# 2006 Native Fish Monitoring Activities in the Colorado River, Grand Canyon

# Annual Report

Prepared for

**Grand Canyon Monitoring and Research Center**

Prepared by

**SWCA Environmental Consultants**

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# 2006 NATIVE FISH MONITORING ACTIVITIES IN THE COLORADO RIVER, GRAND CANYON

# ANNUAL REPORT

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**Grand Canyon Monitoring and Research Center**
2255 North Gemini Drive
Flagstaff, Arizona 86001

Prepared by

Michael W. Ackerman

**SWCA Environmental Consultants**
114 North San Francisco Street, Suite 100
Flagstaff, Arizona 86001
(928) 774-5500
www.swca.com

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# EXECUTIVE SUMMARY

This report presents the results of the fifth and final year of a fish monitoring study in the mainstem Colorado River through Grand Canyon. As in previous years, three trips were conducted in 2006 as follows: 1) stratified random sampling in May; 2) humpback chub (*Gila cypha*) aggregation sampling in June; and 3) backwater seining in September. May and September trips were conducted when river flows and fluctuations were low. The June trip was conducted during a period of high flows and high fluctuations. Three gear types were used—trammel nets, hoop nets, and seines. Altogether, 14 species of fish were caught with these gear types, including 4 species of native fish and 11 non-native species. The native species constituted about 75% of total fish caught and the non-native, about 25%. The three gear types appeared to complement each other in catching different but overlapping suites of fish and distinctly different sizes of fish. Trammel nets selected for seven species, hoop nets selected for five species, and seines selected for only three species. Trammel nets appeared to be important in catching the medium- to large-bodied fishes that were not captured with seines and that were only marginally caught with hoop nets. It was also evident that trammel nets were the most effective at catching the endangered humpback chub >180 mm total length. This monitoring program detected increases in abundance of juvenile humpback chub in the mainstem, especially upstream of the Little Colorado River and in the Middle Granite Gorge and Shinumo aggregations. This program also detected increases in juvenile flannelmouth sucker and bluehead sucker. These responses were concurrent with the increased temperature of water released from Glen Canyon Dam during 2004 and 2005. A preliminary analysis of data collected by this program from 2002–2006 shows that the strategies implemented in 2003, 2004, and 2006 can effectively monitor the fish community of the Colorado River through Grand Canyon. Additional analysis of data is recommended to include the data collected from this program as well as data collected by other investigators prior to, during, and after this program. A reliable, precise, and well-defined monitoring program for the Colorado River through Grand Canyon is long overdue, given the likely prospect of new flow management recommendations, temperature augmentation, and the ongoing and long-term uncertainty of climate change and precipitation in the region.

# INTRODUCTION

The purpose of the 2006 annual report for native fish monitoring in the Colorado River, Grand Canyon, is to provide an analysis and discussion of the 2006 and previous monitoring efforts and, in addition, to address the global objectives and sub-objectives of the native fish monitoring program. Furthermore, this report will provide a 5-year summary of findings for monitoring conducted by SWCA Environmental Consultants (SWCA) between 2002 and 2006.

## Monitoring Objectives

The global objective of the native fish monitoring program in the Colorado River, Grand Canyon, is to develop and implement an effective sampling design for estimating the status of and detecting changes in riverwide distribution and relative abundance of native fish species. This information is also supplemented for non-native species.

Sub-objectives of the program are to:

- Evaluate the utility of different fish-sampling gear types for detection of long-term trends in fish relative abundance, distribution, and length structure.
- Detect changes in the length structure of native and non-native fish populations.
- Refine fish monitoring protocols and data analysis techniques to increase the efficiency of effort applied.
- Increase the number of passive integrated transponder (PIT) tags in humpback chub (HBC) (*Gila cypha*) and other native fishes to increase the precision of the Age-Structured Mark-Recapture (ASMR) model and to increase our ability to detect movement of tagged fishes.

The combined information from the global objective and sub-objectives will be used in conjunction with other long-term monitoring data to elucidate best management for native and non-native fishes in the Colorado River, Grand Canyon. Table 1 provides a list of native and non-native fishes, with their status and approximate relative abundance, found in the Colorado River, Grand Canyon, fish community (Valdez and Ryel 1995).

## Background

In 2002, the Grand Canyon Monitoring and Research Center (GCMRC) initiated a long-term fish monitoring program for the Colorado River between Lees Ferry and Diamond Creek. Monitoring efforts were then extended in 2004 to include the reach between Diamond Creek and the National Park boundary near Lake Mead. The program is a cooperative effort between the GCMRC, the U.S. Fish and Wildlife Service (USFWS), the Arizona Game and Fish Department (AGFD), and SWCA. SWCA's responsibility in the long-term monitoring program is to assist in the development, refinement, and implementation of an effective sampling design for estimating the status of and trends in native fish species.

# METHODS

## Study Area

This report covers monitoring efforts in the Colorado River from Lees Ferry (River Mile [RM] 0) to Diamond Creek (RM 225.7). The RMs referenced in this report were obtained from orthorectified aerial photos provided by GCMRC. Figure 1 depicts the study area with river reaches. Figure 2 depicts the study area with HBC aggregations.

## Sampling Strategy

A sampling strategy was developed to monitor native fishes in the Colorado River that involved a combination of riverwide sampling within designated longitudinal reaches (Table 2, Figure 1) and intensive sampling in known HBC aggregations (Table 2, Figure 2). The longitudinal reaches were defined using historical catch data and a modified version of *sample.exe*, a visual basic program for optimal allocation of samples among strata, developed for GCMRC (Walters et al. 2000). The HBC aggregations were identified by Valdez and Ryel (1995) during studies conducted in the early 1990s. Aggregations were defined as consistent and disjunct groups of fish with no significant exchange of individuals with other aggregations, as indicated by recapture of PIT-tagged juveniles and adults and movement of radio-tagged adults. Aggregations are associated with one or more of four canyon features: 1) warm tributaries; 2) warm springs; 3) a unique geologic association (Muav limestone, Bright Angel shale, Tapeats sandstone, and the Unkar group); and 4) debris fans (Valdez and Ryel 1995). Within each river reach, subreaches have been identified (Table 3; Walters et al. 2000) based on hydrological barriers (rapids) that prevent upstream travel or are considered unsafe to navigate during the night. The gear types selected for native fish monitoring (hoop nets, trammel nets, seines) were demonstrated to be effective in catching HBC and other native species (Valdez and Ryel 1995).

The sampling strategy used in 2006 was similar to that of 2002–2004. In each of the years, two trips were conducted using both trammel and hoop nets. One of the netting trips each year was under a modified stratified sampling design intended to provide data pertaining to the objectives of the monitoring program for areas outside HBC aggregations. These trips provided monitoring data for all species susceptible to trammel and hoop netting and provided the ability to detect the movement of or changes in relative abundance of HBC outside aggregations. The sampling strategy used for the other netting trip each year focused on the nine HBC aggregations. The purpose of this trip was to: 1) provide data pertaining to the objectives of the monitoring program for HBC and other fishes found within the nine HBC aggregations; and 2) to increase the mark-and-recapture information of HBC for the ASMR model.

In 2005, sampling efforts deviated from the developed sampling strategy to increase the mark and recapture information of HBC within Reach 3, particularly the Little Colorado River (LCR) inflow aggregation. In addition, a mark-and-recapture estimate was calculated for adult HBC within the mainstem Colorado in the LCR inflow aggregation using the Chapman-Peterson method (Lauretta and Serrato 2006). The 95% confidence interval (CI) of the population estimate was calculated using a Poisson distribution (Lauretta and Serrato 2006; Lockwood and Schneider 2000).

Seining trips were also conducted every September from 2003 to 2006. In 2002, seining was conducted opportunistically during the trammel and hoop netting trips in July (Trip ID: GC20020717) and September (Trip ID: GC20020911).

## Sampling Methodology

Trip schedules for the three sampling trips conducted in 2006 can be found in Table 4. Fifteen days were spent sampling the Colorado River (riverwide) between Lees Ferry (RM 0.0) and Diamond Creek (RM 225.7) from May 7 to May 23, 2006 (Trip ID: GC20060507). Sampling occurred each day within a different subreach (Table 3) selected from within the 11 river reaches (Table 2, Figure 1). Sample subreaches for the trip were selected by a process of elimination:

- Subreaches that the AGFD randomly selected to electrofish during the same time period were eliminated from consideration.
- Subreaches within known HBC aggregations (Table 2, Figure 2) were eliminated from consideration.
- Of the remaining subreaches, 15 subreaches were selected with preference given to those that had not been previously sampled with hoop and trammel nets over the last four years. At least one subreach was sampled within each reach with the exception of Reaches 3 and 4, which were excluded because they would be sampled during HBC aggregation sampling (GC20060603).

Fourteen days were spent sampling in the nine HBC aggregations from June 3 to June 18, 2006 (Trip ID: GC20060603), including one day at 30-mile, three days at LCR inflow, one day each at Lava Chuar-Hance, Bright Angel Creek, and Shinumo Creek, two days each at Stephen's Aisle, Middle Granite Gorge, and Havasu Creek, and one day at Pumpkin Spring. The LCR inflow aggregation was divided into 3 subreaches, with sampling occurring within a different subreach each night. Subreaches in the LCR inflow were identified by selecting sections of the aggregation where 10 trammel nets could be successfully deployed in one night, which included RMs 57.0–60.0, 60.0–62.7, and 62.7–65.4. Stephen's Aisle, Middle Granite Gorge, and Havasu Creek were each divided into two subreaches, with sampling occurring within a different subreach each night. In a few cases, the subreach length was adjusted to allow for 5 trammel net sets without overlapping sample sites from the previous night (i.e., areas where swift currents prevented setting 5 nets within the subreach).

During riverwide and aggregation sampling, trammel nets and scented hoop nets were used. Trammel nets measured 22.9 m × 1.8 m × 2.54 cm × 20.48 cm (length × width × mesh × panel mesh). In chosen sampling areas, trammel nets were set opportunistically, as limited by high water velocity, typically at current separation points where an eddy current and a main current diverge (also known as eddy fences). Nets were initially deployed each day at approximately 1700 to 1800 hours. Each net was fished for three ≈2-hour hauls, for a total of ≈6 hours of effort per net. Two-hour hauls were conducted to help reduce fish stress and injury associated with longer hauls. Two aluminum-hulled Osprey brand boats equipped with 50-horsepower, 4-stroke outboard motors were used. One boat operator and two net and fish handlers occupied each boat. Each netting boat set 5 trammel nets on opposite sides of the river for a total of 10 samples per night. If a trammel net became entangled in debris or was swept against/toward the shoreline, netters moved or discontinued the trammel net set at their discretion.

Hoop nets used were 0.5 to 0.6 m in diameter and 1.0 m long with a 6-mm mesh and a single 10-cm throat. Hoop nets were set in suitable locations, defined by low-velocity eddies and pools along the shoreline. Nets were set in pods of three to: 1) decrease chances of losing nets; and 2) reduce time required to set and retrieve nets due to logistical constraints. Nets were set at depths typically less than 3 m, but deep enough to ensure that nets would not be exposed during fluctuating flows. Hoop nets were set in the afternoon (≈1500 to 1630 hrs) and pulled the following morning (≈0730 to 0900 hrs). Each of the two netting boats set 18 hoop nets per day (6 pods of 3 nets) for a total of 36 samples (18 on each river side). Hoop nets were scented with commercial trout food (Aqua-Max). Bait was suspended inside the nets in perforated PVC containers ("bait pipes"), which allowed odor to escape but prevented fish from gorging on the bait.

A third trip was conducted from September 21 to October 6, 2006 (Trip ID: GC20060921) in which every backwater encountered along the mainstem was seined with a straight seine measuring 3.65 m × 1.82 m × 3.18 mm (width × depth × mesh). Seine haul length, widths (mouth, center, and end), and depths (mouth, center, and end) were recorded to measure effort. Backwater length, widths (mouth, center, and end), and depths (mouth, center, and end) were recorded to measure habitat size. In very small backwaters, only one width and one depth were measured to approximate effort and it was assumed that haul volume and backwater volume were equal.

Twenty-seven multiple-pass seining depletions were also conducted during GC20060921. Depletion samples were chosen randomly, with typically two depletions were conducted per day. The opening of each backwater was blocked with either a straight seine measuring 5.00 m × 1.82 m × 3.18 mm (width × depth × mesh), a block seine measuring 3.65 m × 1.82 m × 3.18 mm, or a bag seine measuring 9.00 m × 1.82 m × 3.18 mm, depending on the size of the mouth of the backwater. Three passes (A–C) were then made with a straight seine measuring 3.65 m × 1.82 m × 3.18 m. Fish from each pass were held in separate containers until all depletion samples were completed. Then, fish data were taken for each pass and fish were released back into the backwater (see Fish Handling Protocol).

Water quality measurements were taken opportunistically during 2006 seining at various sites (excluding depletion sites) in an effort to supplement existing water quality data for backwater habitats in the Grand Canyon. Water quality measurements include temperature, conductivity, dissolved oxygen, pH, salinity, and turbidity. In many cases, water temperatures were taken at the backwater mouth, center, and end to provide data on the temperature gradient in backwaters seined. For all netting and seining efforts, sample locations were recorded on data sheets and on orthorectified aerial photos provided by GCMRC.

## Fish Handling Protocol

Fish captured during each trip were processed using the standard fish-handling protocol outlined jointly by GCMRC and the cooperating agencies (Ward 2002). A list of the pertinent protocols is given below:

- Total lengths (TLs) were taken on all native and non-native fishes. Fork lengths were also taken on all native fishes.
- Weights were not taken in an effort to reduce handling stress.
- Native fish (≥150 mm) were scanned for PIT tags using both new and old PIT-tag scanners. All tagged and untagged native fish (≥150 mm) were PIT tagged if not already tagged with a "new" 134.2-kHz tag. All PIT-tag numbers were recorded on data sheets and stored in the PIT-tag readers for later download.
- All native fishes were examined for sex, sexual condition, and external parasites.

## Fish Specimen Collection

During GC20060603, SWCA assisted the USFWS with the collection of left pectoral fin clips from HBC for genetic studies. Altogether 56 samples representing various HBC size classes were collected. HBC were captured from all aggregations except Pumpkin Spring.

During GC20060921, SWCA assisted GCMRC in the collection of fish specimens at the request of Dr. Bill Pine of the University of Florida, Department of Fisheries and Aquatic Sciences, for a juvenile flannelmouth sucker (FMS) otolith study. Specimens were collected under the AGFD and GCMRC collection permit and preserved in ethanol. A total of 126 fish was collected (122 FMS, 3 HBC, and 1 green sunfish [GSF]). These samples were then turned over to GCMRC biologists for further analysis.

## Data Analysis

### *Percent Fish Composition and Relative Abundance*

Percent fish composition (by number captured) was calculated by river reach for 2006 captures to evaluate the current fish community composition. In addition, riverwide percent fish composition was calculated for each of the 5 years to detect changes in the fish community over the time period. For all calculations, gear types (trammel, hoop, seine) were kept separate. Also, because of the ability of hoop nets to capture large- and small-bodied fish species, fish composition of these two groups was kept separate. Minimal competition for niches occurs between the two groups; thus, small- and large-bodied fishes represent two unique fish communities.

Trammel and hoop net geometric mean catch-per-unit-efforts (CPUEs) were compared (2 sample t-test) for each species by reach and riverwide for 2002–2006 monitoring data to investigate the status of and changes in the relative abundance of each species. The geometric mean and 95% CI of the CPUE was calculated through the following process and considerations:

First, $X_i$ was defined as the CPUE of the *ith* sample (i.e., $C_i/f_i$). As X contains zeros, a new zero-corrected variable must be defined, $Y_i$…

$$Y_i = X_i + c$$

where: $Y_i$ = corrected CPUE
$X_i$ = CPUE
c = constant

The constant c was generally set equal to the smallest observable value of X. In this case we used $1/\bar{f}$, where 1 represents the smallest observable catch and $\bar{f}$ is the average effort for the gear type in 2006. The CPUE data (X and Y) in the case of Grand Canyon native fish monitoring was often highly right-skewed, and we normalized these data with logarithmic transformation. Thus, CPUE analyses in this report were performed on the log(Y) as demonstrated in Zar (1999).

### *Coefficients of Variation*

Coefficients of variation (CVs) of the mean CPUE was calculated using combined 2002 through 2006 CPUE data to investigate the utility of trammel and hoop nets used for native fish monitoring efforts. CVs were calculated for each species for each reach and riverwide. CVs were also calculated by age class (young-of-year [YoY], juvenile, adult) for the three large-bodied natives (HBC, FMS, bluehead sucker [BHS]). For HBC, CVs were also calculated by aggregation. The CV of the mean CPUE was calculated as:

$$CV_{\bar{x}} = SE \div (C/f)_{\bar{x}}$$

where: SE = SE of the arithmetic mean
$(C/f)_x$ = arithmetic mean of the CPUE

### *Length Frequency Distribution*

To evaluate the status of and changes in the length structures of Grand Canyon fishes over the past 5 years, 2002 and 2006 length frequency histograms were constructed for each species captured by trammel nets. The 2002 and 2006 histograms for each species were investigated for any major changes in the length structure of fish susceptible to capture that may have occurred.

The arithmetic mean TL and 95% CI for each species captured by trammel nets was compared (two sample t-test) for each of the past 5 years to evaluate differences in the mean TL of adult captures riverwide. A comparison of mean TL for each species among years for hoop net captures was considered not appropriate to investigate changes in the length structures of Grand Canyon fishes. Hoop nets capture a variety of size classes for multiple species, and an array of factors may influence the proportion of each size class captured from year to year. Each species would have to be divided into appropriate length classes to conduct this sort of analysis on hoop net captures. Length class divisions (i.e., YoY, juvenile, adult) are only available for the large-bodied natives (HBC, FMS, BHS; Valdez and Ryel 1995), but division into these classes would make sample sizes too small for such an analysis.

In addition, 2006 hoop net length frequency histograms were constructed to supplement information on the current status of length structures provided by trammel nets and to provide length information for small-bodied fishes.

### *Seining Capture Probabilities*

Seining first-pass capture probabilities were calculated for all species captured during depletion seine hauls conducted in 2005 and 2006 to investigate similarities and differences in capture probabilities between years and between species.

Seining capture probabilities were estimated using a likelihood-based depletion model where the catch of each depletion pass was predicted by:

$$C_t = \hat{p}\left(\hat{N}_t - C_{t-1}\right)$$

Where: $C_t =$ catch at depletion pass (t).

$\hat{N}_t =$ estimated abundance after depletion pass (t).

$\hat{p} =$ estimated capture probability over all depletion passes.

The log-likelihood of the observed catch was maximized by iteratively solving for $\hat{N}_0$ and $\hat{p}$ using the natural log of the probability of the data given a Poisson distribution. The variance of $\hat{p}$ was assumed to conform to a Poisson distribution. The 95% confidence limits were, therefore, approximated as:

$$95\%CL = 1.96 \times \hat{p}\sqrt{\left(\frac{1}{\hat{N}_0 \times \hat{p}}\right)}$$

In addition, a riverwide abundance estimate for backwater habitats was made for each species for 2005 and 2006. Riverwide abundance estimates include all size classes vulnerable to capture by seining and were only made for species in which sufficient captures were made during depletion seining efforts to calculate a capture probability. Riverwide abundance estimates for each species captured in backwater habitats were calculated as follows:

$$N = \frac{C_1}{\hat{p}}$$

where: N = riverwide abundance estimate for backwater habitats
$C_1$ = number captured during all initial-pass seining efforts riverwide
$\hat{p}$ = capture probability derived from depletion seining efforts

Confidence limits for riverwide abundance estimates were calculated using the above equation with the 95% confidence limits of $\hat{p}$ (calculated as shown above) substituted for $\hat{p}$. Riverwide abundance estimates for 2005 and 2006 were then compared with corresponding riverwide CPUEs to provide an examination of the biases present in using catch rate to infer riverwide abundance estimates.

### *Tag Histories*

Fish (including tagged fish) were entered into a database template provided by the GCMRC after completion of the three trips conducted by SWCA during 2006 native fish monitoring efforts. After data error-checking, a database was then submitted from each trip for incorporation into the GCMRC fish database. Fish in the database were then available for use in the ASMR model.

The tag history of all 42 HBC recaptured during 2006 netting efforts was examined in order to conduct a preliminary analysis of movement with recaptured HBC.

# RESULTS

The population estimate for adult HBC in the Colorado River within the LCR inflow aggregation in June 2005 was 1,170 (95% CI lower limit = 646; upper limit = 2,340) (Lauretta and Serrato 2006).

Summaries of sampling effort between 2002 and 2006 by gear type for SWCA native fish monitoring activities can be found in Tables 5–7. Summaries of 2006 sampling effort and fish captures by gear type are presented in Table 8.

During riverwide and aggregation sampling, a total of 1,044 hoop net samples (19,002 net hrs; 18.2 net hrs/sample) and 293 trammel net samples (1,570.82 net hrs; 5.36 net hrs/sample) were taken.

During September seining, a total of 244 single-pass seine hauls and 27 three-pass depletions were completed. Only fish captured during the 244 single-pass seine hauls were used in fish composition analysis. Fish captured during depletion seining were used in the calculation of capture probabilities.

## Riverwide Sampling

River discharge during the riverwide May, 2006 sampling trip (GC20060507) at Lee's Ferry ranged from 6,800 to 12,300 cubic feet per second (cfs), with an average of approximately 10,000 cfs (Figure 3; USGS 2006a). River temperatures at Lee's Ferry ranged from 9.3°C to 10.0°C, with an average of approximately 9.7°C (Figure 4; USGS 2006b).

Trammel netting efforts during riverwide sampling in 2006 captured 379 fish. Native fish constituted 66.2% and non-native fish 33.8% of all trammel net captures. FMS was the dominant species captured (59.9%), followed by rainbow trout (RBT [20.1%]), common carp (CRP [7.9%]), BHS (5.0%), channel catfish (CCF [2.9%]), striped bass (STB [2.4%]), HBC (1.3%), black bullhead (BBH [0.3%]), and brown trout (BNT [0.3%]).

Hoop netting efforts during riverwide sampling in 2006 captured 506 fish. Native fish constituted 77.3% and non-native fish 22.7% of all hoop net captures. Speckled dace (SPD) was the dominant species captured (58.1%), followed by fathead minnow (FHM [20.2%]), FMS (13.8%), HBC (2.8%), BHS (2.6%), RBT (2.4%), and BNT (0.2%).

## Aggregation Sampling

River discharge during the June, 2006 aggregation sampling trip (GC20060603) at Lee's Ferry ranged from 9,300 to 18,000 cfs, with an average of approximately 13,500 cfs (Figure 5; USGS 2006c). River temperatures at Lee's Ferry ranged from 9.8°C to 10.7°C, with an average of approximately 10.2°C (Figure 6; USGS 2006c).

Trammel netting efforts during aggregation sampling in 2006 captured 463 fish. Native fish constituted 86.6% and non-native fish 13.4% of all trammel net captures. FMS was the dominant species captured (51.8%), followed by HBC (19.0%), BHS (15.8%), RBT (6.0%), CCF (2.6%), CRP (2.2%), STB (1.1%), BNT (0.9%), and BBH (0.6%).

Hoop netting efforts during aggregation sampling in 2006 captured 418 fish. Native fish constituted 83.7% and non-native fish 16.3% of all hoop net captures. SPD was the dominant species captured (44.3%), followed by FMS (25.6%), FHM (14.8%), HBC (12.7%), BHS (1.2%), RBT (1.0%), BBH (0.2%), and red shiner (RSH [0.2%]).

## Seining

River discharge during the September 2006 seining trip (GC20060921) at Lee's Ferry ranged from 6,800 to 13,000 cfs, with an average of approximately 9,800 cfs (Figure 7; USGS 2006c). River temperatures at Lee's Ferry ranged from 11.6°C to 12.8°C, with an average of approximately 12.4°C (Figure 8; USGS 2006c).

A total of 7,170 fish was captured during first-pass seining efforts during GC20060921. Second-, third-, and fourth-pass captures were not included in composition analysis because unknown capture probability biases potentially exist among passes. Native fish constituted 76.7% and non-native fish 23.3% of all fish captured during initial-pass seining efforts. Of all fish captured during initial passes, SPD was the dominant species captured (33.2%), followed by FMS (32.7%), FHM (17.4%), BHS (8.4%), plains killifish (PKF [5.1%]), HBC (2.4%), CRP (<0.1%), and GSF (<0.1%). Unidentified suckers constituted <0.1% of fish captured and other unidentified fish constituted <0.1% of fish captured.

## Data Analysis

Caution should be exercised when comparing monitoring data for 2002 through 2006. The seasonality of sampling trips and the monitoring protocols have varied over the past 5 years and introduced certain biases. For example, in 2005, trammel and hoop netting targeted HBC at the LCR inflow aggregation, producing very high CPUEs for HBC. An analysis of HBC CPUEs (Figures 9–12) shows that riverwide relative abundance of HBC in 2005 was greater than for all other years. However, this is likely attributed to relatively disproportionate sampling and may not represent an increase in HBC abundance. In addition, the seasonality of trips has varied over the past 5 years. Table 9 summarizes 2002–2006 SWCA native fish monitoring trips with their sampling dates and purpose.

All comparisons of means completed during data analysis were done using an unpaired 2-sample t-test. For all tests, statistical significance was determined using a criterion *p*-value of $\leq 0.05$.

## *Percent Fish Composition and Relative Abundance*

CPUEs among reaches and riverwide for each species captured by trammel and hoop nets in 2002–2006 are summarized in Figures 9–25. Glen Canyon Dam release temperatures for 2003–2006 are presented in Figure 26. Percent fish composition among reaches for 2006 captures are summarized in Figures 27–30. Riverwide fish composition among years for 2002–2006 are summarized in Figures 31–34.

Relative abundance and fish composition data for 2005 and 2006 indicate that at that time, the Colorado River through Grand Canyon was shifting to an environment more suitable to warm-water species (Figure 26). Figures 31 and 32 show that since 2004, percent composition of FMS increased by 39% for trammel nets and 42% for hoop nets. Although an increase in percent composition of BHS did not occur, relative abundance of BHS in 2005 and 2006 for trammel and hoop nets was on an upward trend and was significantly greater than 2002–2004 levels in most cases (Figure 17). Additionally, CPUE of SPD by hoop nets for 2006 was 3.5 to 14 times greater than CPUEs for 2002–2005.

In contrast, percent composition of trout (BNT and RBT) and relative abundance decreased during 2005 and 2006. CPUE of BNT in 2005 and 2006 by trammel nets was significantly lower than 2002–2004 (Figure 20). The percent composition of BNT also decreased for trammel and hoop nets from 2004 to 2006 (Figures 31 and 32). Similarly, relative abundance of RBT in 2005 and 2006 decreased significantly from 2004 (Figure 24). Figures 31 and 32 show that RBT fish composition for trammel nets and hoop nets decreased by 34% and 18%, respectively, since 2004. Reductions in the relative abundance of trout seen riverwide in recent years may be attributed to mechanical removal efforts conducted by AGFD around the confluence of the LCR or to recent increases in river temperatures (Figure 26), or a combination of both factors.

No major differences are seen in the YoY percent fish compositions for seining captures during the 5-year period from 2002 to 2006. In addition, preliminary investigations indicated that no significant differences exist in riverwide seining relative abundance of YoY (all species combined) for the 5-year period.

### Coefficients of Variation

Summaries of CVs for 2002–2006 combined data for trammel and hoop nets are presented in Tables 10 and 11. Coefficient of variation, a measure of relative variability, has been used in Grand Canyon native fish monitoring to investigate whether CPUE data will be adequate to detect changes in abundance and achieve the long-term monitoring program objectives. In the past, a target CV of close to 0.1 was established for each species. A CV of 0.10 equals a 90% chance of detecting a 13% change in relative abundance per 1-year time step and a 53% overall change over 5 years based on a 2-tailed significance test with a linear relationship using the *TRENDS* program (Gerrodette 1987). Tables 10 and 11 show that only 1 data set from 5 years of data combined for all reaches and all species reaches the target CV of 0.1 (FMS, reach 3). This demonstrates that at least 5 times the current annual effort for each species in a given reach is needed to approach CVs near target levels. Power analyses conducted in the past (Johnstone and Lauretta 2007; Lauretta and Serrato 2006) have shown that approximately 330 trammel net samples ($\approx$33 sample nights) would be required to attain a CV of 0.1 for HBC in the LCR inflow aggregation. Levels of effort of this magnitude are not achievable under the current monitoring program.

### *Length Frequency Distribution*

Length frequencies for 2002 and 2006 trammel net captures and 2006 hoop net captures and a comparison of mean TL among years for trammel net captures for all species are presented in Figures 35 through 44. Although no significant differences were seen in FMS mean TL for trammel net captures among years, Figure 37 shows a downward trend in mean TL of FMS. This indicates that subadult FMS (190- to 250-mm range) represented a higher proportion of FMS trammel net captures. This supports the idea that FMS were spawning more successfully in recent years and that YoY were recruiting to the juvenile and subadult populations. In addition, 2006 trammel and hoop nets captured a larger proportion of FMS in the 50- to 250-mm range (Figure 37) than in 2002.

RBT and BNT mean TLs for trammel net captures both increased in 2006. Mean TL of BNT in 2006 was significantly higher than mean TLs over the previous 4 years (Figure 39). It should be noted that only 5 BNT were captured in trammel nets riverwide in 2006. Mean TL of RBT in 2006 was significantly higher than in 2005, and on average, was higher than mean TLs in 2003 and 2004 (Figure 43). This may be attributed to reduced intraspecific competition for available food resources due to reduced abundance (personal communication, Rogers 2007) in 2005 and 2006.

An interesting phenomenon is also seen in HBC length frequency distribution in 2006. Although no significant differences were seen in mean TL of trammel net captures among years for HBC, the mean TL in 2006 was lower than 2002–2005 (Figure 35). In addition, trammel nets and hoop nets riverwide in 2006 captured a large proportion of HBC in the 180- to 280-mm range (Figure 35). This indicates that at least some YoY and juvenile HBC were recruiting to the mainstem adult population.

### *Seining Capture Probabilities*

Figure 45 shows capture probabilities for all species during 2005 and 2006 multiple-pass seining depletions. Interestingly, there were no significant differences ($p < 0.05$) in capture probabilities among species captured within 2006. The overall capture probability for all species combined in 2006 was 0.826 ± 0.050 (95% CI). In 2005, there were also no significant differences ($p < 0.05$) seen for capture probabilities among any species for which at least 67 individuals were captured. For 2005, the overall capture probability for all species combined was 0.680 ± 0.023 (95% CI). In contrast, a significant difference ($p < 0.05$) was seen in the overall capture probabilities between 2005 and 2006.

Figure 46 shows the relationship between seining CPUEs and correlating backwater habitat abundance estimates made for all species captured during 2005 and 2006 seining efforts in which sufficient captures were made during depletion seining efforts to calculate a capture probability. Capture probabilities, CPUE, and abundance estimates for all species shown in Figure 46 are summarized in Table 12. Riverwide abundance in backwater habitats of HBC and BHS for size classes susceptible to seining both remained relatively steady from 2005 to 2006. Riverwide abundance in backwater habitats of FMS, SPD, and FHM all decreased from 2005 to 2006. In contrast, riverwide abundance in backwater habitats of PKF increased from 2005 to 2006 (Table 12).

### *Tag Histories*

In 2006, 562 fish were PIT tagged, including FMS (409), BHS (90), HBC (62), and BNT (1). In addition, there were 116 previously PIT-tagged fish recaptured in 2006, including FMS (68), HBC (42), BHS (3), CRP (2), and BNT (1). A summary of 2006 newly PIT-tagged and recaptured fish can be found in Table 13. Appendix A shows all trammel and hoop net HBC recaptures in 2006 and their tag history.

# DISCUSSION

***Estimate the status of and detect changes in riverwide distribution and relative abundance of native fish species, and supplement this information for non-native species***

Lowered water elevations in Lake Powell led to warmer releases from Glen Canyon Dam, especially in late summer of 2005 and 2006 (Figure 26). These warmer releases evidently resulted in increased survival, growth, and possibly mainstem reproduction by warm-water native species, including FMS and BHS. The abundance of these species increased in 2005 and 2006. Although the relative abundance of HBC riverwide did not increase significantly ($p$ <0.05) from 2002 to 2006 (Figures 9–12), higher numbers of YoY HBC in Marble Canyon in 2005 and 2006 (Table 8) indicate mainstem spawning in this reach in response to higher release temperatures. During these years, mainstem water temperatures were the warmest observed since the 1970s.

In 2005, a total of 193 HBC ranging from 21–59 mm TL were captured between RMs 30 and 57. In 2006, a total of 154 HBC ranging from 13–66 mm TL were captured in the same stretch. For comparison, only 302 YoY HBC were captured riverwide during all of the 2002–2004 seining efforts. An investigation into the swimming capabilities of similarly sized HBC (Berry and Pimentel 1985; Bulkley et al. 1982; Valdez et al. 1990; Ward 2003; Ward and Hilwig 2004) and flow data from the mainstem Colorado River in Marble Canyon (USACE 2006; Wright and Gartner 2005) indicate that these YoY are most likely not progeny of the LCR aggregation that are swimming upstream. Furthermore, the length frequency of HBC captured between RMs 30 and 57 in 2006 (Figure 47) shows two possible cohorts. A preliminary examination into this length frequency data suggests that the larger cohort (Figure 47) may be age 1+, suggesting overwinter survival of YoY HBC in Marble Canyon.

A bioenergetics model for HBC (Petersen and Paukert 2005) was used to test this hypothesis. The model was used to estimate growth rates for HBC residing within the mainstem near RM 30 at a water temperature of 12ºC. Preliminary runs of the model suggest although warmer than recent decades, current river temperatures are still too cool to allow HBC to grow from larval stage to more than 50 mm in a single year. This suggests that the larger fish seen in 2006 were spawned in 2005 and survived over the winter of 2005–2006. The preliminary findings presented here are being further investigated by Andersen et al. (2008). Post-larval HBC were found in a warm spring at RM 30 in July of 1994 (Valdez and Masslich 1999), identifying at least one potential spawning site for the species in Marble Canyon.

Juvenile HBC were not captured with trammel nets or hoop nets in Reach 2 during 2002–2006 (Figures 11 and 15) and it is not known whether progeny of the Marble Canyon spawning are recruiting to the juvenile population. Furthermore, increased river temperatures may greatly increase the relative abundance of warm-water non-natives. Leibfried (2005) demonstrated that total numbers of both STB and CCF collected above Diamond Creek significantly correlated with increased water temperature in the Colorado River ($p$ <0.05, $r^2 = 0.71$). Prolonged periods of warmer conditions (>15°C) may result in longer residence times of STB and an increase in the abundances of CCF and CRP, thereby increasing the potential for negative interactions with native fishes. Figure 25 shows that riverwide relative abundance of STB in 2006 was significantly greater than in the previous 4 years. Although no STB were captured above RM 198 in 2006, a continuation of increased temperatures may allow adult STB to expand their distribution upstream. During warmer water temperatures in 2005, AGFD electrofishing captured three STB between RMs 46.5 and 64.5 (TLs = 85, 141, and 166 mm). Stomach content analyses should be conducted on STB (and possibly other warm-water non-natives) in the near future to investigate potential predation on native fishes in the system, especially if STB and HBC distributions begin to overlap. No significant increases in the relative abundance of CCF or CRP have been observed upstream of Diamond Creek in 2006. However, monitoring below Diamond Creek in 2006 (Ackerman et al. 2006) indicates that the relative abundance of CCF, CRP, and STB may be increasing. Only two recent comparable data points (2005 and 2006) exist for monitoring downstream of Diamond Creek. The relative abundance of these species must be closely monitored in the near future if increased river temperatures persist.

It is also noted that small numbers of smallmouth bass (*Micropterus dolomieui*) were collected by other investigators in the vicinity of the LCR (GCMRC unpublished data) during the time of this overall monitoring program, 2002–2006. A ripe female (348 mm TL) was captured with electrofishing about 2 miles downstream of Glen Canyon Dam in April 2003, and five (74–354 mm TL) were caught with electrofishing between RMs 68 and 261 during early June 2005. This and other invasive fish species that may be in Grand Canyon or have access to Grand Canyon could pose a substantial predation and competition threat to native fish species. The fact that this program did not detect this species is indicative of the lack of sensitivity of a scheduled sampling program and the need to integrate information collected by other investigators.

