Effects of a Low Steady Summer Flow Experiment on Native Fishes of the Colorado River in Grand Canyon, Arizona

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SWCA Environmental Consultants

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EFFECTS OF A LOW STEADY SUMMER FLOW EXPERIMENT ON NATIVE FISHES OF THE COLORADO RIVER IN GRAND CANYON, ARIZONA

FINAL REPORT

Grand Canyon Monitoring and Research Center
U.S. Department of the Interior
Flagstaff, Arizona 86001

Prepared By

SWCA, Inc., Environmental Consultants
114 North San Francisco Street, Suite 100
Flagstaff, Arizona 86001

SWCA

Melissa Trammell
Richard Valdez
Steve Carothers
Ron Ryel

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Executive Summary

A Low Steady Summer Flow (LSSF) experiment was conducted in 2000 with releases from Glen Canyon Dam down the Colorado River through Marble Canyon and Grand Canyon. The purpose of the LSSF was to determine if low steady flows in summer would stabilize habitat and allow the Colorado River to warm sufficiently for increased growth and survival of the endangered humpback chub (*Gila cypha*) and other native fishes. The LSSF consisted of a high steady release of 17,000 cfs from April through May, with a 4-day spike of 30,000 cfs in early May, followed by steady releases of 8,000 cfs from June through September, with a 4-day spike of 30,000 cfs in early September. Data on species composition, relative abundance and distribution of fishes were gathered to provide a baseline for long-term monitoring and an evaluation of short-term response to the experimental flows. Systematic shoreline electrofishing and extensive mark-recapture efforts were used to gather data for stock-recruitment models to understand population dynamics as part of long-term monitoring. Concurrent periodic sampling with seines, hoop nets, and trammel nets was used to monitor short-term fish responses undetected by sampling schemes designed for long-term monitoring. The following is a summary of findings:

- Distribution and relative abundance of native and nonnative fish species in eight longitudinal reaches of the Colorado River through Grand Canyon were described using a variety of gear types. Rainbow trout (*Oncorhynchus mykiss*) were the most abundant species in the upper reaches and dominated the catch by electrofishing and netting. Fathead minnow (*Pimephales promelas*) and speckled dace (*Rhinichthys osculus*) were the most abundant species in the lower reaches and dominated the catch by seining. Adult humpback chub, bluehead sucker (*Catostomus discobolus*), flannelmouth sucker (*Catostomus latipinnis*), and brown trout (*Salmo trutta*) were locally abundant at aggregations. Young-of-year (YOY) native sucker were distributed throughout the study area.

- Efforts to calibrate trammel net catch rates of native fishes by comparing these to simultaneous removal estimators failed. Removal of native fishes from given habitats (e.g., large eddies) was ineffective because of our inability to block and sample the entire habitat. Fish moved to deep swift water, which could not be sampled. Mark-recapture estimates on a small scale were also ineffective because movement of fish to and from the sample area violated the assumptions of sample population closure. Calibration of trammel net catches of native fishes, using short-term abundance estimators, does not appear possible. However, it may be possible to calibrate catch rates with long-term mark-recapture estimates.

- The humpback chub aggregation near 30-Mile was not found during the LSSF of 2000. In 1993, 26 adults were captured and this aggregation was estimated at 52 adults (95% C.I. = 28-136), which was the 4th largest aggregation identified in the Colorado River through Grand Canyon. Also, 14 YOY (18-31 mm TL) humpback chub were collected

and preserved from a school of approximately 100 at a warm shoreline spring at River Mile (RM) 30.8 on July 14, 1994, indicating successful reproduction by this aggregation. Failure to locate this aggregation is cause for concern over loss of a unique stock of mainstem fish. Sampling should continue in this area to determine if the aggregation has been lost or has relocated to other suitable habitat, possibly in one of the other nearby warm springs associated with Fence Fault and Eminence Grabens.

- Mark-recapture population estimates of humpback chub in Middle Granite Gorge (MGG) in 2000 derived an estimated 107.7 fish/mile, compared to a density of 31.1 fish/mile in 1993. These estimates indicate a three-fold increase in numbers of humpback chub at the MGG aggregation in the past 8 years. Average length and range in length were similar for the two sample periods, and estimated maximum age of these fish was 7-9 years, indicating ongoing recruitment to this aggregation. The source of this recruitment is not known, but could be from local mainstem reproduction or downstream drift from the LCR. There are no known warm mainstem springs near or immediately upstream of MGG, and the possibility of these fish originating from thermal springs is discounted.

- Size of humpback chub at the time of transition from the LCR to the mainstem was determined from temperature checks and first annuli on scales. Average size at transition was 83 mm TL, with a minimum of 69 mm TL (compared to mean of 74 mm TL and minimum of 52 mm TL reported in 1995). Current data suggest that fish smaller than about 69 mm TL do not survive the transition from the warm LCR to the cold mainstem. Similar growth checks in fish captured from the LCR suggest stress-related growth checks resulting from summer flooding. Similar lengths at first annuli and circuli disruptions suggest that fish successfully recruiting in the mainstem likely remained in the LCR until age 1.

- Growth patterns of YOY flannelmouth sucker and bluehead sucker were inconclusive during the LSSF because protracted spawning infused newly-hatched larvae into samples and kept average YOY lengths depressed.

- Mean mainstem temperatures were 1.4-3.0EC warmer than under previous dam operations (MLFF), and mean backwater temperatures were 0.3-5.3EC warmer; hence, a marked warming effect was observed. Longitudinal downstream warming greater than that during MLFF was observed.

- Catch-Per-Effort (CPE) of bluehead sucker, and flannelmouth sucker was significantly higher (%0.05) in August 2000 than in July/August from 1991-1997. Fathead minnow CPE was much higher than previous levels but the differences were not significant due to greater variation in CPE. The increase in abundance was likely a result of the warmer, more suitable temperatures, which may have affected reproduction and survival. Following the September flow spike, CPE of all species declined. However, fathead minnow CPE was nearly identical with previous years while CPE of native fishes remained significantly higher (%0.05), suggesting the flow spike was disproportionately detrimental to fathead minnow.

- No population estimate or depletion of channel catfish (*Ictalurus punctatus*) in the LCR confluence area could be made. Few channel catfish and several humpback chub were caught. This effort should be repeated and timed to correspond with catfish spawning times, which probably occurred after the sample period of May 31 to June 5.

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1.0 INTRODUCTION

1.1 Background

A Low Steady Summer Flow (LSSF) experiment was conducted in summer of 2000, as part of Glen Canyon Dam operations, to evaluate effects of special dam releases on endangered and native fishes of the Colorado River in Grand Canyon. This LSSF experiment is a requirement of the Final Biological Opinion (Opinion) issued by the U.S. Fish and Wildlife Service (Service; 1994) as part of the Final Environmental Impact Statement (FEIS) on the Operation of Glen Canyon Dam (U.S. Bureau of Reclamation [Reclamation] 1995). The Service, in the Opinion, determined that modified low fluctuating flows (MLFF), the preferred alternative of the FEIS are *". . . likely to jeopardize the continued existence of the humpback chub (Gila cypha) and razorback sucker (Xyrauchen texanus) and is likely to destroy or adversely modify designated critical habitat . . ."*. The Opinion requires Reclamation to execute the elements of the reasonable and prudent alternative (RPA) to eventually remove the likelihood of further jeopardizing the continued existence of the two endangered fishes. Element 1.A of four elements of the RPA states that *"A program of experimental flows will be carried out to include high steady flows in the spring and low steady flows in summer and fall during low water years (releases of approximately 8.23 maf) to verify an effective flow regime and to quantify, to the extent possible, effects on endangered and native fish"*.

In 1998, the Adaptive Management Work Group (AMWG) of the Grand Canyon Adaptive Management Program directed the Grand Canyon Monitoring and Research Center (GCMRC) to develop and implement a program of experimental flows, consistent with the RPA. A program and hydrograph were developed by SWCA, Inc. (Valdez et al. 2000) on contract with GCMRC, and a modified hydrograph, termed the Low Summer Steady Flow experiment, was implemented following meetings and discussions among AMWG stakeholders, GCMRC, and scientists (GCMRC 2000).

A LSSF experiment similar to that proposed by Valdez et al. (2000) and consistent with the MLFF operating criteria was implemented from March 25 through September 30, 2000. The following schedule describes the releases from Glen Canyon Dam (Figure 1):

- March 25 - April 5: 12-day block of steady releases of about 8,000 cfs
- April 6-8: 3-day upramp to about 17,000 cfs
- April 9 - May 2: 24-day block of high steady releases of about 17,000 cfs
- May 3-6: 4-day spring spike of about 30,000 cfs
- May 7-22: 16-day block of high steady releases of about 17,000 cfs
- May 23-26: 4-day spring spike of about 18,000 cfs
- May 27-31: 5-day downramp to about 8,000 cfs
- June 1 - September 4: 96-day block of low summer steady flow of about 8,000 cfs
- September 5-8: 4-day fall spike of about 30,000 cfs
- September 9-30: 22-day block of low steady flow of about 8,000 cfs
- September 18:1 day increase to 16,000 for emergency power release

1.2 Purpose and Objectives

The purpose of the LSSF experiment was to implement one element of the RPA and to test the overriding hypothesis that high spring releases and low steady summer flows in low water years will benefit the endangered and other native fish species of the Colorado River in Grand Canyon. Because GCMRC determined that baseline data were inadequate for evaluating the effects of these experimental flows on native fish, data collection during the LSSF focused on developing systematic monitoring protocols and gathering reliable baseline data for meaningful long-term monitoring and research efforts. SWCA also gathered data on small-bodied fishes including YOY and juvenile native species in backwater and nearshore areas, and attempted to identify reproduction and growth patterns of humpback chub and other native fishes over the period of experimental flows. Work performed in this study complemented concurrent studies; i.e., Arizona Game and Fish Department (AGFD) determined population estimates for brown trout and rainbow trout, and the Service determined distribution and population estimates for humpback chub (HBC) in the Little Colorado River.

The objectives of this study were to:

Objective 1 Identify distribution and estimate relative abundances and catch per unit effort of native and nonnative fishes in the mainstem Colorado River from Lees Ferry to Diamond Creek by electrofishing and a variety of netting techniques.

Objective 2 Calibrate trammel net catch rates by mark-recapture and depletion estimates.

Objective 3 Sample areas around warm-water springs near 30 Mile for all ages of humpback chub and other species.

Objective 4 Determine size of young humpback chub at time of transition from the LCR to mainstem, using temperature checks on scales from captured fish.

Objective 5 Identify growth patterns for YOY and juvenile humpback chub and small-bodied nonnative fishes in backwater and nearshore habitats during steady summer flows.

Objective 6 Perform mark-recapture/removal studies and diet analysis on channel catfish at the LCR inflow during May/June and September.

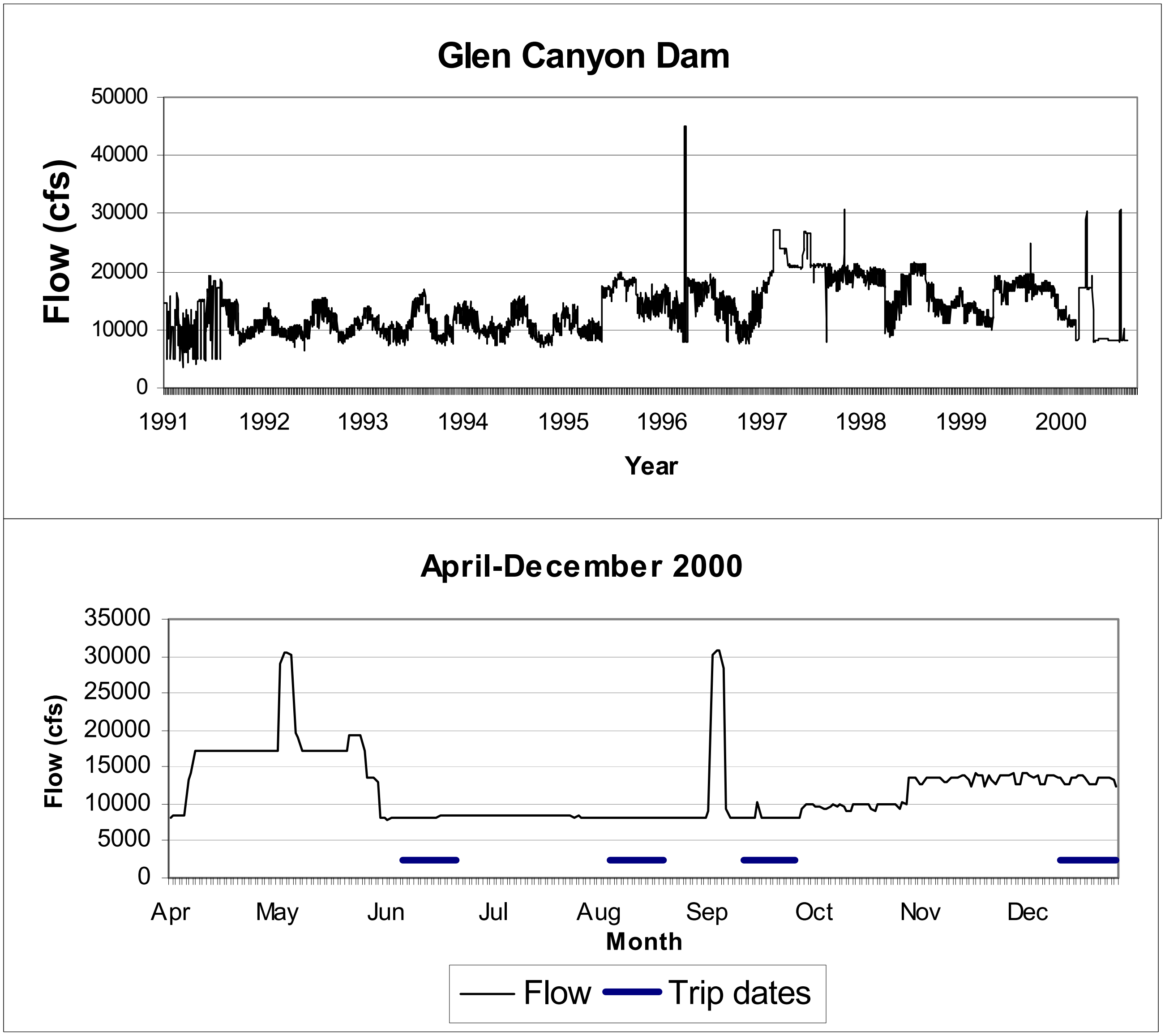


Figure 1. Glen Canyon Dam discharge in cubic feet per second (cfs), daily mean flow from 1991 to 2000. Detail of LSSF release from April 1 to December 31, 2000 with dates for Trips 1-4.

2.0 METHODS

The study area included approximately 363 km (225 mi) of the Colorado River from Lees Ferry to Diamond Creek and selected tributary mouths (i.e., Paria River, Little Colorado River, Shinumo Creek, Kanab Creek, and Havasu Creek; Figure 2). Lees Ferry and Diamond Creek are 25.4 km (15 mi) and 388.6 km (240 mi), respectively, downstream of Glen Canyon Dam. River Mile (RM) designations from Lees Ferry (RM 0) to Diamond Creek (RM 226) were used to identify sampling areas. Four sampling trips were conducted during 2000 through the study area (i.e., June 7-23, August 6-22, September 14-29, December 15-31), and a single trip was conducted May 31-June 5 to the inflow of the Little Colorado River (LCR) to remove channel catfish. Each study objective was addressed during one or more field trips. Fish sampling gears are similar to those used on previous studies (Valdez et al. 1993; Valdez et al. 1995; Valdez and Ryel 1995) and are presented in Table 1.

2.1 Distribution, Relative Abundance, and Catch Rate

Longitudinal distribution of samples to address Objective 1 was determined from sampling distribution and fish capture probabilities from past studies (Valdez and Ryel 1995), and eight sample reaches were defined for distributional fish sampling with electrofishing (Personal communication, C. Walters, University of British Columbia). These reaches were determined to require different sampling frequencies for electrofishing (Table 2). Each electrofishing sample consisted of a run along the shoreline for approximately 600 seconds. Electrofishing efforts took place after sunset. Arithmetic catch-per-unit-effort (CPE) was computed as number of fish per 10 hours (#fish/10 hrs). Data collected from this effort were provided to AGFD for analysis and reporting (Speas 2001).

Fish were handled in similar fashion for each study objective. During electrofishing runs, fish were netted and placed in a live well in the boat. At the end of each electrofishing run, all fish were identified to species and counted. All native fish were measured in millimeters (total length [TL] and forked length [FL]) and weighed in grams. Humpback chub less than 250 mm TL were fin-clipped, and fins were stored in ethanol and delivered to Arizona State University (ASU) for genetic analyses. All native fish were scanned for the presence of a PIT (Passive Integrated Transponder) tag, and PIT-tagged if previously untagged. PIT tag numbers were recorded and fish were released alive. All nonnative fish were also measured for total length in millimeters. Rainbow trout and brown trout were fin-clipped (adipose fin), and brown trout were scanned for PIT tags (initially tagged by AGFD). Approximately 10% of rainbow and most untagged brown trout were sacrificed for stomach content analysis. Stomachs were excised and preserved in ethanol and delivered to GCMRC for analysis. Other predaceous fish species (i.e., channel catfish, black bullhead, striped bass, largemouth bass) were also sacrificed for stomach analysis. Fish captured by trammel nets, hoop nets, and minnow traps were treated similarly, except that no trout were sacrificed.

2.2 Calibrate Trammel Net Catch Rates

Abundance estimates were used to "calibrate" catch rates of fish from trammel nets in order to evaluate use of trammel nets as indices of fish population abundance. Two different methods were used to attempt to calibrate trammel net catch rates. The first method, employed on the first sampling trip only, calibrated an initial trammel net CPE with a short-term removal population estimate in a short reach of river. The second method, employed on Trips 2-4, calibrated an initial trammel net CPE with a 3-day mark-recapture population estimate. In theory, CPE can be correlated to the population estimate for that site. The initial CPE was defined as one night and morning of sampling (approximately five 2-hr sets) with 7-10 nets in one area. All fish captured and all effort expended were pooled for a single arithmetic CPE in fish/10 hrs.

On the first trip, two calibration efforts were made using the removal method, one at RM 30.4, and a second at RM 59.2. An initial trammel net CPE was obtained by setting two to four trammel nets in one eddy for one evening and the following morning, for a total of eight 2-hour sets per net. Two trammel nets were set at the first site, and four nets were set at the second site for the initial CPE index. The following evening, a removal population estimate was attempted in the same eddy using electrofishing and hoop nets.

Very few fish were caught in the original removal effort of the first trip and no fish were recaptured; thus, no abundance estimate could be made. Therefore methods were changed to a longer-term mark-recapture design. The number of days required to perform a mark-recapture estimate at any one site required that only a few sites could be sampled in this manner during one trip. Three sites known to have high densities of native fishes were chosen. Beginning with Trip 2 (August), mark-recapture efforts were conducted in three selected sites; i.e., Crash Canyon to Carbon Creek (RM 62.0-63.2), Middle Granite Gorge (RM 125.8-127.5), and Kanab Creek (RM 141.3-143.5). Crash Canyon and Middle Granite Gorge were chosen for concentrations of humpback chub, and Kanab Creek was chosen for concentrations of flannelmouth sucker.

At each site, an attempt was made to produce reasonable population estimates within limited reaches (1 to 3 miles) in order to calibrate catch rates. On each of three sampling trips, each mark-recapture site was sampled for three consecutive days. In each reach, 8-10 trammel nets were set at dawn and dusk, and were checked and reset every 2 hours for a total of four or five sets. Hoop nets were set in pods of two to five nets (usually two), and minnow traps were set in pods of five traps. Arithmetic CPE was computed as #fish/10 hrs separately for hoop nets and minnow traps by combining all hoop nets or minnow traps in a pod. During Trip 2, electrofishing passes were also conducted within each reach. All native fish with a total length >150 mm were scanned for the presence of a PIT tag, and PIT-tagged if previously untagged. PIT tag numbers were recorded and fish were released alive. All fish captured during sampling were considered "marked" and were used in the population estimates. Fish that had been PIT tagged prior to this study were not considered recaptured until the second capture event.

Population estimates were performed for each of the three mark-recaptures sites and for each of the three native species captured (i.e. humpback chub, flannelmouth sucker, and bluehead sucker) if the number of captures and recaptures was sufficient. Attempts were made to estimate the populations at each site on two different time scales. The first time scale used the 3 days at one site in one trip as three sampling occasions. On this time scale, an interim estimate was obtained for each species, by site and by trip. The assumption of a closed population would be met. The second time scale used trips as sampling occasions. One estimate may be obtained for each species at each site; however, the assumption of closure may be violated. Where sufficient captures and recaptures were obtained, population estimates were generated with several estimator models using program CAPTURE (White et al. 1982), and with a modified Schnabel estimate.

2.3 Native Fish Near 30-Mile

Sampling was conducted near the 30-Mile warm springs on the first three sampling trips to assess the status of humpback chub and the fish community at this site. No sampling was done on Trip 4. An aggregation of about 52 adult humpback chub was reported at these springs in 1993 (Valdez and Ryel 1995) and post-larvae were found in 1994 (Valdez and Masslich 1999). Electrofishing was conducted near the 30-Mile warm springs area on the first three sampling trips. Trammel nets, hoop nets, and minnow traps were set at RM 30.4 on the first trip, as part of the trammel net calibration effort. Hoop nets and minnow traps were also set on the second and third trips. Seines and aquarium dip nets were also used to sample springs, and backwaters and shoreline areas near the springs. Electrofishing and seining included the area from RM 26 to 39, while nets and traps were set more locally to 30-Mile springs. On the first trip, 32 two-hour trammel net sets, 7 hoop net sets, 4 minnow trap sets, 11 electrofishing runs, and 7 seine hauls were made. Several samples were also taken from backwaters and springs with an aquarium dip net. On the second trip, 10 minnow traps (5 traps per set) and 12 hoop net sets (two hoop nets per set) were set overnight. Electrofishing was conducted in the area for 10 runs, and 5 seine hauls were made. On the third trip, 13 seine hauls were made, and 7 pods of 5 minnow traps and 2 hoop nets were set overnight. Ten electrofishing runs were conducted from RM 32.3 to 36.0.

2.4 Size of Young Humpback Chub at Time of Transition From the LCR

Scales were taken from a total of 185 humpback chub during summer 2000. Scales were carefully plucked from larger fish, or scraped from small fish with forceps from above the lateral line and posterior to the dorsal fin, then placed on waxed paper and stored in small coin envelopes. Scales were cleaned and individually mounted between two taped microscope slides. Sample number, total length, and river mile of capture were recorded on each slide. Scale images were digitally captured using video imaging techniques and stored as TIF files. The digital images were then imported into a software package (OPTIMAS) that allowed measurements and circuli counts to be made. For each scale, circuli were counted and measured along a 45^{o} diagonal line from the focus to the anterior edge of the scale. Distance between each circulus, cumulative radius, and total scale radius from the focus to the edge were measured in pixels. Scales were examined and measured without knowledge of total length or capture location. Differences in circuli measurements were evaluated for patterns to reveal temperature checks and annuli. Scales collected by the Service from HBC captured in the LCR were also examined.

2.5 Growth Patterns of Humpback Chub and Small-Bodied Nonnative Fishes

2.5.1 Water Temperature Patterns

Temperature data were collected from the mainchannel and nearshore areas by deploying two 'HOBOtemp' temperature recording devices. Data were downloaded to a database file. HOBOtemps were deployed only at camp sites and the period of data collection varied from 18 to 72 hours, depending on the length of stay at that camp site. Temperatures were recorded in degrees Celsius at 15-minute intervals, and the mean, maximum, and minimum temperatures were calculated for each 24-hour period. The mainstem temperature recorder was suspended from the end of a raft farthest from shore (~12 m) and submerged approximately 0.5 m under the surface. The nearshore recorder was attached to a re-bar support in low velocity water at a depth of approximately 0.15-0.3 m, and no more than 1 m from shore. In addition, temperatures were taken with a hand held thermometer at each seine haul location in each backwater sampled.

2.5.2 Growth of Fish

Distribution, relative abundance, and growth of juvenile humpback chub and small-bodied nonnative fishes were evaluated during the LSSF and compared with data collected during other dam operations. Fish in backwaters and along shorelines were captured primarily by seining. Length-frequency data were supplemented by samples collected by hoop nets, minnow traps, and electrofishing. Backwaters were sampled opportunistically during the first trip, and on the second and third trips, backwaters were sampled at a rate of approximately one every 2 miles, depending on availability. Backwater density varied longitudinally, with very few backwaters available in some reaches, particularly reach 3. The number of backwaters sampled in each reach was limited by the number of backwaters available, therefore effort varied by reach. From one to three seine hauls were made in each backwater, depending on size and shape of the backwater, but in all backwaters, one seine haul was made that included the shallow end. The length and width of each seine haul was measured to calculate area sampled. Seines were primarily pulled across the backwater, where water depth allowed; otherwise seines were pulled parallel to shore. Arithmetic CPE was computed as number of fish per 100 m^2 seined (#fish/100 m^2), and mean CPE was given for 10-mile increments.

Fish captured by seining were placed in a bucket of water for processing. In smaller samples (<200 fish) fish were identified to species, counted, and measured as total length in millimeters. In high-density seine hauls, 30 fish were subsampled with an aquarium dip net for species composition and length measurements, and the remainder of the fish were identified and counted. In the largest samples, the remainder of the sample was only counted and a second subsample was preserved in ethanol and specimens were identified and measured in the laboratory. Species composition and relative abundance were determined from the subsamples and applied to the remainder of the sample to determine the total number of each species captured. Length frequencies were determined only from measured fish. In all samples, native fish greater than 150 mm were scanned and PIT tagged if necessary.

