the Chapman Petersen estimator was used to estimate abundance of adult Humpback Chub in the Atomizer and Chute Falls reaches. This was done because closed Chapman Petersen efforts were not performed in the Atomizer and Chute Falls reaches after 2010 (i.e., only one annual marking trip was conducted, but no recapture trip). Annual catch of adult Humpback Chub in each reach from 2010–2019 was divided by annual *p* data derived from Chapman Petersen mark-recapture efforts conducted from 2006–2009. Capture probabilities were calculated as: $p1$ = R/C, where C = total number of unique adult chub captured during a recapture trip, and R = number of adult chub marked (tagged) during a mark trip and subsequently recaptured during the recapture trip; and $p2$ = R/M, where M = the number of unique adult chub marked. Adult Humpback Chub *p* values in the Chute Falls reach between 2006 and 2009 ranged from 0.35 - 0.91 (mean = 0.67, SE = 0.17, n = 8), while adult Humpback Chub *p* values in the Atomizer reach between 2006 and 2009 ranged from 0.54 - 0.74 (mean = 0.67, SE = 0.15, n = 8). To estimate abundance using the 2006-2009 *p* data, we first bootstrapped the number of expected recaptures given the individual trip *p* estimates and the number of chub marked during the marking trip. We then simulated $p1$ and $p2$ capture probabilities by dividing the bootstrapped number of recaptures by the number of marked fish, and by the number of fish captured during the second trip, respectively. We took the mean of the simulated trip *p* values and used this value as the trip capture probability. Then, using Monte Carlo analysis (10,000 replicates), trip catch was divided by the mean bootstrapped *p* value to obtain abundance estimates with 95% confidence intervals. Because hoop netting effort and turbidity conditions in the Atomizer and Chute Falls reaches during 2010-2019 were nearly identical to those of 2006–2009, we considered it reasonable to assume that detection values were similar between the two time periods and unnecessary to correct for turbidity (see below).

Monte Carlo simulation was also performed to fill in abundance estimates for the fall age 0 (<100 mm) and spring age 1 (100-149 mm) cohorts during years in which the Chapman Petersen estimator was not used (i.e., those years between 2000 and 2019 when those size classes were not PIT tagged). We used the method described above, with the exceptions that the *p* values we used to estimate abundances were size specific, and that the *p* values were segregated into low, intermediate, and high turbidity categories based on Stone (2010). This was because turbidity is a primary factor influencing catch of Humpback Chub (Stone 2010). Finally, we used Monte Carlo simulation to estimate abundances of Bluehead Sucker and Flannelmouth Sucker using available species and size specific (≥150 mm) *p* values segregated by turbidity.

Catch per Unit Effort

Catch per unit effort (CPUE) was also used to monitor relative trends of smaller size classes of Humpback Chub <150 mm, and for Flannelmouth and Bluehead Suckers ≥150 mm. This was because Humpback Chub <150 mm were not PIT tagged during all years of this study, and because in several years numbers of recaptured suckers were insufficient for population estimation. In the LCR, catch rates of these fish in hoop nets can be significantly affected by high turbidities resulting from flood events (Stone 2010). We minimized for the effect of turbidity by calculating CPUEs from data gathered during May of each year, and from October during the fall, although some exceptions were made. For example, in 2015 and 2016 we used CPUEs from September to estimate the relative abundance of the Humpback Chub age-0 cohort (<100 mm) because September had lower turbidities than October during those years. If necessary, we obtained CPUEs from select days within a trip when turbidity was low (e.g., fall 2016 CPUEs from 6 days in September trip when the LCR was experiencing low turbidities [mean = 36 NTUs], spring 2015 CPUEs from five days in May when daily NTUs were <54, spring 2016 CPUEs from 6 days in May when turbidity ranged 58-83 NTUs). Because nets were set very close to 24 hours each, all CPUEs in this report are expressed as number of fish captured per net set (Stone 2010).

Results –rkm 0-13.57

Physical Parameters

Turbidity and Flow

Turbidities encountered during fall 2000-2019 mark-recapture events were generally much higher than those of spring 2001-2019 mark-recapture events (Figure 4). This is because monsoonal flooding events during September tend to cause far higher turbidities than spring runoff flows of April. Further, turbidity tended to be higher during spring mark trips because of snow run-off, and lower during the spring recapture trips when the LCR generally returned to base flows; whereas turbidity tended to be higher during the fall mark trips because of monsoonal flooding, and lower during the fall recapture trips when the LCR generally returned to base flows (Figure 5). Average trip turbidities encountered during the spring ranged from 4 to 6,343 NTUs (grand mean = 483 NTUs, N = 38 trips). Average trip turbidities during the fall ranged from 5 to 75,956 NTUs (grand mean = 12,365 NTUs, N = 39 trips). For 2019, average turbidity during the spring trips was 301 NTUs (SE = 408), and for the fall trip was 618 NTUs (SE =1,838).

Species Composition

Humpback Chub have generally dominated hoop net catches in the lower 13.57 rkm of the LCR since 2000 (Figure 6). Bluehead Sucker displayed high variance in percent species composition because of highly variable annual catches. Native fish have comprised 92% of all fish captured since fall 2000. Fathead Minnow (*Pimephales promelas*) were generally the dominant nonnative fish captured, comprising 6% of catch since 2000. Catches of Fathead Minnow were variable and thought to result either from immigration of fish caused by floods in the mid-upper portions of the LCR watershed (Stone et al. 2007, 2018), or from extended periods of base flows during which local populations may have expanded. Other nonnative fish captured since 2000, listed in order of decreasing catch, included Common Carp (*Cyprinus carpio*), Black Bullhead (*Ameiurus melas*), Channel Catfish (*Ictalurus punctatus*), Red Shiner (*Cyprinella lutrensis*), Plains Killifish (*Fundulus zebrinis)*, Rainbow Trout (*Oncorhynchus mykiss*), Brown Trout (*Salmo trutta*), and Green Sunfish (*Lepomis cyanellus*). A few fish thought to be Razorback Sucker (*Xyrauchen texanus*) and Flannelmouth Sucker hybrids have been captured since 2000, and these fish are treated as Flannelmouth Sucker for this report. Such hybrids were infrequently captured during monitoring efforts in the early 1990s (Douglas and Marsh 1998). Presumably under-represented in hoop net catches were adult Channel Catfish and adult Common Carp, which seldom enter our nets but are seen by field crews and captured by angling, and Plains Killifish which tend to inhabit shallower waters than our hoopnets fish. In 2019, Humpback Chub dominated trip catches (63% of captures), followed by Bluehead Sucker (14%), Speckled Dace (11%), Flannelmouth Sucker (7%), and Fathead Minnow (3%). Native fish comprised 93% of fish captures in 2019.

Overall, both the spring and fall CPUEs of nonnative fishes appear to be declining since 2000 for reasons unknown (Figures 7-A and 7-B). Two obvious exceptions were spring of 2006 and fall 2009, both spikes caused by high captures of fathead minnow that comprised 98% and 94% of the nonnative catch in those instances, respectively.

Length Frequency Distributions

Humpback Chub

Humpback Chub in the lower 13.57 rkm of the LCR show a widely distributed population structure, with all size classes represented and recruitment of young fish apparent (Figure 8-A). Cumulatively from 2001-2018, the spring season shows sizeable production of age 1 fish in the roughly 80-130 mm size class. Note in 2019 the absence of age 0 fish <65 mm; thought to be a result of a late spawn perhaps caused by cooler air temperatures or extended spring runoff.

During the fall in the lower 13.57 rkm of the LCR, there is also indication of a healthy population structure for Humpback Chub, with multiple size class representation (Figure 8-B). Cumulatively since 2000, there has been sizeable production of age 0 Humpback Chub, and 2019 was no exception. These fish hatch during the spring seasons, but most are still <100 mm by fall (Figure 8-B). As during the spring, the mode for length of age 1 Humpback Chub (actually closer to 1.5 year old) was slightly larger in fall 2019 than in previous years, being closer to 155-160 mm rather than 150-155 mm. Noticeably fewer fish are captured in the 200-300 mm size class during the fall (10,817 since 2000) compared to spring (19,982 since 2001), because many of these fish presumably vacate the LCR after the spring spawning season. Finally, captures of large adult Humpback Chub >300 mm are fewer during the fall season (1,028 captured since 2000), compared to the spring (4,889 captured since 2001).

Bluehead Sucker

Bluehead Sucker also show signs of a healthy population structure in the lower 13.57 rkm of the LCR, with adult fish and recruiting young fish present (Figure 9). Cumulatively from 2001-2018, the spring season displays a sizeable group of presumed age 0 fish (mode at 65-70 mm), and another group of sub-adult/adult fish (mode ~240 mm). Like Humpback Chub, there was an absence of age 0 Bluehead Sucker in spring 2019 that became visible in the fall, again likely because of a late spawning season.

Flannelmouth Sucker

Cumulatively (2001-2018), Flannelmouth Sucker show distinct size class patterns during the spring (Figure 10-A), with representatives from the age 0 (<80 mm) and age 1 cohorts (~80-150 mm) being most distinguishable (i.e., older cohorts tend to blur). In 2019, Humpback Chub and both sucker species displayed age 0 catches during the fall trip that were absent during spring 2019 (Figures. 8-B, 9-B, and 10-B).

Parasites

Percent occurrence of the external parasite (*Lernaea cyprinacea*) on Humpback Chub during spring trips was generally lower compared to fall trips, with infestation rate representing the percent of chub captured observed carrying the parasite (Figure 11). Infestation rates during spring trips averaged 1.5% (range 0-8%); while those on fall trips averaged 7.7% (range 0.08% to 35%). The highest infestation rate was during fall 2009 at 35%. Typically, only one or two parasites are seen on individual Humpback Chub in the LCR, although numbers are sometimes higher. Very infrequently, this parasite is seen on other species of native and nonnative fish (e.g., Flannelmouth, Bluehead, Dace, Fathead Minnows), again typically at low frequencies with only one or two parasites per fish. For 2019, infestation rates were 0.2% during the spring trips and 16.4% during the fall trip.

Abundance Estimation (rkm 0-13.57)

Adult and sub-adult Humpback Chub

Following the decline in sub-adult (150-199) and adult (≥200 mm) Humpback Chub abundance documented in the early-mid 90s (Coggins et al. 2006), mark-recapture abundance estimates in the LCR remained at reduced but stable levels during the early-mid 2000s (Figure 12). After 2006, abundance of Humpback Chub ≥150 mm and ≥200 mm in the LCR during the spring and fall seasons significantly increased and remained at elevated levels until 2014. In spring 2015, the abundance of Humpback Chub ≥150 mm and ≥200 mm declined significantly. Since 2015, numbers have rebounded again, and in 2017-2019 have equaled or surpassed the abundance estimates during the 2007-2014 period (Figure 12-A). For spring 2019, the Chapman Petersen abundance estimate of Humpback Chub ≥150 mm was 11,210 (SE = 1,300), of which an estimated 8,987 (SE =

1,048) were ≥200 mm. For fall 2019, the abundance estimate of Humpback Chub ≥150 mm was 2,589 (SE = 275), of which an estimated 1,545 (SE = 160) were ≥200 mm.

