# Long-Term Monitoring of an Endangered Desert Fish and Factors Influencing Population Dynamics

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## Abstract

The lower perennial corridor of the Little Colorado River in Grand Canyon, Arizona, is numerically dominated by endemic desert fishes and therefore significant for conservation of these species. From 2000 to 2012, the U.S. Fish and Wildlife Service conducted monitoring of native fishes in the Little Colorado River near its confluence with the Colorado River. The primary focus of these efforts was to estimate the spring and fall abundance of native fishes, especially the federally endangered humpback chub *Gila cypha*. Because humpback chub in Grand Canyon are influenced by operations of Glen Canyon Dam, our efforts provide managers of the Glen Canyon Dam Adaptive Management Program with abundance estimates and trends of humpback chub in the Little Colorado River, the most important tributary in Grand Canyon for spawning and production of this species. From 2001 to 2006, the spring abundance estimates of humpback chub ≥150 and ≥200 mm remained relatively low (≤3,419 and ≤2,002 fish, respectively), thereafter significantly increasing to highs of 8,083 and 6,250, respectively, by spring 2010. Also from 2000 to 2006, the fall abundance estimates of humpback chub were substantially below those abundances estimated after 2006. In addition, flannelmouth sucker *Catostomus latipinnis* and bluehead sucker *Catostomus discobolus* showed post-2006 increases in relative abundance, suggesting a systemwide event occurred that was beneficial to native fishes. Most of the increases of humpback chub occurred during the spring season in the reaches of the Little Colorado River between 5 and 13.57 km upstream from the confluence. Successful production of age 0 year classes of humpback chub may be partially driven by hydrograph dynamics of the Little Colorado River, whereas water temperatures and predation pressures in the mainstem Colorado River likely influence survivorship of native fishes into subadult and adult life stages.

Keywords: humpback chub; *Gila cypha*; mark–recapture; Little Colorado River; Grand Canyon; desert rivers and streams

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## Introduction

The humpback chub *Gila cypha* (Figure 1) was described by Miller (1946) from a specimen taken near the mouth of Bright Angel Creek, Grand Canyon National Park, Arizona, and was included on the first list of federally endangered species (U.S. Fish and Wildlife Service [USFWS] 1967; US Endangered Species Act [ESA 1973, as amended]). Six populations of humpback chub are recognized, five in the upper Colorado River basin above Lake Powell, and one in Grand Canyon (USFWS 2002). Of these populations, the Grand Canyon population is the largest (USFWS 2002). Critical habitat for the species comprises 610 km of the Colorado River system,


**Figure 1.** Photographs of humpback chub *Gila cypha* taken between 2000 and 2012 in Little Colorado River. (**A**) Age 0 chub. (**B**) Subadult chub. (**C**) Adult in breeding colors. (**D**) Large adult chub. Photo credits USFWS.

including 13 km of the Little Colorado River (LCR) and 280 km of the Colorado River in Grand Canyon (USFWS 1994). Recovery Goals were developed (USFWS 2002) to supplement and amend the 1990 recovery plan (USFWS 1990). In Grand Canyon, status of humpback chub is of interest to the Glen Canyon Dam Adaptive Management Program, a multi-stakeholder federally chartered program resulting from the Glen Canyon Dam Environmental Impact Statement (USBR 1995) and tasked with defining management objectives and policy options downstream of Glen Canyon Dam.

Humpback chub are morphologically unique fish endemic to the Colorado River system (Minckley 1973). Early studies on chub in Grand Canyon began in the 1970s and focused on morphology (Suttkus and Clemmer 1977), life history, and ecology (Kaeding and Zimmerman 1983; Minckley 1996). In Grand Canyon, chub are potadromous, with adults typically migrating from nearby areas in the Colorado River to the LCR to spawn during early spring (Douglas and Marsh 1996; Gorman and Stone 1999). Young rear in the LCR and many remain 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 primary LCR population, there are several small aggregations of chub inhabiting the mainstem Colorado River in Grand Canyon (Valdez and Ryel 1995). With few exceptions, postdam mainstem reproduction in these other aggregations is absent (Valdez and Masslich 1999; Anderson et al. 2010), and exchange of individuals from these aggregations to the LCR is limited (Paukert et al. 2006). 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 incubation period, egg and larval survival, larval-to-juvenile transition time, and growth of chub (Hamman 1982; Clarkson and Childs 2000; Robinson and Childs 2001). These factors are considered to have caused range contraction and decreases in abundances of chub in Grand Canyon (Kaeding and Zimmerman 1983; Douglas and Marsh 1996; USFWS 2002). Because of the need to conserve and recover this unique and relict species, several studies have focused on population abundance of the LCR population (Douglas and Marsh 1996; Coggins et al. 2006; Coggins and Walters 2009; Van Haverbeke 2010).

In Grand Canyon, the LCR (Photo S1, *Supplemental Material*) is the largest tributary and primary spawning ground for humpback chub (Douglas and Marsh 1996;

Gorman and Stone 1999). The LCR also provides important spawning ground for native speckled dace *Rhinichthys osculus*, flannelmouth sucker *Catostomus latipinnis*, and bluehead sucker *Catostomus discobolus,* although these three species also spawn in other tributaries in Grand Canyon (e.g., Maddux and Kepner 1988; Douglas and Douglas 2000).

The LCR encompasses a basin of about 69,000 km$^2$ in eastern Arizona and western New Mexico, with its perennial headwaters arising near Mt. Baldy, Arizona. Below St. Johns, Arizona, the river becomes intermittent throughout most of its remaining river corridor (Stone et al. 2007). It becomes perennial again approximately 21 km above the confluence with the Colorado River at Blue Spring, and along with several other springs, discharges ~6.31 m$^3$/s of bicarbonate-laden spring water (Cooley 1976). Typically, the lower LCR experiences some flooding during early spring because of snowmelt higher in the watershed, and it is prone to sudden and dramatic flood events during late summer and fall because of monsoonal rains. These flood events can alter sediment load and temperature, and they can transport juvenile fish into the Colorado River. Compared with the Colorado River where release temperatures from Glen Canyon Dam are usually $<12\,^{\circ}$C (Wright et al. 2009), the LCR can reach summer temperatures exceeding 25 °C and is conducive for reproduction of native fishes.

Because the LCR is of such importance for native fish in Grand Canyon, this project serves as the core monitoring and data collection effort used to infer status of native fish in Grand Canyon. As such, this project informs decisions regarding Endangered Species Act compliance and recovery issues, management decisions concerning operations of Glen Canyon Dam, and other management actions (e.g., control of nonnative fishes; USFWS 2011). In addition, alternative assessment models aimed at estimating longer term abundance trends in the entire LCR humpback chub population rely heavily on data collected in this project (Coggins et al. 2006; Coggins and Walters 2009). Finally, information collected on smaller size classes of humpback chub informs humpback chub translocation efforts to other tributaries in Grand Canyon and contributes to research on movement and survival of juveniles into the mainstem Colorado River in response to management actions.

This article summarizes more than a decade of monitoring in the lower 13.57 km of the LCR by USFWS from fall 2000 to fall 2012. One of our primary objectives is to provide managers with abundance estimates and trends of subadult (150–199 mm) and adult (≥200 mm) humpback chub in the LCR and to contribute to a further understanding of the fish community in the LCR. We present abundances of chub within reaches of the LCR to illustrate relative importance of habitat for spawning and overwintering. We track relative abundance (catch per unit effort) of bluehead sucker and flannelmouth sucker during their migratory spring spawning run into the LCR, as well as age 0 year (age 0 hereafter) cohorts of chub during the fall (<100 mm) and the following spring when they have grown into the 100–149-mm size category, and we show species composition trend in the LCR. Finally, we offer some hypotheses about factors that may influence recruitment dynamics of chub in the LCR.