2.6 Mark-Recapture/Removal Studies and Diet Analysis on Channel Catfish at the LCR

An attempt was made to estimate the number of channel catfish in the Little Colorado River (LCR) confluence area with a removal method (White et al. 1982). Sampling was conducted as discharge from Glen Canyon Dam was decreased from 17,000 cfs to 8,000 cfs. The decrease in discharge occurred on May 31 and was observed at the LCR on June 2. Sampling and removal were conducted at the LCR inflow area with trot lines, angling, and snorkeling. Snorkeling was used for visual surveys of the area. Trot lines were composed of 200 pound test olive drab spectra with a diameter equivalent to 80 pound test line. Trot lines were approximately 7.6-8.5 m (25-28 ft) long with 25 5/0 heavy duty marine live bait hooks spaced approximately 30-45 cm (12-18 in) apart. Hooks were attached to the trot line via heavy duty 1/0 swivels that were tied directly to the main line. No snells were used. Sinkers (1-3 ounce egg sinkers) were placed at the leading ends and in the middle of the trot lines to provide weight and hold them in place. An additional 6-ounce sinker was attached to the offshore end of the lines to provide stability in the current. Baits used on the trot lines and fishing poles were cheese, salami, bacon, blood bait, and dough baits.

In general, trot lines were checked once each hour if no movement was detected, and immediately if movement was detected. Towards the end of the trot line sampling, humpback chub attacked the bait with increasing frequency, hence lines were pulled and redeployed every 5-15 minutes. For angling efforts, lines were continuously monitored from 0500 hours to around 0900 hours and again from about 1700 hours until midnight.

A snorkel survey of the ‘Carp Eddy’ (a large eddy on the downstream end of the inflow area) was performed once from about 1100 to 1230 hours. No channel catfish or adult humpback chub were observed. Upwards of 50 or more carp were observed in this area along with unidentified cyprinid larvae and YOY holding in tight crevices of ledges. Visual snorkel surveys of the LCR main channel and confluence area were performed on June 2 and 3, 2000. Only one channel catfish was observed during this time. Visibility was moderate to poor. A survey of the Colorado mainstem (100 m upstream of the main landing area) was attempted on June 3, but water temperature was too cold for sustained effort.

Table 1. Gear types used and number of samples taken in the Colorado River mainstem during the LSSF experiment, 2000.

Gear Type	Gear Code	Trip				
		1	2	3	4	Total
Standard Electrofishing	EL	149	64	65	--	278
Standard Minnow Trap	MT	16	53	52	49	170
Hoop Net, small (2' dia and 2.5' dia)	HS	23	58	52	55	188
Trammel Net, 75'x6'x1"x12"	TK	89	130	304	236	759
Trammel Net, 75'x6'x1.5"x 12"	TL	--	140	--	--	140
Trammel Net, 100'x6'x1.5"x12"	TP	--	22	--	--	22
Seine, 15'x4'x1/8"	SW	43	115	133	--	291
Seine, 6'x3'x1/16"	SX	12	28	1	--	41
Seine, long, 30'x6'x1/8"	SY	1	37	--	--	38

Table 2. Reaches defined for distributional fish sampling with electrofishing and number of samples obtained in each reach for the LSSF experiment, 2000. These data were provided to AGFD for analysis (Speas 2001).

Sample reach	River miles	Distance between samples	Trip 1	Trip 2	Trip 3	Total
1	0-56.9	0.4	37	10	10	57
2	57-69.9	0.1	25	10	5	40
3	70-110.9	0.1	9	0	0	9
4	111-130.9	1.0	10	17	12	39
5	131-160.9	2.0	10	6	14	30
6	161-180.9	1.0	19	8	0	27
7	181-220.9	0.5	31	8	24	63
8	221-225	0.5	8	5	0	13

Total			149	64	35	278

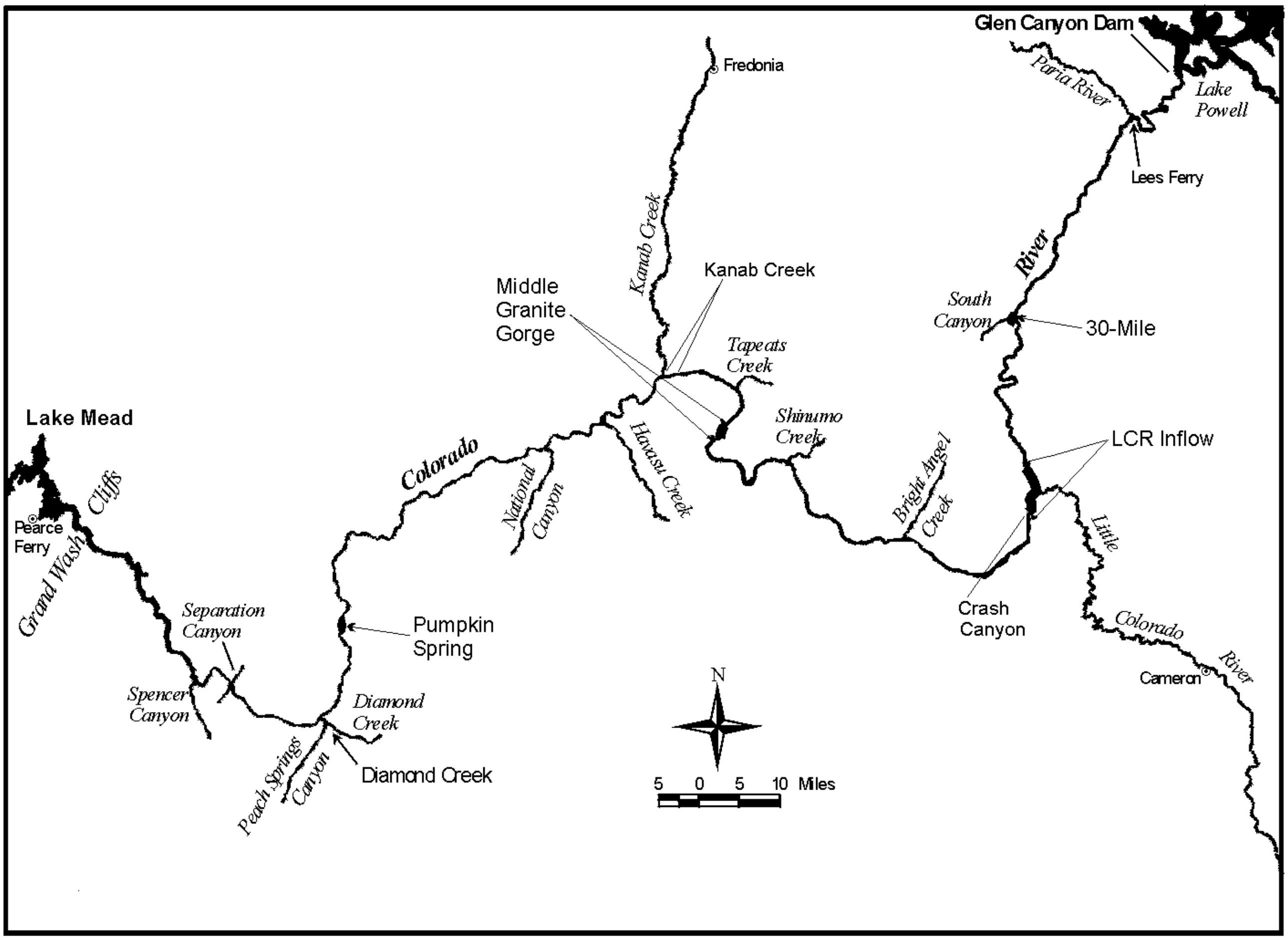


Figure 2. Colorado River through Marble and Grand Canyons with key sampling locations, LSSF experiment, 2000.

3.0 RESULTS AND DISCUSSION

3.1 Distribution, Relative Abundance, and Catch Rate

3.1.1 Electrofishing

Fifteen species of fish were captured during this study (4 native and 11 nonnative; Table 3). Fourteen species were captured with electrofishing (4 native and 10 nonnative; all species except plains killifish); nine with trammel nets (3 native [all except speckled dace] and 6 nonnative); and eleven (4 native and 7 nonnative) each with seines, and with hoop nets and minnow traps combined.

A total of 278 electrofishing samples (48.76 hrs) produced 2,807 fish comprising 14 species. Rainbow trout dominated the catch on all trips, followed by carp, brown trout, and flannelmouth sucker (Figure 3). Collectively, nonnative species comprised the majority of the catch on all trips, with native fish increasing downstream (Figure 4, Table A-1). Relative abundance and species composition differed only slightly by trip; thus, CPE data were pooled for all trips and analyzed by reach.

Relative abundance of all species captured with electrofishing varied by reach, with nonnative species decreasing downstream, and native species generally increasing (Table A-1). The majority of the flannelmouth sucker, bluehead sucker, and speckled dace were captured in reaches 6 and 7. Only nine humpback chub were captured by electrofishing (5 were <200 mm and 4 were >200 mm). Four were captured in reach 4 (Middle Granite Gorge), which supports the second largest aggregation of humpback chub in Grand Canyon, and only two were captured in reach 2 (LCR), which supports the largest aggregation. Reach 7 supported the highest diversity of species, with eleven species captured.

Numbers and CPE of rainbow trout captured with electrofishing decreased downstream, while numbers and CPE of carp and fathead minnow generally increased downstream (Figure 5). Brown trout CPE was highest in reach 4, and other nonnative species were variable. Of native species, speckled dace CPE also increased downstream; however, CPE of other native species was more variable. Flannelmouth sucker and bluehead sucker CPE was highest in reach 6. Electrofishing was the only gear type that produced adult largemouth bass and green sunfish. The electrofishing sample data were provided to AGFD to support a population estimate of rainbow trout and brown trout in Grand Canyon (Speas 2001).

3.1.2 Trammel Nets, Hoop Nets, and Minnow Traps

Trammel nets, hoop nets, and minnow traps were set on all four trips. A total of 1,068 fish were captured from a total of 921 trammel net sets (each a 2-hr set). A total of 201 fish were captured in 188 hoop net sets, and 181 fish were captured in 170 minnow trap sets. Nets were primarily set at selected sites used for mark-recapture and removal estimates in reaches 1, 2, 4, and 5, on trips 2-4, and were not randomly distributed. Therefore species composition, relative abundance, and CPE are given on a site basis for trammel nets for trips 2-4 only (Table A-2). Sites used for mark-recapture were Crash Canyon to Carbon Creek (RM 62.0-63.2 in reach 2), Middle Granite Gorge near Randy's Rock (RM 125.8-127.5 in reach 4), and Kanab Creek (RM 141.3-143.5 in reach 5). Although the majority of hoop net and minnow trap samples were taken at the mark-recapture sites, some samples were taken in other reaches as well. For hoop net and minnow trap samples, species composition and CPE are given on a reach basis for all trips (Tables A-3 and A-4).

Native species comprised a larger percentage of total catch in trammel nets than in electrofishing samples (Figure 6). However, with all sites combined, rainbow trout were the most abundant species captured by trammel nets. Flannelmouth sucker were the second most abundant, followed by humpback chub. At Kanab Creek, flannelmouth sucker were more abundant than rainbow trout. Humpback chub were the second most abundant species at Middle Granite Gorge. Collectively, native species comprised 49.2% of the total number of fish. The relative abundance of native fish ranged from 45.9% at Crash Canyon to 52.2% at Middle Granite Gorge. The relative abundance of rainbow trout decreased downstream, while the relative abundance of carp and channel catfish increased. Similar patterns were seen in catch rates (Table A-2). Rainbow trout had the highest CPE overall, and at each site on each trip except for at Kanab Creek on Trip 2, where flannelmouth sucker had the highest CPE.

Hoop net and minnow trap catches were comprised primarily of native fishes (Figure 7). Humpback chub were the most abundant fish in hoop nets and minnow traps at Crash Canyon, while flannelmouth sucker were most abundant at Middle Granite Gorge and Kanab Creek. Only three nonnative species (brown trout, rainbow trout, and fathead minnow) were captured by these methods.

3.1.3 Seines

Seining backwaters captured the majority of fish. Fish captured from backwaters were small-bodied or YOY native and nonnative species. A total of 370 seine hauls were made in 243 backwaters, producing a total of 18,309 fish comprising eleven species (Tables A-5 and A-6). The majority of fish were captured in August on Trip 2 (72.5%). Species composition, total abundance, and relative abundance differed both seasonally (Figure 8) and longitudinally (Figure 9). In all trips, five species comprised 98.6% of total catch. These species in descending order of abundance were fathead minnow, speckled dace, bluehead sucker, flannelmouth sucker, and humpback chub. Humpback chub comprised a small percentage of the total number. Seining was the only gear type that produced plains killifish and the majority of red shiners (72 of 73).

Collectively native fishes dominated the catch in all trips (mean of 59%). The highest percentage of native fishes was seen in June and the lowest in August. However, the nonnative fathead minnow was the single most abundant species overall, a result of the large increase in numbers of YOY and juvenile fathead minnow in backwaters in August and September, likely due to reproduction after the June trip (see objective 5). The number and CPE of total fish increased downstream, particularly for fathead minnow and speckled dace (Figure 9). In general, the relative abundance of nonnative fishes increased downstream (Figure 10).

Distribution of selected fish species in backwaters was compared to earlier studies. Mean CPE of fishes captured by seining from backwaters from 1991-2000 was plotted against 10-mile river segments (AGFD unpublished data). Distribution of most fish species in backwaters did not appear to differ substantially from earlier studies (Figure 11), although total abundance appeared to increase for all species except humpback chub (see section 3.5).

3.1.4 Summary of Gear Types

Species composition and relative abundance varied by gear type. Nonnative fishes comprised 96% of the catch in electrofishing samples, 51% in netting samples, and 41% in seining samples (Figure 12). The combination of electrofishing and netting may be representative of fish species occupying the mainchannel habitats, while seining is representative of backwater habitats. In all samples combined (trips and gear types), fathead minnow and speckled dace dominate the catch in total number of fish, while rainbow trout dominated the electrofishing and netting samples (Figure 13).

Total distribution of fish by reach with all samples combined is shown (Figure 14). Rainbow trout were most abundant in the upper reaches, and brown trout were most abundant in reaches 4 and 5. Native fish were distributed throughout the study area but were most abundant in the lower reaches, except for humpback chub. Humpback chub were most abundant in reach 2, which corresponds to the large LCR aggregation, and reach 4, corresponding to the Middle Granite Gorge.

Average length of each species captured varied by gear type (Table A-7). Trammel nets produced the largest fish, followed in descending order by electrofishing, hoop nets, minnow traps and seines. Electrofishing captured the widest range of size classes, including YOY, juveniles and adults of most species. Trammel nets produced the most adult bluehead sucker, flannelmouth sucker, and humpback chub. Hoop nets and minnow traps produced YOY and juvenile native and nonnative fishes. Seining produced primarily YOY native and nonnative fishes and adult small-bodied nonnative fishes.

Characterization of the distribution of fish in the Colorado River through Grand Canyon is strongly influenced by gear type, as a function of habitat and susceptibility of fish species and sizes to various gears. Current sampling technology limits the area of river that can effectively be sampled to shorelines, backwaters, and moderately deep, nearshore eddies and pools with low water velocity. These habitats comprise less than about 25% of total river habitat, depending on flow volume. Swift rapids, runs, and deep eddies and pools constitute the majority of habitat that cannot currently be sampled. Radiotelemetry studies of adult native fishes (Kaeding et al. 1990; Karp and Tyus 1990; Tyus 1991a; Valdez and Ryel 1995, 1997) show that the majority of fish inhabit shorelines and low velocity regions, which are the habitats that can be sampled; however, we could not assess the fish community in unsampled habitats.

The variety of gear types used in this investigation was selected to sample as many habitats as possible with reasonable efficiency and success. The gears selected for this investigation have all been previously used in numerous investigations of native fishes throughout the Colorado River

Basin, and are demonstrated to be the most effective gear array for sampling the mosaic of habitats and the different ages and sizes of fish species found in Grand Canyon (Carothers and Minckley 1981; Maddux et al. 1987; Valdez et al. 1993; Valdez and Ryel 1995; Arizona Game and Fish Department 1996). An evaluation of sampling design and gear types in Grand Canyon describes the efficacy of this array of gear types (Valdez et al. 1995).

Electrofishing was conducted along shoreline habitats, including talus, debris fans, sand beaches, cobble bars, and bedrock cliffs. Electrofishing was not effective in water more than a few meters deep because the strength of the electric field is inversely proportional to the distance from the electrodes, and thus electrofishing is not effective in deeper areas. Electrofishing was effective for capturing rainbow trout and brown trout that inhabit nearshore habitats, but it was not effective at capturing the native species (i.e., humpback chub, flannelmouth sucker, bluehead sucker) that prefer deeper eddies, runs, and pools. Compared to electrofishing, trammel nets were more effective at sampling these types of habitats, and were therefore more effective at sampling the native fishes. Hoop nets and minnow traps were more efficient at sampling the intermediate sizes of fish in nearshore habitats. Seines were used in backwater habitats, where small-bodied fish can be effectively trapped and encircled. Small-bodied nonnative fishes, and YOY native fishes have been shown to prefer backwater habitats (Tyus 1991b, Trammell and Chart 1999a,b).

The array of gear types used in this investigation provides an accurate representation of fish species, numbers, and sizes occupying given habitat types. Electrofishing was representative of relative abundance of adult nonnative fish species along shorelines. Electrofishing was also more representative of total species diversity than other gear types; it produced all but one of the total number of species captured. However, electrofishing over-represented the proportion of nonnative fish species, particularly salmonids. In electrofishing samples, nonnative fish species averaged 96% of catch by number, while trammel net, hoop net, and minnow trap samples averaged only 45% nonnatives. Trammel net samples were representative of species composition and relative abundance of fishes in deeper eddy and pool habitats. Hoop nets and minnow traps sampled smaller fish in nearshore habitats than electrofishing or trammel nets. Nonnative species in seine samples averaged 41% of the catch, which reflected fish species and abundance in backwater habitats (AGFD 1996, Hoffnagle et al. 1997). The demonstrable difference in composition and relative abundance of fish species sampled by various gear types shows the need to employ a variety of gear types in monitoring programs in order to adequately represent all species and size classes of fishes in Grand Canyon.

3.2 Calibrate Trammel Net Catch Rates

3.2.1 Removal and Mark-Recapture Estimates

Fish abundances were estimated at two sites using the removal method. At the first site (RM 30.4), five adult rainbow trout were captured during the initial sampling effort, marked, and released (marked fish were counted as “removed”). During the removal efforts, only one rainbow trout was captured (not a recapture). At the second site (RM 59.2), three rainbow trout were captured during the initial calibration efforts, and two rainbow trout and one bluehead sucker were captured during the removal efforts (none were recaptures). Population estimates could not be made because of low fish captures on initial and subsequent passes; i.e., no removal effect was seen. Hence, calibration of trammel net CPE could not be made using the removal method, and efforts were redirected at mark-recapture estimators.

A major flaw in this removal approach was that only a small portion of the river could be sampled (i.e., a single eddy), and local disturbances from sampling activity appear to have frightened the fish into deeper, swifter water, which could not be sampled. Although rainbow trout were captured using this method, few native fishes were captured because these fish were using deeper water that could not be effectively sampled with removal gears. Hence, the abundance estimator was changed from a removal method to a longer-term mark-recapture design. It was hoped that trammel net catch rates could be calibrated using mark-recapture population estimates. In theory, an initial catch rate (defined as one night and morning of sampling at one mark-recapture site) could be correlated to interim population estimates (within trip) and to the final population estimate for that site (all trips). The number of days required to perform a mark-recapture estimate at any one site required that fewer sites could be sampled during a given trip, therefore sample sites were selected with concentrations of native fishes (Crash Canyon, Middle Granite Gorge, and Kanab Creek).

3.2.2 Population Estimates for Humpback Chub

Mark-recapture efforts were conducted at each of three sites on Trips 2-4. Fish were captured primarily with trammel nets, although a few additional fish were captured with hoop nets, minnow traps and electrofishing. The initial trammel net CPE in fish/10 hrs is defined as all effort expended and all fish captured in one evening and the following morning. Catch was usually greater during the evening sets. Initial and subsequent catches and CPEs for each native species at each site were variable by night and by trip (Tables A-8 to A-10). Rainbow trout CPE, as the most abundant species, is also given for comparison.

A summary of native fish captured and recaptured at each site by all gear types is presented in Tables A-11 to A-13. Within each trip few fish were recaptured at any of the sites, and the numbers of recaptures were not sufficient to generate population estimates for within any single trip (Tables 4-6). However, the number of recaptures across trips was sufficient to produce total population estimates for two species at three sites. These instances were humpback chub at Crash Canyon (Table A-11), humpback chub at Middle Granite Gorge (Table A-12), and flannelmouth sucker at Kanab Creek (Table A-13).

Population estimates were generated by Program CAPTURE (White et al. 1982) using several different models. The models were M(o), M(t), M(t) Chao, M(h) Chao, and M(th) Chao (Chao 1987, 1989; Chao et al. 1992). These models produced estimates ranging from 243 to 467 adult humpback chub at Crash Canyon (CC; Table 4), with 95% confidence intervals (CI) lower and upper limits ranging from 129 to 1,205. Estimates for humpback chub at Middle Granite Gorge (MGG; Table 5) ranged from 143 to 235 with 95% CI ranging from 82 to 491. Estimates for flannelmouth sucker ranged from 651 to 1,044, with 95% CI ranging from 352 to 2,072. The maximum likelihood estimator M(o) is likely the most appropriate model. It is the simplest model, and assumes all individuals are equally at risk of capture on all occasions. Hence, the most likely estimates for adult humpback chub were 337 (161-819) at CC and 183 (108-390) at MGG. The best estimate for flannelmouth sucker at Kanab Creek was 756 (428-1440; Table 6).

We hoped an initial catch rate for each species could be correlated to the population estimates for each trip and the final population estimate for that site. Because there were no estimates for individual trips, and only one or two data points (final estimates) for each of two species, the initial CPEs could not be correlated to population estimates. The initial CPE for humpback chub at Crash Canyon was 1.12 fish/10 hrs, and the population estimate was 337 (Model M(o) for HBC >200 mm). The initial CPE for humpback chub at Middle Granite Gorge was 2.42 fish/10 hrs, and the population estimate was 183. Thus, the higher initial CPE was associated with a lower final estimate.

To generate a precise and useful population estimate, the initial catch should be at least 20% of the population estimate, and the estimate should have a lower confidence interval (CI) of approximately 20% less than the estimate. However, during this study initial catches were generally less than 20% of the estimates, and lower CI was generally more than 20%. For the humpback chub estimate at CC, 36 fish were originally captured, or 8-15% of the estimates. The lower CIs were 47-56 % of the estimates. For the humpback chub at MGG, 34 fish were initially captured, or 14-24% of the estimates. The lower CIs were 36-45% of the estimates. For flannelmouth sucker, 57 were originally captured, or 5-9% of the estimates. The lower CIs were 43-66% of the estimates. Thus, the low precision of these estimates is due to the low numbers of fish caught and recaptured on each occasion. In order to increase the precision of the estimate, more effort must be expended to increase the initial and subsequent captures.

Since the capture occasions were separated by as much as 12 weeks, the assumption of population closure may have been violated. Movement of fish in or out of the sample area can inflate the population estimate. Each mark-recapture reach was only a portion of the local area occupied by the species. The estimate applied only to that area sampled within the larger occupied area. Individuals moving into and out of the mark-recapture areas between sampling occasions may have violated the assumption of closure. Despite the low precision of these estimates, we have provided this information as the best population estimates currently available. In order to obtain a more precise estimate for the total population of a species within a concentration area, the entire area must be sampled and sufficient effort must be expended to generate an adequate initial sample size.

The population estimates made with this mark-recapture effort included only those marks that were specific to this effort; however, a large percentage of humpback chub and flannelmouth sucker were previously marked by other studies. The total mark rate is a combination of prior marks, and new marks. During these mark-recapture efforts, the total mark rate increased from the initial sample to the final sample for humpback chub at Crash Canyon, flannelmouth sucker and humpback chub at Middle Granite Gorge, and flannelmouth sucker at Kanab Creek. Total mark rates for HBC were higher at CC than at MGG (Tables A-14 to A-16). A stock synthesis model, proposed by GCMRC to be developed by the Service may provide inferences to population parameters such as recruitment, mortality, and survival by using changes in the total mark rate.

3.2.3 Comparison With Earlier Population Estimates for Humpback Chub

The population estimate made for the humpback chub aggregation at Middle Granite Gorge (MGG) was compared to a population estimate made in 1993 (Valdez and Ryel 1995). The 1993 estimate was made over several months and covered the area from RM 126.1 to RM 129.0, for a total of 2.9 miles, while the estimate made in 2000 covered a smaller area, from RM 125.8-127.5, for a total of 1.7 miles. Several mark-recapture models were used to estimate the abundance of this aggregation in each study and are compared in Table 7. The estimates in 2000 were consistently higher than those in 1993; however, the differences were not statistically significant (%0.05). Confidence intervals were larger for the 2000 estimates (Figure 15, Table 7). Because the length of river sampled in 2000 was 1.2 miles shorter than in 1993, the estimates were standardized to a density of fish/mile. Using the model M(o) and standardizing to 1-mile lengths, the density of humpback chub in 2000 was 107.7 fish/mile, while the density in 1993 was 31.1 fish/mile. Estimates of fish density between 1993 and 2000 were significantly different (%0.05) in all but two models (Table 8). Trammel net CPE at MGG was highly variable in all sampling between 1991 and 2000 (Table 9). CPE could not be correlated to total abundance of HBC because of the high variability of CPE and the low number of point estimates available.

These population estimates and length analyses provide evidence of recruitment to the MGG aggregation of humpback chub, likely through immigration from the LCR although the source of the recruitment is not known. The average length of humpback chub in 1991-1993 was 270 mm TL, compared to an average length of 253 mm in 2000. Length-frequency histograms of humpback chub captured in 2000 for fish less than 325 mm shows modes at lengths of 219, 260, and 305 mm TL. Length frequencies for larger fish are difficult to interpret, because slowed and variable growth of adult humpback chub results in extensive overlap of lengths at ages greater than five. At MGG, 59 of 60 fish were less than 325 mm.

