History and Development of Long-term Fish Monitoring with Electrofishing in Grand Canyon, 2000–2007

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April 2008

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Introduction

Robust, long-term monitoring of aquatic populations is important to adaptive management programs because it characterizes a "baseline" or antecedent context in which response of biota to changing management policies or experiments can be interpreted (Walters and Holling 1990; Thomas 1996; Walters 1997). Long-term fish monitoring in the Colorado River below Glen Canyon Dam (GCD) is an essential component of the Glen Canyon Dam Adaptive Management Program. This monitoring ensures that GCD is operated in a manner consistent with the pertinent sections of Grand Canyon Protection Act of 1992 (Grand Canyon Monitoring and Research Center (GCMRC) 2001a). Non-native salmonids (rainbow trout, *Oncorhynchus mykiss* and brown trout, *Salmo trutta*) increased in abundance in the Colorado River in Glen and Grand Canyons after the early 1990s. It is likely that this increase in abundance was caused by stabilization of discharges from GCD (GCMRC 2001a; McKinney et al. 1999, 2001). Many researchers have suggested that predation by salmonids is a factor limiting recruitment of native fishes in the Colorado River in Grand Canyon (Minckley 1991; Marsh and Douglas 1997; Coggins unpublished data; U.S. Department of Interior 2002). As a result of these findings, the GCMRC Protocol Evaluation Panel advocated long-term monitoring of non-native fish species that pose risk of predation to Colorado River native fishes in Grand Canyon (GCMRC 2001b).

Monitoring and research of Grand Canyon fishes has been conducted for over 20 years, but a robust long-term monitoring program suitable for evaluating river-wide changes in fish density and distribution was not established until 2000. Although analysis was done on data dating back to 1991, limited inference on population trends can be drawn from many of the years prior to 2000.

The objective of this completion report is to provide a history of the current long-term monitoring program for Grand Canyon fishes and to provide the most recent status and trend information for those fish species effectively monitored using electrofishing. These species include rainbow trout, brown trout, common carp (*Cyprinus carpio*), flannelmouth sucker (*Catostomus latipinnis*), and bluehead sucker (*Catostomus discobolus*); other fish species were caught in low numbers, and raw catch data for those species are included in the appendices. The river was divided into eleven reaches, based on geomorphic reaches defined by Schmidt and Graff (1990), for the purpose of designing a long-term monitoring plan. These reaches were aggregated into five reaches for data analysis so that an adequate sample size was available in each reach for long-term analysis of temporal and spatial changes in fish densities for years from 1991 to 2007.

Previous reports provide comprehensive literature reviews of the biology and life history of each fish species in Grand Canyon (Maddux et al. 1987; Valdez and Ryel 1995; SWCA 1997), so life history will not be discussed in this document. For each fish species, historic distribution and background information are briefly summarized, followed by a review of past research in Grand Canyon. Results of current monitoring and research activities are presented along with relevant biological information to evaluate trends for each species.

Chapter 1: Development of Long-Term Monitoring in Grand Canyon

Development of Current Sampling Strategies

In 2000, as a result of recommendations by the Protocol Evaluation Panel, an attempt was made to interpret fisheries data collected since the late 1980s. It was discovered that limited inference could be drawn from electrofishing data because of spatial and temporal inconsistencies in collection of these data (Figures 1 and 2). It was also discovered that electrofishing techniques varied over many of the earlier years of electrofishing. Many of the electrofishing trips prior to 2000 were not standardized to sample the entire fish community but were instead designed to maximize catch rates of humpback chub (Personal communication Mike Yard).

The Arizona Game and Fish Department (AGFD), in cooperation with GCMRC, began a series of studies in 2000 to better understand electrofishing indices and to design a long-term electrofishing program for the Colorado River within Grand Canyon. The first two years of this study (2000 and 2001) were dedicated to evaluating rainbow trout and brown trout capture efficiency to enable us to interpret our index monitoring. We also attempted to standardize electrofishing techniques throughout the canyon to provide a consistent index of fish abundance (Speas 2003, 2004).

In 2002, we used the sample power program Sampling.exe (Walters, unpublished) to determine appropriate sample sizes and distribution of effort for rainbow trout, brown trout, and carp. Using variance estimates (coefficient of variation, CV) from existing Grand Canyon fisheries data (2000–2002), we used Sampling.exe to estimate sample precision of catch per unit effort (CPUE; fish per hour) as a function of sample size and spatial stratification. The program utilized a Monte Carlo procedure to estimate the probabilities of detecting a true temporal population trend given a range of sample sizes. We selected a design based on its projected level of sampling precision, CV = 0.10, whereby the power to detect a 21% decrease and 26% increase in CPUE was 0.80 over a five-year period (Gerrodette 1987). It was determined that approximately 800–900 samples were necessary to monitor the three species of interest (Rogers et al. 2003).

Sample duration of electrofishing varied over the span of this data set (1991–2007, Figure 3). In 2002, we reduced the effort per electrofishing sample from 600 to 300 seconds, based on analysis of rainbow and brown trout catch rate data from 2000 and 2001 (Speas 2003), in order to achieve 800 samples (Speas 2003). Although total effort of electrofishing in 2002 was far less than many years previous to 2002 (Figure 4), sample size and statistical power were greater than or equal to most previous years (Figure 5).

In 2002, we identified a need to be able to measure short-term change in specific reaches of the river for target fish species. In 2003, we increased effort near the Little Colorado River (LCR) specifically for rainbow trout and near Bright Angel Creek (BAC) for brown trout, where management actions were taking place. The increase in sample sizes in these reaches was based on bootstrapping of 2000–2002 data (Rogers el al. 2005).

In 2004, we reevaluated the program Sampling.exe and discovered inconsistencies in the spatial allocation of effort. The habitat available by reach in the program was inconsistent with the miles of shockable river. We recreated the sample allocation part of this program in Excel and redefined shoreline habitat by the number of river miles in each fish reach. We resampled 2000–2004 data over a range of sample sizes (n = 100–1,000) using Resampling Stats 2.0 for MS Excel. The number of samples resampled for each fish reach was proportional to the number of miles in each fish reach. We selected a design based on its projected level of sampling precision, CV = 0.10, whereby the power to detect a 21% decrease and 26% increase in CPUE was 0.80 over a five-year period (Gerrodette 1987). This analysis suggested that 800 samples were necessary to achieve a CV of 0.10 for all species of concern (Figure 6). Spatial allocation of these 800 samples amongst the 11 reaches was done with algorithms from Sampling.exe in which effort was weighted by length of each reach and CV of catch rates by species and reach. We utilized the bootstrapped confidence intervals to approximate minimum detectable yearly changes in salmonid densities for areas and species of special concern, i.e., rainbow trout at the LCR reach [River Mile (RM) 56–65, Figure 7] and brown trout at BAC reach (RM 84.5–90, Figure 8). The current monitoring design is similar to that done since 2002 and is based on the power analysis done in 2004.

Structure of Current Monitoring Program

The current monitoring program consists of two 18-day trips per year conducted in April and May with samples collected between RM 0 and RM 226. In 2007, only one trip was conducted in the spring, and the second trip took place in the fall (September–October) in an attempt to enhance our ability to detect warm-water, non-native species during a period when main channel water temperatures were higher than in the spring and winter. All data are collected at night with two 16′ Achilles inflatable sport boats outfitted for electrofishing with a Coeffelt CPS unit, with two netters and one driver per boat. On average these boats apply 350 volts and 15 amps to the spherical steel anode. Variance introduced by boat drivers and netters may be significant, so an experienced electrofishing boatman and netting crew are on each boat. Sampling is conducted for an average of five hours per night beginning at dusk. Sampling is not conducted when weather conditions such as high wind or rain make sampling unsafe or ineffective.

Each sample consists of a single, 300-s electrofishing pass along shoreline transects. The sample universe (RM 0–225) consists of 11 reaches (Table 1). Each reach is divided into fishable (i.e., where electrofishing is possible) sub-reaches, as defined by campsite availability and location of impassable navigational hazards such as rapids (Appendix 2). Fishable sub-reaches are randomly selected, with replacement, within each reach. The number of fishable sub-reaches sampled is determined by the number of samples needed within a given reach to achieve the desired statistical power. Start miles on river left and right are randomly generated within fishable sub-reaches, and shoreline transects are generally contiguous. Transect start and stop coordinates are recorded with a Garmin III GPS, and river miles are estimated from a Colorado River guide map (Stevens 1983).

All captured fish are handled according to standardized Grand Canyon fish handling protocol (Ward 2002). Maximum total length (MTL mm) is measured for each captured fish. All brown trout >150 mm MTL are implanted with a passive integrated transponder (PIT) tag (Prentice et al. 1990) and their adipose fins are clipped. The adipose clip is used as a secondary mark to evaluate tag loss. We recorded MTL, fork length, and weights (when environmental conditions were favorable) of native fish. We implanted native fish >150 mm MTL with PIT tags if none are found. All PIT tag numbers are recorded on data sheets and also stored electronically with all data entered and stored in an MS Access database.

Chapter 2: Status of Grand Canyon Fishes by Species

Nonnative Fish

Rainbow trout (*Oncorhynchus mykiss)*

Background and historic distribution

Rainbow trout were first introduced into Grand Canyon at Tapeats Creek (RM 134) in 1923 (Valdez and Ryel 1995) to increase sportfishing opportunities. After closure of Glen Canyon Dam in 1964, rainbow trout were stocked extensively at Lees Ferry with stocking continuing until 1998. Since 1998, natural reproduction has sustained the trout population at Lees Ferry and downstream. The Colorado River experienced a major shift in fish fauna after completion of Glen Canyon Dam. By 1980, the cold, clear water released from Glen Canyon Dam had transformed the Colorado River in Grand Canyon from a system dominated by warm water species such as channel catfish (*Ictalurus punctatus*) into a trout-dominated system. Rainbow trout are currently found from Glen Canyon Dam to below Spencer Creek (RM 245; Carothers and Minckley 1981, Valdez and Ryel 1995). Their abundance decreases from the upper to lower reaches of the river and is subject to seasonal shifts (Rogers et al. 2003). Rainbow trout were likely the most abundant fish in the mainstem Colorado River in Grand Canyon from 1991 until recent years when trout abundance has declined and sucker abundance has increased.

Tributaries such as Tapeats Creek, BAC, and Shinumo Creek were historically relied upon heavily by rainbow trout as spawning sites. Since the inception of higher minimum and more stable flows 1991, spawning has been documented in the main channel and is likely where most of the spawning occurs (Hoffnagel 1997). Trout fry are commonly collected from the main channel above Lees Ferry (McKinney et al. 1999) and have been collected downstream in Grand

Canyon in areas with no tributary influence (Maddux et al. 1987). Further research is needed to determine the extent of rainbow trout reproduction in the main channel below Lees Ferry.

History of research and monitoring

The current long-term monitoring program is designed to detect a yearly 6% linear river-wide change in rainbow trout over a 5-year period. River-wide monitoring efforts are insufficient to detect, short-term (less than 5-year) population trends. Since 2000, there has been a desire to detect yearly changes in the rainbow trout abundance in the LCR non-native fish removal reach for assessing impacts of trout on native fish, especially humpback chub (*Gila cypha*). In 2002, the number of samples in this reach was increased to allow assessment of short-term trends.

Status 1991–2007

Electrofishing data from 1991 to 2007 were divided by river mile into five distinct reaches to facilitate analysis (Table 2). Reach 1 of the Colorado River (RM 0–56) typically represents the highest CPUE within the study area (Figure 9). The CPUE from 2000 to 2004 averaged 100 fish/hr and was significantly greater than CPUE from the early 1990s when catch rates remained relatively stable around 40 fish/hour (Figure 2). Catch rates were dramatically reduced from 2003 to 2006. This trend is similar to that of rainbow trout in the Lees Ferry reach just upstream (Makinster et al. 2007).

In reach 2 (RM 57–77), there has been a significant decrease in rainbow trout CPUE over the last three years (Figure 9). This decrease corresponds with a large effort to remove predators, particularly salmonids, from the area around the confluence of the LCR. In 2004, rainbow trout

CPUE was 14.7 fish/hour, which is similar to catch rates reported in that area from the early 1990s.

In reach 3 (RM 80–98), rainbow trout CPUE has been less than 20 fish/hour for the past six years and is significantly lower than the 40–50 fish/hour measured from 1999 to 2001. The lower CPUE of rainbow trout in reach 3 may be caused by high densities of brown trout, which may compete with rainbow trout for limited food and space.

CPUE of rainbow trout in reach 4 (RM 110–160) has been similar to that of reach 3 for the past 6 years. Tapeats Creek lies within this reach and is the original stocking site of rainbow trout in Grand Canyon (Valdez and Ryel 1995). Tapeats Creek was believed to be a major spawning site for rainbow trout in the 90s.

In reach 5 (RM 161–230), rainbow trout CPUE has been less than two fish/hour for the past six years. The population of rainbow trout appears to have increased significantly between 1996 and 2001 and then declined in 2002. The higher water temperatures seen in the mainstem Colorado River since 2000 may be the reason for low CPUE of rainbow trout since 2002. Temperatures in reach 5 are near the lethal limit for rainbow trout, and any increase in temperature would be detrimental to rainbow trout survival in this area of the river.

Recent trends (2000–2007)

In general, trends for rainbow trout in Grand Canyon are similar to those at Lees Ferry. This suggests that the sampling strategies and effort used to sample rainbow trout prior to 2000 were likely sufficient to track rainbow trout trends accurately. Abundance of downstream rainbow trout is driven by the same principles as for trout in the Lees Ferry reach (Makinster et al. 2007). The inception of higher minimum and more stable flows in 1991 allowed rainbow trout abundance to increase throughout the river. Rainbow trout densities peaked in 2000 and 2001. In the most recent six years, densities have decreased significantly river-wide (Figure 10).

Length histograms for rainbow trout are characterized by a bimodal distribution with modes centered on age 1 fish and adults (Figure 11) for most years. The age 1 mode in 2006 is not present, suggesting that there was an unsuccessful spawn in 2005. There is evidence that this unsuccessful spawn was caused by low condition of rainbow trout in 2005 (Figure 12). Condition recovered in 2006, and the relative abundance of age 1 fish in 2007 suggests a strong spawn.

Non-native fish removal was carried out in 2003–2006 in a 10-mile reach bracketing the confluence of the LCR. Abundance indices from our long-term monitoring in this reach show a dramatic decrease in rainbow trout abundance in 2003, with CPUE decreasing each year to a level approaching zero in 2006 (Figure 13). There is evidence of increased abundance in 2007 similar to levels in 2005.

Brown trout (*Salmo trutta*)

Background and historic distribution

Brown trout were introduced into the Grand Canyon in Shinumo Creek (RM 108.5) in 1926 and later stocked into Garden Creek and BAC (RM 87.5), with the last reported stocking in 1934 (summarized in Valdez et al. 1988). Brown trout are currently found in very small numbers in all reaches from Glen Canyon Dam to Diamond Creek but are concentrated between the LCR (RM 61.5) and RM 150, especially near Bright Angel and Shinumo Creeks (RM 108.5) (Valdez and Ryel 1995).

Brown trout are more tolerant of high water temperature and lower water quality than rainbow trout (Valdez and Ryel 1995). Optimal growth and survival of brown trout occurs from 12 to 19°C with 15° C considered optimal (Raleigh et al. 1986). In the Grand Canyon, cold water temperatures appear to limit upstream brown trout distribution, with most fish found below the confluence of the LCR.

Spawning of brown trout in Grand Canyon typically occurs from November to early March with the initiation and duration of spawning correlated with water temperature and photoperiod. Brown trout migrate into tributaries to spawn and show a high degree of site fidelity (Raleigh et al. 1986). Brown trout are largely associated with tributaries and use Bright Angel, Shinumo, Phantom, and Kanab Creeks for spawning (summarized in Valdez et al. 1998). Recruitment of brown trout in the main channel may be controlled by reproduction and recruitment from these tributaries (Maddux et al. 1987).

Brown trout are more piscivorous than rainbow trout (Valdez and Ryel 1995) and feed primarily on invertebrates, fish, and fish eggs (Douglas and Marsh 1996). Piscivory of brown trout is implicated as a factor contributing to the decline of native fish. Douglas and Marsh (1996) found 20% of brown trout caught near the LCR to contain fish, including natives. The greatest threat to native fishes in Grand Canyon may be predation by brown trout, due to their large size, propensity to move, and high degree of piscivory (Valdez et al. 1998).

History of research and monitoring

Monitoring efforts prior to 2000 were likely insufficient to detect accurate population trends in brown trout throughout the Grand Canyon. Boot strapping suggest that effort similar to that since 2000 is necessary to detect long-term (yearly 6% linear change over a five-year period) trends.

Status 1991–2007

Mean CPUE of brown trout by reach is summarized in Figure 14. CPUE of brown trout in reach 1 and reach 2 was near zero from 1991 through 2000 and then increased to 1 to 2 fish/hour from 2000 to 2002. Cold mainstem water temperatures may have prevented brown trout from expanding extensively into areas upstream of the LCR prior to the water temperature warming as a result of the low summer steady flows in 2000.

In reach 3, brown trout CPUE is relatively high (8.2 to 99.7 fish/hour). This area typically represents the highest CPUE for brown trout in Grand Canyon. This reach contains BAC, which is believed to be a major spawning site for brown trout. There was no apparent change in abundance of brown trout from 1991 to 2004. There has been a reduction on abundance of brown trout in this reach in more recent years. It is possible that the weir and brown trout removal project in BAC in 2002, 2003, and 2006 may have had a detrimental affect on this species within this reach.

In reach 4 and reach 5, CPUE of brown trout was low from 1990 to 1997 and then increased, with dramatic increases seen in 2001 and 2002. Warmer water temperatures may have caused a change in brown trout distribution down stream of BAC and may be responsible for this increase in brown trout abundance.

The CPUE trends suggest that the distribution of brown trout changed from 1991to 2004. Brown trout have been very abundant in the area around BAC since monitoring began, but CPUE trends indicate the distribution of brown trout expanded both upstream and downstream from this area starting in 2000 and 2001 (Figure14).   Catch per unit effort of brown trout has been reduced significantly, river wide, since 2004.

Recent trends (2000–2007)

River-wide Brown trout CPUE decreased almost every year since 2000 (Figure 15). We witnessed an expansion in range by this species in 2000 and predicted that it would do well with warmer water. We had warmer water from 2000–2006, and over that span of time this species abundance has been greatly reduced. It is currently unknown why the abundance of this species has been reduced over recent years. Size structure analyses shows a large cohort of brown trout in 2000 (Figure 16), corresponding with the low summer steady flows. There is little evidence of reproduction after 2003. Brown trout catch indices were similar near BAC from 2000 to 2004 but decreased significantly in both 2005 and 2006 to a level near zero fish per hour (Figure 17).

Carp (*Cyprinus carpio)*

Background and historic distribution

Common carp (*Cyprinus carpio*) were stocked by the U.S. Fisheries Commission (currently U.S. Fish and Wildlife Service) as an effort to increase sport-fishing opportunities in the lower reaches of the Colorado River near Yuma, AZ around 1890 (Haden 1992). Carp have since spread throughout much of the mainstem Colorado River and are distributed from Lees Ferry to Separation Rapids ([RM 240; Carothers and Minckley 1981). Relative abundance of carp and channel catfish was highest among all Colorado River fishes in Glen, Marble, and Grand Canyons from 1955 to 1981 (Carothers and Minckley 1981). Most adult carp were believed to be migrants from Lake Mead or recruits from warm water tributaries in the early

1980s (Carothers and Minckley 1981). Many areas utilized by carp are also used by endangered native fish such as the humpback chub. Carp are omnivorous, opportunistic feeders, perhaps preying upon humpback chub larvae and eggs (Haden 1992).

History of research and monitoring

Common carp are currently ubiquitous in the mainstem Colorado River. Haden (1992) found that carp were the most abundant nonnative fish in the LCR during the humpback chub spawning season (April–May) in the late 1980s.

Carp are highly tolerant of turbidity as long as its food base remains relatively abundant (Edwards and Twomey 1982). Increased turbidity (> 200 nephelmetric turbidity units) caused by carp spawning and feeding in areas with silt and sand substrates may negatively impact local native fish (Edwards and Twomey 1982). Monitoring efforts prior to 2002 were insufficient to detect accurate yearly population trends in common carp. Bootstrapped data from 2000-2004 suggests that effort since 2002 is adequate for detecting long-term (5 year) trends. Although present in most of the Colorado River, catches of carp through electrofishing are relatively low compared to catches of other fish.

