Salmonid population size, relative density and distribution in the Colorado River in Grand Canyon during 2001 with reference to sampling designs for long term monitoring

Annual Report
August 2003

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Cooperative Agreement 02WRAG0030

Abstract

We sampled the salmonid population in the Colorado River in Grand Canyon between river miles 39 and 197 during March 9-19, 2001. Using single pass (catch-per-effort, CPE) and depletion electrofishing, we collected 164 EF samples allocated randomly among the 11 geomorphic reaches. To evaluate differences in catchability under varied water clarity conditions, we collected 13 depletion samples in turbid water (ca. > 180 NTU) for comparison with clear-water samples collected during 2000. We calculated population estimates for rainbow and brown trout over a range of sample sizes obtained during June 2000 through March 2001. We evaluated precision of sampling for long-term monitoring of salmonids based on projected and observed coefficients of variation (CV) in relation to sample sizes.

Catchability of rainbow trout was significantly greater in turbid water than in clear water, but catchability of brown trout did not vary with water clarity. We concluded that relatively precise population estimates could be calculated using longitudinal data providing appropriate catchability coefficients are used in the calculations. However, if additional research regarding population estimates is needed—such as effects of varied flow regimes on catchability—such objectives should be relegated to separate river trips rather than adding them to long-term monitoring trips.

Data from the March 2001 trip produced population estimates of 369,000 RBT (95% CI: 240,000, 499,000) between RM 39-196, and 84,000 BNT (95% CI: 55,000, 114,000) between RM 39 and 160. Confidence intervals of population estimates from sample sizes ranging from N = 50 to N = 315 overlapped considerably, suggesting that adequate population estimates can be produced from a minimum of roughly 80 spatially

stratified EF runs/trip. However, minimum sample sizes required for population estimates are likely inadequate to serve the needs of long term monitoring using CPE data.

Bootstrapped CV from the March 2001 trip indicated that approximately 375 EF samples/year are required for adequate long-term monitoring of brown trout, but calculations from data collected during 1991-2000 indicated that 734 samples/year are required. We recommend that the latter, more conservative sample size be adopted for long term monitoring, because it was based on data sets which contained more sources of variation than the single monitoring trip of March 2001. We feel that 700-800 EF samples can be collected annually during two mainstem river trips, providing that sampling duration be reduced from 600 to 300 seconds EF/sample and trip length is increased from 10 to 18 days. These data should provide spatially referenced relative density estimates for rainbow trout, brown trout and common carp.

Error of system-wide estimates of trout population size in Grand Canyon will likely always be substantial in relation to that obtained through relative abundance (CPE) estimates. Sources of catchability variance likely include not only turbidity, but also (at a minimum) local fish density, discharge, water temperature, substrate, and EF crew; considerable uncertainty also exists regarding assumptions on cross-channel distribution of trout and their effects on accuracy of population estimates. Addressing these factors will likely require expensive, additional depletion research, and such research should not take place on regular long-term monitoring trips. We suggest limiting further depletion experiments under varied environmental conditions in favor of pursuing target long-term monitoring index EF sample sizes.

Until comprehensive data frameworks requiring population estimates are developed—such as system-wide bioenergetics or stock assessment models—we recommend that managers place less emphasis on population estimates as a long-term monitoring metric and more emphasis on establishing a long-term relative abundance data set to track fish community response to changes in fishery policy or dam operations.

We sampled Kanab Creek for flannelmouth suckers (FMS) during April of 2002. We did not sample during the spawning event and Only 12 FMS were captured. None of these fish were adults or young of the year.

Introduction

Over the past decade, considerable research and monitoring has been conducted on the effects of varied flow regimes on aquatic biota of the Colorado River below Glen Canyon Dam (GCD). Management recommendations for native fish based on these studies have assumed physical components of the ecosystem (regulated flows, temperature) are the primary factors governing native fish recruitment and survival in Grand Canyon. However, predation by introduced salmonids has also been implicated as a factor limiting native fishes in the Colorado River (Marsh and Douglas 1997, Minckley 1991). Little is known of the population size and dynamics of salmonids in Grand Canyon, and a quantitative evaluation of sample sizes required for adequate monitoring is lacking. Grand Canyon Monitoring and Research Center (GCMRC) is currently developing a long-term monitoring program that will include efforts to monitor status and trends of the fish community.

The focus of this report is to evaluate techniques and level of effort required to obtain powerful, accurate and spatially referenced information on status and trends of salmonid populations in Grand Canyon. Specific objectives were to:

1. Estimate density, distribution, and population size of rainbow trout (*Oncorhynchus mykiss)* and brown trout (*Salmo trutta*) in Grand Canyon. Methodological components of this objective are:
    a) Evaluate catchability (q) estimates under varying water clarity.
    b) Estimate effective shocking distance from the shoreline to facilitate extrapolation of nearshore density estimates across the entire river width.

2. Evaluate required annual sample sizes for long-term monitoring of salmonids in Grand Canyon.

We also conducted a low-cost feasibility study at Kanab Creek in hopes of developing another data set suitable for modeling the flannelmouth sucker population. The flannelmouth sucker PIT tag database extends from 1991 to present. It includes suckers captured throughout the Grand Canyon Ecosystem (GCE). Historic tagging efforts have focused on spawning aggregations. These efforts have yielded a database comprised primarily of adult (>300 mm TL) fish. Efforts to model the FMS population with this data have been unsuccessful in all areas of the Grand Canyon except the Little Colorado River. We need data sets that include all ages of FMS. Since this species exists and spawns throughout the GCE it is risky to only monitor survival and recruitment at only one location. Sampling in 2002 was an attempt to explore the potential of Kanab Creek as another site for monitoring recruitment and survival of FMS within the GCE.