For subadults (150-199 mm), most spring abundance estimates since 2007 have been >1,250 fish, with the exceptions of 2008, 2011, 2015 and 2016 (Figure 13). For spring 2019, the Chapman Petersen abundance estimate for Humpback Chub in the 150-199 mm size class was 2,592 (SE = 437).

Juvenile (age 1 and age 0) Humpback Chub

Mark-recapture estimates of Humpback Chub in the age 1 size class (100-149 mm) during the spring season were conducted in 2001, 2002, and 2009-2018, and ranged between 818 and 11,727 fish (mean = 4,367, SE = 3,150; Figure 14-A). For spring 2019, a Chapman Petersen abundance was not obtained because of too few recaptures (only 3). Instead, we utilized Monte Carlo simulation and obtained an abundance estimate of 875 (SE = 118) for age 1 Humpback Chub. CPUE of age 1 Humpback Chub in years 2001-2019 ranged between 0.14 and 3.52 fish per 24-hour net set (mean = 1.5) during the spring recapture trips (Figure 14-A). For spring 2019, CPUE for age 1 Humpback Chub was 0.20 fish per net set during May. Several years (2001, 2003, 2005, 2007, 2010 and 2019) can be characterized as years with low relative abundance. Five of these years (2001, 2003, 2007, 2010 and 2019) correspond to the low age 0 CPUEs of the previous fall (Figure 14-B). The age 1 mark-recapture estimates show good correlation with the age 1 CPUE calculations ($r^2 = 0.73$, N = 12 years).

Annual Chapman Petersen efforts using VIE tagging to estimate abundance of Humpback Chub in the age 0 size class (40-99 mm) in the LCR began in fall 2010 and continued through fall 2019. Between fall 2010 and fall 2019, Chapman Petersen abundance estimates of the fall age 0 cohorts ranged between 3,455 and 13,049 fish (Figure 14-B), with 2019 being the high of 13,049. However, for 2019 using *p* data and Monte Carlo simulation, we obtained an estimate of 6,745 (SE = 1,112) Humpback Chub in this size class. CPUE in years 2000-2019 has ranged between 0.05 and 3.0 (mean = 1.4) fish per 24-hour net set (Figure 14-B). For October 2019, CPUE for age 0 Humpback Chub was 1.25 fish per net set. Unfortunately, the age 0 mark-recapture estimates show poor correlation with the age 0 CPUE calculations ($r^2 = 0.15$, N = 8 years). However, the annual Chapman Petersen abundance estimates of fall age 0 Humpback Chub show very good correlation to the annual Chapman Petersen abundance estimates of age 1 Humpback Chub the following spring ($r^2 = 0.91$, N = 8 years, Figure 15).

Bluehead and Flannelmouth Sucker

Bluehead Sucker and Flannelmouth Sucker (≥150 mm) abundance and trends in the LCR were estimated using Chapman Petersen mark-recapture, Monte Carlo simulation, and CPUE data from spring recapture trips when turbidities were low (Figure 16). Similar to Humpback Chub, Bluehead and Flannelmouth Sucker underwent a post-2006 period of significant increase, although this increase was of a lesser magnitude for Flannelmouth Sucker. Bluehead Sucker abundance and CPUE reached a peak in 2008, and since then have declined (15-A). Flannelmouth Sucker appeared to reach peaks in 2010 and again in 2018 (Figure 16-B). For May 2019, Bluehead Sucker CPUE was 0.9 (SE = 0.24) fish per net set and Flannelmouth Sucker CPUE was 0.36 (SE = 0.04). Using Monte Carlo simulation, we obtained an estimate of 30,794 (SE = 7,007) Bluehead Sucker ≥150 mm, and 3,913 (SE = 1,118) Flannelmouth Sucker ≥150 mm (Figures 16 A and B).

Results Chute Falls (rkm 13.57 to 17.7)

Physical Parameters

Turbidity and Temperature

Excluding two sampling days during 2015 and three sampling days during 2016 when some flooding occurred, average trip turbidities during the 2006-2018 Chute Falls monitoring trips were consistently low, ranging from 0.9-6.9 NTUs (mean = 2.6 NTUs, N = 17 trips), and were accompanied by base flows. For the 2019 trip, average turbidity in the Chute Falls reach was 36 NTUs (SE = 77). Average daily afternoon water temperature in 2019 at rkm 16.2 was 21.2 ^{o}C.

Length Frequency Distributions and Catch

Length frequencies demonstrate that Humpback Chub translocated to upstream of Chute Falls can remain upstream of Chute Falls and grow to adulthood (Figure 17-A). Most fish were ~80-130 mm at the time of their translocation. Immediately downstream of Chute Falls in the Atomizer reach, a sizeable number of Humpback Chub fall into the approximately 110-160 mm size class (Figure 17-B). Some of these fish represent Humpback Chub that vacated habitat upstream of Chute Falls after translocation, and some were likely the result of spawning in the Atomizer or Chute Falls reaches.

Parasites

Similar to spring trips in the lower 13.57 rkm, infestation rates of *Lernaea cyprinacea* on Humpback Chub in the Atomizer and Chute Falls reaches between 2006-2018 tended to be low, ranging from 0% to 6% (mean = 0.7%). The highest infestation rate was 6% in 2009. During May 2019, infestation rate was 0%, with no infested fish detected.

Population Abundance Estimation

The Chute Falls reach experienced a period of decline (2007-2008) in adult Humpback Chub ≥200 mm that followed no translocations in 2006 and 2007 (Figure 18-A). Translocations resumed in 2008 and this was followed by a higher abundance of adults by 2009. A prolonged spring flood accompanied by heavy sediment deposition and elimination of deep pools in early 2010 is thought to have resulted in a near absence of Humpback Chub in both the Chute Falls and Atomizer reaches during summer of 2010 (Figures 18-A and 18-B). Translocations continued from 2010-2019, again resulting in an increase in abundance of adult Humpback Chub upstream of Chute Falls through 2019 (Figure 18-A) as deep pool habitat returned. On 24 October 2019, 306 juvenile Humpback Chub (range 52-94 mm) were translocated to upstream of Chute Falls (Pillow and Williams 2020).

For May 2019, it was estimated that there were 349 (SE = 44) Humpback Chub ≥100 mm in the Chute Falls reach, of which 263 (SE = 33) were ≥200 mm. For 2019 in the Atomizer reach, it was estimated that there were 587 Humpback Chub ≥100 mm (SE = 26), of which 416 (SE = 20) were ≥200 mm. The capture of 27 unmarked chub (85-228 mm) above Chute Falls in 2019 suggests spawning might be occurring above Chute Falls. Additionally, there was high correlation for the Atomizer and Chute Falls reaches combined between the annual Chapman Petersen abundance estimates (2006-2009) and the annual Monte Carlo simulation abundance estimates (2006-2009), both for Humpback Chub ≥100 mm ($r^2 = 0.90$, N = 8) and for Humpback Chub ≥200 mm ($r^2 = 0.93$, N = 8), respectively.

Discussion

Lower 13.57 rkm of the LCR

Population estimates of Humpback Chub indicate that sometime between the early 1990s and 2000 the abundance of adult Humpback Chub (≥200 mm) underwent a significant decline in the LCR (Coggins et al. 2006). This was followed by a period of relatively low but stable abundance between 2000 and 2006, and by a 2007-2014 period when abundance levels significantly increased again (Van Haverbeke et al. 2013). The post-2006 increases in Humpback Chub ≥150 mm and ≥200 mm are visible during both spring and fall seasons, but are more apparent during spring (Figures 12-A and 12-B). The significant decline in the 2011 spring abundance of Humpback Chub ≥150 mm (Figure 12-A) may be a result of relative low production of age 0 fish during 2009 as suggested by Figure 14-B.

Spring 2015 and 2016 saw a significant lowering of abundance of Humpback Chub ≥150 mm and ≥200 mm compared to the previous several years. This decline was particularly visible during the spring seasons. The cause of this apparent decline remains uncertain, but unusually high CPUEs in the mainstem Colorado River near the LCR in fall 2015 and 2016 (M. Dodrill, pers. com.) suggested that a high proportion of chub may have emigrated into the mainstem and may not have returned to the LCR during these years. This may have been caused by poor condition factor, possibly caused by depressed food resources (C. Yackulic, pers. com.). Regardless, the spring seasons of 2017-2019 witnessed a significant increase in the abundance of Humpback Chub ≥150 mm and ≥200 mm, approaching or exceeding levels seen during the 2007-2014 period.

There is considerable annual variation in the spring abundance estimates of sub-adult Humpback Chub 150-199 mm (Figure 13). Since 2007 there have only been four years (2008, 2011, 2015 and 2016) in which the spring abundance estimate for this size class dropped below 1,250 fish (Figure 13). This is important because the Biological Assessment (USBR 2016) and the Biological Opinion (USFWS 2016) for the Glen Canyon Dam Long-Term Experimental and Management Plan set forth triggers under which additional conservation measures would occur in order to minimize the likelihood for mechanical predator removal. One of the trigger criteria is maintaining a running three-year average of 1,250 sub-adults in the LCR during the spring spawning season (USBR 2016). The mean Chapman Petersen spring estimate for Humpback Chub in the sub-adult category (150-199 mm) during spring in the LCR for the past 3 years (2017-2019) was 2,510 fish.

Concerning juvenile Humpback Chub <150 mm, both the mark-recapture estimates and CPUE indices suggest high annual variability in abundance of the fall 40-99 mm size class (age 0) and the spring 100-149 mm (largely age 1) size class of Humpback Chub (Figures 14-B and 14-A, respectively). Despite this annual variability, there was high correlation between the abundance of age 0 chub in the fall and the abundance of age 1 chub the following spring ($r^2 = 0.89$, N = 9 years; Figure 15), suggesting that much of the variability of age 0 outmigration to the mainstem may occur during the summer monsoon period prior to our fall sampling efforts. Annual variation in the abundance of the fall age 0 cohort is thought to stem from springtime hydrology of the LCR and cleansing of spawning substrate materials (Van Haverbeke et al. 2013). High spring runoff cleans marl and silt from the system, exposing gravels, which may be more favorable for Humpback Chub spawning habitat. Notable for 2019 was the high production of age 0 Humpback Chub. Between the end of August 2018 and into May 2019 the LCR received a substantial amount of runoff above base flow, which appeared to clean substrates of thick depositions of marle during the spring spawning season (D. Van Haverbeke, pers. obs.), and likely led to the high production of age 0 Humpback Chub.

One reason for estimating the abundances of the juvenile cohorts is to gain insight into what percentages of these fish are being harvested (cropped) each year for various translocation projects and for maintaining a refuge at SNARRC. Beginning in 2014, chub cropped for translocation activities outside of the LCR have been harvested as larval fish (<30 mm), thus alleviating concerns about potential overharvesting of age 0 chub (Pine et al. 2013). In June 2019, approximately 650 larval Humpback Chub were collected and transported to SNARRC to for purposes of supplementing the genetic refuge of Humpback Chub at SNARRC, and for a future tanslocation, likely into Bright Angel Creek (Healy 2019).