#### ***Evaluate the utility of different fish-sampling gears for detection of long-term trends in fish relative abundance, distribution, and length structure***

Understanding the effectiveness of gear types is important in development of a monitoring program. The gear types used for this monitoring program were trammel nets, hoop nets, and seines. These gear types captured different suites and sizes of fishes, and an evaluation of these attributes for each species will help to identify the most efficient gear types and strategies for the species present in Grand Canyon, as well as possible new invasive species. Catch data for 2002–2006 show that trammel nets and hoop nets caught a similar suite of species (11 and 12 species, respectively), but that trammel nets caught a greater number of fish (Table 14, Figure 48). The most common species caught with trammel nets were RBT, FMS, HBC, and BHS. The most common species caught with hoop nets were HBC, SPD, FMS, and FHM, and the most common species caught with seines were SPD, FMS, FHS, BHS, and PKF.

A chi-square test was performed to determine selection of trammel nets, hoop nets, and seines for fish species in the Colorado River through Grand Canyon using the 2002–2006 capture data (Table 15). This analysis showed that trammel nets selected for seven species (BBH, BHS, BNT, CCF, CRP, HBC, and RBT), hoop nets selected for five species (BBH, CCF, GSF, HBC, and RBT), and seines selected for only three species (FHM, PKF, and SPD). Only the trammel nets and hoop nets were used in approximately the same habitats and the analysis shows that both gears are effective at capturing BBH, CCF, HBC, and RBT. Seines, however, were used exclusively in backwaters and selection of fish species is greatly influenced by the species of fish commonly found in backwaters.

Further analysis of gear selectivity was done by examining the sizes of each fish species captured with the three gear types. Lengths of BHS, HBC, and FMS captured with trammel nets, hoop nets, and seines during 2002–2006 in the Colorado River through Grand Canyon show distinct patterns of size selection (Figure 49). Trammel nets captured fish larger than about 180 mm TL and an average of 247, 308, and 348 mm TL for BHS, HBC, and FMS, respectively. Trammel nets were set along the river bed extending out from shore and tended to fish deep habitats inhabited by larger fish. Hoop nets captured a wider range of fish sizes starting at about 40 mm TL, with an average of 126, 142, and 141 mm TL, respectively. However, hoop nets caught more fish smaller than about 150 mm TL than trammel nets, primarily because these are set overnight along the river banks in habitats occupied primarily by small-bodied fishes and juveniles of large-bodied species. Seines clearly caught primarily small fish less than about 100 mm TL with an average of 51, 52, and 53 mm TL, respectively. Seines were used exclusively in backwaters where small-bodied fish predominate.

These analyses show that trammel nets, hoop nets, and seines complement each other in sampling the native and non-native fishes of the Colorado River through Grand Canyon. Each gear type samples a different but overlapping suite of fishes and, more importantly, each gear type captures a different size range of fish. Capturing the full array of species in the system is important for documenting absence, presence, and distribution of each species. Capturing the full range of fish sizes is important to ensure that small-, medium-, and large-bodied species are documented. But equally important is the need to document and monitor the different size categories (and presumably ages) of fish by species. This information provides a better understanding of presence or absence of reproduction by a species, growth rates, recruitment, and concentration areas of certain species by size class.

The length analysis shows that seines captured the small-bodied fish in backwaters and provides a suitable assessment of species composition and precise abundances of the more numerous species. This analysis also showed that hoop nets captured a variety of species and sizes, but did not capture the medium- and large-bodied fish as well as the trammel nets. Use of trammel nets, especially for native species in Grand Canyon, brings risk of stress to the fish, skin abrasions that may lead to infections, and latent mortality. Despite sets being reduced to 2 hours' duration, there continues to be concern over their use. Thus emerges a dilemma over whether the capture efficiency of trammel nets for medium- to large-bodied fish outweighs the risks to fish health. Studies of fish stress to different gear types are important in helping to address this question. Also, it should be possible to compare survival of PIT-tagged fish captured with hoop nets, electrofishing, and trammel nets with the existing database.

It cannot be said with certainty that the three gear types employed in this project are capable of detecting all fish species present in Grand Canyon with sufficient precision to reliably detect changes in abundance. The fact that smallmouth bass were captured by other investigators and not by this program indicates that for certain species, numbers of fish may have to increase to a minimum level before detection can occur. Alternatively, different gear types may be necessary to capture certain species because of species-specific habitat uses or behavioral attributes. This preliminary analysis of gear selectivity indicates that trammel nets, hoop nets, and seines complement each other by collectively sampling the fish species commonly known to be in Grand Canyon. Further analysis is needed that concurrently evaluates effectiveness and selectivity of trammel nets, hoop nets, seines, as well as electrofishing for monitoring of native and non-native fish in the Colorado River through Grand Canyon. Data collected by various investigators should be assimilated and analyzed appropriately to better understand the current reliability of the monitoring program, to identify necessary refinements, and to develop a well-defined program.

Caution should be exercised in the reliance of CVs in the Grand Canyon as an indicator of catch rate precision and data adequacy. CVs have been used by managers in an assortment of fisheries, including various sizes of lentic and lotic systems (Allen et al. 1999; DeVries et al. 1995; Meador and McIntyre 2003; Walters and Bonfil 1998), as a measure of sampling precision and bias. Allen et al. (1999) sampled pelagic black crappie (*Pomoxis nigromaculatus*) in Florida lakes using various trap nets and trawls. Meador and McIntyre (2003) applied CVs to species richness in lotic systems in the Midwest and eastern United States characterized by slow flows, wide floodplains, and warm water temperatures. DeVries et al. (1995) applied CVs to pelagic gizzard shad (*Dorosoma cepedianum*) in Lake Texoma. Walters and Bonfil (1998) applied CVs to a multi-species ground fish trawl fishery in British Columbia.

In each of these cases, populations were relatively evenly distributed throughout the habitat and all habitats available to the populations could be sampled. This is not the situation in the Grand Canyon. In the Grand Canyon fish community, high site fidelity and habitat selection by particular species (i.e., HBC) likely play a major role in influencing the CV. For example, a trammel net incidentally set over a warm-water influx (i.e., Fence Fault Springs) or in a HBC "school" might produce an unusually high catch rate. On the other hand, a trammel net set in habitat nearby with no warm-water influence may catch no HBC. A series of samples with this influence from high site fidelity would produce a high CV that is heavily influenced by habitat selection by the species. A similar phenomenon may be seen riverwide for a species. In the case of CCF, a six-fold increase in trammel net CPUEs was seen between Shinumo Creek (RM 108.7) and Diamond Creek (RM 225.8). The high variability in catch rates produces a high CV that is influenced in part by habitat selection of CCF as a result of temperature differences. Additionally, not all habitats available to each of the species in the Grand Canyon are available for sampling.

Coefficients of variation can prove to be a useful tool when used in trend-monitoring programs such as *TRENDS* (Gerrodette 1987). However, when management of an aquatic system produces a favorable habitat for the target species, a large-scale increase in relative abundance is often observed. For example, since 2002, the geometric mean CPUE of FMS riverwide has increased by 1,056% for trammel netting and by 607% for hoop netting. Similarly, the geometric mean CPUE of BHS has increased riverwide by 169% for trammel netting and by 1,400% for hoop netting. If conditions in the Grand Canyon river ecosystem become favorable for HBC, a similar situation will likely occur. Grand Canyon fish managers have reported significant increases in sucker populations over the past 2 years without consideration of the CV. Caution needs to be exercised regarding the use of CV to evaluate the power of monitoring program data sets in the Grand Canyon, where species are not evenly distributed throughout available habitats and not all habitats are available for sampling.

#### *Detect changes in length structure of native and non-native fish populations over time*

Decreases in mean TLs of FMS and HBC and increases in mean TLs of RBT and BNT (Figures 35–44) support the idea introduced above that the Grand Canyon aquatic ecosystem may be shifting toward an environment more suitable to warm-water species. A higher proportion of juvenile warm-water species appear to be recruiting to the adult populations than are cold-water species. This is supported by a shift in percent fish composition for trammel and hoop net captures toward a higher proportion of warm-water native species (BHS, HBC, FMS) than cold-water species in 2006 (Figures 31 and 32).

#### *Refine fish monitoring protocols and data analysis techniques to increase the efficiency of effort applied*

The principal variables that affect fish monitoring in the Colorado River through Grand Canyon are time of year (season), river flow, river temperature, habitat occurrence and distribution, and gear types. The timing of field sampling trips in the Colorado River through Grand Canyon is important to minimize the effect of river flow and temperature on sample variance. Releases from Glen Canyon Dam vary seasonally and are generally high with high fluctuations in winter and summer and low with low fluctuations in spring and fall, mostly as a reflection of peaking power demand. The timing of flows is important to ensure similar flow and temperature conditions among years for a given monitoring element. Field trips were conducted at different times of year and were standardized during 2003, 2004, and 2006 to coincide with river flow as follows: 1) stratified random sampling: low flows and fluctuations in May (range, 7,520–11,500; mean, 9,708 cfs); 2) aggregation sampling: high flows and fluctuations in June (range, 10,700–15,700; mean, 13,910 cfs); and 3) backwater seining: low flows and fluctuations in September (range, 7,270–10,500; mean, 8,593 cfs). This strategy helped to reduce the effect of flow and temperature on sampling. Stratified random riverwide sampling, aggregation sampling, and backwater sampling also helped to reduce sampling variability and to focus on key river locations where concentrations of certain fish species are reliable.

A principal aspect of resource protection in Grand Canyon is flow management. Several flow management scenarios have been implemented (e.g., beach-habitat building flows, low steady summer flows, modified low fluctuating flows, etc.) and others are likely to be implemented. The adequacy of any monitoring program to reliably and precisely measure fish response in Grand Canyon needs to be evaluated, particularly for major management actions such as flow management, temperature modification, and non-native fish removal.

An important aspect of evaluating the efficiency of sampling effort is consideration of the metrics used to measure accuracy and precision. One important metric is capture probability or catchability. Capture probability provides a gauge for how effectively and consistently a given gear type is at capturing fish. Understanding capture probability helps to determine whether catch rate indices are comparable.

According to the equation,

$$C/f = \hat{p}\, N$$

where: $C/f$ = catch per unit effort (relative abundance)
$\hat{p}$ = capture probability
$N$ = total abundance

Capture probability must remain constant in order to make inferences about the total abundance of YoY fishes in backwater habitats from catch rate metrics in the Grand Canyon. An evaluation of 2005 and 2006 depletion seining capture probabilities indicates that this is not the case from year to year in Grand Canyon fish monitoring (Figure 45). However, preliminary investigations show that there is a strong correlation ($r^2$ analysis; $r^2 = 0.95$) between CPUE and abundance estimates made for 2005 and 2006 for species in which sufficient captures were made to calculate a capture probability (Figure 46). This suggests that catch rate metrics may be sufficient to make riverwide abundance estimates in the future for young native and small-bodied nonnative species in backwater habitats.

Only 2 years of capture probability data were available from depletion seining efforts. As a result, at least a portion of all seining done each year in the Grand Canyon should be depletions in order to provide capture probability data. This will allow Grand Canyon managers to calculate annual abundance estimates and continue to investigate whether a strong correlation between seining CPUE and abundance estimates persists. If a strong correlation persists, seining efforts should continue under the current protocols. If not, either: 1) capture probabilities must be refined (via refining seining protocols) in the future for Grand Canyon backwater seining before making inferences towards total abundance of fishes in these habitats; or 2) investigations should be conducted to determine what factors influence the capture probability from year to year.

In addition to potentially providing riverwide abundance estimates of young native and small-bodied non-native species in backwater habitats, riverwide seining efforts also provide valuable presence/absence data for these fishes. For example, 2002–2006 seining efforts have documented the absence of FHM, PKF, and RSH upstream of the LCR confluence. This suggests that the majority of individuals for these species are introduced into the Colorado River via the LCR. Additionally, a large number of YoY HBC and FMS have been captured during 2005 and 2006 seining in Reach 2, which suggests that HBC and FMS have spawned in this reach in each of the past 2 years. Seining data suggest that areas within Marble Canyon may be an important stretch for rearing native species YoY.

***Increase the number of PIT tags in HBC and other native fishes to increase the precision of the ASMR model and to increase our ability to detect movement of tagged fishes***

Only one HBC recaptured in 2006 moved a considerable distance. The individual was captured on June 10, 2006, at RM 109.0 (0.4 RMs downstream of Shinumo Creek inflow aggregation). The only previous capture of this fish was on June 22, 2004, at RM 126.3 within the Middle Granite Gorge aggregation. This is an upstream movement of 17.3 RMs. Interestingly, this individual was the only 2006 HBC recapture found outside the LCR inflow aggregation.

All remaining recaptures found within the LCR inflow aggregation moved little distance from all past recapture events. This supports the accepted theory that HBC spawned and reared within the LCR inflow aggregation demonstrate high site fidelity. Thirty-eight of 42 HBC recaptured in 2006 in the mainstem of the LCR inflow aggregation were previously captured in the LCR. This supports the well-founded belief that many of the adults in the LCR inflow aggregation move freely between the LCR and the mainstem Colorado River.

## RECOMMENDATIONS

1. A comprehensive, riverwide monitoring program is needed for the Colorado River through Grand Canyon to provide a reliable and precise means by which to measure responses by the fish community to management actions.
2. The most important components of the fish community in Grand Canyon that should be monitored are the riverwide mainstem fish community, HBC aggregations, and backwaters.
3. The best gear types for monitoring the three components of the fish community are trammel nets, hoop nets, and electrofishing for the riverwide sampling and HBC aggregations, and beach seines for backwaters. Slow electrofishing should be tested as a more effective gear for large, deep backwaters.
4. The best time to monitor fishes in Grand Canyon is May for riverwide stratified random sampling, June for HBC aggregation sampling, and September/October for backwater seining. Under current dam operations, this sampling schedule occurs during low flows and low fluctuations in May, high flows and high fluctuations in June, and low flows and low fluctuations in September/October. This timing of sampling periods reduces the inter-annual effect of river flow and possibly river temperature.
5. A monitoring schedule should be maintained annually to ensure consistency of sampling, reduce variance, and provide year-to-year assessments of fish species abundance. The hiatus from monitoring in 2005 disrupted the sampling schedule for this program and made it difficult to fully assess fish population status and trends.
6. Caution is advised for over-reliance on coefficient of variation as a metric that must be met by all sampling strategies. A CV $<0.10$ can only be met with less abundant species with an inordinate—and expensive—increase in sample effort, or an increase in fish abundance. For less abundant species, a catch rate metric or an abundance estimator (e.g., removal estimator) should be used. Precision will increase as species become more abundant, as with FMS following strong year classes in 2004 and 2005.
7. A fish monitoring program for Grand Canyon should be tiered off three levels of detection: 1) sample timing, geographic coverage, and gear types should be sensitive to fish species present and their distributions; 2) reproduction by species, especially new invasive species, should be detectable; 3) approximate numbers of less abundant species (where CV $<0.10$ is not possible) should be monitored with catch rate indices or abundance estimators; 4) more abundant species should be monitored with catch rate indices; and 5) HBC aggregations should continue to be monitored with mark-recapture estimators or the ASMR model.
8. HBC aggregations should be sampled regularly and monitored for evidence of reproduction, recruitment, and increased numbers. The establishment of a second spawning aggregation in Grand Canyon is an important aspect of species recovery and existing aggregations may be the most viable manner to achieve this population redundancy (Valdez et al. 2000). The intensive monitoring conducted in the LCR inflow over the past few years has decreased our resolution to detect the status of and changes in other aggregations. For example, minimal

detections of HBC have been made in the Havasu Creek inflow aggregation and the Pumpkin Spring aggregation over the past 5 years. However, only 51 and 33 samples, respectively, were made in these aggregations over that time period. Questions exist regarding whether the relative abundance in these aggregations is even significantly higher than areas outside HBC aggregations. If CPUEs in these aggregations are not significantly higher than areas outside aggregations after a few years of sampling, eliminating their status as aggregations should be considered.

9. Occurrence of young HBC in the Colorado River upstream of the LCR should continue to be evaluated. Seining efforts in 2005 and 2006 detected unusually high captures of YoY HBC in Marble Canyon, which indicates that HBC are likely spawning successfully somewhere between RMs 30 and 57. Two or three nights sampling should occur within this stretch in an effort to discover the location of these adults. Provided that PIT-tagged adult fish are captured, the origin of this spawning group may be discovered.

10. A comprehensive analysis of all monitoring data should be conducted to assimilate and synthesize all available information, evaluate gear effectiveness and selectivity, assess timing of sampling, and develop and implement a reliable monitoring program for the fish community of the Colorado River through Grand Canyon.

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# TABLES

**Table 1.** Status and approximate relative abundance of fish species in the Colorado River, Grand Canyon, referenced in the 2006 Grand Canyon native fish monitoring report (Valdez and Ryel 1995).

| Common name | Abbreviation | Scientific Name | Status | Relative Abundance |
|---|---|---|---|---|
| Black bullhead | BBH | *Ictalurus melas* | NN | R |
| Bluehead sucker | BHS | *Catostomus discobolus* | N | C |
| Brown trout | BNT | *Salmo trutta* | NN | LC |
| Channel catfish | CCF | *Ictalurus punctatus* | NN | LC |
| Common carp | CRP | *Cyprinus carpio* | NN | C |
| Fathead minnow | FHM | *Pimephales promelas* | NN | LC |
| Flannelmouth sucker | FMS | *Catostomus latipinnis* | N | A |
| Green sunfish | GSF | *Lepomis cyanellus* | NN | R |
| Humpback chub | HBC | *Gila cypha* | N, E | LC |
| Plains killifish | PKF | *Fundulus zebrinus* | NN | LC |
| Rainbow trout | RBT | *Oncorhynchus mykiss* | NN | LC |
| Red shiner | RSH | *Cyprinella lutrensis* | NN | LC |
| Speckled dace | SPD | *Rhinichthys osculus* | N | A |
| Striped bass | STB | *Morone saxatilis* | NN | R |

Status: N=native; NN=non-native; E=endangered.

Relative abundance: A=abundant; C=common; LC=locally common; R=rare.

**Table 2.** River reaches (Walters and Korman 1999) and HBC aggregation (Valdez and Ryel 1995) river mile designations in the Colorado River, Grand Canyon.

| Reach | River Miles |
|---|---|
| 1 | 0.0–30.9 |
| 2 | 31.0–56.9 |
| 3 | 57.0–69.9 |
| 4 | 70.0–79.9 |
| 5 | 80.0–109.9 |
| 6 | 110.0–129.9 |
| 7 | 130.0–159.9 |
| 8 | 160.0–179.9 |
| 9 | 180.0–199.9 |
| 10 | 200.0–219.9 |
| 11 | 220.0–225.7 |
| **Aggregation** | **River Miles** |
| 30-Mile | 29.8–31.3 |
| Little Colorado River Inflow | 57.0–65.4 |
| Lava Chuar-Hance | 65.7–76.3 |
| Bright Angel Creek Inflow | 83.8–92.2 |
| Shinumo Creek Inflow | 108.1–108.6 |
| Stephen Aisle | 114.9–120.1 |
| Middle Granite Gorge | 126.1–129.0 |
| Havasu Creek Inflow | 155.8–156.7 |
| Pumpkin Spring | 212.5–213.2 |

**Table 3.** Subreach river mile designations (Walters and Korman 1999) in the Colorado River, Grand Canyon.

| Reach | Subreach | Start Mile | End Mile | Reach | Subreach | Start Mile | End Mile |
|---|---|---|---|---|---|---|---|
| 1 | 1.1 | 1 | 7.8 | 6 | 6.1 | 108.6 | 112.3 |
| | 1.2 | 8 | 11.2 | | 6.2 | 112.4 | 116.5 |
| | 1.3 | 11.3 | 16.8 | | 6.3 | 116.5 | 122.7 |
| | 1.4 | 17 | 20.5 | | 6.4 | 122.7 | 125 |
| | 1.5 | 20.8 | 23.2 | | 6.5 | 125 | 127 |
| | 1.5 | 23.2 | 24.5 | | 6.6 | 127 | 129 |
| | 1.5 | 25.5 | 29.1 | 7 | 7.1 | 130.5 | 131.8 |
| 2 | 2.1 | 29.1 | 36 | | 7.2 | 131.9 | 133.7 |
| | 2.2 | 36 | 43.7 | | 7.3 | 133.8 | 136 |
| | 2.3 | 43.7 | 52 | | 7.4 | 134 | 137.7 |
| | 2.4 | 52 | 56 | | 7.5 | 137.8 | 139.1 |
| 3 | 3.1 | 56 | 65.5 | | 7.6 | 139.1 | 143.5 |
| | 3.2 | 65.6 | 68.6 | | 7.7 | 143.5 | 149.7 |
| 4 | 4.1 | 68.7 | 72.5 | | 7.8 | 149.8 | 156.9 |
| | 4.2 | 72.6 | 75.5 | | 7.9 | 157 | 166.6 |
| | 4.3 | 75.5 | 76.7 | 8 | 8.1 | 166.6 | 179.5 |
| 5 | 5.1 | 78.8 | 81.2 | 9 | 9.1 | 179.8 | 190 |
| | 5.2 | 81.6 | 84.5 | | 9.2 | 190 | 200 |
| | 5.3 | 85 | 88.8 | 10 | 10.1 | 200 | 205.6 |
| | 5.4 | 90.2 | 93.5 | | 10.2 | 205.7 | 208.9 |
| | 5.5 | 93.6 | 94.8 | | 10.3 | 209.2 | 220 |
| | 5.6 | 95.1 | 98 | 11 | 11.1 | 220 | 225 |
| | 5.7 | 102 | 104.5 | | | | |
| | 5.7 | 106 | 108.5 | | | | |

**Table 4**. Sampling schedules for 2006 SWCA native fish monitoring trips.

| Date | Day | Camp RM | Travel RM | Sampling Reach | |
|---|---|---|---|---|---|
| | | | | Start RM | End RM |
| GC20060507 | | | | | |
| 5/6/2006 | Rig | 0.0 | 0.0 | No Sampling | |
| 5/7/2006 | 1 | 5.8 | 5.8 | 1.0 | 7.8 |
| 5/8/2006 | 2 | 19.0 | 13.2 | 17.0 | 20.5 |
| 5/9/2006 | 3 | 38.4 | 19.4 | 36.0 | 43.7 |
| 5/10/2006 | 4 | 44.8 | 6.4 | 43.7 | 46.0 |
| 5/11/2006 | 5 | 53.0 | 8.2 | 52.0 | 56.0 |
| 5/12/2006 | 6 | 84.0 | 31.0 | No Sampling | |
| 5/13/2006 | 7 | 96.0 | 12.0 | 95.1 | 98.0 |
| 5/14/2006 | 8 | 114.0 | 18.0 | 112.4 | 116.5 |
| 5/15/2006 | 9 | 133.0 | 19.0 | 131.9 | 133.7 |
| 5/16/2006 | 10 | 138.4 | 5.4 | 137.8 | 139.1 |
| 5/17/2006 | 11 | 164.5 | 26.1 | 162.0 | 166.6 |
| 5/18/2006 | 12 | 171.5 | 7.0 | 166.6 | 175.0 |
| 5/19/2006 | 13 | 182.8 | 11.3 | 179.8 | 190.0 |

**Table 4**. Sampling schedules for 2006 SWCA native fish monitoring trips. (Continued)

| Date | Day | Camp RM | Travel RM | Sampling Reach | |
|---|---|---|---|---|---|
| | | | | Start RM | End RM |
| **GC20060507, continued** | | | | | |
| 5/20/2006 | 14 | 192.2 | 9.4 | 195.0 | 200.0 |
| 5/21/2006 | 15 | 204.5 | 12.3 | 200.0 | 205.6 |
| 5/22/2006 | 16 | 222.0 | 17.5 | 220.0 | 223.0 |
| 5/23/2006 | 17 | Takeout | 3.7 | No Sampling | |
| **GC20060603** | | | | | |
| 6/2/2006 | Rig | 0.0 | 0.0 | No Sampling | |
| 6/3/2006 | 1 | 30.0 | 30.0 | 29.8 | 31.3 |
| 6/4/2006 | 2 | 60.8 | 30.8 | 57 | 60 |
| 6/5/2006 | 3 | 60.8 | 0.0 | 60 | 62.7 |
| 6/6/2006 | 4 | 60.8 | 0.0 | 62.7 | 65.4 |
| 6/7/2006 | 5 | 74.0 | 13.2 | 65.7 | 76.3 |
| 6/8/2006 | 6 | 87.0 | 13.0 | 83.8 | 92.2 |
| 6/9/2006 | 7 | 96.0 | 9.0 | No Sampling | |
| 6/10/2006 | 8 | 108.0 | 12.0 | 108 | 108.7 |
| 6/11/2006 | 9 | 118.0 | 10.0 | 114.9 | 117.5 |
| 6/12/2006 | 10 | 118.0 | 0.0 | 117.5 | 120.1 |
| 6/13/2006 | 11 | 127.0 | 9.0 | 126.1 | 127.5 |
| 6/14/2006 | 12 | 127.0 | 0.0 | 127.5 | 129 |
| 6/15/2006 | 13 | 158.0 | 31.0 | 155 | 156.7 |
| 6/16/2006 | 14 | 158.0 | 0.0 | 156.7 | 158.5 |
| 6/17/2006 | 15 | 190.0 | 32.0 | No Sampling | |
| 6/18/2006 | 16 | 213.0 | 23.0 | 212.5 | 213.2 |
| 6/19/2006 | 17 | Takeout | 12.7 | No Sampling | |
| **GC20060921** | | | | | |
| 9/20/2006 | Rig | 0.0 | 0.0 | 0.0 | 0.0 |
| 9/21/2006 | 1 | 14.3 | 14.3 | 0.0 | 14.3 |
| 9/22/2006 | 2 | 31.6 | 17.3 | 14.3 | 31.6 |
| 9/23/2006 | 3 | 31.6 | 0.0 | No Sampling | |
| 9/24/2006 | 4 | 44.2 | 12.6 | 31.6 | 44.2 |
| 9/25/2006 | 5 | 57.5 | 13.3 | 44.2 | 57.5 |
| 9/26/2006 | 6 | 74.4 | 16.9 | 57.5 | 74.4 |
| 9/27/2006 | 7 | 91.4 | 17.0 | 74.7 | 91.4 |
| 9/28/2006 | 8 | 114.5 | 23.1 | 91.4 | 114.5 |
| 9/29/2006 | 9 | 122.9 | 8.4 | 114.5 | 122.9 |
| 9/30/2006 | 10 | 144.2 | 21.3 | 122.9 | 144.2 |
| 10/1/2006 | 11 | 164.9 | 20.7 | 144.2 | 164.9 |
| 10/2/2006 | 12 | 179.6 | 14.7 | 164.9 | 179.6 |
| 10/3/2006 | 13 | 194.8 | 15.2 | 179.6 | 194.8 |
| 10/4/2006 | 14 | 209.5 | 14.7 | 194.8 | 209.5 |
| 10/5/2006 | 15 | 219.9 | 10.4 | 209.5 | 219.9 |
| 10/6/2006 | 16 | Takeout | 5.7 | 219.9 | 225.6 |

**Table 5.** Trammel netting effort by reach and by aggregation for SWCA native fish monitoring trips, 2002–2006.

| TRAMMEL NETTING | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reach | 2002 | | 2003 | | 2004 | | 2005 | | 2006 | | Total | |
| | Samples | Effort (hrs) | Samples | Effort (hrs) | Samples | Effort (hrs) | Samples | Effort (hrs) | Samples | Effort (hrs) | Samples | Effort (hrs) |
| 1 | 20 | 109.45 | 18 | 103.27 | 26 | 144.20 | 0 | 0.00 | 27 | 142.27 | **91** | **499.19** |
| 2 | 10 | 42.35 | 24 | 127.50 | 25 | 144.03 | 6 | 35.62 | 34 | 168.48 | **99** | **517.98** |
| 3 | 31 | 177.65 | 33 | 194.02 | 41 | 238.18 | 115 | 664.75 | 31 | 177.82 | **251** | **1452.42** |
| 4 | 22 | 130.72 | 29 | 144.25 | 0 | 0.00 | 0 | 0.00 | 10 | 57.30 | **61** | **332.27** |
| 5 | 49 | 282.00 | 60 | 358.28 | 51 | 268.62 | 0 | 0.00 | 30 | 153.33 | **190** | **1062.23** |
| 6 | 30 | 167.47 | 62 | 344.40 | 82 | 436.45 | 0 | 0.00 | 50 | 262.77 | **224** | **1211.09** |
| 7 | 35 | 200.57 | 50 | 269.65 | 47 | 272.82 | 0 | 0.00 | 40 | 225.93 | **172** | **968.97** |
| 8 | 20 | 116.05 | 31 | 177.70 | 14 | 82.78 | 0 | 0.00 | 20 | 116.62 | **85** | **493.15** |
| 9 | 20 | 100.03 | 30 | 173.08 | 20 | 117.08 | 0 | 0.00 | 21 | 115.75 | **91** | **505.94** |
| 10 | 31 | 178.53 | 0 | 0.00 | 21 | 117.70 | 0 | 0.00 | 20 | 112.20 | **72** | **408.43** |
| 11 | 18 | 89.50 | 20 | 75.18 | 20 | 99.30 | 0 | 0.00 | 10 | 38.35 | **68** | **302.33** |
| **Aggregation** | **2002** | | **2003** | | **2004** | | **2005** | | **2006** | | **Total** | |
| | **Samples** | **Effort (hrs)** | **Samples** | **Effort (hrs)** | **Samples** | **Effort (hrs)** | **Samples** | **Effort (hrs)** | **Samples** | **Effort (hrs)** | **Samples** | **Effort (hrs)** |
| 30-Mile | 8 | 45.97 | 11 | 63.52 | 19 | 104.12 | 0 | 0.00 | 8 | 41.50 | **46** | **255.11** |
| LCR Inflow | 21 | 122.73 | 30 | 176.70 | 41 | 238.18 | 94 | 547.05 | 31 | 177.82 | **217** | **1262.48** |
| Lava Chuar-Hance | 20 | 114.83 | 26 | 127.07 | 0 | 0.00 | 21 | 117.70 | 10 | 57.30 | **77** | **416.90** |
| BAC Inflow | 10 | 55.93 | 23 | 138.92 | 16 | 80.02 | 0 | 0.00 | 10 | 56.02 | **59** | **330.89** |
| SHI Inflow | 3 | 16.33 | 16 | 95.10 | 14 | 80.52 | 0 | 0.00 | 3 | 17.68 | **36** | **209.63** |
| Stephen Aisle | 10 | 59.03 | 20 | 116.28 | 23 | 127.70 | 0 | 0.00 | 25 | 124.15 | **78** | **427.16** |
| Middle Granite Gorge | 11 | 57.85 | 37 | 200.37 | 39 | 200.65 | 0 | 0.00 | 20 | 115.82 | **107** | **574.69** |
| HAV Inflow | 0 | 0.00 | 8 | 47.66 | 9 | 54.50 | 0 | 0.00 | 3 | 17.85 | **20** | **120.01** |
| Pumpkin Spring | 2 | 11.48 | 0 | 0.00 | 6 | 28.75 | 0 | 0.00 | 0 | 0.00 | **8** | **40.23** |
| Total Aggregations | 85 | 484.15 | 171 | 965.62 | 167 | 914.44 | 115 | 664.75 | 110 | 608.14 | **648** | **3637.10** |
| Outside of Aggregations | 201 | 1110.15 | 186 | 1001.72 | 180 | 1006.73 | 6 | 35.62 | 183 | 962.68 | **756** | **4116.90** |
| **Total** | **286** | **1594.32** | **357** | **1967.33** | **347** | **1921.16** | **121** | **700.37** | **293** | **1570.82** | **1404** | **7754.00** |

**Table 6.** Hoop netting effort by reach and by aggregation for SWCA native fish monitoring trips, 2002–2006.

| HOOP NETTING | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Reach** | **2002** | | **2003** | | **2004** | | **2005** | | **2006** | | **Total** | |
| | **Samples** | **Effort (hrs)** | **Samples** | **Effort (hrs)** | **Samples** | **Effort (hrs)** | **Samples** | **Effort (hrs)** | **Samples** | **Effort (hrs)** | **Samples** | **Effort (hrs)** |
| 1 | 72 | 1214.17 | 96 | 1744.87 | 99 | 1833.73 | 0 | 0.00 | 99 | 1806.0 | **366** | **6598.8** |
| 2 | 36 | 615.67 | 48 | 944.43 | 81 | 1408.95 | 12 | 237.75 | 117 | 2000.2 | **294** | **5207.0** |
| 3 | 72 | 1444.32 | 120 | 2301.58 | 144 | 2736.90 | 420 | 9401.82 | 108 | 2262.1 | **864** | **18146.8** |
| 4 | 75 | 1330.25 | 96 | 1813.65 | 0 | 0.00 | 0 | 0.00 | 36 | 610.7 | **207** | **3754.6** |
| 5 | 174 | 3031.50 | 223 | 4167.50 | 180 | 3192.50 | 0 | 0.00 | 108 | 1834.3 | **685** | **12225.8** |
| 6 | 93 | 1672.30 | 216 | 4338.70 | 288 | 5774.02 | 0 | 0.00 | 180 | 3443.9 | **777** | **15228.9** |
| 7 | 153 | 2667.77 | 180 | 3649.00 | 177 | 3405.90 | 0 | 0.00 | 144 | 2704.0 | **654** | **12426.7** |
| 8 | 45 | 772.52 | 107 | 1817.65 | 39 | 694.00 | 0 | 0.00 | 72 | 1291.7 | **263** | **4575.8** |
| 9 | 69 | 1184.48 | 108 | 1835.55 | 72 | 1188.62 | 0 | 0.00 | 72 | 1265.2 | **321** | **5473.9** |
| 10 | 108 | 1847.37 | 0 | 0.00 | 72 | 1212.75 | 0 | 0.00 | 72 | 1200.3 | **252** | **4260.4** |
| 11 | 0 | 0.00 | 25 | 317.60 | 36 | 432.82 | 0 | 0.00 | 36 | 584.4 | **97** | **1334.8** |
| **Aggregation** | **2002** | | **2003** | | **2004** | | **2005** | | **2006** | | **Total** | |
| | **Samples** | **Effort (hrs)** | **Samples** | **Effort (hrs)** | **Samples** | **Effort (hrs)** | **Samples** | **Effort (hrs)** | **Samples** | **Effort (hrs)** | **Samples** | **Effort (hrs)** |
| 30-Mile | 27 | 450.20 | 66 | 1262.00 | 63 | 1274.40 | 0 | 0.00 | 36 | 589.9 | **192** | **3576.5** |
| LCR Inflow | 72 | 1444.32 | 108 | 2089.93 | 144 | 2736.90 | 348 | 7756.57 | 108 | 2262.13 | **780** | **16289.9** |
| Lava Chuar-Hance | 33 | 573.85 | 99 | 1874.20 | 0 | 0.00 | 72 | 1645.25 | 36 | 610.7 | **240** | **4704.0** |
| BAC Inflow | 36 | 594.78 | 87 | 1431.70 | 78 | 1272.60 | 0 | 0.00 | 36 | 628 | **237** | **3927.1** |
| SHI Inflow | 30 | 508.50 | 73 | 1460.20 | 51 | 1055.60 | 0 | 0.00 | 9 | 156.4 | **163** | **3180.7** |
| Stephen Aisle | 36 | 641.20 | 63 | 1074.30 | 75 | 1457.10 | 0 | 0.00 | 75 | 1387.45 | **249** | **4560.1** |
| Middle Granite Gorge | 36 | 644.70 | 126 | 2733.85 | 141 | 3088.07 | 0 | 0.00 | 72 | 1430.85 | **375** | **7897.5** |
| HAV Inflow | 0 | 0.00 | 30 | 591.65 | 0 | 0.00 | 0 | 0.00 | 21 | 427.25 | **51** | **1018.9** |
| Pumpkin Spring | 12 | 208.45 | 0 | 0.00 | 21 | 357.35 | 0 | 0.00 | 0 | 0 | **33** | **565.8** |
| Total Aggregations | 282 | 5066.00 | 652 | 12517.83 | 573 | 11242.02 | 420 | 9401.82 | 393 | 7492.68 | **2320** | **45720.35** |
| Outside of Aggregations | 615 | 10714.23 | 567 | 10412.70 | 615 | 10638.17 | 12 | 237.75 | 651 | 11510.15 | **2460** | **43513.00** |
| **Total** | **897** | **15780.35** | **1219** | **22930.53** | **1188** | **21880.19** | **432** | **9639.57** | **1044** | **19002.83** | **4780** | **89233.5** |