## Methods

Between 2000 and 2012, sampling with hoop nets (Photo S2, *Supplemental Material*) was conducted in the lower portion of the LCR to conduct a series of biannual (spring and fall) closed mark–recapture experiments and to collect information on community species compositions. Because subadult and adult humpback chub exhibit migratory behavior between the LCR and the Colorado River, we provide spring and fall abundance estimates. Spring efforts are aimed at providing estimates of the magnitude of annual spawning events in the LCR. Fall efforts provide abundance estimates that are more representative of overwintering juvenile chub.

## Study Area

Monitoring occurred in the lower 13.57 km of the LCR, with specific locations given in river kilometers (rkm) upriver from 0-rkm at the confluence with the Colorado River. During monitoring trips, biologists used three camps named Boulders (1.5 rkm), Coyote (9 rkm), and Salt (10.4 rkm). Biologists at each camp were responsible for fishing a reach of river approximately 4.5–5 km in length (Boulders, Coyote, and Salt reaches; Figure 2). Each reach was subdivided into three ~1.5-km length subreaches. A natural travertine dam structure called Lower Atomizer Falls exists at 13.57 rkm, above which monitoring during these trips did not occur. Some humpback chub naturally inhabit a 0.5 km reach above this falls, but it can be unsafe to monitor this section of river because of flooding. Because of extensive faulting and progressively higher calcium carbonate depositions with proximity to Blue Spring from the confluence, the LCR is characterized by increasing numbers of travertine ledges and deep pools ascending the river from Boulders to Salt reach (Cooley 1976).

### Gear

Fish were captured using hoop nets (0.5–0.6 m in diameter, 1.0 m in length, 6-mm mesh, with a single 0.1-m throat; Memphis Net and Twine, Inc.). During 2001 and 2002, all nets were baited with Aquamax Grower 600 for Carnivorous Species (Purina Mills, Inc., Brentwood, MO), but baiting was not used in other years because of concerns of tagging engorged fish (Stone 2005). With few exceptions, ~540 net sets were deployed during each monitoring trip, resulting in ~180 net sets being deployed per reach, or ~60 net sets being deployed per subreach. Each net set consisted of a hoop net being deployed in the river for ~24 h, after which it was checked for fish. Nets were set for three 24-h periods in each subreach. An exception was during 2001 and spring 2002 when nets were set for four 24-h periods rather than three. Nets were positioned in habitat suspected of catching humpback chub, and they were frequently repositioned or moved if the catch was poor, or if an alternative site was available. Nets were spread throughout each subreach uniformly, within the constraints of river hydrology and depth. Most nets were set near shore, but some were set further

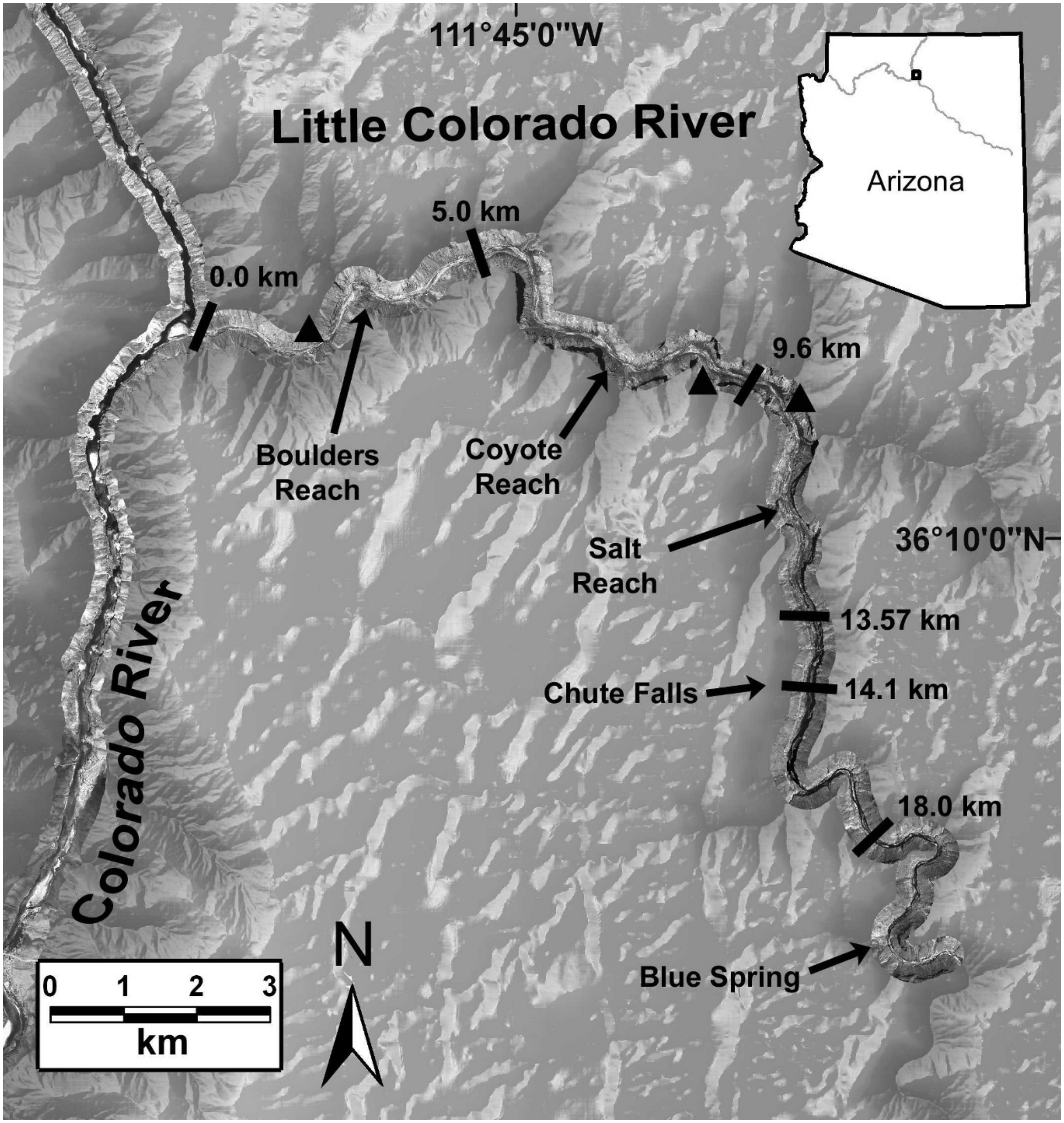


**Figure 2.** Map of Little Colorado River showing Boulders, Coyote, and Salt reaches and camp locations (triangles) used during humpback chub *Gila cypha* mark–recapture studies between 2000 and 2012.

midstream if access allowed. In total, 27,416 net sets were deployed during this project, with an average set time of 23.52 h (SD = 3.3). Average number of ~24-h net sets per monitoring trip was 548 (SD = 58), yielding an average of 12,815 (SD = 1,281) net hours per trip.

## Biological sampling

Data collected from fish included species, total length, and fork length (mm), and location (km). All fish lengths reported refer to total length. Humpback chub, flannelmouth, and bluehead suckers ≥150 mm were scanned for a passive integrated transponder (PIT) tag (Biomark Inc., Boise, ID), and if lacking a tag were PIT tagged. PIT tagging native fish in Grand Canyon began in May 1989 in part to investigate migratory patterns, but it has generally been restricted to fish ≥150 mm. Between 2000 and 2002 and from 2009 onward, all chub ≥100 mm in this study were PIT tagged.