The length modes correlate to slightly different ages using two different age-growth curves. The formula for the growth curve developed by Valdez and Ryel (1995) was:

$$(143.92*LN(age+1)+1.0938).$$

This relationship gives the ages of the fish as 4, 5, and 7 at the modes of 219, 260, and 305 mm TL, respectively. A Von Bertalanffy age-growth formula was also developed (Personal communication, C. Walters, University of British Columbia):

$$(380*(1-e^{-0.18*age}))$$

This relationship gives the ages of the fish as 5, 6, and 9 at the respective modes. Thus, humpback chub captured at MGG in 2000 were estimated to be 7 to 9 years of age or less, indicating a substantial replacement of this population since the 1993 estimate. The estimated age of many of these fish corresponded to the strong year-class of humpback chub detected in 1993 (Valdez and Ryel 1995). The recapture histories of nine individual fish captured during previous studies and recaptured in MGG during this study were examined for corroboration. All fish were captured and recaptured at MGG except for one fish that was originally captured at Havasu Creek in June, 1998.

The ages of these fish at the original capture event were more accurately estimated from their smaller size at that time. Of these fish, four were >300 mm and were estimated to be age 7 to 8+ in 2000 using the formula from Valdez and Ryel (1995). At original capture, which averaged 6.75 years earlier, their ages were estimated to be 3 to 6; adding 6.75 years to these estimates yielded ages of 10 to 12.5, thus not part of the year class of 1993. Three fish were >250 and < 280 mm TL and were estimated to be age 5+ in 2000. Estimated ages at original capture, plus years between captures, yielded ages of 5 to 6. Two fish were <250 mm TL and were estimated to be age 3 and 4 in 2000. Estimated ages at original capture plus years between captures yielded ages of 4. Thus at least 50% of recaptured fish were less than 7 years of age. Valdez and Ryel (1995) estimated annual adult survival of 0.75-0.91 per year. Using these survival estimates and assuming a population size of 90 adults in 1993, between 50 and 80% of the population could have been replaced between 1993 and 2000. The estimates of age support a 50% replacement.

Length frequencies at Middle Granite Gorge were compared to length frequencies at Crash Canyon (Figure 16). The mode at 260 mm TL (age 5-6) was conspicuously absent from the latter, although fish were captured from the 219-mm mode (age 4-5). Only 12 of 63 fish were less than 325 mm TL and the remainder were greater than 340 mm. Valdez and Ryel (1995) also reported similar differences in length-frequency distributions between MGG and the LCR reach. One possible explanation for the lack of fish near 260 mm at Crash Canyon and the lack of larger HBC at MGG is that younger fish move downstream from the LCR and older fish expand from the Middle Granite Gorge area into other suitable habitats. However, careful examination of PIT tag records from 1993 to 2000 (Personal communication, Lew Coggins, Grand Canyon Monitoring and Research Center) revealed little movement of fish tagged at MGG to other reaches. Out of 75 fish tagged at MGG from 1993 to 2000, one moved upstream to Shinumo (RM 108), and one upstream less than 10 miles. Two fish were recaptured at MGG that were tagged outside MGG. Of these two fish, one moved downstream less than 10 miles, and one moved upstream, from Havasu Creek.

3.3 Native Fish Near 30-Mile

No humpback chub were captured in and around the warm springs near RM 30 on any sampling trip in 2000, although adult and YOY humpback chub had been captured in the area in past investigations (Valdez and Ryel 1995). During the first trip, four juvenile rainbow trout were captured with dipnets. A total of 26 adult rainbow trout were captured with trammel nets, and 49 rainbow trout and one brown trout were caught with electrofishing. On the second trip, 19 flannelmouth suckers and 15 rainbow trout were captured in hoop nets and minnow traps, and only adult rainbow trout were captured with electrofishing. Thirteen rainbow trout were caught with hoop nets and minnow traps, and three flannelmouth sucker and one rainbow trout were caught with seines. On the third trip, seven rainbow trout and two flannelmouth sucker were captured with the nets, traps, and seines. Only adult rainbow trout were captured by electrofishing. Table 10 presents all fish captured by all gear types during Trips 1-3 near 30-Mile.

In past investigations 26 adult humpback chub (including 6 recaptures) were captured and released in the area during eight sampling trips in 1993 (Valdez and Ryel 1995). The estimated number of adults in this aggregation in 1993 was 52 (95% C.I. = 28-136), which was the 4th largest aggregation identified in the Colorado River through Grand Canyon. Additionally, 14 YOY (18-31 mm TL) humpback chub were captured and preserved from a school of approximately 100 at a warm shoreline spring at RM 30.8 on July 14, 1994 (Valdez and Masslich 1999). This was the only evidence of successful reproduction from the eight warm springs associated with the Fence Fault and Eminence grabens, 74-82 km downstream of Glen Canyon Dam. However, during 1993, no juveniles were captured from this aggregation, indicating an absence of recruitment to this aggregation. This aggregation of humpback chub may be reduced in numbers from natural mortality; individuals handled in 1993 were large adults and may have been near maximum life expectancy. Alternatively, this aggregation may have switched location to another warm spring during habitat changes associated with the LSSF. The only humpback chub captured from the vicinity of this spring complex in 2000 was one adult captured 5 miles upstream, near Tiger Wash (RM 25) in June (Personal communication, M. Douglas, Arizona State University).

Efforts to capture humpback chub in this area should continue in the future. Alterations in dam operation and management made to benefit humpback chub could result in increased numbers and expanded distribution of this species. The expansion could include areas of former occupation; therefore, these areas should be monitored.

3.4 Size of Young Humpback Chub at Time of Transition From the LCR

Some samples taken from the 185 fish contained no scales. A large proportion of scales taken from fish > 200 mm TL were difficult to read due to increased incidence of damage and regrowth, complete regeneration, or resorption, particularly in scales from larger fish. These factors resulted in a large proportion of unusable scales; scales from only 53 fish were used for analysis. Scales were classified as taken from either LCR or mainstem fish. Scales from YOY captured from the mainstem at the LCR confluence were classified as LCR fish (12). An additional 56 scale samples collected in the LCR were provided by the Service, of which 31 were used in the analysis. This provided a total of 41 mainstem fish (53-12) and 43 LCR fish (12 + 31).

Scales were examined for disruption in circuli patterns related to transition from the warm LCR to the relatively cold mainstem. For each scale, circuli were counted and measured along a 45^{o} diagonal line from the focus to the anterior edge of the scale using digital imaging software (Figure 17). There is expected to be differential mortality of YOY humpback chub leaving the LCR and entering the colder mainstem, with younger, smaller fish experiencing greater mortality (Valdez and Ryel 1995), although YOY humpback chub have been captured in the mainchannel as small as 15 mm long (AGFD 1996).

This technique was previously used to determine the average size of young fish descending from the LCR to the mainstem (Valdez and Ryel 1995). The method of scale examination was modified from that described by Valdez and Ryel (1995). Instead of examining scales directly under a binocular scope, we made digital images of each scale to facilitate storage and accuracy in reading circuli and annuli. Temperature checks appear as discontinuities in a circulus, and not as more closely spaced circuli, or wide disruptions as occurs at an annulus. Therefore each digital scale image was visually examined for a temperature check. However, the digital scale images represented scale circuli and annuli at one surficial plane and precluded our ability to ensure detection of discontinuities and cross-overs of circuli by changing focal planes. This made identification of transition checks difficult because of the greater number of apparent disrupted circuli. To resolve this difficulty, we reexamined all scale digital images to ensure that transition checks and annuli were consistent with pre-set criteria; i.e., transition checks were often single disruptions in a circulus as discontinuities or cross-overs, and an annulus was a series of disrupted circuli. Frequently, no transition check was seen, or it appeared to merge with the first annulus. Annular rings were reasonable to distinguish.

Differences in circuli spacing and disruptions in circuli were expected to correspond to the time of transition between the seasonally-warmed LCR and the isothermal mainstem; however, circuli spacing was extremely variable (Figure 18) and no spacing patterns could be detected. Circuli formation and scale growth have been shown to be correlated to fish age, fish length, and growth rates for many fish species such as walleye (*Stizostedion vitreum*; Glenn and Mathius. 1985), chum salmon (*Oncorhynchus keta*; Healey 1982), and red drum (*Sciaenops ocellatus*; Silva and Bumguardner 1998). Changes in growth rate due to stress or changes in temperature can disrupt circuli formation (Summerfelt and Hall 1987). The relationship between total length and scale radius, and between total length and circuli count has been shown to be approximately linear. Models for these relationships were developed and applied to radius measurements at disrupted circuli and annuli to back calculate total length from the scale radius at annuli or checks (Figure 19).

Valdez and Ryel (1995) determined that average size of young fish descending from the LCR to the mainstem was 74 mm TL, and minimum size of fish surviving the transition was 52 mm TL. A similar examination of scales in this study showed an average size of transition of 83 mm TL and a minimum size of 69 mm TL, with the transition check appearing to merge with the first annulus. Surprisingly, similar disruptions in circuli were seen for fish captured from the LCR.

Many YOY humpback chub are flushed from the LCR into the Colorado River mainstem during summer monsoonal floods (Valdez and Ryel 1995). These floods typically occur approximately 4-5 months after spawning in the LCR, when the YOY chub are about 60-70 mm in length (see objective 5), corresponding closely with the minimum transition check. An explanation for the similar pattern seen in LCR fish may be a stress related growth check during the monsoonal floods. YOY chub remaining in the LCR are subject to perturbation of the LCR system during the monsoons, and may even be flushed out temporarily and later return to the LCR. These stresses may result in a growth check resembling that found in mainstem fish. The similarity of the back-calculated length at first annulus and the circuli disruptions for both mainstem and LCR fish suggests that the majority of fish that successfully recruit into the mainstem are likely to have remained in the LCR until age 1 (>80mm).

Correlations between fish length or growth rates, and circuli spacing, count or scale radius have been shown for many fish species, as have correlations between these variables and environmental variables such as temperature or habitat (Fisher and Pearcy 1990; Cook 1982; Doyle et al. 1987; Skurdal and Andersen 1985; Silva and Bumguardner 1998; Healey 1982; Glenn and Mathias 1985). Differences in these relationships within species have been used to classify fish raised in different temperature or habitat regimes. However, all of these studies analyzed fish of known age in controlled studies, or recaptured fish where time and absolute growth between captures was known. Patterns and correlations determined from known classified fish could then be applied to unclassified samples. However, in this study, no fish of known age were available, increasing the risk of mis-classification. To resolve this issue, a study performed under controlled conditions is recommended.

3.5 Growth Patterns of Juvenile Humpback Chub and Small-Bodied Nonnative Fishes

3.5.1 Water Temperature Patterns

Mean mainstem and nearshore temperatures were nearly identical on each trip, although nearshore areas experienced more diel fluctuation than the mainstem (Figure 20). In all trips, mean temperatures increased downstream. Mean mainstem temperatures were highest in August, although June and August temperatures were similar (Figures 20-21). Mainstem temperatures declined in September. Mean mainstem temperatures reached 16^{o} C by RM 130 in June, while during the MLLF regime, mainstem temperatures did not reach 16^{o} C until Diamond Creek (RM 226) in July.

Mean backwater temperatures were warmer than mainstem temperatures during all trips and were highest in June (Tables A-17 and A-18). Backwater temperatures were highly variable, commonly reaching 25^{o} C and as high as 30^{o} C near Diamond Creek in June. Differences between mean backwater and mainstem temperatures averaged 3.3^{o} C in June and 1.3^{o} C in August. Differences between maximum backwater temperature and mainstem temperatures were 9.6^{o} C in June and 8.6^{o} C in August. Both mainstem and backwater temperatures declined in September. Mean backwater temperatures also increased downstream at a rate of approximately 1^{o} C/22.7 mi between Lees Ferry and Diamond Creek in June, similar to that seen in the mainstem.

Mean mainstem and backwater temperatures in 2000 were compared to mean mainstem and backwater temperatures in 1991-1994 by reach (AGFD 1996). For this analysis the same reaches were used for 2000 as in 1991-1994 for ease of comparison. A greater longitudinal increase in temperatures was observed in 2000 than during the MLFF of 1991-1994 (Table A-19, Figure 21). Greater longitudinal warming than under modified low fluctuating flows (MLFF) was expected during the LSSF of summer 2000, as a result of low water volume (8,000 cfs) during the hottest time of year. Mean, minimum, and maximum water temperatures in the mainstem and backwaters all increased longitudinally downstream. Mean mainstem temperatures during the LSSF reached 16EC in June below RM 130, compared to 13EC in June 1991-94, under the MLFF. Mean mainstem temperature below RM 160 in June of the LSSF was 18.5EC, compared to 16EC in June 1991-94. During the LSSF, mean mainstem temperature increased at a rate of 1^{o}C/12.6 mile in June between Lees Ferry and the LCR, and by a rate of 1^{o}C/23 miles from the LCR to Diamond Creek. During the MLFF regime, mainstem temperatures increased 1^{o}C/32 miles to the LCR in July, the month of highest water temperatures (Valdez and Ryel 1995, AGFD 1996). No temperature data were recorded in July during this LSSF study, but temperatures could be expected to be higher than in either June or August.

Optimum spawning temperature with highest egg hatching success and larval survival is 16-20EC (Hamman 1982; Marsh 1985). Although investigators have recorded ripe humpback chub in the mainstem at temperatures of 10-14^{o}C, spawning activity and success appear to be limited by cool temperatures (Kaeding and Zimmerman 1983; Valdez and Ryel 1995). During the LSSF, mainstem temperatures were suitable in June for spawning by humpback chub at about RM 130, and for other native fishes as far upstream as about RM 80. This would produce appropriate spawning temperatures in the lower four humpback chub aggregation areas identified by Valdez and Ryel (1995), including Stephen Aisle, Middle Granite Gorge, Havasu Creek inflow, and Pumpkin Spring (Figure 22). Warmer July temperatures could have extended suitable spawning conditions far enough upstream to include Shinumo Creek inflow and Bright Angel Creek inflow.

Nearshore temperatures were also expected to be higher than mainstem temperatures during the LSSF. No marked difference was recorded for nearshore temperatures when compared to mainstem temperatures at our few sample locations. This lack of shoreline warming was attributed to constant circulation of water along shorelines even at lower flows. Vernieu (2001) reported substantial near-shore temperature increases in areas with little or no water velocity. Backwater temperatures were significantly higher (%0.05) than mainstem or nearshore temperatures during the LSSF, and a greater longitudinal increase in temperatures was observed in backwaters during the LSSF than during the modified low fluctuating flow regime of 1991-94.

Warmer river conditions during the LSSF provided suitable spawning temperatures for native fishes, including humpback chub. Putative spawning success by humpback chub is reported. Four larval humpback chub (15-17 mm) were captured from a single backwater at RM 197 in June. These fish were preserved as part of a large sample and were later identified using morphometric criteria including fin ray counts and myomere counts. Identification was later confirmed (Dr. Kevin Bestgen, Larval Fish Laboratory, personal communication). Using the age-length formula for larval humpback chub from Muth (1990), these fish were back-calculated to be approximately 12 days old, and to have been hatched on June 6, 2000.

The origin of these fish could not be determined. While capture of larval humpback chub from this area of the river is not unprecedented (AGFD unpublished data), it is rare. Although passive drift at 4-5 miles/hour could have transported these fish from the LCR in 2 days, capture of these fish in a single location, coupled with abundance of predators between the LCR and RM 197, suggests that these fish originated from local reproduction. Possibly, these larvae were hatched from eggs deposited at warm springs near Lava Falls (RM 179.5) or Beecher Springs (RM 183.5), or a warm tributary. The warmer mainstem temperatures could have improved the likelihood of early survival for these larval fish. However, the possibility also exists that these fish may have been spawned in the mainstem, since mainstem temperatures were adequate to induce spawning.

Substantial evidence for mainstem spawning by flannelmouth sucker and bluehead sucker was also recorded during the LSSF. Numbers of larvae and YOY of both species were significantly higher (%0.05) than in previous investigations, and the numbers of recently hatched larvae appeared over much of the summer, indicating a protracted mainstem spawning period, which is uncharacteristic of spawning in seasonally warmed tributaries.

3.5.2 Growth of Fish

Length frequencies of selected fish species (i.e., HBC, SPD, BHS, FMS and FHM) were plotted by trip (Figures 23-25). Native fish captured in June were primarily age 1 juveniles, with a few YOY and larvae also captured. In August, a large influx of larvae and YOY native bluehead sucker and flannelmouth sucker, as well as nonnative fathead minnow was observed. Capture of larval fish of all species continued in the September samples.

Length frequency historgrams of these species were examined for growth. For all species, length frequencies of age 1 fish appeared to overlap with age 0 fish, obscuring the growth rate of age 0 fish. However, an attempt was made to separate year classes by observing modes on the length frequency histograms, giving a more accurate mean total length for YOY for each trip. Mean total length was less in September than in August for flannelmouth sucker, and increased only slightly for other species. Mean total length and range of lengths are shown (Figure 26). An increase in the minimum and maximum length from August to September was seen for humpback chub. Length-frequency of young humpback chub captured near the LCR (RM 59-72) compared to that of young captured below the LCR (RM 125-226) reveal smaller fish downstream from the LCR (Figure 27). This may indicate greater growth rates of fish while in the LCR. However, for most species maximum lengths did not increase, contrary to expectation. Larger specimens of bluehead sucker and flannelmouth sucker were expected to be captured by other gear types (electrofishing, hoop nets and minnow traps) in September but that was not the case. Increases in mean, minimum and maximum TL were observed for most species between September and December. In December no fish were captured by seining, and only a few fish were captured by gear types other than seining.

A number of factors affected our ability to determine growth and growth rates. Protracted spawning of each species and continuous influx of newly-hatched larvae into samples depressed mean total length in September, confounding growth analyses. Also, downstream movement of fish and movement in and out of backwaters exposed individuals to a wide range of temperatures, which likely affected growth. Finally, a shift in habitat use away from backwaters occurs as native fish increase in size, rendering them less available to seining.

Mean total lengths of fish captured in 2000 were compared to mean total lengths from 1991-1997 for August and September (Figure 28). No comparable December samples were taken from 1991-1997. Few samples were taken in August from 1991 to 1997 and most samples were taken in July; therefore, July data from 1991 to 1997 was used where necessary. Mean total length in 2000 for all species was usually less than that seen in 1991-1997 in both August and September. Growth rates from August to September observed during the LSSF did not appear to be greater than during the MLFF. Slopes of growth from August to September were similar in humpback chub for most years.

Analysis of growth rates of YOY humpback chub, flannelmouth sucker, and bluehead sucker was inconclusive because protracted spawning and constant influx of newly-hatched larvae confounded and depressed mean lengths; average total lengths of flannelmouth sucker actually declined between August and September. For flannelmouth sucker and bluehead sucker, this effect was a result of prolonged spawning occurring over the summer, which is suggested by the continued presence of sucker larvae in seine samples from June through September. In addition, the maximum length of fish captured by seining did not increase from August to September, suggesting a shift in habitat use. Although a shift in habitat use away from backwaters, seen in YOY suckers, could truncate the maximum length of fish captured by seining, larger YOY would be expected to appear in other sampling gears, such as hoop nets, minnow traps, and electrofishing. However, the expected larger YOY were not captured by other sampling gears in September and may be a result of decreased survival. Survival of this year class cannot be assessed until these fish are available to other sampling gears or are recruited into the adult population.

3.5.3 Relative Abundance of Fish

Although effect of the LSSF on growth rates was inconclusive, a substantial effect on abundance of fish in backwaters was observed (Figures 29-30). In August, catch rates (arithmetic CPE) of native flannelmouth sucker and bluehead sucker were significantly higher (%0.05) than in seining samples in August from 1990-1997 (AGFD unpublished data). Nonnative fathead minnow CPE was much higher, but was not significant due to greater variation in CPE. No samples were taken in 1998 and 1999. The increase in abundance did not appear to occur prior to 2000; in June, prior to the peak of the reproductive season, catch rates were not significantly higher (%0.05) than in seining samples from 1990-1997. However, in September, following the 4-day flow spike, CPE of fathead minnow was nearly identical to previous years' samples while CPEs of the two native fish species were still significantly higher (%0.05). This suggests that the flow spike was more detrimental to the nonnative fathead minnow than to native fish, although native fish were also displaced from backwater habitats. Sampling and observations during the beach-habitat building flow of 45,000 cfs during 1996 showed that nonnative fish became displaced by high flows while native species used cracks and crevices along adjacent shorelines as shelter from high water velocities (Valdez et al. 2001).

Estimates of relative abundance and CPE from 1991-1997 and 2000 did not appear to be affected by differences in effort across years. Effort (m^2 seined) combined for June, August, and September in 2000 was commensurate with combined effort from 1991-1997 for those months (Figure 30). Both total catch and CPE of all species combined and of selected species (i.e., bluehead sucker, flannelmouth sucker, speckled dace, and fathead minnow) were highest during the LSSF.

Mean daily fluctuation in discharge from Glen Canyon Dam remained fairly constant from 1991-1997 while CPE was variable; the highest CPE did occur during the steady flows, when mean daily fluctuation was low (Figure 30). However, temperature was likely an important variable influencing fish abundance during the LSSF. The higher temperatures available during the LSSF likely influenced reproduction of native fishes and fathead minnow. In addition, warmer temperatures combined with stable water levels in backwaters likely increased productivity, thereby providing more suitable habitat than during MLFF. It is not known if increased temperatures alone would have a similar effect on abundance without accompanying steady flows.

3.6 Mark-Recapture/Removal Estimates and Diet Analysis of Channel Catfish in the LCR Inflow

A total of eight channel catfish were captured during the trip to the LCR (Table 14). All were captured with trot lines or angling in the confluence area of the LCR. No channel catfish were captured within the left channel of the LCR (Carp Eddy) prior to or after the LSSF. The majority (63%) of the channel catfish captured were large adults (>350 mm TL). Of the catfish captured, 50% were males that displayed sexual characteristics such as bluish color, swollen heads, and extrudable gametes. All catfish were captured over sand or boulder substrate. Channel catfish measurements and PIT tag numbers are presented in Table 15. Stomachs were taken from three channel catfish and two rainbow trout, preserved in 75% ethanol, and contents were analyzed in the laboratory under a dissecting scope at 4X power. All stomachs were empty except for detritus and some strands of algae.

Thirty humpback chub were captured with trot lines and angling incidental to sampling for channel catfish (Table 16). Of 11 fish examined for PIT tags, only one was not a recapture, and it was PIT-tagged and released. An additional 19 chub were captured by trot lines but were not processed to avoid stress and injury. All humpback chub captured were adults greater than 350 mm TL; 73% of the processed fish were captured with trot lines and 27% were captured by angling.

Few channel catfish (8) were captured or observed during this effort, and no population estimate could be made with removal estimators. Most channel catfish appeared to be males nearing spawning condition. However, no females in spawning condition were captured. This disproportionate number of males indicates that sampling occurred prior to spawning, when most males and females were still in deep mainstem habitats. Large numbers of catfish have been observed in the LCR confluence in spawning condition in the past (Valdez and Ryel 1995), thus seasonal changes in distribution could have influenced the low catch. In addition, sampling was suspended daily from 0900 to 1700 hours to minimize activities in the LCR during visits by commercial river trips.

During the sampling trip humpback chub were increasingly vulnerable to both trot lines and standard angling and were frequently hooked No mortality of hooked humpback chub was observed, although some fish were visibly stressed. Humpback chub caught on trot lines were sometimes hooked by the fins, dorsal humps, operculum, or eyes, and trot lines were discontinued on day 4 of the study.

As the Colorado River mainstem began to ramp down to 8,000 cfs, the LCR began to incise through a large silt deposit just above the confluence on June 2. This event quickly released a large amount of silt and detritus. The LCR mainstem incised approximately 5 vertical feet in under 24 hours. After channelization was complete turbidity returned to normal. Large numbers of humpback chub were observed in the confluence area after turbidity decreased and catch of this species increased.

Increasingly large hooks were employed to discourage humpback chub from attempting to swallow baits. Humpback chub were hooked on all sizes of hooks including 16/0 Marlin hooks. They responded to all types of bait except large dead fish. Bait type appeared to be more important than hook size. Channel catfish seemed to respond well to half and quarter sections of rainbow trout, which were not attacked by humpback chub. To consistently catch channel catfish and possibly exclude humpback chub, large hook sizes should be used with large sections of dead fish as bait. After completion of the sampling trip, this effort was discontinued for the year due to low catch of channel catfish and a high catch and associated risk of mortality to humpback chub.

Table 3. Fish species and number caught by gear type in the Colorado River mainstem during the LSSF experiment, 2000.

				Gear Types Number of fish captured			
Species Code	**Common Name**	**Scientific Name**	**Status**	**Electro-fishing**	**Trammel nets**	**Hoop nets/ minnow traps**	**Seines**
BBH	black bullhead	*Ameiurus melas*	X	1	1	0	0
BHS	bluehead sucker	*Catostomus discobolus*	N	7	79	10	2,613
BNT	brown trout	*Salmo trutta*	X	91	24	8	2
CCF	channel catfish	*Ictalurus punctatus*	X	6	16	1	0
CRP	carp	*Cyprinus carpio*	X	279	39	2	27
FHM	fathead minnow	*Pimephales promelas*	X	14	0	19	7,320
FMS	flannelmouth sucker	*Catostomus latipinnis*	N	57	287	64	2,398
GSF	green sunfish	*Lepomis cyanellus*	X	1	0	0	0
HBC	humpback chub	*Gila cypha*	N, E	9	128	104	76
LMB	largemouth bass	*Micropterus salmoides*	X	3	0	0	4
PKF	plains killifish	*Fundulus zebrinus*	X	0	0	0	40
RBT	rainbow trout	*Oncorhynchus mykiss*	X	2,300	493	52	34
RSH	red shiner	*Cyprinella lutrensis*	X	1	0	1	72
SPD	speckled dace	*Rhinichthys osculus*	N	31	0	121	5,648
STB	striped bass	*Morone saxatilis*	X	8	1	0	0
SUC	unidentified sucker	*Catostomus* spp	N	0	0	0	75

N = Native; X = Exotic (Nonnative); E = Endangered

Table 4. Estimated population (N) of adult humpback chub (>200 mm) at Crash Canyon, using six estimators for closed populations. Estimates shown are for August-December, 2000.