**Table 7.** Seining effort by reach and by aggregation for SWCA native fish monitoring trips, 2002–2006.

| SEINING | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Reach** | **2002** | | **2003** | | **2004** | | **2005** | | **2006** | | **Total** | |
| | **Samples** | **Effort ($m^2$)** | **Samples** | **Effort ($m^2$)** | **Samples** | **Effort ($m^2$)** | **Samples** | **Effort ($m^2$)** | **Samples** | **Effort ($m^2$)** | **Samples** | **Effort ($m^2$)** |
| 1 | 6 | 181.60 | 41 | 1064.49 | 51 | 1680.43 | 25 | 1138.15 | 40 | 1226.2 | **163** | **5290.9** |
| 2 | 29 | 1116.32 | 47 | 2006.28 | 55 | 3116.92 | 44 | 2562.18 | 77 | 2516.4 | **252** | **11318.1** |
| 3 | 7 | 364.80 | 27 | 1005.33 | 21 | 915.04 | 18 | 932.04 | 21 | 747.1 | **94** | **3964.3** |
| 4 | 6 | 211.00 | 6 | 247.41 | 13 | 520.40 | 7 | 216.36 | 7 | 299.1 | **39** | **1494.3** |
| 5 | 5 | 234.00 | 15 | 431.47 | 12 | 386.37 | 7 | 231.90 | 15 | 276.2 | **54** | **1559.9** |
| 6 | 15 | 509.60 | 32 | 1392.82 | 22 | 1007.16 | 14 | 570.13 | 30 | 859.2 | **113** | **4338.9** |
| 7 | 10 | 234.00 | 18 | 370.75 | 24 | 616.08 | 7 | 192.03 | 17 | 332.0 | **76** | **1744.8** |
| 8 | 23 | 796.20 | 44 | 914.60 | 44 | 1210.74 | 26 | 912.52 | 38 | 1078.0 | **175** | **4912.1** |
| 9 | 18 | 500.40 | 37 | 1024.91 | 37 | 1049.75 | 30 | 947.15 | 36 | 1309.7 | **158** | **4831.9** |
| 10 | 13 | 466.60 | 33 | 910.34 | 28 | 769.34 | 29 | 1094.65 | 33 | 1063.8 | **136** | **4304.7** |
| 11 | 5 | 102.20 | 5 | 188.10 | 6 | 129.60 | 4 | 110.15 | 10 | 250.1 | **30** | **780.2** |
| **Aggregation** | **2002** | | **2003** | | **2004** | | **2005** | | **2006** | | **Total** | |
| | **Samples** | **Effort ($m^2$)** | **Samples** | **Effort ($m^2$)** | **Samples** | **Effort ($m^2$)** | **Samples** | **Effort ($m^2$)** | **Samples** | **Effort ($m^2$)** | **Samples** | **Effort ($m^2$)** |
| 30-Mile | 6 | 181.60 | 3 | 85.90 | 4 | 95.76 | 3 | 188.82 | 5 | 82.05 | **21** | **634.1** |
| LCR Inflow | 3 | 86.80 | 22 | 856.93 | 15 | 725.49 | 16 | 800.96 | 16 | 514.51 | **72** | **2984.7** |
| Lava Chuar-Hance | 10 | 489.00 | 9 | 395.81 | 17 | 648.90 | 6 | 265.63 | 11 | 519.38 | **53** | **2318.7** |
| BAC Inflow | 0 | 0.00 | 1 | 90.00 | 5 | 208.45 | 2 | 82.24 | 6 | 88.59 | **14** | **469.3** |
| SHI Inflow | 0 | 0.00 | 5 | 127.98 | 0 | 0.00 | 0 | 0.00 | 0 | 0 | **5** | **128.0** |
| Stephen Aisle | 4 | 106.00 | 14 | 261.40 | 6 | 339.66 | 6 | 205.16 | 14 | 459.38 | **44** | **1371.6** |
| Middle Granite Gorge | 0 | 0.00 | 2 | 47.85 | 2 | 103.65 | 2 | 81.56 | 4 | 111.94 | **10** | **345.0** |
| HAV Inflow | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 1 | 14.40 | 0 | 0 | **1** | **14.4** |
| Pumpkin Spring | 0 | 0.00 | 2 | 75.31 | 2 | 48.00 | 1 | 43.57 | 4 | 161 | **9** | **327.9** |
| Outside of Aggregations | 114 | 3853.32 | 247 | 7615.32 | 262 | 9231.92 | 174 | 7224.89 | 264 | 8020.94 | **1061** | **35946.4** |
| **Total** | **137** | **4716.72** | **305** | **9556.50** | **313** | **11401.83** | **211** | **8907.26** | **324** | **9957.79** | **1290** | **44540.1** |

**Table 8.** Sampling effort and fish captures by gear type for 2006 SWCA native fish monitoring activities.

**Hoop Netting**

| Reach | # of Samples | BBH | BHS | BNT | FHM | FMS | HBC | RBT | RSH | SPD |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 99 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| 2 | 117 | 0 | 0 | 0 | 0 | 4 | 1 | 0 | 0 | 5 |
| 3 | 108 | 0 | 1 | 0 | 20 | 20 | 38 | 0 | 0 | 8 |
| 4 | 36 | 1 | 0 | 0 | 13 | 9 | 7 | 1 | 0 | 3 |
| 5 | 108 | 0 | 4 | 0 | 3 | 4 | 2 | 0 | 0 | 21 |
| 6 | 180 | 0 | 2 | 0 | 39 | 46 | 6 | 2 | 0 | 84 |
| 7 | 144 | 0 | 8 | 1 | 24 | 40 | 2 | 12 | 1 | 117 |
| 8 | 72 | 0 | 2 | 0 | 25 | 27 | 10 | 0 | 0 | 138 |
| 9 | 72 | 0 | 0 | 0 | 8 | 18 | 1 | 0 | 0 | 69 |
| 10 | 72 | 0 | 1 | 0 | 32 | 7 | 0 | 0 | 0 | 32 |
| 11 | 36 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 1 |
| **Total** | **1044** | **1** | **18** | **1** | **164** | **177** | **67** | **16** | **1** | **479** |

**Trammel Netting**

| Reach | # of Samples | BBH | BHS | BNT | CRP | CCF | FMS | HBC | RBT | STB |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 27 | 0 | 1 | 0 | 0 | 0 | 10 | 0 | 24 | 0 |
| 2 | 34 | 0 | 2 | 0 | 0 | 0 | 23 | 0 | 52 | 0 |
| 3 | 31 | 0 | 49 | 0 | 1 | 0 | 116 | 60 | 11 | 0 |
| 4 | 10 | 0 | 5 | 1 | 0 | 0 | 28 | 0 | 7 | 0 |
| 5 | 30 | 0 | 7 | 2 | 3 | 0 | 18 | 8 | 1 | 0 |
| 6 | 50 | 0 | 12 | 1 | 8 | 1 | 65 | 19 | 3 | 0 |
| 7 | 40 | 0 | 11 | 0 | 2 | 3 | 51 | 1 | 6 | 0 |
| 8 | 20 | 0 | 3 | 0 | 4 | 1 | 92 | 1 | 0 | 0 |
| 9 | 21 | 1 | 2 | 0 | 8 | 6 | 43 | 2 | 0 | 1 |
| 10 | 20 | 3 | 0 | 1 | 13 | 9 | 15 | 2 | 0 | 7 |
| 11 | 10 | 0 | 0 | 0 | 1 | 3 | 6 | 0 | 0 | 6 |
| **Total** | **293** | **4** | **92** | **5** | **40** | **23** | **467** | **93** | **104** | **14** |

**Seining**

| Reach | # of Samples | BHS | CRP | FHM | FMS | GSF | HBC | PKF | SPD | UIF | UIS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 33 | 3 | 0 | 0 | 1 | 0 | 0 | 0 | 5 | 0 | 3 |
| 2 | 56 | 46 | 0 | 0 | 626 | 1 | 142 | 0 | 342 | 8 | 22 |
| 3 | 17 | 30 | 4 | 109 | 63 | 0 | 12 | 67 | 9 | 1 | 4 |
| 4 | 5 | 61 | 1 | 70 | 19 | 0 | 1 | 86 | 1 | 2 | 0 |
| 5 | 9 | 19 | 0 | 13 | 20 | 0 | 0 | 17 | 10 | 0 | 0 |
| 6 | 22 | 100 | 3 | 59 | 135 | 0 | 7 | 34 | 57 | 0 | 3 |
| 7 | 13 | 20 | 1 | 110 | 47 | 0 | 4 | 19 | 224 | 0 | 4 |
| 8 | 29 | 250 | 1 | 533 | 954 | 0 | 3 | 64 | 635 | 1 | 0 |
| 9 | 29 | 20 | 1 | 47 | 148 | 0 | 0 | 35 | 418 | 0 | 0 |
| 10 | 25 | 53 | 0 | 301 | 328 | 0 | 0 | 44 | 656 | 0 | 0 |
| 11 | 6 | 1 | 0 | 2 | 4 | 0 | 0 | 0 | 25 | 0 | 1 |
| **Total** | **244** | **603** | **11** | **1,244** | **2,345** | **1** | **169** | **366** | **2382** | **12** | **37** |

**Table 9.** Summary of SWCA native fish monitoring trips, 2002–2006.

| Year | Trip | Start Date | End Date | Description |
|---|---|---|---|---|
| 2002 | GC20020718 | 7/18/2002 | 8/2/2002 | Stratified Random Sampling; Opportunistic Seining |
| | GC20020912 | 9/12/2002 | 9/27/2002 | Primarily Aggregation Sampling; Secondarily Stratified Random Sampling; Opportunistic Seining |
| 2003 | GC20030503 | 5/3/2003 | 5/21/2003 | Stratified Random Sampling |
| | GC20030614 | 6/14/2003 | 6/30/2003 | Aggregation Sampling |
| | GC20030913 | 9/13/2003 | 9/28/2003 | Backwater Seining |
| 2004 | GC20040515 | 5/15/2004 | 6/1/2004 | Stratified Random Sampling |
| | GC20040612 | 6/12/2004 | 6/28/2004 | Aggregation Sampling |
| | GC20040915 | 9/15/2004 | 9/29/2004 | Backwater Seining |
| 2005 | GC20050611 | 6/11/2005 | 6/27/2005 | LCR Inflow Population Estimate; Increase HBC Mark and Recapture Information |
| | GC20050922 | 9/22/2005 | 10/7/2005 | Backwater Seining |
| 2006 | GC20060507 | 5/7/2006 | 5/23/2006 | Stratified Random Sampling |
| | GC20060603 | 6/3/2006 | 6/19/2006 | Aggregation Sampling |
| | GC20060921 | 9/21/2006 | 10/6/2006 | Backwater Seining |

**Table 10**. Summary of CVs for all 2002–2006 trammel netting data combined.

| TRAMMEL NETTING | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | Reach | | | | | | | | | | | Riverwide |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | |
| **HBC** | 0.62 | 1.00 | 0.11 | 0.57 | 0.26 | 0.17 | 0.37 | 1.00 | 0.70 | 1.00 | x | 0.09 |
| **yoy HBC** | x | x | x | x | x | x | x | x | x | x | x | x |
| **juv HBC** | x | x | 0.23 | 1.00 | 0.62 | 0.61 | 0.71 | x | x | 1.00 | x | 0.19 |
| **adlt HBC** | 0.61 | 1.00 | 0.11 | x | 0.27 | 0.17 | 0.43 | 1.00 | 0.70 | 1.00 | x | 0.10 |
| **FMS** | 0.32 | 0.25 | 0.09 | 0.35 | 0.23 | 0.18 | 0.16 | 0.20 | 0.23 | 0.26 | 0.36 | 0.06 |
| **yoy FMS** | x | x | x | x | x | x | x | x | x | x | x | x |
| **juv FMS** | x | x | 0.71 | x | x | x | x | 1.00 | x | x | x | 0.62 |
| **adlt FMS** | 0.32 | 0.29 | 0.10 | 0.36 | 0.25 | 0.18 | 0.17 | 0.21 | 0.23 | 0.29 | 0.36 | 0.07 |
| **BHS** | 1.00 | 1.00 | 0.11 | 0.30 | 0.24 | 0.21 | 0.18 | 0.52 | 0.40 | 0.70 | x | 0.08 |
| **yoy BHS** | x | x | x | x | x | x | x | x | x | x | x | x |
| **juv BHS** | x | x | x | x | x | x | x | x | x | x | x | x |
| **adlt BHS** | 1.00 | 1.00 | 0.12 | 0.44 | 0.32 | 0.24 | 0.23 | 0.60 | 0.49 | x | x | 0.09 |
| **BBH** | x | x | 0.40 | x | x | x | x | x | 1.00 | 0.57 | x | 0.32 |
| **BNT** | x | 0.70 | 0.40 | 1.00 | 0.18 | 0.19 | 0.32 | 0.38 | 1.00 | 1.00 | x | 0.13 |
| **CCF** | x | x | 0.71 | x | 1.00 | 0.61 | 0.46 | 0.52 | 0.35 | 0.23 | 0.29 | 0.15 |
| **CRP** | x | x | 0.58 | 1.00 | 0.33 | 0.29 | 0.30 | 0.31 | 0.20 | 0.24 | 0.36 | 0.11 |
| **RBT** | 0.15 | 0.12 | 0.13 | 0.22 | 0.16 | 0.15 | 0.16 | 0.29 | 0.70 | x | x | 0.06 |
| **STB** | x | x | x | x | x | x | 1.00 | x | 0.70 | 0.30 | 0.46 | 0.26 |

| Species | Aggregation | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 30MILE | LCRINF | LAVACH | BACINF | SHIINF | STEAIS | MIDGRA | HAVINF | PUMPSP | OUTAGG |
| **HBC** | 0.56 | 0.11 | 0.33 | 0.66 | 0.33 | 0.34 | 0.20 | 1.00 | x | 0.24 |
| **yoy HBC** | x | x | x | x | x | x | x | x | x | x |
| **juv HBC** | x | 0.25 | 0.62 | 1.00 | 0.70 | 1.00 | 0.74 | x | x | 0.58 |
| **adlt HBC** | 0.51 | 0.12 | 0.38 | 0.57 | 0.34 | 0.35 | 0.20 | 1.00 | x | 0.28 |

x = No Fish Capture

Aggregations: 30MILE = 30-Mile; LCRINF = Little Colorado River Inflow; LAVACH = Larva Chuar-Hance; BACINF = Bright Angel Creek Inflow; SHIINF = Shinumo Creek Inflow; STEAIS = Stephen Aisle; MIDGRA = Middle Granite Gorge; HAVINF = Havasu Creek Inflow; PUMPSP = Pumpkin Spring; OUTAGG = Outside of Aggregations

**Table 11**. Summary of CVs for all 2002–2006 hoop netting data combined.

| HOOP NETTING | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | Reach | | | | | | | | | | | Riverwide |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | |
| **HBC** | 1.00 | 0.71 | 0.12 | 0.20 | 0.22 | 0.19 | 0.35 | 0.42 | 0.58 | 0.74 | 1.00 | 0.10 |
| **yoy HBC** | x | 1.00 | 0.15 | 0.43 | 0.38 | 0.29 | 0.71 | 0.45 | 0.71 | 0.74 | 1.00 | 0.14 |
| **juv HBC** | x | x | 0.15 | 0.44 | 0.37 | 0.41 | 1.00 | 1.00 | 1.00 | x | x | 0.13 |
| **adlt HBC** | 1.00 | 1.00 | 0.13 | x | 0.50 | 0.32 | 0.72 | x | x | x | x | 0.12 |
| **FMS** | 1.00 | 0.48 | 0.23 | 0.89 | 0.33 | 0.17 | 0.16 | 0.21 | 0.19 | 0.33 | 0.40 | 0.08 |
| **yoy FMS** | x | 0.61 | 0.29 | 1.00 | 0.46 | 0.21 | 0.22 | 0.29 | 0.24 | 0.36 | 0.57 | 0.11 |
| **juv FMS** | x | 1.00 | 0.41 | 1.00 | x | 0.45 | 0.51 | 0.71 | 0.44 | 0.71 | x | 0.20 |
| **adlt FMS** | 1.00 | 1.00 | 0.58 | 1.00 | 0.53 | 0.30 | 0.25 | 0.46 | 0.37 | x | 0.58 | 0.14 |
| **BHS** | x | x | 0.33 | x | 0.61 | 0.71 | 0.38 | 0.71 | 0.66 | 1.00 | x | 0.21 |
| **yoy BHS** | x | x | 0.71 | x | 0.74 | 1.00 | 0.60 | 0.71 | 1.00 | x | x | 0.32 |
| **juv BHS** | x | x | 0.58 | x | x | x | 0.58 | x | x | x | x | 0.41 |
| **adlt BHS** | x | x | 0.50 | x | x | 1.00 | 1.00 | x | 0.79 | 1.00 | x | 0.40 |
| **SPD** | 1.00 | 0.53 | 0.34 | 0.44 | 0.25 | 0.24 | 0.18 | 0.16 | 0.14 | 0.18 | 0.39 | 0.07 |
| **BBH** | x | x | 0.35 | 1.00 | x | x | x | x | x | x | x | 0.34 |
| **BNT** | x | 1.00 | x | x | 0.50 | 0.50 | 1.00 | x | x | x | x | 0.30 |
| **CCF** | x | x | 1.00 | x | x | x | x | x | x | x | x | 1.00 |
| **CRP** | x | x | 0.50 | x | x | x | 1.00 | x | 0.74 | x | x | 0.41 |
| **FHM** | x | x | 0.28 | 0.47 | 0.52 | 0.38 | 0.39 | 0.29 | 0.33 | 0.48 | 1.00 | 0.15 |
| **GSF** | x | x | 0.71 | x | x | 1.00 | x | x | x | x | x | 0.58 |
| **PKF** | x | x | x | 0.71 | x | x | x | x | x | x | x | 0.71 |
| **RBT** | 0.23 | 0.27 | 0.23 | 0.36 | 0.27 | 0.17 | 0.17 | 0.50 | 0.58 | x | x | 0.09 |
| **RSH** | x | x | 0.58 | x | x | x | 1.00 | x | x | x | x | 0.51 |

| Species | Aggregation | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 30MILE | LCRINF | LAVACH | BACINF | SHIINF | STEAIS | MIDGRA | HAVINF | PUMPSP | OUTAGG |
| **HBC** | 1.00 | 0.13 | 0.22 | 0.42 | 0.27 | 0.43 | 0.22 | x | 1.00 | 0.17 |
| **yoy HBC** | x | 0.17 | 0.27 | 0.57 | 0.50 | 0.50 | 0.41 | x | 1.00 | 0.27 |
| **juv HBC** | x | 0.16 | 0.27 | 0.71 | 0.45 | x | 0.41 | x | x | 0.45 |
| **adlt HBC** | 1.00 | 0.13 | 1.00 | 0.71 | 0.71 | 0.74 | 0.33 | x | x | 0.58 |

x = No Fish Capture

Aggregations: 30MILE = 30-Mile; LCRINF = Little Colorado River Inflow; LAVACH = Larva Chuar-Hance; BACINF = Bright Angel Creek Inflow; SHIINF = Shinumo Creek Inflow; STEAIS = Stephen Aisle; MIDGRA = Middle Granite Gorge; HAVINF = Havasu Creek Inflow; PUMPSP = Pumpkin Spring; OUTAGG = Outside of Aggregations

**Table 12.** Summary of capture probabilities, CPUE, and abundance estimates for all species capture in 2005 and 2006 in which sufficient captures were made during depletion seining efforts to calculate a capture probability.

| 2005 | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Species** | **Capture Probability** | | | | **Abundance Estimate** | | |
| | **p** | **L 95% CI** | **U 95% CI** | **CPUE (#/m²)** | **N** | **Lower N** | **Upper N** |
| **HBC** | 0.7639 | 0.6185 | 0.9093 | 0.0320 | 369 | 310 | 456 |
| **FMS** | 0.6299 | 0.5907 | 0.6691 | 0.2653 | 3715 | 3497 | 3961 |
| **SPD** | 0.6308 | 0.5836 | 0.6780 | 0.3452 | 4827 | 4491 | 5217 |
| **BHS** | 0.6528 | 0.5322 | 0.7734 | 0.0534 | 722 | 609 | 885 |
| **CRP** | 0.5159 | 0.1449 | 0.8868 | 0.0006 | 10 | 6 | 35 |
| **FHM** | 0.6554 | 0.6205 | 0.6904 | 0.2512 | 3381 | 3210 | 3571 |
| **PKF** | 0.5784 | 0.4023 | 0.7546 | 0.0086 | 131 | 101 | 189 |

| 2006 | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Species** | **Capture Probability** | | | | **Abundance Estimate** | | |
| | **p** | **L 95% CI** | **U 95% CI** | **CPUE (#/m²)** | **N** | **Lower** | **Upper** |
| **HBC** | 0.7181 | 0.4676 | 0.9686 | 0.0203 | 237 | 176 | 506 |
| **FMS** | 0.8560 | 0.7510 | 0.9610 | 0.2618 | 2555 | 2276 | 3402 |
| **BHS** | 0.8350 | 0.6418 | 1.0281 | 0.0725 | 726 | 589 | 1131 |
| **SPD** | 0.8299 | 0.7491 | 0.9108 | 0.2876 | 2895 | 2638 | 3865 |
| **FHM** | 0.8080 | 0.7076 | 0.9084 | 0.1485 | 1536 | 1366 | 2171 |
| **PKF** | 0.7494 | 0.4469 | 1.0519 | 0.0456 | 508 | 362 | 1138 |

**Table 13.** Summary of newly tagged fish and recaptured fish during 2006 SWCA native fish monitoring activities.

| Species | New Tags | Recaptures |
|---|---|---|
| **BHS** | 90 | 3 |
| **BNT** | 1 | 1 |
| **CRP** | 0 | 2 |
| **FMS** | 409 | 68 |
| **HBC** | 62 | 42 |
| **Total** | **562** | **116** |

**Table 14.** Numbers of fish caught by species with trammel nets, hoop nets, and seines during 2002–2006 in the Colorado River through Grand Canyon.

| | Trammel Nets | | | | | | Hoop Nets | | | | | | Seines | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Species** | **2002** | **2003** | **2004** | **2005** | **2006** | **Totals** | **2002** | **2003** | **2004** | **2005** | **2006** | **Totals** | **2002** | **2003** | **2004** | **2005** | **2006** | **Totals** |
| **BBH** | 0 | 0 | 1 | 5 | 4 | 10 | 0 | 0 | 3 | 5 | 1 | 9 | 0 | 0 | 0 | 0 | 0 | 0 |
| **BHS** | 55 | 35 | 14 | 73 | 92 | 269 | 1 | 6 | 0 | 8 | 18 | 33 | 29 | 182 | 43 | 472 | 603 | 1,329 |
| **BNT** | 70 | 67 | 43 | 2 | 5 | 187 | 4 | 5 | 2 | 0 | 1 | 12 | 0 | 2 | 0 | 0 | 0 | 2 |
| **CCF** | 26 | 17 | 20 | 2 | 23 | 88 | 5 | 22 | 0 | 0 | 0 | 27 | 0 | 1 | 1 | 0 | 0 | 2 |
| **CRP** | 35 | 39 | 17 | 2 | 40 | 133 | 0 | 4 | 0 | 4 | 0 | 8 | 8 | 12 | 14 | 5 | 11 | 50 |
| **FHM** | 0 | 0 | 159 | 0 | 0 | 159 | 12 | 22 | 12 | 92 | 164 | 302 | 311 | 840 | 1,328 | 2,216 | 1,244 | 5,939 |
| **FMS** | 52 | 154 | 0 | 153 | 467 | 826 | 48 | 54 | 43 | 17 | 177 | 339 | 1,100 | 1,377 | 1,877 | 2,451 | 2,345 | 9,150 |
| **GSF** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 1 | 1 |
| **HBC** | 38 | 69 | 82 | 178 | 93 | 460 | 21 | 73 | 79 | 669 | 67 | 909 | 13 | 125 | 163 | 286 | 169 | 756 |
| **PKF** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 308 | 226 | 347 | 76 | 366 | 1,323 |
| **RBT** | 163 | 259 | 279 | 46 | 104 | 851 | 46 | 89 | 42 | 17 | 16 | 210 | 19 | 43 | 46 | 2 | 0 | 110 |
| **RSH** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 4 | 14 | 10 | 7 | 9 | 0 | 40 |
| **SPD** | 3 | 1 | 0 | 0 | 14 | 18 | 20 | 55 | 148 | 6 | 479 | 708 | 1,414 | 1,746 | 3,821 | 3,049 | 2,382 | 12,412 |
| **STB** | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 15.** Chi-square test of heterogeneity and independence to determine selection (+), negative selection (-), or no selection (0) of trammel nets, hoop nets, and seines for fish species in the Colorado River through Grand Canyon using 2002–2006 capture data.

| Species | Statistic | Trammel | Hoop | Seines | Species | Statistic | Trammel | Hoop | Seines |
|---|---|---|---|---|---|---|---|---|---|
| BBH | Observed | 10 | 9 | 0 | GSF | Observed | 0 | 3 | 1 |
| | Expected | 1.56 | 1.33 | 16.12 | | Expected | 0.33 | 0.28 | 3.39 |
| | Chi-square | + | + | 0 | | Chi-square | 0 | + | 0 |
| BHS | Observed | 269 | 33 | 1329 | HBC | Observed | 460 | 909 | 756 |
| | Expected | 133.49 | 114.01 | 1383.50 | | Expected | 173.92 | 148.54 | 1802.54 |
| | Chi-square | + | - | 0 | | Chi-square | + | + | - |
| BNT | Observed | 187 | 12 | 2 | PKF | Observed | 0 | 0 | 1323 |
| | Expected | 16.45 | 14.05 | 170.50 | | Expected | 108.28 | 92.48 | 1122.24 |
| | Chi-square | + | 0 | - | | Chi-square | - | - | + |
| CCF | Observed | 88 | 27 | 2 | RBT | Observed | 851 | 210 | 110 |
| | Expected | 9.58 | 8.18 | 99.25 | | Expected | 95.84 | 81.86 | 993.31 |
| | Chi-square | + | + | - | | Chi-square | + | + | - |
| CRP | Observed | 133 | 8 | 50 | RSH | Observed | 0 | 4 | 40 |
| | Expected | 15.63 | 13.35 | 162.02 | | Expected | 3.60 | 3.08 | 37.32 |
| | Chi-square | + | 0 | - | | Chi-square | 0 | 0 | 0 |
| FHM | Observed | 159 | 302 | 5939 | SPD | Observed | 18 | 708 | 12412 |
| | Expected | 523.79 | 447.37 | 5428.83 | | Expected | 1075.25 | 918.37 | 11144.4 |
| | Chi-square | - | - | + | | Chi-square | - | - | + |
| FMS | Observed | 826 | 339 | 9150 | STB | Observed | 1 | 0 | 0 |
| | Expected | 844.21 | 721.04 | 8749.75 | | Expected | 0.08 | 0.07 | 0.85 |
| | Chi-square | 0 | - | 0 | | Chi-square | 0 | 0 | 0 |