Status (1991–2007)

A summary of carp CPUE by year is listed in Figure18. In reach 1, CPUE of carp is below 1 fish/hr with high variance. A few fish are typically caught in backwater areas, but CPUE has remained relatively low since 1991. Mean CPUE from 1991 to 2001 was 0.23 fish/hour and did not differ significantly from the CPUE from 2002 to 2007. In 2000, 2001 and 2003 to 2005, there were no carp caught in this reach. The low catch is likely caused by lower water temperatures in the tailwater to Gen Canyon Dam. With warmer mainstem water temperatures because of drought conditions and low water levels in Lake Powell, we expected to see an increase in carp in these upstream reaches in most recent years. No evidence of an increase in abundance of carp in the tailwater exists to date.

Reach 2 is of special concern because it includes the confluence of the Colorado and Little Colorado Rivers (LCR). The LCR supports the largest self-sustaining population of the endangered humpback chub and serves as the main spawning site for this fish. Carp are believed to have a negative impact on the chub in the LCR. Carp often increase turbidity during feeding by rooting and plowing the bottom (Minckley 1973, Haden 1992) and are known to decimate entire egg and larval stocks (Haden 1992, Valdez and Ryel 1995). CPUE of carp in reach 2 has remained low and highly variable since 1991.

In reach 3, carp CPUE has remained between 1 and 4 fish/hour since 2000. This value is higher than the mean CPUE from 1991 to 1999. The increases in CPUE of carp since 2000 indicate possible increases in carp abundance within the reach. While an increase in carp abundance is probable, the differences may represent the increased and more focused effort to monitor carp in recent years. It is likely that from 1991 to 2001, CPUE underestimated carp abundance due to insufficient effort or a sampling bias.

In reach 4, carp CPUE is highly variable but may indicate a trend of increasing abundance from1996 to 2003 and then a decrease over most recent years to a level similar to that prior to 1996. A relatively high CPUE is expected because of warm tributaries such as Havasu Creek that enter the mainstem within this reach and have temperatures 18-26°C, which is near optimum for carp spawning and rearing (Carothers and Minckley 1981; SWCA 1997).

In reach 5, the same trends in carp CPUE are evident as are seen in reach 4. A high carp CPUE is expected in this reach where tributary temperatures (notably Diamond Creek) are optimal for carp spawning.

Recent trends (2000–2007)

The cold, hypolimnetic water released from Glen Canyon Dam appears to limit upriver carp movement. We have seen no evidence of carp movement from the lower reaches of the river upstream with recent warmer water temperatures. Passive Integrated Transponder tags (PIT tags) were inserted in carp from 2003 to 2006 but failed to reveal much movement data because of limited returns. Carp CPUE peaked in 2003 and we have witnessed a downward trend over most recent years (Figure 19) in spite of warmer main channel water temperatures. Length histograms show little evidence of recruitment in the main channel with the exception of 2007. This increase in young of the year carp in 2007 may be because of flooding in the LCR in prior to the sampling trip rather than an increase in main channel spawning.

Native Fish

Flannelmouth sucker (*Catostomus latipinnis*)

Background and historic distribution

Flannelmouth suckers are found from Glen Canyon Dam to the Lake Mead inflow at Grand Wash Cliffs (RM 276.0; Maddux et al. 1987; Valdez and Ryel 1995; Valdez et al. 1995) and have been documented in most tributaries (SWCA 1997), but the species is not found in Lake Mead. Tributaries and confluence areas have generally had higher densities of flannelmouth sucker than the mainstem, and the importance of tributaries for flannelmouth spawning has been documented by many researchers (Weiss 1998; Gorman 1994; Otis 1994; Valdez and Ryel 1995, Thieme 1997). Mainstem spawning has also been documented in the tailwaters of Glen Canyon Dam and in western Grand Canyon (AGFD 1996; McKinney et al. 1999). The canyon-wide distribution of flannelmouth suckers does not appear to have changed since completion of Glen Canyon Dam (McDonald and Dotson 1960), although Valdez and Ryel (1995) found declining abundance downstream of the LCR.

History of research and monitoring

In the 1970s, flannelmouth suckers appeared to be reproducing in many reaches of the mainstem and its tributaries in Grand Canyon (Minckley and Blinn 1976; Carothers and Minckley 1981). Fish of all size classes were collected, and the species was considered common or abundant in nine separate surveys from 1957 to 1987. In 1990–1993, flannelmouth suckers were common in the mainstem from Lees Ferry to Diamond Creek, but with declining abundance downstream and evidence of poor recruitment (Valdez and Ryel 1995). Highest catch rates were near the LCR and the Paria River inflows, indicating that these seasonally warmed tributaries were principal spawning and nursery areas, but survival of young fish descending from the warm tributaries into the cold mainstem was low.

The canyon-wide population of flannelmouth sucker has never been formally estimated but is considered to be relatively stable (SWCA 1997). In surveys conducted in 1991–1994, Hoffnagle (1997) found flannelmouth suckers throughout the Colorado River between Lees Ferry and Diamond Creek; 35% were caught in the reach between the LCR and BAC, and 48% were caught in the reach from National Canyon to Diamond Creek (RM 166.5–RM 226.0). Most of the larval and juvenile flannelmouth suckers were captured in mainstem backwaters, particularly below National Canyon, but very few were found in tributaries or tributary inflows. None were captured in the mainstem above RM 44.0.

Simultaneous studies in the major tributaries, including the LCR (AGFD 1994, 1995), Paria River (Weiss 1998), BAC, Kanab Creek (Otis 1994), and Shinumo Creek (Haden 1992), seemed to support the hypothesis of poor reproductive success by flannelmouth suckers. Large numbers of adult flannelmouth suckers ascended these tributaries in spring, but little or no evidence of successful reproduction was observed.

Douglas and Marsh (1996a) estimated a range of 502–7,886 large subadults and adults in the LCR during 1991–1994, indicating movements of large numbers of spawning fish from the mainstem into that tributary. Robinson et al. (1996) found moderate densities of young flannelmouth suckers drifting in the LCR, but length-frequency analysis indicated low survival. Between 1993 and 1995, abundance of flannelmouth suckers increased between National Canyon and Diamond Creek; catches in trammel nets increased from 2–3 fish/net during 1990–1993 (Valdez and Ryel 1995) to 6–15 fish/net in 1995 (Leibfried and Zimmerman 1996). Average size of flannelmouth suckers caught in 1995 was 334 mm TL. The estimated age of 4–5 years for these fish corresponds to the implementation of interim flows and greater longitudinal warming that produced water temperatures of up to 18.0 C in lower Grand Canyon. Leibfried and Zimmerman (1996) also captured 335 flannelmouth suckers in 1995 between National Canyon and Diamond Creek, including 141 juveniles and 81 young of year (YOY), indicating that greater longitudinal warming had also increased survival of young. The possible beneficial effect of lower flow fluctuations was also seen farther downstream with the capture of post-larval flannelmouth suckers from mainstem cobble riffles near Spencer Creek (RM 246.0; Valdez et al. 1995) and Surprise Creek (RM 248.3; Leibfried and Zimmerman 1996).

Status (1991–2007)

In reach 1, CPUE of flannelmouth suckers has remained low at less than 3 fish/hour (Figure 21). It is likely that cold water temperatures preclude spawning and survival of young flannelmouth suckers in this area (Rogers 2003). Adult fish are caught in low numbers in this reach.

In reach 2, there has been no measurable change in CPUE of flannelmouth suckers since 1991 until 2005 and 2006 when catch rates increased. Variance in catch was relatively high. The confluence of the LCR is in reach 2, which may account for the high variance in catch rate as flannelmouth suckers often aggregate near the confluence of the LCR.

In reach 3, CPUE of flannelmouth suckers has remained low at less than 3 fish/hour, although catch rates in 2006 and 2007 were higher than most previous years.

In reach 4, there does appear to be an increase in flannelmouth sucker CPUE after 2003, although increases are not statistically significant until the dramatic increase in 2006.

Reach 5 shows a strong increasing trend in CPUE of flannelmouth suckers since 2001. This increase is likely due to warmer mainstem water temperature that has resulted from drought conditions and low water levels in Lake Powell.

Recent trends (2000–2007)

Hoopnetting and trammel netting in the mainstem Colorado River are the sampling methods that were used prior to 2000 for index monitoring of flannelmouth suckers. Since 2002, data from electrofishing indicates that flannelmouth sucker population trends throughout the mainstem Colorado River are best monitored using electrofishing. Warmer mainstem water temperatures, beginning with the low summer steady flows in 2000 and continuing in the following years as the result of drought, appear to have caused large population increases in flannelmouth suckers in the lower river. Large numbers of juvenile fish were detected in reaches 4 and5 in 2006. As these fish reach length at maturity, we expect to see them move upstream and be caught throughout Grand Canyon. There has been an upward trend canyon-wide for flannelmouth sucker catch indices since 2003 (Figure 22). Catch rates in 2006 were dramatically higher than any previous years for this species, and the decrease in 2007 may be because of high turbidity and corresponding lower capture probabilities. Length histograms reveal relatively low recruitment prior to 2002 and 2003, and data from 2006 show at least three strong cohorts (2003–2005; Figure 23).

Bluehead sucker (Catostomus discobolus)

Background and Historic distribution

Bluehead suckers are found from Glen Canyon Dam to the Lake Mead inflow at Grand Wash Cliffs (Maddux et al. 1987; Valdez and Ryel 1995; Valdez et al. 1995) and have been documented in most tributaries (SWCA 1997).

History of research and monitoring

In the 1970s, bluehead suckers appeared to be reproducing in many of the Colorado River's tributaries in Grand Canyon (Minckley and Blinn 1976; Carothers and Minckley 1981). This species was considered primarily a tributary fish until recent years, and main channel monitoring has not focused on this species until recently.

Status (1991–2007)

No bluehead suckers have been captured by electrofishing in reach 1 from 1991 to 2007. Few blueheads were captured in reach 2 until 2006 and 2007 (Figure 24). Reach 2 includes the LCR, where bluehead suckers are known to spawn. Few blueheads were captured in reach 3. There was a dramatic increase in CPUE of blueheads in reach 4 in 2005. Reach 4 includes Havasu and Kanab Creeks, where blueheads are known to spawn. Catch rates showed a significant increase for blueheads in reach 5 in 2006. The decreases in catch rates in reach 4 and 5 in 2007 for blueheads are likely because of reduced capture probabilities caused by high turbidity in that year.

Recent trends (2000–2007)

Bluehead sucker catch rates have increased since 2002 (Figure 25). This increase has occurred primarily in reaches with known spawning aggregations of this species. Length histograms show little evidence of recruitment in the main channel of the Colorado River prior to 2005. It is likely that warmer mainstem water temperature caused by the drought have increased mainstem survival for this species over recent years.

Summary

The current monitoring program was designed to be able to detect population level changes in target species over a five-year time scale. Localized questions or questions on a time scale shorter than five years require additional, separate effort beyond that outlined for long-term monitoring. We have increased effort near the LCR and BAC to better enable us to measure the relative densities of rainbow and brown trout, respectively, in these areas. It is critical that monitoring programs remain constant over time. If monitoring designs are compromised to answer short-term questions, the effectiveness of the monitoring program may be lost. Consistent, long-term monitoring will be essential to the success of the adaptive management program by allowing the effects of management actions to be measured.

Temporal variance in electrofishing CPUE is poorly understood in the Grand Canyon for all species. For this reason, we are hesitant to combine spring and fall sampling to compare with previous years' data that were collected only in the spring. Only data from the spring of 2007 were compared to previous years in this report. We have reduced the number of days spent electrofishing in the fall to afford spring sampling. This comes with a potential cost to long-term monitoring. In order to maintain statistical power, we have increased the number of samples taken per night, but since we no longer sample for 38 days, our spatial coverage is reduced from previous years. This concentration of effort in fewer locations may act to artificially reduce variance by eliminating some of the spatial variance inherent in previous years.

The current monitoring program appears to be working well for the three primary non-native species (rainbow trout, brown trout, common carp) and is likely sufficient for the native species flannelmouth sucker and bluehead sucker. Non-native species including the warmwater non-native common carp have seen significant decreases in abundance over recent years while flannelmouth sucker and bluehead suckers have increased in abundance. It is likely that the reduction in rainbow trout over recent years was driven by resource limitations and was density driven. Food may the limiting resource. With high densities of trout and limited food, the increase in water temperatures over recent years and corresponding increased basal metabolism of rainbow and brown trout may have effectively reduced the carrying capacity for these species. It is also possible that the weir and brown trout removal project in BAC in 2002, 2003, and 2006 may have had a detrimental affect on this species river wide. It is uncertain how important this tributary is to the main channel population of brown trout. We expected to see an increase in carp over the most recent years with warmer water temperatures but have seen evidence to the contrary. The dramatic increase in the native suckers (bluehead and flannelmouth) is likely the result of warmer water temperatures combined with reduced competition from the non-native species.

Acknowledgements

Grand Canyon Monitoring and Research Center funded this study under cooperative Agreement No. 04WRA0016 and provided essential logistical support. We thank Dr. Carl Walters for his help in development of the long-term monitoring program. We also thank the many talented boatmen and volunteers who have assisted in collecting these data.

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Tables

Table 1. Fish reaches and associated river miles used for power analysis and development of long-term monitoring design.

Fish reach	Start river mile	End river mile
1	0	29.1
2	29.2	56
3	56	68.6
4	68.7	76.7
5	78.8	108.5
6	108.6	129
7	130.5	166.6
8	166.7	179.5
9	179.8	200
10	200.1	220
11	220.1	236

Table 2. Fish reaches and associated river miles used for analysis of abundance indices (catch per hour of electrofishing) in this report (Colorado River, 1991-2007).

Reach	Start RM	End RM
1	0	56
2	56	77
3	80	98
4	110	160
5	160	230

Figures

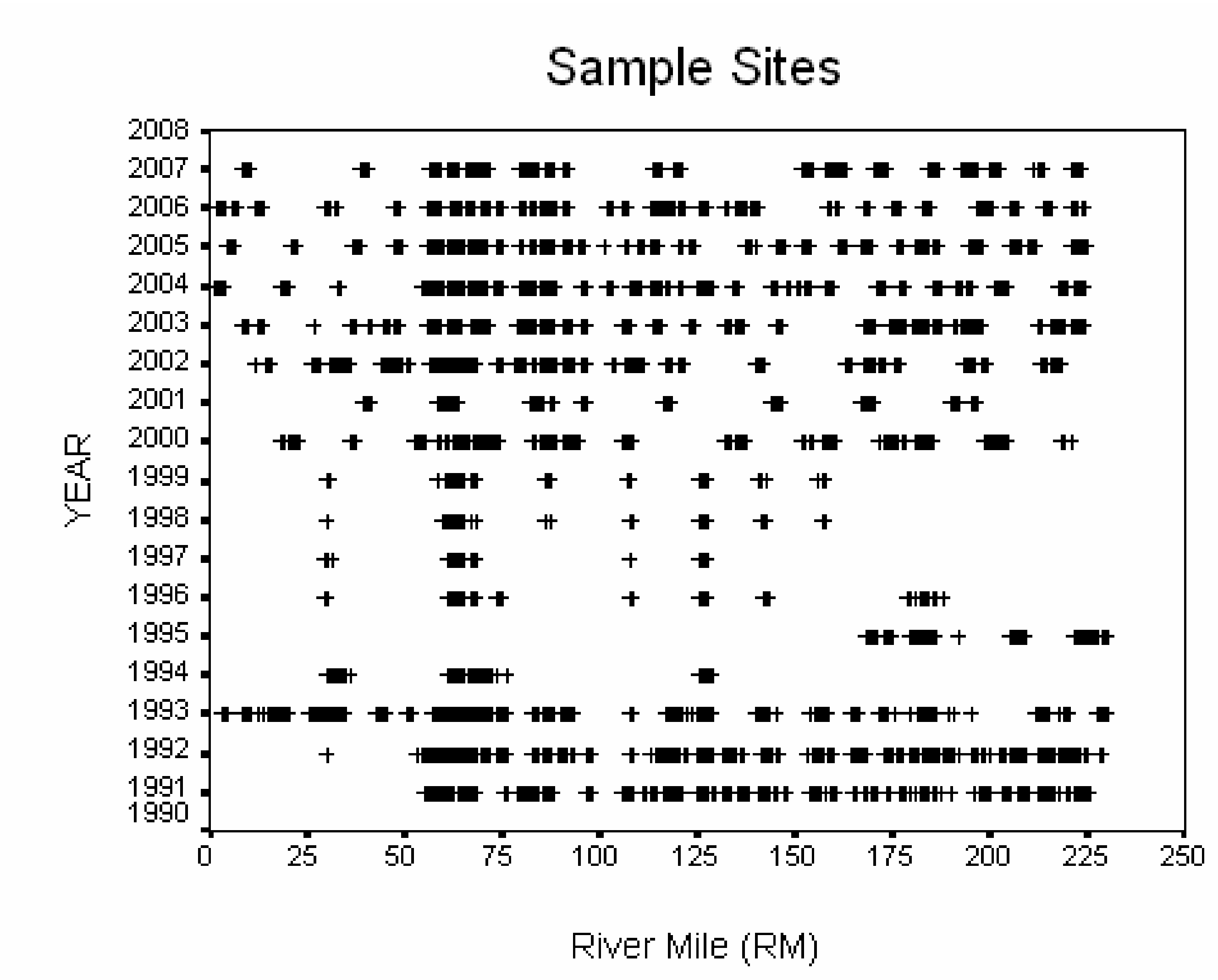

Figure 1. Spatial distribution of electrofishing data by year used in this report, Colorado River (RM 0 to 225, 1991–2007).

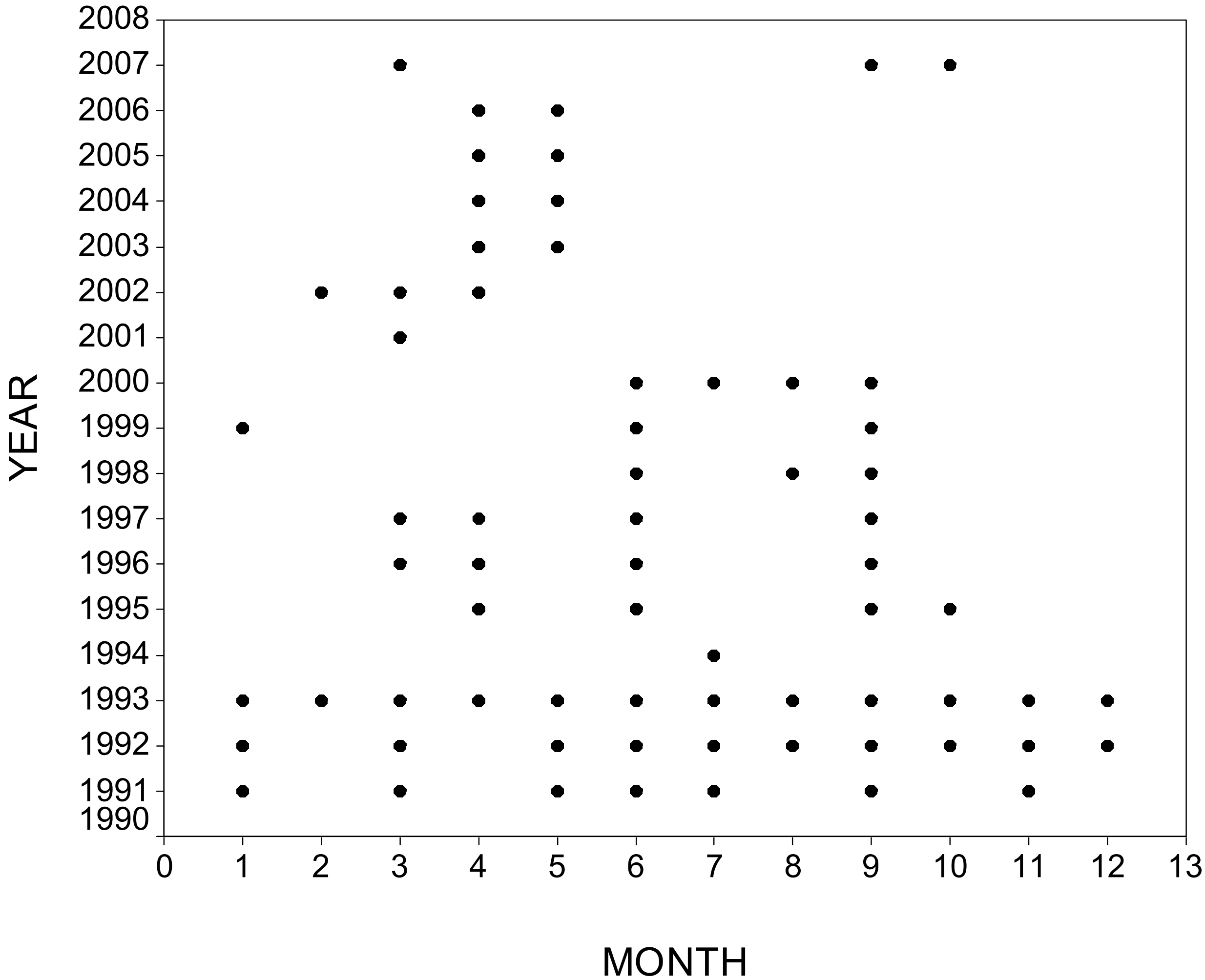

Figure 2. Monthly distribution of electrofishing sampling trips by year on the Colorado River (RM 0 to 225, 1991–2007).