Both abundance and relative abundance (CPUE) of Bluehead Sucker and Flannelmouth Sucker ≥150 mm significantly increased in the post-2006 timeframe during the spring spawning season (Figure 16), with Bluehead Sucker reaching peak abundance in 2008 and Flannelmouth Sucker reaching peak abundances in 2010 and 2018. These data suggest that Bluehead Sucker can become very abundant in the LCR during the spring spawning season, reaching peak abundances into the tens of thousands, whereas Flannelmouth Sucker are less numerous, reaching peak abundances of only several thousand individuals. In May 2010 we saw an outbreak of fungus on many Bluehead Sucker, with dead suckers seen in nets and along the shorelines (Van Haverbeke, pers. obs.). Bluehead Sucker catches have been about 12-fold lower during the fall season, suggesting mass annual emigration for this species from the LCR to the mainstem. It is possible that movement of Bluehead Sucker in and out of the LCR between April and May might be inflating their abundance estimates in some years (e.g., 2007-2009), but CPUE also tracked high in those years. Finally, because few age 0 suckers are captured in the fall season, this may indicate that both sucker species tend to drift as larvae and emigrate from the LCR before the onset of the fall season (see Robinson et al. 1998).

Chute Falls (rkm 13.57-17.7)

Since 2003, ~3,776 juvenile Humpback Chub have been translocated from the lower reaches of the LCR to upstream of Chute Falls and have been found to grow to adulthood, although not all translocated chub have remained upstream of Chute Falls. Most have either eventually moved into the short Atomizer reach immediately below Chute Falls, or moved further downriver (below Lower Atomizer Falls). A few have been recaptured in the mainstem Colorado River. Between summer of 2009 and summer 2010, nearly all Humpback Chub vacated the Chute Falls and Atomizer reaches (Figure 18), as well as the upper portion of Salt reach (12.3 to 13.57 km). It is thought that this was a result of a prolonged spring flood during 2010 that deposited a heavy sand load in the upper reaches of the LCR, filling in much of the available deep pool habitat. This phenomenon may explain why there were no Humpback Chub upstream of Chute Falls prior to the translocation efforts. High environmental stochasticity causing emigration in this section of river may over-ride lower colonization rates. Since 2003, only eight chub have been documented ascending Chute Falls on their own accord. With the re-commencement of translocation activities in 2010, Humpback Chub have again been found to remain and grow to adulthood in the upper and lower reaches of Chute Falls. The capture of 27 unmarked chub (85-228 mm) above Chute Falls in 2019 suggests spawning might be occurring above Chute Falls.

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Table 1. List of reaches, subreaches, and river kilometers within each subreach; Little Colorado River.

Sub-reach	Reach	River km (range)
	Boulders	
Confluence-Jump Off Rock		0.0-1.8
Jump Off Rock-Powell Pool		1.8-3.0
Powell Pool-5.0 rkm		3.0-5.0
	Coyote	
5.0 rkm - White Spot (Kachina Falls)		5.0-6.5
White Spot-Redbud Canyon		6.5-8.0
Redbud Canyon-House Rock		8.0-9.6
	Salt	
House Rock-Hell Hole		9.6-11.2
Hell Hole-Triple Drop		11.2-12.3
Triple Drop-Lower Atomizer Falls		12.3-13.57
	Chute Falls	
Lower Atomizer Falls-Chute Falls		13.57-14.1
Chute Falls-17.7 rkm		14.1-17.7

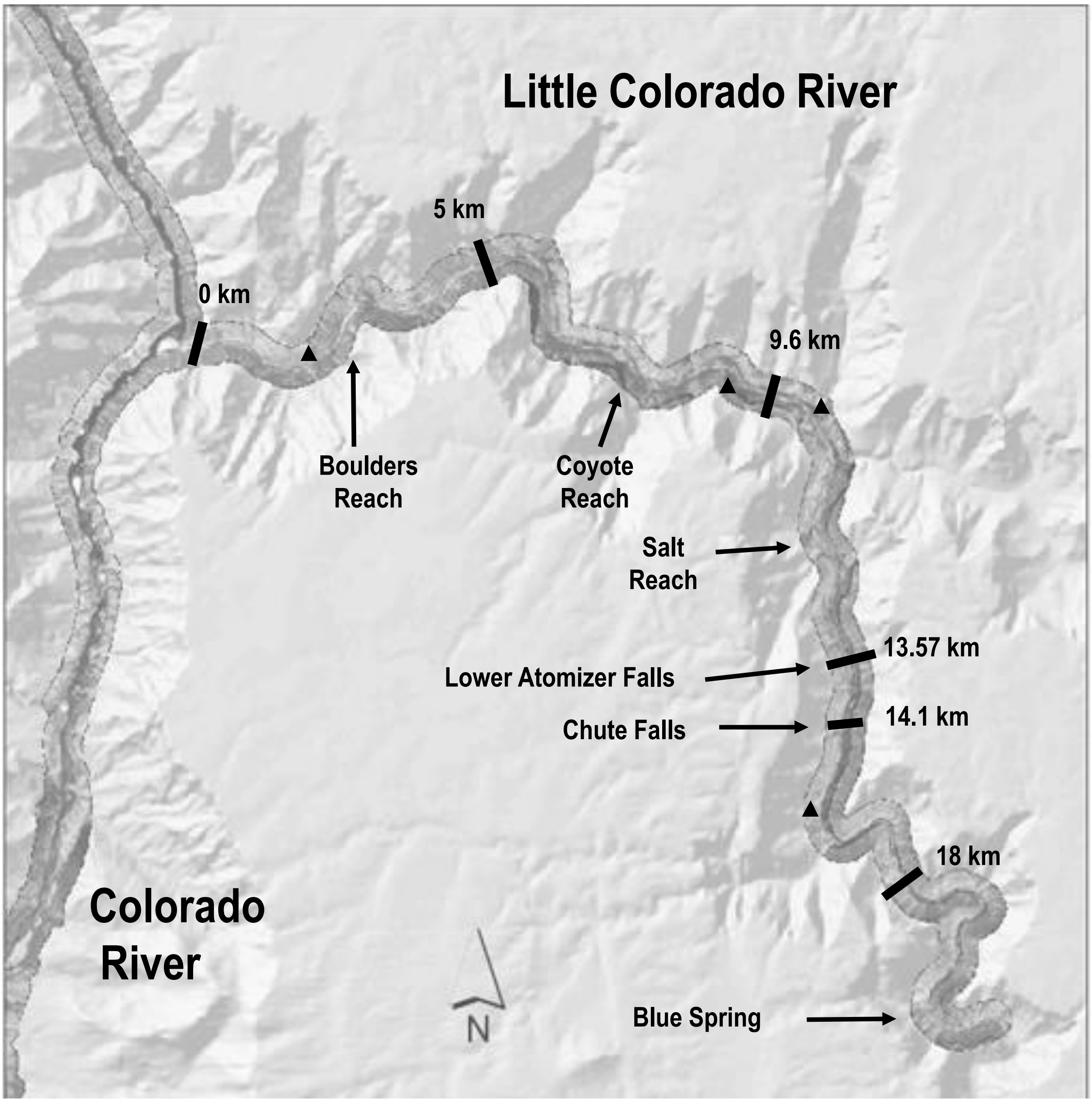


Figure 1. Map of study areas, showing Boulders (river km [rkm] 0 to 5), Coyote (rkm 5 to 9.6) and Salt (rkm 9.6 to 13.57) reaches, and lower Chute Falls (rkm 13.57 to 14.1) and upper Chute Falls (rkm 14.1 to 17.7) reaches; Little Colorado River. Camps are designated by triangles.

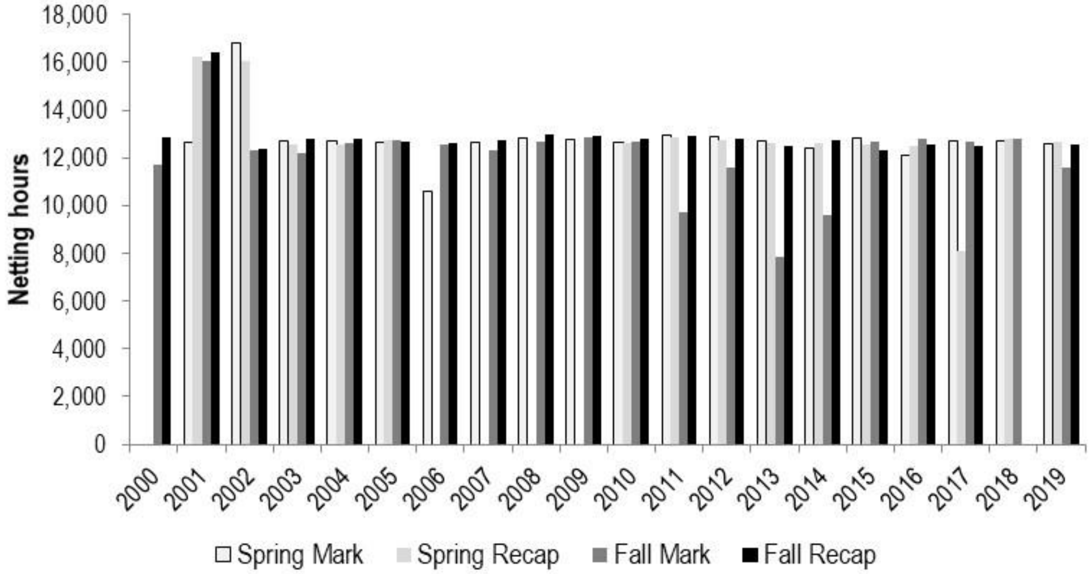


Figure 2. Hoop net sampling effort (hours) across all spring and fall monitoring trips 2000 to 2019 in lower 13.57 river km of the Little Colorado River.