# FIGURES

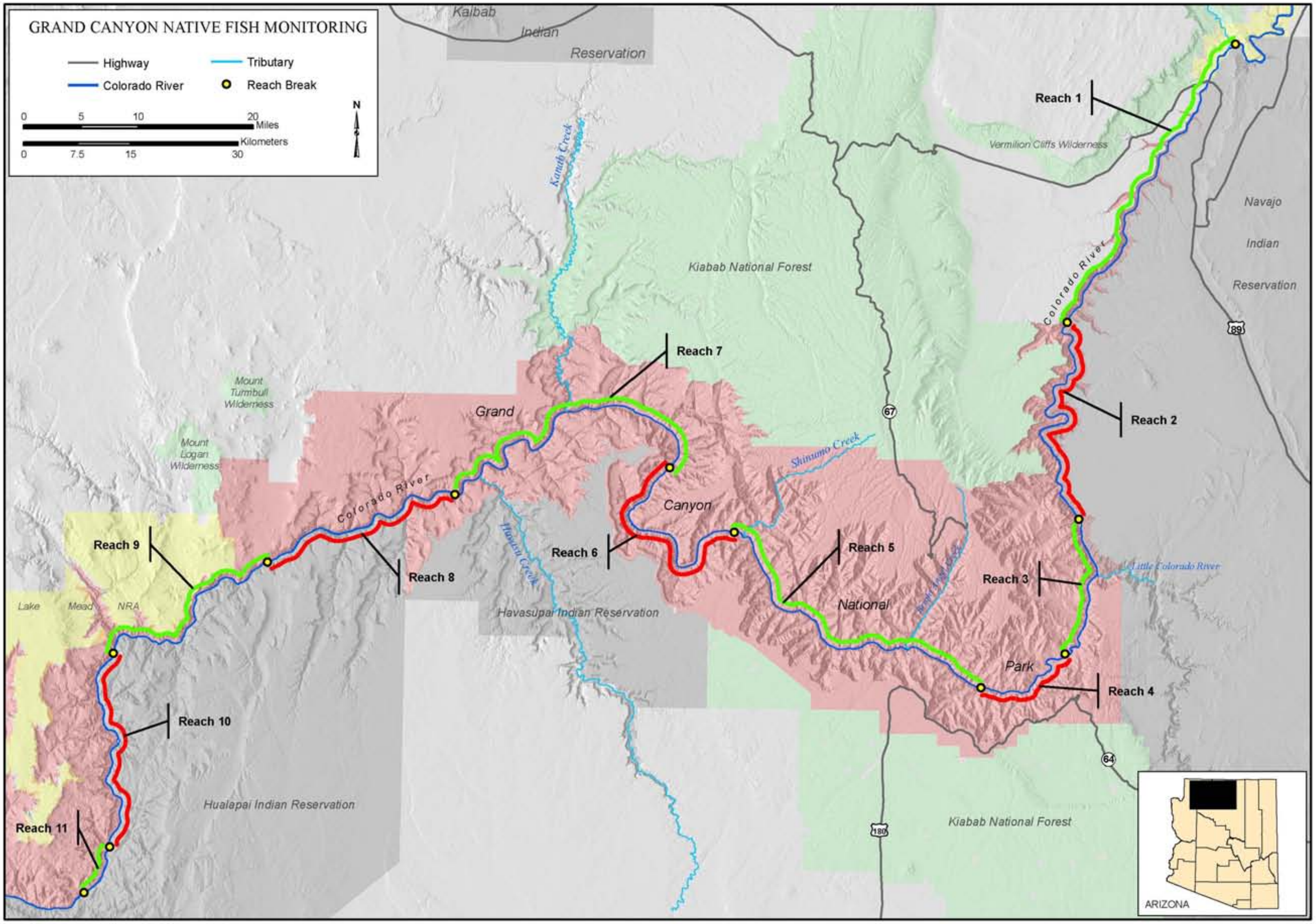



**Figure 1.** Designated river reaches in the Colorado River, Grand Canyon (Walters and Korman 1999).

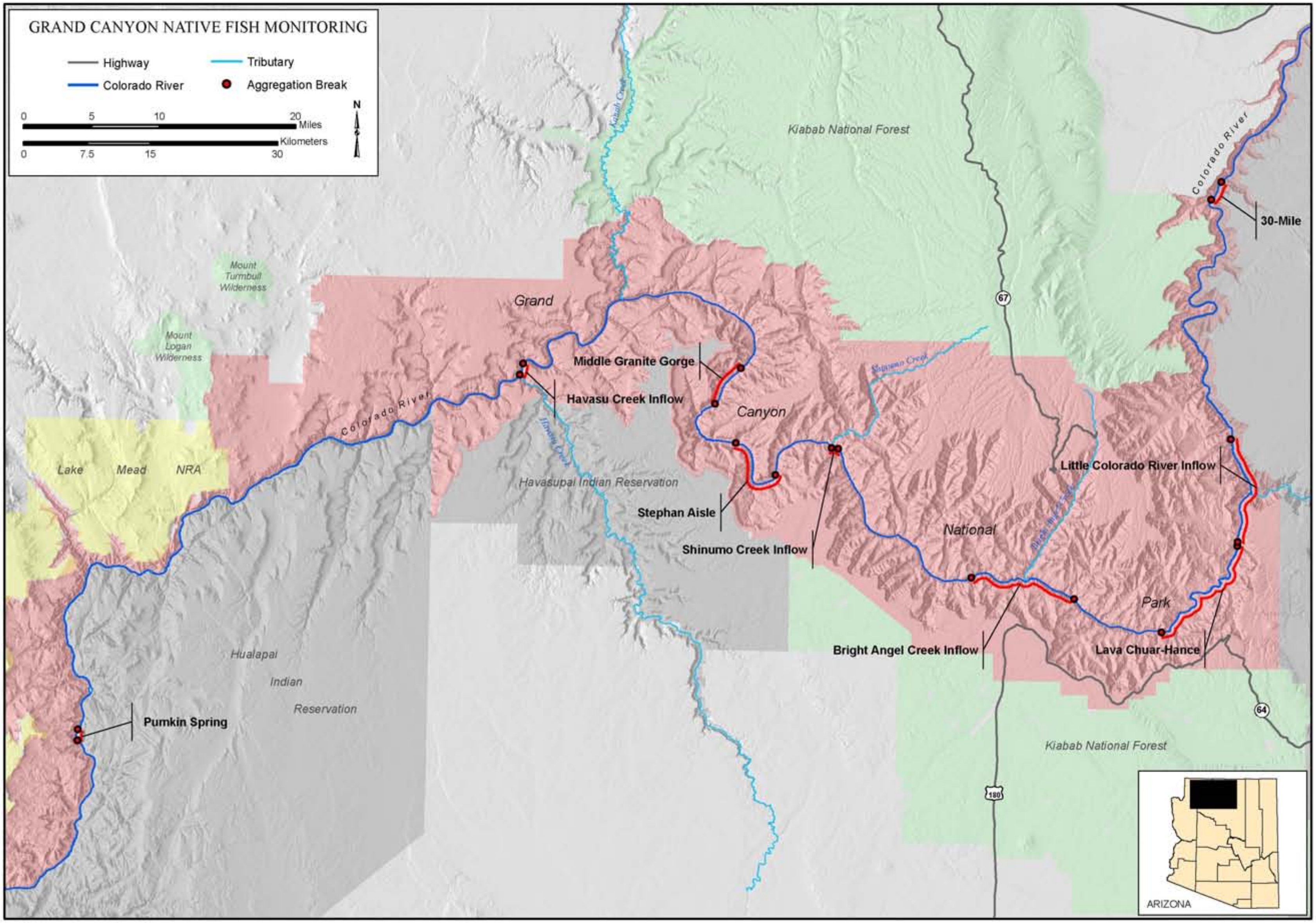



**Figure 2.** Designated HBC aggregations in the Colorado River, Grand Canyon (Valdez and Ryel 1995).

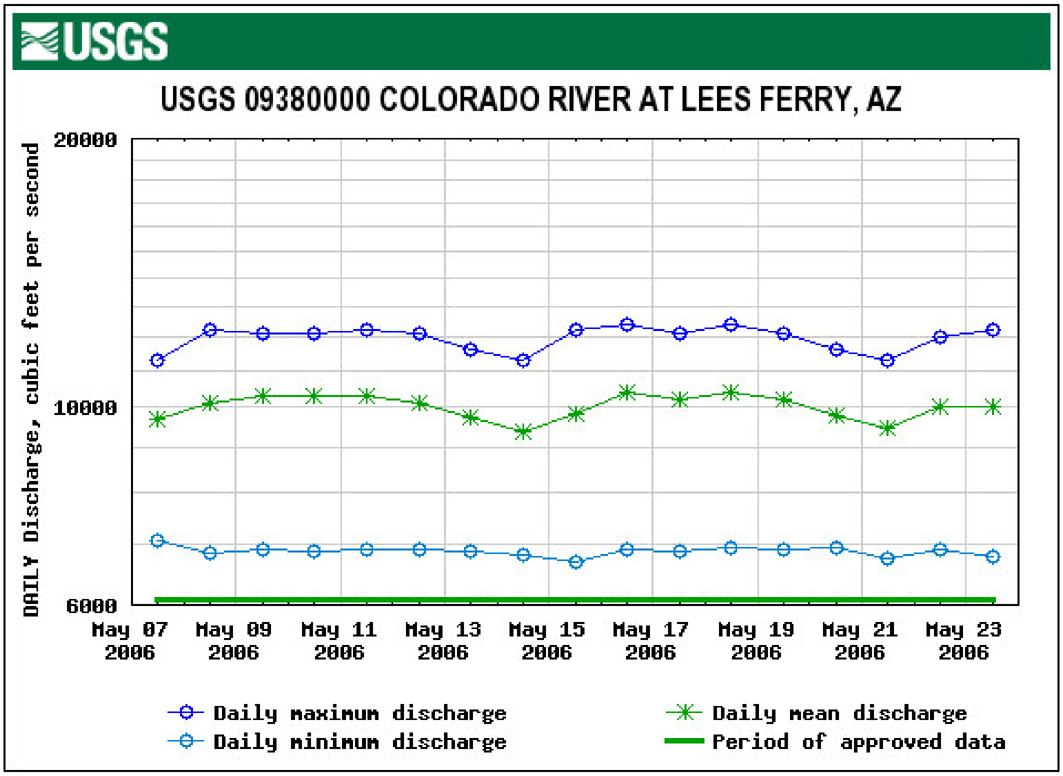



**Figure 3.** Daily minimum, maximum, and mean discharge during Trip ID GC20060507 (USGS 2006).

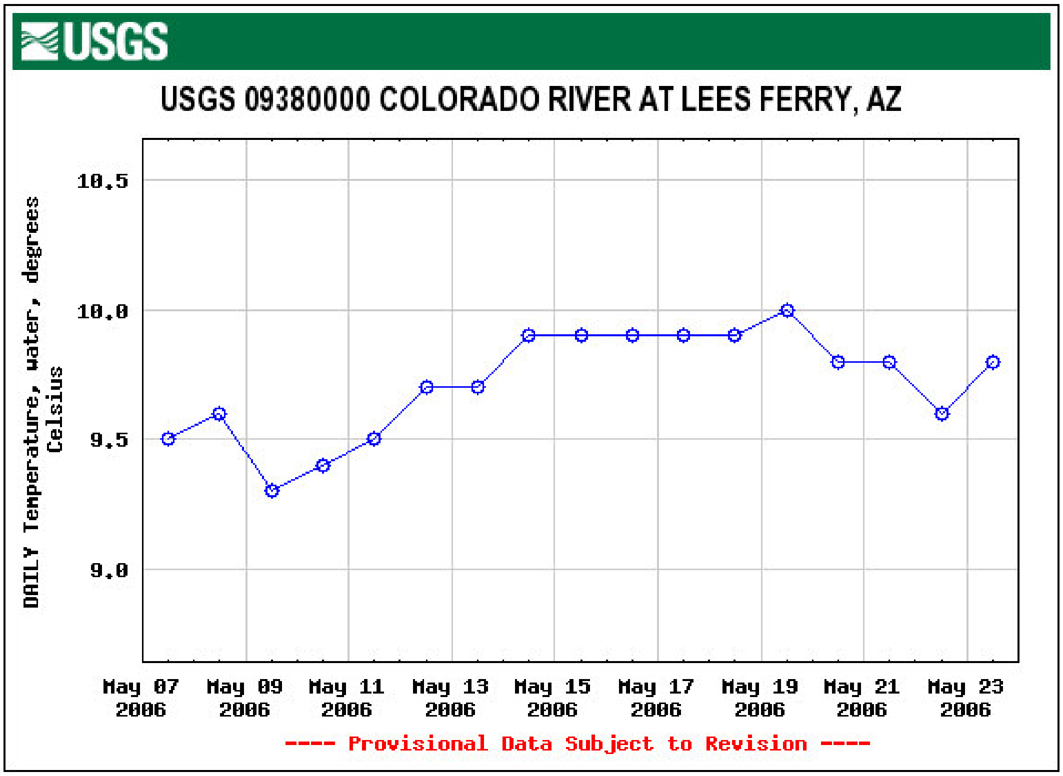



**Figure 4.** Daily mean temperature during Trip ID GC20060507 (USGS 2006).

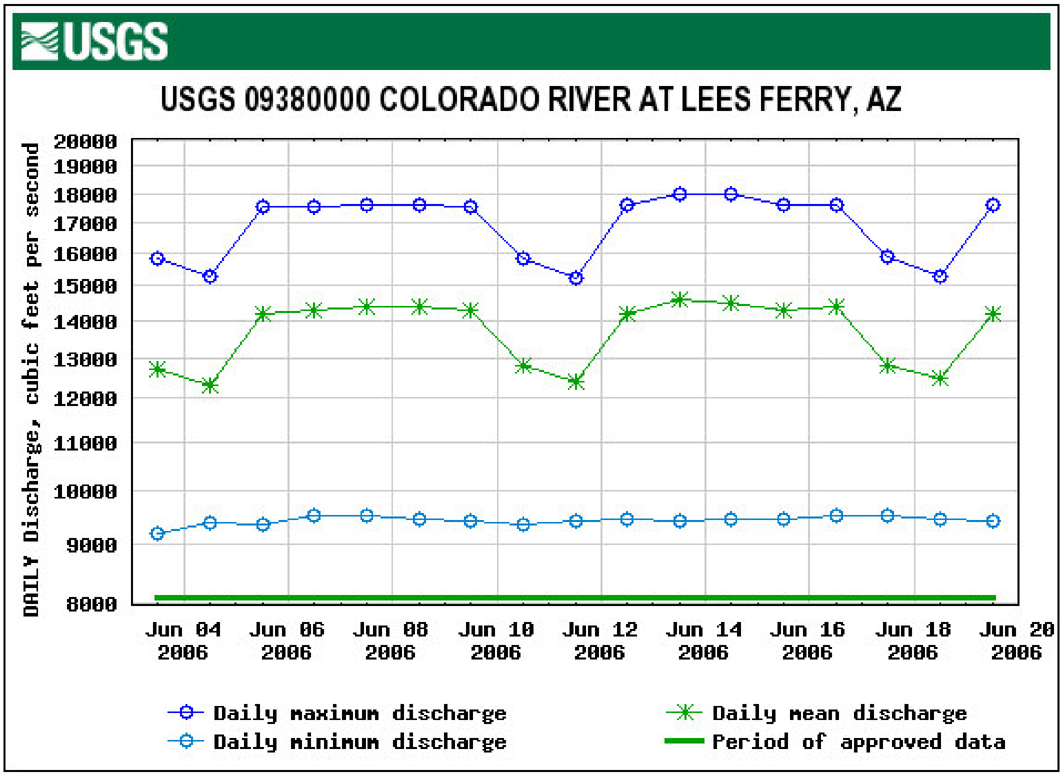



**Figure 5.** Daily minimum, maximum, and mean discharge during Trip ID GC20060603 (USGS 2006).

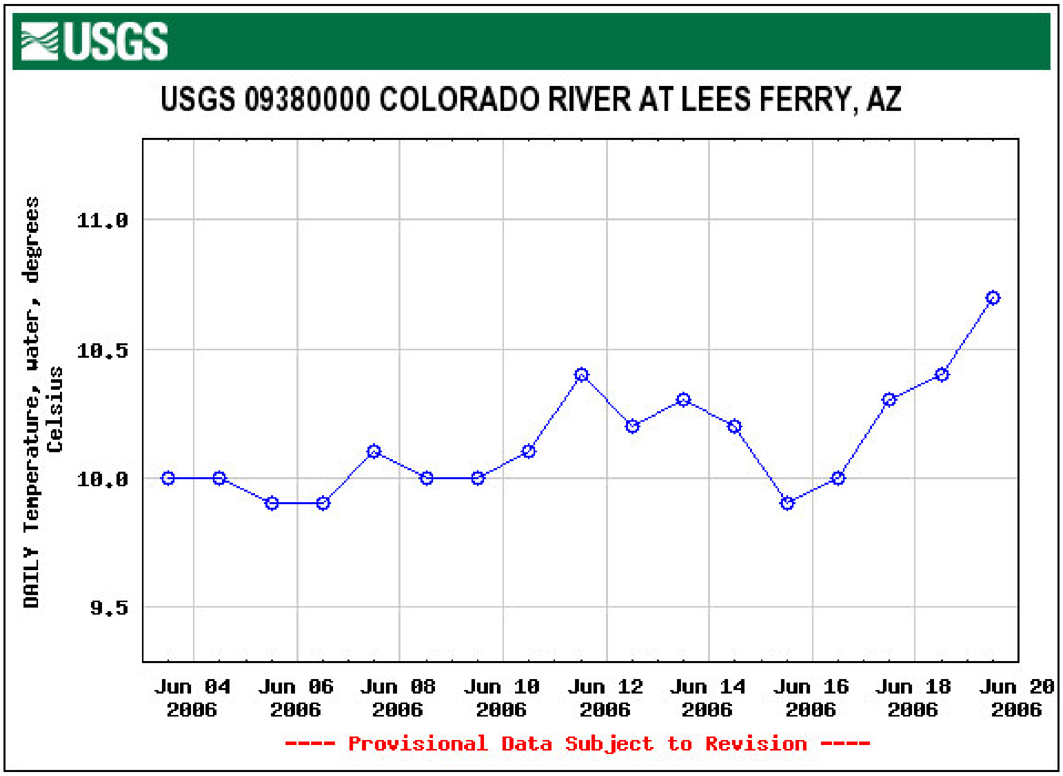



**Figure 6.** Daily mean temperature during Trip ID GC20060603 (USGS 2006).

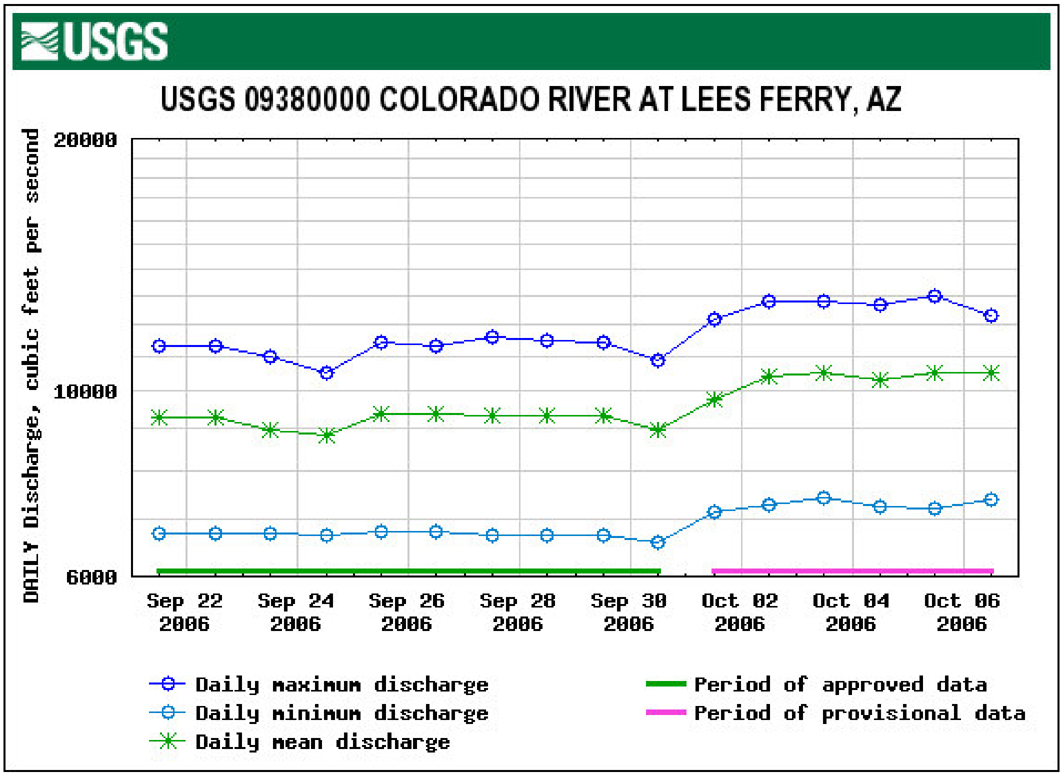



**Figure 7.** Daily minimum, maximum, and mean discharge during Trip ID GC20060921 (USGS 2006).

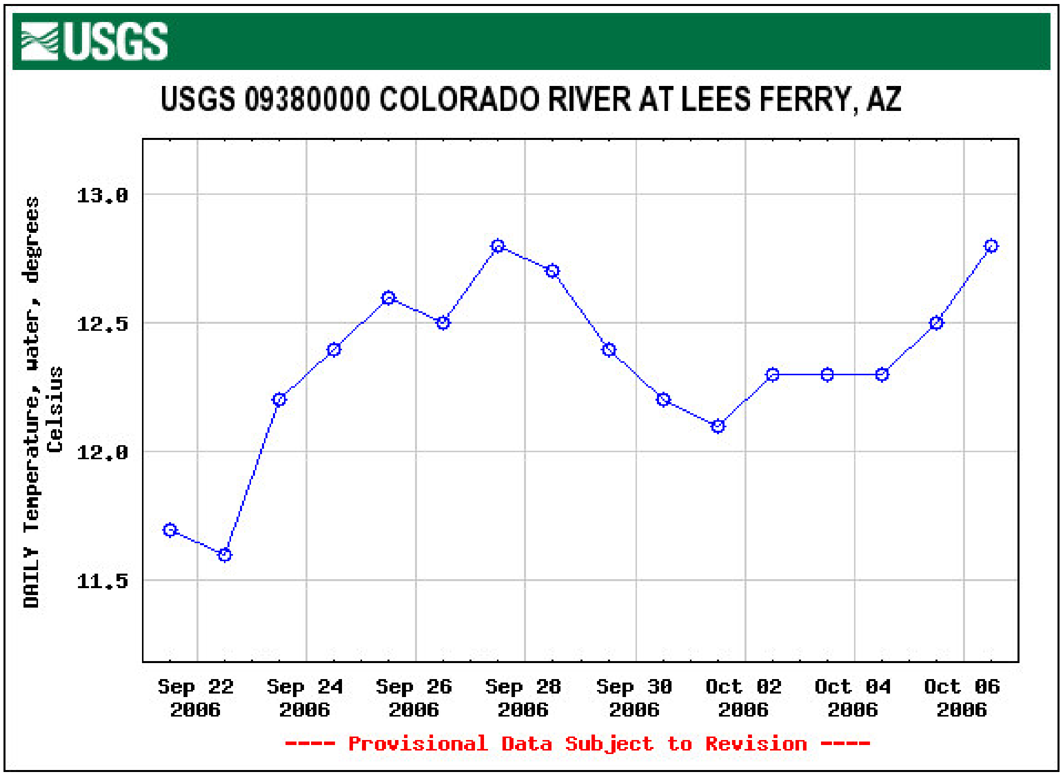



**Figure 8.** Daily mean temperature during Trip ID GC20060921 (USGS 2006).

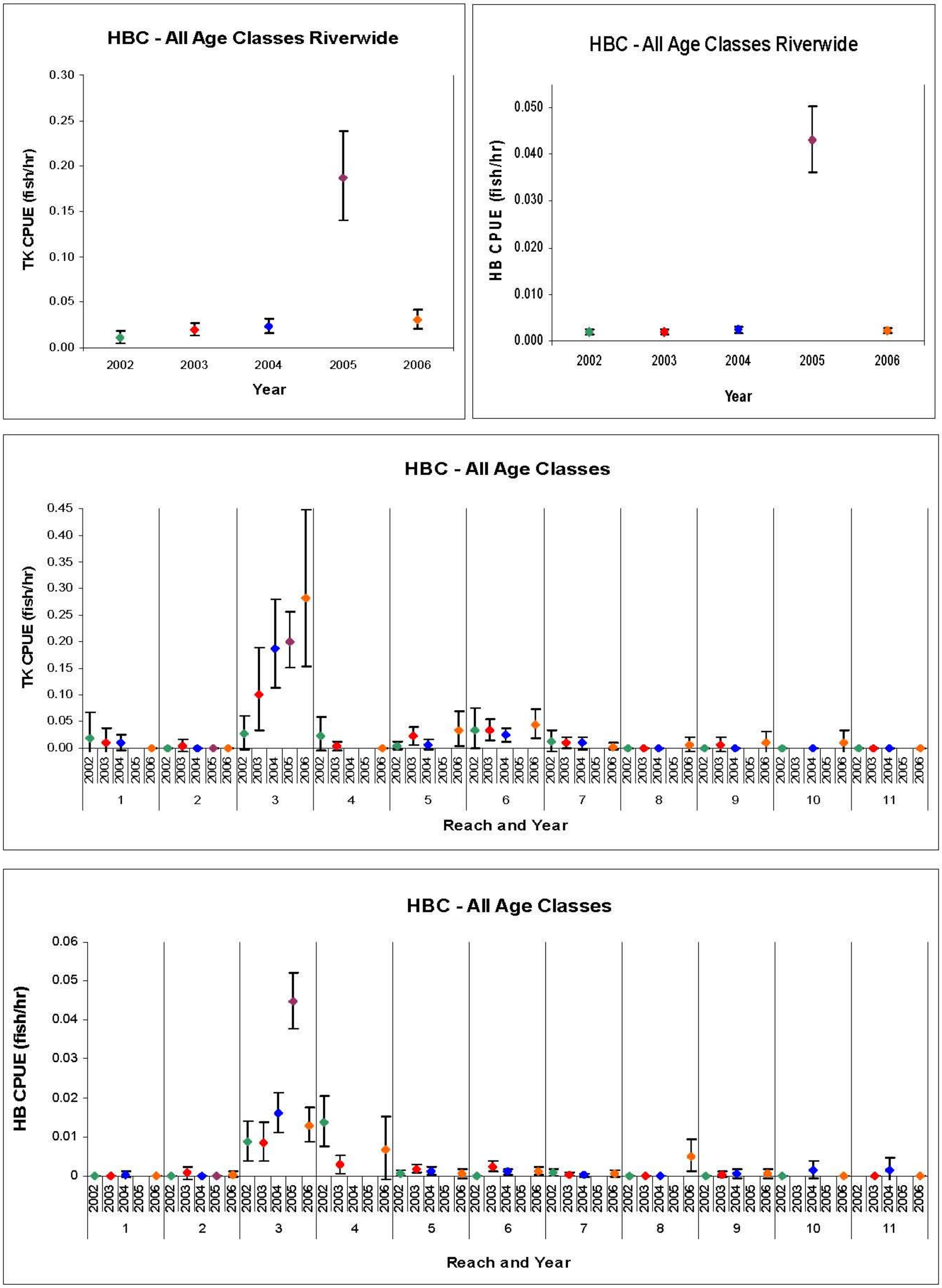
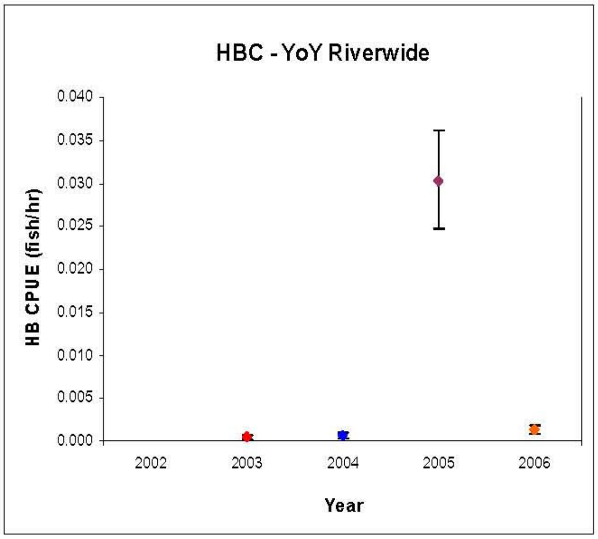



**Figure 9.** Humpback chub (HBC) trammel (TK) and hoop net (HB) geometric mean CPUEs (± 95% CI) by reach and riverwide in the Colorado River, Grand Canyon, 2002–2006.



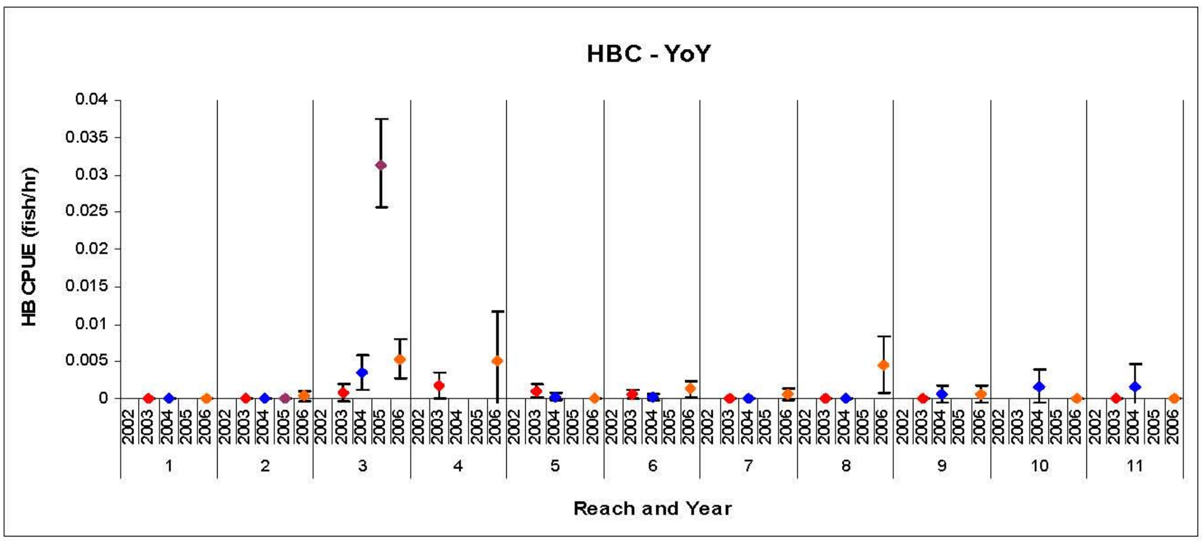




**Figure 10**. YoY humpback chub (HBC) hoop net (HB) geometric mean CPUEs (± 95% CI) by reach and riverwide in the Colorado River, Grand Canyon, 2002–2006.

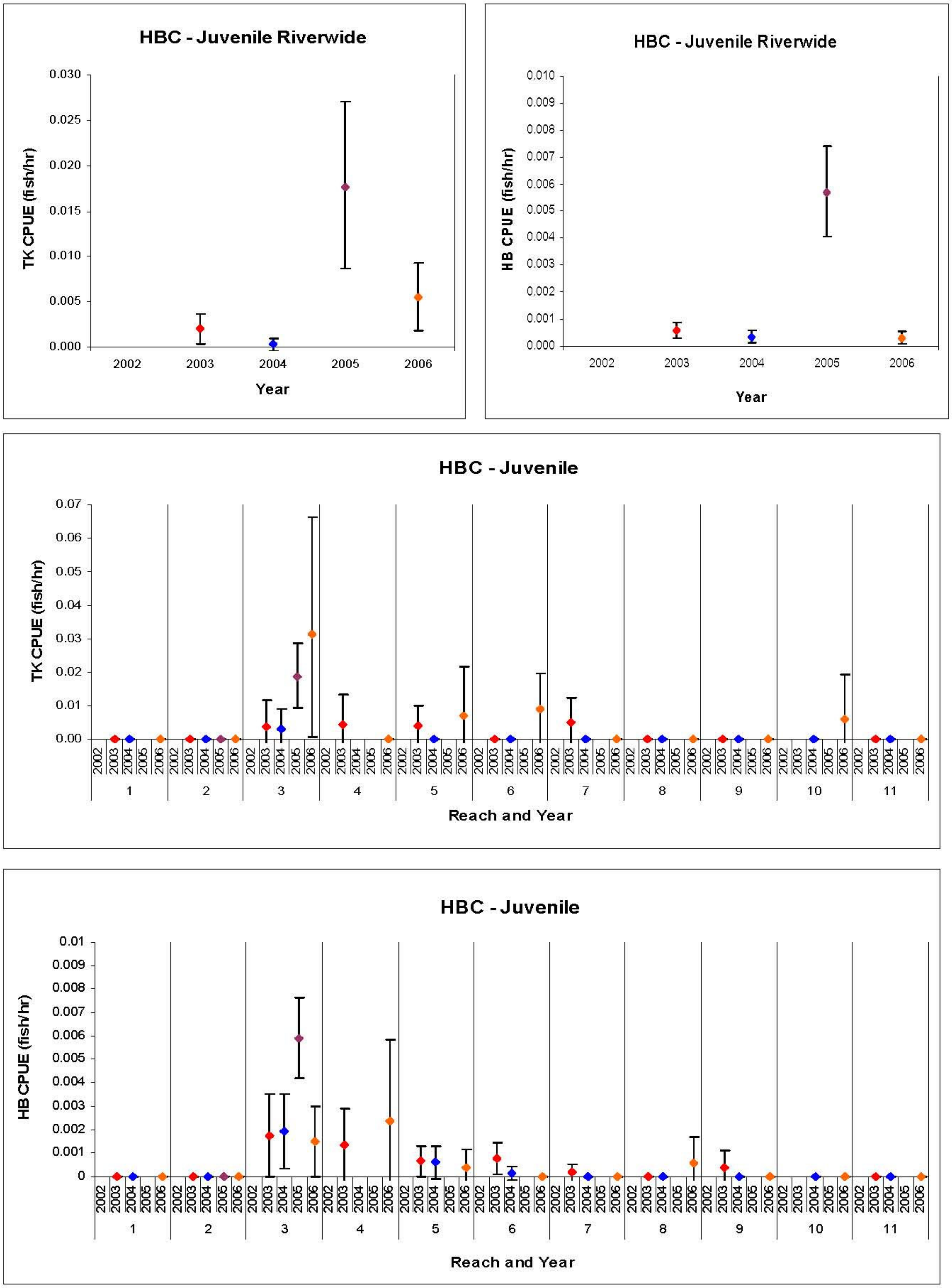



**Figure 11**. Juvenile humpback chub (HBC) trammel (TK) and hoop net (HB) geometric mean CPUEs (± 95% CI) by reach and riverwide in the Colorado River, Grand Canyon, 2002–2006.

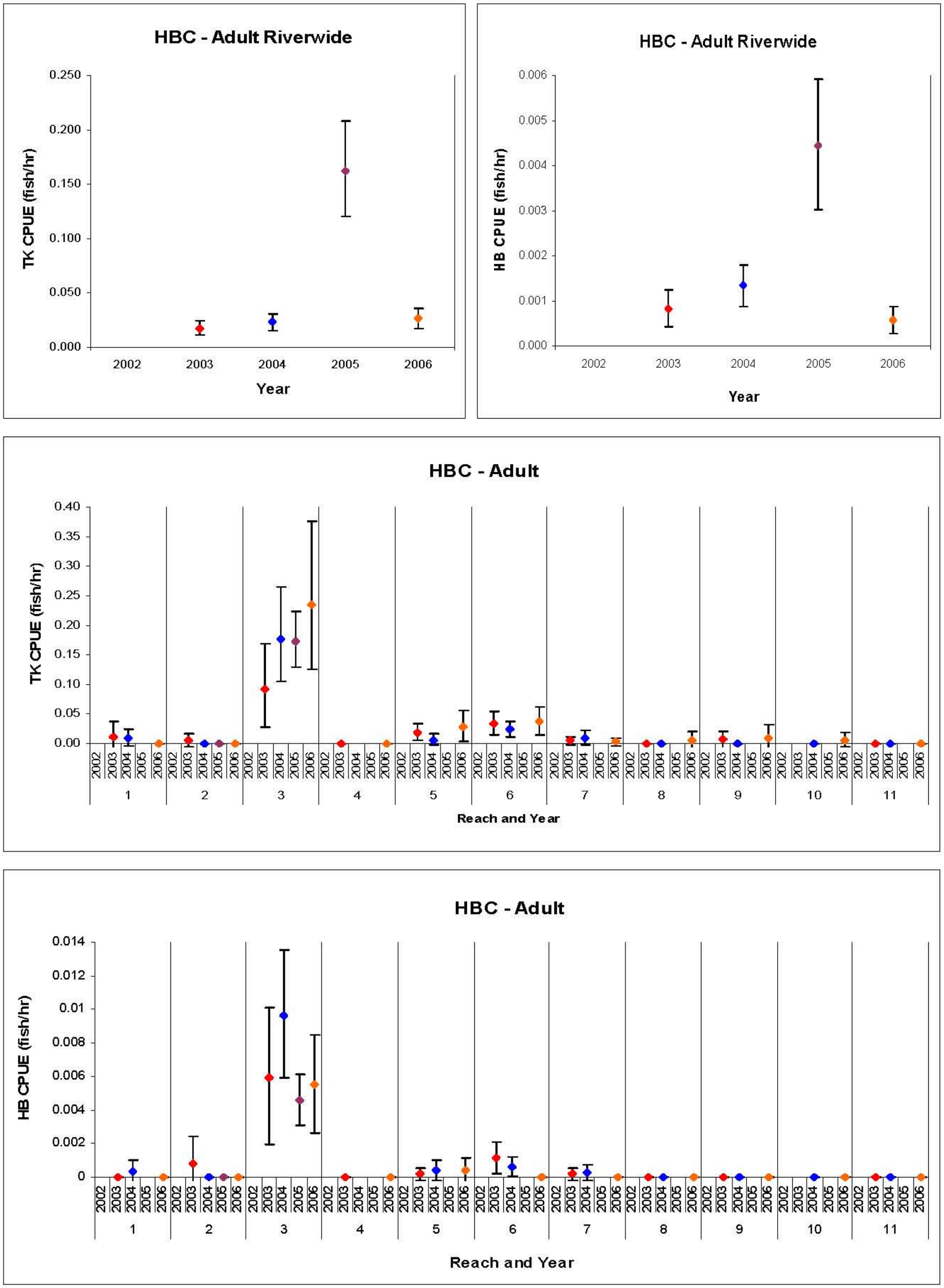



**Figure 12.** Adult humpback chub (HBC) trammel (TK) and hoop net (HB) geometric mean CPUEs (± 95% CI) by reach and riverwide in the Colorado River, Grand Canyon, 2002–2006.

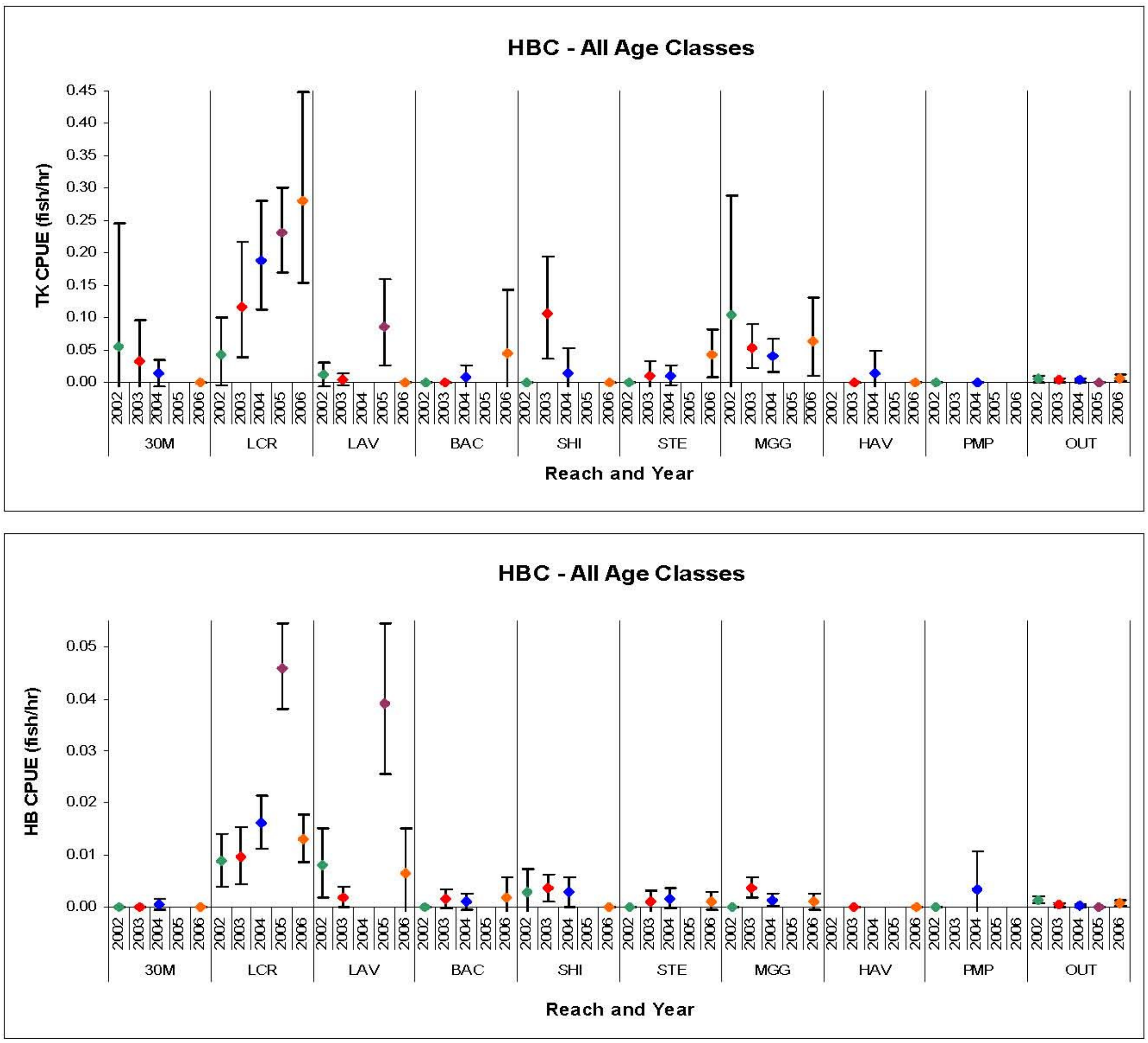



**Figure 13.** Humpback chub (HBC) trammel (TK) and hoop net (HB) geometric mean CPUEs (± 95% CI) by aggregation in the Colorado River, Grand Canyon, 2002–2006.