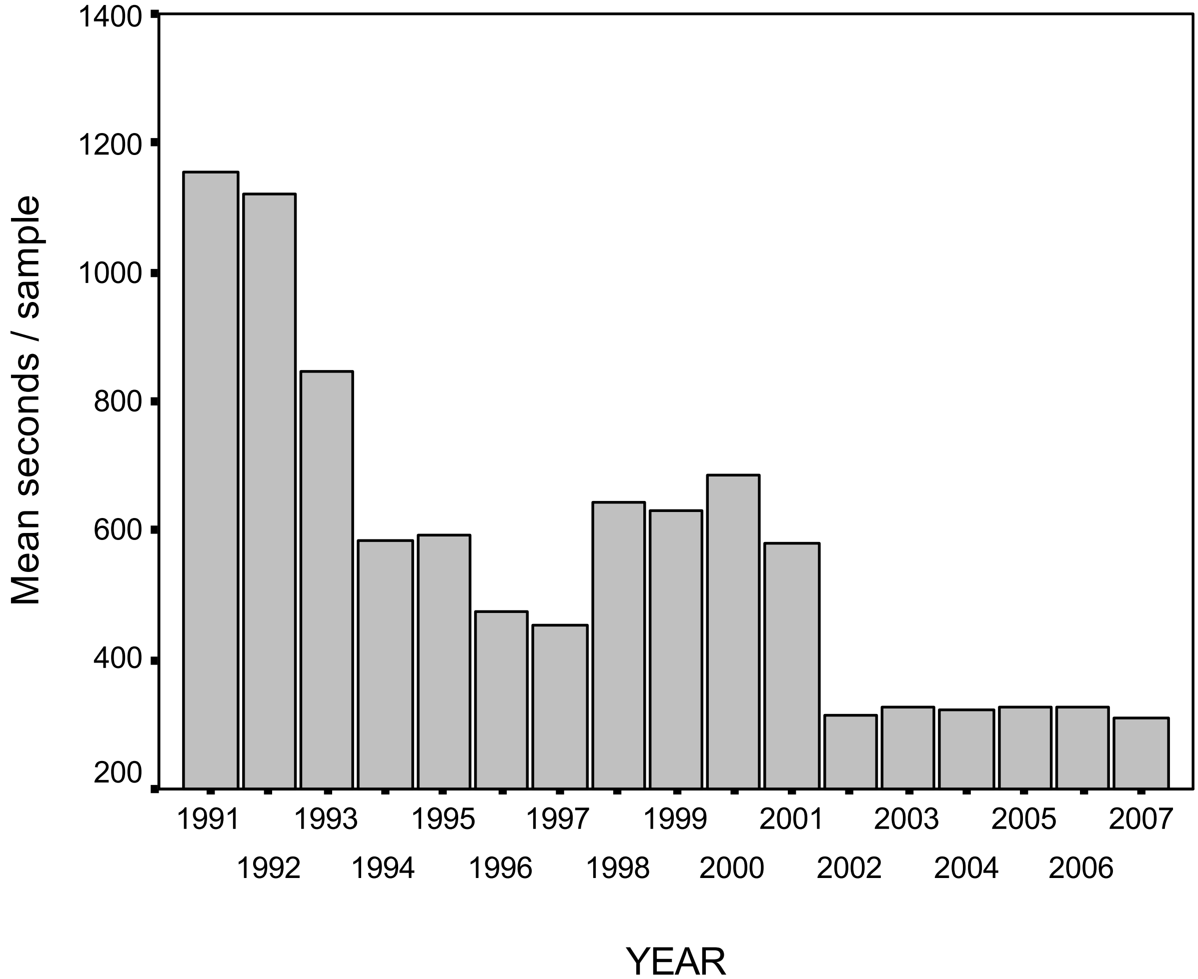

Figure3. Mean effort (seconds) per sample of electrofishing on the Colorado River (RM 0 to 225, 2000–2007).

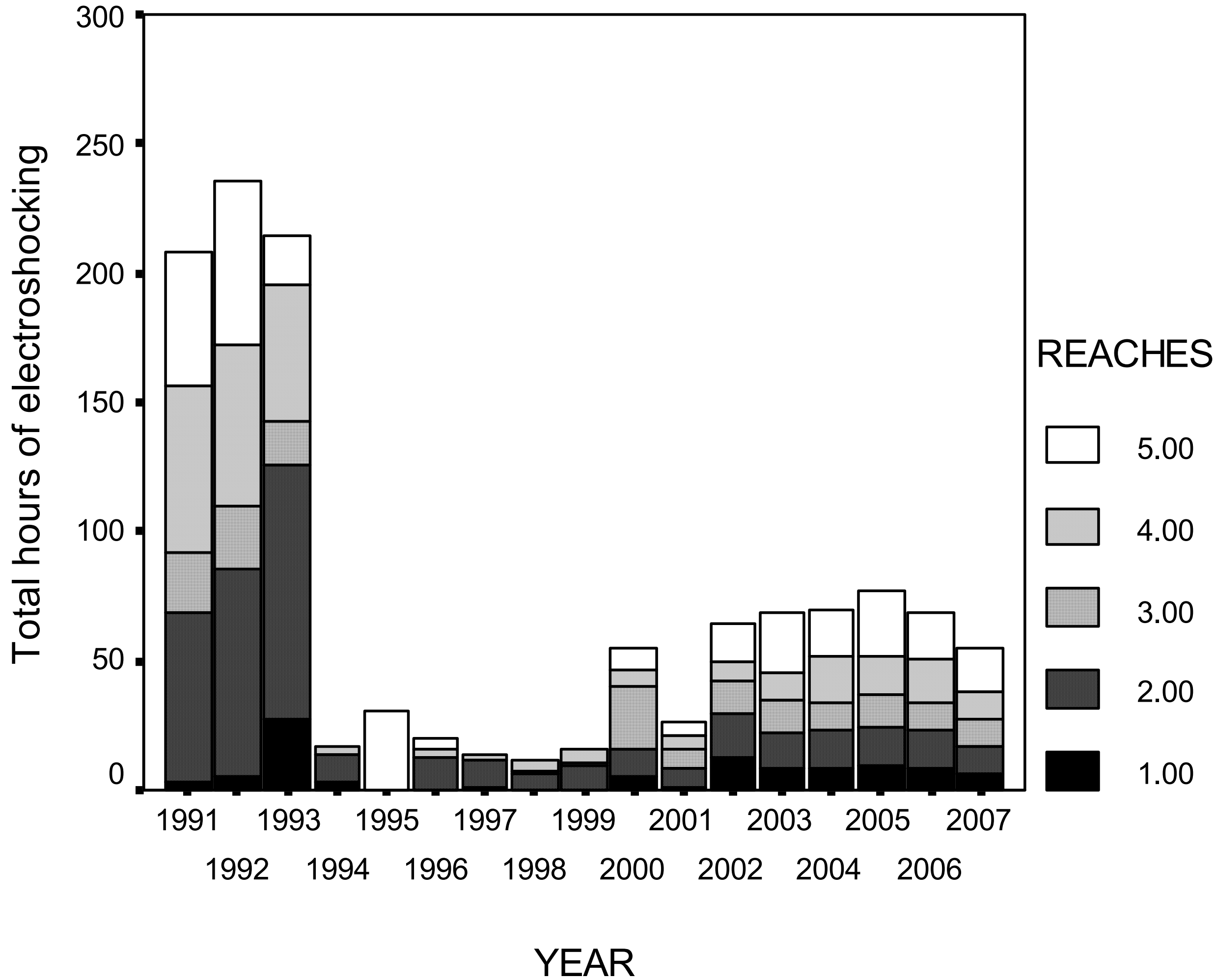

Figure 4. Total hours of electrofishing by year and reach on the Colorado River (RM 0 to 225, 2000–2007).

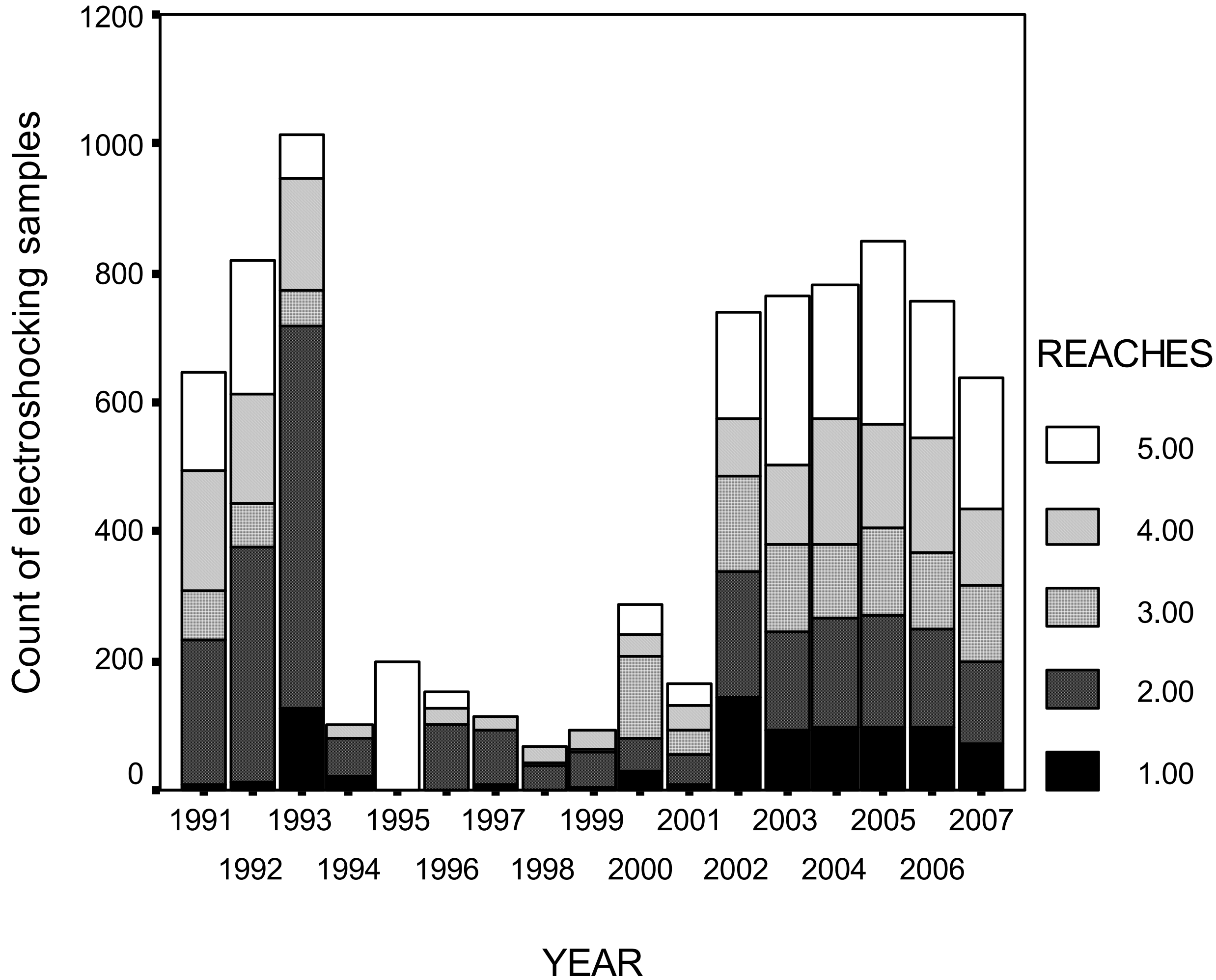

Figure 5. Count of electrofishing samples by year and reach on the Colorado River (RM 0 to 225, 2000–2007).

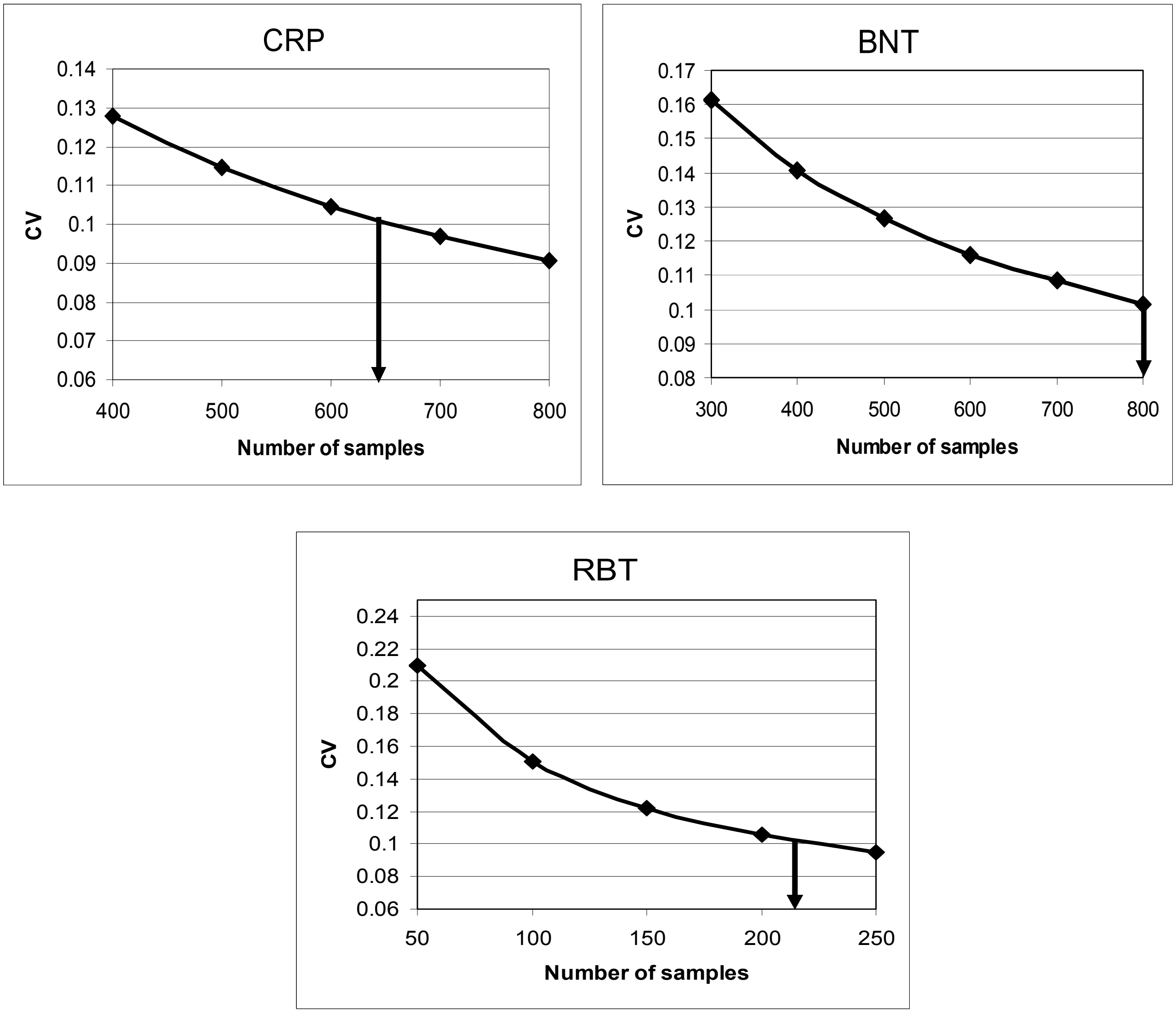

Figure 6. Bootstrapped coefficient of variance (CV) of electrofishing catch rates for common carp (CRP) brown trout (BNT) and rainbow trout (RBT) captured in the Colorado River (RM 0 to 225, 2000–2004).

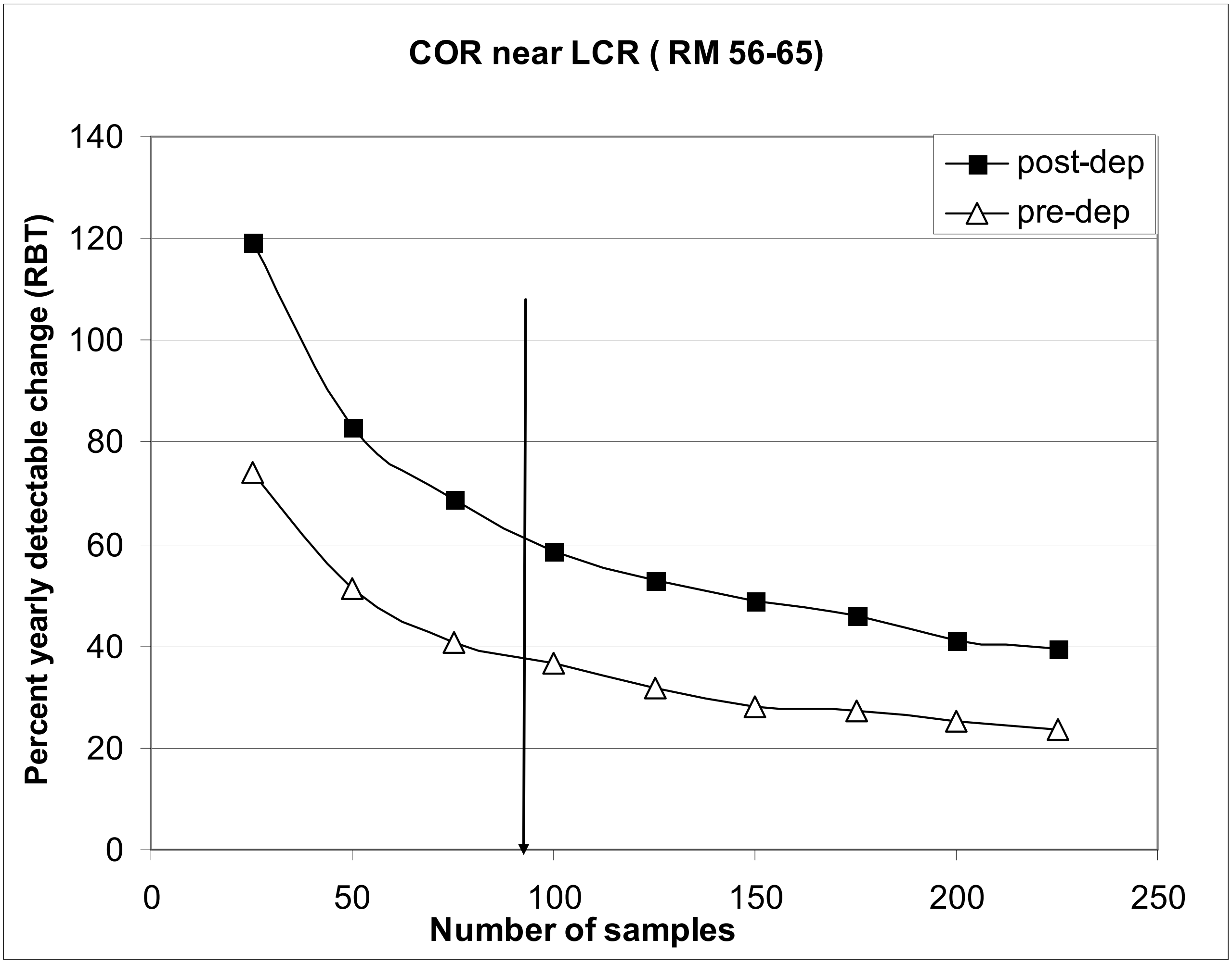

Figure 7. Percent detectable yearly change in rainbow trout in the Little Colorado River (LCR) depletion reach based on bootstrapped data from 2000 - 2002 (pre-depletion) and 2004 (post-depletion) (Colorado River [COR], RM 56 to 65).