Estimator	N	SE (N)	95% confidence intervals
M(o)	337	152.2	161-819
Darroch M (t)	300	132.6	148-720
Chao M (t)	243	97.2	129-546
Chao M (h)	467	230.7	205-1205
Chao M (th)	347	180.9	153-952
Schnabel	255	146	113-783

Table 5. Estimated population (N) of adult humpback chub (>200 mm) at Middle Granite Gorge, using six estimators for closed populations. Estimates shown are for August-December, 2000.

Estimator	N	SE (N)	95% confidence intervals
M(o)	183	58.2	108-390
Darroch M (t)	161	48.5	98-336
Chao M (t)	144	41.3	93-267
Chao M (h)	235	85.4	130-491
Chao M (th)	176	66.8	100-389
Schnabel	145	59	83-349

Table 6. Estimated population (N) of adult flannelmouth sucker (>200 mm) at Kanab Creek, using six estimators for closed populations. Estimates shown are for August-December, 2000.

Estimator	N	SE (N)	95% confidence intervals
M(o)	756	244.7	428-1440
Darroch M (t)	846	322.6	438-1792
Chao M (t)	651	200.2	382-1208
Chao M (h)	1044	365.1	359-2072
Chao M (th)	736	244.6	413-1427
Schnabel	665	252	352-1418

Table 7. Estimated population (N) of adult humpback chub (>200 mm) at Middle Granite Gorge in 1993 (Valdez and Ryel 1995), using six estimators for closed populations, and statistical comparison of estimates between 1993 and 2000. Estimates shown are for 1993. See Table 5 for 2000 estimates.

Estimator	N	SE (N)	95% confidence intervals	1.96 SE	1993-2000 Significant Difference (%0.05)
M(o)	99	15	77-140	117.7998	not different
Darroch M (t)	96	14	76-135	97.43566	not different
Chao M (t)	89	15	70-132	85.01725	not different
Chao M (h)	98	19	74-153	171.4766	not different
Chao M (th)	93	15	75-139	136.1014	not different
Schnabel	91	20	68-155	122.1034	not different

Table 8. Comparison of estimated fish density at Middle Granite Gorge in 1993 and 2000 using estimated population (N) of adult humpback chub (>200 mm) divided by length of sampled reach in miles (2.9 miles in 1993, and 1.7 miles in 2000).

Estimator	1993 (fish/mile)	2000 (fish/mile)	SE (N)	1.96 SE	1993-2000 Significant Difference (%0.05)
M(o)	107.65	34.14	34.62	67.86	Significant
Darroch M (t)	94.12	33.10	28.47	55.80	Significant
Chao M (t)	84.12	30.69	24.49	48.1	Significant
Chao M (h)	138.24	33.79	50.66	99.29	Significant
Chao M (th)	104.71	32.07	40.22	78.82	Not different
Schnabel	84.12	31.38	35.38	69.35	Not different

Table 9. Variability of catch, effort, and CPE for humpback chub captured with trammel nets for Middle Granite Gorge 1991 - 2000, summer and fall.

Summer				Fall			
Date	**HBC**	**Hours**	**CPE (fish/100ft/10hrs)**	**Date**	**HBC**	**Hours**	**CPE (fish/100ft/10hrs)**
Jul-91	4	100.27	0.39	**Sep-91**	5	60.78	0.82
Jul-92	17	44.37	3.83				
Jul-93	12	148.39	0.81	**Sep-93**	14	124.55	1.12
Jul-94	10	60.37	1.65				
				Sep-95	6	45.66	1.31
				Sep-96	1	20.92	0.47
				Sep-97	0	29.83	0
Aug-98	2	13.98	1.43				
				Sep-99	10	24.7	4.05
Aug-00	34	182.2	1.87	**Sep-00**	22	132.33	0.94

Table 10. Fish captured by all gear types from RM 26 to RM 39 during LSSF Trips 1-3, 2000.

	Fish Species		
Trip	**FMS**	**BNT**	**RBT**
1	0	1	81
2	22	0	436
3	2	0	360

Table 11. Fish captured by each gear type during LCR channel catfish trip, May 2000.

Gear Type	CCF	HBC	CRP	RBT
Trot line	4	27	2	0
Angling	4	3	1	2

Table 12. Channel catfish measurements and PIT tag numbers for LCR channel catfish trip, May 2000. AS = angling; AT = trot lines.

Gear Type	TL	FL	PIT Tag	Disposition
AS	648	600	5326570105	Released Alive
AS	761	710	-	Dead–Preserved
AS	265	235	5326410102	Released Alive
AS	705	660	532658146A	Released Alive
AT	418	374	-	Dead–Stomach Taken
AT	390	363	-	Dead–Stomach Taken
AT	570	517	-	Dead–Stomach Taken
AT	585	540	53255D5315	Released Alive

Table 13. Humpback chub captured during LCR channel catfish trip, May 2000. AS = angling; AT = trot lines.

Gear Type	TL	FL	Recapture (y/n)	PIT Tag #	Disposition
AT	455	420	Y	1F46600F2C	Released Alive
AT	430	390	Y	1F466BOE22	Released Alive
AT	404	360	Y	7F7F39073F	Released Alive
AT	428	380	Y	7F7D225A0E	Released Alive
AT	383	355	Y	7F7F050C1D	Released Alive
AT	435	395	N	5325564C04	Released Alive
AT	438	364	Y	7F7B07370A	Released Alive
AS	363	335	Y	7F7F282131	Released Alive
AS	432	383	Y	1F7A714C2A	Released Alive
AS	410	381	Y	7F7F45656B	Released Alive

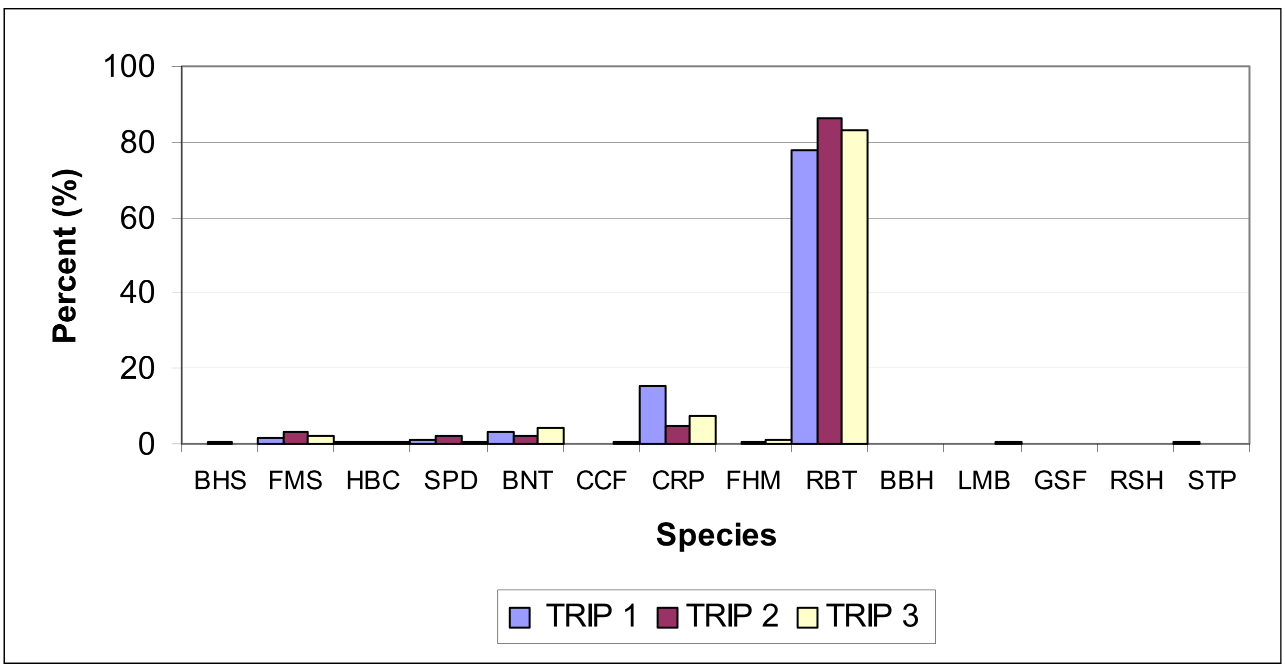


Figure 3. Species composition of electrofishing samples, LSSF, 2000. See Table 3 for species codes.

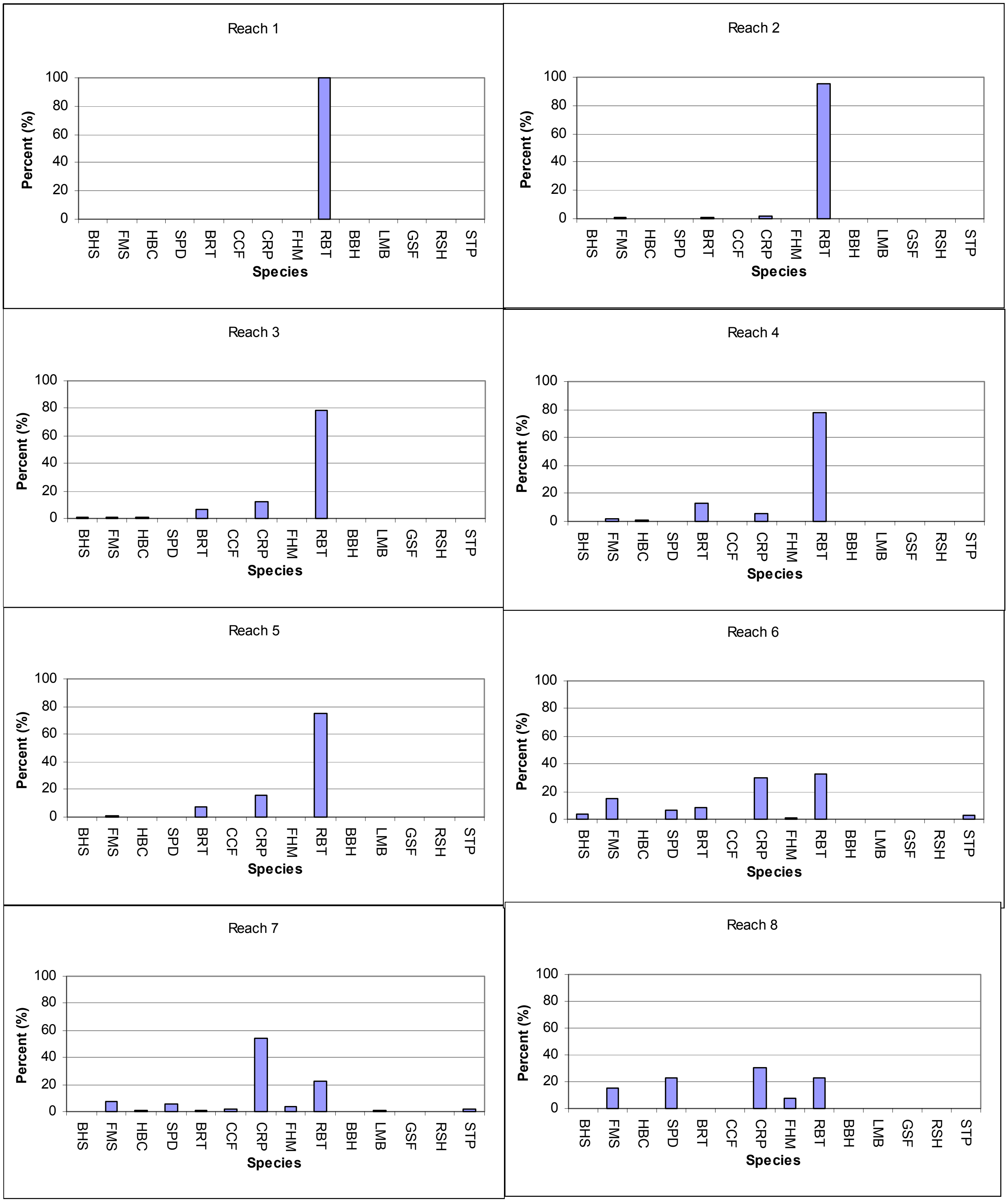


Figure 4. Species composition and relative abundance of native and nonnative fish in electrofishing samples by reach, Trip 1-Trip 3, 2000. See Table 3 for species codes, and Table 2 for reaches.

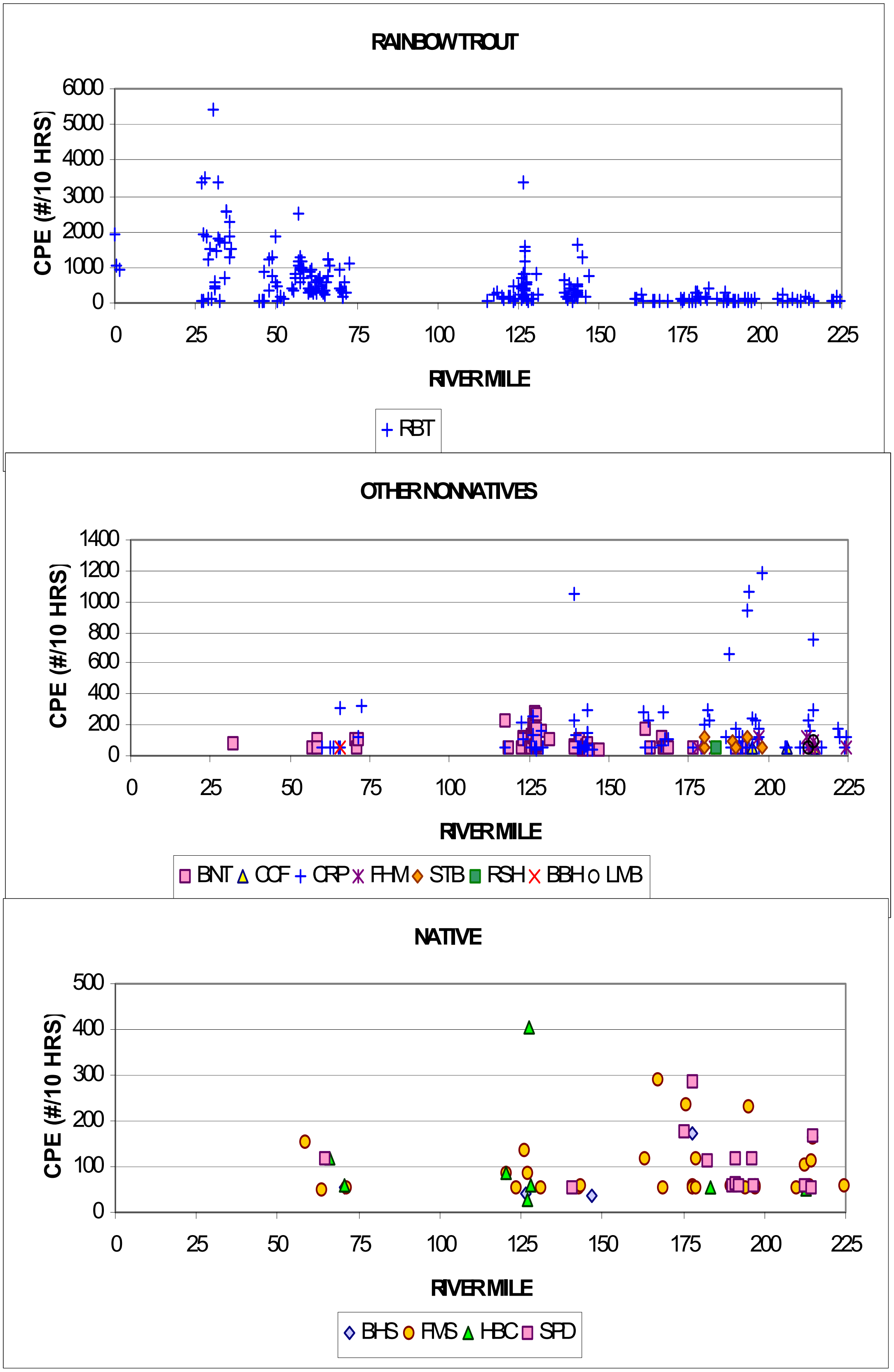


Figure 5. Electrofishing catch rate (CPE in #fish/10 hrs) of rainbow trout, other nonnatives, and native fish species, from all sampling trips, 2000. See Table 3 for species codes.

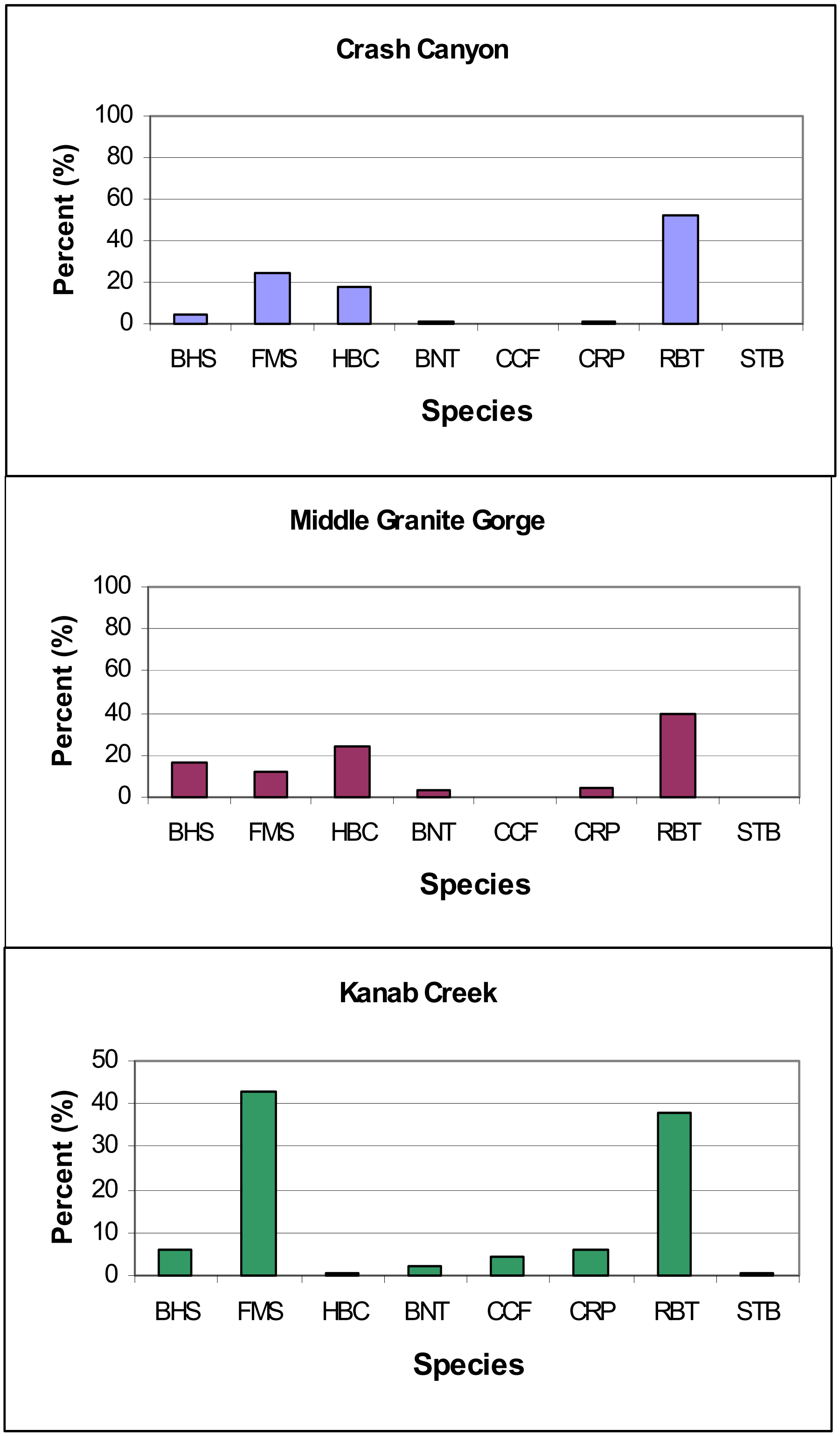


Figure 6. Species composition and relative abundance of fish captured with trammel nets at the mark-recapture sites during LSSF, 2000. See Table 3 for species codes.

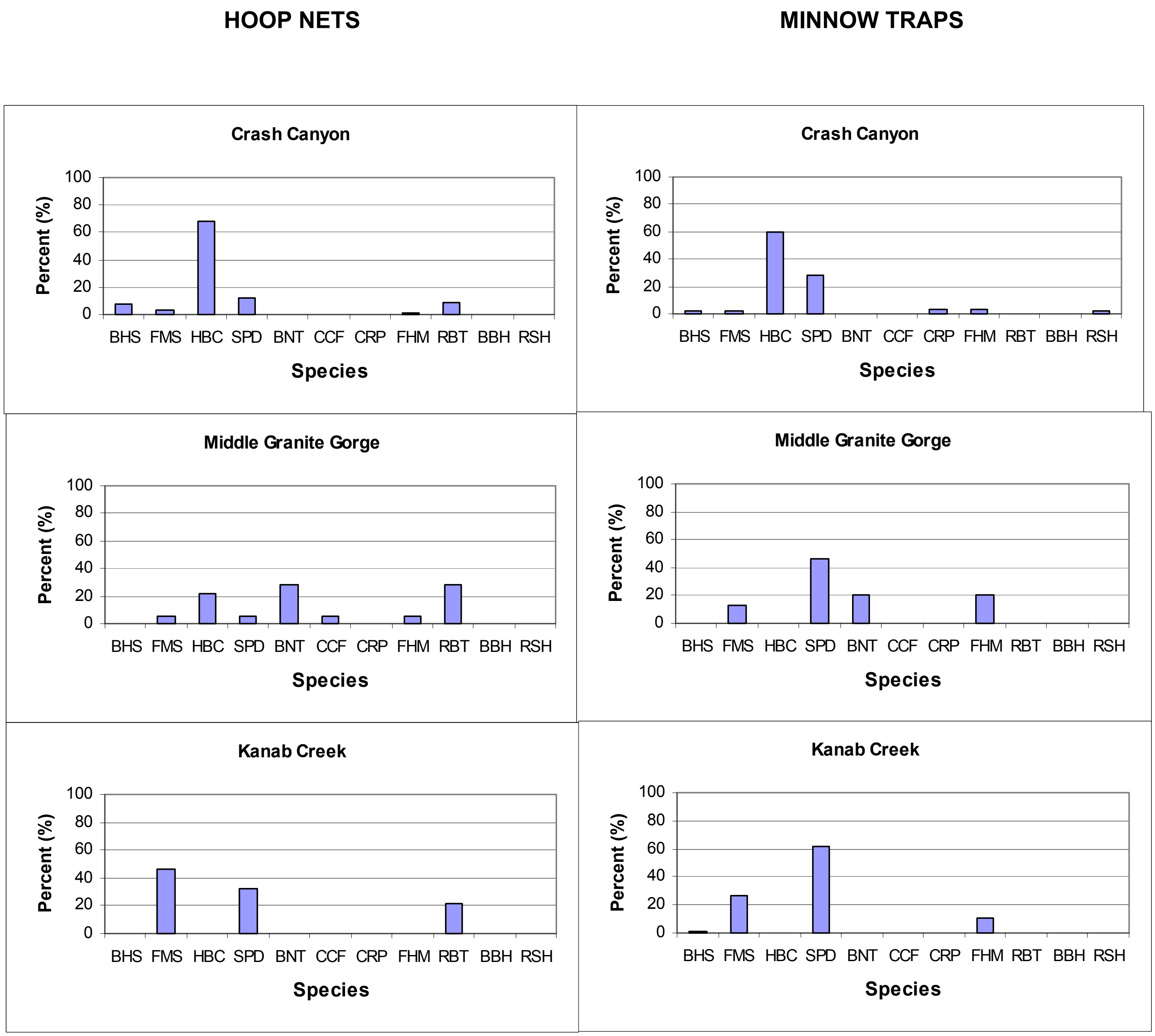


Figure 7. Species composition and relative abundance of fish captured with hoop nets and minnow traps at selected sites during LSSF, 2000. See Table 3 for species codes.

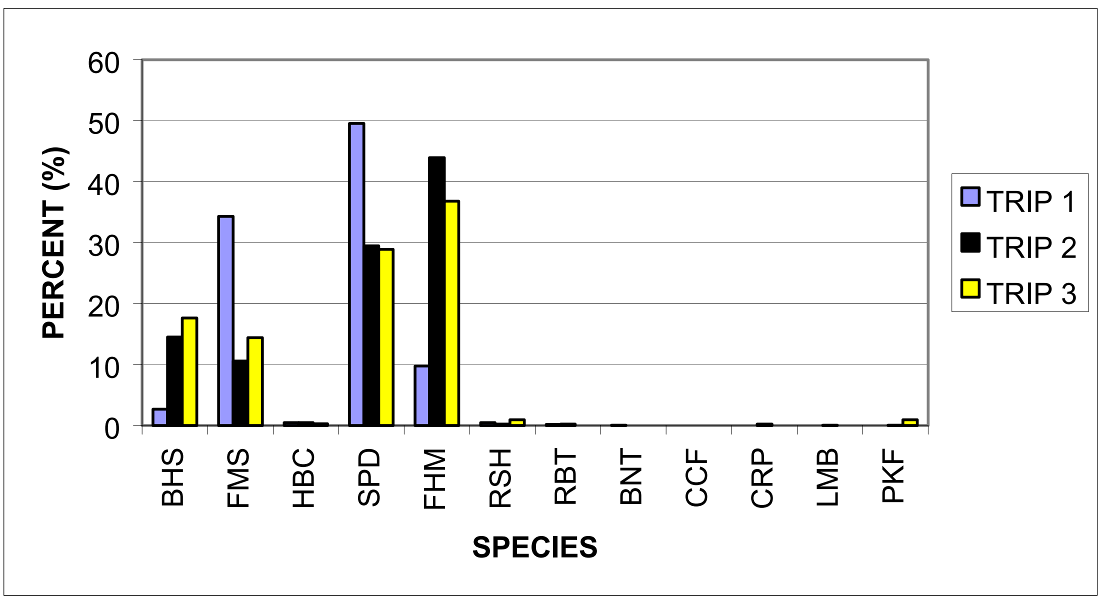


Figure 8. Species composition and relative abundance of fish captured by seining during Trips 1-3, 2000. See Table 3 for species codes.