Methods

We collected electrofishing (EF) samples from March 9 - 19, 2001 between RM 39 and RM 197 on the Colorado River in Grand Canyon National Park (Figure 1). Discharge from GCD ranged from 7,530 cfs to 13,400 cfs during the study period. All data for population estimates were collected at night with two 16' Achilles inflatable sport boats outfitted for electrofishing, with two netters per boat. Sampling was conducted for an average of 5 hours per night beginning at about 7 pm. We anesthetized all captured salmonids with clove oil and recorded maximum total length (mm) for each fish. We clipped the adipose fin on all salmonids over 100 mm and implanted all brown trout >120mm with passive integrated transponder (PIT) tags. We released all fish alive.

Index Electrofishing and Sample Size

We used single-pass (index) electrofishing to estimate relative density (catch per effort, CPE) and longitudinal distribution of salmonids within Grand Canyon. Each sample consisted of a single (600 sec) electrofishing pass through the selected transect. We selected electrofishing transects from within the 11 geomorphic reaches identified by Schmidt and Graff (1990). Each geomorphic reach was divided into fishable sub-reaches in which transect start miles were randomly selected through a MS Excel spreadsheet ("RAND" function). Fishable sub-reaches were selected by campsite availability and location of impassable navigational hazards such as rapids (Table 1).

We used the sample power program Sampling.exe (Carl Walters, unpublished) to determine appropriate sample sizes within each geomorphic reach. Using variance estimates from existing Grand Canyon fisheries data, Sampling.exe estimates CPE sample precision as a function of sample size and spatial stratification. The program also utilizes a Monte Carlo procedure to estimate the probabilities of detecting a true temporal population trend given a range of sample sizes.   We selected the design in the present study based on its projected level of sampling precision (coefficient of variation, CV, or standard error of the mean / mean) of 0.10, whereby power for detecting a 19% change in salmonid relative abundance from one year to the next is 0.80 using bi-directional tests for significance, or a 13% change for one directional tests (Gerrodette 1987, 1993; Gerrodette and Brandon 2002). These parameters reflect conventional usage by diverse monitoring programs (Carl Walters, personal communication), but they are also maximized within known logistical and budgetary constraints of sampling trips. We evaluated the predictions of Sampling.exe by bootstrapping trip CVs from the March 2001 data over a range of sample sizes using Resampling Stats 1.1 for MS Excel (Resampling Stats, Inc., 1999).

For the present study design, the Sampling.exe Monte Carlo procedure "sampled" EF data collected by BioWest during 1991-1994; input variance/mean ratios were also approximated from that data. We subsequently re-evaluated the present design using variance/mean estimates and EF data collected by multiple agencies from 1991-2000. We feel the larger data set provides a more conservative estimate of sample variance because it incorporates more sources of variance than the Bio/West data set, particularly extreme values resulting from positive trends in salmonid relative abundance observed from 1991-2000. We then compared predictions using the 1991-2000 data set with predictions made from shorter-term data sets (Bio/West data, bootstrapped data from the present study).

Depletion electrofishing, catchability and population estimates

Depletion sampling in 2000 indicated catchability (q, or fraction of fish present that are captured per electrofishing pass) might change with water clarity (Arizona Game and Fish Department [AGFD], unpublished). To further evaluate water clarity-specific differences in q, we completed 13 multiple pass depletion samples during March 2001 in the area between RM 83 to RM 88 where both BNT and RBT were abundant and turbidity was high (Table 2). Each depletion experiment was conducted over a period of 2-3 hours and consisted of a series of consecutive passes through the selected transect. Effort was approximately 600 seconds per pass. Depletion experiments were concluded after catches declined to approximately 20% of the initial pass. To minimize within-sample effects of immigration/emigration, depletion transects were selected according to presence or absence of natural barriers (sand bars, debris fans) at the upper and lower ends of the transect. We withheld captured fish in a live well during successive passes and released them following sampling. We compared q values estimated from sampling under turbid and clear water conditions using two-sample *t*-tests.

Using data from depletion electrofishing, we searched for an estimate of absolute fish abundance in an EF transect (N_0) which maximized likelihoods for individual EF passes, which are expressed as

$$P\{C_i|N_i, q\} = \ln [(N_i!/C_i! * (N_i - C_i)!) * q^{Ci} * (1-q)^{Ni - Ci}].$$

The joint likelihood of N_0 is the sum of likelihoods for passes 1 through i, C_i is the number of fish captured during the i^{th} pass, and N_i is the number of fish remaining in the transect after the i^{th} pass if N_0 were true. Thus, $N_1 = N_0 - C_1$ for the first pass, $N_2 = N_1 - C_2$ for the second pass, and so on. The catchability coefficient q (fraction of fish removed per EF pass) is also expressed as total fish captured per depletion experiment divided by N_0. We used a maximum binomial likelihood search routine developed by Carl Walters (unpublished) in conjunction with MS Excel spreadsheet formulas to search for N_0.

We calculated population estimates for RBT and BNT by scaling transect-specific estimates of local fish abundance from depletion electrofishing to their associated first-pass CPE values, and extrapolating these numbers to system-wide estimates according to longitudinal patterns in CPE from index runs. Relation of first-pass CPE values from depletion EF to associated estimates of local fish abundance (N_0) was made through simple linear regression (forced zero intercept).