### Flows and turbidity

Discharge data were downloaded from U.S. Geological Service (USGS) gage station 0904000 Little Colorado River near Cameron, Arizona (http://waterdata.usgs.gov/az/nwis/uv?site_no=09402000) and represent incoming flows that are in addition to the base Blue Spring–fed discharge of the LCR. Daily afternoon turbidity measurements (nephelometric turbidity units) were collected at Salt camp between 1200 and 1800 hours (Model 2100P turbidimeter; Hach, Loveland, CO).

### Population abundance estimation

Two pass mark–recapture methods were used to estimate abundances of humpback chub. Between September 2000 and October 2012, 50 field trips were conducted to perform 25 mark–recapture efforts to estimate abundance of chub ≥150 and ≥200 mm. A mark–recapture event occurred each spring (generally during April and May) and each fall (generally during September and October). Abundances were estimated using the Chapman modified Petersen closed population estimator with standard formula presented by Seber (1982, p. 60). The method of subcategories described by Seber (1982, pp. 100–101) was used to apportion Chapman Peterson estimates of the entire sample to estimates of abundance for chub within a specific size interval (e.g., ≥200 or 150–199 mm) or spatial location (e.g., Coyote reach). The 95% confidence intervals of the abundance estimates were approximated with a normal distribution. Although construction of confidence intervals assuming a normally distributed estimate is frequently appropriate considering the sample sizes observed in this study (Seber 1982), in some instances this method may produce biased intervals (i.e., coverage that is symmetric about the point estimate and too narrow). Although less biased methods of interval construction are available (Seber 1982), such methods are generally not amenable to the stratification methods (see below) we used to reduce bias in the point estimates. As such, we acknowledge the possibility that our confidence intervals may overstate estimator precision. However, we believe this is an acceptable trade-off to obtain relatively less biased point estimates with a simplistic and easily understandable estimation procedure. Assumptions of the Chapman Petersen estimator are as follows: 1) the population is closed with no additions or losses between marking and recapture events, either through recruitment, immigration, mortality, or emigration; 2) marking does not affect capture probability during the recapture event; 3) all individuals in the target population have an equal probability of capture during the marking event or the recapture event; or marked individuals mix completely with unmarked fish before the recapture event; 4) marks (tags) are not lost between the mark–recapture events; and 5) all marked individuals captured can be recognized from unmarked fish.

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 spring than during fall mark–recapture events. Humpback chub movement and migration is known to occur during springtime, but it is thought to be much lower during fall and winter (Kaeding and Zimmerman 1983; Douglas and Marsh 1996). We minimized the potential for violating this assumption by allowing less than a month to elapse between mark–recapture events (Data S1, *Supplemental Material*). In addition, the short time span between trips minimized growth-related recruitment, provided some time for fish to recover from the marking experience, and provided time for mixing to occur.

Abundance estimates also can be biased when the assumption of equal capture probability of individuals is violated. Stratified Chapman Petersen estimators were used if capture probability was determined to vary with fish length or between geographic reach (Seber 1982). To test for a relationship between capture probability and length, a contingency table analysis (Zar 1996) was used to determine whether capture probability varied significantly ($P < 0.05$) among 50-mm size classes. In addition, Kolmogorov–Smirnov tests were used to test for significant ($P < 0.05$) differences in the length frequency distributions of fish captured between the mark and recapture events, as would occur if capture probability varied with fish length. If indicated by these tests, length strata bounds were determined using a computer program that conducted sequential contingency table calculations, each with a different length strata bound, to find the bound that maximized the test statistic value (i.e., $\chi^2$). The goal of this procedure was to minimize abundance estimate bias by defining length strata with homogenous capture probability (Seber 1982). A similar procedure was used to evaluate the need for geographic reach stratification using contingency table analyses and pooling reaches with equal capture probability. To remain 95% confident that bias of the population estimate was negligible, seven or more recaptures were maintained within any given geographic or length-based stratum (Seber 1982). Finally, all fish were handled with care to avoid injury or stress-related mortality. It was assumed that tag loss was negligible because of high PIT tag retention rates demonstrated in bonytail (*Gila elegans*) and Gila chub (*Gila intermedia*), two surrogate species (Ward et al. 2008).

### Catch per unit effort

Catch per unit effort (CPUE) was used to monitor relative trends in smaller size classes of humpback chub (<150 mm) and for flannelmouth and bluehead suckers ≥150 mm because chub <150 mm were not PIT tagged during all years of this study and because in several years, numbers of recaptured native 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). To minimize for this effect, we calculated CPUEs using only data gathered during the second spring trip (May or June) of each year and only from October trips during the fall. During these trips, LCR conditions were generally at base flow and low turbidities. Because nets were set very close to 24 h each, CPUE is expressed as number of fish captured per net set (Stone 2010).

We used discharge, CPUE, and abundance data to test three hypotheses: 1) the magnitude of spring runoff flows in the LCR are related to age 0 humpback chub production, 2) relative catch of age 0 chub during the fall transitions into relative catch of chub in the 100–149-mm size class the following spring, and 3) relative catch of chub in the 100–149-mm size class during the spring translates into relative absolute abundances of subadult chub in the 150–199-mm size class 1 y later. A Pearson correlation test was used to examine the relationship between CPUE of the age 0 cohort of chub (<100 mm) during October of each year and the sum of mean daily flows between 1 January and 31 May from USGS gage station 0904000 the preceding spring. In addition, Pearson correlation tests were used to examine the relationship between October CPUEs of age 0 chub and CPUEs of these chub growing into the 100–149-mm size class by the following spring and between spring CPUEs of chub in the 100–149-mm size class and abundance of chub in the 150–199-mm size class the next spring. All CPUE, abundance, and flow data were $\log_{10}$ transformed to better meet assumptions for parametric tests, with $P$ values $< 0.05$ considered significant. Length frequency histograms were used to verify that age 0 chub in the fall were <100 mm (mode ~75 mm) and that these fish grew predominately into the 100–149-mm (mode ~120 mm) size category by the following spring.

## Results

### Mark–recapture

An increase in abundance of humpback chub ≥150 and ≥200 mm was documented after 2006, indicating increases in the subadult and adult populations. From 2001 to 2006, spring abundance estimates for humpback chub ≥150 mm ranged between 2,086 and 3,419 fish. Thereafter, these numbers increased to a high of 8,083 fish in spring 2010. Also between 2001 and 2006, spring abundance of adult chub (≥200 mm) ranged between 1,339 and 2,002 fish. Thereafter, these numbers increased to a high of 6,250 chub in 2010 (Figure 3; Table S1, *Supplemental Material*).

Likewise, increases were documented for subadult and adult humpback chub during the fall season, although to a lesser degree. From 2000 to 2006, fall abundance estimates for chub ≥150 mm ranged between 1,120 and 2,849 fish. Thereafter, these numbers reached a high of 6,389 fish in fall 2012. Also, between 2001 and 2005, fall abundance estimates for chub ≥200 mm ranged between 511 and 882. These numbers subsequently increased and reached a high of 2,825 fish in fall 2011 (Figure 3; Table S1, *Supplemental Material*).

Estimates for humpback chub abundances also were made by reach in the LCR (Figure 4). Post-2006 increases in chub ≥150 and ≥200 mm occurred in all three reaches, being most visible during the spring. The highest spring abundance estimates for chub ≥150 mm occurred during 2009, 2010, and 2012 in the Coyote reach. Much of the decline in chub ≥150 and ≥200 mm in spring 2011 is because of a significant decline in abundance of these fish in the Coyote reach. During fall, most years show that significantly more chub reside in the Salt reach, suggesting it may be preferable as overwintering habitat. In nearly all years, abundance of chub in the Boulders reach remains lower than in the Coyote or Salt reaches, both in spring and during fall. Nevertheless, spring abundances are generally higher than fall abundances of chub in the lowermost Boulders reach, consistent with influx of fish from the Colorado River during this season (Douglas and Marsh 1996).