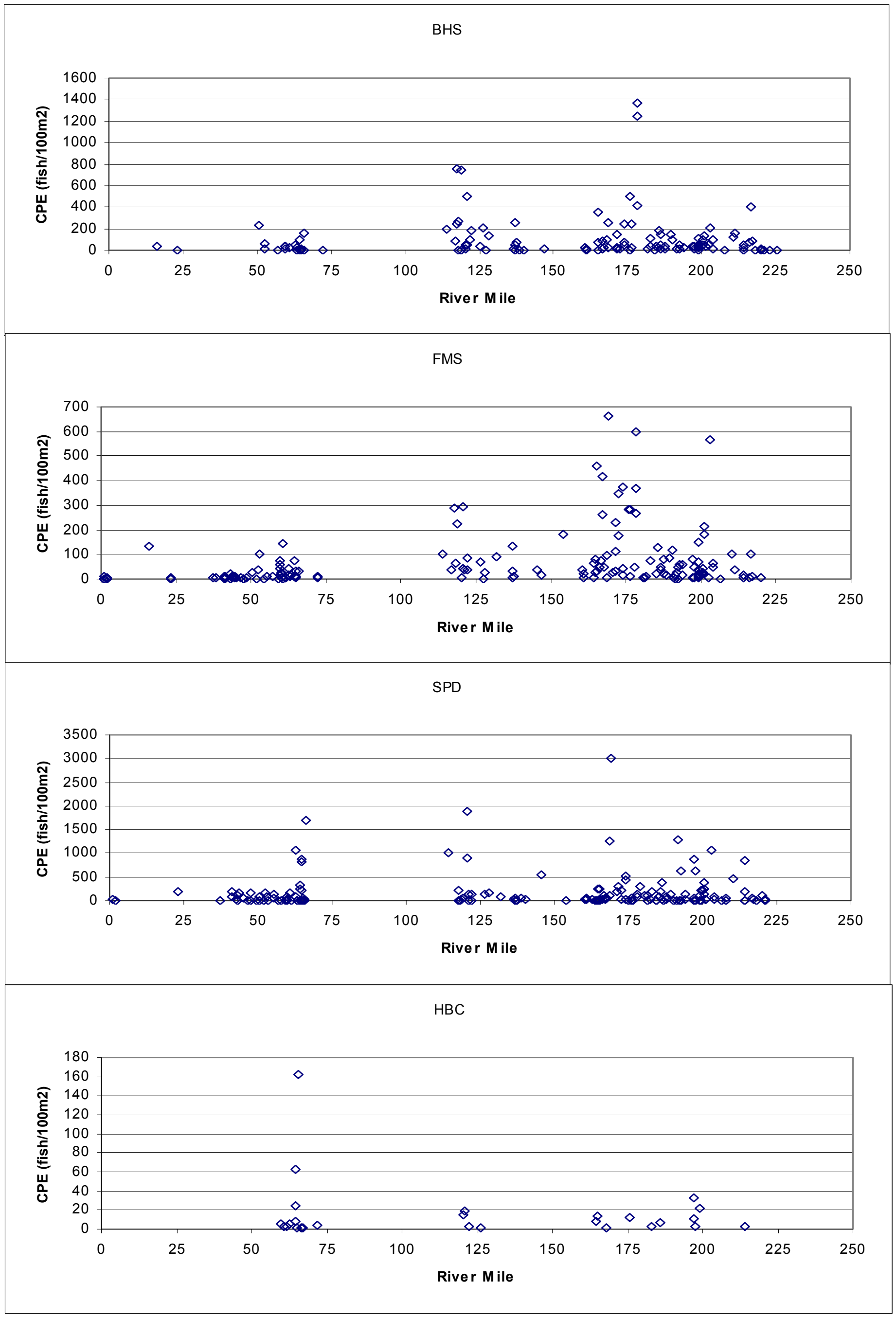


Figure 9a. Catch rates (CPE in #fish/100 m^2) by river mile for native fish captured by seining, Trips 1-3 combined, 2000. Note difference in scale for each species. See Table 3 for species codes.

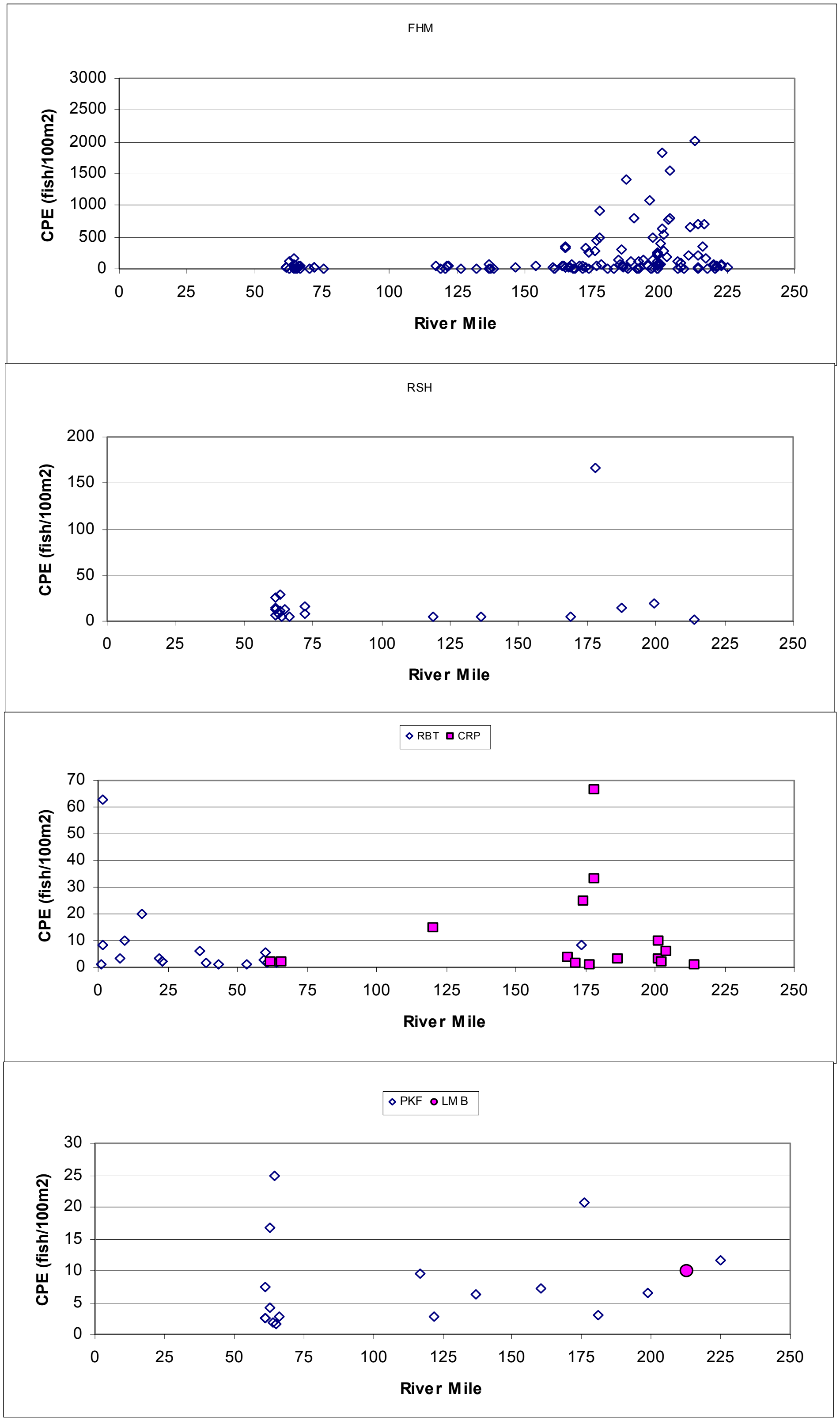


Figure 9b. Catch rates (CPE in #fish/100 m^2) by river mile for selected species of nonnative fish captured by seining, Trips 1-3, 2000. One CPE value for FHM (7,660) was not graphed. Note difference in scale for each species. See Table 3 for species codes.

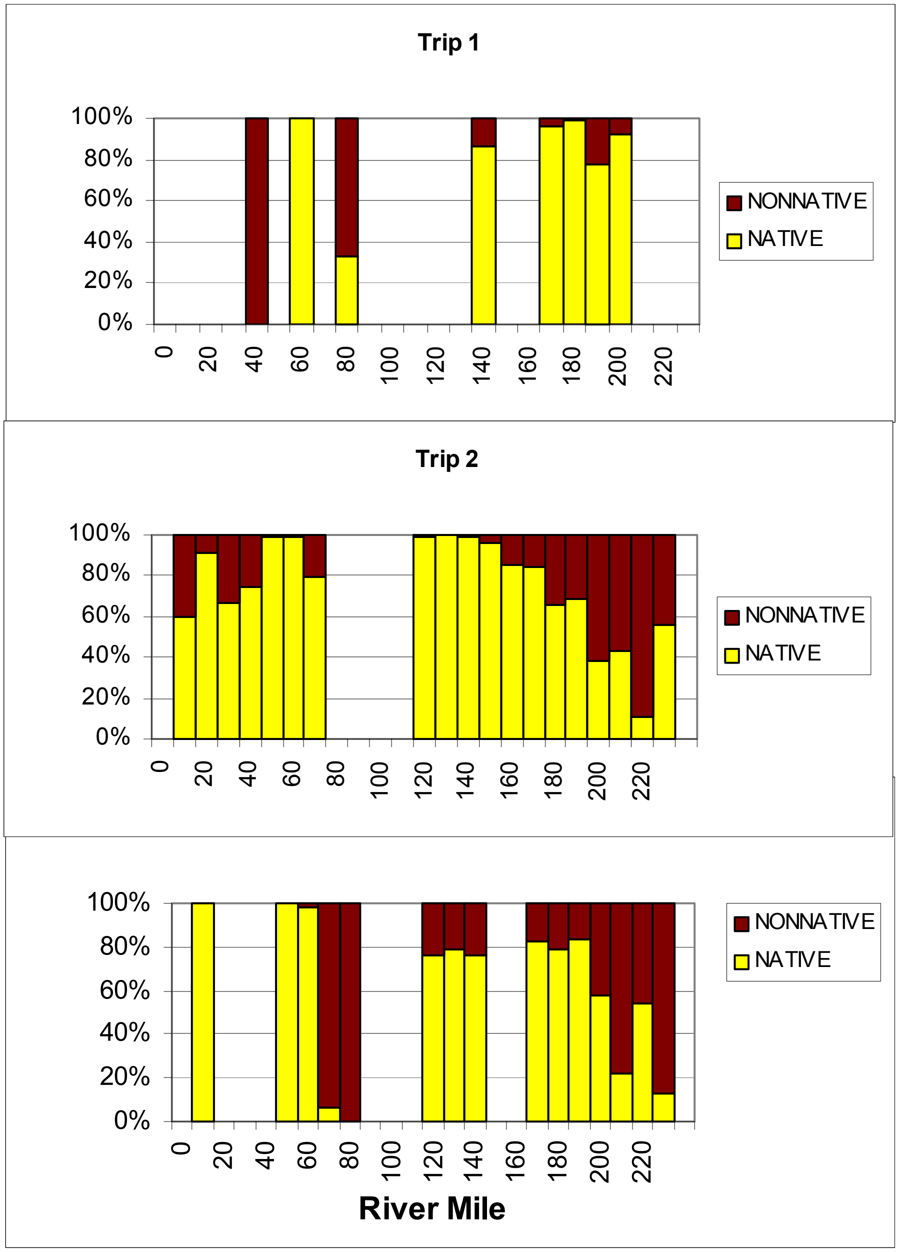


Figure 10. Relative abundance of native and nonnative species captured by seining by 10-mile increments, Trips 1-3, 2000.

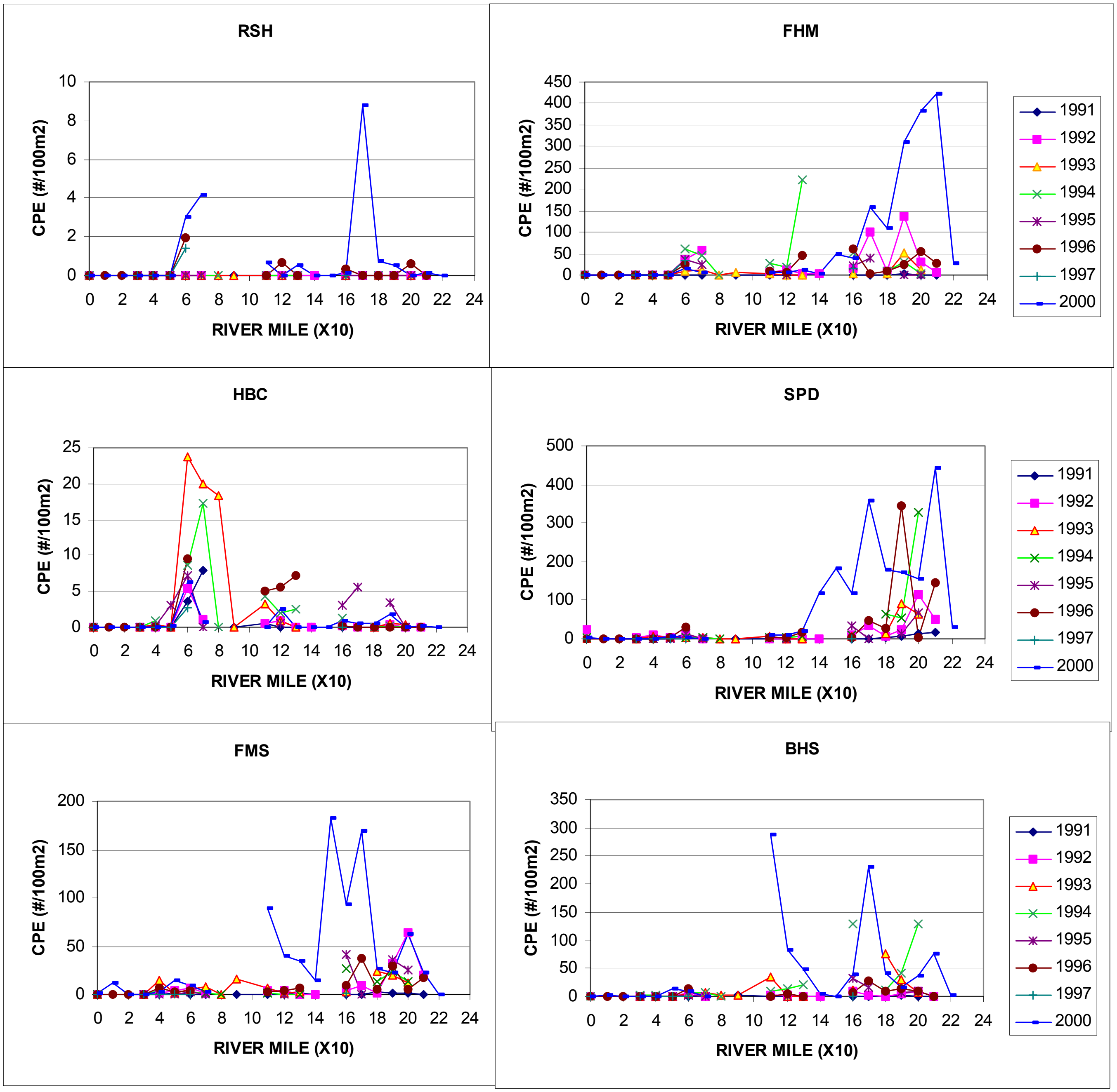


Figure 11. Distribution of arithmetic mean CPE by 10-mile increments of selected species captured by seining in backwaters from 1991 to 2000. Data for 1991-1997 from AGFD (unpublished data). Note difference in scale for each species. See Table 3 for species codes.

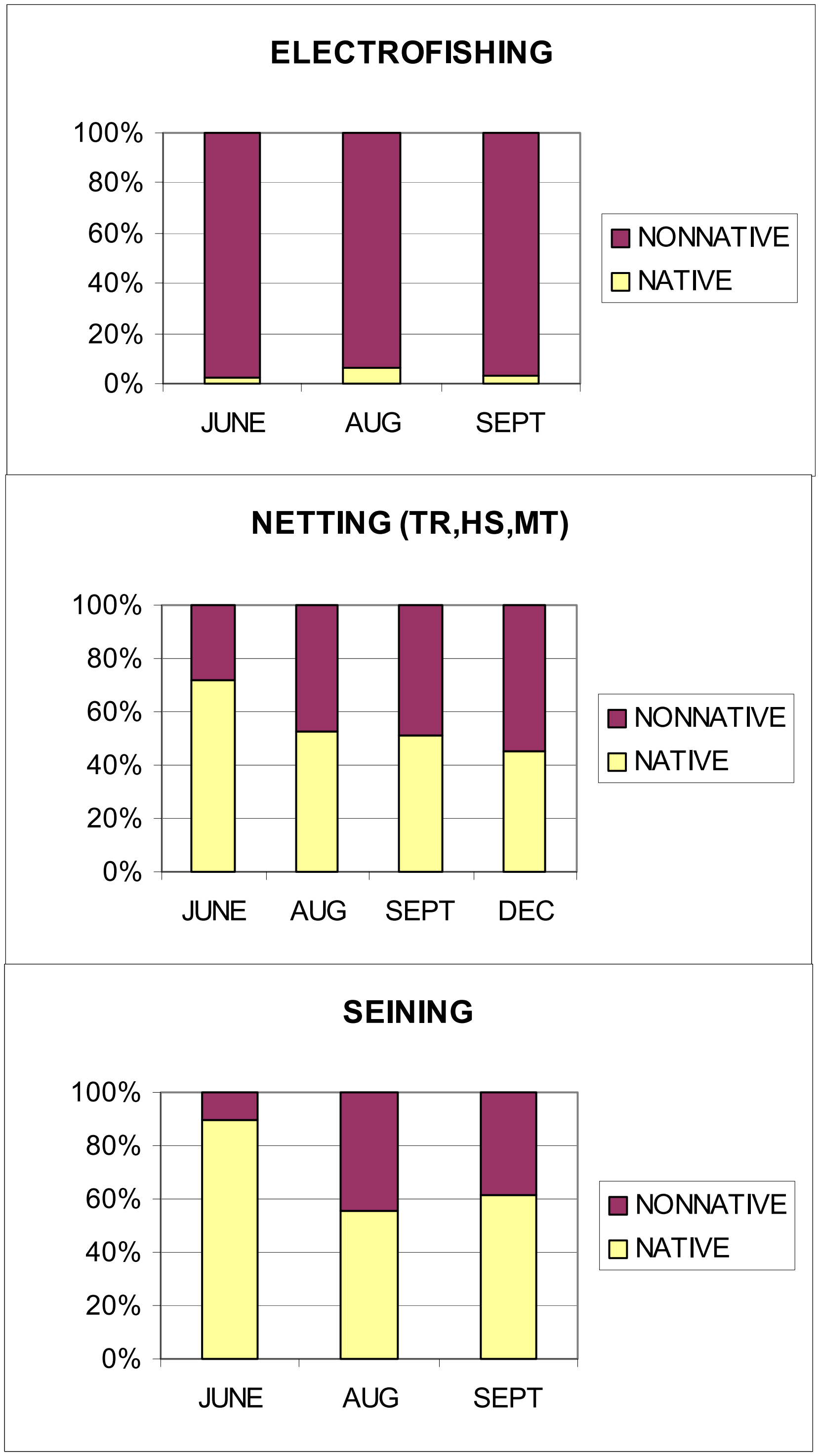


Figure 12. Comparison of relative abundance of native and nonnative species in electrofishing, netting, and seining samples, Trips 1-4 (June, August, September, December), 2000.

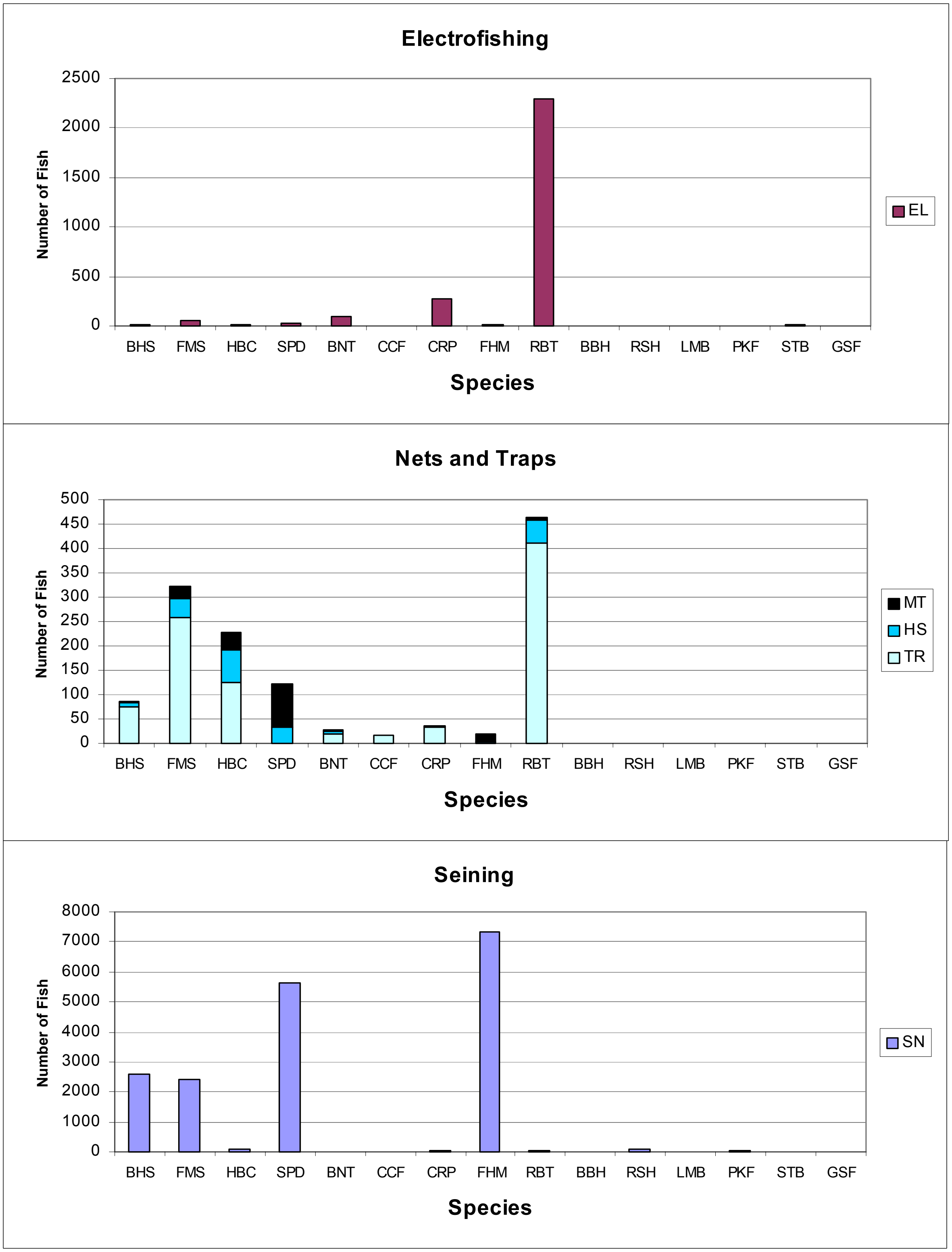


Figure 13. Species composition and abundance by gear type, captured during LSSF, Trips 1-4, 2000. See Table 3 for species codes.

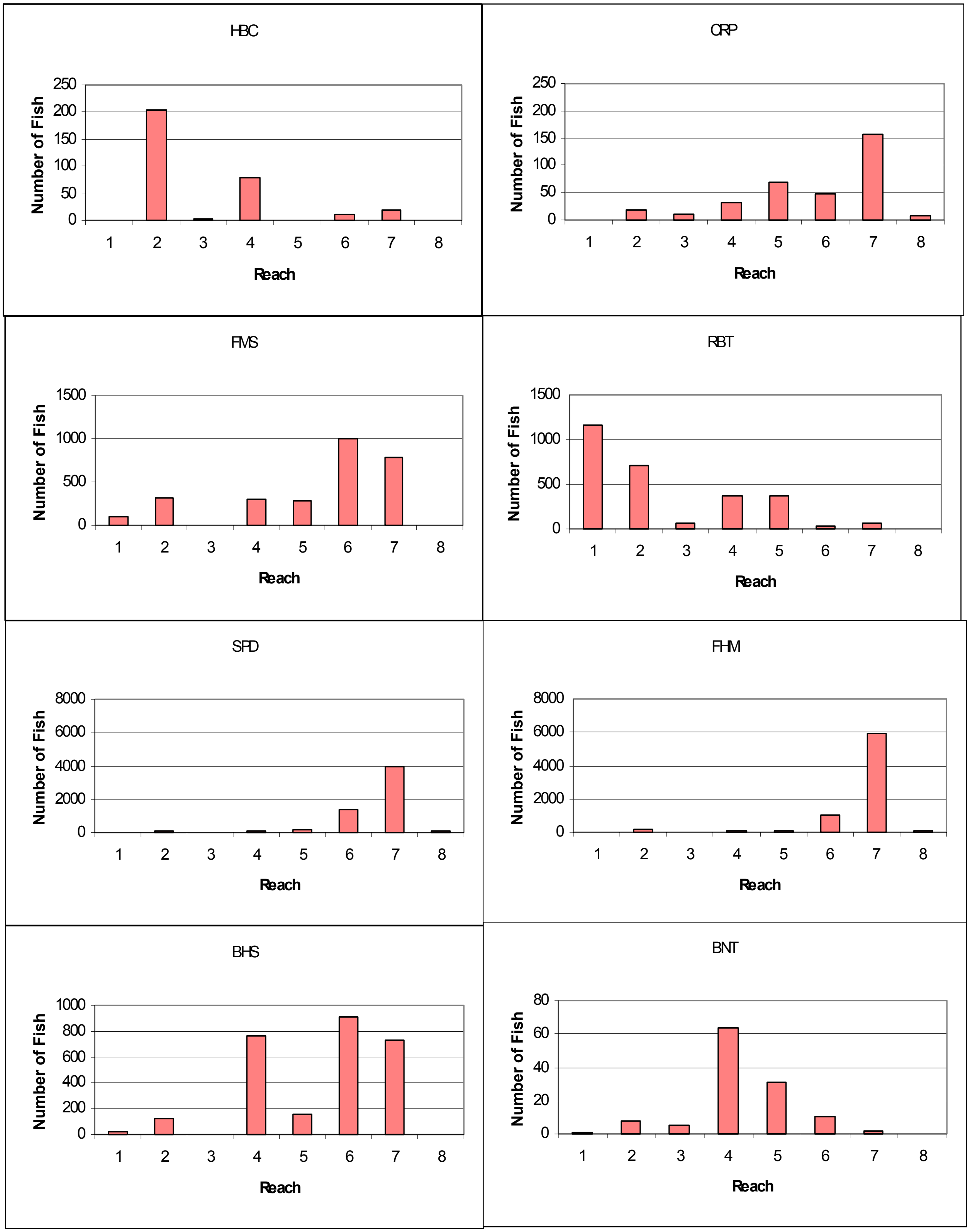


Figure 14. Longitudinal distribution by reach of eight most abundant species captured with all gear types during LSSF, Trips 1-4, 2000. Sampling with electrofishing (EL) and seining (SN) was continuous while trammel nets (TN), hoop nets (HS) and minnow traps (MT) were concentrated in reaches 2,4, and 5. Note differences in scale between species.