We plotted abundance estimates (fish/RM) predicted from observed CPE values against river miles and fitted the data with a third order polynomial regression line. We then integrated the curve to produce system-wide population estimates. Confidence intervals were estimated from the variance of the regression line. Additional details of depletion-based population estimates and system-wide expansion techniques can be found in AGFD 2001.

To evaluate sample size efficiency of these population estimates, we compared population estimates from data collected during five mainstem river trips in 2000 to those derived from the single March 2001 trip. Water was predominantly clear during 2000 sampling but highly turbid during March 2001, creating the need to test the ability of our population model to predict appropriate values for q under turbid (q_{turbid}) and clear (q_{clear}) water conditions. To do this, we compared population estimates from data collected during June, July and September 2000 (clear water conditions, N = 222) with estimates from data collected during August 2000 (turbid water conditions, N = 93). We treated turbidity as a categorical variable due to the lack of intermediate data points between extremes of ca. ≤10 NTU (low turbidity) and several hundred NTU (high turbidity). Effects of recruitment on population estimates were assumed to be minimal given the temporal proximity of the estimates to one another. We assumed similar population estimates for the two periods to indicate that the model was predicting q accurately.

Next, we compared estimates from 2000 (5 river trips) to those obtained during March 2001. We recalculated population estimates for each trip conducted during 2000 and an estimate from aggregated 2000 samples to provide estimates from sample sizes ranging from 43 to 315 EF samples. To provide comparability, we calculated estimates over the smallest river-mile interval common to all samples, which was RM 39-196 for RBT and 39-160 for BNT. We used water clarity-specific values q_{turbid} or q_{clear} to derive population estimates from data gathered under turbid or clear water, respectively.

We evaluated the estimates from 2000 and March 2001 by their approximations of orders of magnitude of fish numbers and by overlap of associated confidence intervals. We relaxed assumptions on occurrence of recruitment between summer 2000 and March 2001 in order to evaluate performances of a single river trip versus multiple trips to obtain population estimates.

Effective shocking distance

We estimated the effective shocking distance of each electrofishing boat in relation to the shoreline to facilitate extrapolation of near-shore population estimates to the entire river. Each netter visually estimated average width of shocked area between the front of the shocking boat and the shoreline several times during each run. Reference marks at meter intervals on the handle of each net assisted in estimating the width of the shocked area.

Flannelmouth sucker sampling

Scott Rogers (AGFD) and Lainie Johnstone (SWCA) participated in the second half of the Grand Canyon exotic fish monitoring trip (Trip # GC20020404) and were dropped at the Kanab Creek confluence on April 16, 2002. One large (3 ft. diameter $^{3}/_{8}$

inch mesh) winged hoop net was placed in the center of the tributary 100 meters upstream from the confluence. The mouth of the net was placed downriver and wings extended to each shore to capture all fish traveling upriver to spawn. Two other hoop nets (2ft. diameter $^3/_8$ inch mesh) were place 150 and 250 meters upstream of the confluence to capture fish already in the creek. Nets were checked daily April 17-20. All fish were weighed (g) and measured (mm). FMS and bluehead suckers (BHS) greater than 150 mm total length were scanned for tags and pit tagged if none was present. Scott and Lainie departed Kanab Creek on April 20th when they joined the kanab amber snail crew for the run out to Diamond Creek.

Results

Index Electrofishing and Sample Size

Each boat completed an average of eight, 600-second electrofishing samples per night (Table 1). Thirty-one percent of samples were collected in areas with known high brown trout densities (RM 80-109), with 20 % of samples collected near the Little Colorado River (RM 57-69; Figure 1). The remaining river miles (except RM 0-39 and 197-225) were also sub-sampled (Figure 1). We captured a total of 1654 fish in 164 electrofishing samples comprising 5 non-native and 4 native species (Table 3). Catch per effort estimates by river mile indicate rainbow trout densities generally decrease downstream while brown trout are concentrated from river mile 84 to 97 in the area around Bright Angel Creek in the Inner Granite Gorge (Figures 1, 2, 3).

Sample CV during the March 2001 trip was 0.08 for RBT and 0.16 for BNT. Bootstrapped CV from the data indicate that in contrast to output from Sampling.exe, approximately 375 samples collected annually are needed for adequate long-term monitoring (i.e., CV ≤ 0.10) of BNT relative density and distribution (Figure 4). For RBT, only 100 samples are needed annually for such levels of precision (Figure 5). Iterative runs of Sampling.exe using the 1991-2000 EF database indicated that 734 EF CPE samples collected annually are required for adequate long term monitoring of BNT, but only 106 samples are required for RBT.

Depletion electrofishing, catchability and population estimates

Over similar river miles, mean CPE of rainbow trout was higher in turbid water (764.3 fish/10 h) than in clear water during summer 2000 (440.3 fish/10 h; two sample t-test, df = 304, $P < 0.001$). Average CPE of brown trout in turbid water was not significantly different than in clear water. Mean q of rainbow trout was significantly higher in turbid water (0.65) than in clear water (0.50) (two-sample *t*-test, df = 70, $P < 0.001$). Mean q of brown trout was not significantly different in turbid water than in clear water. Despite results from statistical comparisons, however, constants for scaling CPE to N_0 for both species were different from one another, so all subsequent population estimates were carried out using values specific to turbid or clear water clarity conditions (Figures 6,7).