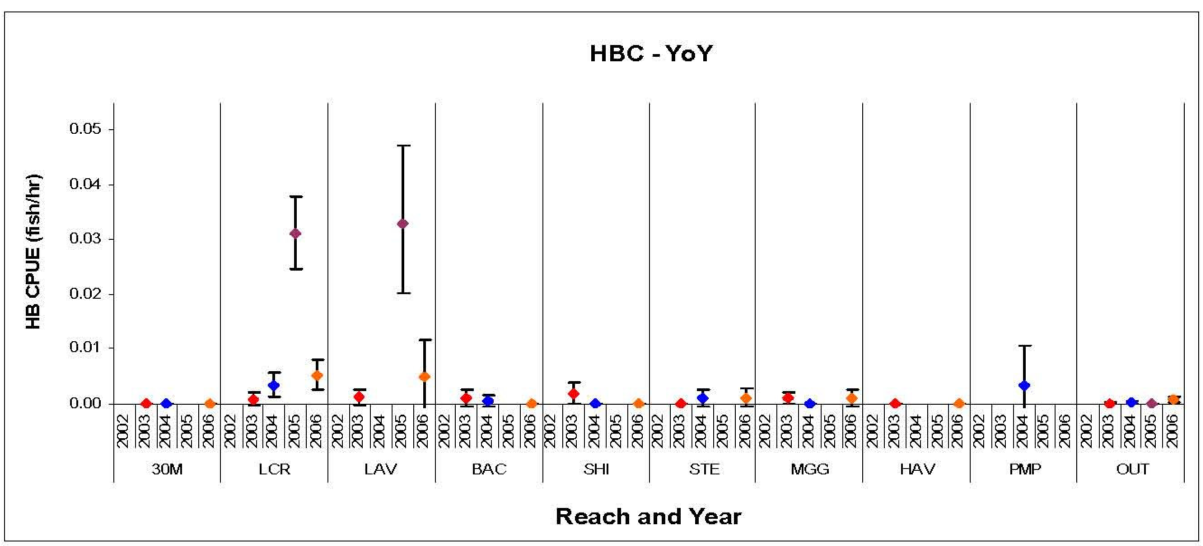
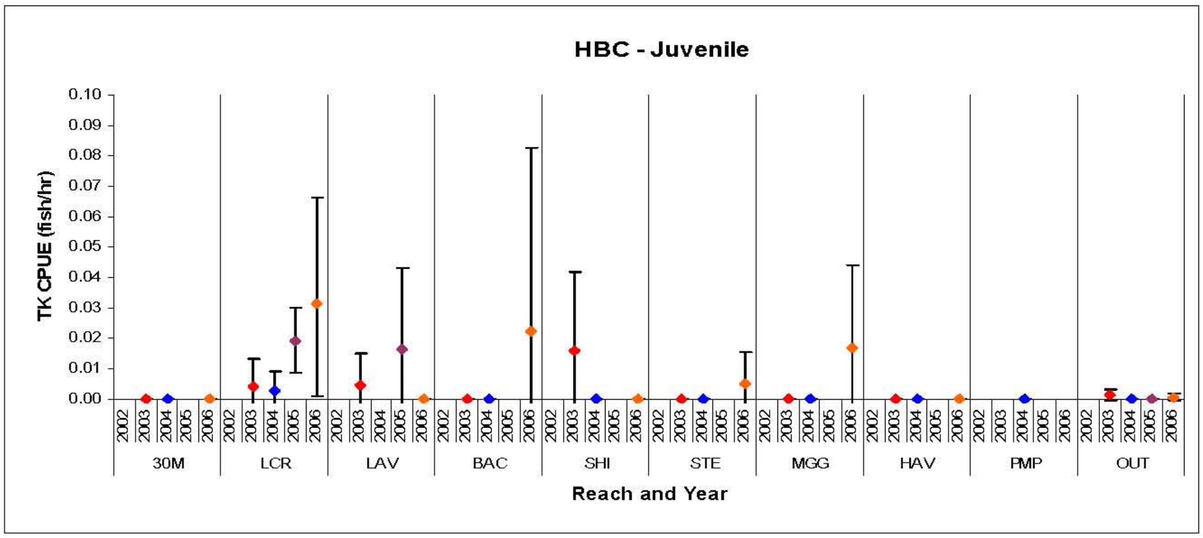



**Figure 14.** YoY humpback chub (HBC) hoop net (HB) geometric mean CPUEs (± 95% CI) by aggregation in the Colorado River, Grand Canyon, 2002–2006.



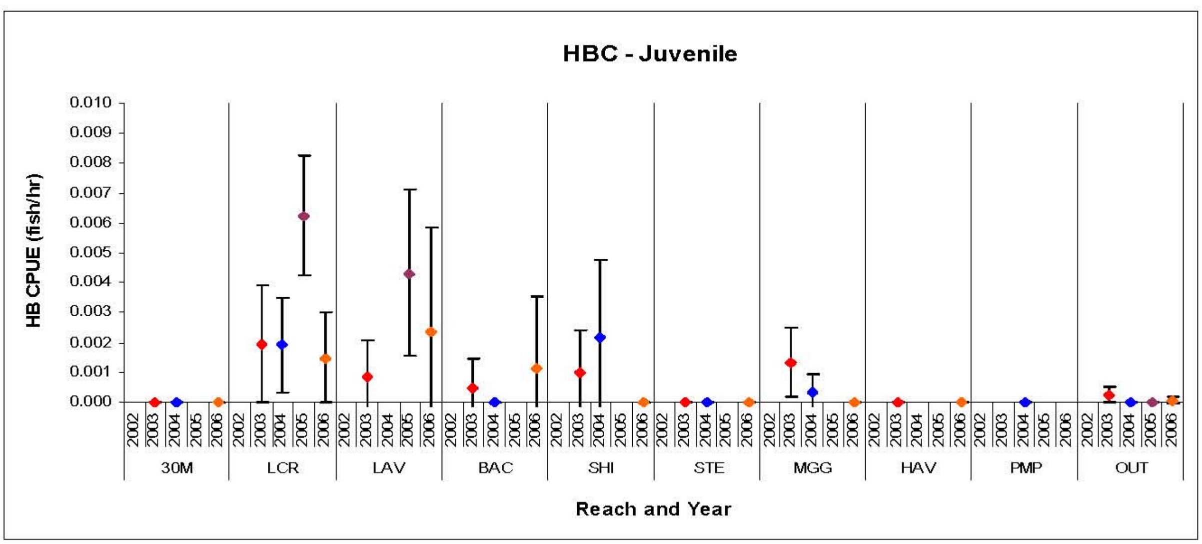




**Figure 15**. Juvenile humpback chub (HBC) trammel (TK) and hoop net (HB) geometric mean CPUEs (± 95% CI) by aggregation in the Colorado River, Grand Canyon, 2002–2006.

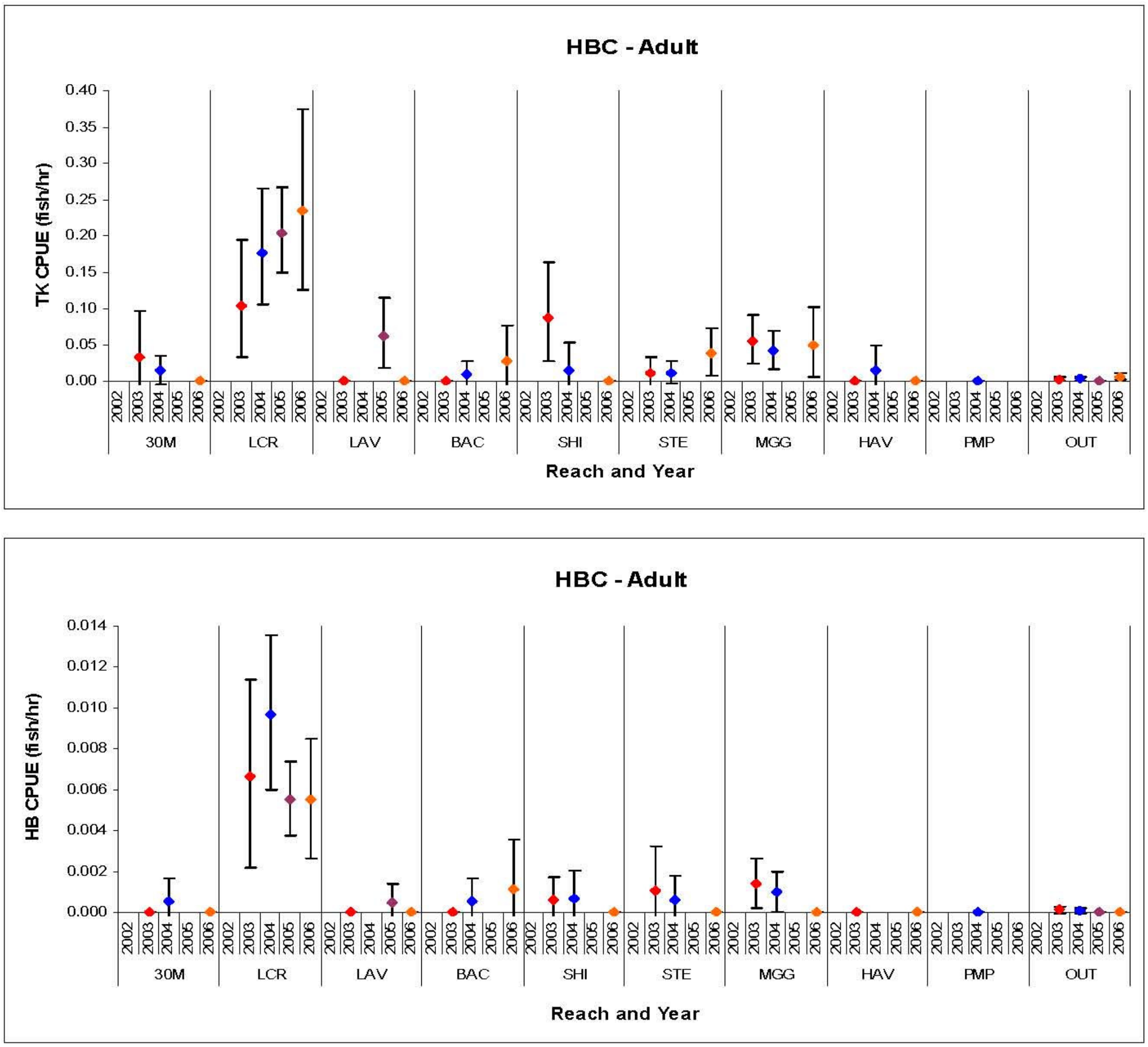



**Figure 16.** Adult humpback chub (HBC) trammel (TK) and hoop net (HB) geometric mean CPUEs (± 95% CI) by aggregation in the Colorado River, Grand Canyon, 2002–2006.

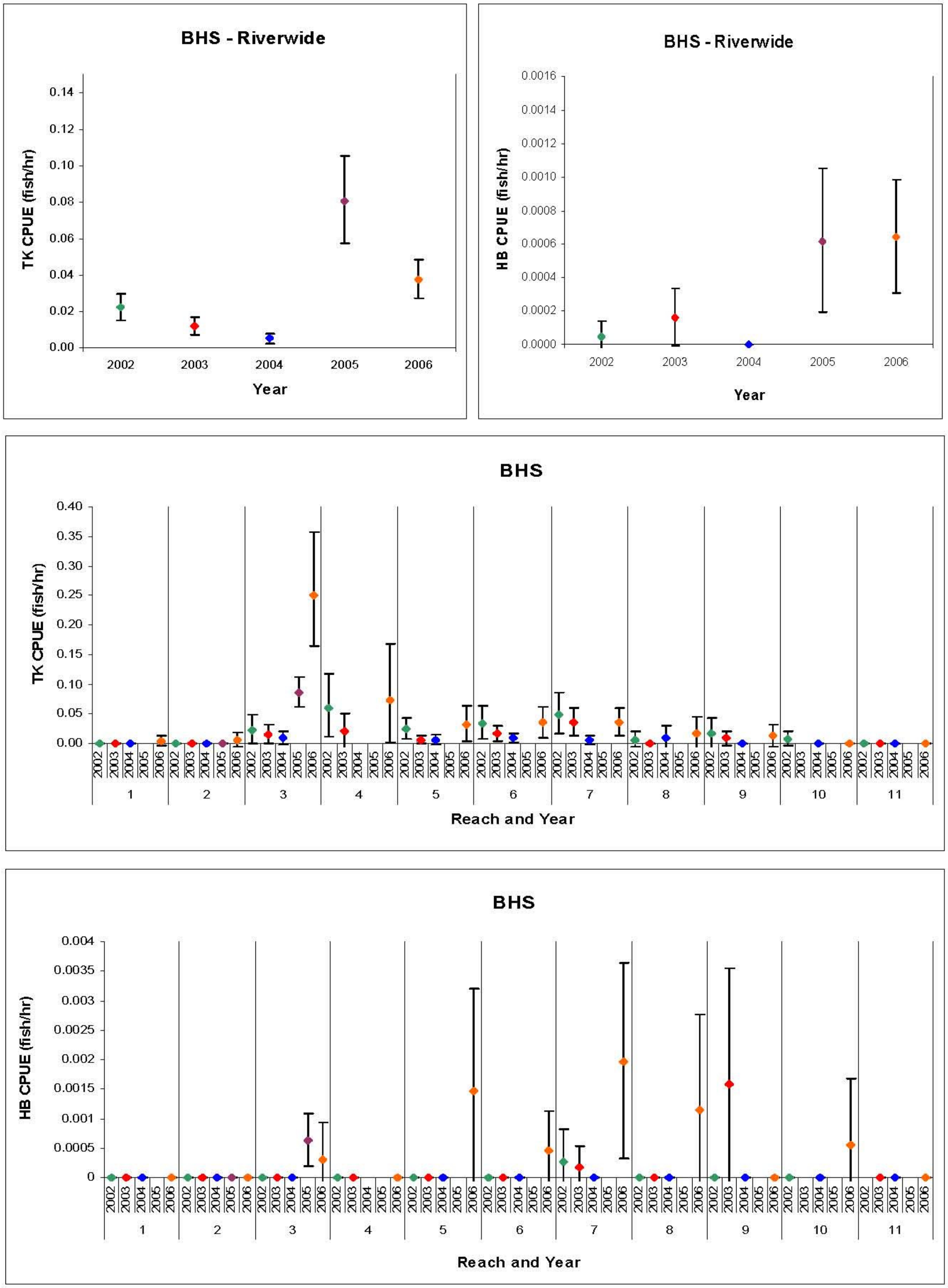



**Figure 17.** Bluehead sucker (BHS) trammel (TK) and hoop net (HB) geometric mean CPUEs (± 95% CI) by reach and riverwide in the Colorado River, Grand Canyon, 2002–2006.

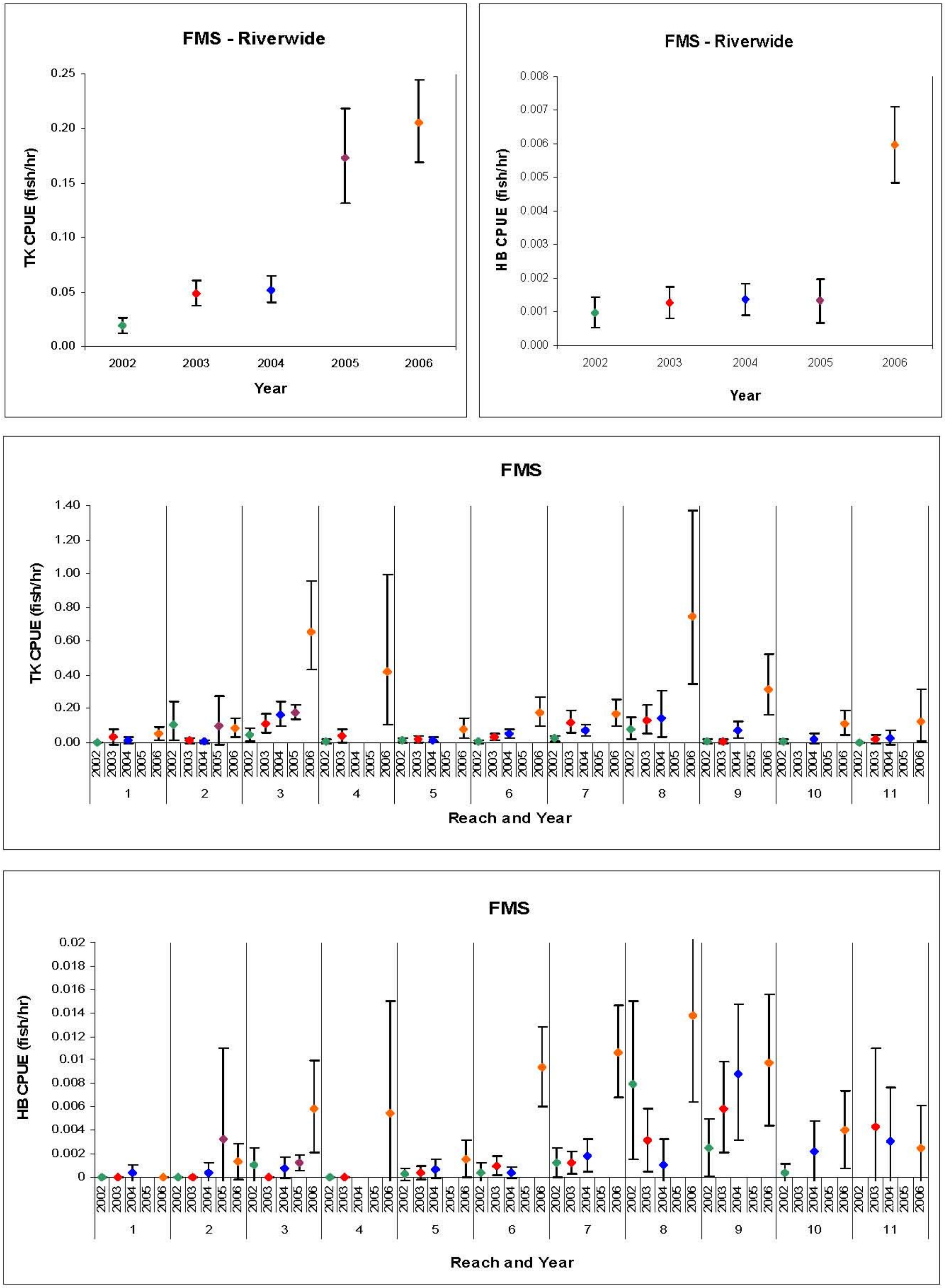
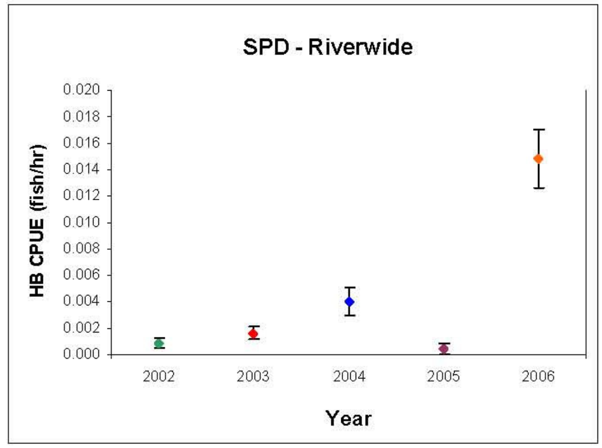



**Figure 18.** Flannelmouth sucker (FMS) trammel (TK) and hoop net (HB) geometric mean CPUEs (± 95% CI) by reach and riverwide in the Colorado River, Grand Canyon, 2002–2006.



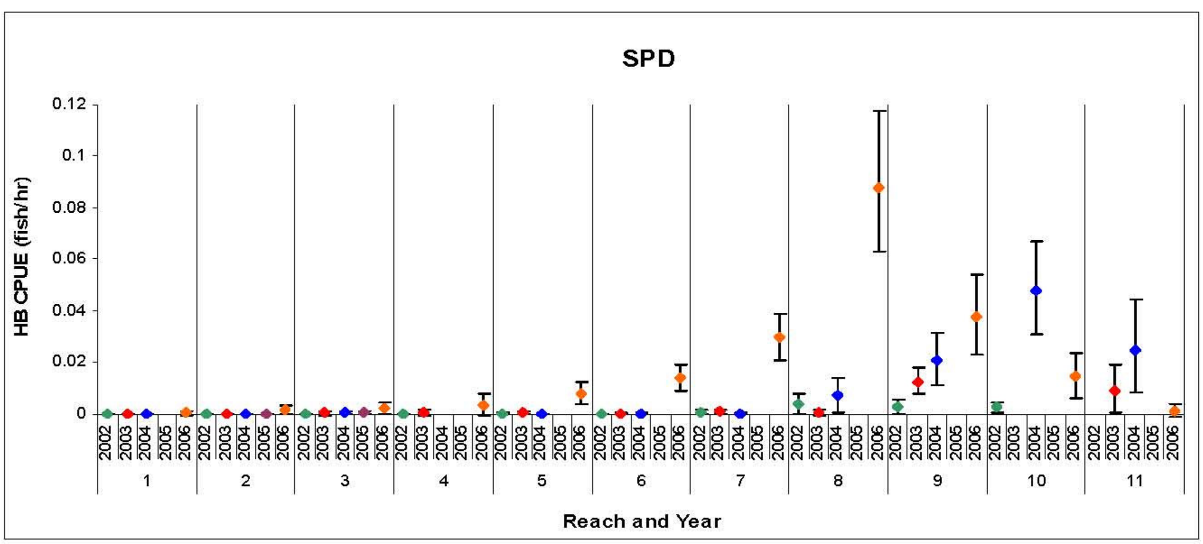
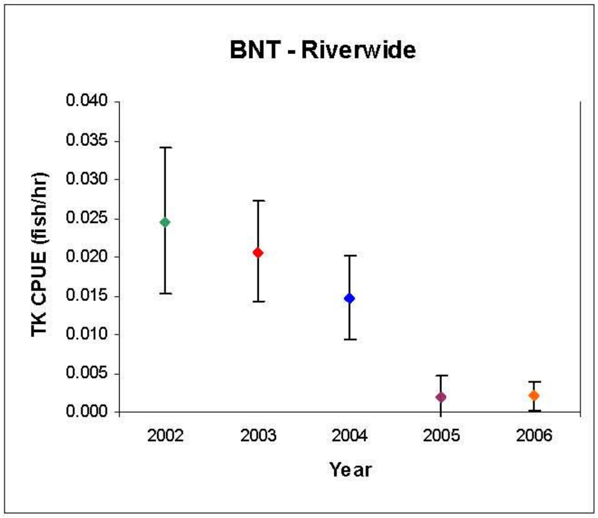




**Figure 19.** Speckled dace (SPD) hoop net (HB) geometric mean CPUEs (± 95% CI) by reach and riverwide in the Colorado River, Grand Canyon, 2002–2006.



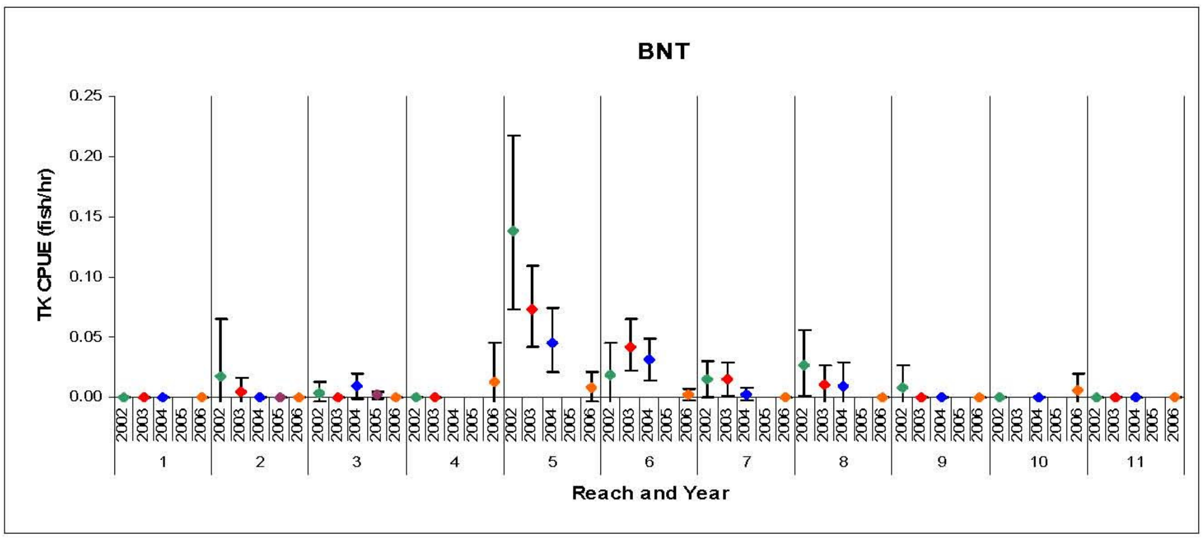
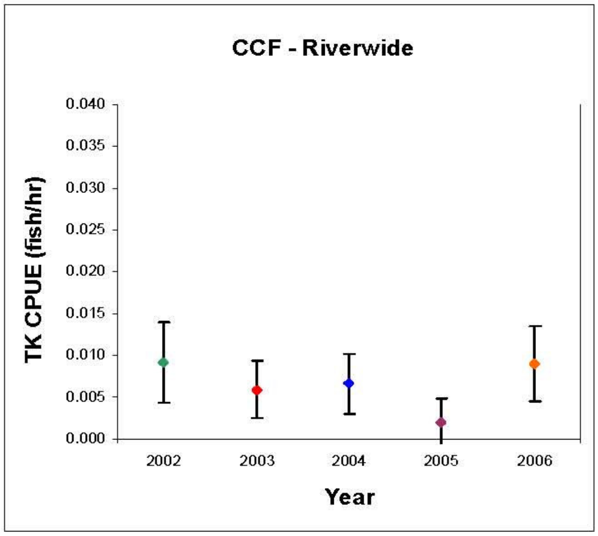




**Figure 20.** Brown trout (BNT) trammel net (TK) geometric mean CPUEs (± 95% CI) by reach and riverwide in the Colorado River, Grand Canyon, 2002–2006.



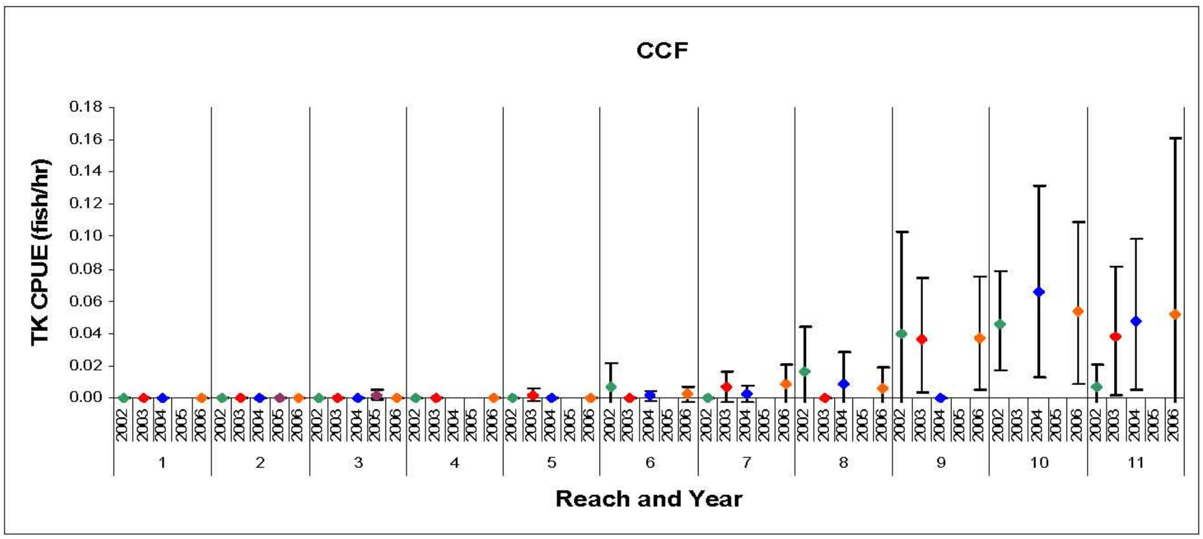
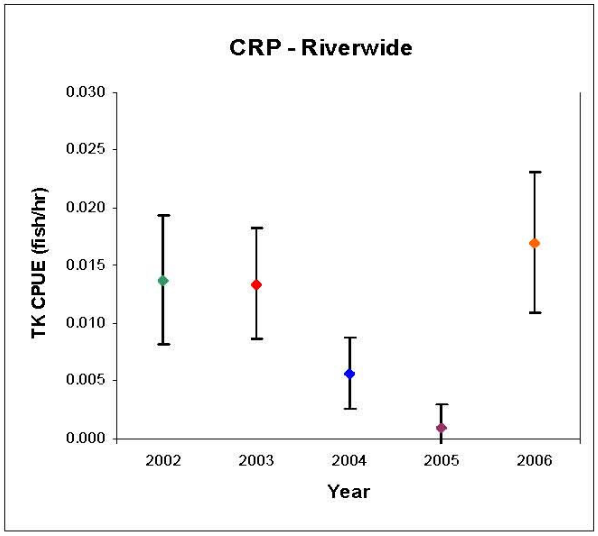




**Figure 21.** Channel catfish (CCF) trammel net (TK) geometric mean CPUEs (± 95% CI) by reach and riverwide in the Colorado River, Grand Canyon, 2002–2006.



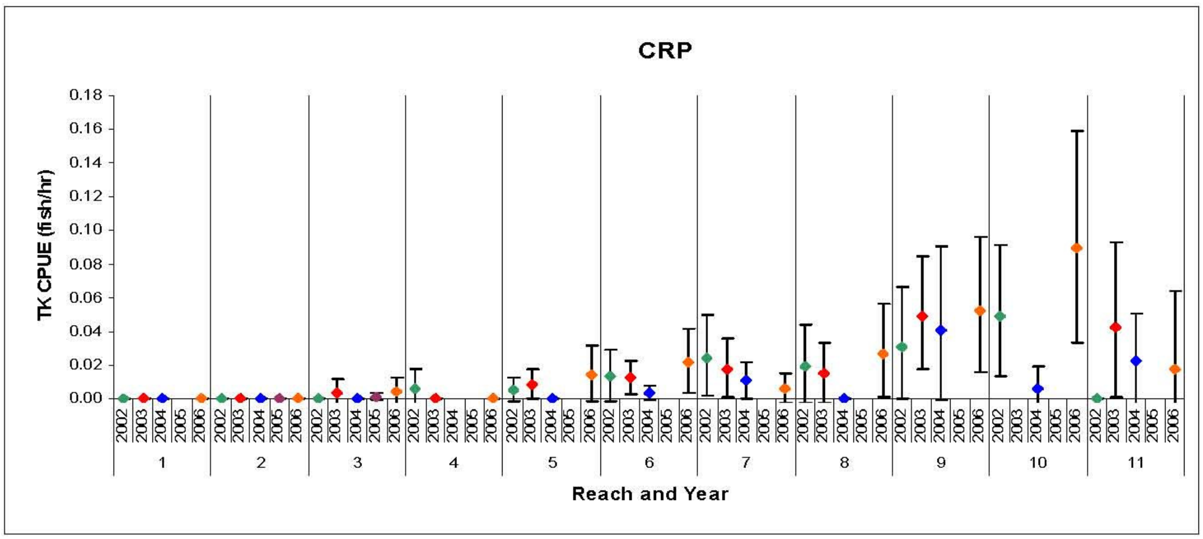
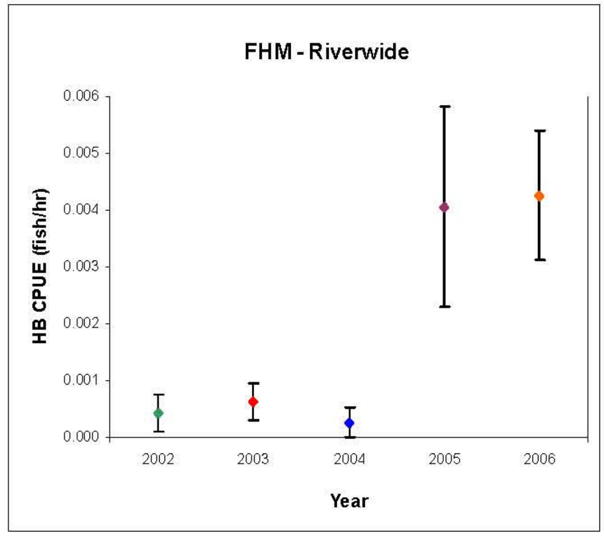




**Figure 22.** Common carp (CRP) trammel net (TK) geometric mean CPUEs (± 95% CI) by reach and riverwide in the Colorado River, Grand Canyon, 2002–2006.



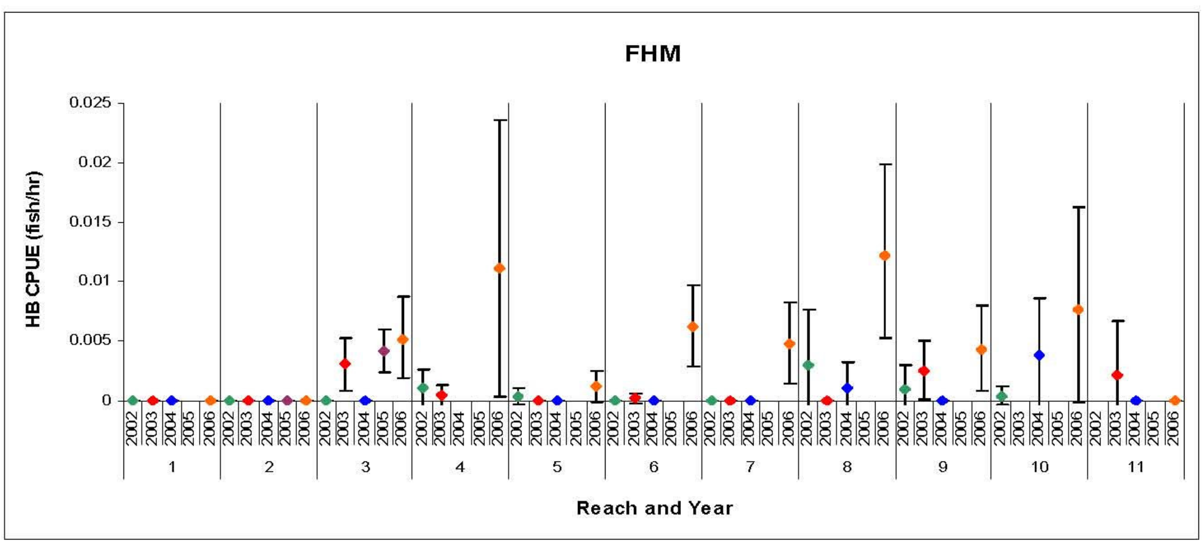




**Figure 23.** Fathead minnow (FHM) hoop net (HB) geometric mean CPUEs (± 95% CI) by reach and riverwide in the Colorado River, Grand Canyon, 2002–2006.