### Catch per unit effort

Trends in abundance of smaller size classes of humpback chub (40–99 and 100–149 mm) and for bluehead and flannelmouth suckers (≥150 mm) are indexed using relative abundance (CPUE) rather than estimating absolute abundance. Trends in CPUE of bluehead sucker suggest a dramatic post-2006 increase in abundance (Figure 5). Subsequently, bluehead sucker abundance declined, particularly in 2010–2011. Flannelmouth sucker abundance also increased post-2006, although to a lesser degree (Figure 5). Both species continue to remain somewhat above pre-2006 levels. Small humpback chub CPUE suggests a highly variable temporal pattern in abundance and year-class strength (Figure 6). In addition, the data suggest a pattern of oscillation of chub in the 100–149-mm size class favoring even years, particularly between 2001 and 2007.

There was a positive correlation between fall CPUEs of age 0 humpback chub and the sum of mean daily flows between 1 January and 31 May of the preceding spring runoff in the LCR ($n = 13$, $r = 0.755$, $P = 0.003$). Note that the three lowest CPUE years for fall age 0 chub (2000, 2002, and 2006, Figure 6) were preceded by nearly nonexistent spring runoff in the LCR, with an average summed mean daily flow of ~4 $m^3/s$ above base flow discharge (Figure 7). The remaining 10 y had summed mean daily flows of at least 70 $m^3/s$ above base discharge (2012), with an average of 953 $m^3/s$ above base discharge.

Catch per unit effort analysis also suggests that production of fall age 0 humpback chub translates into catch of chub in the 100–149-mm size class the following spring. However, factors such as flooding in the LCR during late fall to early winter, or emigration, can weaken this relationship. Since fall 2000, four cohorts of fall age 0 chub (2000, 2002, 2006, and 2009) appear to have been relatively small (average CPUE = 0.21 chub/net set, Figure 6). Average CPUE for fall age 0 chub in the remaining nine years was 2.0 chub/net set. By the following spring, the four low fall age 0 cohorts translated into low CPUEs for chub in the 100–149-mm size class (average = 0.59 chub/net set), whereas the remaining years translated into an average CPUE of 2.36 chub/net set. Noticeable is that although the 2004 fall age 0 cohort was relatively strong, it did not transition well into the 100–149-mm size category by the following spring (Figure 6), possibly due to fairly extensive winter flooding in the LCR between sampling events (Figure 7), or because turbidities were high during spring 2005.

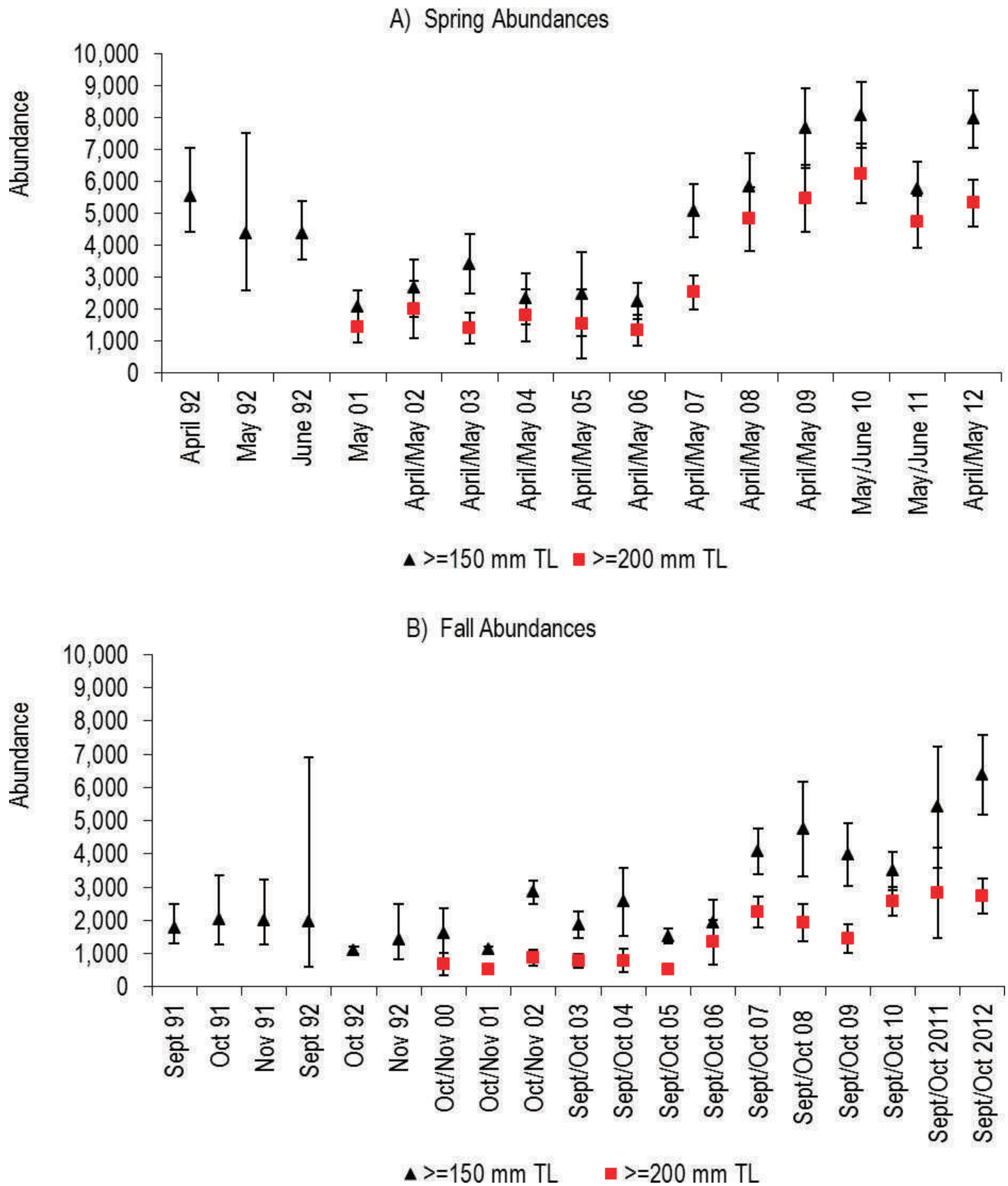


**Figure 3.** Abundance estimates (±95% CI) of humpback chub *Gila cypha* ≥150 and ≥200 mm between 2000 and 2012, Little Colorado River during (**A**) spring and (**B**) fall. Comparable closed abundance estimates of humpback chub >150 mm in the Little Colorado River during 1991 and 1992 are from Douglas and Marsh (1996).

Without the effect of high turbidity, CPUE of juvenile humpback chub in this instance would likely have been five-fold higher (Stone 2010). With exclusion of this abnormality, we obtained a positive correlation between CPUEs of fall age 0 chub and CPUEs of chub in the 100–149-mm size class ($n = 12$, $r = 0.61$, $P = 0.036$).