Data collected under turbid and clear water conditions during summer 2000 returned similar population estimates for both RBT (Figure 8) and BNT (Figure 9) indicating that our model was predicting appropriate values for q under varied water clarity. Data from the March 2001 trip produced population estimates of 369,000 RBT (95% CI: 240,000,499,000; Figure 10) between RM 39-196, and 84,000 BNT (95% CI: 55,000, 114,000; Figure 11) between RM 39 and 160. Estimates for RBT over RM 39-

196 from trips conducted during 2000 ranged from 208,000 to 868,000 RBT and from 11,000 to 122,000 BNT over RM 39-160 (Figures 10 and 11; Table 6). Samples comprised of at least 50-80 EF runs/trip tended to produce estimates with overlapping confidence intervals.

Effective shocking distance

The estimated average width of shocked area was 4.15 m (standard deviation = 0.7 m; Table 4).

Flannelmouth sampling

Only 12 FMS were captured during this feasibility study (Table 7). No adult FMS were captured and no young of the year FMS were present in our samples (Figure 13).

Discussion

Catchability and Population Estimates

We feel that depletion samples were conducted on highly discrete spatial (delimited transects ca. 0.1 mile in length) and temporal (consecutive EF removal passes) scales. During 2000, AGFD (2001) observed that mean q for RBT including first depletion passes (0.52) was nearly identical to that based on second and later passes only (0.51), suggesting that catchability variance among successive passes was minimal. Nevertheless, magnitude of error associated with fish immigration and/or emigration during experiments in conjunction with uncertainties surrounding assumptions on fish distribution along cross-channel gradients of the river is unknown and probably substantial. In practice, negative biases of 30-50% in depletion estimates are not uncommon (Hilborn and Walters 1992). Through comparison of population estimates from depletion with results from concurrent 24 h mark/recapture experiments, AGFD (2001) estimated that despite relatively uniform catchability among passes, depletion estimates may be biased negatively by a factor of at least 1.5 and as much as 3.

It is very possible, however, that negative biases associated with depletion estimators may be overwhelmed by positive biases introduced by extrapolation. Based on observations of non-uniform distribution of rainbow trout in the Lee's Ferry reach (Speas et al. *in revision*), our assumption of uniform distribution of trout across the Colorado River channel in Grand Canyon is invalid. In at least half of the transects surveyed in Speas et al. (*in revision*), the majority of fish were found within ca. 10 m of the shoreline. None of the current estimates made for Grand Canyon account for cross-channel distribution, so they are likely biased positively. Grand Canyon Monitoring and Research Center and AGFD continue to evaluate quantification of fish distribution across the river channel and categorization of fish density by habitat type, and we hope to integrate these data with future population estimates.

High turbidity may lead to behavioral differences in trout that increase q and alter resultant population estimates. Water transparency has been shown to affect electrofishing catch rates, with the highest catch rates often occurring in water with intermediate transparency (Reynolds 1983). Moderate levels of turbidity apparently decrease the likelihood that fish will perceive and actively avoid the electrofishing boat before they are captured (Kirkland 1965), but stunned fish are more difficult to observe and net when turbidity levels are too high (Dewey 1992). Turbidity and reduced light penetration alter trout behavior in laboratory studies by reducing reactive distances, altering foraging behavior and decreasing association with substrates (Barrett et al. 1992, Gradall and Swenson 1982, Noggle 1978). In highly turbid water rainbow trout may remain closer to the water surface than in clear water making them more vulnerable to capture. We hypothesize that turbidity levels observed in our study concealed the boat from rainbow trout, yet were not high enough to conceal the fish from the netting crews.

Turbidity during the March trip was classified as high, which corresponds to NTU measurements ranging from 180 to over 600. Coefficients for q_{clear} or q_{turbid} available from the present data are probably sufficient for future population estimates. We suggest that turbidity data remain categorical as "low", or ≤10 NTU observed during EF trips conducted in June and July of 2000, and "high", i.e., hundreds of NTU as observed in August of 2000 and March 2001 (U.S. Geological Survey, unpublished data). Development of linear variation of q with absolute NTU data among intermediate ranges of turbidity would require considerable extra research, and such precision is likely unimportant given other sources of variance associated with population. Furthermore, gathering such data within the framework of a single, annual salmonid monitoring trip would severely compromise reaching target sample sizes. With the additional objectives of hoopnetting and depletion sampling during March 2001, for example, we were unable to complete the target 240 index electrofishing samples needed for long term monitoring. There is clearly a trade-off associated with adding research objectives to monitoring trips.

Our population model works well in capturing effects of changing water clarity on catchability, particularly for RBT. The model returned comparable population estimates for data gathered under both categorically turbid and clear conditions because the model allows q estimates to vary with individual samples. Since CPE was greater during turbid conditions, CPE = q (N_0) dictates that q should increase as well, assuming negligible changes in N_0. The use of q_{clear} on data gathered under turbid conditions would lead to 23% and 33% overestimates of RBT and BNT densities, respectively. Environmental factors that cause variations in q can lead to bias in density estimates (Bohlin and Sundstrom 1977; McInery and Cross 2000; Bayley and Austen 2002).

Previous population estimates for rainbow and brown trout in the Grand Canyon were based on extrapolation of densities from undetermined sample areas. Estimating the actual area shocked during each run allows density estimates to be extrapolated across the entire river width. The effective shocking distance of 4.15 m was incorporated into density estimates to allow extrapolation of nearshore estimates across the channel width. This measurement has the effect of scaling estimates reported by AGFD (2001) upward by about 9.0%.