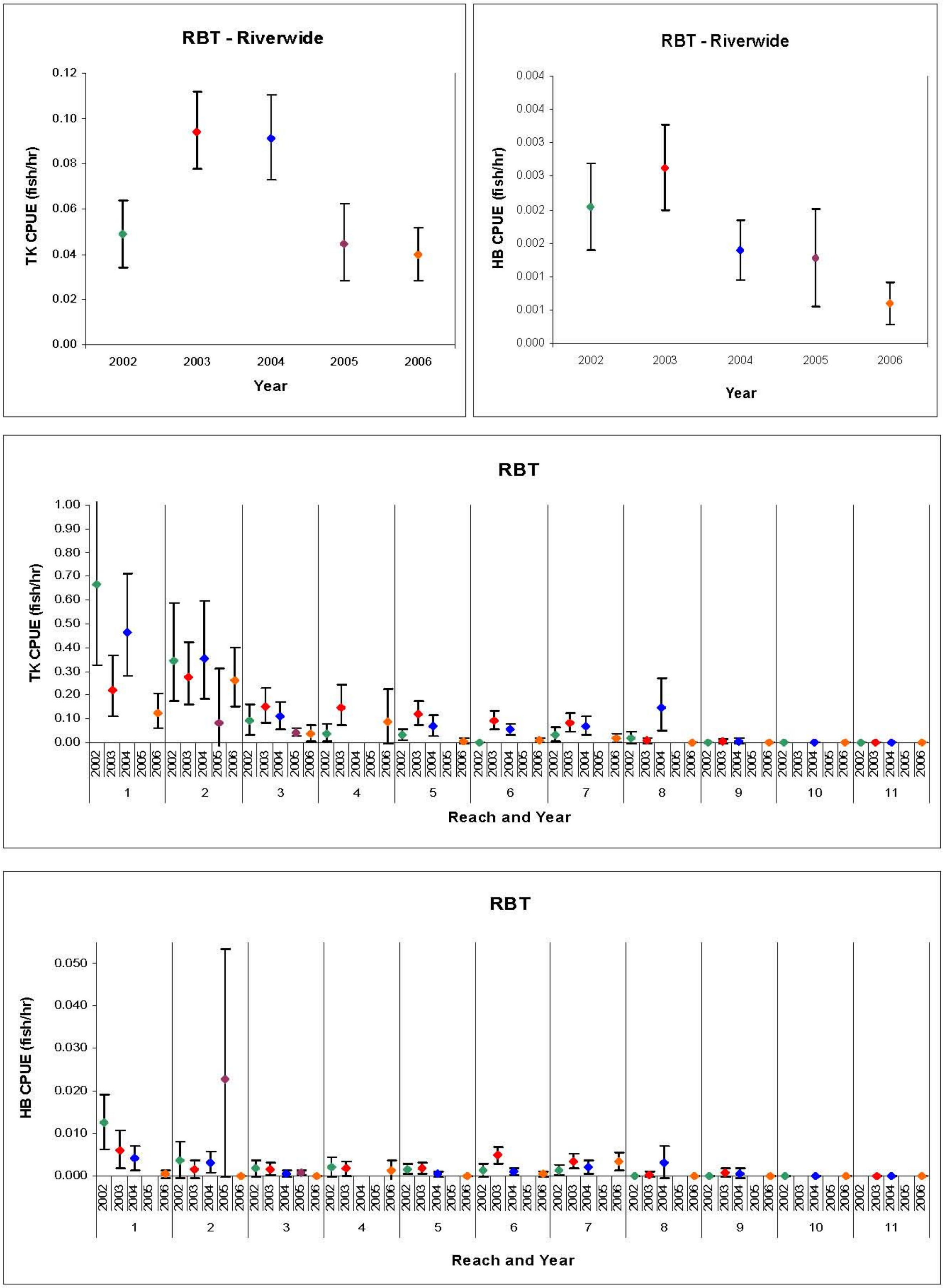
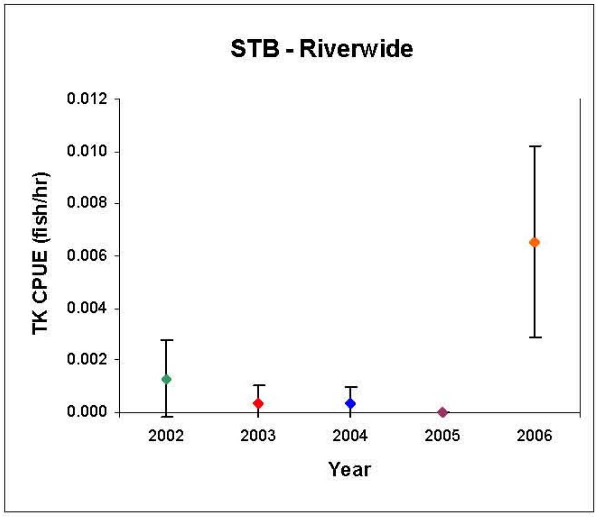



**Figure 24.** Rainbow trout (RBT) trammel (TK) and hoop net (HB) geometric mean CPUEs (± 95% CI) by reach and riverwide in the Colorado River, Grand Canyon, 2002–2006.



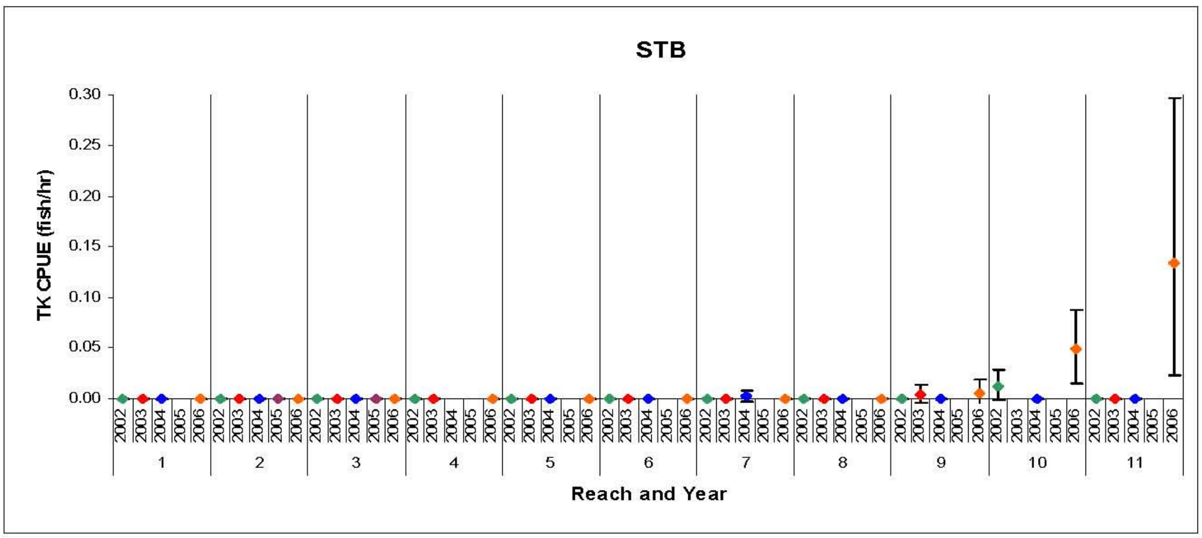




**Figure 25.** Striped bass (STB) trammel net (TK) geometric mean CPUEs (± 95% CI) by reach and riverwide in the Colorado River, Grand Canyon, 2002–2006.

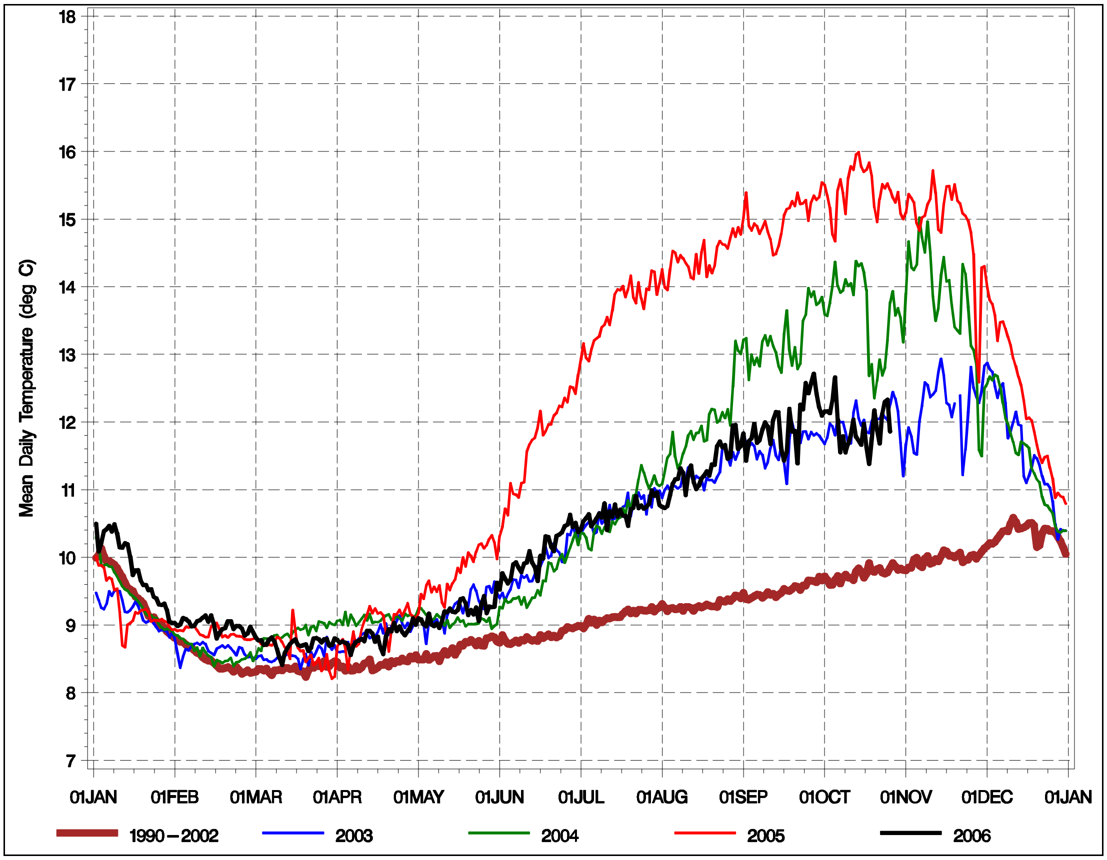



**Figure 26.** 2002–2006 Glen Canyon Dam mean daily release temperatures with 1990–2002 baseline temperatures (Vernieu 2006).

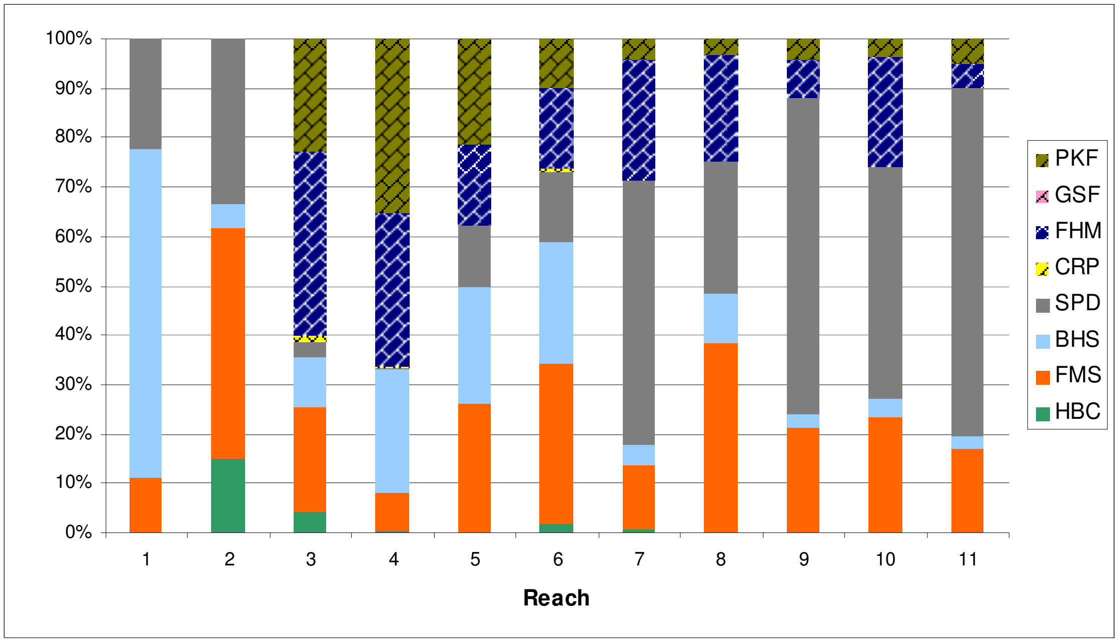



**Figure 27.** 2006 percent fish composition for all species, by abundance, between reaches for trammel net captures, Colorado River, Grand Canyon. Non-native species are represented by brick patterns.

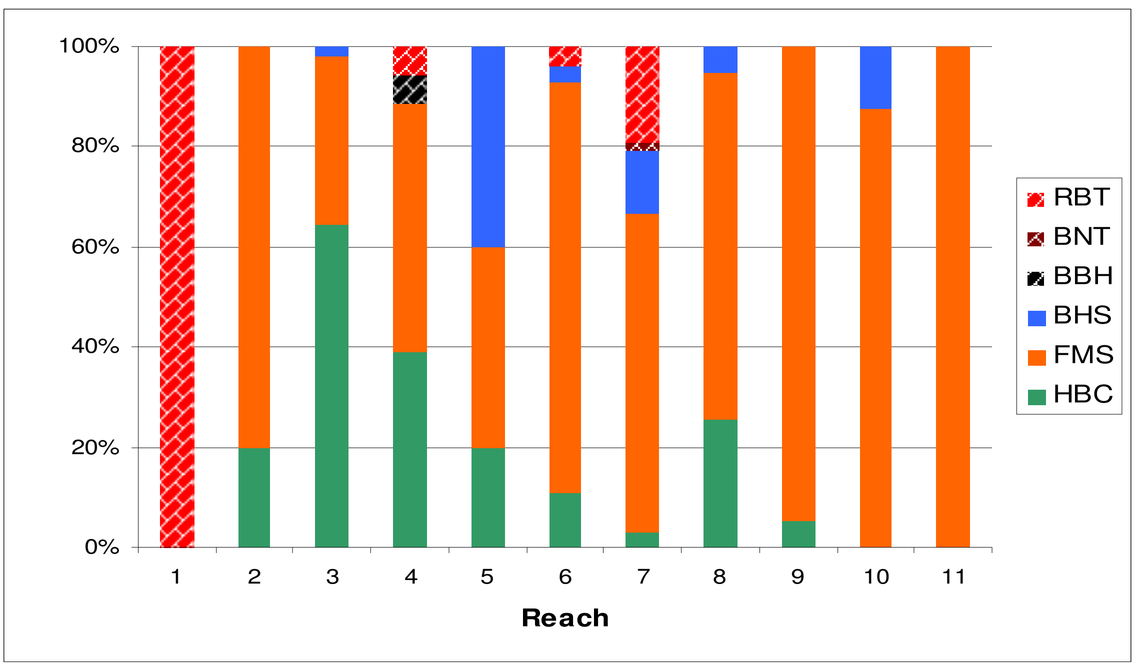



**Figure 28.** 2006 percent fish composition for large-bodied species, by abundance, between reaches for hoop net captures, Colorado River, Grand Canyon. Non-native species are represented by brick patterns.

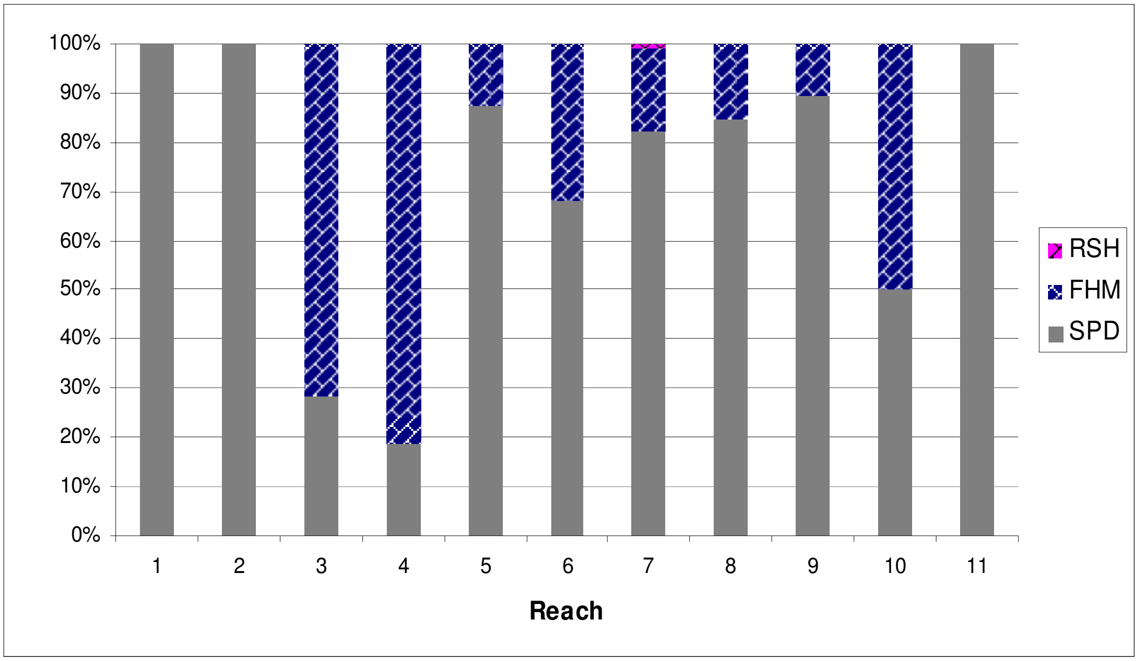



**Figure 29.** 2006 percent fish composition for small-bodied species, by abundance, between reaches for hoop net captures, Colorado River, Grand Canyon. Non-native species are represented by brick patterns.

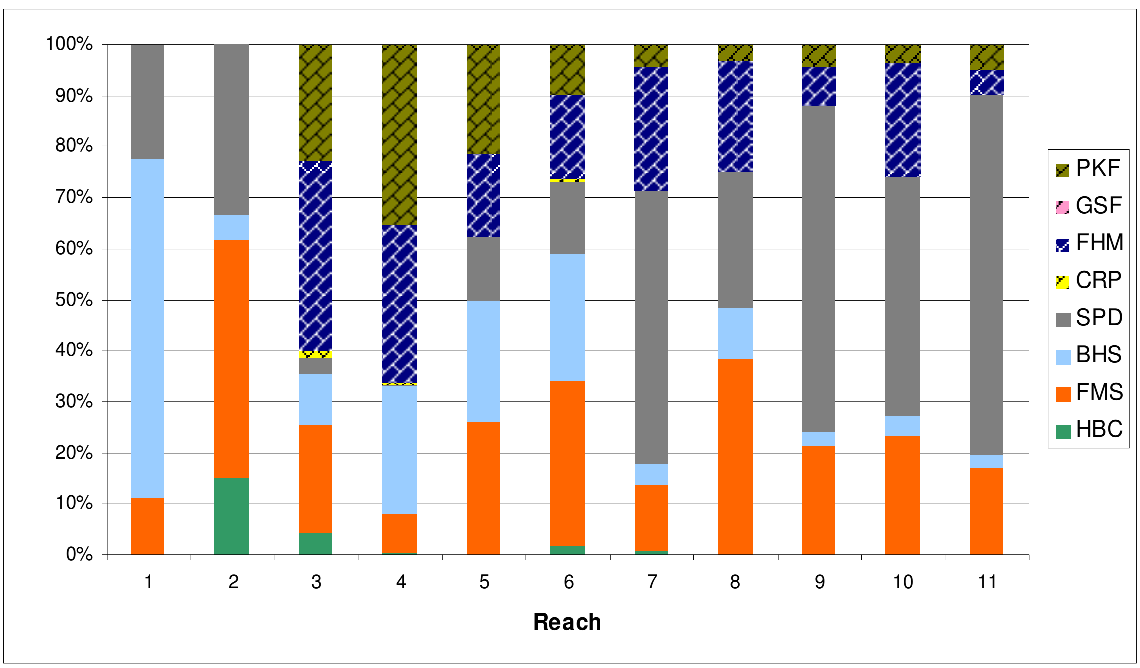



**Figure 30.** 2006 percent fish composition for all species, by abundance, between reaches for seining captures, Colorado River, Grand Canyon. Non-native species are represented by brick patterns.

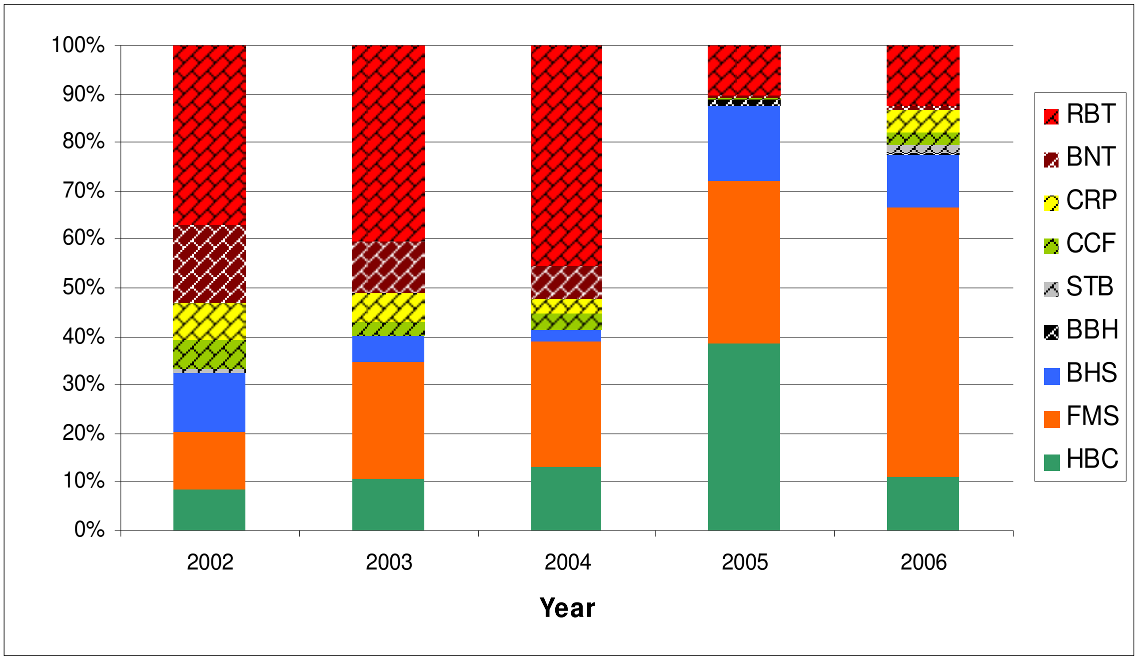



**Figure 31.** Percent fish composition for all species, by abundance, between years for trammel net captures, Colorado River, Grand Canyon. Non-native species are represented by brick patterns.

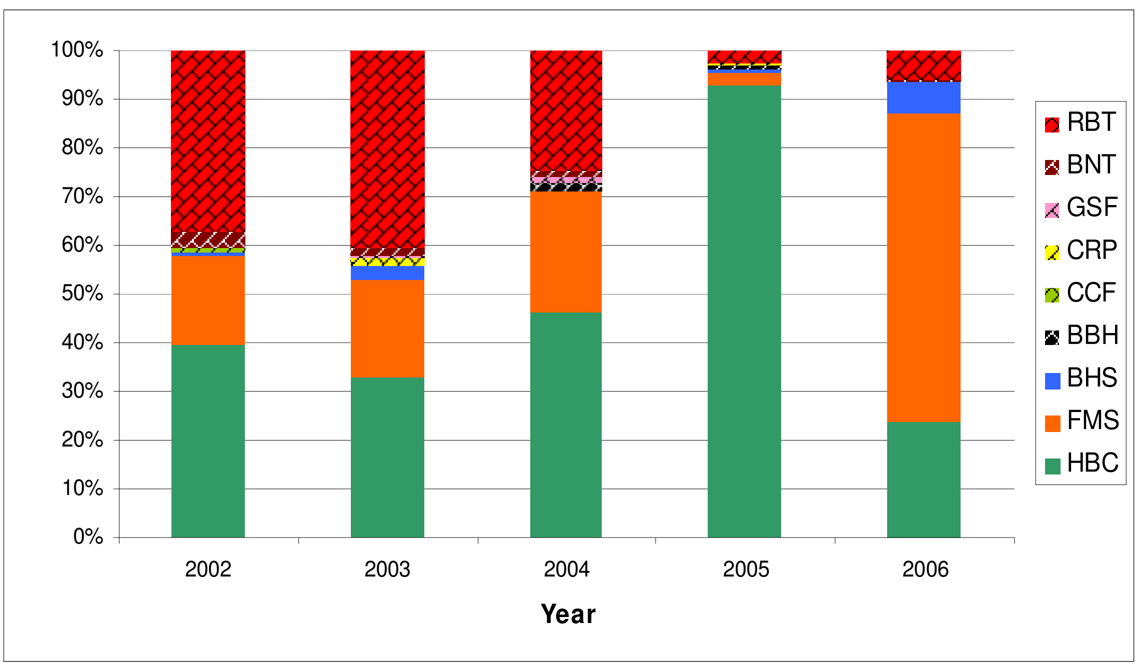



**Figure 32.** Percent fish composition for large-bodied species, by abundance, between years for hoop net captures, Colorado River, Grand Canyon. Non-native species are represented by brick patterns.

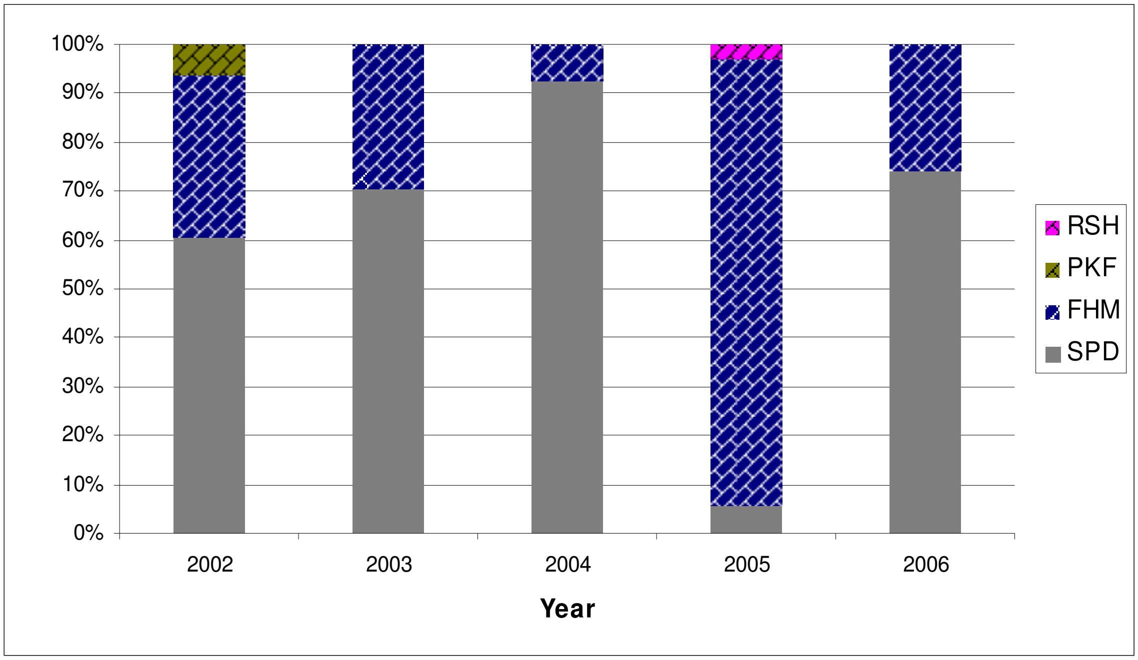



**Figure 33.** Percent fish composition for small-bodied species, by abundance, between years for hoop net captures, Colorado River, Grand Canyon. Non-native species are represented by brick patterns.

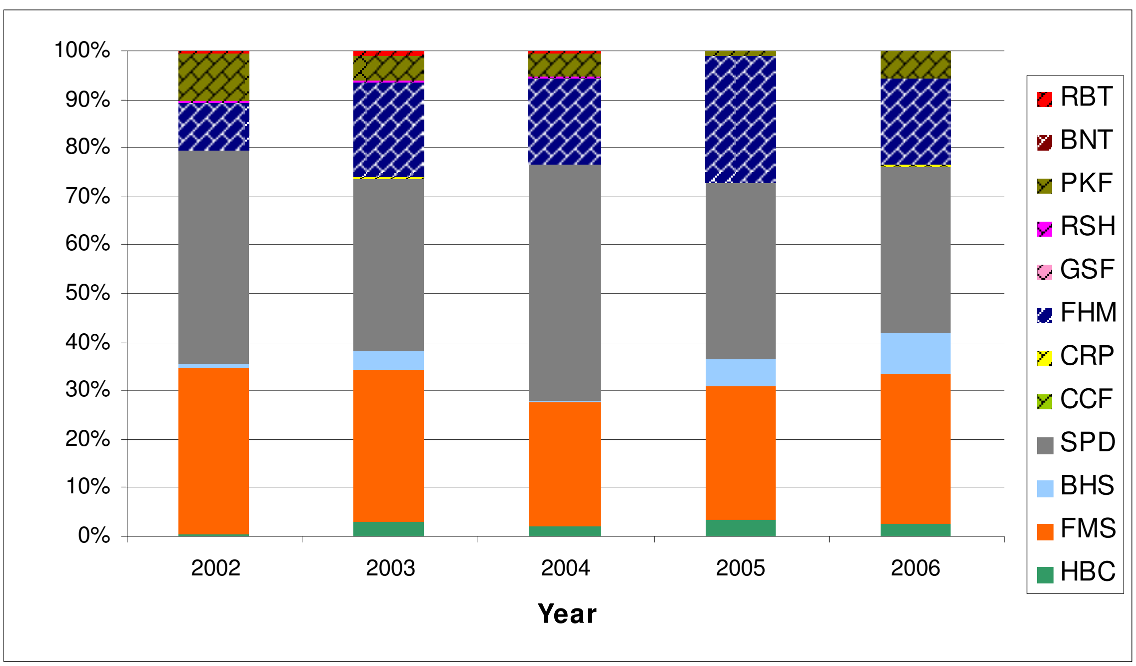



**Figure 34.** Percent fish composition for all species, by abundance, between years for seining captures, Colorado River, Grand Canyon. Non-native species are represented by brick patterns.

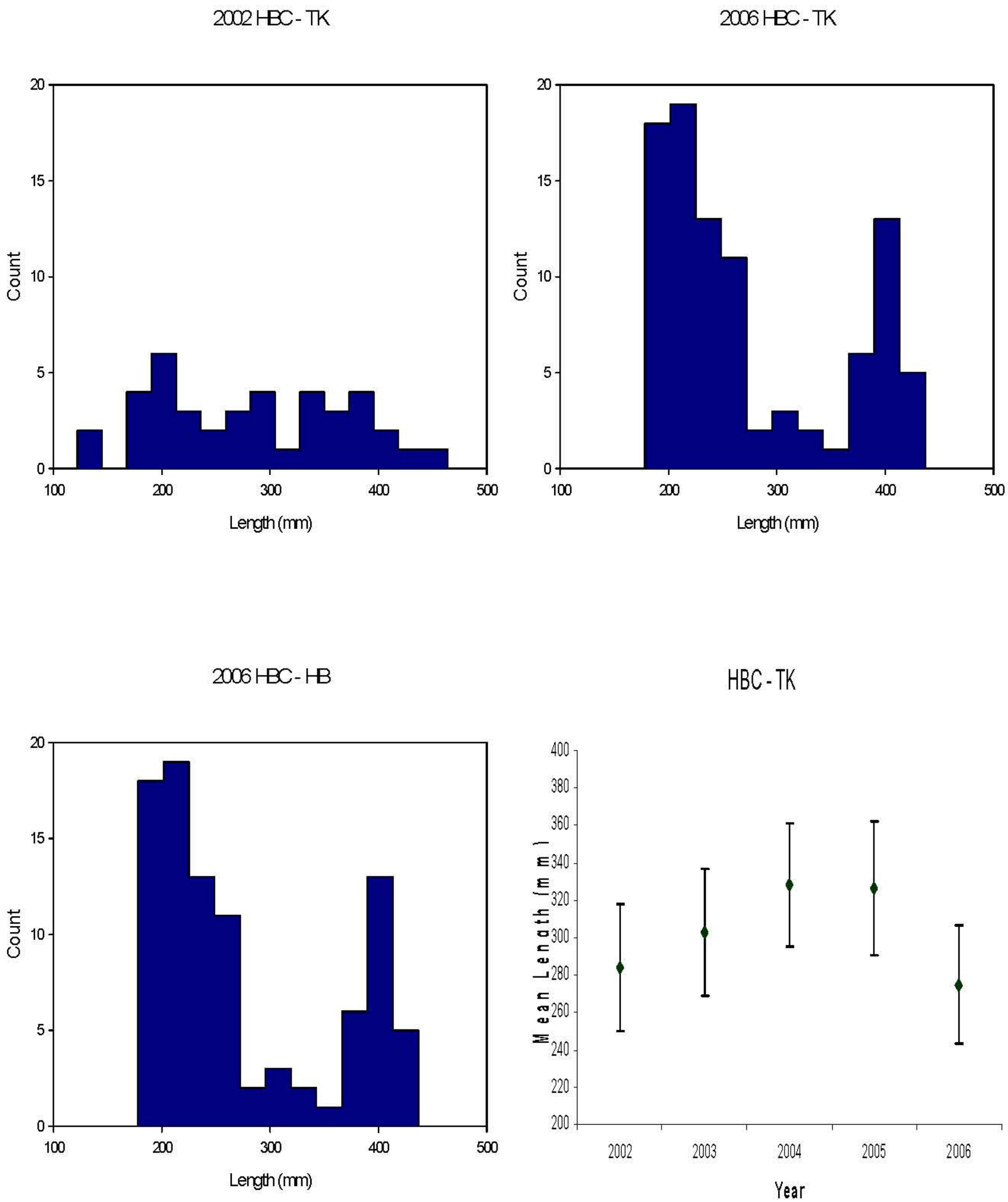



**Figure 35.** Humpback chub (HBC) length frequencies for 2002 and 2006 trammel net captures, 2006 hoop net captures, and mean TL (± 95% CI) comparison between years for trammel net captures, Colorado River, Grand Canyon.

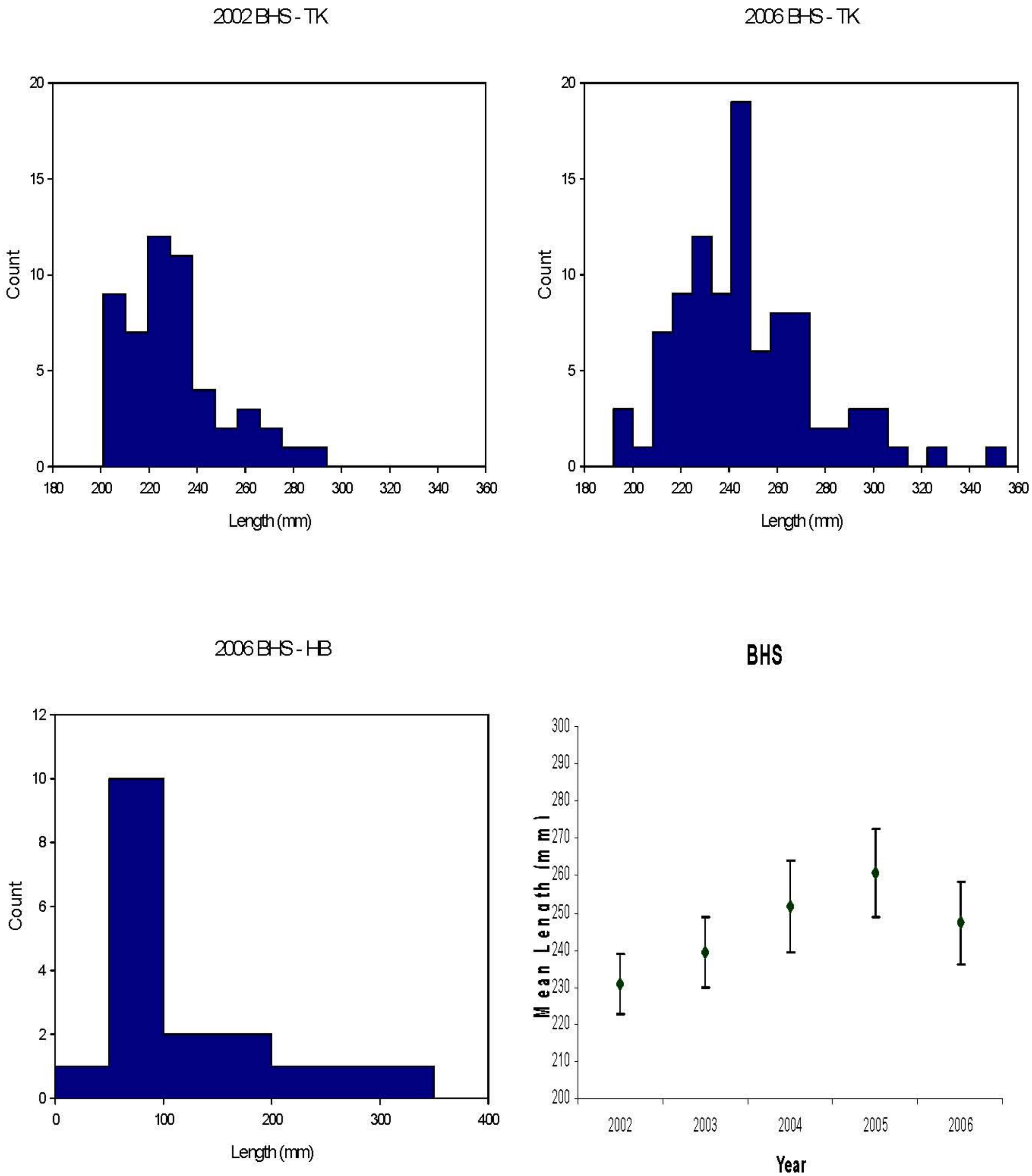



**Figure 36.** Bluehead sucker (BHS) length frequencies for 2002 and 2006 trammel net captures, 2006 hoop net captures, and mean TL (± 95% CI) comparison between years for trammel net captures, Colorado River, Grand Canyon.