Finally, there was a significant, positive correlation between the spring CPUEs of chub in the 100–149-mm size class with abundance of chub in the 150–199-mm size class the following spring ($n = 11$, $r = 0.725$, $P = 0.012$). The higher correlation between juvenile CPUE to subadult abundance verses the lower correlation between age 0 and juvenile CPUE seems reasonable because as humpback chub grow, they are presumably less influenced by the vagaries of floods in the LCR. In all, it appears there were five cohorts of age 0 chub (2001,

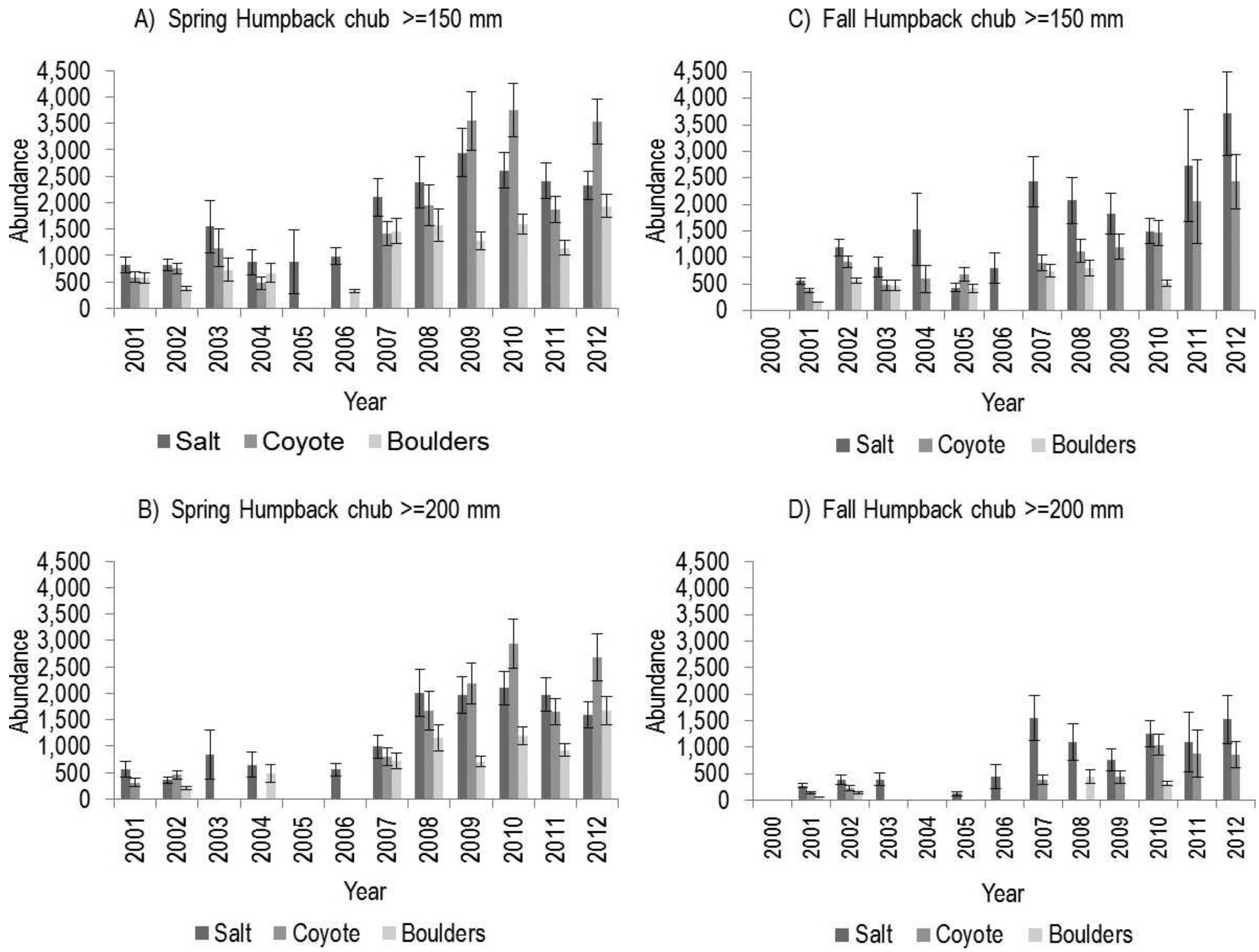


**Figure 4.** Abundances (±95% CI) of humpback chub *Gila cypha* between 2000 and 2012 in the Salt, Coyote, and Boulders reaches, Little Colorado River. (**A**) Spring chub ≥150 mm. (**B**) Spring chub ≥200 mm. (**C**) Fall chub ≥150 mm. (**D**) Fall chub ≥ 200 mm. Reach estimates without seven or more recaptures were excluded.

2005, 2007, 2008, and 2010) that likely recruited >1,500 fish into the 150–199-mm size category within the next 2 y (Figure 6).

## Species composition

Humpback chub numerically dominated the hoop net catch (Figure 8). Bluehead sucker show high variance in percent species composition because from 2001 to 2005 catches of bluehead sucker were low, but they dramatically increased post-2006 (Table S2, *Supplemental Material*). Native fish including humpback chub, flannelmouth sucker, bluehead sucker, and speckled dace have made up 90% of all fish captured since fall 2000. Fathead minnow *Pimephales promelas* was generally the dominant nonnative fish captured, making up 7.6% of catch since 2000, but catches were variable and thought to be a result of seasonal flooding in the LCR. Other nonnative fish captured since 2000, listed in order of decreasing catch, included common carp *Cyprinus carpio*, black bullhead *Ameiurus melas*, red shiner *Cyprinella lutrensis*, channel catfish *Ictalurus punctatus*, plains killifish *Fundulus zebrinis*, rainbow trout *Oncorhynchus mykiss*, green sunfish *Lepomis cyanellus*, and brown trout *Salmo trutta*. A few fish thought to be razorback-flannelmouth sucker hybrids have been captured since 2000 (treated as flannelmouth sucker for the purposes of this article). Such hybrids were infrequently captured during monitoring efforts in the early 1990s (Douglas and Marsh 1998). Presumably underrepresented in hoop net catches were adult channel catfish and adult common carp, fish that seldom enter our nets but that are commonly seen by field crews or captured by angling.

# Discussion

A decade of intensive and consistent monitoring in the LCR provides a wealth of information on fish population dynamics to managers and researchers engaged in endangered fish management. Annual abundance estimates suggest that sometime between the early 1990s and 2000, abundance of humpback chub ≥150 mm underwent a decline in the LCR (Coggins et al. 2006). This decline was followed by a period of relatively low but stable abundance between 2000 and 2006 and then by a post-2006 period of significant increasing trend. The post-2006 abundance increase also is observed in adult