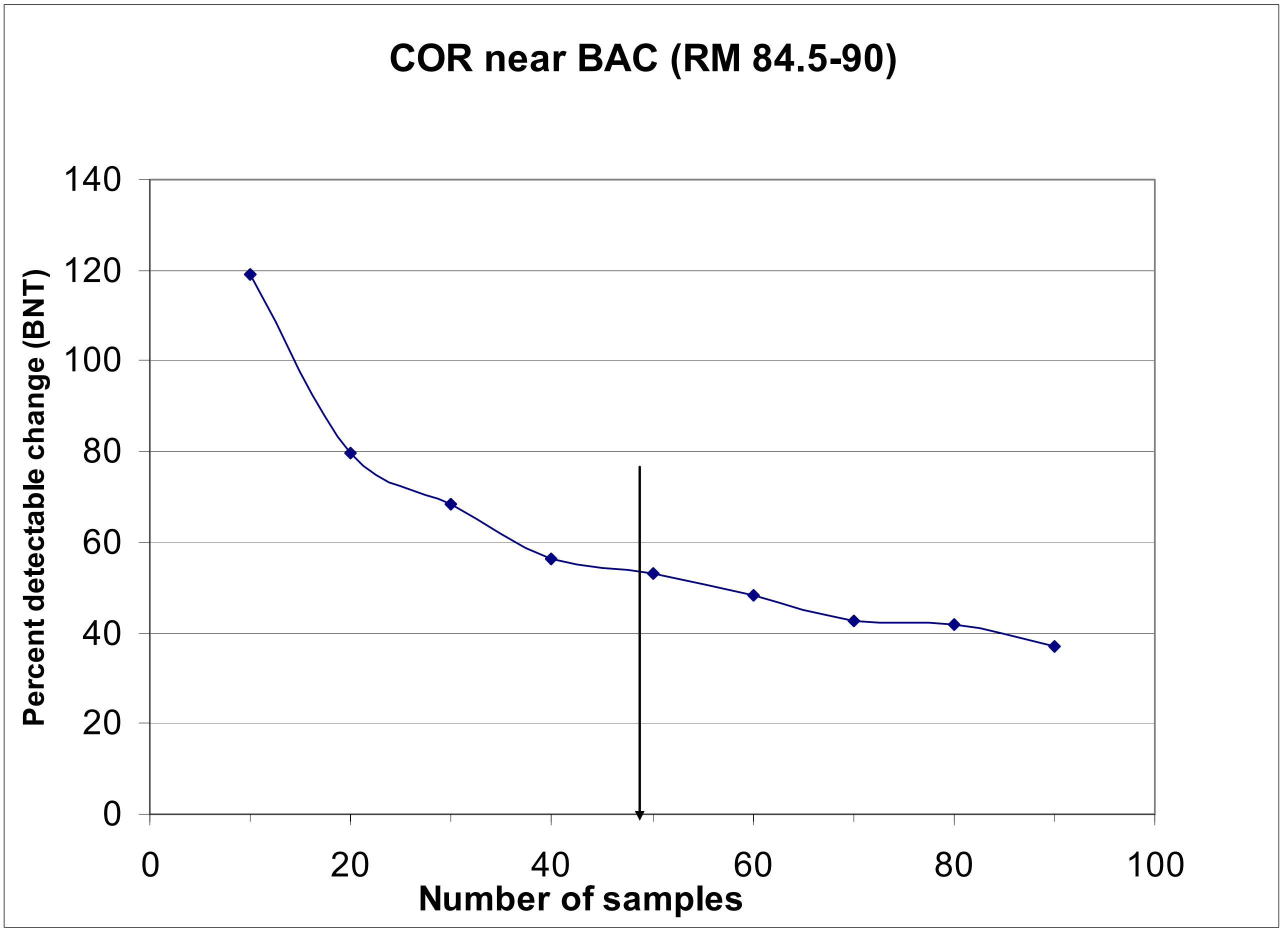

Figure 8. Percent detectable yearly change in brown trout (BNT) near Bright Angel Creek 2000 - 2004 (Colorado River [COR], RM 84.5 to 90).

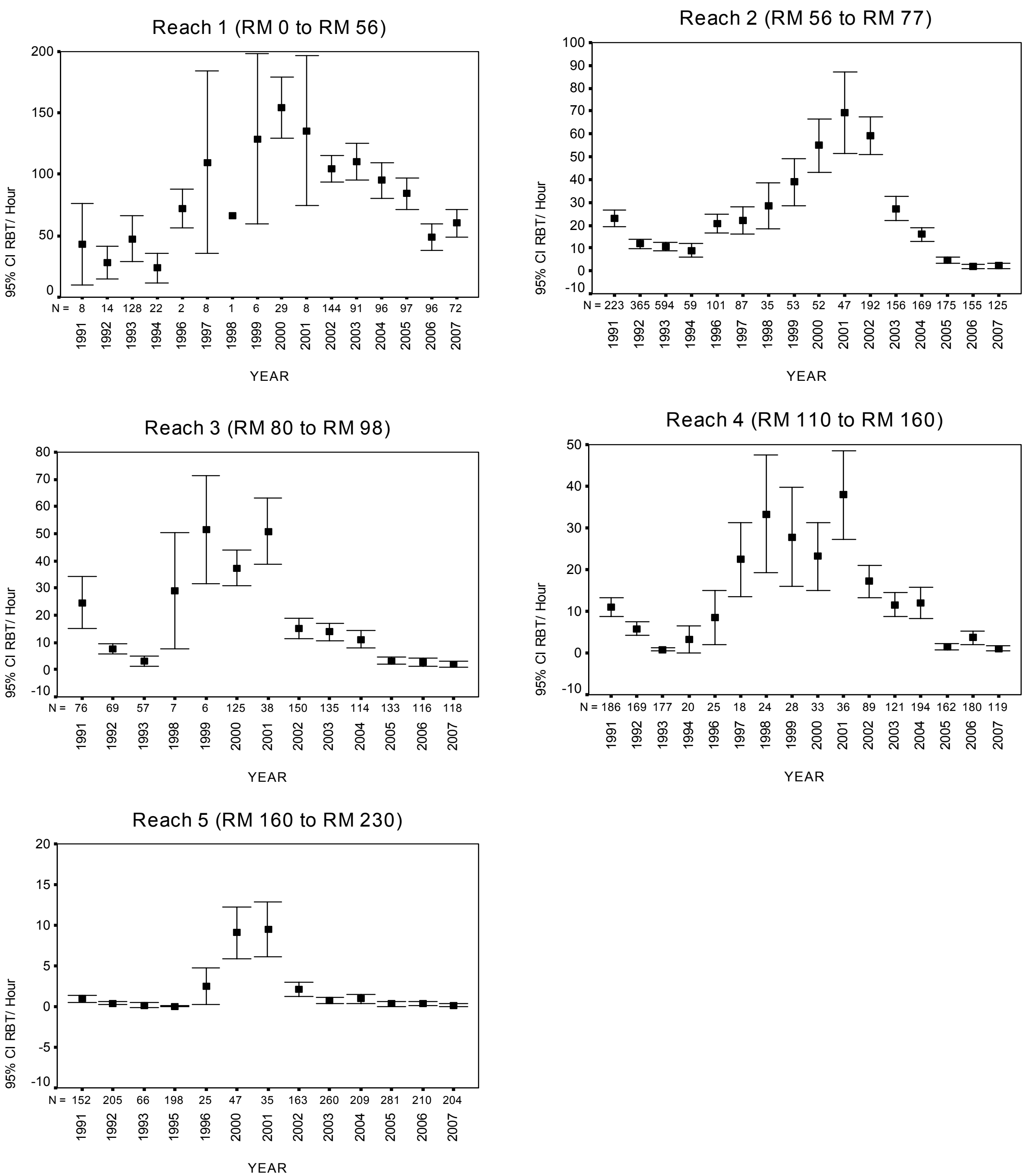

Figure 9. Rainbow trout (RBT) catch per unit effort (RBT / Hour) and number of samples taken, reaches 1-5, Colorado River (1991-2007).

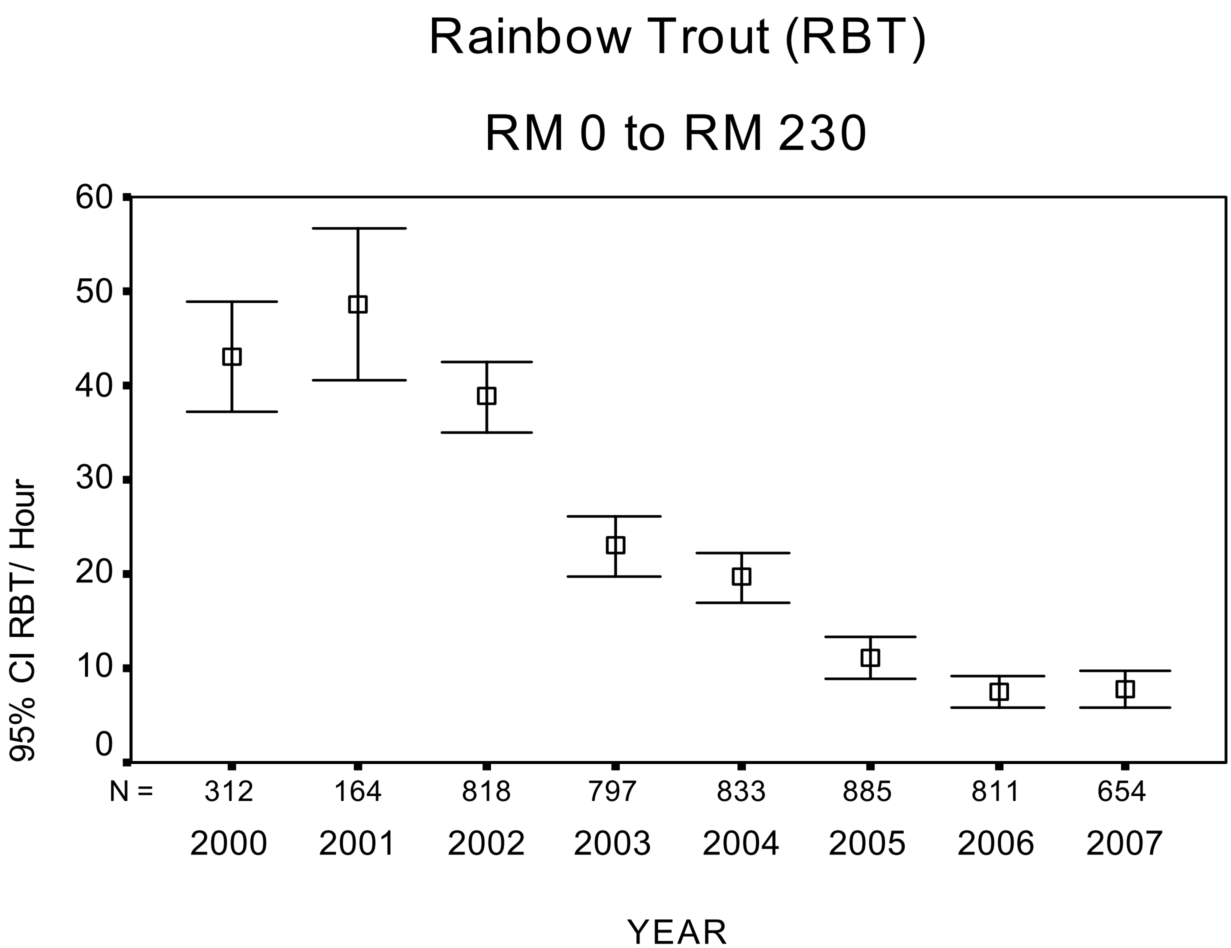

Figure 10. Rainbow trout (RBT) catch per unit effort (RBT / Hour) and number of samples taken, Colorado River (RM 0 to 230, 2000-2007).

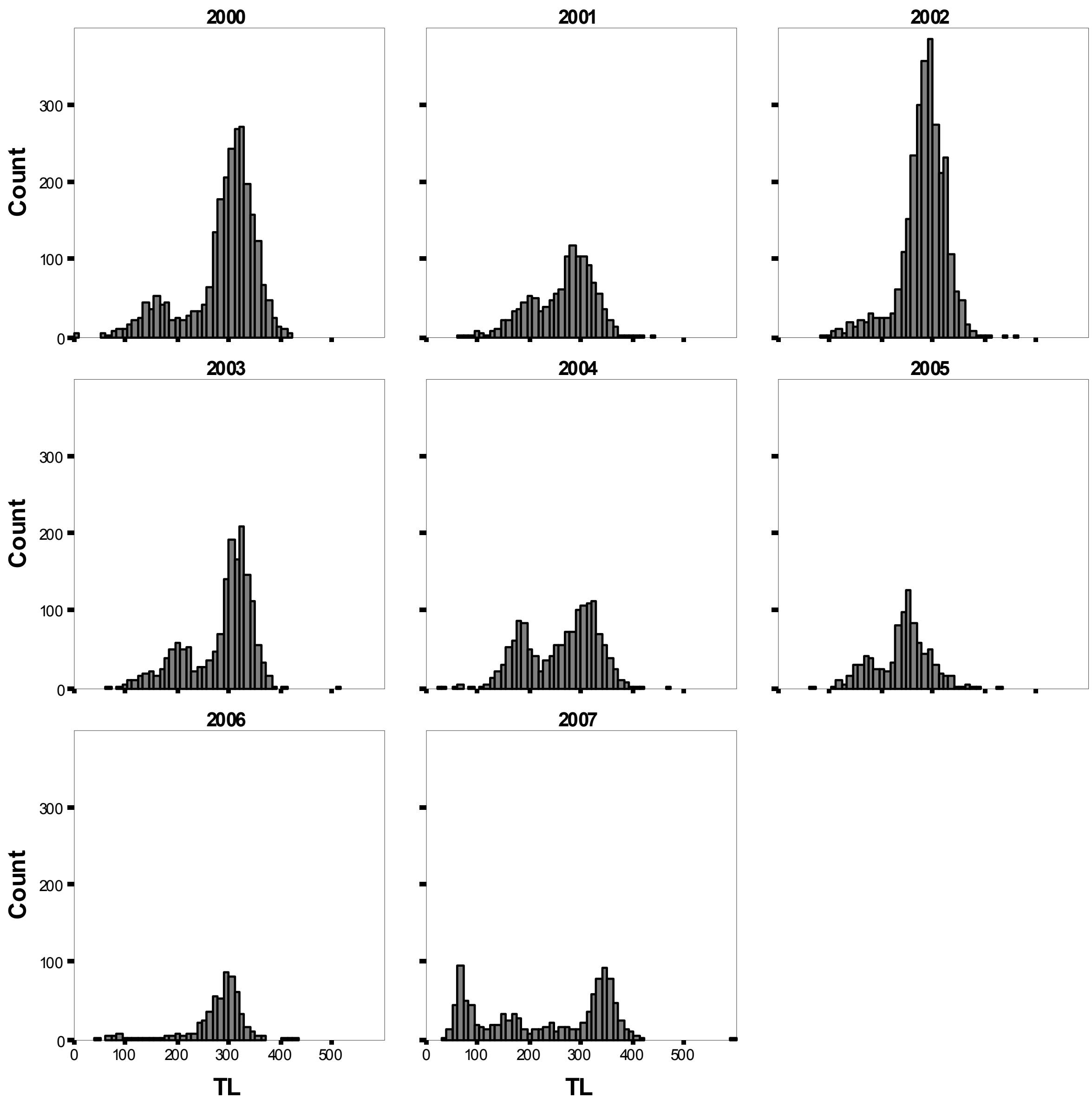

Figure 11. Length histograms for rainbow trout, by year (2000 to 2007), sampled by electrofishing on the Colorado River (RM 0 to 225, 2000-2007).

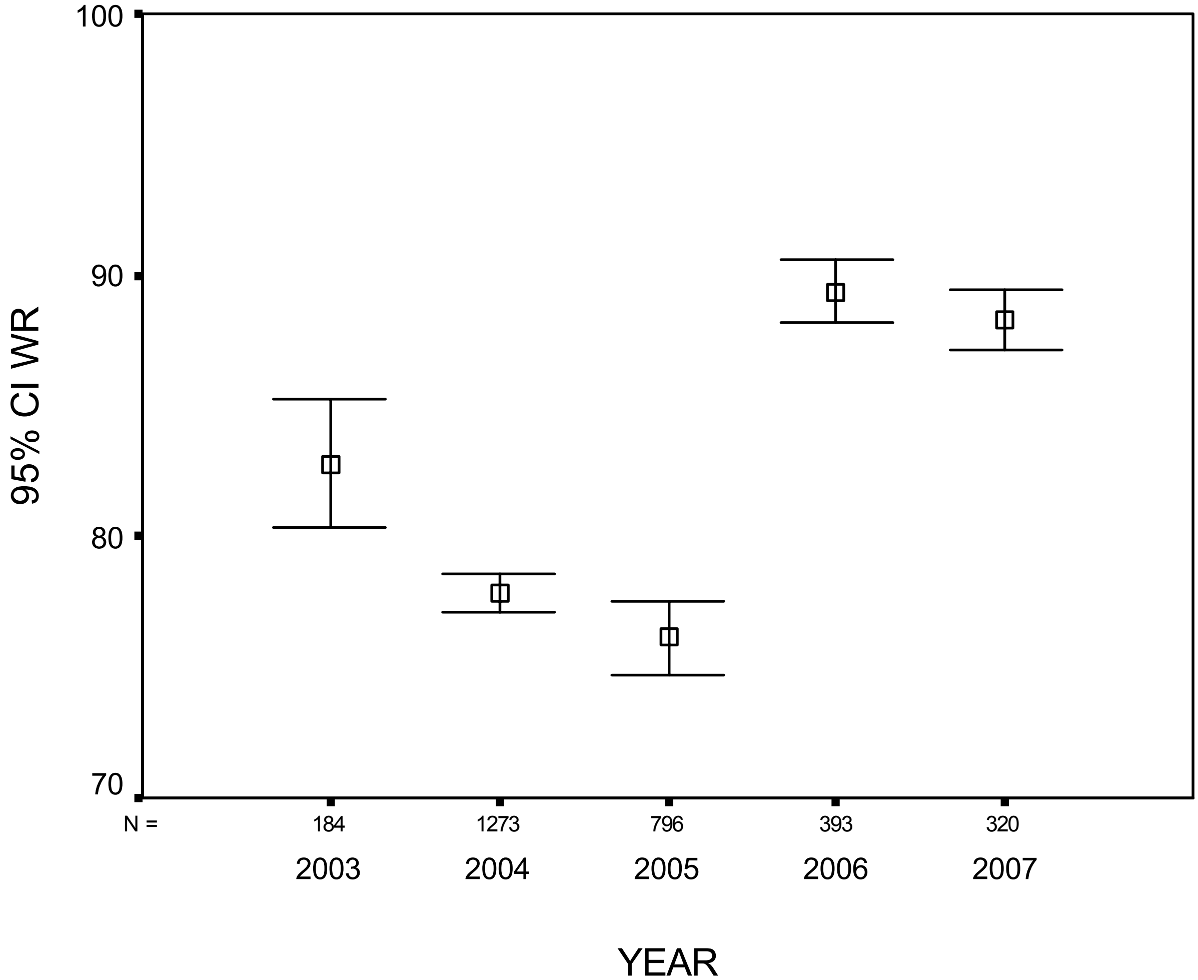

Figure 12. Relative weight (WR) for rainbow trout greater than 150 mm total length captured by electrofishing on the Colorado River (RM 0 to 225, 2003-2007).

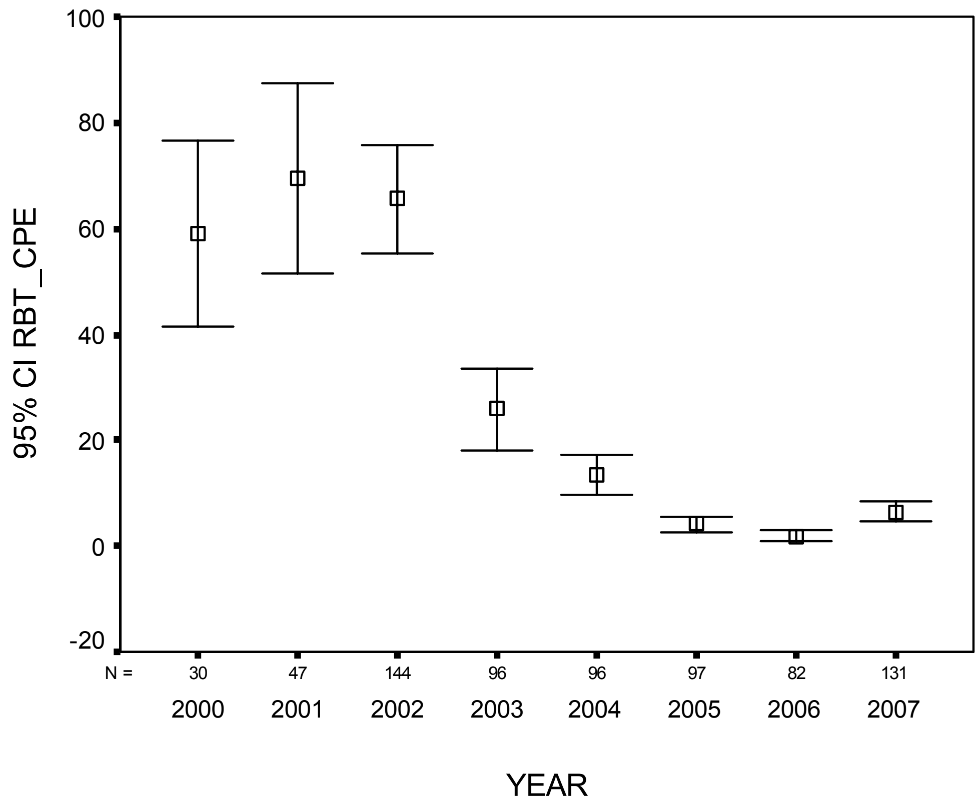

Figure 13. Rainbow trout (RBT) catch per unit effort (RBT / Hour) and number of samples taken, in the Colorado River LCR depletion reach (RM 56 to 65, 2000-2007).