Comparisons of population estimates over a wide range of sample sizes indicate that adequate estimates can be produced from a minimum of roughly 80 EF runs/trip, providing the CPE data is gathered over sufficient river distance. Stratification according to the 11 geomorphic reaches should ensure adequate longitudinal coverage necessary for population estimates. Sample sizes less than 80 tended to produce estimates that were slightly different from those produced from larger sample sizes (Table 6), especially for BNT in which confidence intervals intercepted zero for N=50. However, minimum sample sizes required for population estimates are likely inadequate to serve the needs of long term monitoring (see *Sample Size*). The need for long-term monitoring of salmonid relative abundance (CPE) and distribution—rather than needs for population estimates—

should therefore dictate minimum sample sizes and trip duration rather than annual population estimates.

Population estimates must account for differences in catchability between trips to accurately reflect population size, and local population estimates should be expanded with realistic estimates of cross-channel fish distribution. Moreover, sources of catchability variance not only include turbidity, but also (at a minimum) local fish density, discharge, water temperature, substrate, and EF crew (Speas et al., *in review*). Addressing these factors will likely require expensive, additional depletion research, and such research should not take place on regular long-term monitoring trips (see S*ample Size*).

Error of system-wide estimates of trout population size in Grand Canyon will likely always be substantial in relation to that obtained through relative abundance (CPE) estimates. Moreover, we believe that in and of themselves, population estimates serve few long-term monitoring information needs and generate more questions than they answer. Until comprehensive data frameworks requiring population estimates are developed—such as system-wide bioenergetics or stock assessment models—we recommend that managers place less emphasis on population estimates and more emphasis on establishing a long-term relative abundance data set to track fish community response to changes in fishery policy or dam operations.

Sample size

Iterative runs using Sampling.exe (Bio/West 1991-1994 EF data input) suggested that 240 electrofishing samples are needed each year for brown trout and 100 samples per year are needed for rainbow trout to detect 10-20 % changes in density over 5 years.

Bootstrapped CVs from the March 2001 trip provides a more conservative projection (375 samples for BNT) for attaining appropriate sample sizes given the logistics of a single, annual salmonid monitoring trip. The lower estimate is likely due to misspecification of variance/mean ratios during initial usage of Sampling.exe in the planning phase of the March 2001 trip. However, addition of data from 1991-2000 to the program produced even more conservative predictions, i.e., about 730 samples are required for adequate BNT monitoring.

We feel that the larger sample size has the best probability of detecting long term trends because input variance estimates for that simulation contained more sources of variation than either the Bio/West data or data from the present study (Gerrodette 1987), and is probably a better approximation of the true, underlying CPE distribution for BNT in the system (Walters, personal communication; Hilborn and Mangel 1997). There is also a strong possibility that the larger sample sizes (700-800 EF runs/year) may lend themselves well to long-term monitoring of non-salmonid fishes such as common carp, humpback chub, and perhaps others.

The 1991-2000 data set reflected the disparity between frequencies of zero and non-zero catches obtained by sampling across the entire system for nearly a decade. By contrast, the temporally discrete data from the March 2001 trip were concentrated in areas of high BNT occurrence, which artificially diminished variance estimates by decreasing occurrence of zero catches. Data of such limited scope should not be used to make projections on required sample sizes.

Due to our need to clarify effects of turbidity on catchability by conducting depletion experiments during March 2001, we were unable to obtain the required samples for adequate monitoring. A total of 164 electrofishing samples were obtained which appears to be sufficient to monitor changes in rainbow trout (CV=0.08). However, sample CV for brown trout (CV=0.16) was to high for long term monitoring.

Collecting the required 730 index EF runs for adequate BNT monitoring will likely require two annual river trips, each consisting of approximately 18 shocking nights with two boats completing 12 runs per boat per night. Reducing each sample period from 600 seconds to 300-400 seconds should increase the number of samples that can be collected per night without a significant decrease in precision (Figure 12). We should also consider a crew rotation at Phantom Ranch to avoid fatigue, ensure data quality and river safety.

Electrofishing trips should be conducted during months when days are short and probability of rainfall is low or intermediate (Table 5). While periods of closure to motorized watercraft in Grand Canyon prevent sampling from September 15 through December 15, EF trips could be conducted from December 15 through April, with the latter month having the best balance between chance of rain and day length (table 5).

Flannelmouth sampling

The timing of the spawning event is critical in successful sampling of FMS at spawning sites. We missed the FMS spawning in Kanab Creek in 2002.   No adult fish were captured. And no young of the year FMS were present in our sample. Either fish were too small to be vulnerable to our nets or we sampled prior to the spawn. The lengths of the fish that were captured are encouraging. Flannelmouth suckers between 150-300mm have eluded us throughout much of the historic sampling and are necessary for population models. We need to continue to search for another site for monitoring and modeling FMS in the GCE. I still believe that Kanab Creek is our most likely site. This year's effort was an attempt to sample this spawning aggregate with little cost. We need to discuss means of detecting spawning activity in the creek and placing people in the field opportunistically to sample. There are many science trips on the river during this time of the year and we may be able to continue sharing costs to keep this monitoring effort less expensive.

Summary and Recommendations

1. Error of system-wide estimates of trout population size in Grand Canyon will likely always be substantial in relation to that obtained through relative abundance (CPE) estimates. Until comprehensive data frameworks requiring population estimates are developed—such as system-wide bioenergetics or stock assessment models—we recommend that managers place less emphasis on population estimates as a long-term monitoring metric and more emphasis on establishing a long-term relative abundance data set to track fish community response to changes in fishery policy or dam operations.
2. Conduct two annual mainstem river trips utilizing EF for monitoring of spatial salmonid distribution and relative density. Target sample size is 734 EF runs selected randomly within the 11 geomorphic reaches. To ensure target sample sizes are attained, no depletion or special research objectives should be added to these trips. Trip duration should be 18 shocking nights, with two boats

completing 12, 300-400 second EF runs per night. We should consider rotating crews at Phantom Ranch.