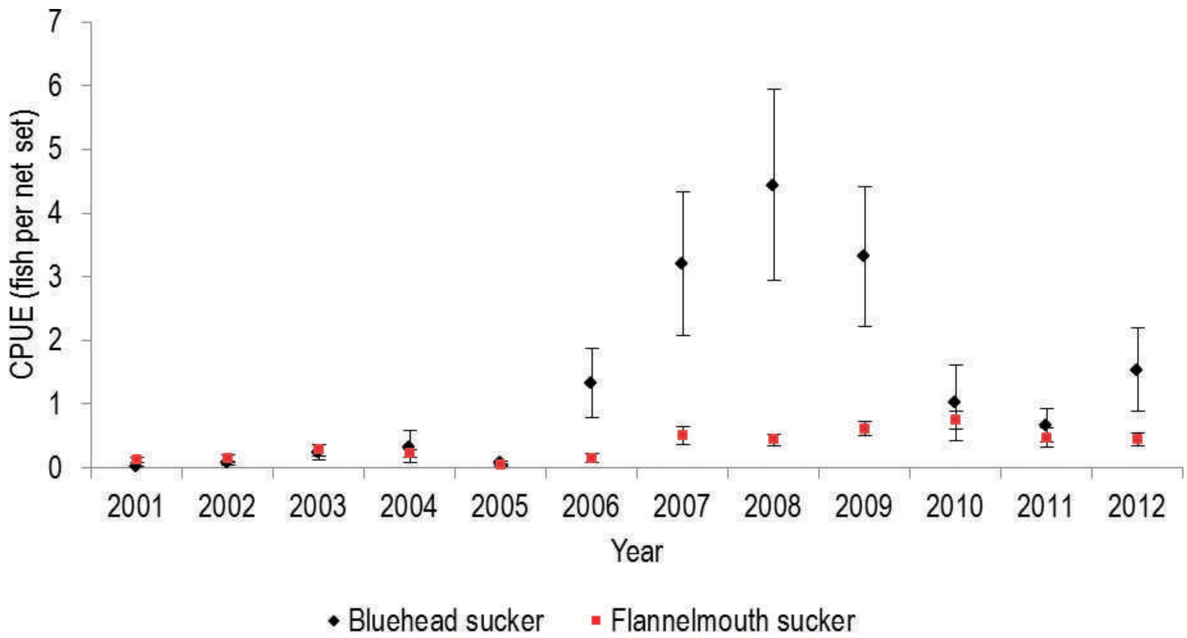


**Figure 5.** Catch per unit effort ([CPUE], mean no. fish captured/net set ±95% CI) of bluehead sucker *Catostomus discobolus*, and flannelmouth sucker *C. latipinnis*, during spring monitoring efforts between 2000 and 2012, Little Colorado River.

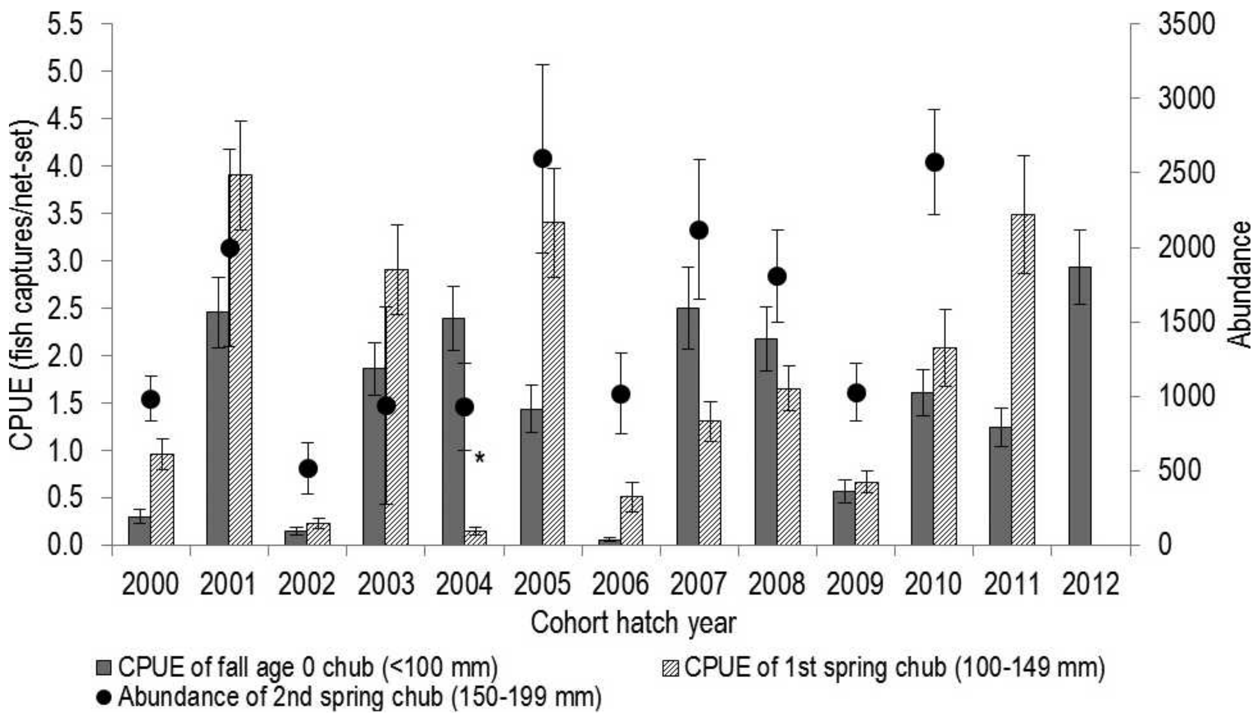


**Figure 6.** Catch per unit effort (CPUE ± 95% CI) and absolute abundance (±95% CI) of humpback chub *Gila cypha* between 2000 and 2012, Little Colorado River. The CPUEs of fall age 0 chub <100 mm (approximately 6 mo after hatch) are depicted by solid bars. By the following spring, these chub have grown into the 100–149-mm size class, are approximately 1 y old, and CPUEs are represented by hatched bars. Finally, these chub grow into the 150–199-mm size category, approximately 2 y after hatching, and closed abundance estimates for these fish are depicted by black circles. Asterisk over 2004 cohort hatched bar indicates that the Little Colorado River was turbid in spring 2005 and that catch rate of humpback chub in the 100–149 mm size class may have been at least five-fold higher without these conditions (Stone 2010).

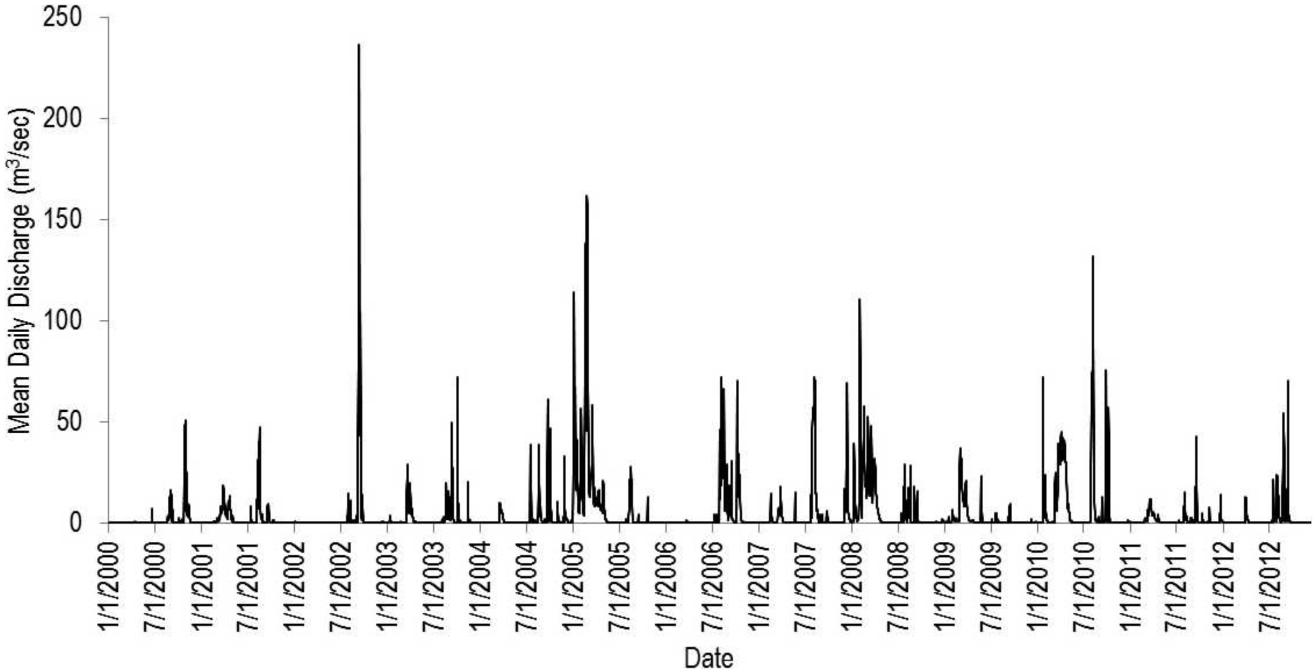


**Figure 7.** Hydrograph of Little Colorado River between January 2000 and December 2012 constructed from data (mean daily discharge $m^3/s$) at USGS gage 09402000 near Cameron, Arizona.

chub ≥200 mm and is particularly visible during the spring in the upper portions of the LCR. The large increase (nearly a doubling) in adult chub abundance in spring 2008 appears to have stemmed from a relatively large number of chub (~2,600) in the 150–199-mm size category during spring 2007.