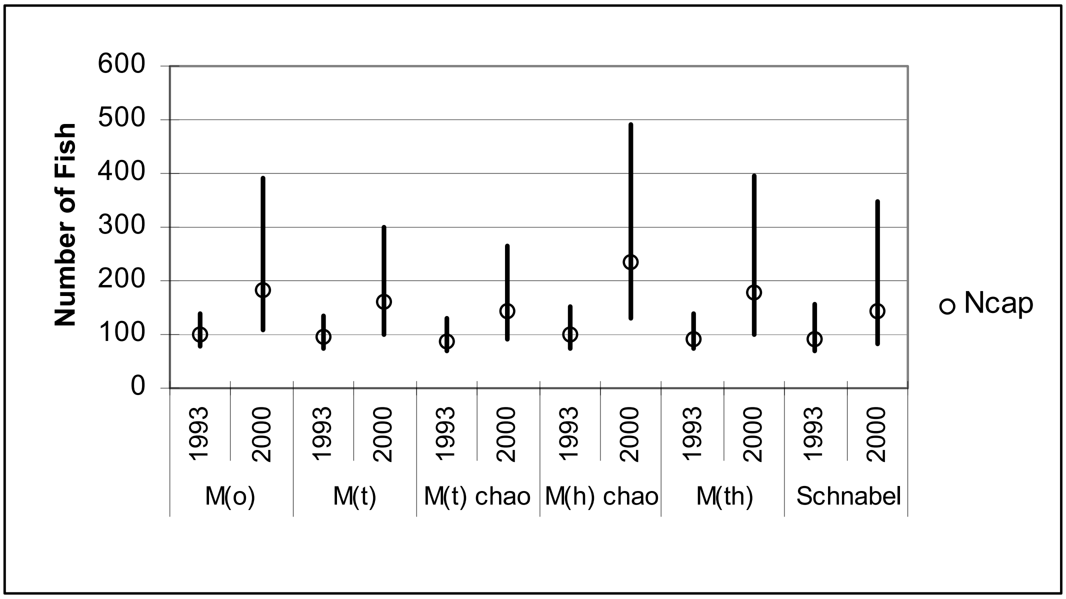


Figure 15. Comparison of population estimates (95% confidence intervals) made at Middle Granite Gorge in 1993 and 2000 using models in program CAPTURE (White et al. 1982).

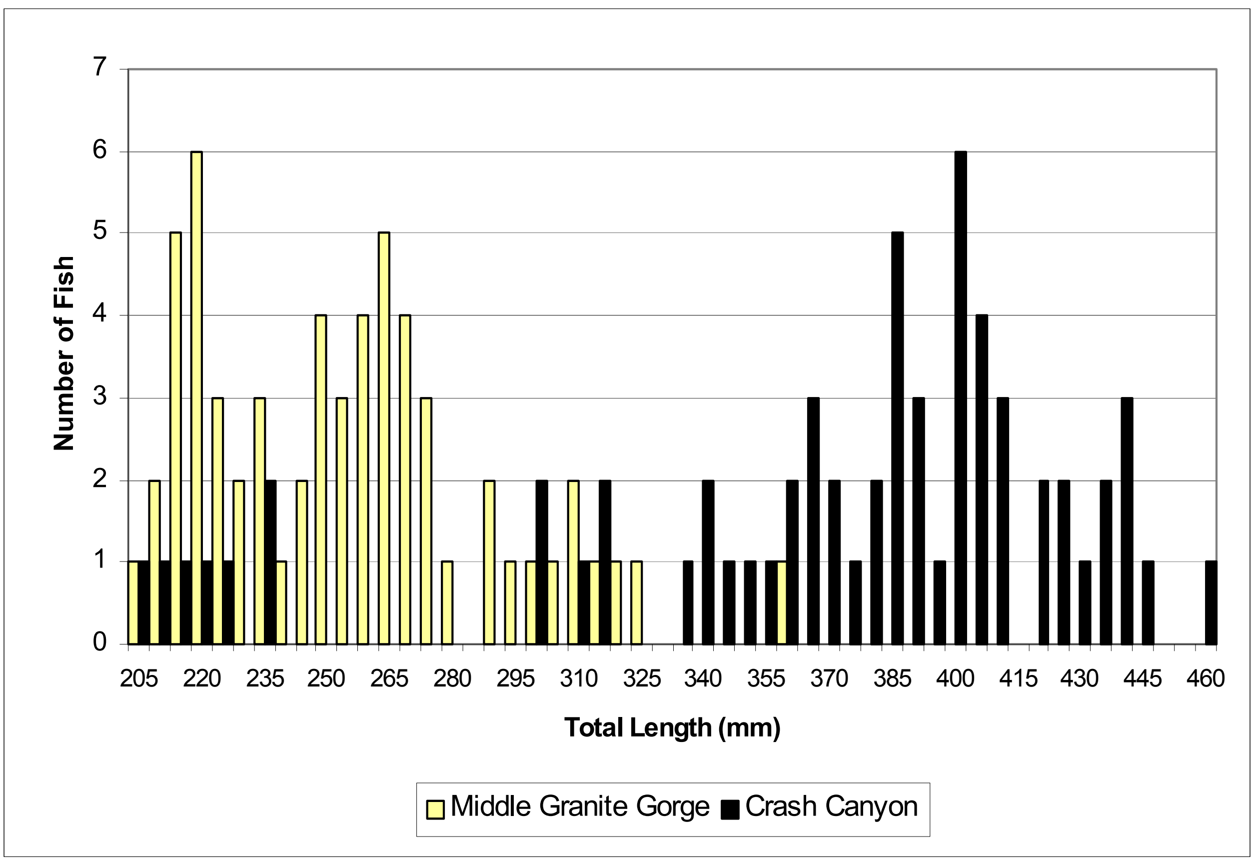


Figure 16. Length frequencies of humpback chub captured with trammel nets at Middle Granite Gorge (RM 125.8-127.5) and Crash Canyon (RM 62.0-63.2).

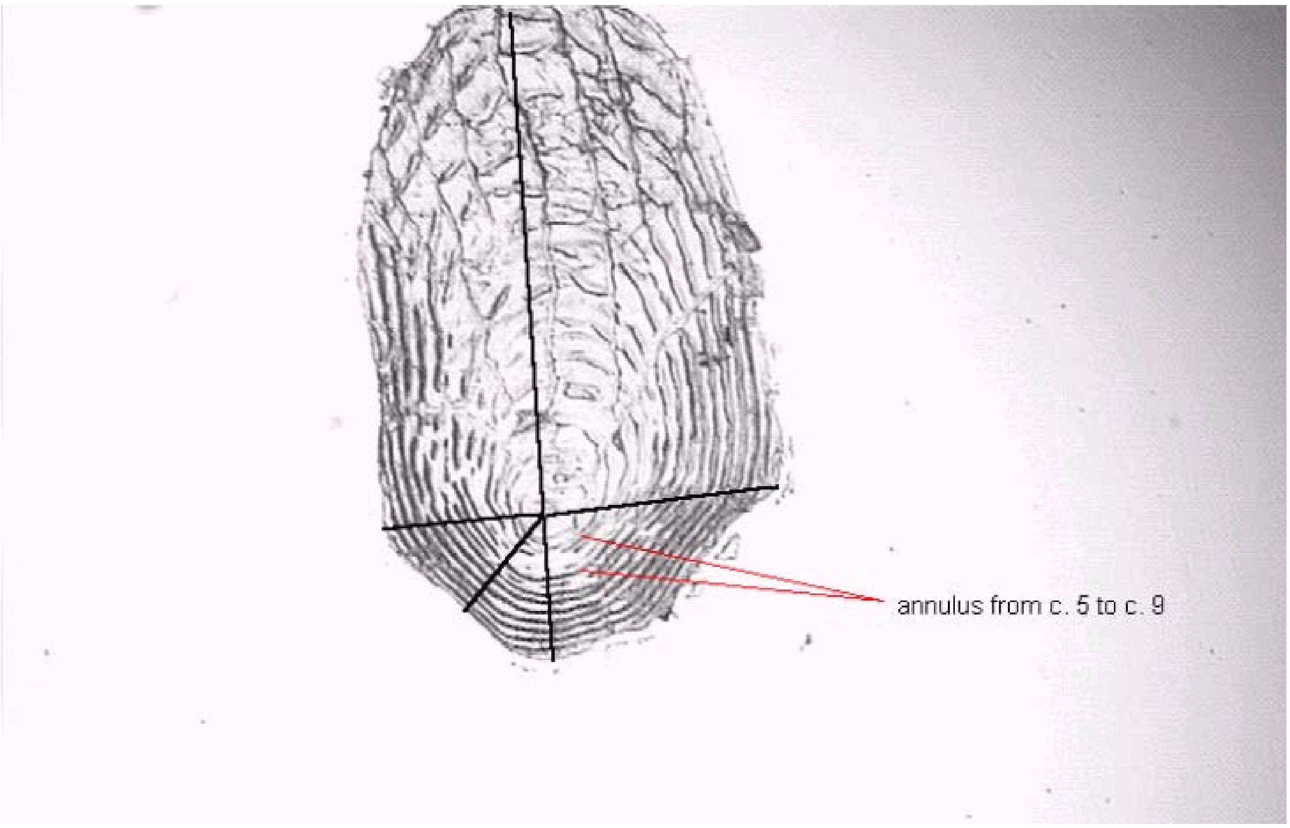


Figure 17. Example of scale from humpback chub (111 mm TL; age 1) captured on June 14 from the mouth of the Little Colorado River. Wide band of disrupted circuli beginning at c.5 through c.9 is identified as an annulus. Scale features are measured along a 45^{o} angle from the focus to the anterior edge.

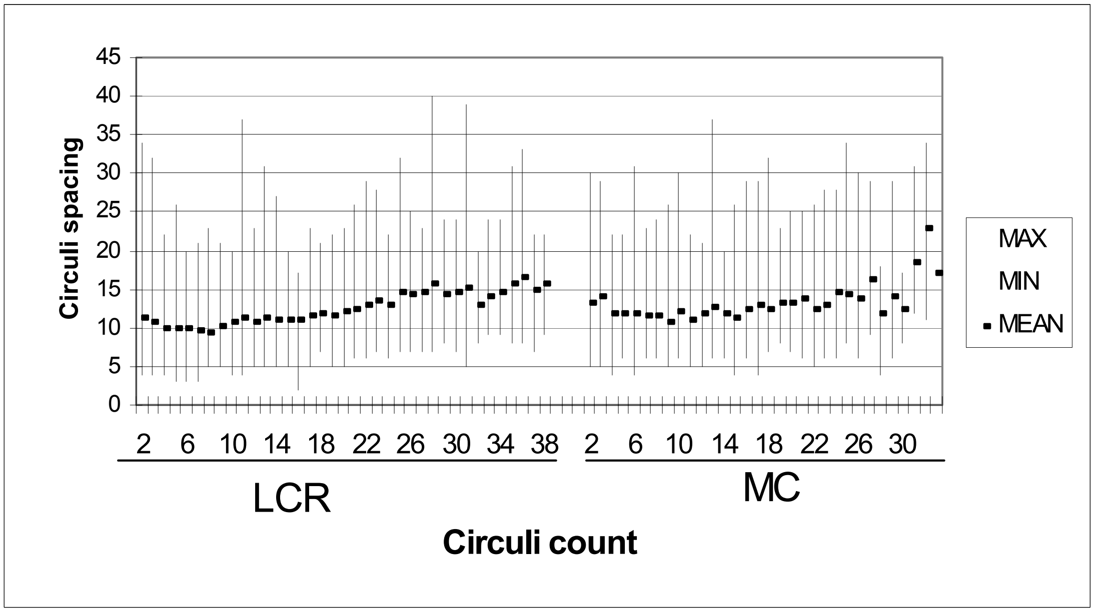


Figure 18. Variation in circuli spacing in fish captured in the LCR and the mainstem during LSSF, 2000.

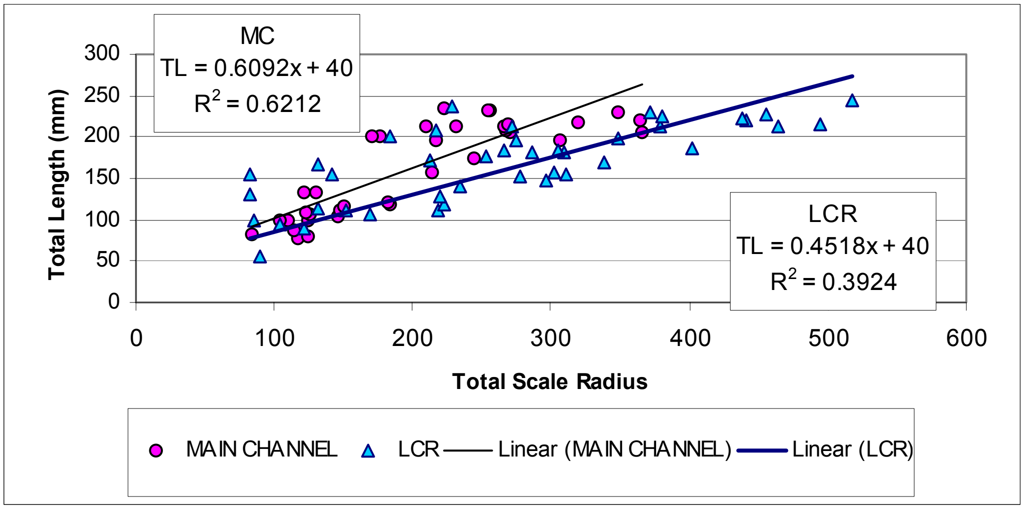


Figure 19. Correlation between total scale radius and fish total length for fish captured in the LCR and mainstem during LSSF, 2000.

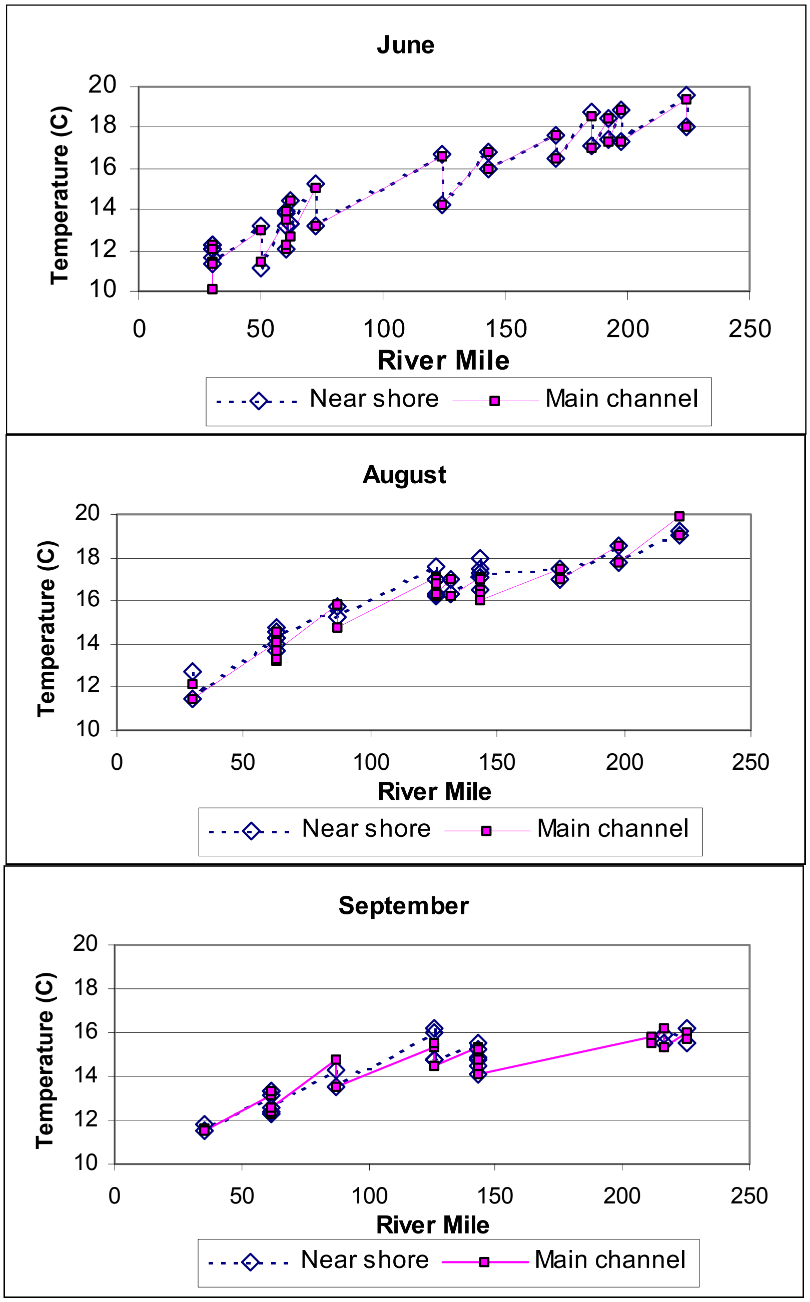


Figure 20. Daily minimum and maximum temperature in mainstem and nearshore at selected sites during LSSF, 2000.

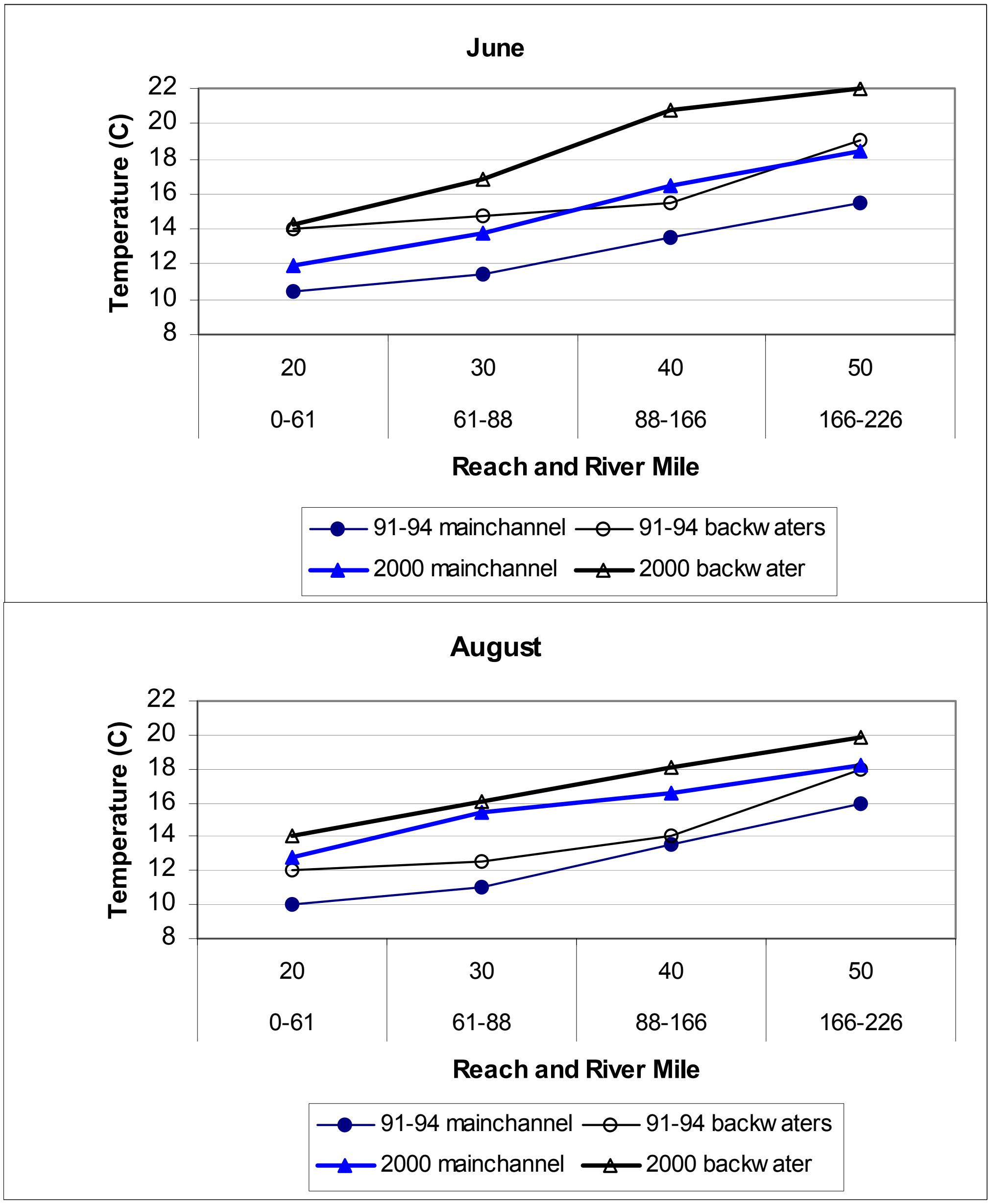


Figure 21. Mean mainstem and backwater temperatures by reach during MLFF (1991-1994) and during LSSF (2000). Data for 1991-1994 adapted from AGFD (1996).

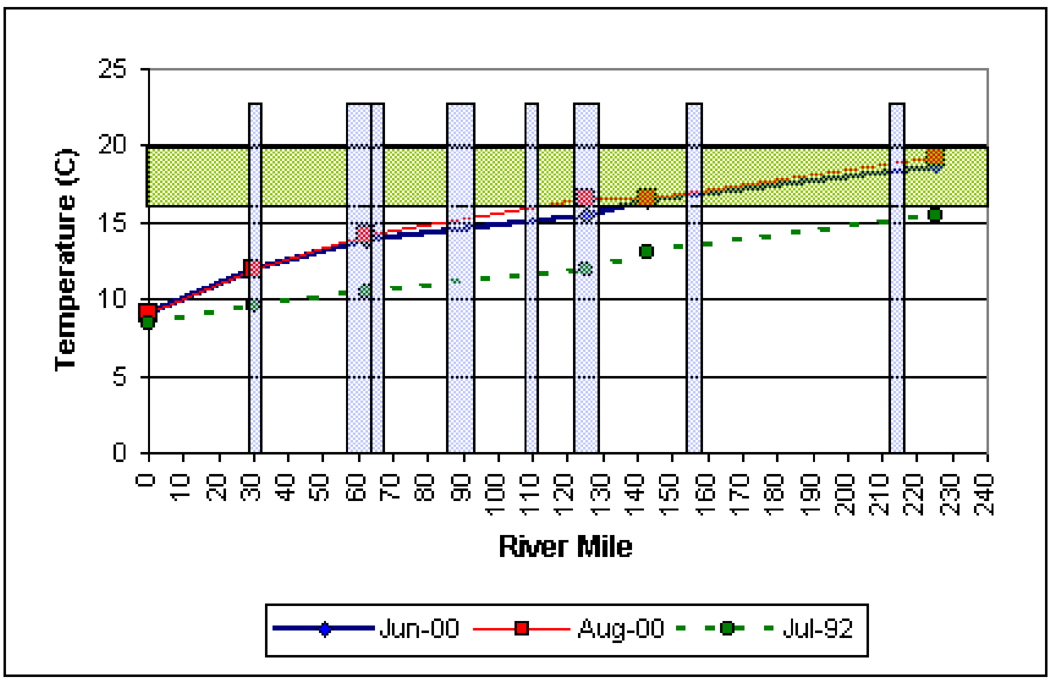


Figure 22. Mean mainstem temperature in June and August, 2000, during LSSF, and mean mainstem temperature in July 1992, during MLFF. Nine humpback chub aggregations, as defined by Valdez and Ryel (1995) are shown by vertical shaded bars. Optimum spawning temperature for humpback chub of 16-20EC is shown by horizontal shaded bar.