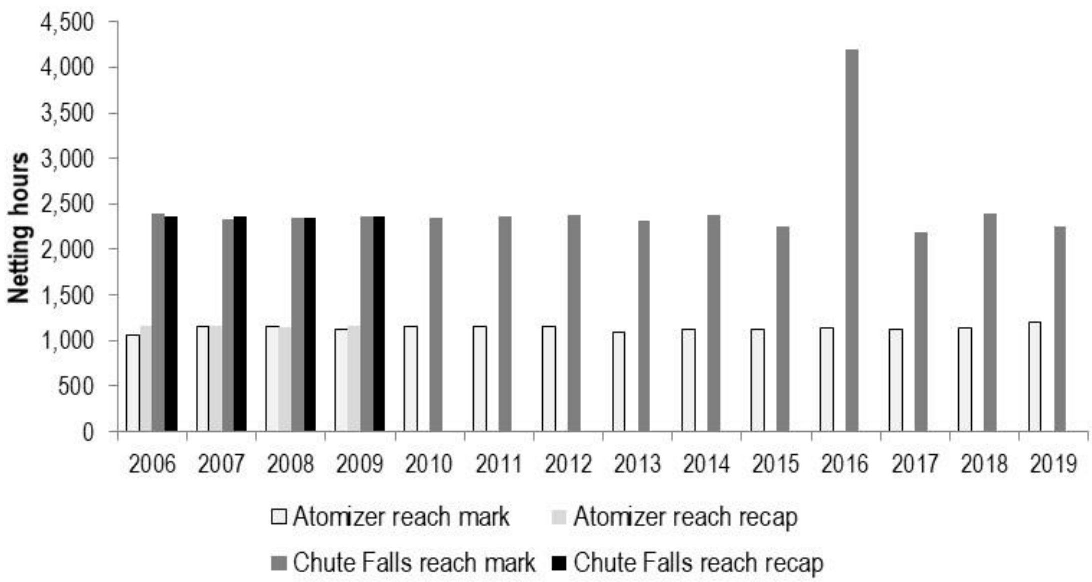


Figure 3. Hoop netting effort (hours) in the Atomizer and Chute Falls reaches during monitoring efforts between 2006 and 2019, Little Colorado River. Note: Atomizer reach extended from Lower Atomizer Falls (river km 13.57) to Chute Falls (river km 14.1). Chute Falls reach extended from top of Chute Falls (river km 14.1) to river km 17.7. Both reaches included a mark and recapture event from 2006-2009, but thereafter these reaches only included one trip per year.

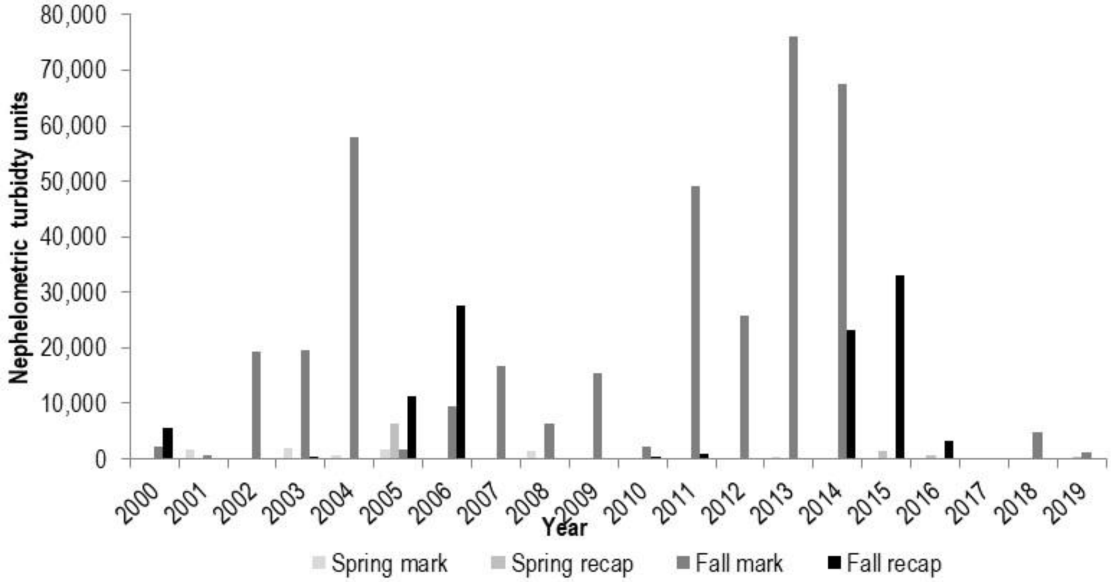


Figure 4. Average trip turbidities (nephelometric turbidity units, NTU) during spring and fall mark-recapture trips in the Little Colorado River, 2000-2018. Note, daily turbidity readings were taken on each trip. “Missing” bars represent low trip turbidities (most < 54 NTUs), not missing data.

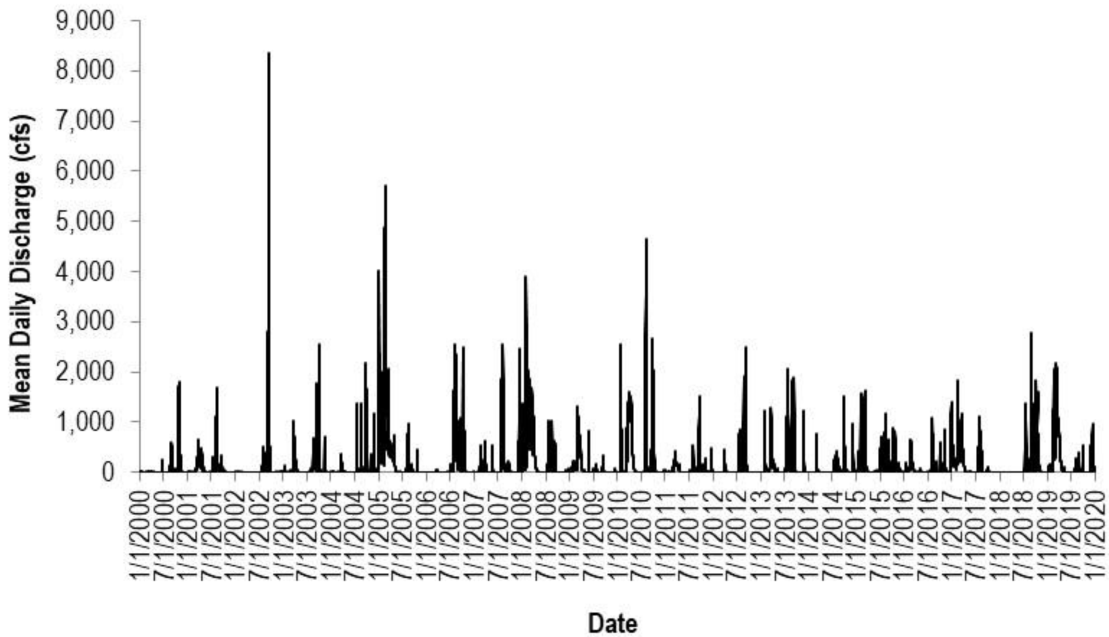


Figure 5. Provisional mean daily discharge (cubic feet/second; cfs) from USGS gage station 0940200; Little Colorado River (LCR), Arizona, 1 January 2000 – 1 January 2020.

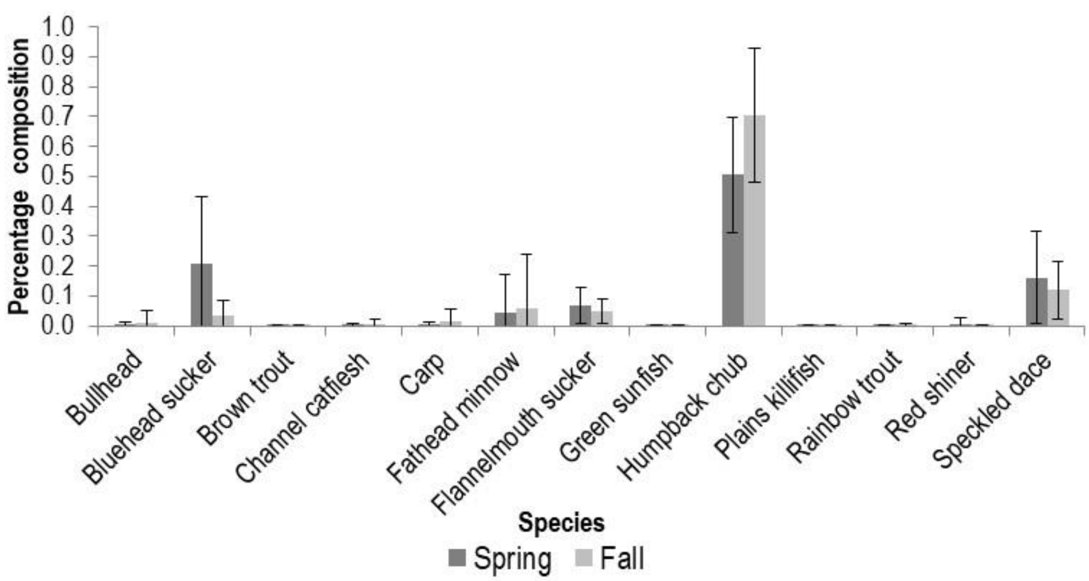
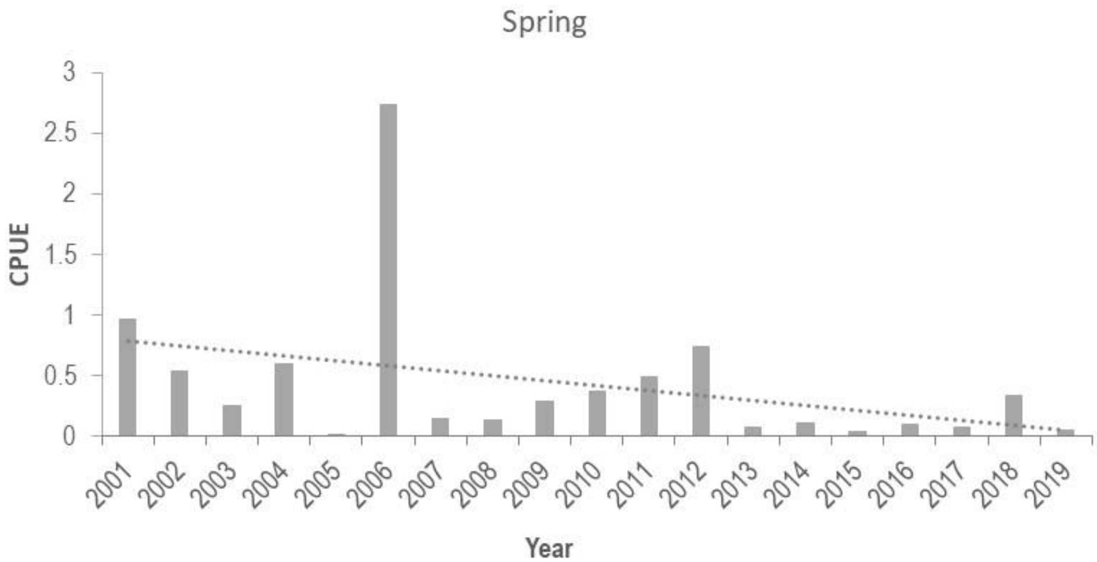


Figure 6. Observed spring and fall species composition (±95% CI) of fish captured in hoop nets between fall 2000 and fall 2019; Little Colorado River (river km 0-13.57, N = 208,243 fish).

A.



B.