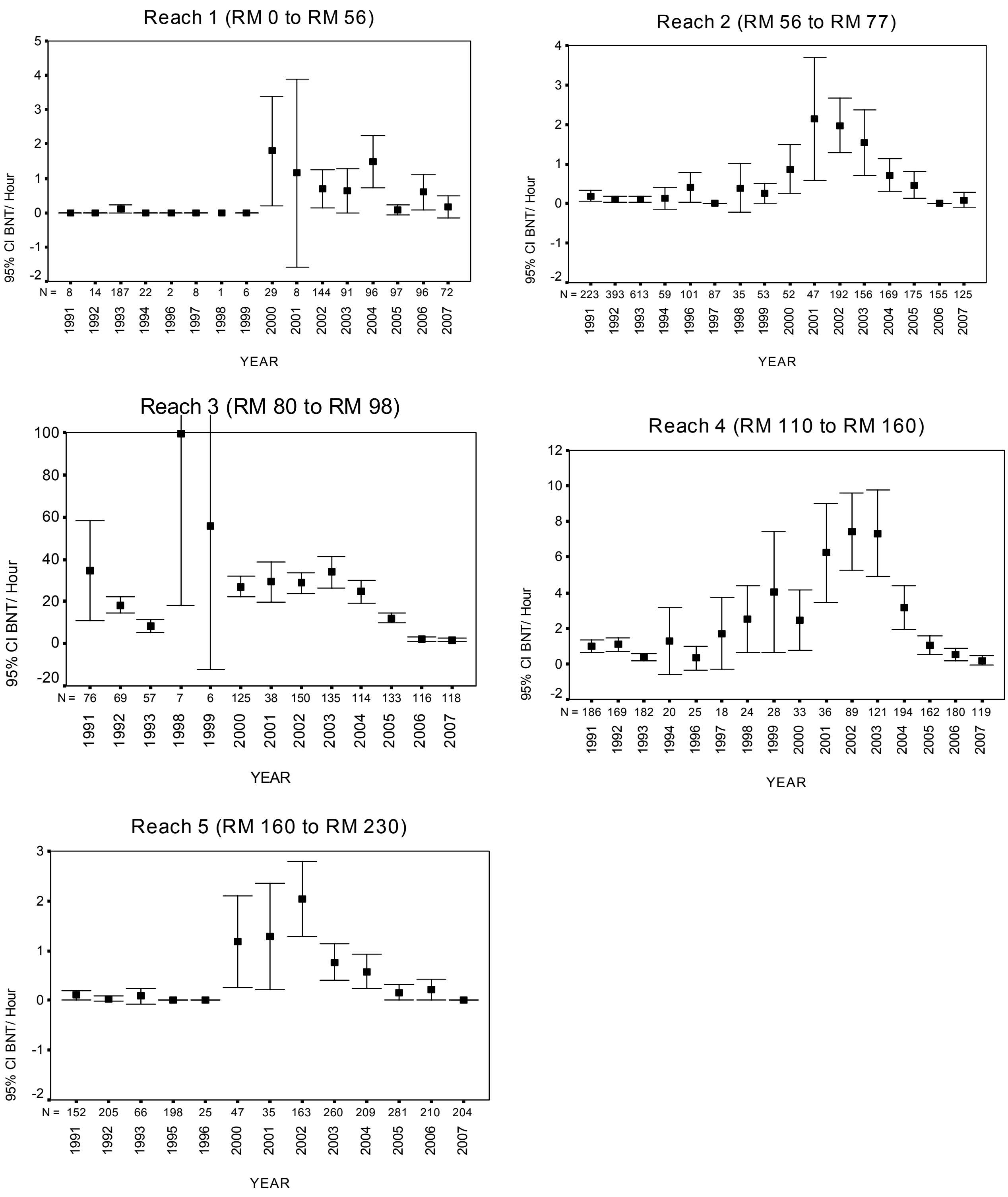

Figure 14. Brown trout (BNT) catch per unit effort (BNT / Hour) and number of samples taken, reaches 1-5, Colorado River (1991-2007).

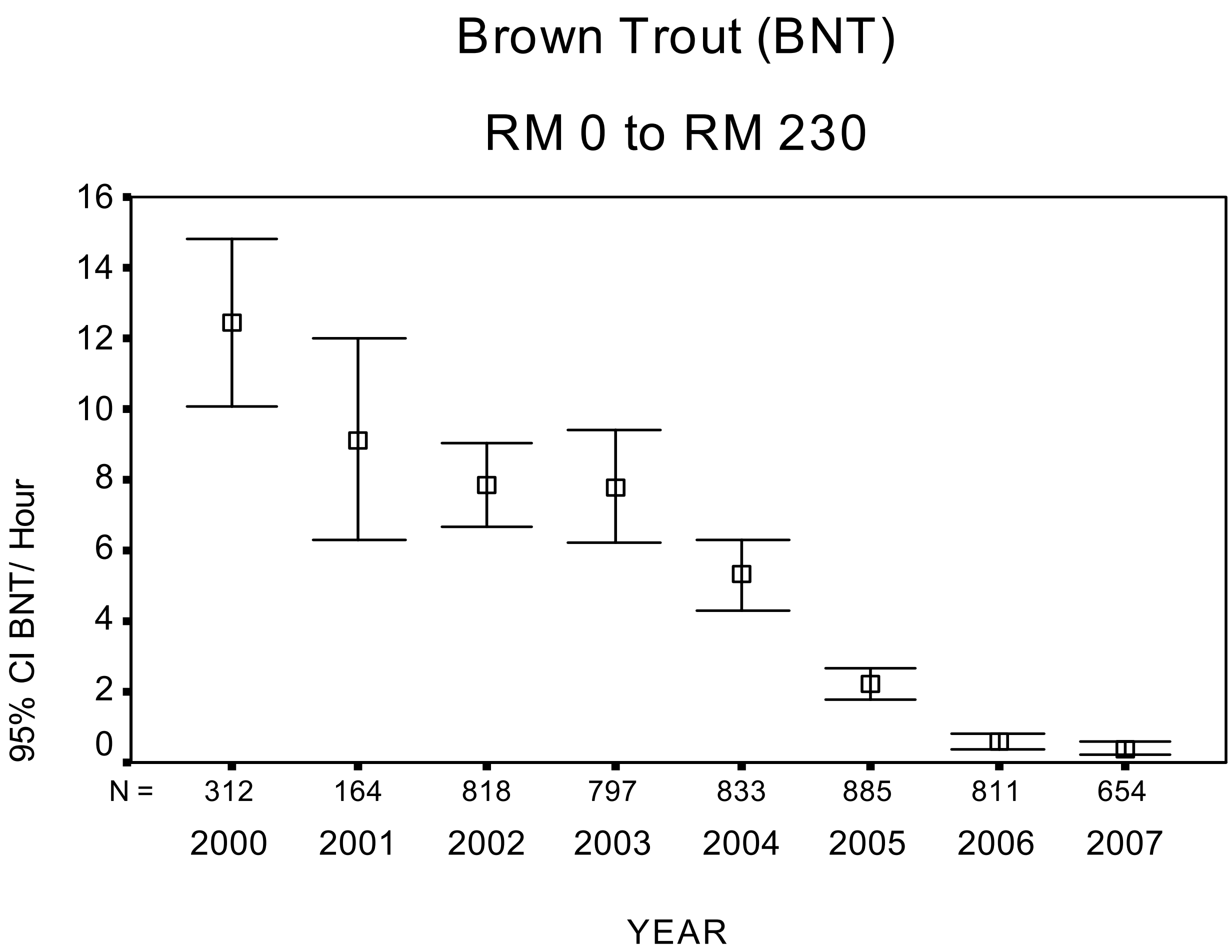

Figure 15. Brown trout (BNT) catch per unit effort (BNT / Hour) and number of samples taken, Colorado River (RM 0 to 230, 2000-2007).

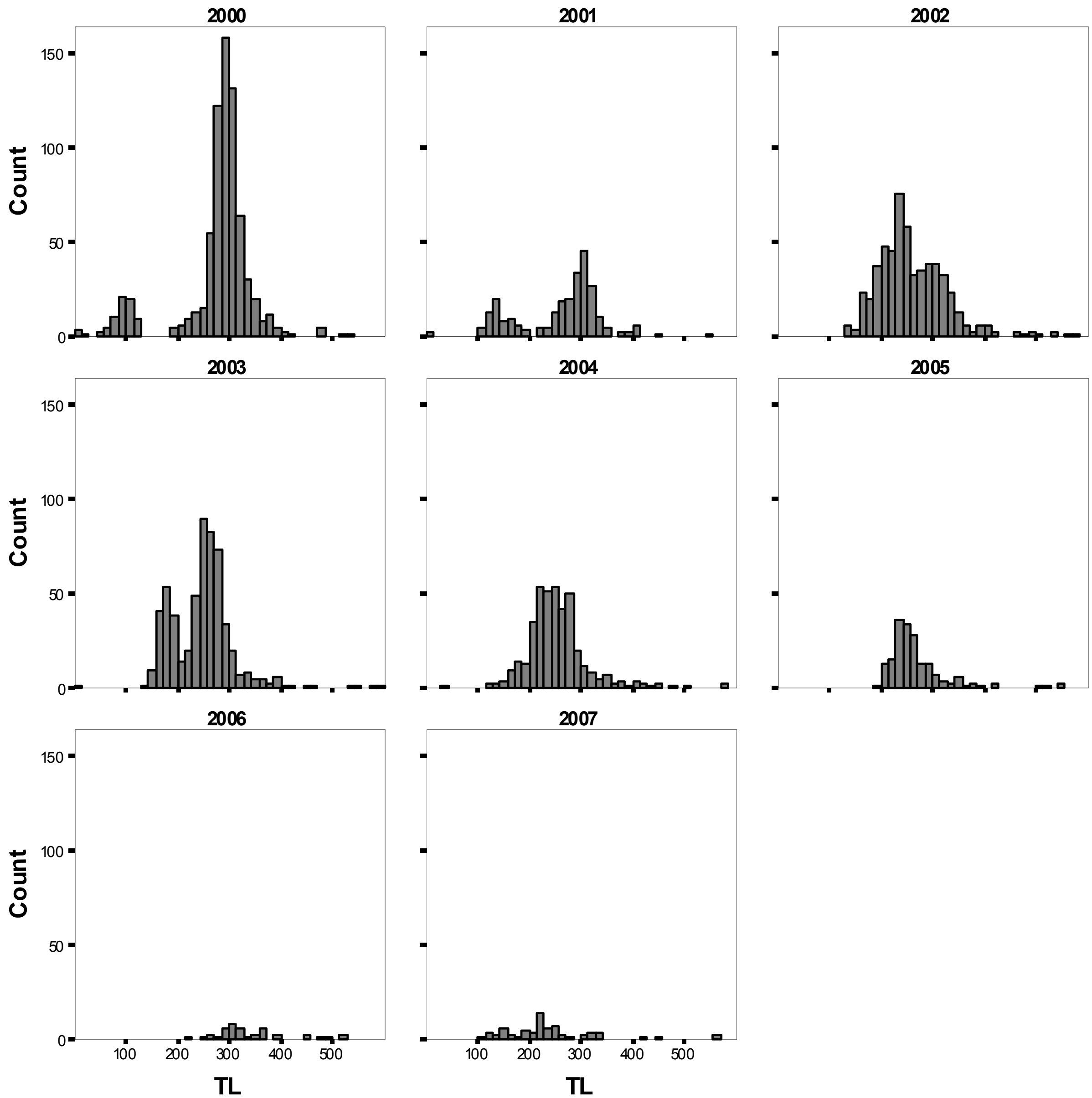

Figure 16. Length histograms for brown trout, by year (2000 to 2007), sampled by electrofishing on the Colorado River (RM 0 to 225, 2000-2007).

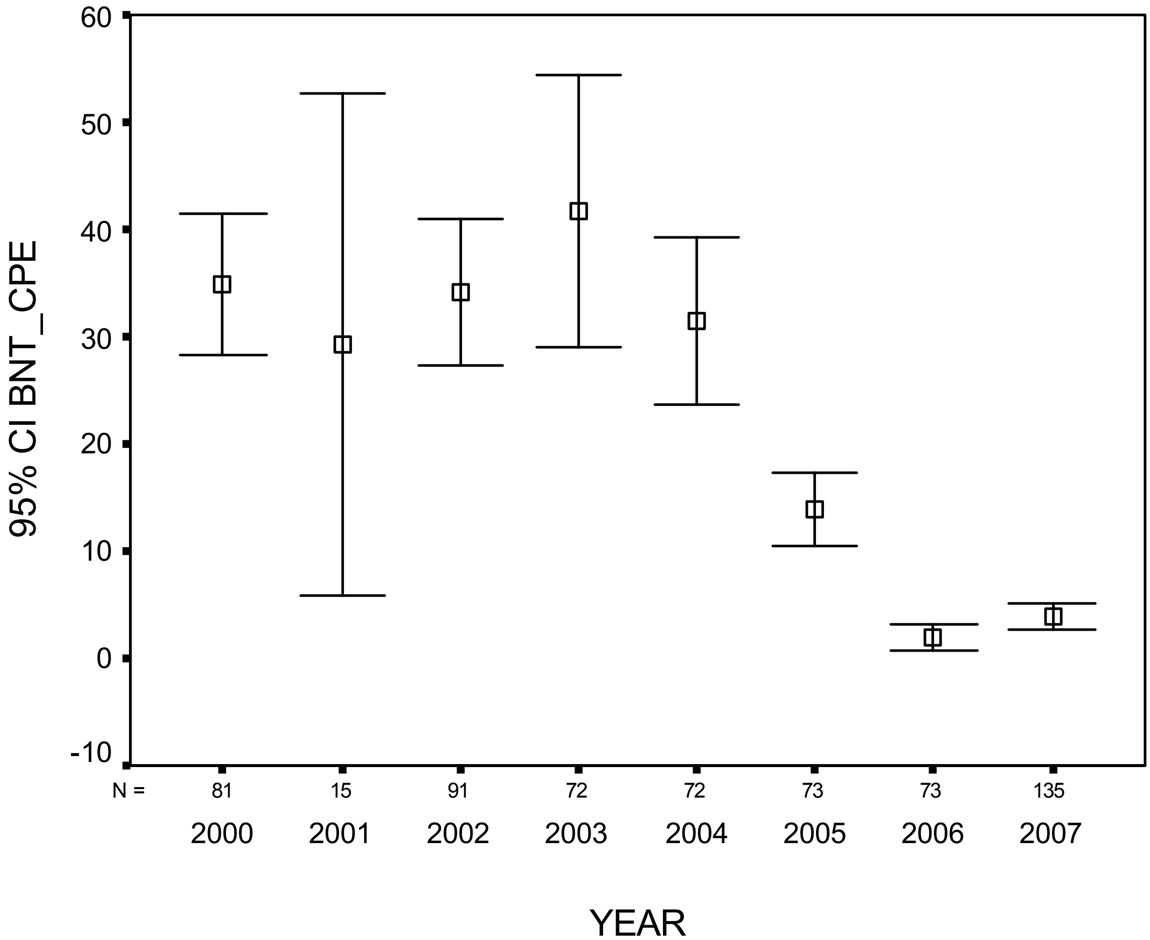

Figure 17. Brown trout (BNT) catch per unit effort (RBT / Hour) and number of samples taken, in the Colorado River near Bright Angel Creek (RM 81 to 89, 2000-2007).

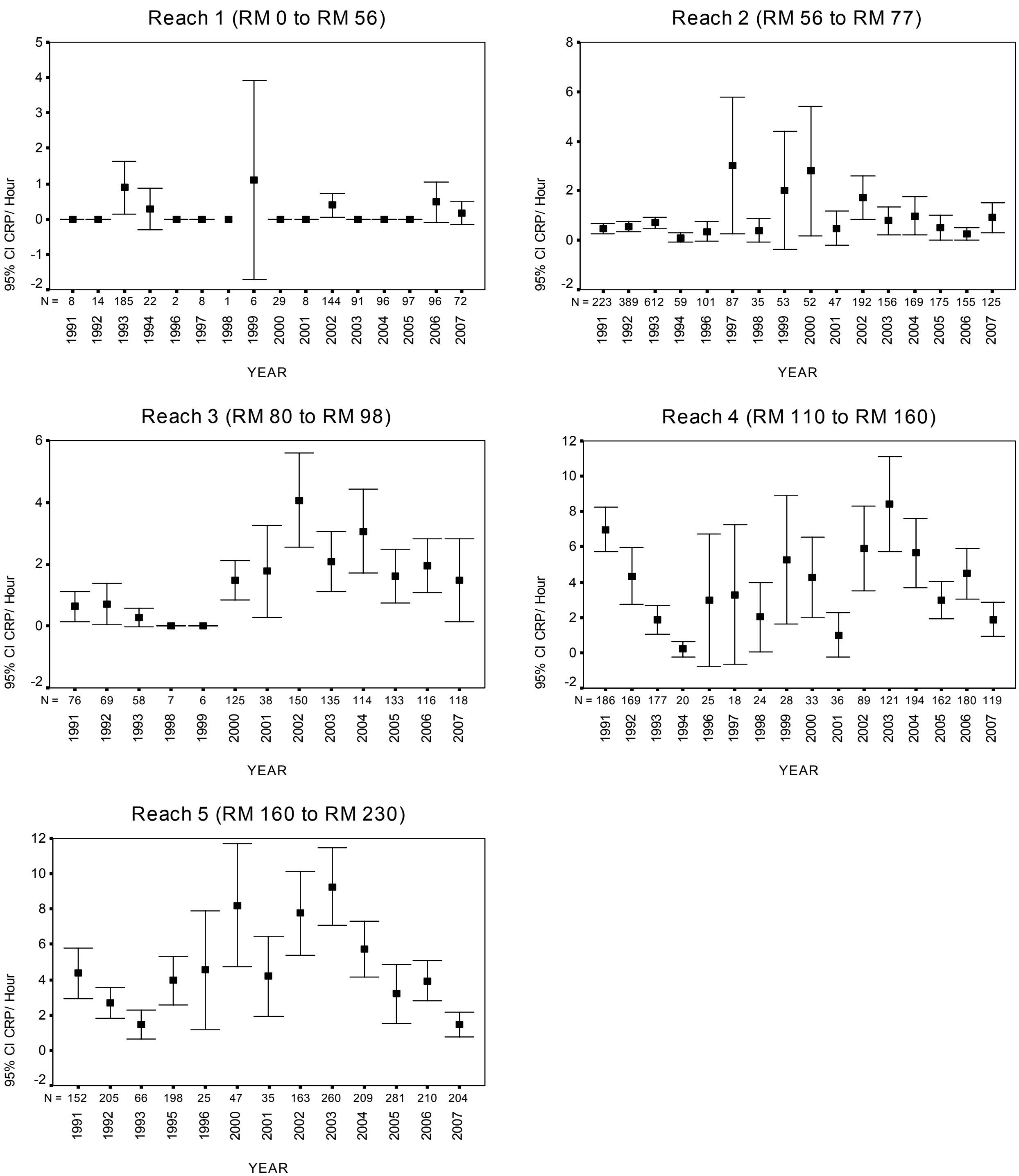

Figure 18. Common carp (CRP) catch per unit effort (CRP / Hour) and number of samples taken, reaches 1-5, Colorado River (1991-2007).