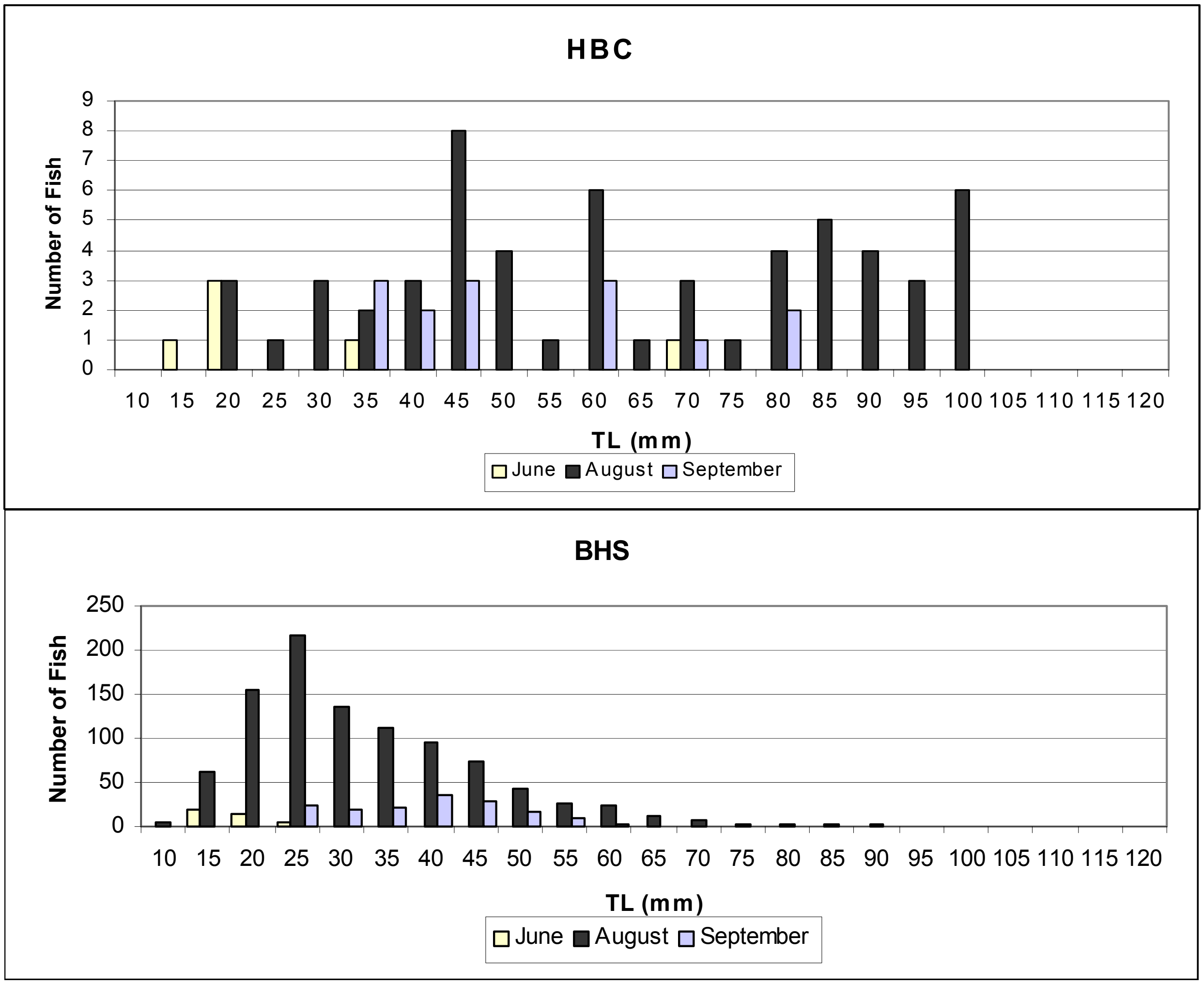
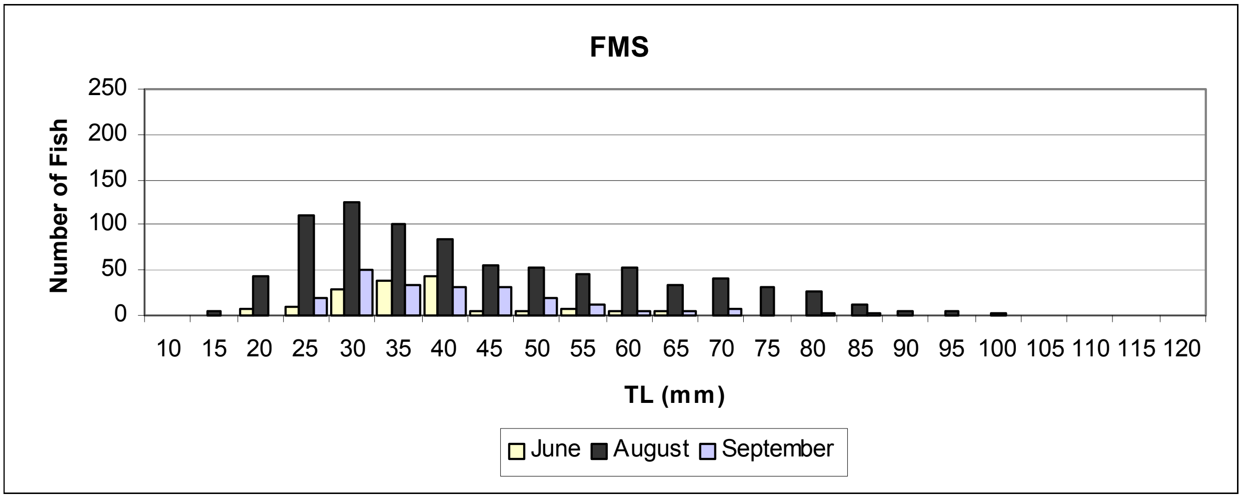


Figure 23. Length-frequency histogram for humpback chub (HBC) and bluehead sucker (BHS) <200 mm Total Length (TL) captured on Trips 1-3, 2000.



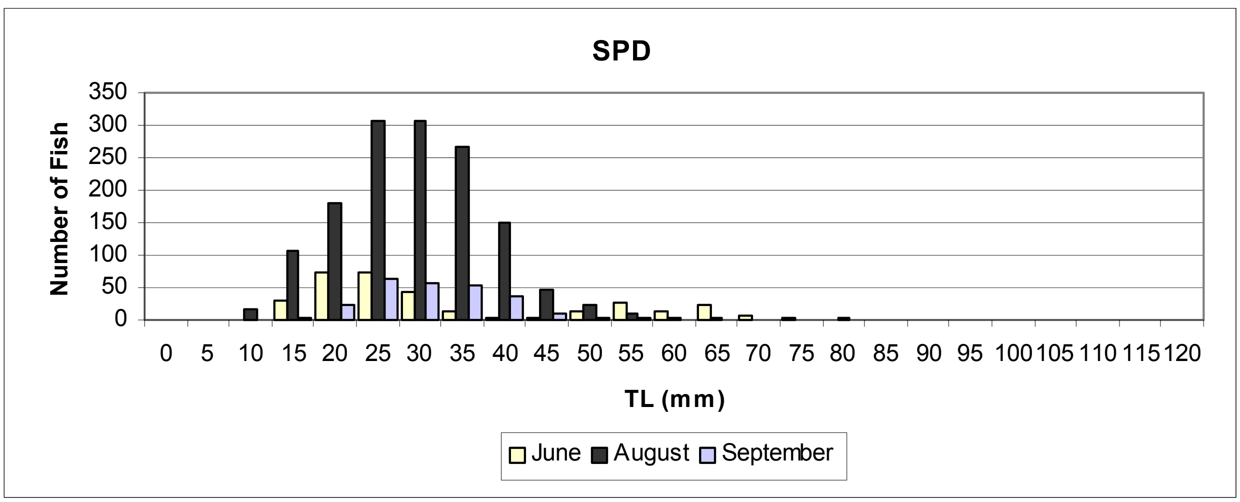


Figure 24. Length-frequency histogram for flannelmouth sucker (FMS) and speckled dace (SPD) <200 mm (Total Length (TL) captured on Trips 1-3, 2000.

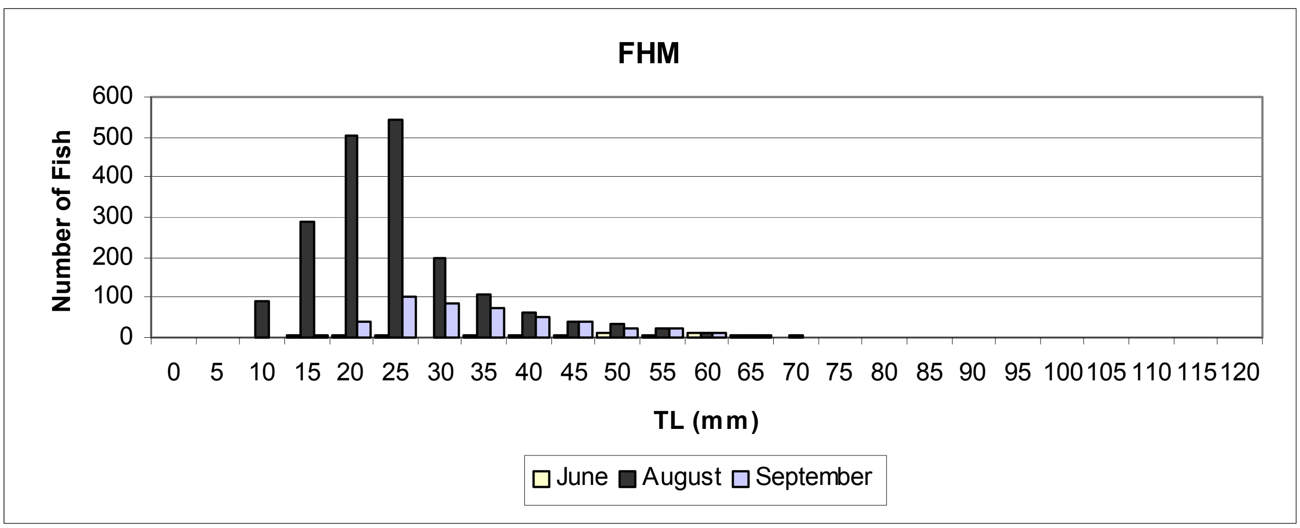


Figure 25. Length-frequency histogram for fathead minnow (FHM) captured on Trips 1-3, 2000.

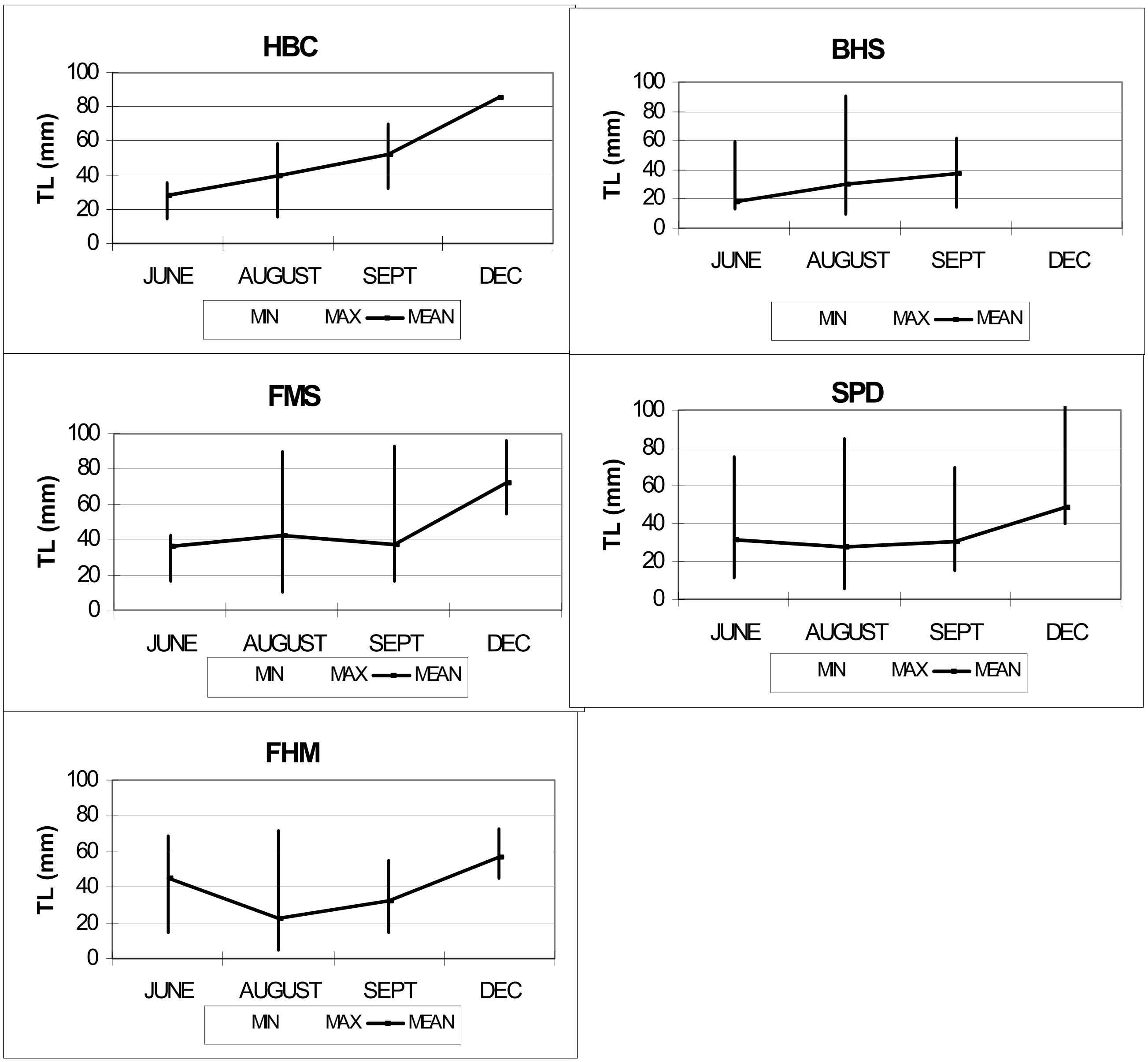


Figure 26. Range and mean total length (TL in mm) of selected fish species captured from backwaters and nearshore areas during Trips 1-4 (June, August, September, December), 2000. See Table 3 for species codes.

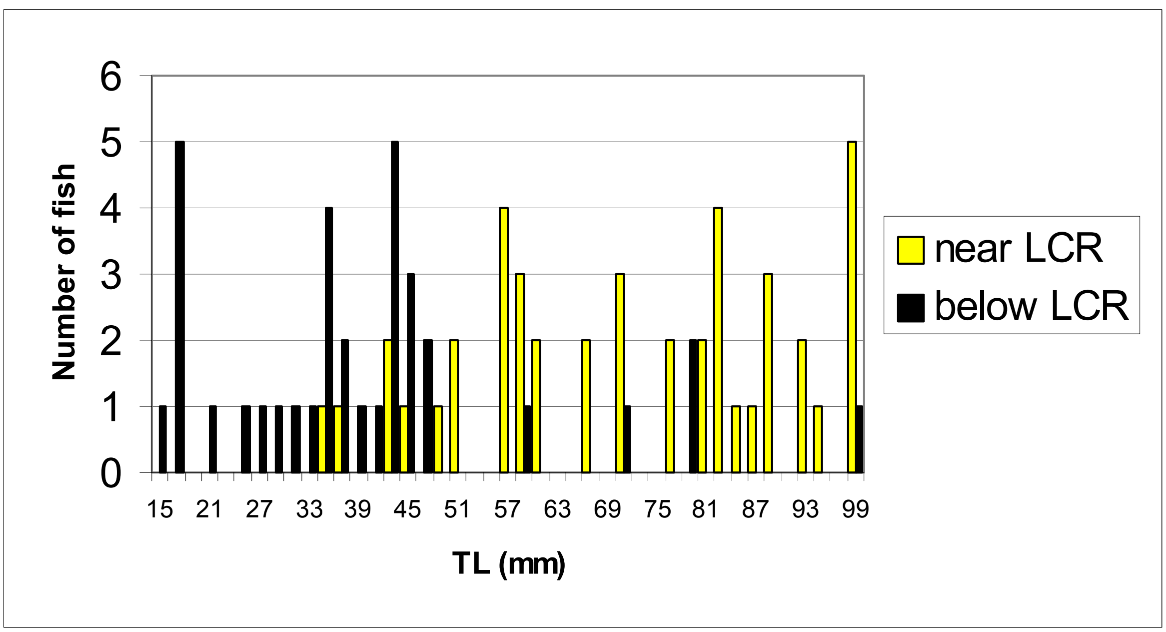


Figure 27. Length-frequency of YOY humpback chub captured near the LCR (RM 59-72) and below the LCR (RM 125-226).

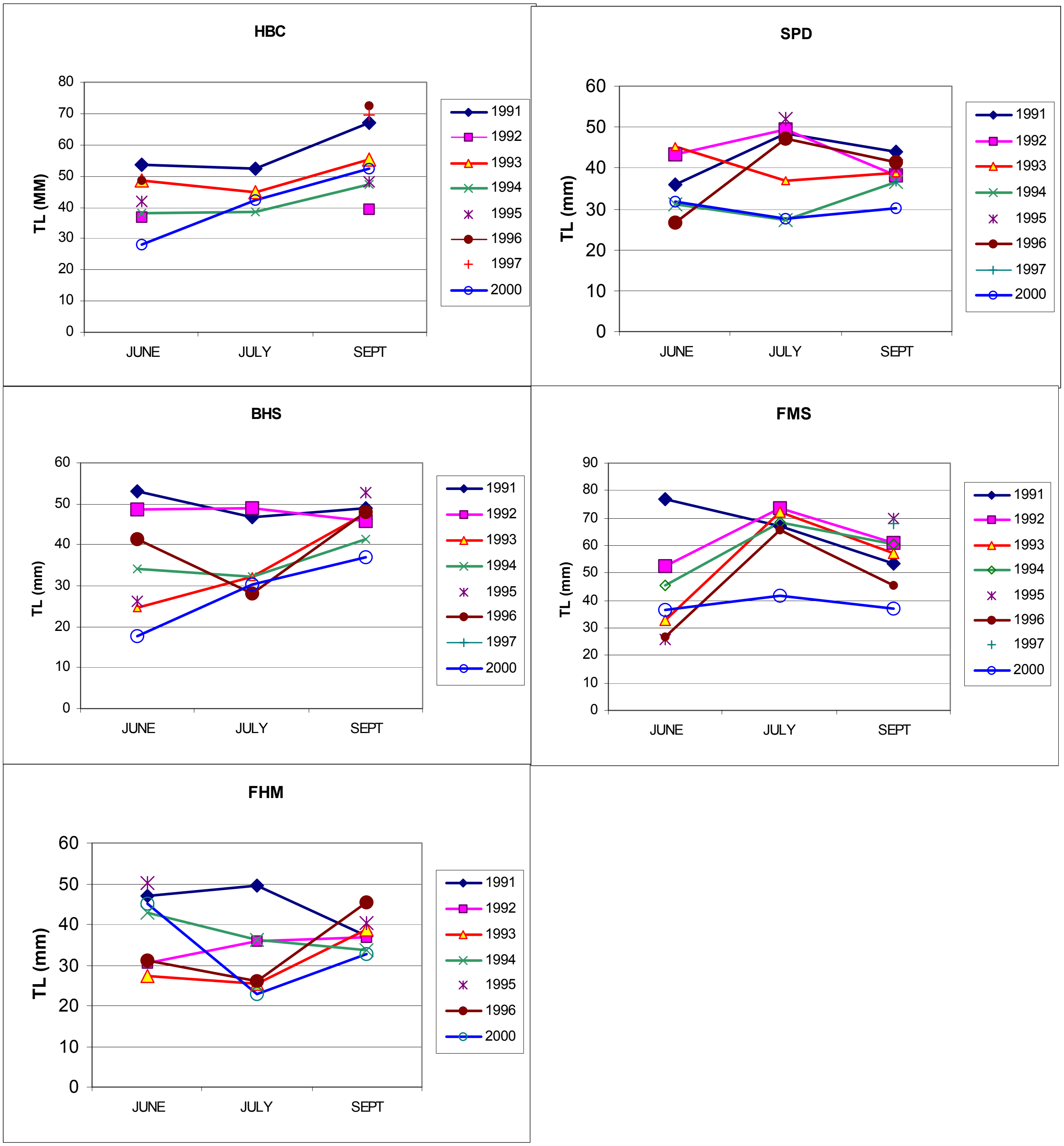


Figure 28. Comparison of mean total length (TL in mm) of selected fish species in June, July/August, and September from 1991-1997 and 2000.

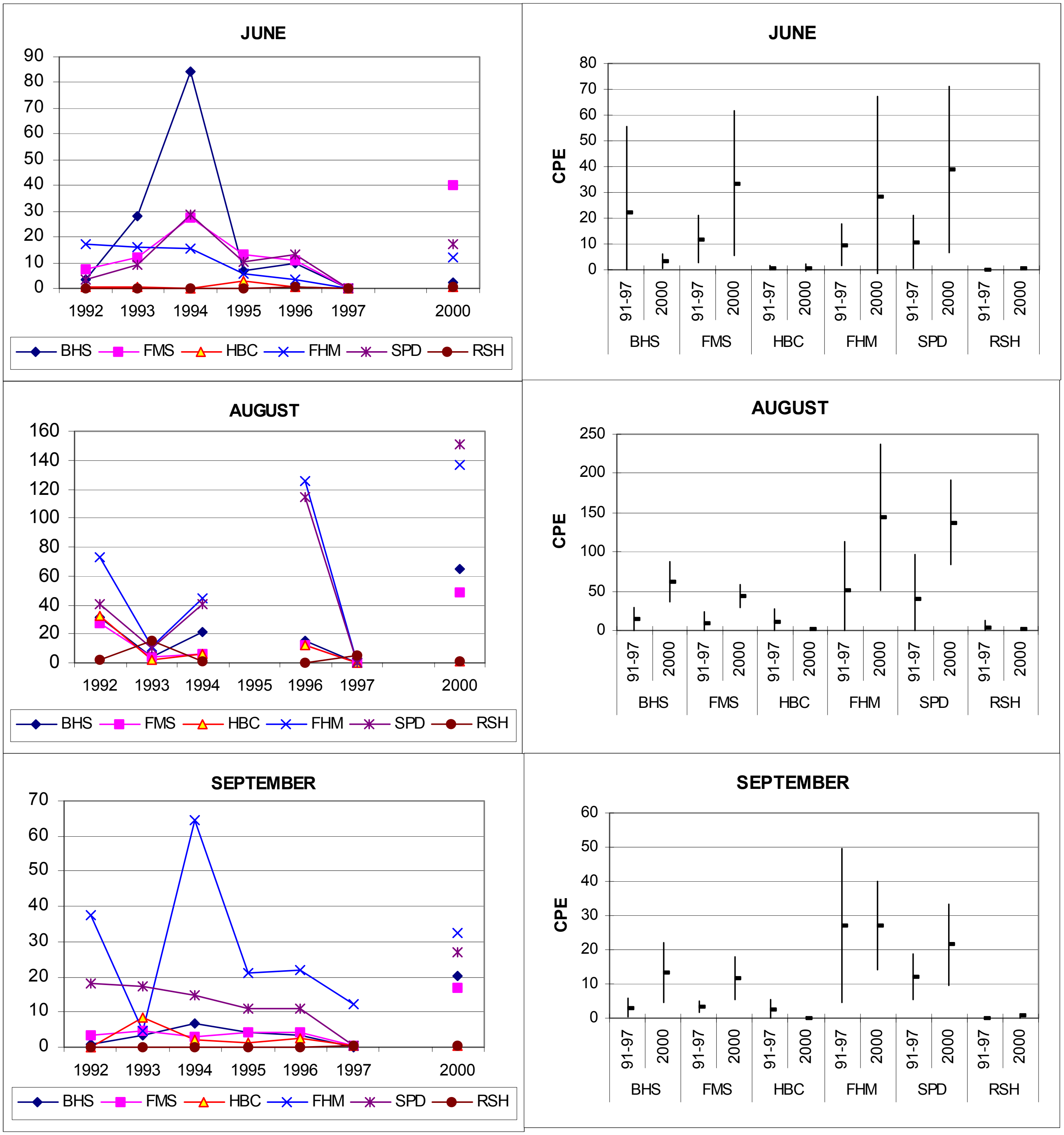


Figure 29. Mean CPE (#fish/100 m^2) of selected fish species captured by seining in June, July-August, and September 1991-1997 and 2000 (left); and mean CPE with 95% confidence intervals from 1991-1997 and 2000 (right).

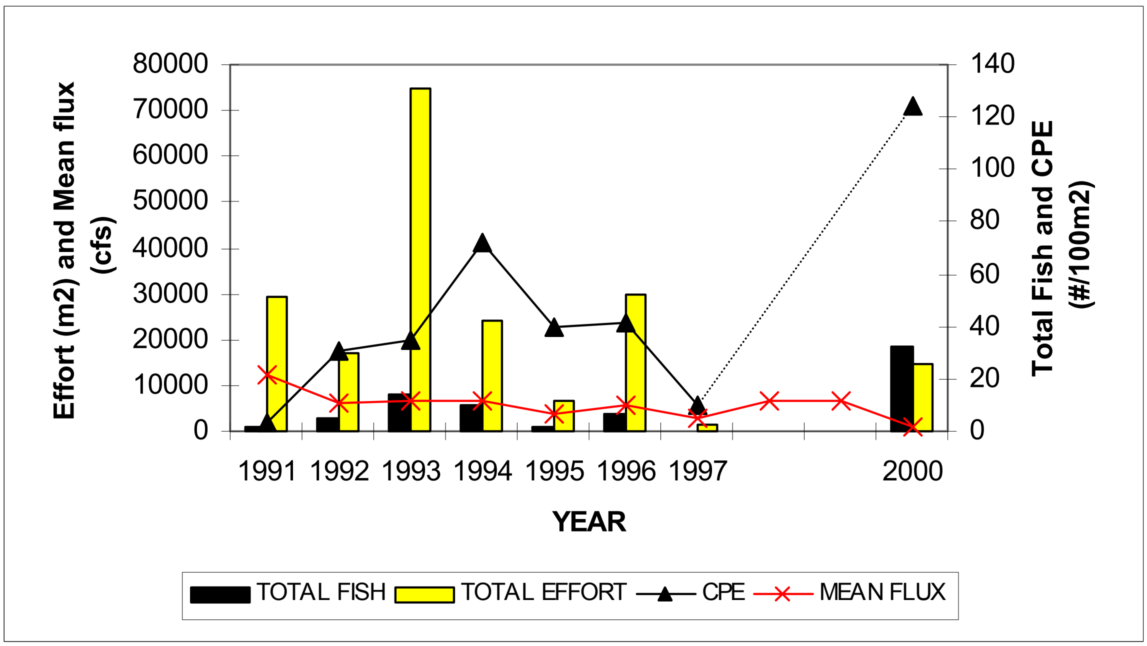


Figure 30. Total seining effort (m^2), total fish captured, and CPE (#fish/100 m^2) and mean daily fluctuation of releases (flux) from Glen Canyon Dam from 1991-2000.