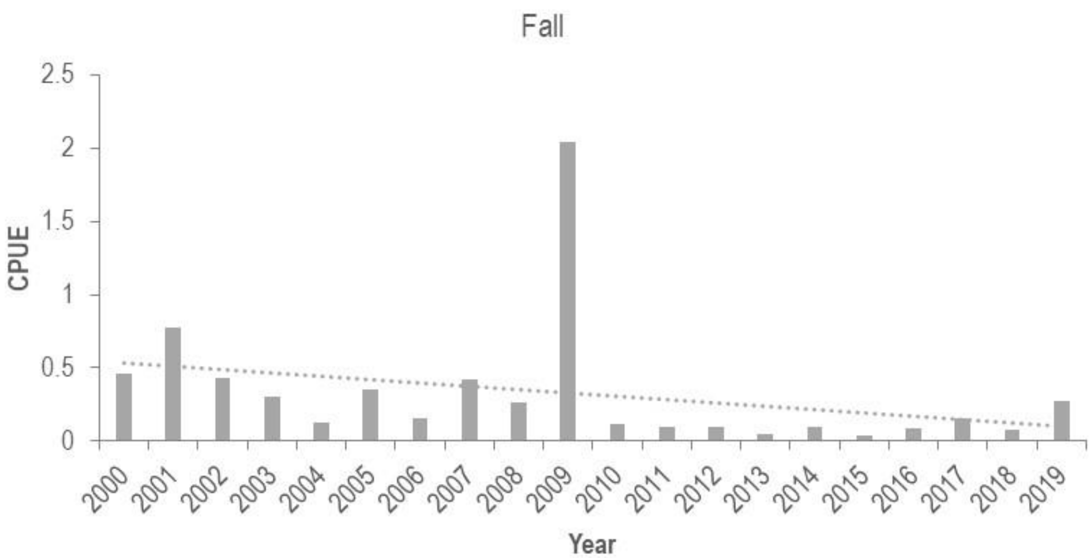
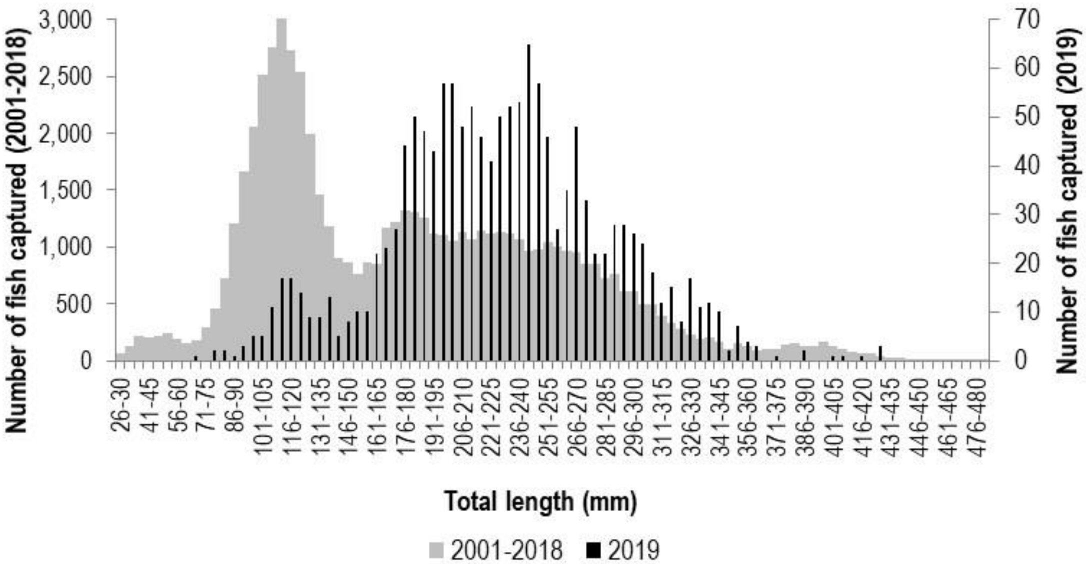


Figure 7. Catch per unit effort (CPUE, fish/net) of non-native fish species in the lower 13.57 km of the Little Colorado River during A) spring and B) fall seasons. Note: dotted lines are linear trend lines.

A.



B.

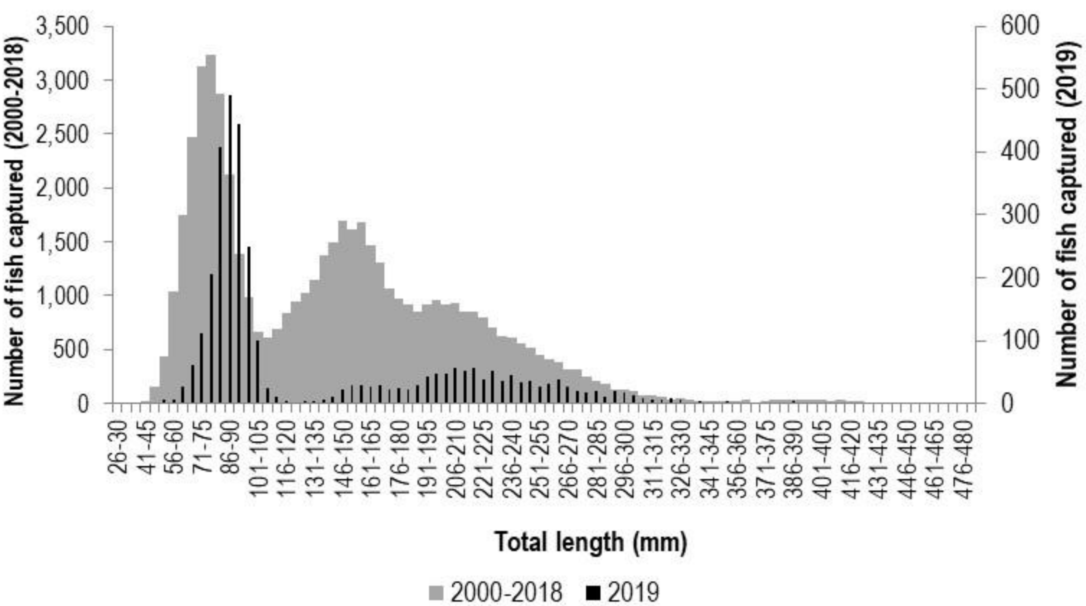
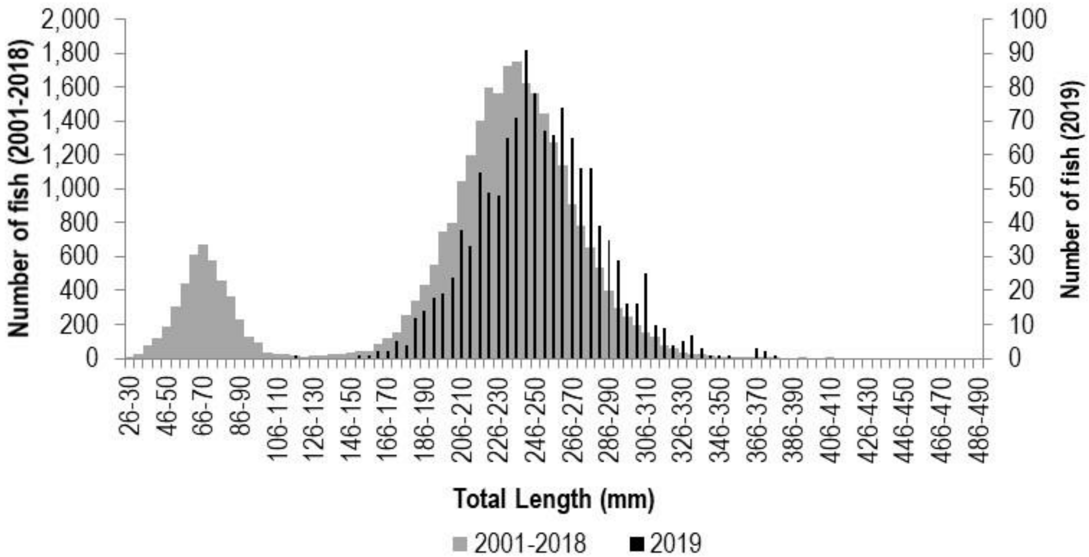


Figure 8. Length frequency distributions of Humpback Chub captured in the Little Colorado River (river km 0-13.57) during (A) spring 2001-2018 and 2019 and (B) fall 2000-2018 and 2019.

A.



B.

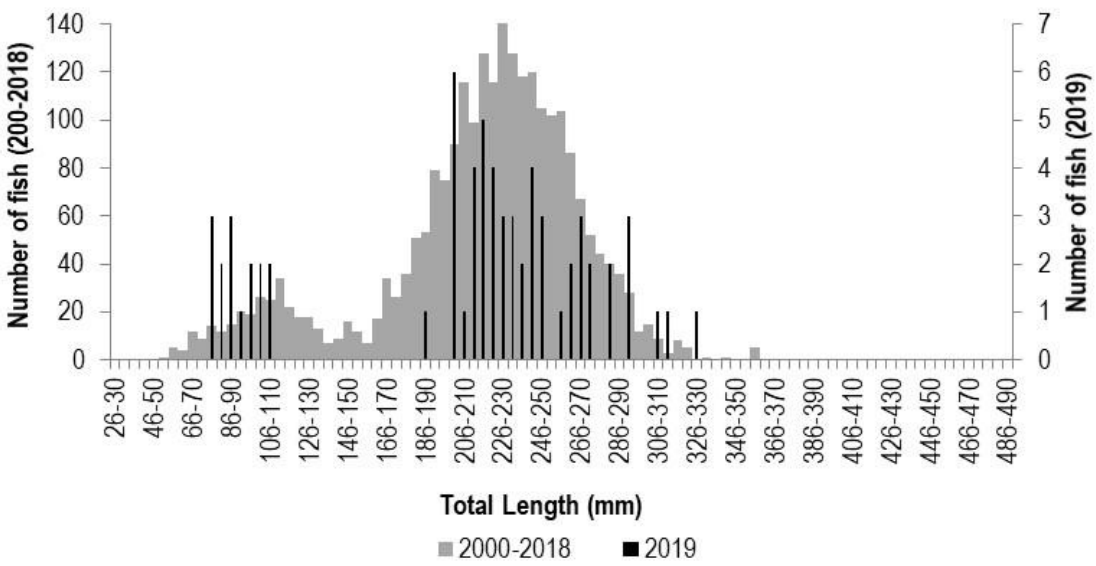
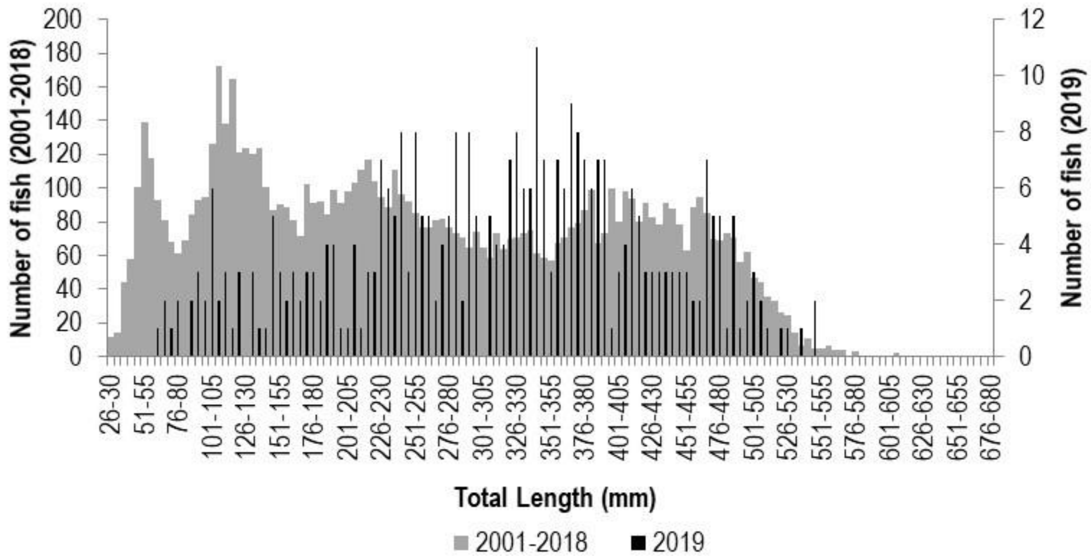


Figure 9. Length frequency distributions of Bluehead Sucker captured in the Little Colorado River (river km 0-13.57) during (A) spring 2001-2018 and 2019 and (B) fall 2000-2018 and 2019.