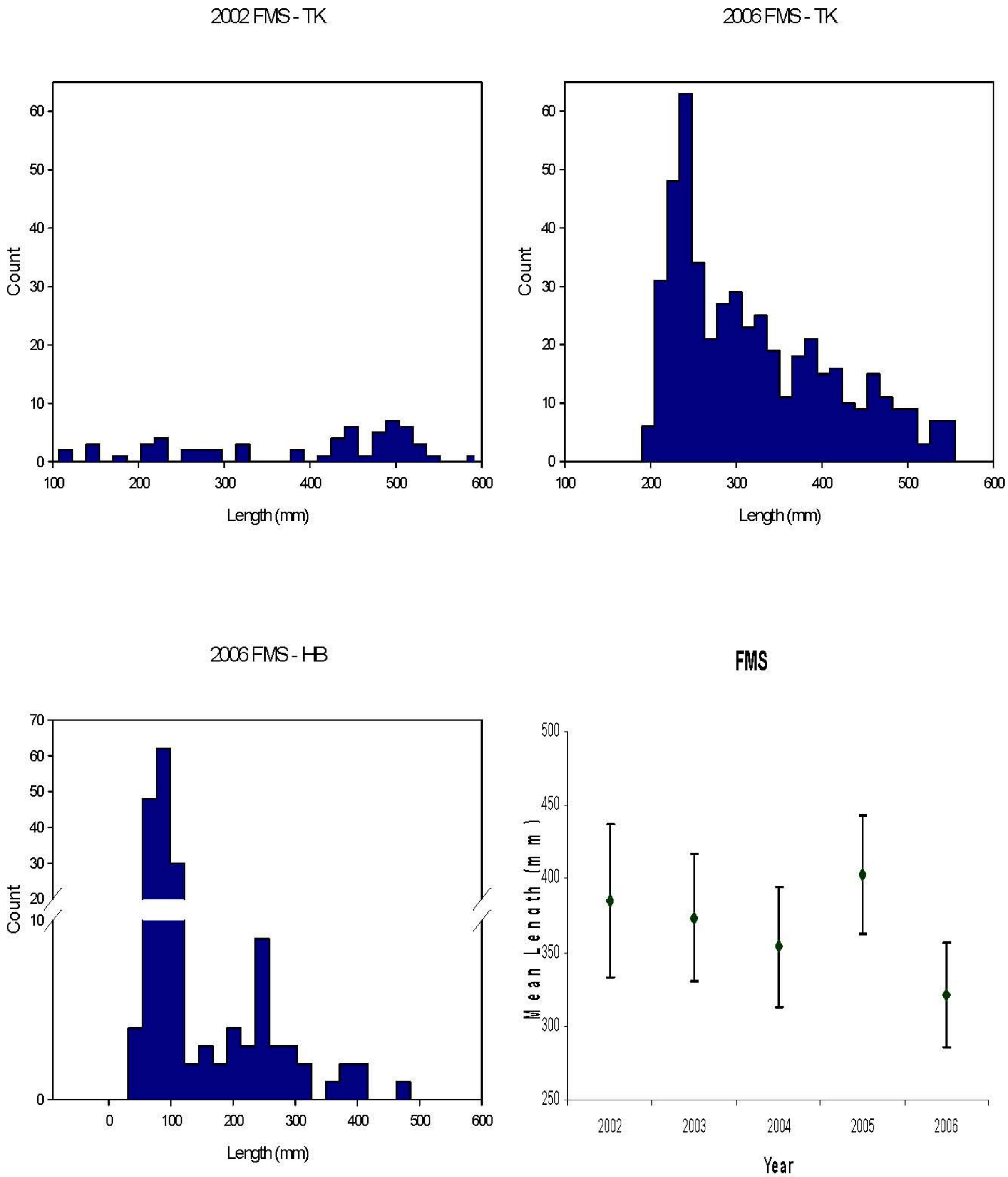



**Figure 37.** Flannelmouth sucker (FMS) length frequencies for 2002 and 2006 trammel net captures, 2006 hoop net captures, and mean TL (± 95% CI) comparison between years for trammel net captures, Colorado River, Grand Canyon.

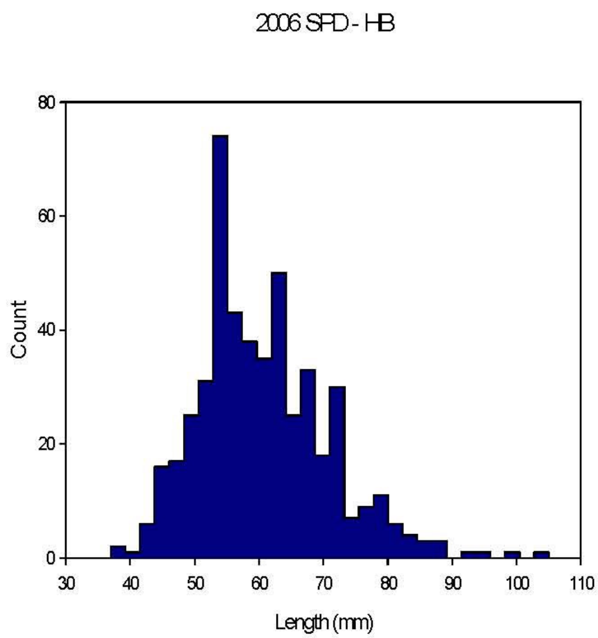



**Figure 38.** Speckled dace (SPD) length frequency for 2006 hoop net captures, Colorado River, Grand Canyon.

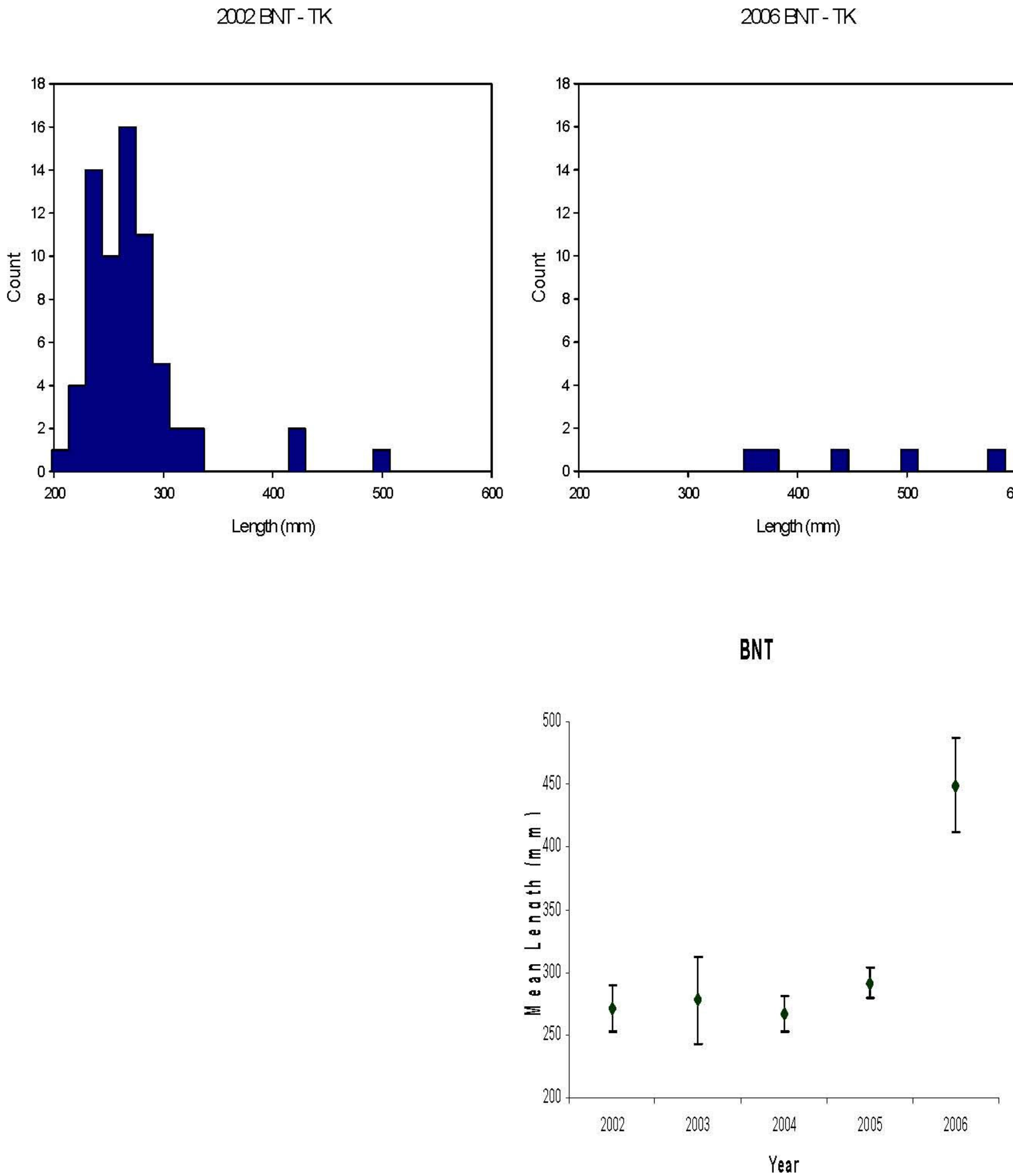



**Figure 39.** Brown trout (BNT) length frequencies for 2002 and 2006 trammel net captures, and mean TL (± 95% CI) comparison between years for trammel net captures, Colorado River, Grand Canyon.

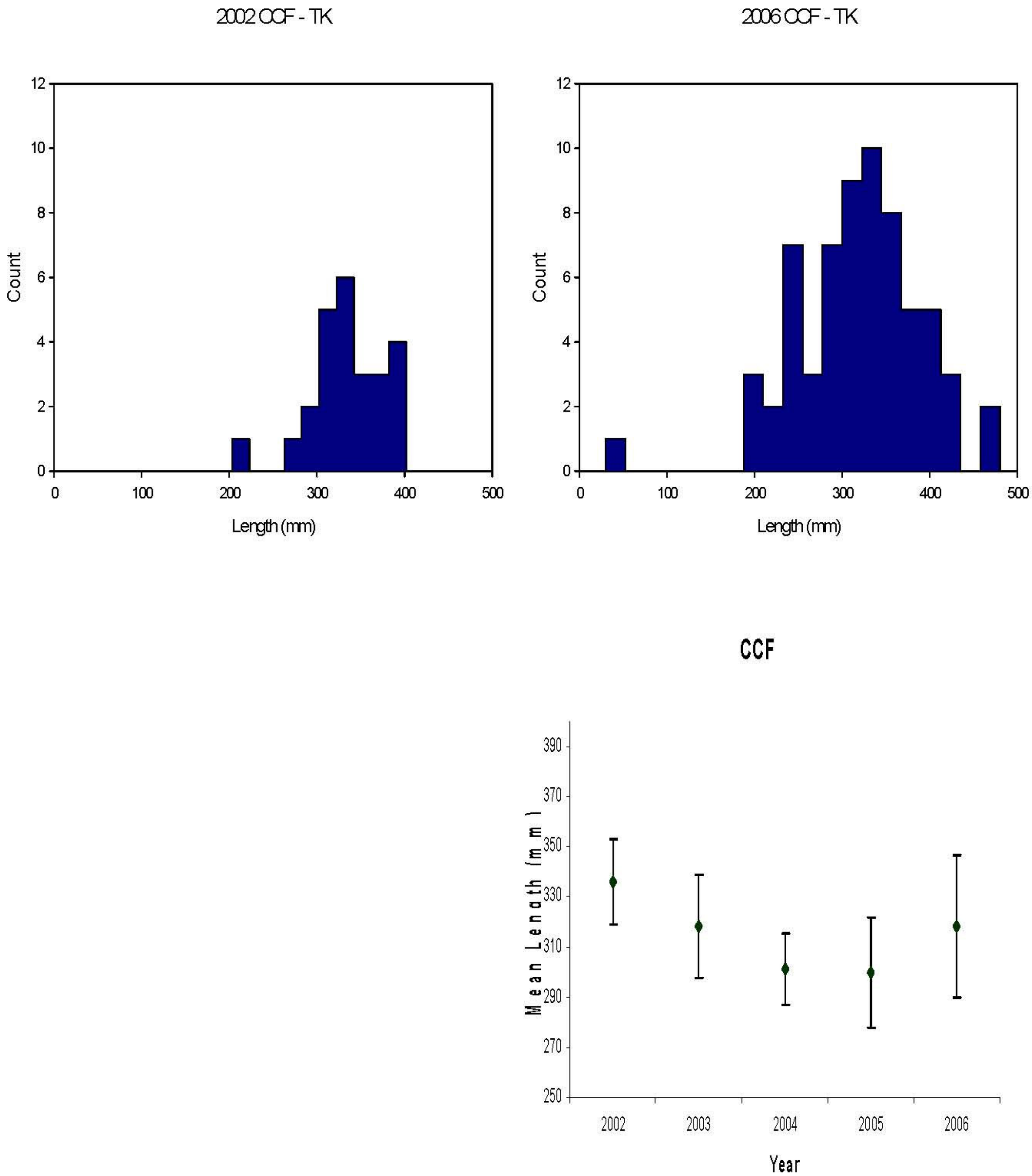



**Figure 40**. Channel catfish (CCF) length frequencies for 2002 and 2006 trammel net captures, and mean TL (± 95% CI) comparison between years for trammel net captures, Colorado River, Grand Canyon.

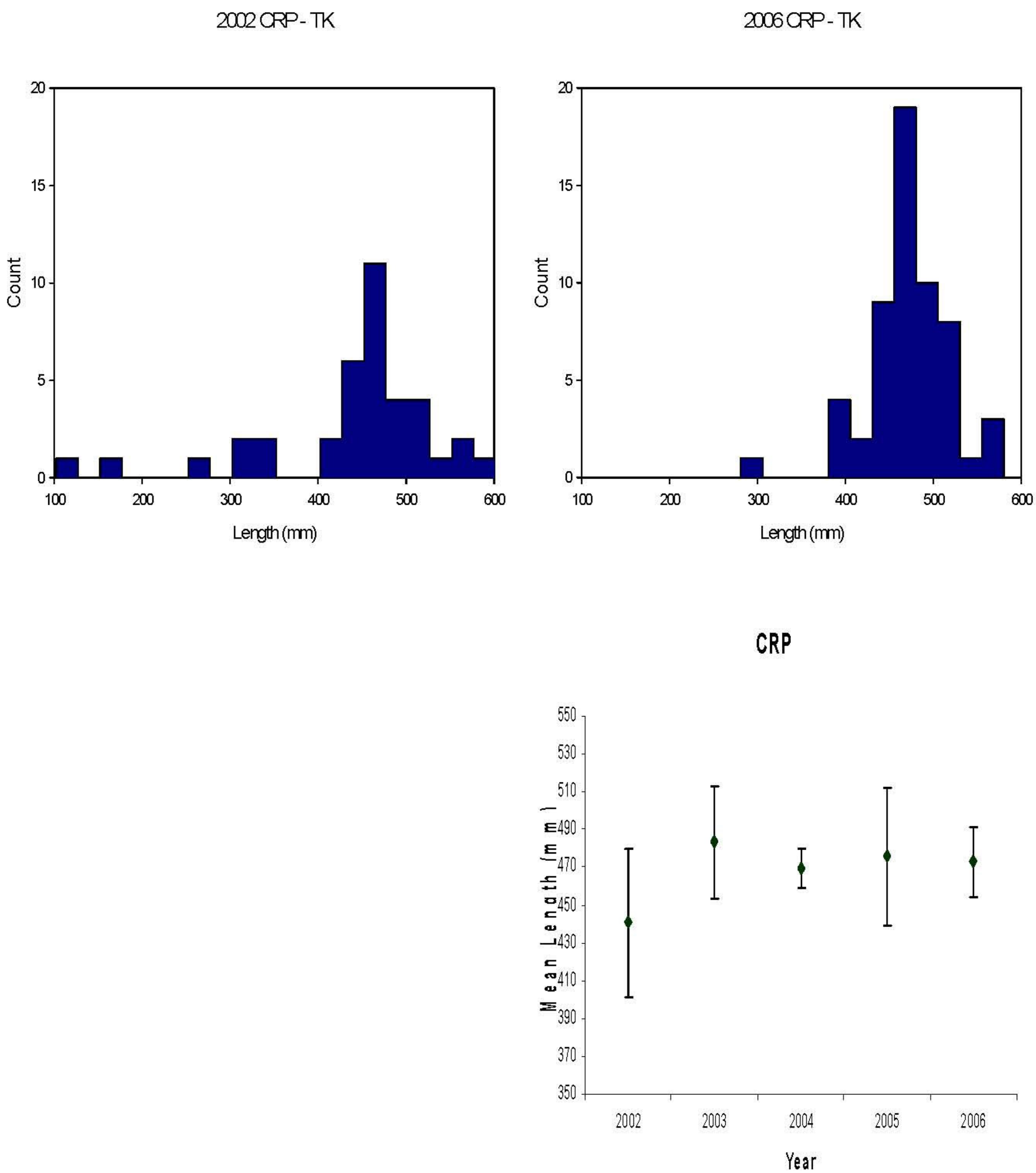



**Figure 41.** Common carp (CRP) length frequencies for 2002 and 2006 trammel net captures, and mean TL (± 95% CI) comparison between years for trammel net captures, Colorado River, Grand Canyon.

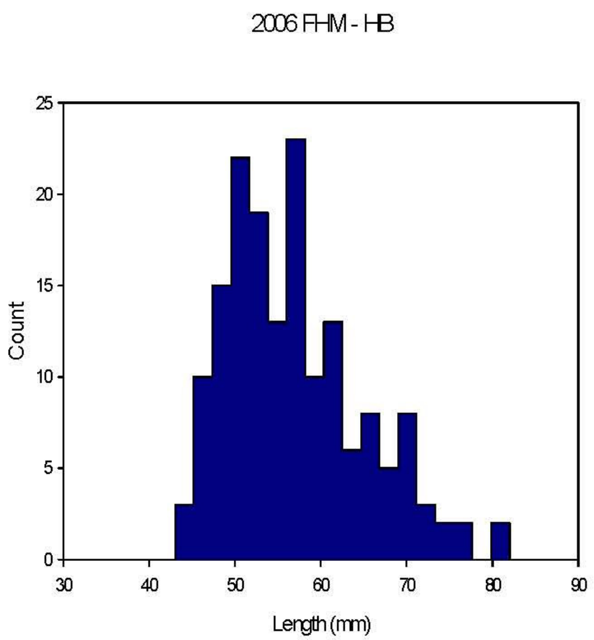



**Figure 42**. Fathead minnow (FHM) length frequencies for 2006 hoop net captures, Colorado River, Grand Canyon.

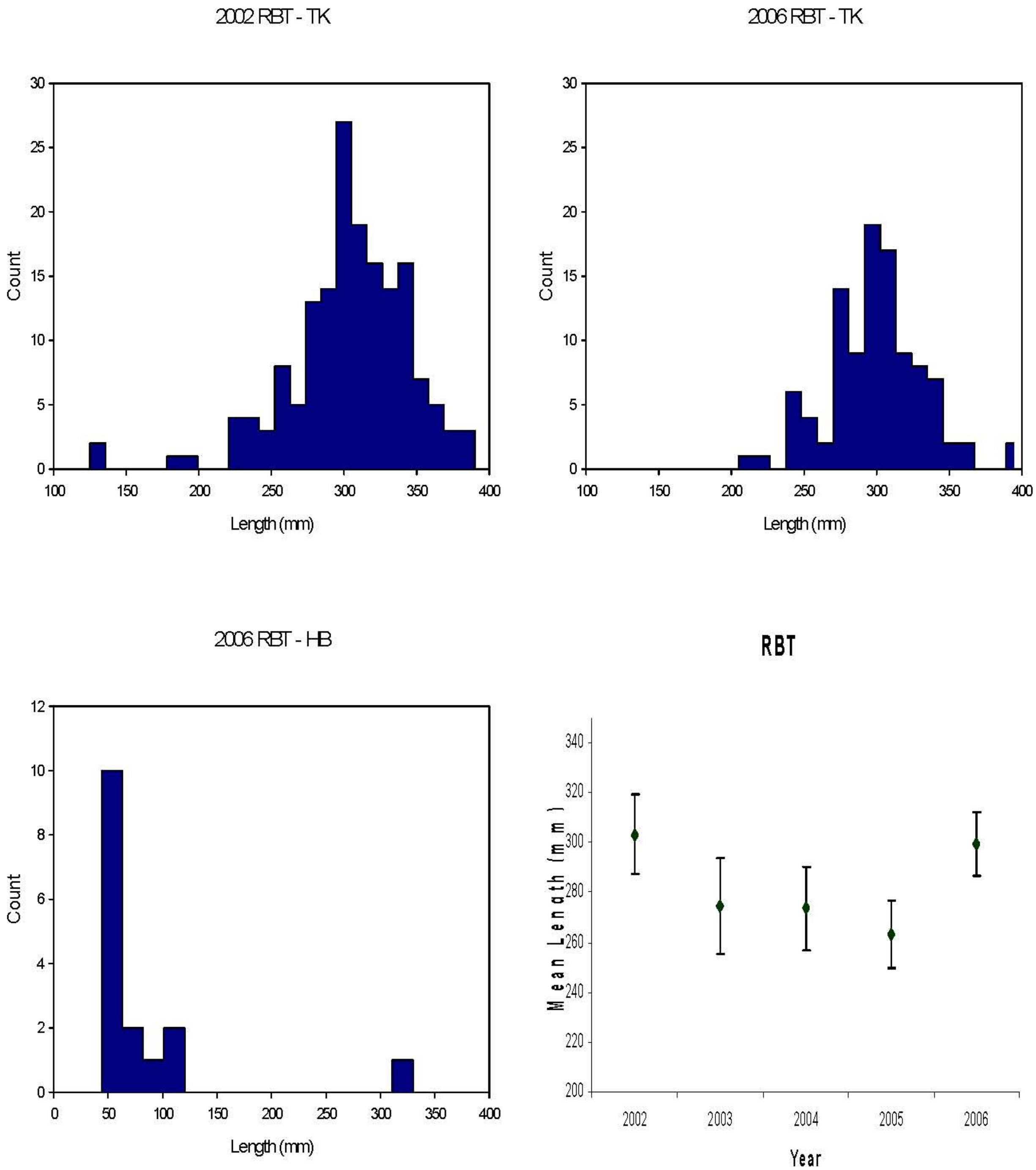



**Figure 43.** Rainbow trout (RBT) length frequencies for 2002 and 2006 trammel net captures, 2006 hoop net captures, and mean TL (± 95% CI) comparison between years for trammel net captures, Colorado River, Grand Canyon.

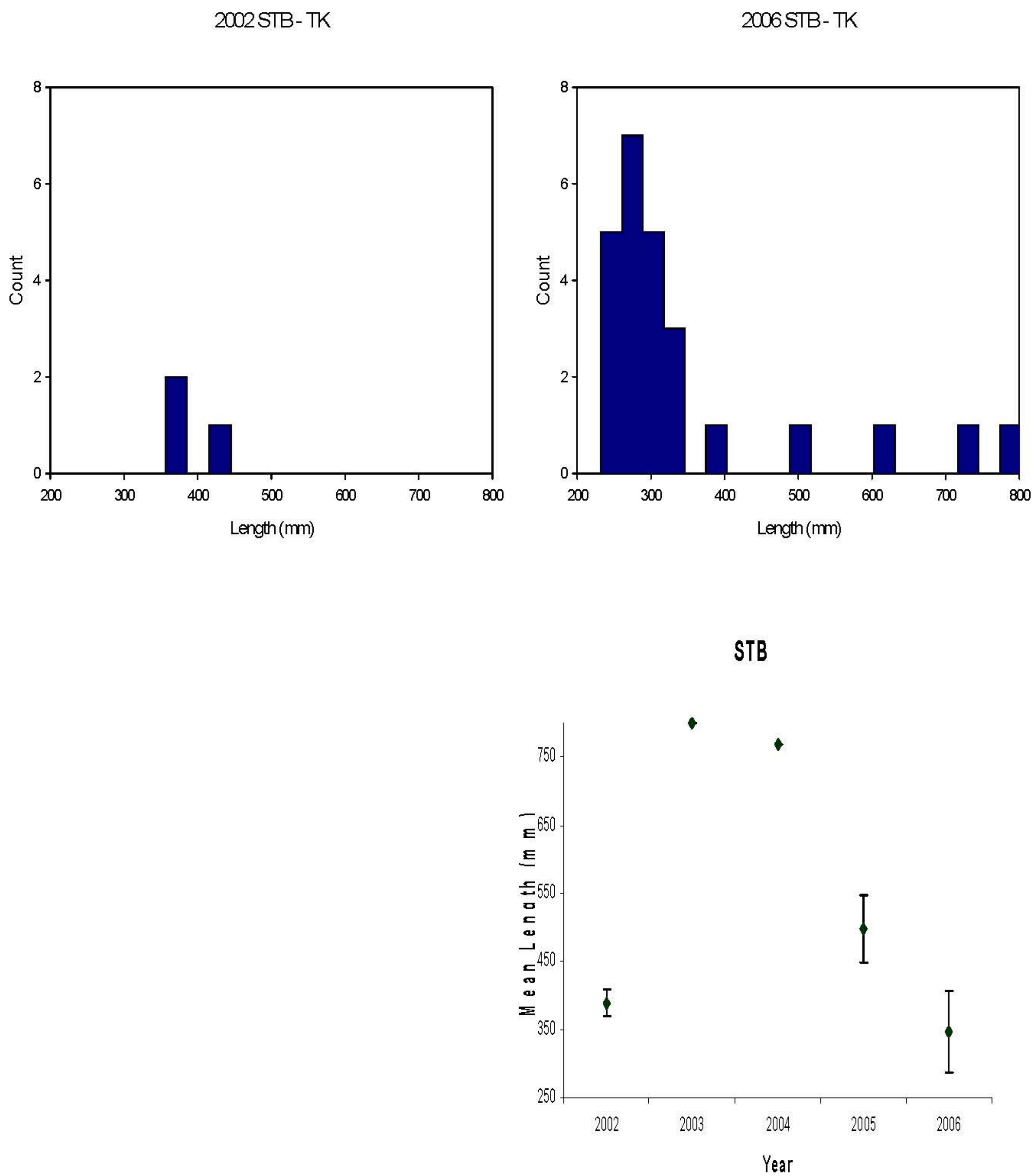



**Figure 44.** Striped bass (STB) length frequencies for 2002 and 2006 trammel net captures, and mean TL (± 95% CI) comparison among years for trammel net captures, Colorado River, Grand Canyon.

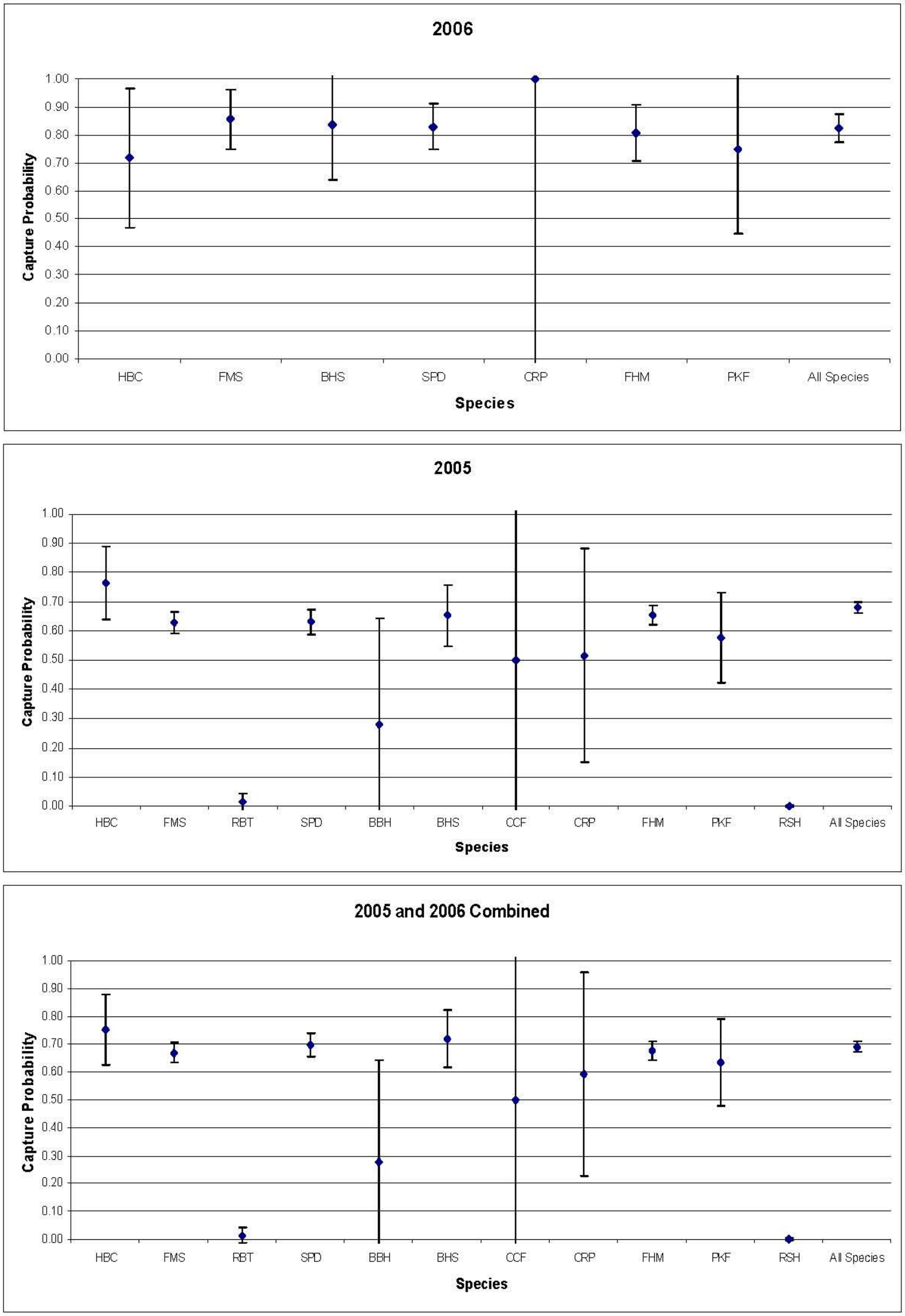



**Figure 45**. Capture probabilities (± 95% CI) for all species captured in 2005 and 2006 seining depletions, Colorado River, Grand Canyon. Capture probabilities are segregated into 2005, 2006, and 2005 and 2006 data combined.

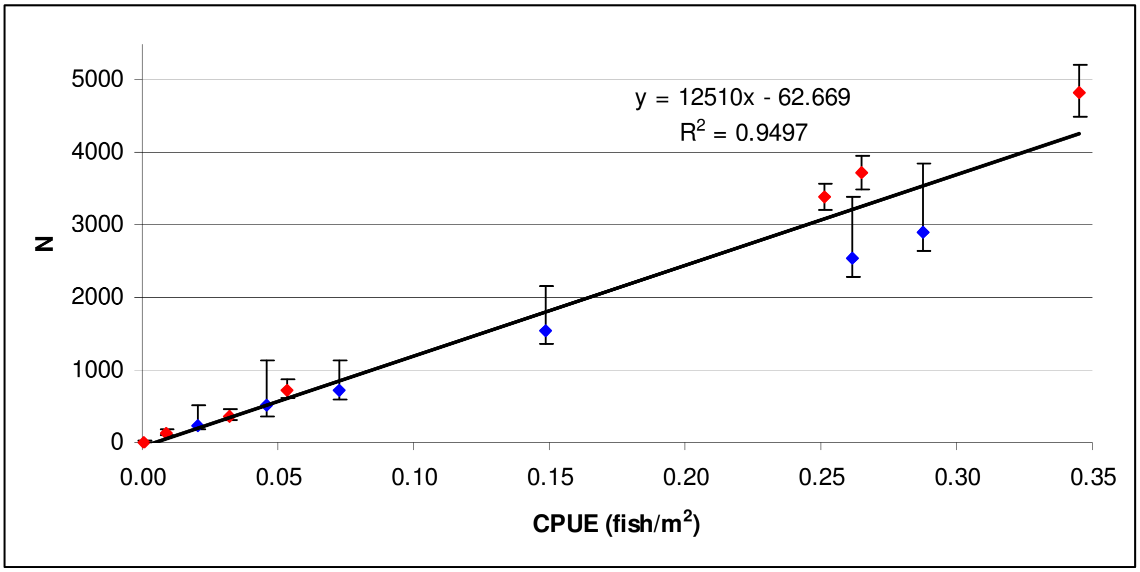



**Figure 46.** CPUEs and correlating riverwide backwater habitat abundance estimates for each species captured during 2005 and 2006 seining efforts in which sufficient captures were made during depletion seining efforts to calculate a capture probability. Red data points represent 2005 abundance estimates. Blue data points represent 2006 abundance estimates.

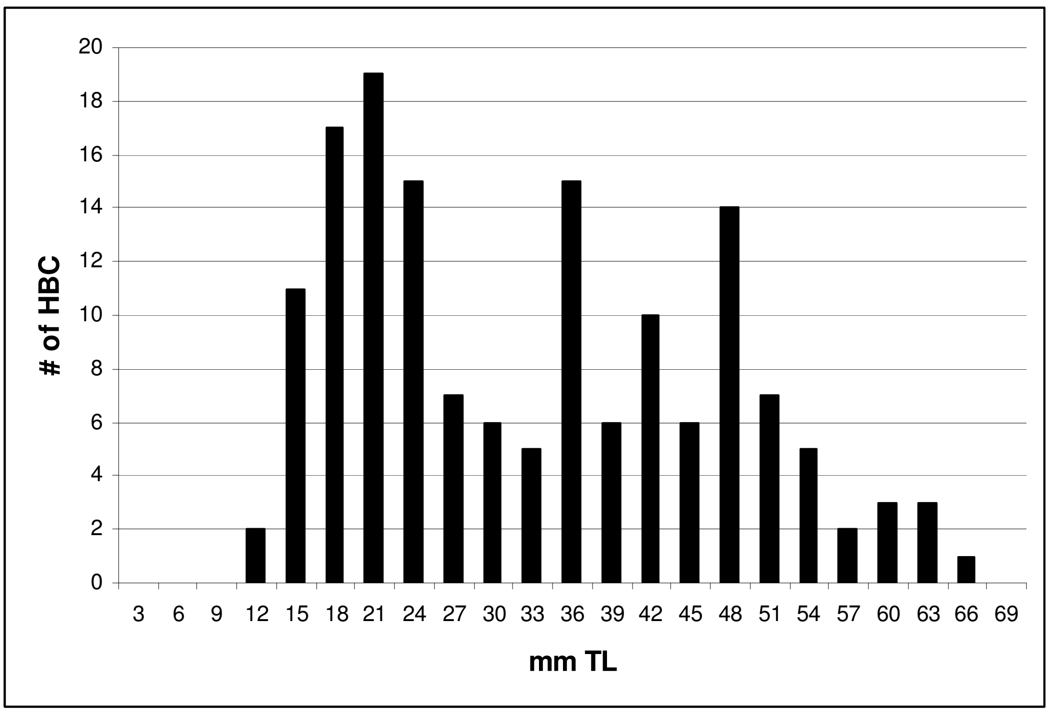



**Figure 47.** Length frequency of humpback chub (HBC) captured between RMs 30 and 57 during Trip ID GC20060921.

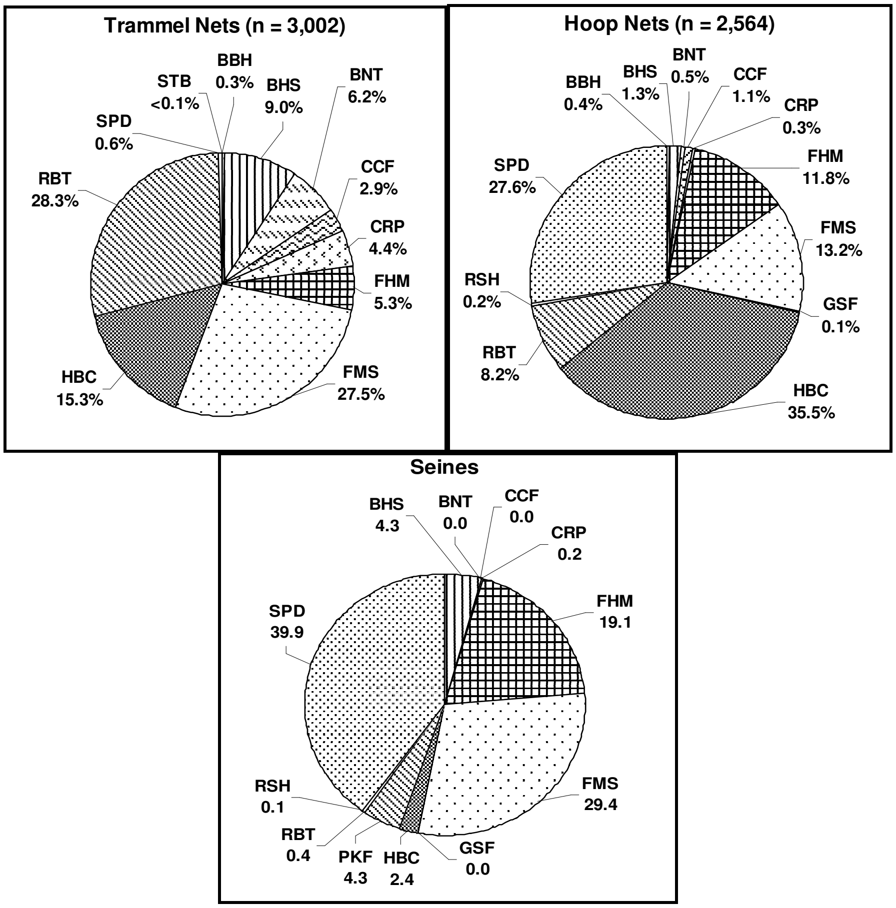



**Figure 48.** Proportion of fish caught by species with trammel nets (left), hoop nets (center), and seines (right) during 2002–2006 in the Colorado River through Grand Canyon.