3. Population estimates can be calculated with relative precision using longitudinal data collected under either turbid (>180 NTU) or clear water clarity conditions by using the respective coefficients derived from q_{turbid} or q_{clear}. However, sources of catchability variance likely not only include turbidity, but also (at a minimum) local fish density, discharge, water temperature, substrate, and EF crew. Addressing these factors will likely require expensive, additional depletion research, and such research should not take place on regular long-term monitoring trips. We suggest limiting further depletion experiments under varied environmental conditions in favor of pursuing target long-term monitoring index EF sample sizes.
4. If additional research regarding population estimates is needed—such as effects of varied flow regimes on catchability—such objectives should be relegated to separate river trips rather than adding them to long-term monitoring trips. Alternatively, catchability could be evaluated during monitoring trips less frequently than annually (every other year, for example), or perhaps only when flow regimes begin to differ from those under which catchability data has already been collected.
5. Conduct electrofishing trips between December 15th and April. Planning trips to minimize the chance of rainfall while maximizing night length will increase the number of samples that can safely be obtained per trip.

6. GPS waypoints were used to identify start and stop locations for each electrofishing transect. While the waypoints are highly useful in pinpointing sample locations on digital river maps, without actual river miles on the data sheet, query of the data in the Microsoft Access database is limited. Both the river mile from the river guide and GPS waypoints need to be recorded on the data sheet to facilitate exploration of data without the use of Arcview software.
7. While it appears that mainchannel brown trout density can be monitored adequately under recommendation (2), little is known of their population biology in tributaries. A second sampling trip focusing on brown trout in the tributaries could provide an opportunity to study or remove large numbers of brown trout.
8. Continue exploring locations other than the Little Colorado River to develop a time series of FMS mark-recapture data that is adequate for modeling recruitment and densities of this species.

Acknowledgements

Grand Canyon Monitoring and Research Center funded this study under Cooperative Agreement No. 1425-98-FC-40-22690 and provided essential logistical support. We thank Dr. Carl Walters for his help in development of the catchability and population size model. We also thank the following agencies and individuals who participated in March 2001 sampling.

Agency	Crew Member
AGFD	Roland Scott Rogers
AGFD	Schuyler Sampson
U.S. Fish and Wildlife Service	David R. VanHaverbeke
U.S. Fish and Wildlife Service	Ben Galuardi
SWCA, Inc., Environmental Consultants	Jennifer Monks
GCMRC	Carol Fritzinger
GCMRC	Steve Jones
GCMRC	Stewart Reider
GCMRC	Lynn Roeder
GCMRC	Peter Weiss

Table 1. Scheduled campsites, scheduled randomized electroshocking (CPE) sites (see Table 3 for actual start miles) and depletion (DEP) sites, and actual campsites and completed samples.

Day	Date	Scheduled camp	Scheduled boat A start	Scheduled boat B start	Scheduled samples	Actual camp	Actual samples
1	3-9	Buck Farm	40.0	40.3	22 CPE	Buck Farm	8 CPE**
2	3-10	Awatubi	58.6	59.0	24 CPE	LCR Point	24 CPE
3	3-11	LCR Point	60.6	61.6	24 CPE	LCR Point	24 CPE
4	3-12	Clear creek/ Cremation	n.a.	n.a.	6 DEP	Clear Crk	7 DEP
5	3-13	Cremation	n.a.	n.a.	6 DEP	Cremation	6 DEP
6	3-14	Boucher	95.2	96.0	24 CPE	Boucher	23 CPE
7	3-15	RM 118	118.4	118.1	18 CPE	RM 118	18 CPE
8	3-16	Kanab/Olo	143.5	143.6	18 CPE	Olo	18 CPE
9	3-17	Fern Glen	167.1	169.2	18 CPE	Stairway	18 CPE
10	3-18	RM 192	193.5	192.8	18 CPE	195	18 CPE
11	3-19	Take out	n.a.	n.a.	n.a.	Take out	n.a.
				Total	178	Total	164

** Rained out on 3-9-2001. Only 8 of 22 samples were completed.

Table 2. Turbidity readings obtained during March 2001 non-native sampling trip.

Location	River Mile	Date	Turbidity (NTU)
Lee's Ferry	0	3/9	180
LCR Point (above LCR)	61	3/10	310
LCR Point (above LCR)	61	3/11	320
Clear Creek	82	3/12	647
Cremation	87	3/13	535
RM 118	118	3/15	330
Olo	144	3/16	646
Stairway	167	3/17	635
RM 195	195	3/18	660

Table 3. Total catch by species and location during March 2001. Species codes: FMS = flannelmouth sucker; CRP = common carp; CCF = channel catfish; SUC = unidentified sucker; SPD = speckled dace; RBT = rainbow trout; HBC = humpback chub; BNT = brown trout; BHS = bluehead sucker.