A.



B.

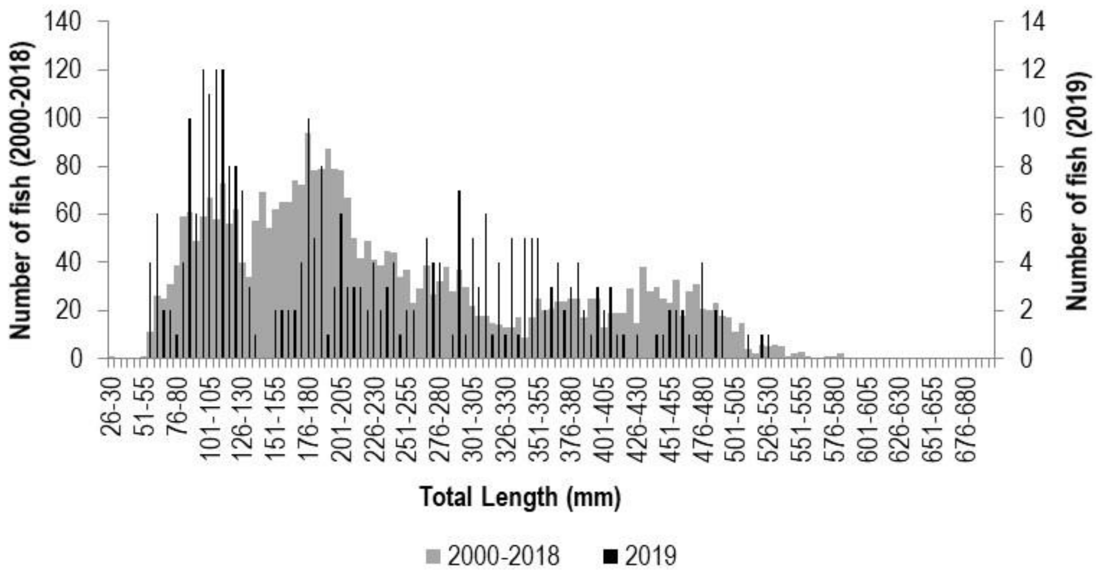


Figure 10. Length frequency distributions of Flannelmouth Sucker captured in the Little Colorado River (river km 0-13.57) during (A) spring 2001-2018 and 2019 and (B) fall 2000-2018 and 2019.

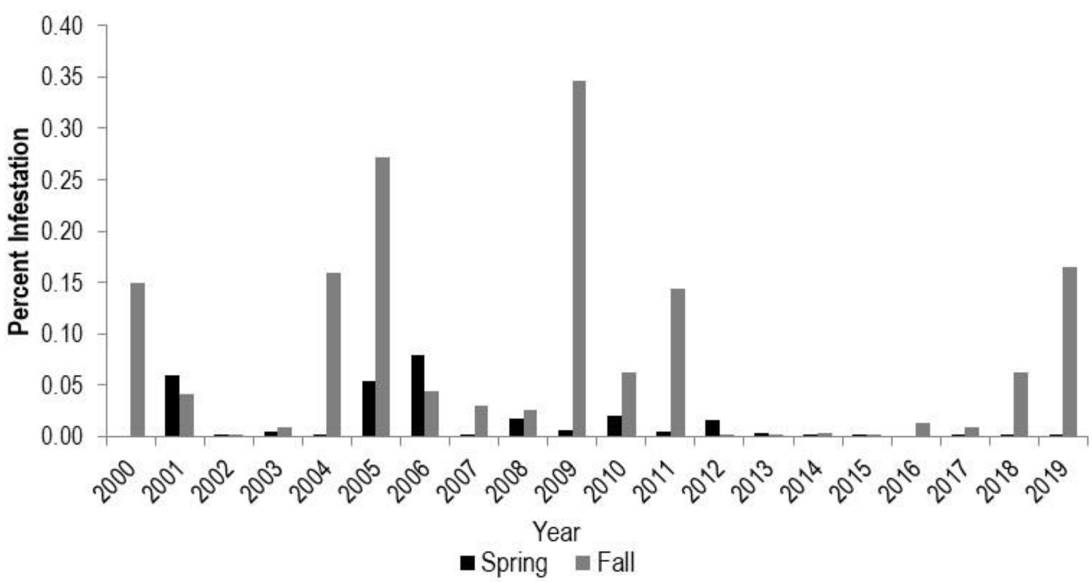
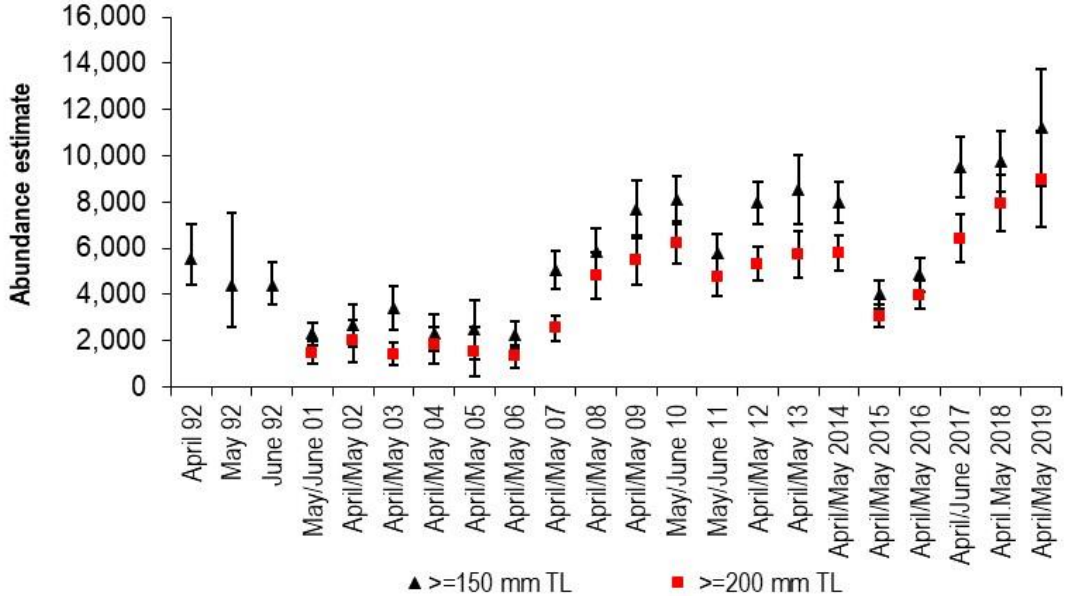


Figure 11. Percent occurrence of the external copepod parasite (*Lernaea cyprinacea*) on Humpback Chub in the Little Colorado River (river km 0-13.57), 2000-2019.

A.



B.

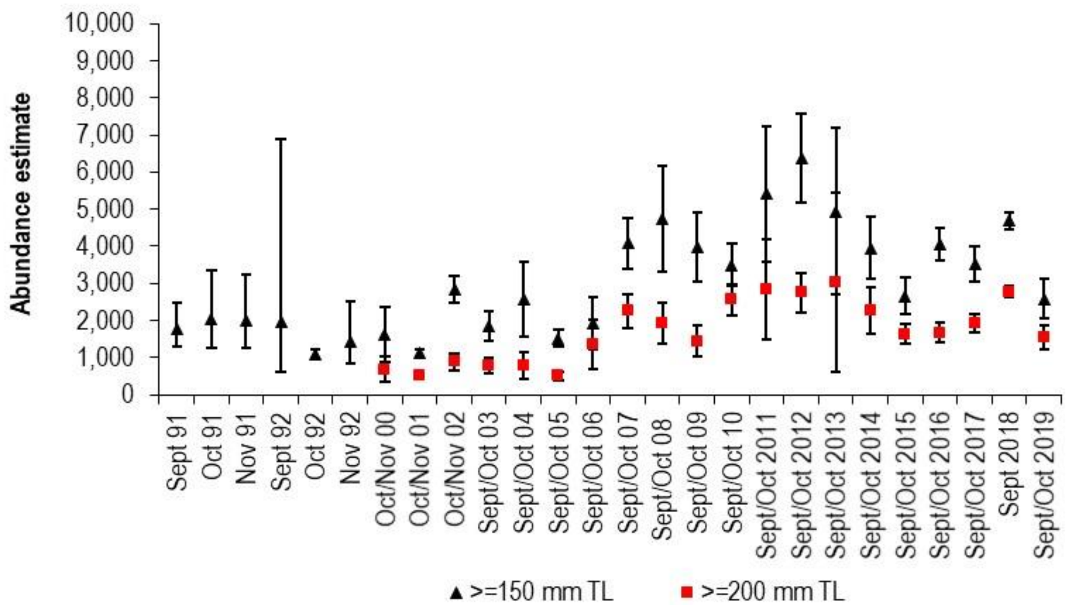


Figure 12. Chapman Petersen abundance estimates (±95% CI) of Humpback Chub ≥150 mm and ≥200 mm in the Little Colorado River (0-13.57 river km) during (A) spring (2001-2019) and (B) fall seasons (2000-2019). Note: closed spring and fall abundance estimates of Humpback Chub >150 mm in the Little Colorado River during 1991 and 1992 are from Douglas and Marsh (1996). Note: the fall 2018 estimates were calculated using capture probability data and Monte Carlo simulation (see Methods).