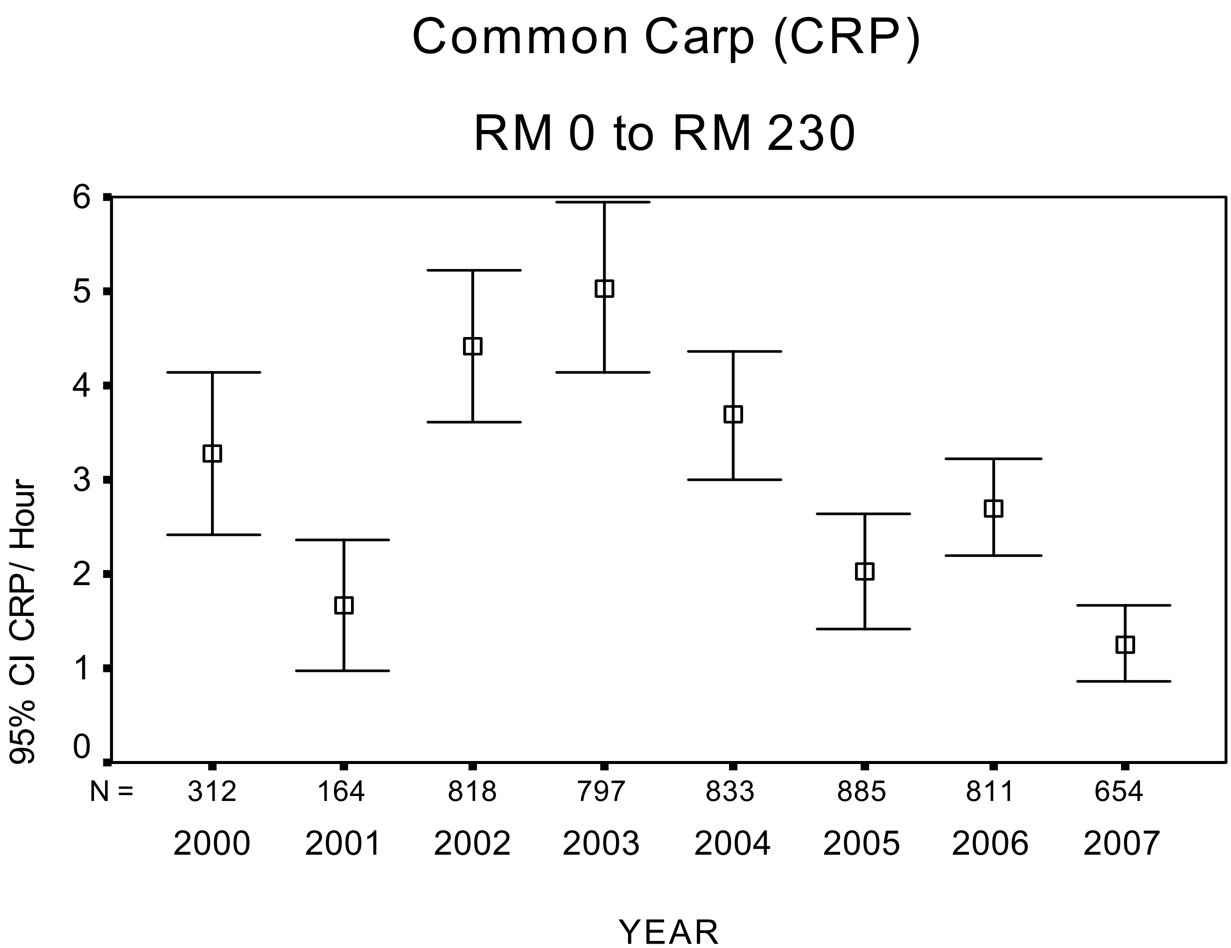

Figure 19. Common Carp (CRP) catch per unit effort (CRP / Hour) and number of samples taken, Colorado River (RM 0 to 230, 2000-2007).

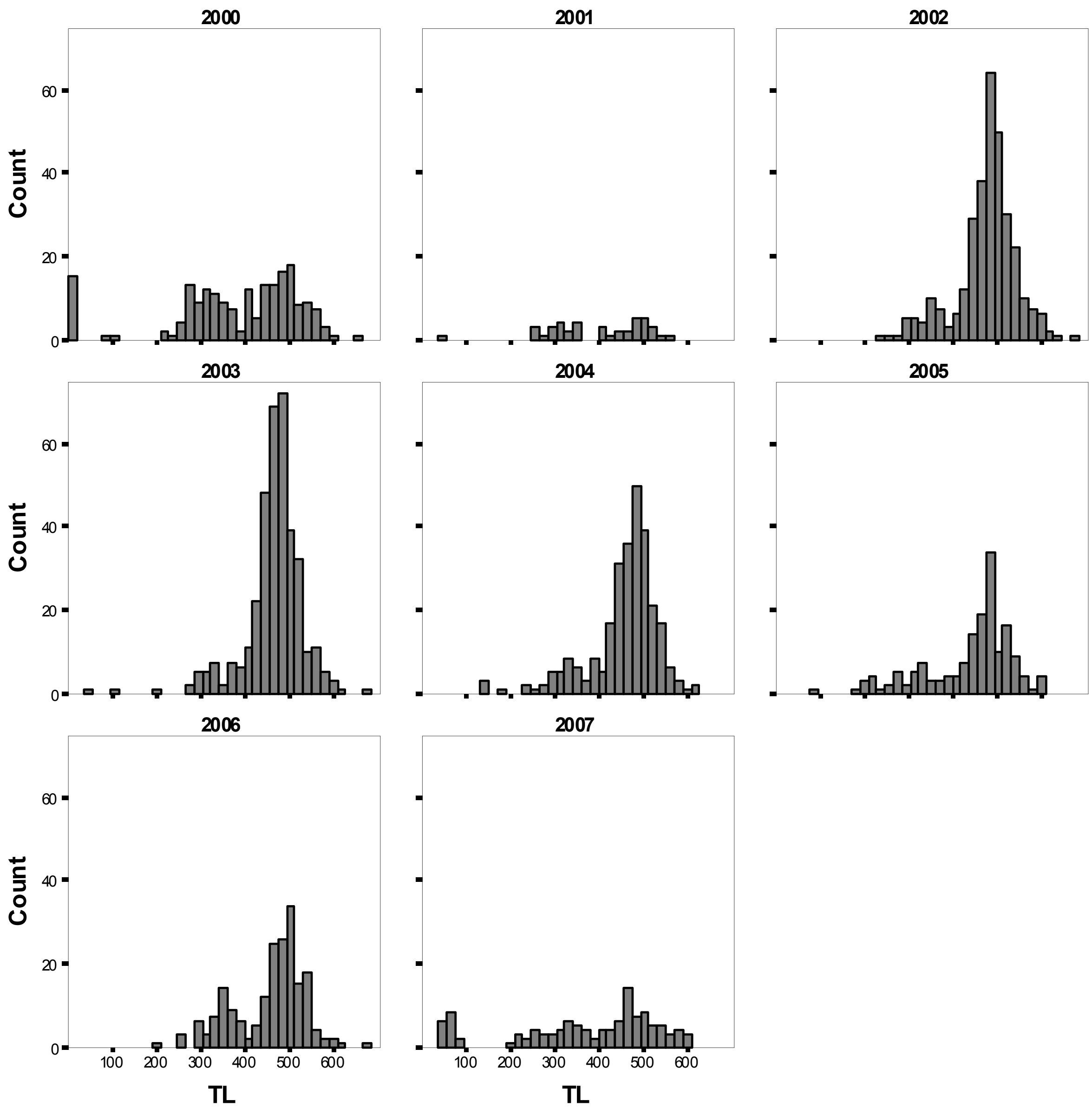

Figure 20. Length histograms for common carp, by year (2000 to 2007), sampled by electrofishing on the Colorado River (RM 0 to 225, 2000-2007).

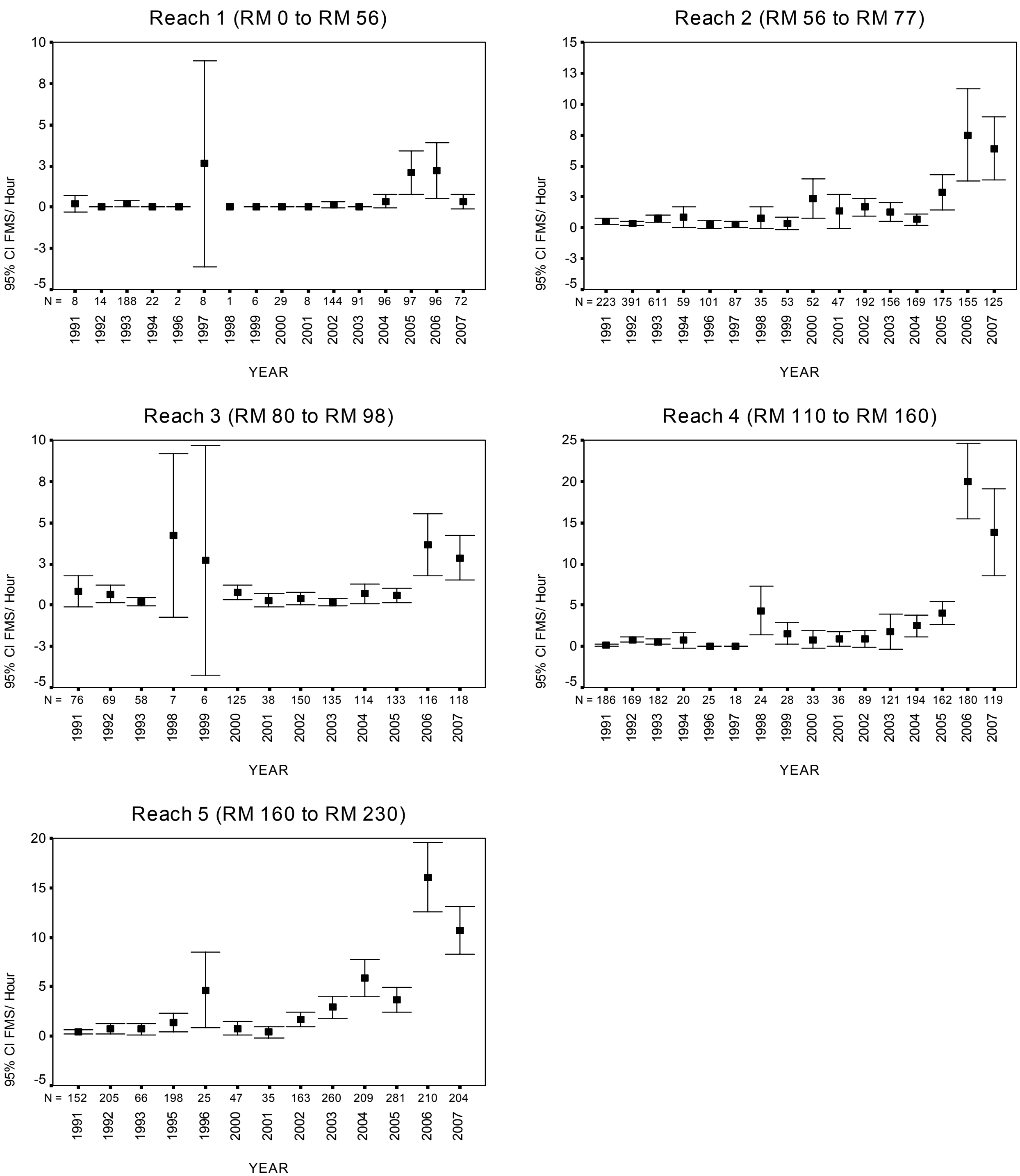

Figure 21. Flannelmouth sucker (FMS) catch per unit effort (FMS / Hour) and number of samples taken, reaches 1-5, Colorado River (1991-2007).

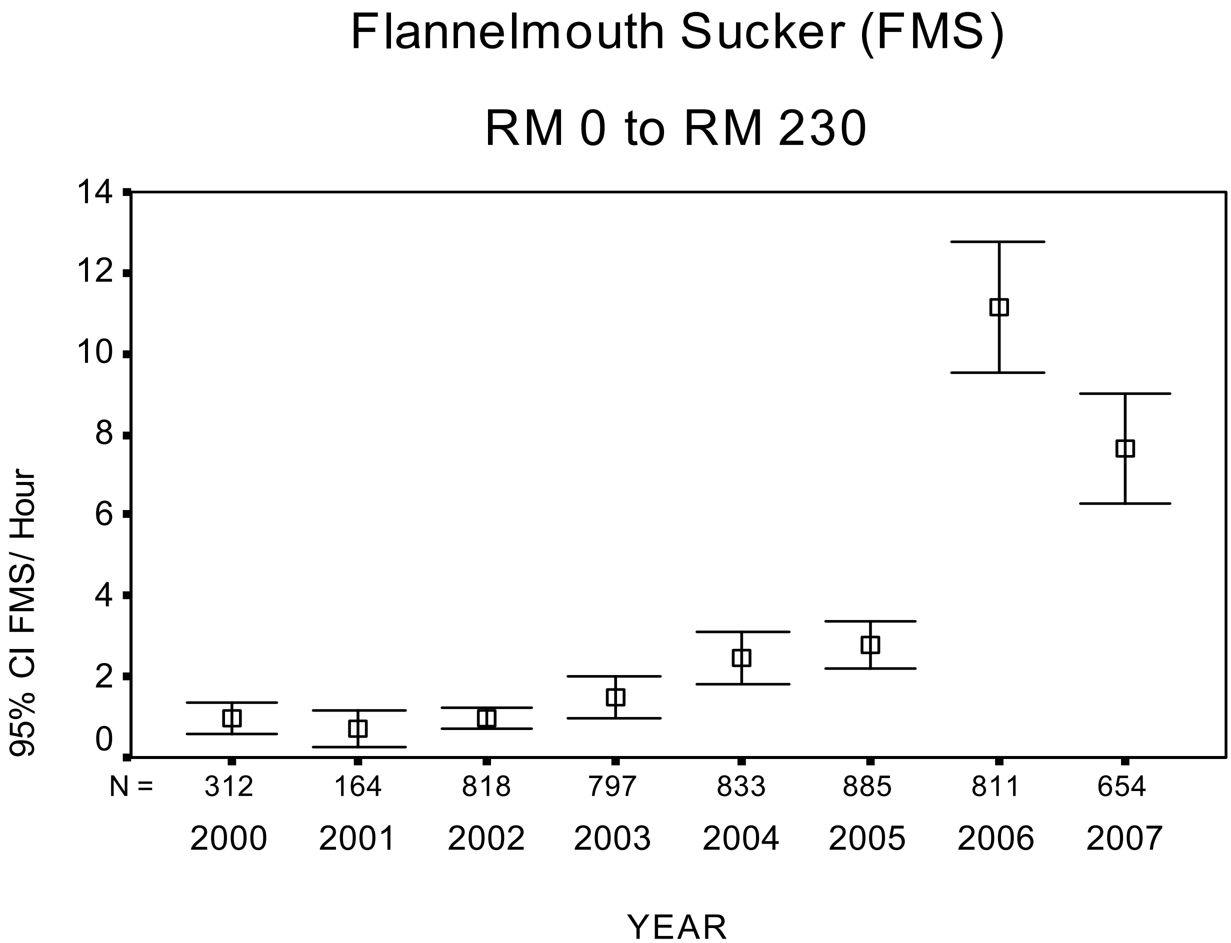

Figure 22. Flannelmouth sucker (FMS) catch per unit effort (FMS / Hour) and number of samples taken, Colorado River (RM 0 to 225, 2000-2007).

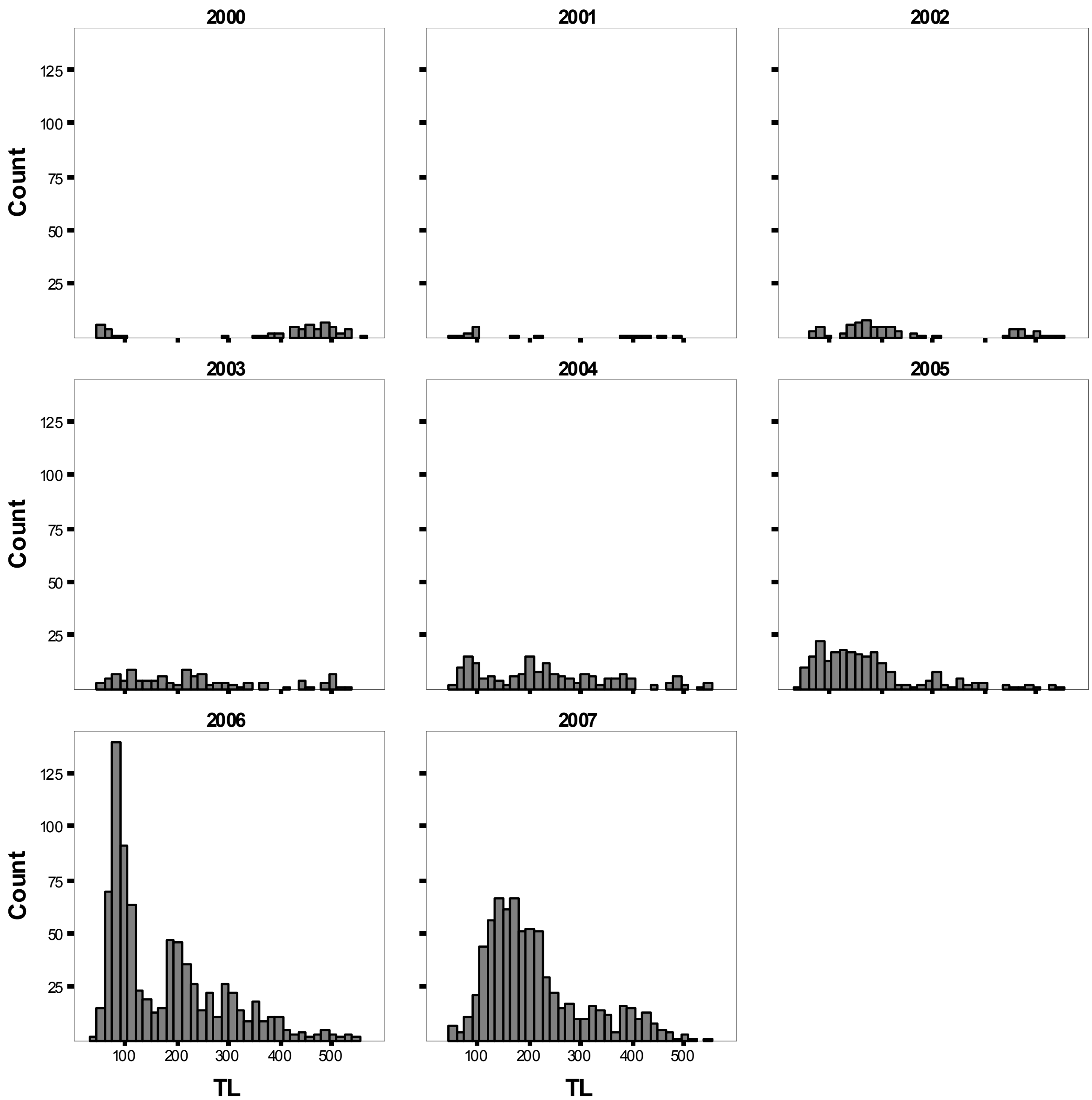

Figure 23. Length histograms for flannelmouth sucker, by year (2000 to 2007), sampled by electrofishing on the Colorado River (RM 0 to 225, 2000-2007).

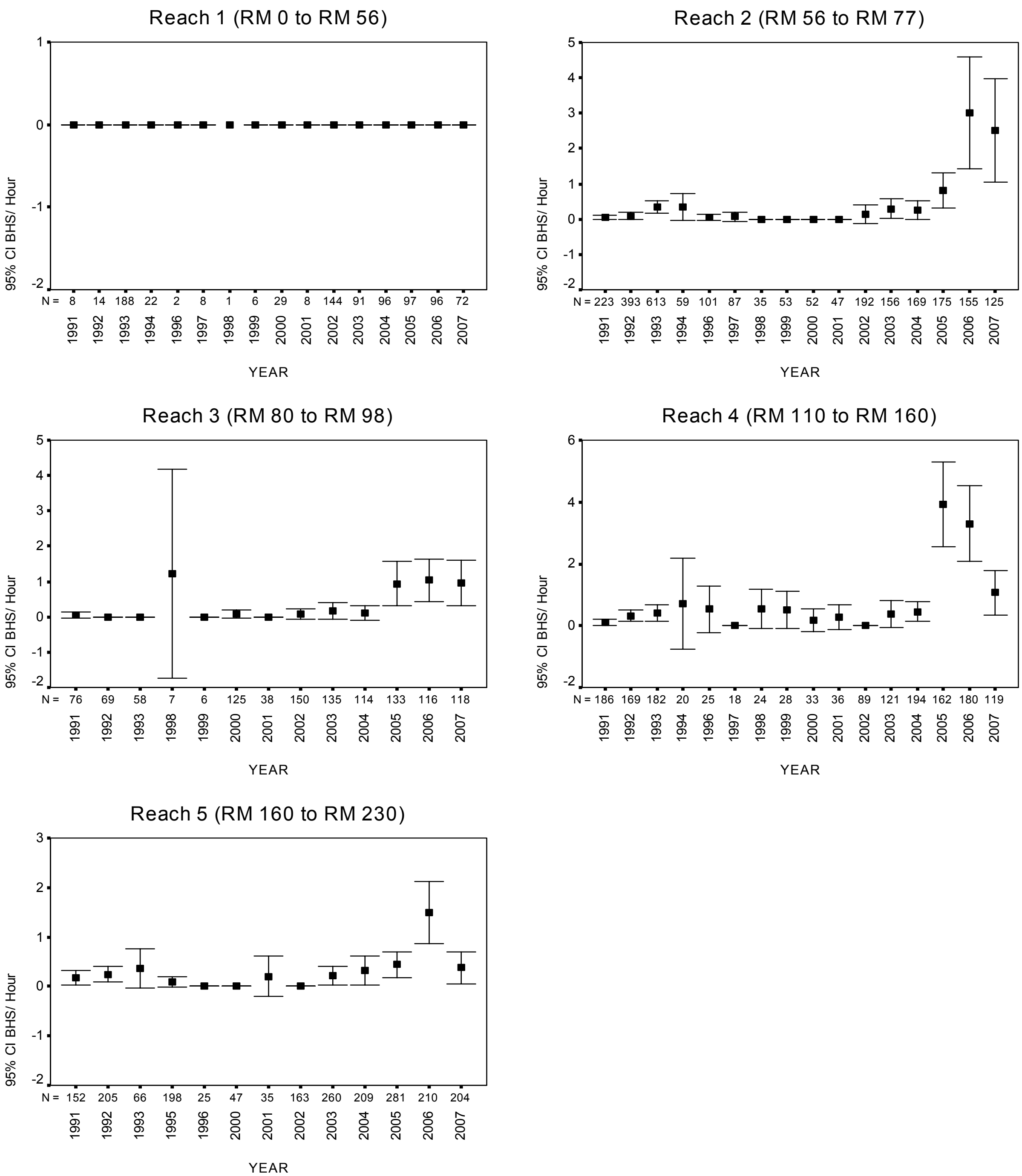

Figure 24. Bluehead sucker (BHS) catch per unit effort (BHS / Hour) and number of samples taken, reaches 1-5, Colorado River (1991-2007).