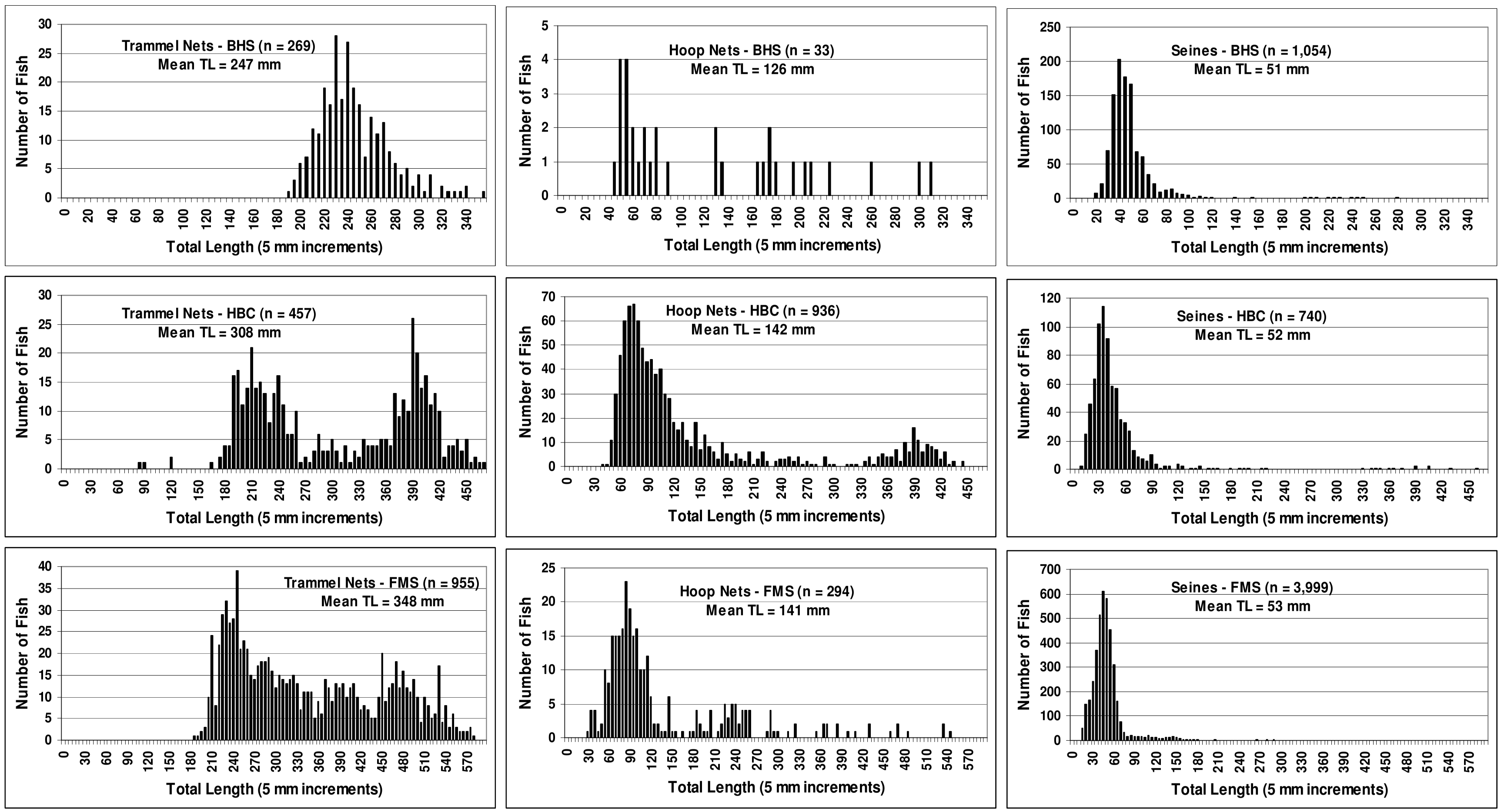



**Figure 49.** Lengths of bluehead sucker (BHS, top), humpback chub (HBC, middle), and flannelmouth sucker (FMS, bottom) captured with trammel nets, hoop nets, and seines during 2002–2006 in the Colorado River through Grand Canyon.

# APPENDIX A

## 2006 Trammel Net and Hoop Net HBC Recaptures with Tag Histories for Colorado River, Grand Canyon

**Appendix A.** 2006 trammel net and hoop net HBC recaptures with tag histories for Colorado River, Grand Canyon

| 2006 Recapture Information | | | | | | | | Original Capture | | | | | 1st Recapture | | | | | 2nd Recapture | | | | | 3rd Recapture | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Trip ID | Capture Date | Species | Sex | TL | RM | 1st PIT Tag | 2nd PIT Tag | Date | River | TL | RM | RKM | Date | River | TL | RM | RKM | Date | River | TL | RM | RKM | Date | River | TL | RM | RKM |
| GC20060603 | 6/4/06 | HBC | U | 379 | 59.7 | 7F7F7E5E3F | | 4/27/92 | LCR | 366 | | 2.78 | 2/16/94 | LCR | 373 | | 0.08 | | | | | | | | | | |
| GC20060603 | 6/4/06 | HBC | U | 392 | 59.7 | 7F7F3F3226 | | 3/6/91 | COR | 346 | 58.8 | | 3/5/95 | LCR | 360 | | 1.14 | 3/27/95 | LCR | 364 | | 3.03 | 4/28/03 | LCR | 390 | | 2.95 |
| GC20060603 | 6/4/06 | HBC | U | 311 | 58.6 | 42402D2F08 | | 6/10/01 | LCR | 151 | | 11.4 | | | | | | | | | | | | | | | |
| GC20060603 | 6/4/06 | HBC | U | 420 | 59.75 | 3D9.1BF1CD3907 | 1F787C105D | 5/19/04 | COR | 412 | | 60.8 | 4/21/97 | LCR | 372 | | 0.435 | 6/18/97 | COR | 378 | 61.35 | | | | | | |
| GC20060603 | 6/4/06 | HBC | | 400 | 58.7 | 3D9.1BF1CD460D | 7F7D177F6B | 6/22/91 | LCR | 337 | | 0.132 | 4/27/93 | LCR | 349 | | 10.515 | 7/12/93 | COR | 353 | 58.8 | | 7/31/01 | COR | 382 | 59.25 | |
| GC20060603 | 6/4/06 | HBC | | 252 | 58.7 | 3D9.1BF1D89BE9 | | 5/2/05 | LCR | 183 | | 11.16 | | | | | | | | | | | | | | | |
| GC20060603 | 6/5/06 | HBC | F | 405 | 61.35 | 3D9.1BF253AE95 | 7F7F7E5F50 | 4/25/92 | LCR | 391 | | 3.1 | 6/23/92 | LCR | 393 | | | 5/10/93 | LCR | 392 | | 3.015 | 5/12/93 | LCR | 390 | | 3.166 |
| GC20060603 | 6/5/06 | HBC | U | 405 | 61.35 | 3D9.1BF1E92679 | 7F7B035F34 | 4/20/93 | LCR | 376 | | | 4/9/02 | LCR | 416 | | 6.8 | 5/14/02 | LCR | 399 | | 0.1 | 4/2/05 | LCR | 401 | | 7.05 |
| GC20060603 | 6/5/06 | HBC | U | 271 | 60.2 | 3D9.1BF24DCF65 | 4362580105 | 9/15/02 | COR | 158 | 77.8 | | 4/3/06 | LCR | 269 | | 7.82 | | | | | | | | | | |
| GC20060603 | 6/5/06 | HBC | U | 250 | 62.68 | 3D9.1BF1D8AF7E | | 4/9/05 | LCR | 212 | | 1.16 | | | | | | | | | | | | | | | |
| GC20060603 | 6/5/06 | HBC | U | 446 | 60.75 | 3D9.1BF198CA2E | 7F7F042E1A | 5/3/89 | LCR | 402 | | 0 | 2/12/93 | LCR | 420 | | 1.09 | 2/11/94 | LCR | 423 | | 0.08 | 9/17/03 | COR | 440 | 59.2 | |
| GC20060603 | 6/5/06 | HBC | U | 294 | 60.75 | 423F0B3B59 | | 6/7/01 | LCR | 221 | | 12.1 | 8/31/01 | COR | 225 | 60.85 | | 4/24/02 | LCR | 229 | | 0.137 | 5/4/03 | LCR | 246 | | 1.25 |
| GC20060603 | 6/5/06 | HBC | U | 397 | 62.2 | 3D9.1BF237BF05 | 7F7D1A4C25 | 6/13/92 | LCR | 220 | | 0.482 | 6/14/00 | LCR | 375 | | 0 | 9/2/01 | COR | 384 | 63.1 | | 4/26/06 | LCR | 392 | | 4.99 |
| GC20060603 | 6/5/06 | HBC | U | 430 | 61.1 | 7F7D026134 | | 5/14/93 | COR | 422 | 61.2 | | 8/14/93 | COR | 424 | 60.8 | | 4/18/95 | LCR | 420 | | 5.1 | 4/25/99 | COR | 430 | 61.1 | |
| GC20060603 | 6/5/06 | HBC | U | 390 | 61.1 | 7F7D1B702A | | 7/7/91 | LCR | 260 | | 13.8 | 10/22/91 | LCR | 280 | | 12.9 | 4/23/92 | LCR | 283 | | 6.81 | 6/22/92 | LCR | 285 | | 13.96 |
| GC20060603 | 6/5/06 | HBC | U | 399 | 60.7 | 3D9.1BF1D890F1 | 7F7F053C0B | 5/5/89 | LCR | 379 | | 0.598 | 6/18/92 | LCR | 387 | | | 5/2/04 | LCR | 397 | | 9.85 | | | | | |
| GC20060603 | 6/5/06 | HBC | U | 405 | 61.29 | 7F7D180568 | | 6/19/91 | LCR | 345 | | 0.2 | 3/11/92 | COR | 348 | 61.1 | | 4/26/92 | LCR | 343 | | 9.088 | 5/14/93 | COR | 356 | 61.3 | |
| GC20060603 | 6/5/06 | HBC | U | 383 | 61.2 | 3D9.1BF1CD46C8 | 7F7F39114D | 6/16/92 | LCR | 215 | | 5.78 | 6/18/92 | LCR | 215 | | 5.92 | 11/8/92 | COR | 255 | 61.8 | | 4/15/93 | COR | 262 | 61.5 | |
| GC20060603 | 6/5/06 | HBC | U | 394 | 60.5 | 3D9.1BF1E8B14F | 7F7E43220D | 3/9/93 | LCR | 362 | | | 4/19/95 | LCR | 365 | | 8.36 | 5/21/95 | LCR | 361 | | 6.05 | 6/5/01 | LCR | 390 | | 0 |
| GC20060603 | 6/5/06 | HBC | U | 405 | 60.5 | 7F7A141533 | | 2/10/95 | LCR | 398 | | 6.52 | | | | | | | | | | | | | | | |
| GC20060603 | 6/5/06 | HBC | U | 401 | 61.1 | 3D9.1BF1A05B01 | 7F7E427710 | 3/11/92 | LCR | 394 | | 2.4 | 5/13/93 | LCR | 389 | | 1.52 | 4/25/96 | LCR | 393 | | 0.165 | 4/15/02 | LCR | 409 | | 1.23 |
| GC20060603 | 6/5/06 | HBC | U | 197 | 61.1 | 3D9.1BF1E8FC94 | | 9/11/05 | COR | 178 | 60.8 | | | | | | | | | | | | | | | | |
| GC20060603 | 6/5/06 | HBC | U | 390 | 60.7 | 1F0F6F174C | | 6/14/93 | LCR | 340 | | | | | | | | | | | | | | | | | |
| GC20060603 | 6/5/06 | HBC | U | 259 | 60.7 | 3D9.1BF1A075B0 | | 6/14/04 | COR | 197 | 63.9 | | 9/4/05 | COR | 253 | 60.3 | | | | | | | | | | | |
| GC20060603 | 6/5/06 | HBC | U | 240 | 61.29 | 3D9.1BF1CD265C | | 1/21/05 | COR | 156 | 62.3 | | 4/3/06 | LCR | 232 | | 6.51 | 5/1/06 | LCR | 241 | | 10.43 | 5/3/06 | LCR | 241 | | 1.9 |
| GC20060603 | 6/5/06 | HBC | U | 182 | 61.29 | 3D9.1BF24E0419 | | 3/17/06 | COR | 180 | 57.3 | | | | | | | | | | | | | | | | |
| GC20060603 | 6/6/06 | HBC | M | 371 | 63.5 | 3D9.1BF1A0CABD | 7F7D22586C | 7/11/91 | LCR | 209 | | 2.2 | 6/22/92 | LCR | 140 | | 2.23 | 4/18/93 | LCR | 250 | | | 3/20/94 | LCR | 265 | | |
| GC20060603 | 6/6/06 | HBC | U | 392 | 63.8 | 3D9.1BF1A02E10 | 7F7D1B7310 | 7/5/91 | LCR | 325 | | 10.4 | 4/27/93 | LCR | 336 | | 10.3 | 3/21/94 | LCR | 336 | | 0.26 | 4/18/95 | LCR | 345 | | 10.48 |
| GC20060603 | 6/6/06 | HBC | U | 389 | 64.1 | 3D9.1BF22D54BF | | 6/22/05 | COR | 391 | 63.7 | | | | | | | | | | | | | | | | |
| GC20060603 | 6/6/06 | HBC | U | 382 | 62.29 | 7F7F271B1C | | 2/13/92 | LCR | 366 | | | | | | | | | | | | | | | | | |
| GC20060603 | 6/6/06 | HBC | M | 371 | 64.2 | 3D9.1BF198D3F6 | 7F7F45676F | 4/26/90 | LCR | 288 | | 5.432 | 3/27/92 | LCR | 321 | | 2.55 | 6/18/92 | LCR | 326 | | 9.56 | 7/10/92 | LCR | 329 | | 0.11 |
| GC20060603 | 6/6/06 | HBC | U | 428 | 63.5 | 7F7F390E04 | | 4/23/92 | LCR | 383 | | 7.04 | 6/20/92 | LCR | 385 | | 12.51 | 5/12/94 | LCR | 392 | | 12.86 | 5/1/98 | LCR | 403 | | 1.58 |
| GC20060603 | 6/6/06 | HBC | M | 355 | 64.2 | 1F0F6F5A09 | | 8/12/93 | LCR | 186 | | | | | | | | | | | | | | | | | |
| GC20060603 | 6/6/06 | HBC | U | 255 | 62.6 | 3D9.1BF1CD3B53 | | 9/26/05 | LCR | 251 | | 2.02 | | | | | | | | | | | | | | | |
| GC20060603 | 6/6/06 | HBC | U | 267 | 62.7 | 3D9.1BF1991E9C | | 10/27/03 | LCR | 186 | | 11.09 | | | | | | | | | | | | | | | |
| GC20060603 | 6/10/06 | HBC | U | 264 | 108.97 | 3D9.1BF1CD53C1 | | 6/22/04 | COR | 227 | 126.3 | | | | | | | | | | | | | | | | |
| GC20060603 | 6/4/06 | HBC | U | 390 | 59.63 | 3D9.1BF22A9740 | 7F7F32245B | 3/11/92 | LCR | 285 | | 10.428 | 3/8/93 | LCR | 300 | | 1.63 | 1/18/95 | LCR | 323 | | 1.14 | 6/10/01 | LCR | 370 | | 11.2 |
| GC20060603 | 6/4/06 | HBC | U | 416 | 59.92 | 3D9.1BF1D89BE6 | 7F7D2C204C | 8/23/91 | LCR | 283 | | 12.68 | 9/18/92 | LCR | 311 | | 12.667 | 3/6/93 | LCR | 316 | | 1.63 | 5/4/01 | LCR | 389 | | 12.6 |
| GC20060603 | 6/4/06 | HBC | M | 408 | 60.1 | 7F7B035D55 | | 5/14/93 | LCR | 374 | | | 5/12/95 | LCR | 383 | | 11.657 | 7/31/01 | COR | 401 | 59 | | | | | | |
| GC20060603 | 6/4/06 | HBC | U | 423 | 59.75 | 3D9.1BF2561079 | 7F7F3E637C | 1/12/92 | COR | 362 | 59.5 | | 3/11/92 | LCR | 362 | | 2.4 | 8/1/01 | COR | 413 | 59.3 | | | | | | |
| GC20060603 | 6/4/06 | HBC | U | 391 | 58.6 | 3D9.1BF1CD4771 | 7F7F183264 | 4/28/92 | LCR | 157 | | 0.17 | 4/18/93 | LCR | 190 | | 3.88 | 4/16/95 | LCR | 262 | | 10.48 | 5/9/95 | LCR | 274 | | 10.709 |
| GC20060603 | 6/4/06 | HBC | U | 437 | 58.7 | 7F7F332F28 | | 7/9/92 | COR | 425 | 58.8 | | 7/10/92 | COR | 425 | 58.6 | | 2/10/95 | LCR | 434 | | 6.52 | 4/26/06 | LCR | 433 | | 1.11 |

**Appendix A, cont.** 2006 trammel net and hoop net HBC recaptures with tag histories for Colorado River, Grand Canyon

| 2006 Recapture Information | | | | | | | | 4th Recapture | | | | | 5th Recapture | | | | | 6th Recapture | | | | | 7th Recapture | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Trip ID | Capture Date | Species | Sex | TL | RM | 1st PIT Tag | 2nd PIT Tag | Date | River | TL | RM | RKM | Date | River | TL | RM | RKM | Date | River | TL | RM | RKM | Date | River | TL | RM | RKM |
| GC20060603 | 6/4/06 | HBC | U | 379 | 59.7 | 7F7F7E5E3F | | | | | | | | | | | | | | | | | | | | | |
| GC20060603 | 6/4/06 | HBC | U | 392 | 59.7 | 7F7F3F3226 | | | | | | | | | | | | | | | | | | | | | |
| GC20060603 | 6/4/06 | HBC | U | 311 | 58.6 | 42402D2F08 | | | | | | | | | | | | | | | | | | | | | |
| GC20060603 | 6/4/06 | HBC | U | 420 | 59.75 | 3D9.1BF1CD3907 | 1F787C105D | | | | | | | | | | | | | | | | | | | | |
| GC20060603 | 6/4/06 | HBC | | 400 | 58.7 | 3D9.1BF1CD460D | 7F7D177F6B | 6/13/05 | COR | 395 | 58.9 | | | | | | | | | | | | | | | | |
| GC20060603 | 6/4/06 | HBC | | 252 | 58.7 | 3D9.1BF1D89BE9 | | | | | | | | | | | | | | | | | | | | | |
| GC20060603 | 6/5/06 | HBC | F | 405 | 61.35 | 3D9.1BF253AE95 | 7F7F7E5F50 | 4/27/02 | LCR | 405 | | 0.1 | | | | | | | | | | | | | | | |
| GC20060603 | 6/5/06 | HBC | U | 405 | 61.35 | 3D9.1BF1E92679 | 7F7B035F34 | 6/14/05 | COR | 400 | 60.7 | | 5/30/06 | LCR | 406 | | 2.2 | | | | | | | | | | |
| GC20060603 | 6/5/06 | HBC | U | 271 | 60.2 | 3D9.1BF24DCF65 | 4362580105 | | | | | | | | | | | | | | | | | | | | |
| GC20060603 | 6/5/06 | HBC | U | 250 | 62.68 | 3D9.1BF1D8AF7E | | | | | | | | | | | | | | | | | | | | | |
| GC20060603 | 6/5/06 | HBC | U | 446 | 60.75 | 3D9.1BF198CA2E | 7F7F042E1A | 4/5/04 | LCR | 448 | | 1.93 | 7/10/05 | COR | 448 | 59.5 | | | | | | | | | | | |
| GC20060603 | 6/5/06 | HBC | U | 294 | 60.75 | 423F0B3B59 | | | | | | | | | | | | | | | | | | | | | |
| GC20060603 | 6/5/06 | HBC | U | 397 | 62.2 | 3D9.1BF237BF05 | 7F7D1A4C25 | | | | | | | | | | | | | | | | | | | | |
| GC20060603 | 6/5/06 | HBC | U | 430 | 61.1 | 7F7D026134 | | | | | | | | | | | | | | | | | | | | | |
| GC20060603 | 6/5/06 | HBC | U | 390 | 61.1 | 7F7D1B702A | | 4/19/93 | LCR | 311 | | | 6/7/01 | LCR | 359 | | 12.4 | | | | | | | | | | |
| GC20060603 | 6/5/06 | HBC | U | 399 | 60.7 | 3D9.1BF1D890F1 | 7F7F053C0B | | | | | | | | | | | | | | | | | | | | |
| GC20060603 | 6/5/06 | HBC | U | 405 | 61.29 | 7F7D180568 | | 7/16/93 | COR | 356 | 60.9 | | 5/12/97 | LCR | 371 | | 0.1 | 5/6/01 | LCR | 386 | | 10.6 | 5/8/01 | LCR | 386 | | 10.6 |
| GC20060603 | 6/5/06 | HBC | U | 383 | 61.2 | 3D9.1BF1CD46C8 | 7F7F39114D | 4/19/95 | LCR | 308 | | 6.5 | 8/30/01 | COR | 370 | 60.44 | | 5/19/04 | COR | 385 | 60.7 | | | | | | |
| GC20060603 | 6/5/06 | HBC | U | 394 | 60.5 | 3D9.1BF1E8B14F | 7F7E43220D | 4/28/04 | LCR | 390 | | 8 | | | | | | | | | | | | | | | |
| GC20060603 | 6/5/06 | HBC | U | 405 | 60.5 | 7F7A141533 | | | | | | | | | | | | | | | | | | | | | |
| GC20060603 | 6/5/06 | HBC | U | 401 | 61.1 | 3D9.1BF1A05B01 | 7F7E427710 | 5/19/02 | LCR | 409 | | 1.25 | 4/27/05 | LCR | 409 | | 6.4 | 4/4/06 | LCR | 405 | | 2.03 | | | | | |
| GC20060603 | 6/5/06 | HBC | U | 197 | 61.1 | 3D9.1BF1E8FC94 | | | | | | | | | | | | | | | | | | | | | |
| GC20060603 | 6/5/06 | HBC | U | 390 | 60.7 | 1F0F6F174C | | | | | | | | | | | | | | | | | | | | | |
| GC20060603 | 6/5/06 | HBC | U | 259 | 60.7 | 3D9.1BF1A075B0 | | | | | | | | | | | | | | | | | | | | | |
| GC20060603 | 6/5/06 | HBC | U | 240 | 61.29 | 3D9.1BF1CD265C | | | | | | | | | | | | | | | | | | | | | |
| GC20060603 | 6/5/06 | HBC | U | 182 | 61.29 | 3D9.1BF24E0419 | | | | | | | | | | | | | | | | | | | | | |
| GC20060603 | 6/6/06 | HBC | M | 371 | 63.5 | 3D9.1BF1A0CABD | 7F7D22586C | 4/16/95 | LCR | 268 | | 9.9 | 5/7/01 | LCR | 341 | | 10.6 | 4/4/04 | LCR | 361 | | 10.2 | 6/14/04 | COR | 364 | 63.2 | |
| GC20060603 | 6/6/06 | HBC | U | 392 | 63.8 | 3D9.1BF1A02E10 | 7F7D1B7310 | 4/10/02 | LCR | 395 | | 7.2 | 6/14/04 | COR | | 63.45 | | 6/22/05 | COR | 393 | 63.6 | | | | | | |
| GC20060603 | 6/6/06 | HBC | U | 389 | 64.1 | 3D9.1BF22D54BF | | | | | | | | | | | | | | | | | | | | | |
| GC20060603 | 6/6/06 | HBC | U | 382 | 62.29 | 7F7F271B1C | | | | | | | | | | | | | | | | | | | | | |
| GC20060603 | 6/6/06 | HBC | M | 371 | 64.2 | 3D9.1BF198D3F6 | 7F7F45676F | 7/19/03 | COR | 371 | | | | | | | | | | | | | | | | | |
| GC20060603 | 6/6/06 | HBC | U | 428 | 63.5 | 7F7F390E04 | | 5/1/03 | LCR | 421 | | 11.73 | | | | | | | | | | | | | | | |
| GC20060603 | 6/6/06 | HBC | M | 355 | 64.2 | 1F0F6F5A09 | | | | | | | | | | | | | | | | | | | | | |
| GC20060603 | 6/6/06 | HBC | U | 255 | 62.6 | 3D9.1BF1CD3B53 | | | | | | | | | | | | | | | | | | | | | |
| GC20060603 | 6/6/06 | HBC | U | 267 | 62.7 | 3D9.1BF1991E9C | | | | | | | | | | | | | | | | | | | | | |
| GC20060603 | 6/10/06 | HBC | U | 264 | 108.97 | 3D9.1BF1CD53C1 | | | | | | | | | | | | | | | | | | | | | |
| GC20060603 | 6/4/06 | HBC | U | 390 | 59.63 | 3D9.1BF22A9740 | 7F7F32245B | 6/19/05 | COR | 401 | 59.2 | | | | | | | | | | | | | | | | |
| GC20060603 | 6/4/06 | HBC | U | 416 | 59.92 | 3D9.1BF1D89BE6 | 7F7D2C204C | 6/7/01 | LCR | 396 | | 12.7 | 4/1/05 | LCR | 420 | | 11.69 | 6/13/05 | COR | 415 | 59.1 | | | | | | |
| GC20060603 | 6/4/06 | HBC | M | 408 | 60.1 | 7F7B035D55 | | | | | | | | | | | | | | | | | | | | | |
| GC20060603 | 6/4/06 | HBC | U | 423 | 59.75 | 3D9.1BF2561079 | 7F7F3E637C | | | | | | | | | | | | | | | | | | | | |
| GC20060603 | 6/4/06 | HBC | U | 391 | 58.6 | 3D9.1BF1CD4771 | 7F7F183264 | 9/15/97 | COR | 335 | 60.31 | | 4/15/02 | LCR | 380 | | 1.35 | 6/12/05 | COR | 386 | 57.7 | | | | | | |
| GC20060603 | 6/4/06 | HBC | U | 437 | 58.7 | 7F7F332F28 | | | | | | | | | | | | | | | | | | | | | |

**Appendix A, cont.** 2006 trammel net and hoop net HBC recaptures with tag histories for Colorado River, Grand Canyon

| 2006 Recapture Information | | | | | | | | 8th Recapture | | | | | 9th Recapture | | | | | New Tag Info | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Trip ID | Capture Date | Species | Sex | TL | RM | 1st PIT Tag | 2nd PIT Tag | Date | River | TL | RM | RKM | Date | River | TL | RM | RKM | New Tag? | New Tag # |
| GC20060603 | 6/4/06 | HBC | U | 379 | 59.7 | 7F7F7E5E3F | | | | | | | | | | | | Yes | 3D9.1BF252FDC1 |
| GC20060603 | 6/4/06 | HBC | U | 392 | 59.7 | 7F7F3F3226 | | | | | | | | | | | | Yes | 3D9.1BF252ECB6 |
| GC20060603 | 6/4/06 | HBC | U | 311 | 58.6 | 42402D2F08 | | | | | | | | | | | | Yes | 3D9.1BF252E9A1 |
| GC20060603 | 6/4/06 | HBC | U | 420 | 59.75 | 3D9.1BF1CD3907 | 1F787C105D | | | | | | | | | | | | |
| GC20060603 | 6/4/06 | HBC | | 400 | 58.7 | 3D9.1BF1CD460D | 7F7D177F6B | | | | | | | | | | | | |
| GC20060603 | 6/4/06 | HBC | | 252 | 58.7 | 3D9.1BF1D89BE9 | | | | | | | | | | | | | |
| GC20060603 | 6/5/06 | HBC | F | 405 | 61.35 | 3D9.1BF253AE95 | 7F7F7E5F50 | | | | | | | | | | | Yes | 3D9.1BF253AE95 |
| GC20060603 | 6/5/06 | HBC | U | 405 | 61.35 | 3D9.1BF1E92679 | 7F7B035F34 | | | | | | | | | | | | |
| GC20060603 | 6/5/06 | HBC | U | 271 | 60.2 | 3D9.1BF24DCF65 | 4362580105 | | | | | | | | | | | | |
| GC20060603 | 6/5/06 | HBC | U | 250 | 62.68 | 3D9.1BF1D8AF7E | | | | | | | | | | | | | |
| GC20060603 | 6/5/06 | HBC | U | 446 | 60.75 | 3D9.1BF198CA2E | 7F7F042E1A | | | | | | | | | | | | |
| GC20060603 | 6/5/06 | HBC | U | 294 | 60.75 | 423F0B3B59 | | | | | | | | | | | | Yes | 3D9.1BF25315D9 |
| GC20060603 | 6/5/06 | HBC | U | 397 | 62.2 | 3D9.1BF237BF05 | 7F7D1A4C25 | | | | | | | | | | | | |
| GC20060603 | 6/5/06 | HBC | U | 430 | 61.1 | 7F7D026134 | | | | | | | | | | | | Yes | 3D9.1BF2539E27 |
| GC20060603 | 6/5/06 | HBC | U | 390 | 61.1 | 7F7D1B702A | | | | | | | | | | | | Yes | 3D9.1BF253A07A |
| GC20060603 | 6/5/06 | HBC | U | 399 | 60.7 | 3D9.1BF1D890F1 | 7F7F053C0B | | | | | | | | | | | | |
| GC20060603 | 6/5/06 | HBC | U | 405 | 61.29 | 7F7D180568 | | 4/6/03 | LCR | 395 | | 10.12 | 5/19/04 | COR | 393 | 61.29 | | Yes | 3D9.1BF252F4B6 |
| GC20060603 | 6/5/06 | HBC | U | 383 | 61.2 | 3D9.1BF1CD46C8 | 7F7F39114D | | | | | | | | | | | | |
| GC20060603 | 6/5/06 | HBC | U | 394 | 60.5 | 3D9.1BF1E8B14F | 7F7E43220D | | | | | | | | | | | | |
| GC20060603 | 6/5/06 | HBC | U | 405 | 60.5 | 7F7A141533 | | | | | | | | | | | | Yes | 3D9.1BF253A269 |
| GC20060603 | 6/5/06 | HBC | U | 401 | 61.1 | 3D9.1BF1A05B01 | 7F7E427710 | | | | | | | | | | | | |
| GC20060603 | 6/5/06 | HBC | U | 197 | 61.1 | 3D9.1BF1E8FC94 | | | | | | | | | | | | | |
| GC20060603 | 6/5/06 | HBC | U | 390 | 60.7 | 1F0F6F174C | | | | | | | | | | | | Yes | 3D9.1BF25301A6 |
| GC20060603 | 6/5/06 | HBC | U | 259 | 60.7 | 3D9.1BF1A075B0 | | | | | | | | | | | | | |
| GC20060603 | 6/5/06 | HBC | U | 240 | 61.29 | 3D9.1BF1CD265C | | | | | | | | | | | | | |
| GC20060603 | 6/5/06 | HBC | U | 182 | 61.29 | 3D9.1BF24E0419 | | | | | | | | | | | | | |
| GC20060603 | 6/6/06 | HBC | M | 371 | 63.5 | 3D9.1BF1A0CABD | 7F7D22586C | | | | | | | | | | | | |
| GC20060603 | 6/6/06 | HBC | U | 392 | 63.8 | 3D9.1BF1A02E10 | 7F7D1B7310 | | | | | | | | | | | | |
| GC20060603 | 6/6/06 | HBC | U | 389 | 64.1 | 3D9.1BF22D54BF | | | | | | | | | | | | | |
| GC20060603 | 6/6/06 | HBC | U | 382 | 62.29 | 7F7F271B1C | | | | | | | | | | | | Yes | 3D9.1BF25621F2 |
| GC20060603 | 6/6/06 | HBC | M | 371 | 64.2 | 3D9.1BF198D3F6 | 7F7F45676F | | | | | | | | | | | | |
| GC20060603 | 6/6/06 | HBC | U | 428 | 63.5 | 7F7F390E04 | | | | | | | | | | | | Yes | 3D9.1BF253B780 |
| GC20060603 | 6/6/06 | HBC | M | 355 | 64.2 | 1F0F6F5A09 | | | | | | | | | | | | Yes | 3D9.1BF25609B4 |
| GC20060603 | 6/6/06 | HBC | U | 255 | 62.6 | 3D9.1BF1CD3B53 | | | | | | | | | | | | | |
| GC20060603 | 6/6/06 | HBC | U | 267 | 62.7 | 3D9.1BF1991E9C | | | | | | | | | | | | | |
| GC20060603 | 6/10/06 | HBC | U | 264 | 108.97 | 3D9.1BF1CD53C1 | | | | | | | | | | | | | |
| GC20060603 | 6/4/06 | HBC | U | 390 | 59.63 | 3D9.1BF22A9740 | 7F7F32245B | | | | | | | | | | | | |
| GC20060603 | 6/4/06 | HBC | U | 416 | 59.92 | 3D9.1BF1D89BE6 | 7F7D2C204C | | | | | | | | | | | | |
| GC20060603 | 6/4/06 | HBC | M | 408 | 60.1 | 7F7B035D55 | | | | | | | | | | | | Yes | 3D9.1BF25611F8 |
| GC20060603 | 6/4/06 | HBC | U | 423 | 59.75 | 3D9.1BF2561079 | 7F7F3E637C | | | | | | | | | | | | |
| GC20060603 | 6/4/06 | HBC | U | 391 | 58.6 | 3D9.1BF1CD4771 | 7F7F183264 | | | | | | | | | | | | |
| GC20060603 | 6/4/06 | HBC | U | 437 | 58.7 | 7F7F332F28 | | | | | | | | | | | | Yes | 3D9.1BF25619F7 |