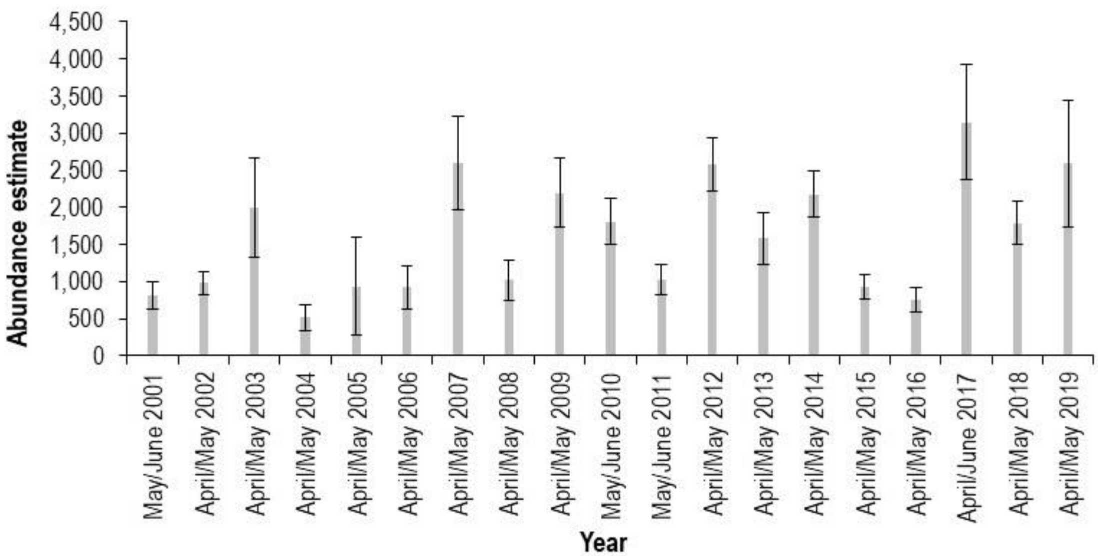
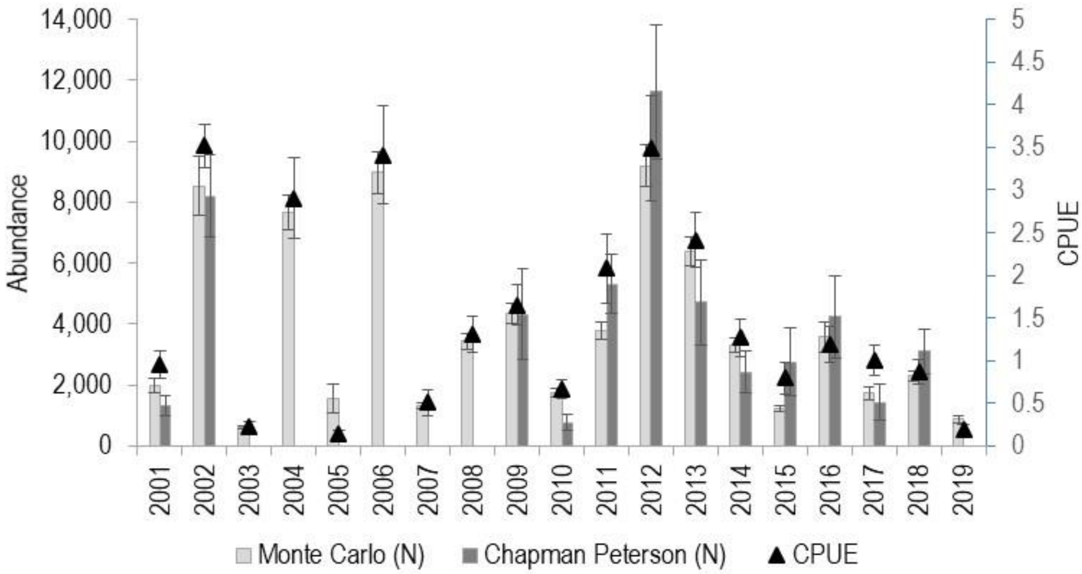


Figure 13. Chapman Petersen spring abundance estimates (±95% CI) of Humpback Chub in the 150-199 mm size category; Little Colorado River (0-13.57 river km), 2001-2019.

A.



B.

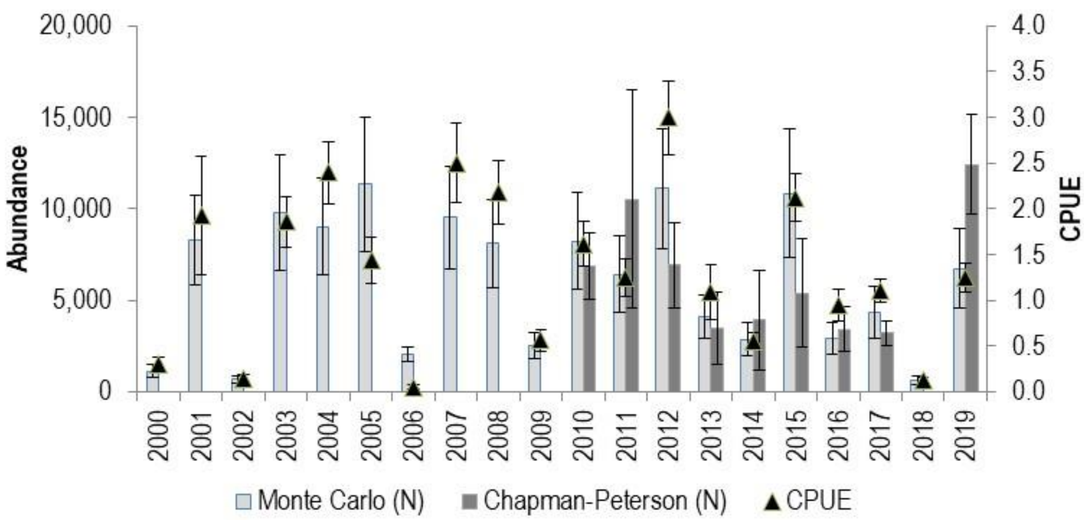


Figure 14. (A) Spring season Chapman Petersen abundance estimates (±95% CI), Monte Carlo simulated abundance estimates (±95% CI), and catch per unit effort (CPUE, ±95% CI), of Humpback Chub (HBC) in the 100-149 mm size class (largely age 1). (B) Fall season Chapman Petersen abundance estimates (±95% CI), and CPUE (±95% CI), of HBC in the 40-99 mm size class (age 0); Little Colorado River (0-13.57 river km). Note: Chapman Petersen abundance estimates were not performed in all years.

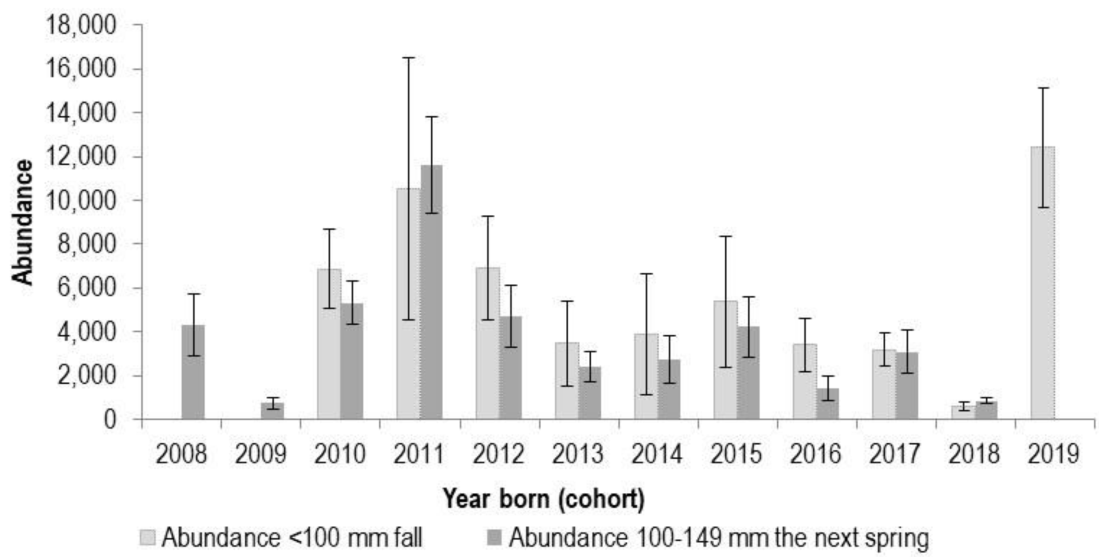
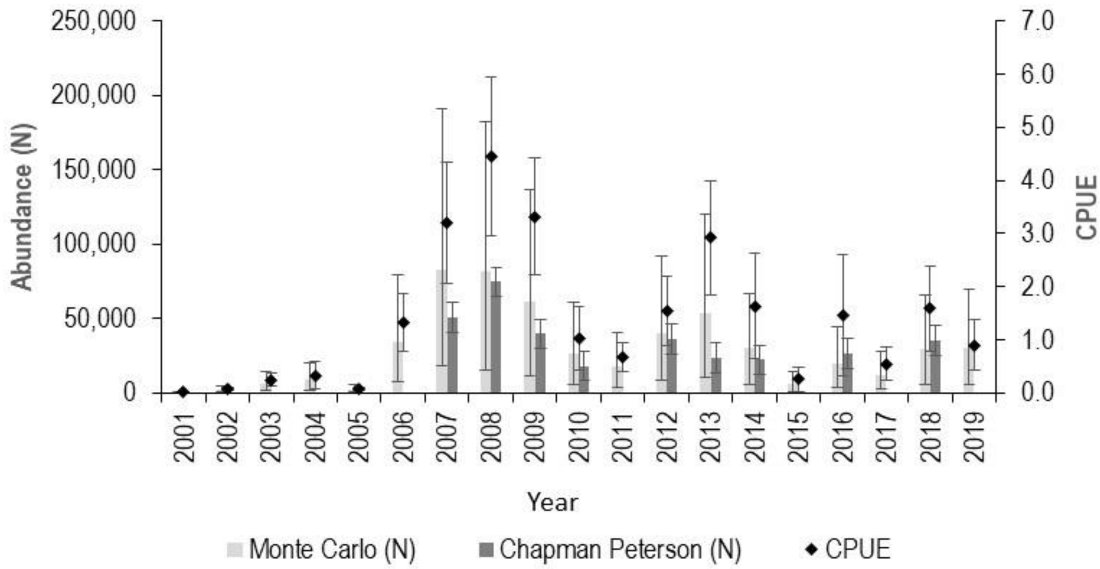


Figure 15. Annual abundances of Humpback Chub <100 mm (age 0 fish) during the fall, and abundances of Humpback Chub 100-149 mm (predominantly age 1 fish) the following spring, Little Colorado River (0-13.57 river km).

A.



B.