Camp	RM	Boat	Total Catch	RBT	BNT	Other species	Recap-tures
Buck Farm	39 – 40.4	A	128	128	0	0	1 RBT
Buck Farm	39 – 40.5	B	54	53	1	0	0
LCR Point	58.3 – 63.2	A	317	303	4	6 FMS 2 CRP 1 CCF 1 SUC	14 RBT
LCR Point	59 –63.4	B	184	170	8	1 SPD 1 FMS 1 CRP 1 HBC	6 RBT
Clear Creek	83.5 – 84.1	A	49	45	3	1 CRP	0
Clear Creek	82.0 – 84.0	B	53	45	7	1 CRP	1 BNT
Cremation	84.5 – 85.5	A	76	49	25	2 CRP	1 RBT 7 BNT
Cremation	87.3 – 88.0	B	130	53	75	1 FMS 1 SPD	5 RBT 18 BNT
Boucher	95.2-96.8	A	198	121	77	1 CRP 1 FMS	4 RBT 3 BNT
Boucher	95.2 – 96.8	B	85	43	35	6 CRP 1 FMS	2 RBT
RM 118	116.6-118.2	A	136	107	27	1 FMS 1 BHS	2 RBT
RM 118	117.2–118.4	B	58	49	3	1 FMS 3 CRP	2 RBT
Olo	144.2–146.4	A	32	28	2	1 SUC 1 CRP	1 BNT
Olo	144.1–145.6	B	52	41	7	1 FMS 2 CRP 1 BHS	0
Stairway	168.6–170.5	A	43	28	6	1 FMS 5 CRP 1 CCF 1 FHM	1 RBT
Stairway	167–170.1	B	14	11	1	1 BHS 1 CRP	0
RM 195	191.2–196.8	A	17	9	1	7 CRP	0
RM 195	190.2–196.5	B	15	7	0	8 CRP	0
	Totals		1654	1316	272	66	49

Table 4 Sample size, mean, minimum, maximum, and standard deviation of distance from shoreline sampled for both boats A and B.

Boat	Total Runs Measured	Mean Distance M	Min Distance M	Max Distance M	Std. Dev Distance M
A	43	4.3	3	7	0.8
B	28	3.9	3	6	0.6
Both A and B	71	4.15	3	7	0.7

Table 5. Average monthly precipitation (mm) for locations near the Grand Canyon (from www.weather.com) and average monthly hours of darkness/night.

Location	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Page, AZ	11	11	13	10	10	5	20	27	13	17	12	11
Grand Canyon, AZ	37	41	42	26	17	14	41	54	38	30	26	38
Kingman, AZ	29	31	29	15	7	6	23	36	23	19	18	32
Average of 3 sites	27	27	28	17	11	8	28	39	24	22	19	27
Hours of darkness/night	13.9	13.1	12.0	10.9	10.0	9.5	9.7	10.6	11.6	12.7	13.7	14.2

Table 6. Species-specific population estimates, confidence intervals and CPE sample CV in relation to trip sample sizes. RM refers to river mile intervals over which population estimates were estimated. N.A. refers to lack of population estimates due to inadequate river coverage or lack of significant regression line.

Species	Trip	N	RM	Pop.est.	CI lower	CI upper	Trip CV
RBT	AGFD (8/00)	42	18-97	N.A.	N.A.	N.A.	0.11
RBT	SWCA (9/00)	43	39-196	868,000	688,000	1,048,000	0.20
RBT	SWCA (8/00)	50	39-196	389,000	161,000	618,000	0.25
RBT	AGFD (7/00)	82	39-196	208,000	120,000	295,000	0.16
RBT	AGFD (6/00)	98	39-196	320,000	142,000	498,000	0.12
RBT	AGFD (3/01)	164	39-196	369,000	240,000	499,000	0.08
RBT	**All 2000**	**315**	**39-196**	**396,000**	**215,000**	**577,000**	**0.08**
BNT	AGFD (8/00)	42	18-97	N.A.	N.A.	N.A.	0.21
BNT	SWCA (9/00)	43	32-216	N.A.	N.A.	N.A.	0.71
BNT	SWCA (8/00)	50	39-160	11,000	<0	25,000	0.36
BNT	AGFD (7/00)	82	39-160	82,000	57,000	107,000	0.20
BNT	AGFD (6/00)	98	39-160	123,000	79,000	166,000	0.20
BNT	AGFD (3/01)	164	39-160	84,000	55,000	114,000	0.16
BNT	**All 2000**	**315**	**39-160**	**92,000**	**59,000**	**124,000**	**0.12**

Table 7. Number of fish captured by species (bluehead sucker (BHS), flannelmouth sucker (FMS), speckled dace (SPD), brown trout (BNT), fathead minnow (FHM), plains killifish (PKF)) and gear type (small hoop net (HS), winged hoop net (HW)) May 17-20, 2002, Kanab Creek.

Date	Temp	Gear Type	BHS	FMS	SPD	BNT	FHM	PKF
4/17/2002	17.9	HS	1	0	0	0	1	0
		HW	10	2	11	1	0	0
		Subtotal	**11**	**2**	**11**	**1**	**1**	**0**
4/18/2002	15.7	HS	0	1	0	0	1	0
		HW	7	2	11	0	1	1
		Subtotal	**7**	**3**	**11**	**0**	**2**	**1**
4/19/2002	13.6	HS	1	0	0	0	9	0
		HW	15	1	19	1	0	0
		Subtotal	**16**	**1**	**19**	**1**	**9**	**0**
4/20/2002	15.0	HS	0	1	0	0	16	0
		HW	4	5	25	0	0	0
		Subtotal	**4**	**6**	**25**	**0**	**16**	**0**
		TOTAL	**38**	**12**	**66**	**2**	**28**	**1**
	Cumulative TOTAL		**147**					