4.0 CONCLUSIONS

4.1 Distribution

There was concern the low steady summer flows would warm the river and slow water velocity, allowing nonnative warmwater fish species to increase in abundance and/or distribution. The concern was that the LSSF would provide suitable spawning conditions for nonnative fishes and/or allow for upstream invasion of fish from Lake Mead or from canyon tributaries. Significant increases in abundance and/or distribution of most fish species did not occur, and there was no apparent movement of fishes upstream from Lake Mead. Only two species of nonnative fishes appeared to respond to the LSSF conditions in summer, 2000. Catch rate of fathead minnow was much higher (although not significant due to high variation) at the end of the LSSF prior to the spike flow than during previous years, indicating that this species reproduced in the mainstem during the experiment. Also, three adult largemouth bass (232 to 280 mm TL) were captured by electrofishing on Trip 4 from two large backwaters (RM 214.1 and 212.6), and four fry were captured from a backwater at RM 212.8 on Trip 3. There are no previous records of largemouth bass reproducing above Diamond Creek (RM 226; Valdez and Carothers 1998), but it appears that this species also spawned in the mainstem during the experiment. Although numbers and distribution of large nonnative warmwater species did not increase as hypothesized, it is possible that these species would reproduce and increase in numbers and distribution if low steady summer flows were implemented every year for multiple years.

4.2 Growth

Growth analysis of YOY humpback chub, flannelmouth sucker, and bluehead sucker was inconclusive because of the protracted spawning period and the constant influx of newly-hatched fish. Average total lengths of flannelmouth sucker declined between August and September. For flannelmouth sucker and bluehead sucker, this effect was a result of prolonged spawning occurring over the summer, which is suggested by the continued presence of sucker larvae in seine samples from June through September. Also, maximum length of fish captured by seining did not increase from August to September, suggesting a shift in habitat use. Although a shift in habitat use away from backwaters could truncate maximum length of fish captured by seining, larger YOY would be expected to appear in other sampling gears such as hoop nets, minnow traps, and electrofishing. The expected larger YOY were not captured by other sampling gears in September, and survival of this year class will need to be assessed when these fish are available to other sampling gears or are recruited into the adult population.

4.3 Relative Abundance

Although effect of the LSSF on growth rates was not apparent, a substantial effect on abundance of fish in backwaters was observed. In August, catch rates (arithmetic CPE) of the native flannelmouth sucker and bluehead sucker were significantly higher (%0.05) than in seine samples during 1990-1997 (AGFD unpublished data). No samples were taken in 1998 and 1999. The increase in abundance did not appear to occur prior to 2000; in June, prior to the peak of the reproductive season, catch rates were not significantly higher than in seine samples from 1990-1997. However, in September, following the 4-day flow spike, CPE of fathead minnow was nearly identical with earlier samples, while CPEs of the flannelmouth and bluehead suckers were still significantly higher (%0.05). This suggests that the flow spike was more detrimental to the nonnative fathead minnow than to native fish, although native fish were also displaced from backwater habitats by the high inundating flows.

Estimates of relative abundance and CPE were not affected by differences in effort. Effort (m^2 seined) in 2000 was commensurate with effort from 1991 to 1997, being well within the range of effort expended in those years in the months of June, July/August and September. Both total catch and CPE of all species combined and of selected species (bluehead sucker, flannelmouth sucker, speckled dace, and fathead minnow) were highest in 2000. Mean daily fluctuation from 1991 to 1997 remained fairly constant, while CPE was variable; however, the highest CPE occurred during the steady flows. Increased temperature likely influenced abundance during the LSSF by affecting reproduction and survival. The higher temperatures available during the LSSF likely influenced reproduction of native fishes and fathead minnow. In addition, constant warm temperatures in backwaters likely increased productivity in backwaters providing more suitable habitats than during MLFF. It could not be determined if increased temperatures alone would have a similar effect on abundance without accompanying steady flows.

4.4 Sampling Gears

This investigation and past studies clearly show the need for a variety of sample gears to monitor distribution and abundance of fishes of the Colorado River in Grand Canyon. Electrofishing, trammel nets, hoop nets, minnow traps, and seines are the recommended array of gears that can effectively sample the variety of habitats and fish species and sizes encountered. Shoreline electrofishing is most effective for capturing nonnative salmonids, as well as small-bodied nonnatives and young native species. Trammel nets are most effective at capturing adults in deep eddies and pools, while hoop nets effectively sample intermediate depths. Minnow traps and seines effectively sample small-bodied forms along shorelines and in backwaters. Collectively, these gear types, at a minimum, are necessary for long-term monitoring of fish populations in the Colorado River through Grand Canyon.

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APPENDIX A. MISCELLANEOUS TABLES

.

Table A-1. Total catch and CPE (in parentheses in fish/10 hrs) of all species captured by electrofishing, Trips 1-3, 2000. Refer to Table 3 for species codes and names.

REACH	EFFORT	Native Species				Nonnative Species										
	SEC (HRS)	BHS	FMS	HBC	SPD	BNT	CCF	CRP	FHM	RBT	BBH	LMB	GSF	RSH	STB	TOTAL
1	35331 (9.81)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (1.0)	0 (0.0)	0 (0.0)	0 (0.0)	1109 (1130.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1110
2	25512 (7.09)	0 (0.0)	4 (5.6)	2 (2.8)	1 (1.4)	4 (5.6)	0 (0.0)	11 (15.5)	0 (0.0)	516 (728.1)	1 (1.4)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	539
3	5799 (1.61)	1 (6.2)	1 (6.2)	1 (6.2)	0 (0.0)	5 (31.0)	0 (0.0)	10 (62.1)	0 (0.0)	64 (397.3)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	82
4	22027 (6.12)	1 (1.6)	7 (11.4)	4 (6.5)	0 (0.0)	46 (75.2)	0 (0.0)	19 (31.1)	0 (0.0)	269 (439.6)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	346
5	21904 (6.08)	1 (1.6)	4 (6.6)	0 (0.0)	1 (1.6)	23 (37.8)	0 (0.0)	49 (80.5)	0 (0.0)	237 (389.5)	0 (0.0)	0 (0.0)	1 (1.6)	0 (0.0)	0 (0.0)	316
6	16690 (4.64)	4 (8.6)	17 (36.7)	0 (0.0)	8 (17.3)	10 (21.6)	0 (0.0)	34 (73.3)	1 (2.2)	38 (82.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	3 (6.5)	115
7	39962 (11.10)	0 (0.0)	20 (18.0)	2 (1.8)	15 (13.5)	2 (1.8)	6 (5.4)	148 (133.3)	11 (9.9)	61 (55.0)	0 (0.0)	3 (2.7)	0 (0.0)	1 (0.9)	5 (4.5)	274
8	8156 (2.27)	0 (0.0)	4 (17.7)	0 (0.0)	6 (26.5)	0 (0.0)	0 (0.0)	8 (35.3)	2 (8.8)	6 (26.5)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	26

Table A-2. Total catch and CPE (in parentheses in fish/10 hrs) of all species captured with trammel nets by site, Trips 2-4, 2000. Refer to Table 3 for species codes and names.

			Native			Nonnative					
Trip	**Site**	**Hours**	**BHS**	**FMS**	**HBC**	**BNT**	**CCF**	**CRP**	**RBT**	**STB**	**Total**
	CC	235.08	7 (0.30)	30 (1.28)	34 (1.45)	0 (0.00)	0 (0.00)	3 (0.13)	80 (3.40)	0 (0.00)	154 (6.55)
TRIP 2	**MGG**	182.2	5 (0.27)	8 (0.44)	34 (1.87)	4 (0.22)	1 (0.05)	9 (0.49)	44 (2.41)	0 (0.00)	105 (5.76)
	KC	183.85	7 (0.38)	61 (3.32)	1 (0.05)	4 (0.22)	10 (0.54)	18 (0.98)	54 (2.94)	1 (0.05)	156 (8.49)
	CC	218.28	4 (0.18)	34 (1.56)	17 (0.78)	4 (0.18)	0 (0.00)	0 (0.00)	67 (3.07)	0 (0.00)	126 (5.77)
TRIP 3	**MGG**	233	32 (1.37)	18 (0.77)	22 (0.94)	5 (0.21)	0 (0.00)	1 (0.04)	45 (1.93)	0 (0.00)	123 (5.28)
	KC	207.53	10 (0.48)	53 (2.55)	0 (0.00)	2 (0.10)	3 (0.14)	2 (0.10)	62 (2.99)	0 (0.00)	132 (6.36)
	CC	175.27	3 (0.17)	20 (1.14)	12 (0.68)	0 (0.00)	0 (0.00)	0 (0.00)	36 (2.05)	0 (0.00)	71 (4.05)
TRIP 4	**MGG**	149.35	4 (0.27)	4 (0.27)	5 (0.33)	0 (0.00)	0 (0.00)	0 (0.00)	12 (0.80)	0 (0.00)	25 (1.67)
	KC	105.1	4 (0.38)	31 (2.95)	0 (0.00)	1 (0.10)	2 (0.19)	0 (0.00)	11 (1.05)	0 (0.00)	49 (4.66)

CC = Crash Canyon, MGG = Middle Granite Gorge, KC = Kanab Creek

Table A-3. Total catch and CPE (in parentheses in fish/10 hrs) of fish captured with hoop nets by reach, Trips 1-4, 2000. Refer to Table 3 for species codes and names.

		Native Species				Nonnative Species				
REACH	**EFFORT (HRS)**	**BHS**	**FMS**	**HBC**	**SPD**	**BNT**	**CCF**	**FHM**	**RBT**	**TOTAL**
1	411.21	1 (0.02)	16 (0.39)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	24 (0.58)	41 (1.00)
2	1208.68	7 (0.06)	3 (0.03)	64 (0.53)	11 (0.09)	0 (0)	0 (0)	1 (0.01)	8 (0.7)	94 (0.78)
3	41.06	0 (0)	0 (0)	0 (0)	10 (2.44)	0 (0)	0 (0)	0 (0)	1 (0.24)	11 (2.68)
4	1090.02	0 (0)	1 (0.01)	4 (0.04)	1 (0.01)	5 (0.05)	1 (0.01)	1 (0.1)	5 (0.05)	18 (0.17)
5	1013.83	0 (0)	17 (0.17)	0 (0)	12 (0.12)	0 (0)	0 (0)	0 (0)	8 (0.08)	37 (0.37)
6	0	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
7	67.48	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
8	0	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

Table A-4. Total catch and CPE (in parentheses in fish/10 hrs) of fish captured with minnow traps by reach, Trips 1-4, 2000. Refer to Table 3 for species codes and names.

		Native Species				Nonnative Species					
REACH	**EFFORT (HRS)**	**BHS**	**FMS**	**HBC**	**SPD**	**BNT**	**CRP**	**FHM**	**RBT**	**RSH**	**TOTAL**
1	314.17	0 (0)	5 (0.16)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	4 (0.13)	0 (0)	9 (0.29)
2	1145.03	1 (0.01)	1 (0.01)	34 (0.23)	16 (0.14)	0 (0)	2 (0.02)	2 (0.02)	0 (0)	1 (0.01)	57 (0.30)
3	38.8	0 (0)	0 (0)	1 (0.26)	18 (4.64)	0 (0)	0 (0)	5 (1.29)	2 (0.52)	0 (0)	26 (6.70)
4	1043.88	0 (0)	2 (0.02)	0 (0)	7 (0.07)	3 (0.03)	0 (0)	3 (0.03)	0 (0)	0 (0)	15 (0.174
5	921.22	1 (0.01)	18 (0.19)	0 (0)	41 (0.45)	0 (0)	0 (0)	7 (0.08)	0 (0	0 (0)	67 (0.73
6	0	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
7	44.13	0 (0)	0 (0)	1 (0.23)	5 (1.13)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	6 (1.36)
8	11	0 (0)	1 (0..91)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0.91)

Table A-5. Total catch and CPE (in parentheses in fish/100m^2) of fish captured by seining, Trips 1-3, 2000. Refer to Table 3 for species codes and names.

		Native					Nonnative							
Trip	**EFFORT (m^2)**	**BHS**	**FMS**	**HBC**	**SPD**	**SUC**	**FHM**	**RSH**	**RBT**	**BNT**	**CRP**	**LMB**	**PKF**	**Total fish**
1	2769.5	36 (1.30)	464 (16.80)	6 (0.22)	671 (24.20)	36 (1.30)	132 (4.77)	6 (0.22)	2 (0.07)	1 (0.04)	0 (0.00)	0 (0.00)	0 (0.00)	1354 (48.89)
2	6041.7	1929 (31.90)	1404 (23.20)	59 (0.98)	3914 (64.80)	37 (0.61)	5835 (96.60)	31 (0.51)	31 (0.51)	1 (0.02)	27 (0.45)	4 (0.07)	5 (0.08)	13277 (219.76)
3	5918.85	648 (10.90)	530 (8.95)	11 (0.19)	1063 (18.00)	2 (0.03)	1353 (22.90)	35 (0.59)	1 (0.02)	0 (0.00)	0 (0.00)	0 (0.00)	35 (0.59)	3678 (62.14)
Total	14730.1	2613 (17.70)	2398 (16.30)	76 (0.52)	5648 (38.30)	75 (0.51)	7320 (49.70)	72 (0.49)	34 (0.23)	2 (0.01)	27 (0.18)	4 (0.03)	40 (0.27)	

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Table A-6. Total catch and CPE (in parentheses in fish/100m^2) of fish captured by seining by reach, Trips 1-3, 2000. Refer to Table 3 for species codes and names

		Native Species					Nonnative Species							
REACH	**EFFORT (m^2)**	**SUC**	**BHS**	**FMS**	**HBC**	**SPD**	**FHM**	**RSH**	**RBT**	**BNT**	**CRP**	**LMB**	**PKF**	**TOTAL**
1	5289	7 (0.13)	23 (0.43)	71 (1.34)	0 (0.00)	33 (0.62)	0 (0.00)	0 (0.00)	28 (0.53)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	162 (3.06)
2	2933.7	19 (0.65)	98 (3.34)	226 (7.70)	40 (1.36)	94 (3.20)	202 (6.89)	40 (1.36)	5 (0.17)	0 (0.00)	2 (0.07)	0 (0.00)	16 (0.55)	742 (25.30)
3	131.6	0 (0.00)	1 (0.76)	3 (2.28)	1 (0.76)	1 (0.76)	9 (6.84)	6 (4.56)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	21 (15.96)
4	663.9	9 (1.36)	720 (108.00)	262 (39.50)	9 (1.36)	64 (9.64)	52 (7.83)	1 (0.15)	0 (0.00)	1 (0.15)	3 (0.45)	0 (0.00)	4 (0.60)	1125 (169.45)
5	348.2	0 (0.00)	133 (38.20)	104 (29.90)	0 (0.00)	119 (34.18)	40 (11.49)	1 (0.29)	0 (0.00)	1 (0.29)	0 (0.00)	0 (0.00)	3 (0.86)	401 (115.16)
6	1197.2	2 (0.17)	901 (75.30)	976 (81.50)	11 (0.92)	1356 (113.30)	1029 (85.95)	11 (0.92)	1 (0.08)	0 (0.00)	14 (1.17)	0 (0.00)	7 (0.58)	4308 (359.84)
7	3821.6	37 (0.97)	733 (19.20)	756 (19.80)	15 (0.39)	3929 (102.80)	5902 (154.40)	13 (0.34)	0 (0.00)	0 (0.00)	8 (0.21)	4 (0.10)	2 (0.05)	11399 (298.28)
8	344.8	1 (0.29)	4 (1.16)	0 (0.00)	0 (0.00)	52 (15.08)	86 (24.94)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	8 (2.32)	151 (43.79)

Table A-7. Average total length (TL in mm) of fish species captured by gear type, Trips 1-4, 2000. For gear types, refer to Table 1; for species codes and names refer to Table 3. Blanks indicate no individuals of that species were captured.

	Native Species				Nonnative Species										
GEAR	**BHS**	**FMS**	**HBC**	**SPD**	**BNT**	**CCF**	**CRP**	**FHM**	**RBT**	**BBH**	**LMB**	**GSF**	**RSH**	**STB**	**PKF**
TN*	240.7	427.9	337.1		284.8	336.9	425.8		251.8	194.0				447.0	
EL	198.9	223.7	171.3	47.9	237.0	324.2	436.7	51.8	291.6	188.0	252.3	155.0	42.0	224.4	
HS	186.3	107.9	141.5	62.7	149.4	60.0		67.5	232.5						
MT	52.5	62.6	82.2	66.6	98.0		63.0	51.6	63.7				55.0		
SN*	28.3	38.4	43.5	30.0	54.0		83.8	33.4	41.3		21.8		36.9		26.5

*** All sizes of nets**

Table A-8. Trammel net catch rate (CPE) in fish/10 hrs for Trips 2, 3, and 4, mark-recapture Site 1 (Crash Canyon).

Trip	Date	BHS	FMS	HBC	RBT	Effort (hours)
2	Night 1	0.45	1.01	1.12	3.92	89.26
	Night 2	0.25	1.48	1.60	3.70	81.02
	Night 3	0.15	1.39	1.70	2.31	64.80
	Total	0.30	1.28	1.45	3.40	235.08
3	Night 1	0.28	1.95	0.56	3.89	71.91
	Night 2	0.12	0.97	0.97	2.66	82.67
	Night 3	0.16	1.88	0.78	2.67	63.73
	Total	0.18	1.56	0.78	3.07	218.31
4	Night 1	0.00	0.79	0.53	1.58	75.78
	Night 2	0.32	1.44	0.64	2.73	62.27
	Night 3	0.29	1.46	1.17	2.05	34.22
	Total	0.17	1.16	0.70	2.09	172.27

One night is defined as all net sets in one evening plus all net sets the following morning.

Table A-9. Trammel net catch rate (CPE) in fish/10 hrs for Trips 2, 3, and 4, mark-recapture Site 2 (Middle Granite Gorge).

Trip	Date	BHS	FMS	HBC	RBT	Effort (hours)
2	Night 1	0.49	0.32	2.43	2.75	61.80
	Night 2	0.15	0.30	1.49	2.39	66.93
	Night 3	0.19	0.75	1.68	2.06	53.46
	Total	0.27	0.44	1.87	2.41	182.19
3	Night 1	1.07	0.43	1.61	1.61	93.42
	Night 2	1.61	0.99	0.25	1.86	80.73
	Night 3	1.53	1.02	0.85	2.55	58.80
	Total	1.37	0.77	0.94	1.93	232.95
4	Night 1	0.29	0.00	0.00	1.14	34.98
	Night 2	0.00	0.31	0.16	0.63	63.88
	Night 3	0.59	0.40	0.79	0.79	50.48
	Total	0.27	0.27	0.33	0.80	149.34

One night is defined as all net sets in one evening plus all net sets the following morning.

Table A-10. Trammel net catch rate (CPE) in fish/10 hrs for Trips 2, 3, and 4, mark-recapture Site 3 (Kanab Creek).

Trip	Date	BHS	FMS	HBC	RBT	Effort (hours)
2	Night 1	0.18	2.75	0.00	3.30	54.50
	Night 2	0.67	4.41	0.00	3.21	74.80
	Night 3	0.18	2.38	0.18	2.20	54.55
	Total	0.38	3.32	0.05	2.94	183.85
3	Night 1	0.45	2.41	0.00	3.47	66.36
	Night 2	0.74	2.60	0.00	3.46	80.86
	Night 3	0.17	2.65	0.00	1.83	60.27
	Total	0.48	2.55	0.00	2.99	207.49
4	Night 1	0.44	3.10	0.00	1.18	67.70
	Night 2	0.27	2.67	0.00	0.80	37.40
	Total	0.38	2.95	0.00	1.05	105.10

One night is defined as all net sets in one evening plus all net sets the following morning.

Table A-11. Captures and recaptures of native fishes >150 mm at mark-recapture site 1 (Crash Canyon) on Trips 2, 3, and 4, 2000.

Status	BHS				FMS				HBC			
	T 2	T 3	T 4	Total	T 2	T 3	T 4	Total	T 2	T 3	T 4	Total
Caught	7	4	3	**14**	26	33	20	**79**	36	16	13	**65**
Recapture	0	0	0	**0**	0	1	0	**1**	0	1	3	**4**
New Mark	7	4	3	**14**	26	32	20	**78**	36	15	10	**61**
Total Mark	7	11	14	**14**	26	58	78	**78**	36	51	61	**61**

Table A-12. Captures and recaptures of native fishes > 150 mm at mark-recapture site 2 (Middle Granite Gorge) on Trips 2, 3, and 4, 2000.

Status	BHS				FMS				HBC			
	T 2	T 3	T 4	Total	T 2	T 3	T 4	Total	T 2	T 3	T 4	Total
Caught	5	33	4	**42**	7	17	4	**28**	34	23	5	**62**
Recapture	0	0	0	**0**	0	0	0	**0**	0	5	0	**5**
New Mark	5	33	4	**42**	7	17	4	**28**	34	18	5	**57**
Total Mark	5	38	42	**42**	7	24	28	**28**	34	52	57	**57**

Table A-13. Captures and recaptures of native fishes > 150 mm at mark-recapture site 3 (Kanab Creek) on Trips 2, 3, and 4, 2000.

Status	BHS				FMS				HBC			
	T 2	T 3	T 4	Total	T 2	T 3	T 4	Total	T 2	T 3	T 4	Total
Caught	7	8	4	**19**	57	49	31	**137**	1	0	0	**1**
Recapture	0	0	0	**0**	0	3	5	**8**	0	0	0	**0**
New Mark	7	8	4	**19**	57	46	26	**129**	1	0	0	**1**
Total Mark	7	15	19	**19**	57	103	129	**129**	1	1	1	**1**

Table A-14. Mark-Recapture site 1; Crash Canyon. Total mark rate including prior marks and new marks.

MR-1	BHS				FMS				HBC			
	T2	T3	T4	Total	T2	T3	T4	Total	T2	T3	T4	Total
Caught	7	4	3	14	26	33	20	79	36	16	13	65
Prior Mark/Recap[a]	1	0	0	1	10	9	7	26	25	11	10	46
Total Mark (%)	14.3	0	0	7.1	38.5	27.3	35.0	32.9	69.4	68.8	76.9	70.8

[a] prior marks are PIT tagged fish from all previous studies starting in 1989.

Table A-15. Mark-Recapture site 2; Middle Granite Gorge. Total mark rate including prior marks and new marks.

MR-2	BHS				FMS				HBC			
	T2	T3	T4	Total	T2	T3	T4	Total	T2	T3	T4	Total
Caught	5	33	4	42	7	17	4	28	34	23	5	62
Prior Mark/Recap[a]	0	1	0	1	0	3	1	4	4	9	2	15
Total Mark (%)	0	3.0	0	2.4	0	17.6	25.0	14.3	11.8	39.1	40.0	24.2

[a] prior marks are PIT tagged fish from all previous studies starting in 1989.

Table A-16. Mark-Recapture site 3; Kanab Creek. Total mark rate including prior marks and new marks.

MR-3	BHS				FMS				HBC			
	T2	T3	T4	Total	T2	T3	T4	Total	T2	T3	T4	Total
Caught	7	8	4	19	57	49	31	137	1	0	0	1
Prior Mark/Recap[a]	0	0	0	0	11	14	12	37	0	0	0	0
Total Mark (%)	0	0	0	0	19.3	28.6	38.7	27.0	0	0	0	0

[a] prior marks are PIT tagged fish from all previous studies starting in 1989.

Table A-17. Mean mainstem temperature and range in 1991-1994 and 2000, in June, August, and September. Data from 1991-1994 were adapted from AGFD (1996).

Mean Mainstem Temperature (Range)							
		1991-1994			2000		
RM	**Reach**	**June 91-94**	**Aug 91-94**	**Sept 91-94**	**Jun-00**	**Aug-00**	**Sept-00**
0-61	20	10.5 (10-12)	10 (10)	11 (10.5-11.5)	11.9 (11.6-12.3)	12.8 (11.5-14.4)	12 (11.5-13.3)
61-88	30	11.5 (11-12)	11 (11)	12 (11-18)	13.8 (12.1-15.2)	15.4 (14.7-15.8)	13.9 (13.5-14.7)
88-166	40	13.5 (12.5-17)	13.5 (13-16)	13 (6-15)	16.5 (14.3-17.6)	16.6 (16.1-17.1)	14.8 (14.1-15.4)
166-226	50	15.5 (15-17)	16 (15-16)	14.5 (13-18)	18.5 (17.1-19.6)	18.2 (17.7-19.8)	15.6 (15.3-16.2)

Table A-18. Mean backwater temperatures and range in 1991-1994 and 2000, in June, August, and September. Data from 1991-1994 were adapted from AGFD (1996).

Mean Backwater Temperature (Range)							
		1991-1994			2000		
RM	**Reach**	**June 91-94**	**Aug 91-94**	**Sept 91-94**	**Jun-00**	**Aug-00**	**Sept-00**
0-61	20	14 (11-17.5)	12 (12)	12.5 (10-19)	14.3 (12.5-18.5)	14.1 (11-25)	13.4 (10.3-22.2)
61-88	30	14.75 (11-23.5)	12.5 (12.5)	14.5 (11.5-22)	16.8 (14-25)	16.1 (13-22.3)	15.6 (12.2-18.3)
88-166	40	15.5 (13-21.5)	14 (12.5-15.5)	14.5 (12-21.5)	20.8 (17-23)	18.1 (15.8-24.3)	16.3 (14-21.5)
166-226	50	19 (17-23)	18 (15.5-21.5)	16 (13-28)	22.05 (13-30)	19.8 (17.3-25)	17 (14.4-22.6)

Table A-19. Mean difference in temperature between 1991-1994 and 2000, in mainstem and backwaters in June and August. Data from 1991-1994 were adapted from AGFD (1996).

		Mainstem (C)			Backwaters (C)		
RM	**Reach**	**June**	**August**	**Sept**	**June**	**August**	**Sept**
0-61	20	+1.4	+2.8	+1.0	+0.3	+2.1	+0.8
61-88	30	+2.3	+4.4	+1.9	+2.05	+3.6	+0.9
88-166	40	+3	+3.1	+1.8	+5.3	+4.1	+0.8
166-226	50	+3	+2.2	+0.9	+3.05	+1.8	+1.0