In addition to subadult and adult humpback chub abundance increases, CPUEs of bluehead sucker and

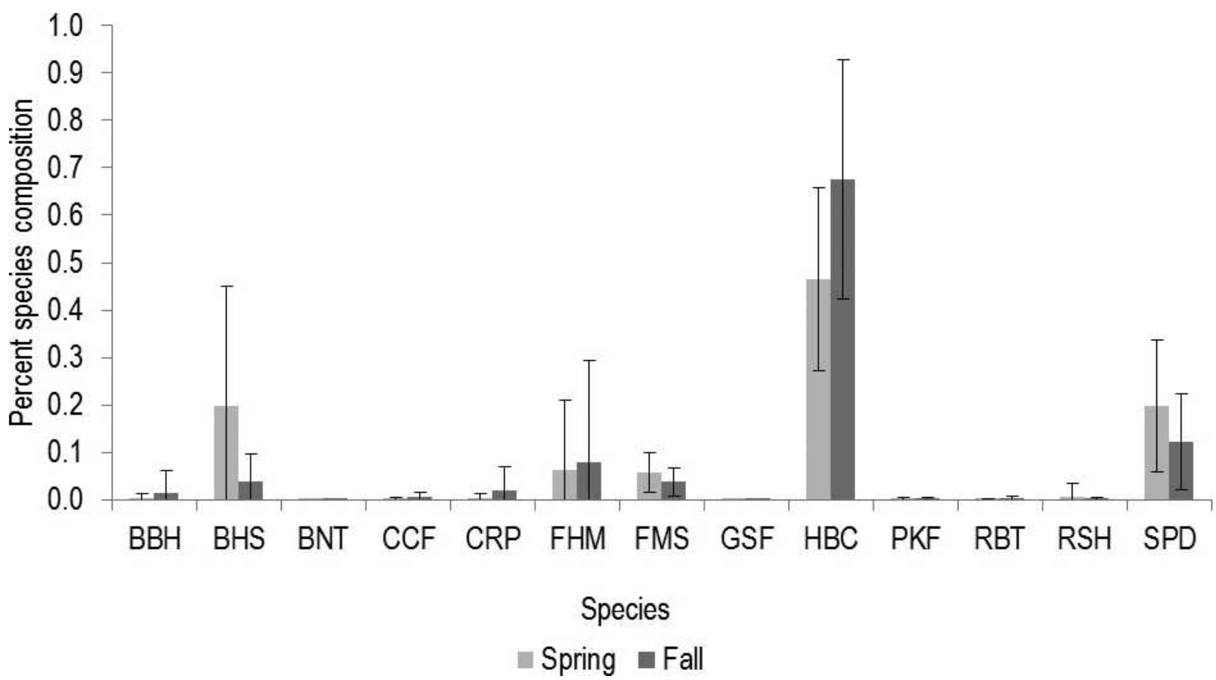


**Figure 8.** Spring and fall species composition of fish captured between 2000 and 2012, Little Colorado River. BBH = black bullhead *Ameiurus melas*; BHS = bluehead sucker *Catostomus discobolus*; BNT = brown trout *Salmo trutta*; CCF = channel catfish *Ictalurus punctatus*; CRP = common carp *Cyprinus 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*.

flannelmouth sucker (≥150 mm) significantly increased in the post-2006 timeframe, particularly during the spring spawning season. The increases in all three of these species suggest a systemwide change beneficial to the native fish community. However, it is uncertain which factors acting alone or in unison led to most of the post-2006 increases. Flooding in the LCR can transport large numbers of larval and small size classes of native fishes into the mainstem Colorado River (Valdez and Ryel 1995; Robinson et al. 1998), where cold water temperatures reduce or halt growth rates (Clarkson and Childs 2000; Coggins and Pine 2010). From 2003 to 2006, water temperatures in the Colorado River increased because a drought resulted in release of warmer waters from Glen Canyon Dam (Wright et al. 2009; Coggins et al. 2011). Concurrently, there was a systemwide decline in CPUE of rainbow trout in the Colorado River below the dam (Makinster et al. 2010), with the cause of this decline being uncertain (Coggins et al. 2011). In addition, from 2003 to 2006, a large scale effort was conducted in the Colorado River near the confluence of the LCR to remove nonnative fishes (Coggins et al. 2011; Yard et al. 2011). Combined, these factors should have increased the survival and growth rates of small humpback chub transported into the mainstem Colorado River. Together, these factors are temporally correlated with enhanced recruitment at the adult population level for all three large-bodied native fish species in the LCR.

Finally, from 2003 to 2008, approximately 1,450 juvenile humpback chub (50–136 mm) were captured in Boulders reach and translocated to above Chute Falls where they were released at 16.2 km. These actions were attempts to augment survival of juvenile chub by decreasing proximity and risk of exiting into the Colorado River during LCR flood events, and to increase growth by being in proximity to the relatively warm waters of Blue Springs (20.5 °C), particularly during the winter. It also was hoped to result in range expansion for the species (Robinson et al. 1996). These efforts resulted in hundreds of chub that grew to adulthood at unprecedented rates (within 2 y). Most of these fish subsequently migrated downriver; many lingering for several years in the 0.5-km section of the LCR between Lower Atomizer Falls and Chute Falls, as documented in additional closed mark–recapture studies (Van Haverbeke 2010). Nearly all chub vacated the stretch of the river above 13.57 km between the summers of 2009 and 2010, presumably during a prolonged winter–spring flood that carried an atypically high sediment load.

Our results suggest that upper portions of the LCR (Coyote and Salt reaches) may be more important than Boulders reach in terms of providing adult spawning and overwintering humpback chub habitat. Robinson et al. (1998) concluded that humpback chub spawn throughout most of the LCR below 14.1 km (Chute Falls), based on the distributions of proto and mesolarvae. During the post-2006 increases, abundances of adult humpback chub were higher in Salt and Coyote reaches than in Boulders reach, particularly during the spring spawning season. The Salt and Coyote reaches are characterized by structurally complex deep pool habitat conducive to adult humpback chub (Gorman and Stone 1999; Stone and Gorman 2006), whereas this type of habitat is less prevalent in the Boulders reach. During the fall, Salt reach (and to a lesser extent Coyote reach) were again inhabited to a greater extent than Boulders reach by both adult and subadult humpback chub. This trend may be partially because winter water temperatures are often warmer with proximity to Blue Spring (Stone 2010).

Coggins and Walters (2009) suggested that the increasing trend in adult humpback chub abundance began earlier than 2007. However, they explain that because of an effect of aging error, the least biased estimates for recruitment and adult abundance trends are those most proximal to the end of the data set being analyzed. As such, one might expect to see the adult increases in abundances beginning earlier in their age-structured mark–recapture models.