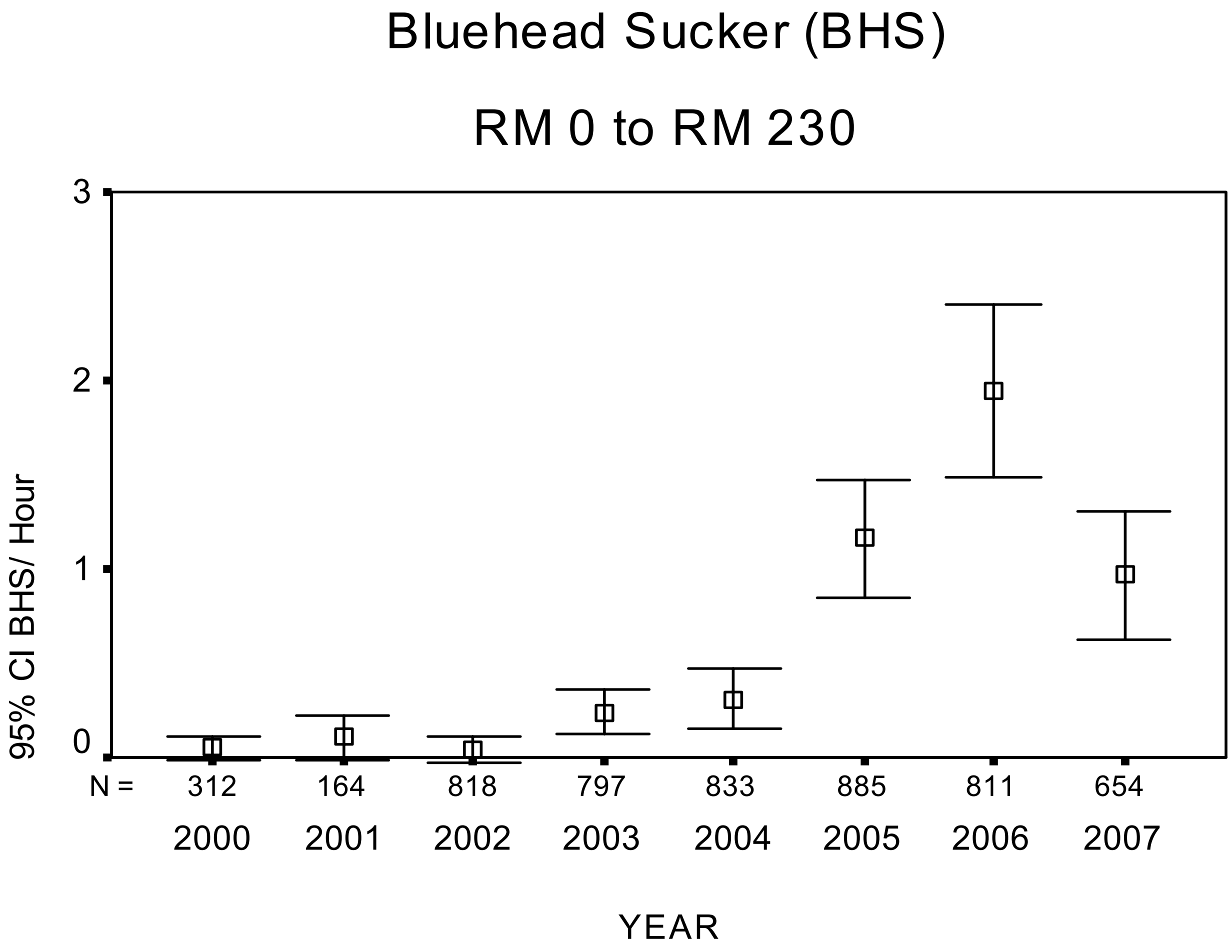

Figure 25. Bluehead sucker (BHS) catch per unit effort (BHS / Hour) and number of samples taken, Colorado River (RM 0 to 225, 2000-2007).

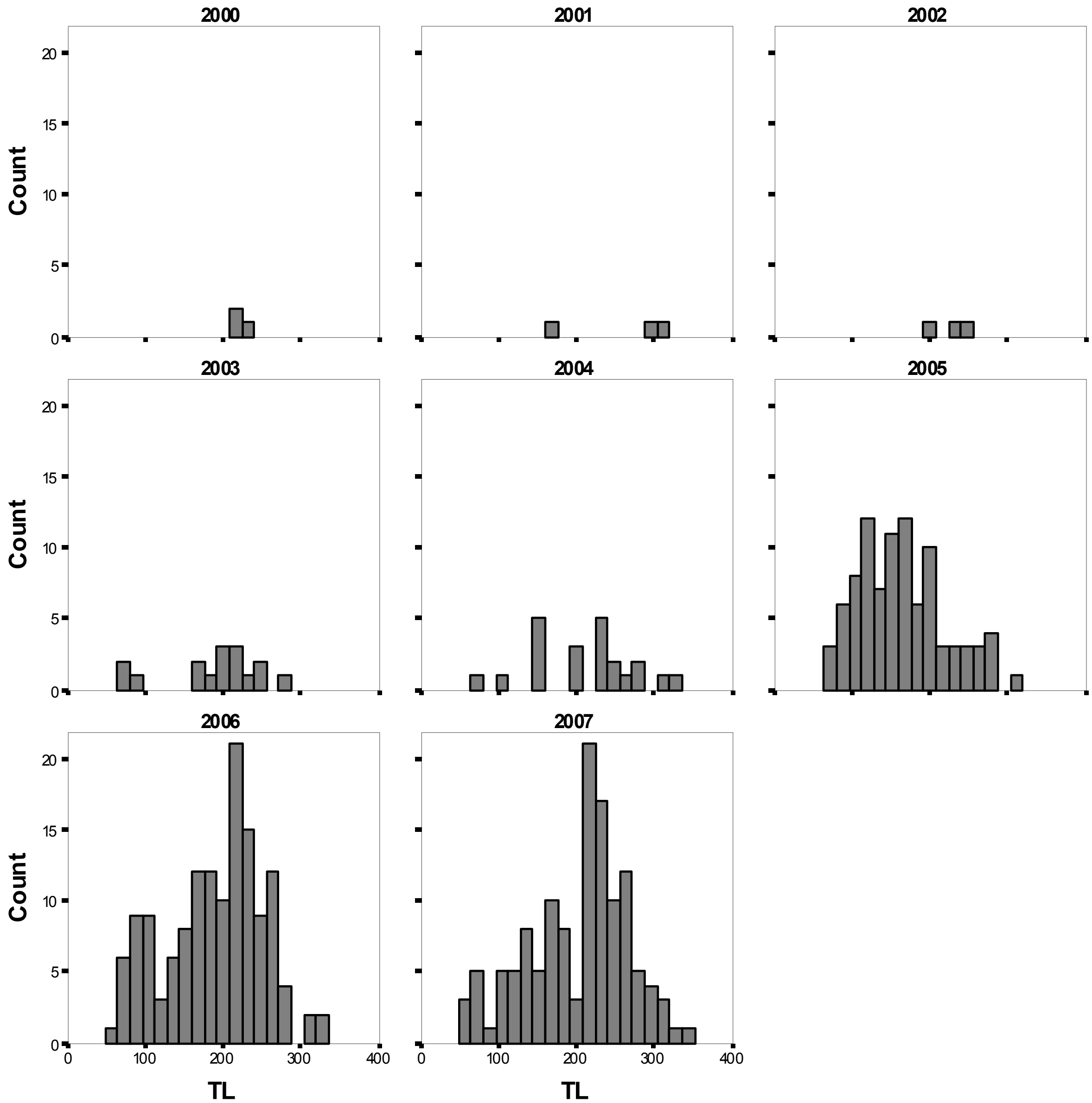

Figure 26. Length histograms for bluehead sucker sampled, by year (2000 to 2007), by electrofishing on the Colorado River (RM 0 to 225, 2000-2007).

Appendices

Appendix 1. Count of fish species captured by electrofishing on the Colorado River (RM 0 to 225, 1991-2007).

Year	BBH	BGS	BHS	BKC	BKT	BNT	CCF	CRP
1991	1		22		1	535	1	760
1992	1		37	2	1	522	11	721
1993	2		58	2	1	192	26	278
1994			5			4		3
1995		1	3				39	175
1996			5			8		31
1997			1			10		50
1998			5			116		17
1999			4			80	1	41
2000			3			727	1	193
2001			3			254	2	42
2002	1		3			559	2	315
2003			17			565	4	363
2004			22			396	7	274
2005			92			180	2	164
2006			141			44	11	197
2007	2		55			23	1	72

Year	FHM	FMS	GSF	HBC	LMB	MOS	PKF	RBT
1991	11	78		333			1	2946
1992	149	131	2	456	19	8	3	1872
1993	211	146	6	1379	11	1	2	2371
1994	108	10	1	175				189
1995	64	48	5		6	1		2
1996	105	30		45				283
1997	186	6		14				369
1998	50	31	1	73				407
1999	10	13		79				556
2000	8	58		16			1	2541
2001	1	17		1				1258
2002	10	70		8				2789
2003	8	108		3				1684
2004	9	179		9			1	1461
2005	37	226		17				916
2006	101	804		15				574
2007	29	436	1	10				442

Year	RSH	RTC	SPD	STB	SUC	TFS	UID	YBH
1991			96	7			1	
1992	326		109	3	4	51		
1993	76		313	22		6		
1994			37		9			
1995	220	2	142	42		10	1	
1996			27					
1997	4		12					
1998	11		52					
1999	4		13					
2000			1	8	4		1	
2001			1					
2002	2		13	1	1			
2003			13					
2004			65					1
2005	1		129					
2006	2		201	19	8			
2007	2		194					

Appendix 2. Reach designation by river mile for the fish reaches (1 – 11), Colorado River (RM 0 to 225, 2000-2007).

Fish Reach	Sub Reach	Miles Available	Camp RM	Camp	Start Mile	Start name	End Mile	End name
1	1.1	6.8	2.8	Cathedral	1.0	Paria riffle	7.8	Badger
1	1.1	6.8	5.8	6 mile wash	1.0	Paria riffle	7.8	Badger
1	1.2	3.2	8.0	Jackass	8.0	Badger	11.2	Soap
1	1.2	3.2	11.2	Soap	8.0	Badger	11.2	Soap
1	1.3	5.5	11.2	Soap	11.3	Soap	16.8	House Rock
1	1.3	5.5	12.2		11.3	Soap	16.8	House Rock
1	1.3	5.5	16.5	Hot Na Na	11.3	Soap	16.8	House Rock
1	1.4	3.5	17.0	Below House Rock	17.0	Below House Rock	20.5	North
1	1.4	3.5	18.0	18 Mile Wash	17.0	Below House Rock	20.5	North
1	1.4	3.5	19.0	19 mile canyon	17.0	Below House Rock	20.5	North
1	1.4	3.5	20.0	20 Mile	17.0	Below House Rock	20.5	North
1	1.4	3.5	20.7	North	17.0	Below House Rock	20.5	North
1	1.5	2.4	21.9	21.9 Mile	20.8	Below North	23.2	Indian Dick
1	1.5	2.4	23.0	23 Mile	20.8	Below North	23.2	Indian Dick
1	1.5	1.3	24.5	Above 24.5 Mile	23.2	Indian Dick	24.5	Above 24.5
1	1.5	3.6	26.5	Above Tiger Wash	25.5	Below 25.5	29.1	Silver Grotto
1	1.5	3.6	29.1	Silver grotto	25.5	Below 25.5	29.1	Silver Grotto
2	2.1	6.9	29.1	Silver grotto	29.1	Silver Grotto	36.0	36 Mile
2	2.1	6.9	30.2		29.1		36.0	
2	2.1	6.9	31.6	South	29.1		36.0	
2	2.1	6.9	33.8		29.1		36.0	
2	2.1	6.9	34.9	Nautiloid	29.1		36.0	
2	2.2	7.7	37.3	Tatahatso	36.0		43.7	Harding
2	2.2	7.7	38.4		36.0		43.7	Harding
2	2.2	7.7	41.0	Buck Farm	36.0		43.7	Harding
2	2.2	7.7	43.2	Above Harding	36.0		43.7	Harding
2	2.3	8.3	43.7	Below Harding	43.7	Harding	52.0	Nankoweap
2	2.3	8.3	44.7		43.7	Harding	52.0	Nankoweap
2	2.3	8.3	44.8		43.7	Harding	52.0	Nankoweap
2	2.3	8.3	46.2		43.7	Harding	52.0	Nankoweap
2	2.3	8.3	46.4		43.7	Harding	52.0	Nankoweap
2	2.3	8.3	47.0	Saddle	43.7	Harding	52.0	Nankoweap
2	2.3	8.3	47.5		43.7	Harding	52.0	Nankoweap
2	2.3	8.3	48.3		43.7	Harding	52.0	Nankoweap
2	2.3	8.3	48.8		43.7	Harding	52.0	Nankoweap
2	2.3	8.3	50.0		43.7	Harding	52.0	Nankoweap
2	2.3	8.3	50.2		43.7	Harding	52.0	Nankoweap
2	2.3	8.3	51.7	Little Nankoweap	43.7	Harding	52.0	Nankoweap
2	2.3	8.3	52.5	Nankoweap	43.7	Harding	52.0	Nankoweap
2	2.4	4.0	53.0	Below Nanko	52.0	Nankoweap	56.0	Kwagunt
3	3.1	9.5	56.1	Below Kwagunt	56.0	Kwagunt	65.5	Lava Chuar
3	3.1	9.5	56.5		56.0	Kwagunt	65.5	Lava Chuar
3	3.1	9.5	58.0	Awatubi	56.0	Kwagunt	65.5	Lava Chuar
3	3.1	9.5	58.5		56.0	Kwagunt	65.5	Lava Chuar
3	3.1	9.5	58.7		56.0	Kwagunt	65.5	Lava Chuar
3	3.1	9.5	61.0	LCR Point	56.0	Kwagunt	65.5	Lava Chuar
3	3.1	9.5	62.5	Crash	56.0	Kwagunt	65.5	Lava Chuar
3	3.1	9.5	64.8	Carbon	56.0	Kwagunt	65.5	Lava Chuar
3	3.1	9.5	65.4	Above Lava Chuar	56.0	Kwagunt	65.5	Lava Chuar
3	3.2	3.0	65.6	Below Lava Chuar	65.6	Below Lava Chuar	68.6	Above Tanner
3	3.2	3.0	68.5	Above Tanner	65.6	Below Lava Chuar	68.6	Above Tanner
4	4.1	3.8	69.1	Below Tanner	68.7	Below Tanner	72.5	Above Unkar

Appendix 2 (cont). Reach designation by river mile for the fish reaches (1 – 11), Colorado River (RM 0 to 225, 2000-2007).

Fish Reach	Sub Reach	Miles Available	Camp RM	Camp	Start Mile	Start name	End Mile	End name
4	4.1	3.8	69.2		68.7	Below Tanner	72.5	Above Unkar
4	4.1	3.8	71.1	Cardenas	68.7	Below Tanner	72.5	Above Unkar
4	4.1	3.8	72.0	Above Unkar	68.7	Below Tanner	72.5	Above Unkar
4	4.2	2.9	74.3	Above Nevills	72.6	Below Unkar	75.5	Above Nevills
4	4.2	2.9	75.7	Above Nevills	72.6	Below Unkar	75.5	Above Nevills
4	4.3	1.2	76.7	Above Hance	75.5	Below Nevills	76.7	Above Hance
5	5.1	2.4	81.2	Grapevine	78.8	Sock	81.2	Above Grapevine
5	5.2	2.9	84.0	Clear Ck	81.6	Grapevine	84.5	Zoraster
5	5.2	2.9	84.2	Clear Ck	81.6	Grapevine	84.5	Zoraster
5	5.3	3.8	87.0	Cremation	85.0	85 Mile	88.8	Pipe Creek
5	5.4	3.3	91.5	Trinity Ck	90.2	Below Horn	93.5	Granite
5	5.4	3.3	93.4	Above Granite	90.2	Below Horn	93.5	Granite
5	5.5	1.2	94.0	94 mile	93.6	Below Granite	94.8	Above Hermit
5	5.5	1.2	94.9	Above Hermit	93.6	Below Granite	94.8	Above Hermit
5	5.6	2.9	96.0	Below Hermit	95.1	Below Hermit	98.0	Crystal
5	5.6	2.9	96.8	Boucher	95.1	Below Hermit	98.0	Crystal
5	5.7	2.5	103.0	103R	102.0	Turquoise	104.5	Ruby
5	5.7	2.5	107.7	Upper Bass	106.0	Serpentine	108.5	Shinumo
5	5.7	2.5	108.1	Bass	106.0	Serpentine	108.5	Shinumo
5	5.7	2.5	108.5	Shinumo	106.0	Serpentine	108.5	Shinumo
6	6.1	3.7	109.3		108.6	Below Shinumo	112.3	Waltenberg
6	6.2	4.1	114.0	Garnet	112.4	Waltenberg	116.5	Elves
6	6.2	4.1	116.0		112.4	Waltenberg	116.5	Elves
6	6.3	6.2	116.5	Elves	116.5	Elves	122.7	Forster
6	6.3	6.2	118.2		116.5	Elves	122.7	Forster
6	6.3	6.2	119.0		116.5	Elves	122.7	Forster
6	6.3	6.2	120.0	Blacktail	116.5	Elves	122.7	Forster
6	6.3	6.2	122.2	122 Mile	116.5	Elves	122.7	Forster
6	6.3	6.2	122.8	Forster	116.5	Elves	122.7	Forster
6	6.4	2.3	124.0	124 Mile	122.7	Forster	125.0	Fossil
6	6.5	2.0	125.4	Below Fossil	125.0	Fossil	127.0	127 Mile
6	6.5	2.0	126.3	Randys Rock	125.0	Fossil	127.0	127 Mile
6	6.6	2.0	128.0	128 Mile	127.0	127 Mile	129.0	Specter
7	7.1	1.3	131.8	Above Deubendorff	130.5	Bedrock	131.8	Above Dubendorff
7	7.2	1.8	132.0	Stone Creek	131.9	Below Dooby	133.7	Tapeats
7	7.2	1.8	133.0		131.9	Below Dooby	133.7	Tapeats
7	7.2	1.8	133.7	Above Tapeats	131.9	Below Dooby	133.7	Tapeats
7	7.3	2.2	133.8	Below Tapeats	133.8	Below Tapeats	136.0	Deer Creek
7	7.4	3.7	134.3	134 Mile	134.0	134 Mile	137.7	Doris
7	7.4	3.7	134.6		134.0	134 Mile	137.7	Doris
7	7.4	3.7	136.0	Across Deer Ck	134.0	134 Mile	137.7	Doris
7	7.4	3.7	136.5		134.0	134 Mile	137.7	Doris
7	7.4	3.7	136.6		134.0	134 Mile	137.7	Doris
7	7.5	1.3	137.9	Below Doris	137.8	Doris	139.1	Fishtail
7	7.5	1.3	138.4		137.8	Doris	139.1	Fishtail
7	7.5	1.3	138.5		137.8	Doris	139.1	Fishtail
7	7.5	1.3	138.9	Fishtail	137.8	Doris	139.1	Fishtail
7	7.6	4.4	139.8		139.1	Fishtail	143.5	Kanab
7	7.6	4.4	143.3	Kanab	139.1	Fishtail	143.5	Kanab
7	7.7	6.2	145.7	Olo	143.5	Below Kanab	149.7	Upset
7	7.8	7.1	150.2	Below Upset	149.8	Below Upset	156.9	Havasu
7	7.8	7.1	151.5		149.8	Below Upset	156.9	Havasu
7	7.8	7.1	155.5		149.8	Below Upset	156.9	Havasu
7	7.8	7.1	156.0		149.8	Below Upset	156.9	Havasu
7	7.8	7.1	156.7	Last chance	149.8	Below Upset	156.9	Havasu

Appendix 2 (cont). Reach designation by river mile for the fish reaches (1 – 11), Colorado River (RM 0 to 225, 2000-2007).