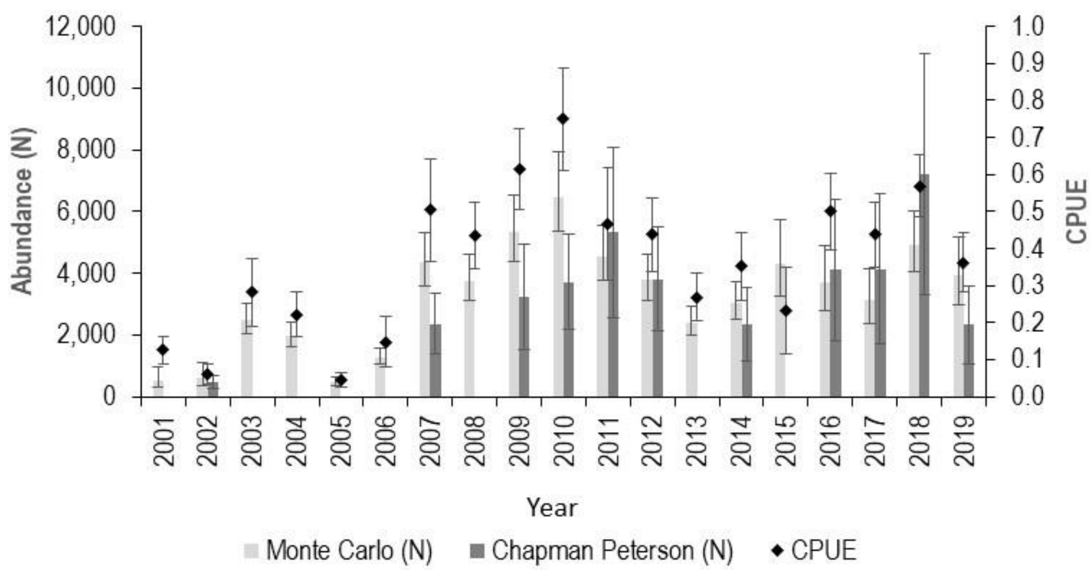
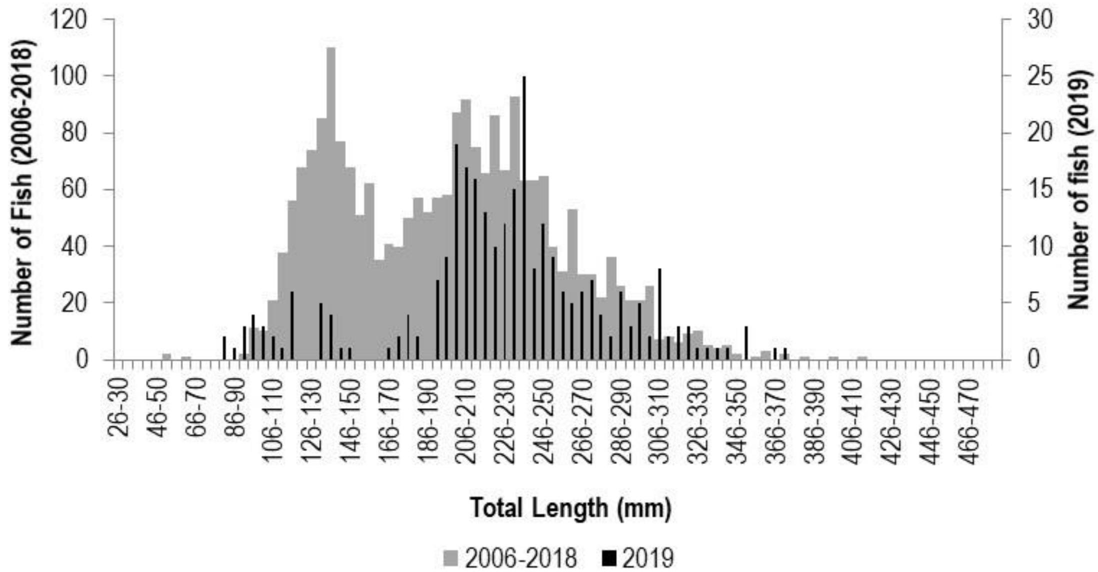


Figure 16. (A) Spring season Chapman Petersen abundance estimates (±95% CI), Monte Carlo simulated abundance estimates (±95% CI), and catch per unit effort (CPUE, ±95% CI), of Bluehead Sucker ≥150 mm, and (B) Flannelmouth Sucker; Little Colorado River (0-13.57 river km). Note: Chapman Petersen abundance estimates were not performed in all years.

A.



B.

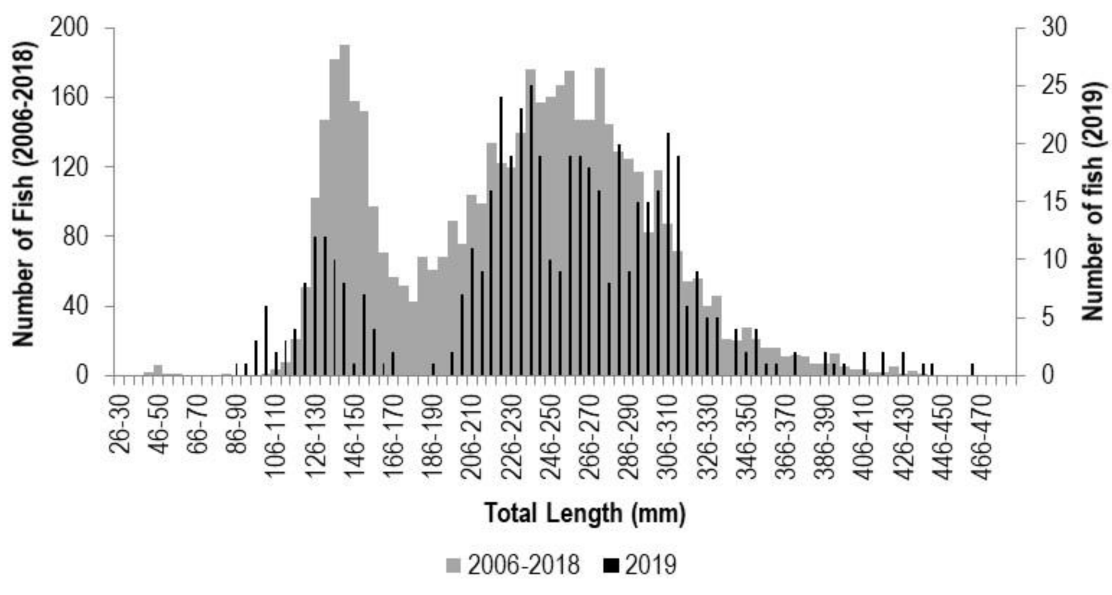
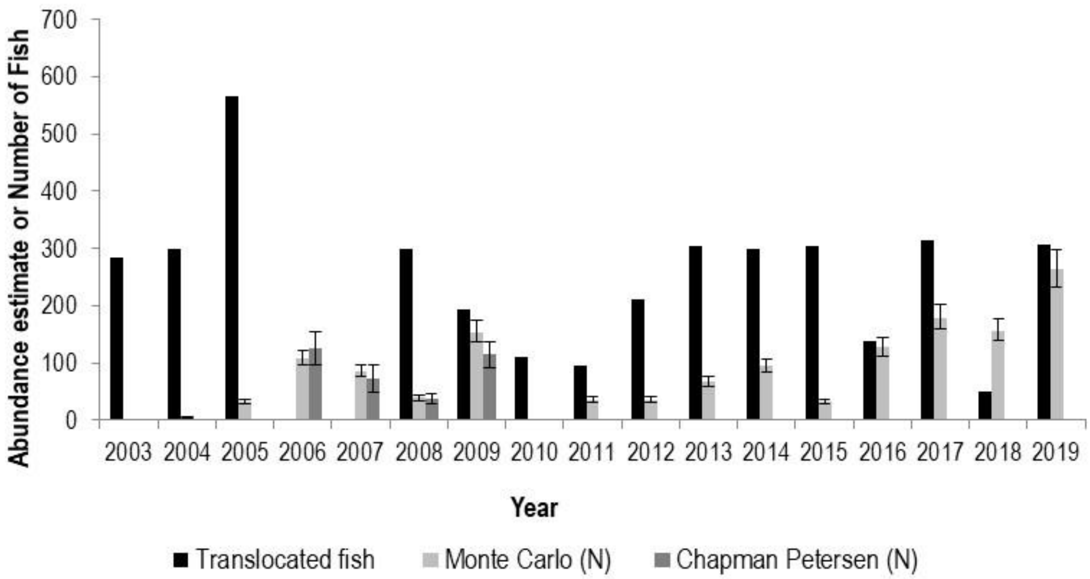


Figure 17. Length frequency distributions of unique Humpback Chub captured A) Chute Falls reach (river km 14.1-17.7), and B) Atomizer reach (river km 13.57-14.1) during Chute Falls monitoring trips 2006-2018, and 2019; Little Colorado River.

A.



B.

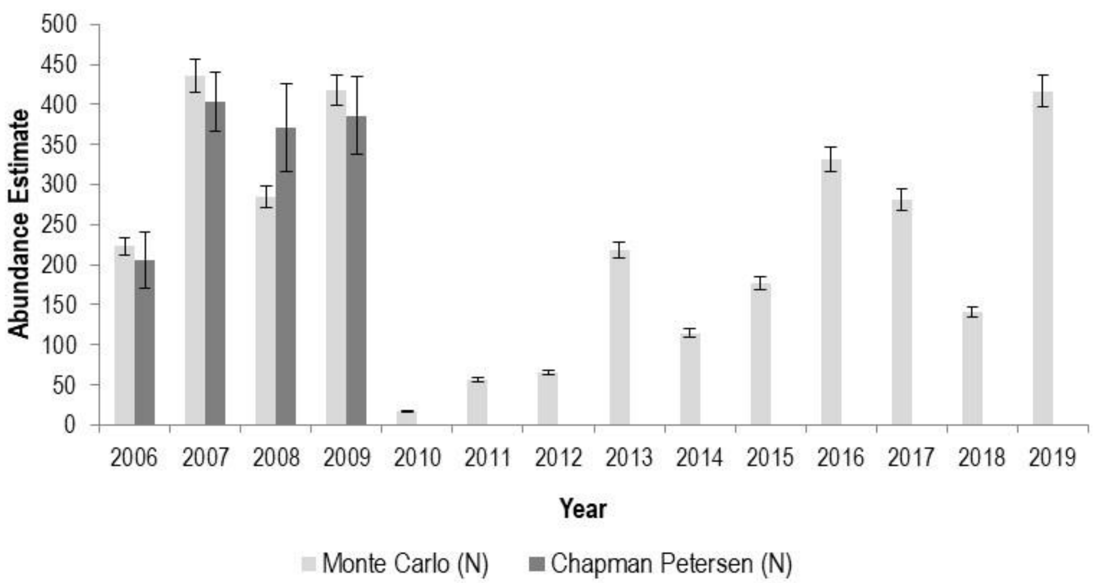


Figure 18. (A) Numbers of Humpback Chub that have been translocated to the Chute Falls reach since 2003 (black bars); and abundances (±95% CI) calculated with Chapman Petersen method (dark grey bars), and Monte Carlo simulation (light grey bars) of adult Humpback Chub (≥ 200 mm) in the Chute Falls reach (river km 14.1-17.7), and (B) abundances (±95% CI) calculated with Chapman Petersen method (dark grey bars) and Monte Carlo simulation (light grey bars) of adult Humpback Chub in the Atomizer reach immediately downstream of Chute Falls (river km 13.57–14.1); Little Colorado River.