Trends in CPUE support our hypothesis that production of age 0 humpback chub is influenced by the LCR hydrograph. Gorman and Stone (1999) suggested that spring flooding in the LCR restructures substrate material, cleanses interstitial space for eggs, and leads to enhanced production of humpback chub. Similarly, Brouder (2001) found a strong positive relationship between peak late winter–early spring flooding and CPUE (recruitment) of age 1 roundtail chub *Gila robusta* in the Verde River, Arizona. In the LCR, flooding can clear substrates of heavy marl depositions precipitated from the water column (Cooley 1976).

In addition, strong age 0 cohorts can be followed through into higher abundance of humpback chub in the 150–199-mm size class. These findings highlight the importance of the Little Colorado River serving as a primary rearing ground for humpback chub into the subadult size category. The average number of subadults detected recruiting in the LCR between 2001 and 2012 was 1,435/y. This number is important because with an estimated adult population of 7,650 humpback chub and an assumed adult mortality rate of 13% (Coggins and Walters 2009), this average number of subadults entering the population each year should stem population decline. Besides humpback chub, there are some hints that production in the LCR influences the adult abundance of bluehead sucker. Walters et al. (2012) noted that a large mode of 40–80-mm bluehead suckers first appeared in the LCR in spring 2002 and that these fish began reaching adulthood in 2005–2006, becoming markedly more abundant thereafter (∼2007–2008).

The LCR remains a system dominated by the native fish community. Consistent with past LCR fish studies, humpback chub were the numerically dominant native species in overall catch, followed by speckled dace, bluehead sucker, and flannelmouth sucker (Kaeding and Zimmerman 1983; Gorman and Stone 1999; Stone and Gorman 2006). Fortunately, the LCR is a system that is apparently not conducive to the establishment of salmonids. During summer base flow periods, the river is mildly saline and temperatures can reach or exceed 25 °C, within lethal temperature range for rainbow trout (Mathews and Berg 1997). During flooding events, the river becomes highly turbid, often reaching levels of tens of thousands of nephelometric turbidity units (Stone 2010) and thus nonconducive to sight feeders. Based on species distribution in the upper LCR watershed, it is thought that several species of nonnatives (e.g., fathead minnow, black bullhead, channel catfish, and common carp) invade the lower LCR from flood events originating in the mid-upper portions of the watershed (Stone et al. 2007). There is also concern that uncontrolled warming of mainstem Colorado River waters could result in invasion of the LCR by undesirable warm water predators, but it is equally recognized that some degree of controlled warming could be highly beneficial to the growth and survival of humpback chub in the mainstem. Currently, there are no preventative management actions taking place to adequately address the potential problem of enhanced nonnative invasion from upper portions of the LCR watershed. This last factor highlights the need to continue consistent monitoring in the LCR to not only relay trends in the current fish community to managers but also to detect changes in the fish community as might result from introduction of novel species from upstream reaches of the watershed.

## Supplemental Material

Please note: The *Journal of Fish and Wildlife Management* is not responsible for the content or functionality of any supplemental material. Queries should be directed to the corresponding author for the article.

**Photo S1.** Four photographs of the Little Colorado River during the course of studies between 2000 and 2012. Photos A and B show the river under base flow, spring-fed, ''blue water'' conditions. Photos C and D show the river under turbid and slightly flooding conditions. Photo credits USFWS.

Found at DOI: http://dx.doi.org/10.3996/082012-JFWM-071.S1 (1560 KB JPG).

**Photo S2.** Four photographs of USFWS staff or volunteers working with hoop nets in the Little Colorado River between 2000 and 2012. (A) Dewey Wesley (USFWS), (B) David K. Van Haverbeke-McDermitt (volunteer), (C) Amy Nowakowski (volunteer), NS (D) Jim Walters (USFWS). Photo credits USFWS.

Found at DOI: http://dx.doi.org/10.3996/082012-JFWM-071.S2 (1517 KB JPG).

**Data S1.** Database from Little Colorado River between 2000 and 2012.

Found at DOI: http://dx.doi.org/10.3996/082012-JFWM-071.S3 (12 MB XLSX).

**Table S1.** Abundance estimates (*N*) of humpback chub *Gila cypha* ≥150 and ≥200 mm during spring and fall mark–recapture studies in the lower 13.57 km of the Little Colorado River between 2000 and 2012. Marked fish from the marking event are designated by M, fish examined for marks in the recapture event are designated by C, and recaptured fish are designated by R. The *N*, SE, confidence level (±95% CI) also are given. If geographic stratifications were performed, they are designated in the Geostrat column, where, for example (B/C), S represents that data from Boulders and Coyote were pooled and segregated from Salt reach. Length stratifications (mm) are given in the Lenstrat 1 and Lenstrat 2 columns; with pooled geographic reaches in Lenstrat 1, and the segregated reach in Lenstrat 2. For example, 120 and 150 (B/C) in the Lenstrat 1 column means that length stratifications occurred at 120 and 150 mm for the pooled Boulders and Coyote data. Length stratifications without an accompanied reach designation denote that no geographic stratification occurred and that data from all three reaches were pooled. Estimates for humpback chub ≥200 mm were constructed from the Chapman Petersen estimates of the entire sample and apportioned to the strata of interest using the method of subcategories described by Seber (1982, pp. 100–101).

Found at DOI: http://dx.doi.org/10.3996/082012-JFWM-071.S4 (17 KB XLSX).

**Table S2.** Catch table of fish captured in hoop nets during mark–recapture studies in the Little Colorado River between 2000 and 2012. BBH = black bullhead *Ameiurus melas*; BHS = bluehead sucker *Catostomus discobolus*; BNT = brown trout *Salmo trutta*; 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*.

Found at DOI: http://dx.doi.org/10.3996/082012-JFWM-071.S5 (13 KB XLSX).

**Reference S1.** Coggins LG Jr, Walters CJ 2009. Abundance trends and status of the Little Colorado River population of humpback chub; an update from 1989–2008: U.S. Geological Survey Open-File Report 2009-1075.

Found at DOI: http://dx.doi.org/10.3996/082012-JFWM-071.S6; also available at http://pubs.usgs.gov/of/2009/1075/of2009-1075.pdf (717 KB PDF).

**Reference S2.** Cooley ME. 1976. Spring flow from pre-Pennsylvanian rocks in the southwestern part of the Navajo Indian Reservation, Arizona. Geologic Survey Professional Paper 521-F.

Found at DOI: http://dx.doi.org/10.3996/082012-JFWM-071.S7; also available at http://pubs.usgs.gov/pp/0521f/report.pdf (3.97 MB PDF).

**Reference S3.** Makinster AS, Persons WR, Avery LA, Bunch AJ. 2010. Colorado River fish monitoring in Grand Canyon, Arizona: 2000–2009 summary. U.S. Geological Survey Open-File Report 2010-1246.

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Found at DOI: http://dx.doi.org/10.3996/082012-JFWM-071.S9; also available at http://www.nativefishlab.net/library/textpdf/21260.pdf (6.16 MB PDF).

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Found at DOI: http://dx.doi.org/10.3996/082012-JFWM-071.S10; also available at http://www.usbr.gov/uc/library/envdocs/eis/gc/gcdOpsFEIS.html (60.5 MB, 8 PDFs including appendices).

**Reference S6.** [USFWS] U.S. Fish and Wildlife Service. 1990. Humpback chub 2nd revised recovery plan. Denver, Colorado.

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**Reference S7.** [USFWS] U.S. Fish and Wildlife Service. 2002. Humpback chub (*Gila cypha*) Recovery Goals: amendment and supplement to the humpback chub Recovery Plan. Denver, Colorado.

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Found at DOI: http://dx.doi.org/10.3996/082012-JFWM-071.S13; also available http://www.fws.gov/southwest/es/arizona/Documents/Biol_Opin/110112_HFE_NNR.pdf (1.3 MB PDF).

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