Fish Reach	Sub Reach	Miles Available	Camp RM	Camp	Start Mile	Start name	End Mile	End name
7	7.9	9.6	157.7	Below Havasu	157.0	Havasu	166.6	National
7	7.9	9.6	158.5		157.0	Havasu	166.6	National
7	7.9	9.6	159.9		157.0	Havasu	166.6	National
7	7.9	9.6	160.9		157.0	Havasu	166.6	National
7	7.9	9.6	164.5	Tuckup	157.0	Havasu	166.6	National
8	8.1	12.9	166.6	National	166.6	National	179.5	Lava Falls
8	8.1	12.9	167.3		166.6	National	179.5	Lava Falls
8	8.1	12.9	168.0	Fern Glen	166.6	National	179.5	Lava Falls
8	8.1	12.9	171.0	Stairway	166.6	National	179.5	Lava Falls
8	8.1	12.9	171.5	Mohawk	166.6	National	179.5	Lava Falls
8	8.1	12.9	173.0		166.6	National	179.5	Lava Falls
8	8.1	12.9	174.2	Cove	166.6	National	179.5	Lava Falls
8	8.1	12.9	177.0	Honga Spring	166.6	National	179.5	Lava Falls
8	8.1	12.9	177.8		166.6	National	179.5	Lava Falls
8	8.1	12.9	179.0	Above Lava Falls	166.6	National	179.5	Lava Falls
9	9.1	10.2	179.8	Below Lower Lava	179.8	Below Lava Falls	190.0	
9	9.1	10.2	180.8		179.8	Below Lower Lava	190.0	
9	9.1	10.2	182.8		179.8	Below Lower Lava	190.0	
9	9.1	10.2	186.2		179.8	Below Lower Lava	190.0	
9	9.1	10.2	188.0	Whitmore	179.8	Below Lower Lava	190.0	
9	9.1	10.2	190.0		179.8	Below Lower Lava	190.0	
9	9.2	10	190.9		190.0		200.0	
9	9.2	10	191.8	192 Mile Canyon	190.0		200.0	
9	9.2	10	192.2		190.0		200.0	
9	9.2	10	193.1		190.0		200.0	
9	9.2	10	194.2	Common 194 Mi	190.0		200.0	
9	9.2	10	194.6	194 Mi Can	190.0		200.0	
9	9.2	10	196.0		190.0		200.0	
9	9.2	10	198.6	Parashant	190.0		200.0	
10	10.1	5.6	204.5		200.0		205.6	205 Mile Rapid
10	10.2	3.2	208.0		205.7	Below 205 Mi	208.9	Above Granite Pk
10	10.2	3.2	208.9	Granite Park	205.7	Below 205 Mi	208.9	Above Granite Pk
10	10.3	10.8	209.8		209.2	Below Granite Pk	220.0	220 Mile
10	10.3	10.8	211.5	Fall Cnyn	209.2	Below Granite Pk	220.0	220 Mile
10	10.3	10.8	212.8	Pumpkin	209.2	Below Granite Pk	220.0	220 Mile
10	10.3	10.8	214.0		209.2	Below Granite Pk	220.0	220 Mile
10	10.3	10.8	215.5	Three Springs	209.2	Below Granite Pk	220.0	220 Mile
10	10.3	10.8	219.2	Trail Cnyon	209.2	Below Granite Pk	220.0	220 Mile
11	11.1	5	220.0	220 Mile	220.0		225.0	
11	11.1	5	222.0		220.0		225.0	
11	11.1	5	222.3		220.0		225.0	
11	11.1	5	224.5		220.0		225.0	
11	11.1	5	225.0	Diamond	220.0		225.0	Above Diamond

Appendix 3. Species codes, common names and scientific names used in this report.

Code	Common name	Scientific name
BBH	black bullhead	*Ameiurus melas*
BGS	bluegill	*lepomis macrochirus*
BHS	bluehead sucker	*Catostomus discobolus*
BKC	black crappie	*Pomoxis nigromaculatus*
BKT	brook trout	*Salvelinus fontinalis*
BNT	brown trout	*salmo trutta*
CCF	channel catfish	*Ictalurus punctatus*
CRP	common carp	*Cyprinus carpio*
FHM	fathead minnow	*Pimephales promelas*
FMS	flannelmouth sucker	*Catostomus latipinnis*
GSF	green sunfish	*Lepomis cyanellus*
HBC	humpback chub	*Gila cypha*
LMB	Largemouth bass	*Micropterus salmoides*
MOS	Mosquitofish	*Gambusia affinis*
PKF	plains killifish	*Fundulus zebrinus*
RBT	rainbow trout	*Oncorhynchus mykiss*
RSH	red shiner	*Cyprinella lutrensis*
RTC	round tail chub	*Gila robusta*
SMB	smallmouth bass	*Micropterus dolomieu*
SPD	speckled dace	*Rhinichthys osculus*
STB	striped bass	*Morone saxatilis*
SUC	Unidentified sucker	
TFS	threadfin shad	*Dorosomo petenense*
UID	Unidentified fish	
YBH	yellow bullhead	*Ameiurus natalis*

Appendix 4. Fish reaches used for stratification in power analysis and effort allocation with associated river miles.

Fish reach	Start river mile	End river mile
1	0	29.1
2	29.2	56
3	56	68.6
4	68.7	76.7
5	78.8	108.5
6	108.6	129
7	130.5	166.6
8	166.7	179.5
9	179.8	200
10	200.1	220
11	220.1	225

Appendix 5. Mean, standard error, and sample size for rainbow trout catch per unit effort (fish / hour, electrofishing) for the fish reaches (1 – 11), Colorado River (RM 0 to 225, 2000-2007).

Rainbow Trout

	Reach 1			Reach 2			Reach 3			Reach 4		
Year	**Mean**	**SE**	**N**	**Mean**	**SE**	**N**	**Mean**	**SE**	**N**	**Mean**	**SE**	**N**
2000	180.1	13.2	15	127.1	18.7	14	54.9	7.2	38	55.3	9.1	14
2001			0	135.6	25.9	8	69.3	9.0	47			0
2002	100.1	8.5	49	107.1	7.1	95	62.1	4.7	168	38.0	5.6	24
2003	117.8	12.3	43	104.0	9.2	48	24.2	3.3	117	36.7	4.5	39
2004	107.2	10.1	48	82.9	10.0	48	12.2	1.6	119	24.9	3.2	50
2005	108.7	8.6	48	60.9	8.4	49	3.5	0.7	124	8.0	1.6	51
2006	50.7	8.3	48	47.3	7.2	48	1.4	0.4	106	2.8	0.9	49
2007	88.5	7.5	36	32.2	5.0	36	1.6	0.5	89	3.9	1.6	36

	Reach 5			Reach 6			Reach 7			Reach 8		
Year	**Mean**	**SE**	**N**	**Mean**	**SE**	**N**	**Mean**	**SE**	**N**	**Mean**	**SE**	**N**
2000	32.6	2.9	151			0	23.0	3.8	35	10.7	2.5	15
2001	50.9	5.9	38	50.0	8.8	18	25.9	4.3	18	13.3	2.5	18
2002	15.1	1.5	210	15.6	2.0	82	11.3	2.1	48	3.8	1.1	48
2003	14.1	1.5	169	8.4	1.7	48	13.7	2.1	73	2.1	0.7	72
2004	11.7	1.5	157	10.9	1.3	107	13.5	3.5	96	2.6	1.0	48
2005	2.8	0.5	169	1.3	0.4	95	2.1	0.6	91	0.2	0.2	47
2006	2.0	0.5	170	2.0	0.6	96	5.0	1.5	96	0.7	0.4	48
2007	2.1	0.5	129	1.3	0.5	72	0.9	0.4	69	0.3	0.3	36

	Reach 9			Reach 10			Reach 11		
Year	**Mean**	**SE**	**N**	**Mean**	**SE**	**N**	**Mean**	**SE**	**N**
2000	15.6	4.1	12	1.7	0.8	14	4.1	1.4	4
2001	5.4	1.7	17			0			0
2002	1.6	0.8	48	0.0	0.0	43			0
2003	0.4	0.2	115	0.0	0.0	48	0.0	0.0	25
2004	0.9	0.4	60	0.4	0.3	60	0.0	0.0	40
2005	0.1	0.1	91	0.2	0.2	59	0.0	0.0	60
2006	0.2	0.2	56	0.2	0.2	54	0.0	0.0	40
2007	0.0	0.0	69	0.0	0.0	47	0.0	0.0	30

Appendix 6. Mean, standard error, and sample size for brown trout catch per unit effort (fish / hour, electrofishing) for the fish reaches (1 – 11), Colorado River (RM 0 to 225, 2000-2007).

Brown Trout

	Reach 1			Reach 2			Reach 3			Reach 4		
Year	**Mean**	**SE**	**N**	**Mean**	**SE**	**N**	**Mean**	**SE**	**N**	**Mean**	**SE**	**N**
2000	0.4	0.4	15	3.3	1.5	14	0.7	0.3	38	1.3	0.7	14
2001			0	1.2	1.2	8	2.1	0.8	47			0
2002	0.5	0.5	49	0.8	0.4	95	1.7	0.3	168	3.9	1.5	24
2003	0.0	0.0	43	1.2	0.6	48	1.1	0.4	117	2.9	1.2	39
2004	0.4	0.3	48	2.5	0.7	48	0.3	0.2	119	1.7	0.6	50
2005	0.1	0.1	48	0.0	0.0	49	0.3	0.2	124	0.9	0.4	51
2006	0.2	0.2	48	0.9	0.5	48	0.0	0.0	106	0.0	0.0	49
2007	0.3	0.3	36	0.0	0.0	36	0.1	0.1	89	0.0	0.0	36

	Reach 5			Reach 6			Reach 7			Reach 8		
Year	**Mean**	**SE**	**N**	**Mean**	**SE**	**N**	**Mean**	**SE**	**N**	**Mean**	**SE**	**N**
2000	24.2	2.1	151			0	2.3	0.8	35	2.5	1.2	15
2001	29.4	4.7	38	9.6	2.3	18	2.9	1.0	18	2.2	0.9	18
2002	23.3	1.9	210	7.5	1.2	82	3.0	0.9	48	4.8	1.0	48
2003	28.7	3.1	169	12.4	2.7	48	4.0	0.8	73	1.7	0.5	72
2004	21.0	2.1	157	6.6	1.2	107	0.4	0.2	96	1.4	0.5	48
2005	9.8	1.0	169	1.5	0.4	95	0.3	0.2	91	1.0	0.5	47
2006	1.7	0.4	170	0.5	0.2	96	0.6	0.3	96	0.5	0.3	48
2007	1.7	0.4	129	0.3	0.2	72	0.0	0.0	69	0.0	0.0	36

	Reach 9			Reach 10			Reach 11		
Year	**Mean**	**SE**	**N**	**Mean**	**SE**	**N**	**Mean**	**SE**	**N**
2000	1.0	0.7	12	0.4	0.4	14	0.0	0.0	4
2001	0.3	0.3	17			0			0
2002	1.7	0.6	48	0.0	0.0	43			0
2003	0.7	0.2	115	0.0	0.0	48	0.0	0.0	25
2004	0.7	0.4	60	0.2	0.2	60	0.0	0.0	40
2005	0.0	0.0	91	0.0	0.0	59	0.0	0.0	60
2006	0.2	0.2	56	0.0	0.0	54	0.0	0.0	40
2007	0.0	0.0	69	0.0	0.0	47	0.0	0.0	30

Appendix 7. Mean, standard error, and sample size for common carp catch per unit effort (fish / hour, electrofishing) for the fish reaches (1 – 11), Colorado River (RM 0 to 225, 2000-2007).

Common Carp

	Reach 1				Reach 2				Reach 3				Reach 4		
Year	**Mean**	**SE**	**N**		**Mean**	**SE**	**N**		**Mean**	**SE**	**N**		**Mean**	**SE**	**N**
2000	0.0	0.0	15		0.0	0.0	14		3.8	1.8	38		0.0	0.0	14
2001			0		0.0	0.0	8		0.5	0.3	47				0
2002	0.5	0.3	49		0.4	0.2	95		1.8	0.5	168		1.5	0.8	24
2003	0.0	0.0	43		0.0	0.0	48		1.0	0.4	117		0.3	0.3	39
2004	0.0	0.0	48		0.0	0.0	48		0.6	0.3	119		2.0	1.2	50
2005	0.0	0.0	48		0.0	0.0	49		0.3	0.2	124		1.1	0.7	51
2006	0.0	0.0	48		1.0	0.6	48		0.2	0.2	106		0.4	0.3	49
2007	0.0	0.0	36		0.3	0.3	36		0.9	0.4	89		0.9	0.5	36

	Reach 5				Reach 6				Reach 7				Reach 8		
Year	**Mean**	**SE**	**N**		**Mean**	**SE**	**N**		**Mean**	**SE**	**N**		**Mean**	**SE**	**N**
2000	2.3	0.4	151				0		4.5	1.1	35		5.0	1.4	15
2001	1.8	0.7	38		1.0	1.0	18		0.9	0.7	18		2.4	1.3	18
2002	5.0	0.8	210		9.3	2.0	82		7.8	2.2	48		6.2	2.0	48
2003	2.7	0.5	169		6.5	1.6	48		9.7	2.0	73		4.8	0.9	72
2004	3.3	0.6	157		7.4	1.6	107		4.1	0.9	96		4.9	1.3	48
2005	1.9	0.5	169		3.3	0.8	95		2.0	0.5	91		2.1	0.6	47
2006	2.8	0.5	170		4.9	1.0	96		3.7	0.9	96		3.3	0.9	48
2007	1.4	0.6	129		2.3	0.6	72		0.9	0.6	69		2.5	1.1	36

	Reach 9				Reach 10				Reach 11		
Year	**Mean**	**SE**	**N**		**Mean**	**SE**	**N**		**Mean**	**SE**	**N**
2000	15.1	4.9	12		6.1	3.1	14		6.7	4.0	4
2001	6.1	1.8	17				0				0
2002	10.5	2.4	48		5.5	1.9	43				0
2003	13.8	2.1	115		5.7	2.2	48		8.1	3.1	25
2004	10.5	2.0	60		2.6	1.1	60		4.2	1.7	40
2005	7.0	2.5	91		1.5	0.6	59		1.0	0.4	60
2006	6.6	1.5	56		3.6	1.2	54		2.0	0.8	40
2007	2.1	0.8	69		0.5	0.5	47		1.1	0.6	30

Appendix 8. Mean, standard error, and sample size for flannelmouth sucker catch per unit effort (fish / hour, electrofishing) for the fish reaches (1 – 11), Colorado River (RM 0 to 225, 2000-2007).

Flannelmouth Sucker

	Reach 1			Reach 2			Reach 3			Reach 4		
Year	**Mean**	**SE**	**N**	**Mean**	**SE**	**N**	**Mean**	**SE**	**N**	**Mean**	**SE**	**N**
2000	0.0	0.0	15	0.0	0.0	14	2.8	1.0	38	1.2	1.2	14
2001			0	0.0	0.0	8	1.3	0.7	47			0
2002	0.0	0.0	49	0.2	0.2	95	1.8	0.4	168	0.5	0.5	24
2003	0.0	0.0	43	0.0	0.0	48	1.4	0.5	117	0.9	0.5	39
2004	0.2	0.2	48	0.5	0.3	48	0.7	0.3	119	0.5	0.3	50
2005	1.5	0.6	48	2.7	1.2	49	3.1	0.9	124	2.4	1.2	51
2006	0.8	0.5	48	3.6	1.6	48	6.5	2.5	106	9.7	2.6	49
2007	0.3	0.3	36	0.3	0.3	36	7.6	1.7	89	3.5	1.0	36

	Reach 5			Reach 6			Reach 7			Reach 8		
Year	**Mean**	**SE**	**N**	**Mean**	**SE**	**N**	**Mean**	**SE**	**N**	**Mean**	**SE**	**N**
2000	0.8	0.2	151			0	0.9	0.5	35	1.1	0.7	15
2001	0.3	0.2	38	1.2	0.7	18	0.5	0.5	18	0.8	0.5	18
2002	0.4	0.2	210	1.0	0.5	82	1.5	0.7	48	3.1	0.9	48
2003	0.1	0.1	169	0.7	0.5	48	2.5	1.8	73	4.2	1.0	72
2004	0.7	0.2	157	2.4	1.0	107	3.3	1.3	96	9.2	2.5	48
2005	0.5	0.2	169	4.7	0.9	95	3.3	0.8	91	8.2	2.9	47
2006	4.1	0.8	170	22.4	3.5	96	16.8	2.6	96	30.7	5.2	48
2007	2.6	0.6	129	19.4	4.1	72	7.6	1.7	69	21.2	4.8	36

	Reach 9			Reach 10			Reach 11		
Year	**Mean**	**SE**	**N**	**Mean**	**SE**	**N**	**Mean**	**SE**	**N**
2000	0.4	0.4	12	0.8	0.5	14	0.0	0.0	4
2001	0.0	0.0	17			0			0
2002	1.5	0.6	48	0.3	0.3	43			0
2003	3.6	1.0	115	0.2	0.2	48	0.9	0.6	25
2004	7.6	2.1	60	3.7	1.5	60	2.8	1.0	40
2005	4.3	0.8	91	1.3	0.5	59	1.6	1.0	60
2006	19.2	3.5	56	8.9	2.5	54	4.5	1.2	40
2007	10.4	2.0	69	5.9	1.3	47	4.7	1.6	30

Appendix 9. Mean, standard error, and sample size for bluehead sucker catch per unit effort (fish / hour, electrofishing) for the fish reaches (1 – 11), Colorado River (RM 0 to 225, 2000-2007).

Bluehead Sucker

	Reach 1			Reach 2			Reach 3			Reach 4		
Year	**Mean**	**SE**	**N**	**Mean**	**SE**	**N**	**Mean**	**SE**	**N**	**Mean**	**SE**	**N**
2000	0.0	0.0	15	0.0	0.0	14	0.0	0.0	38	0.0	0.0	14
2001			0	0.0	0.0	8	0.0	0.0	47			0
2002	0.0	0.0	49	0.0	0.0	95	0.1	0.1	168	0.0	0.0	24
2003	0.0	0.0	43	0.0	0.0	48	0.3	0.2	117	0.3	0.3	39
2004	0.0	0.0	48	0.0	0.0	48	0.3	0.2	119	0.2	0.2	50
2005	0.0	0.0	48	0.0	0.0	49	1.0	0.3	124	0.5	0.3	51
2006	0.0	0.0	48	0.0	0.0	48	2.6	0.9	106	3.9	1.7	49
2007	0.0	0.0	36	0.0	0.0	36	2.0	0.7	89	3.9	1.9	36

	Reach 5			Reach 6			Reach 7			Reach 8		
Year	**Mean**	**SE**	**N**	**Mean**	**SE**	**N**	**Mean**	**SE**	**N**	**Mean**	**SE**	**N**
2000	0.1	0.0	151			0	0.2	0.2	35	0.0	0.0	15
2001	0.0	0.0	38	0.3	0.3	18	0.3	0.3	18	0.4	0.4	18
2002	0.1	0.1	210	0.0	0.0	82	0.0	0.0	48	0.0	0.0	48
2003	0.3	0.1	169	0.5	0.3	48	0.3	0.3	73	0.1	0.1	72
2004	0.1	0.1	157	0.7	0.5	107	0.6	0.3	96	0.7	0.5	48
2005	0.7	0.3	169	3.4	0.9	95	3.7	0.9	91	1.2	0.5	47
2006	1.2	0.3	170	2.8	0.8	96	3.4	0.8	96	5.4	1.1	48
2007	0.9	0.3	129	0.8	0.4	72	1.0	0.5	69	1.2	0.6	36

	Reach 9			Reach 10			Reach 11		
Year	**Mean**	**SE**	**N**	**Mean**	**SE**	**N**	**Mean**	**SE**	**N**
2000	0.0	0.0	12	0.0	0.0	14	0.0	0.0	4
2001	0.0	0.0	17			0			0
2002	0.0	0.0	48	0.0	0.0	43			0
2003	0.4	0.2	115	0.0	0.0	48	0.0	0.0	25
2004	0.6	0.3	60	0.0	0.0	60	0.0	0.0	40
2005	0.5	0.2	91	0.0	0.0	59	0.0	0.0	60
2006	0.8	0.4	56	0.2	0.2	54	0.0	0.0	40
2007	0.3	0.3	69	0.2	0.2	47	0.0	0.0	30