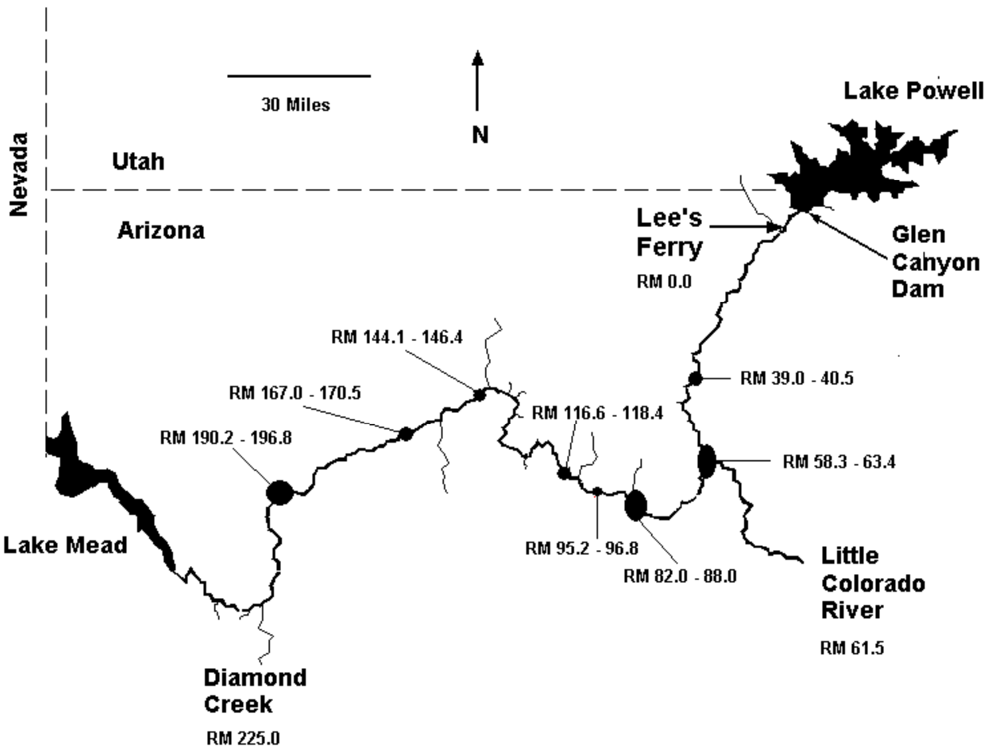

Figure 1. The Colorado River in Grand Canyon showing areas sampled during the March 2001 mainstem electrofishing survey.

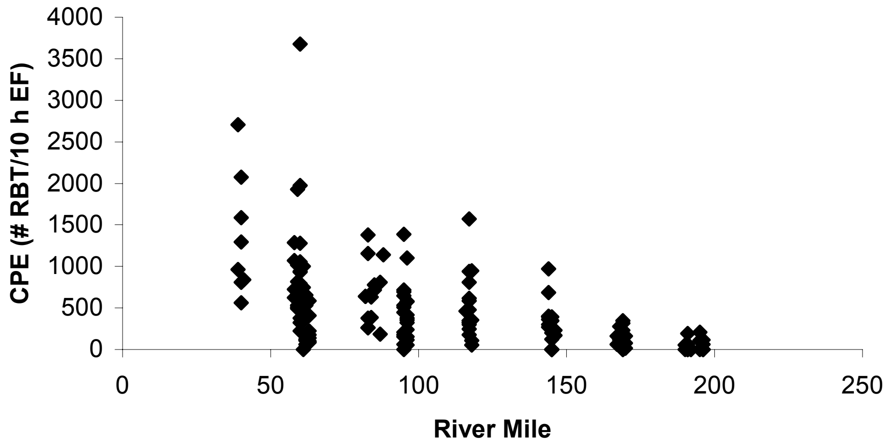

Figure 2. Catch-per-effort (# fish/10 h EF) of rainbow trout by river mile, Colorado River in Grand Canyon, March 2001.

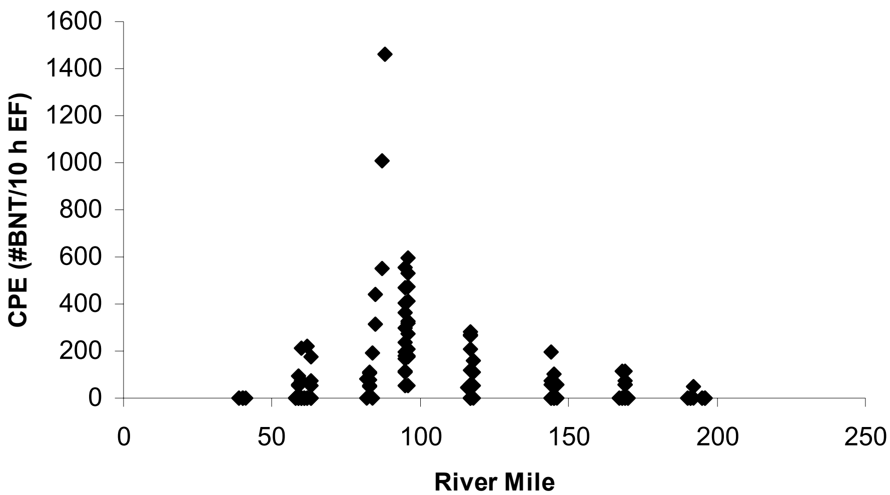

Figure 3. Catch-per-effort (# fish/10 h EF) of brown trout by river mile, Colorado River in Grand Canyon, March 2001.

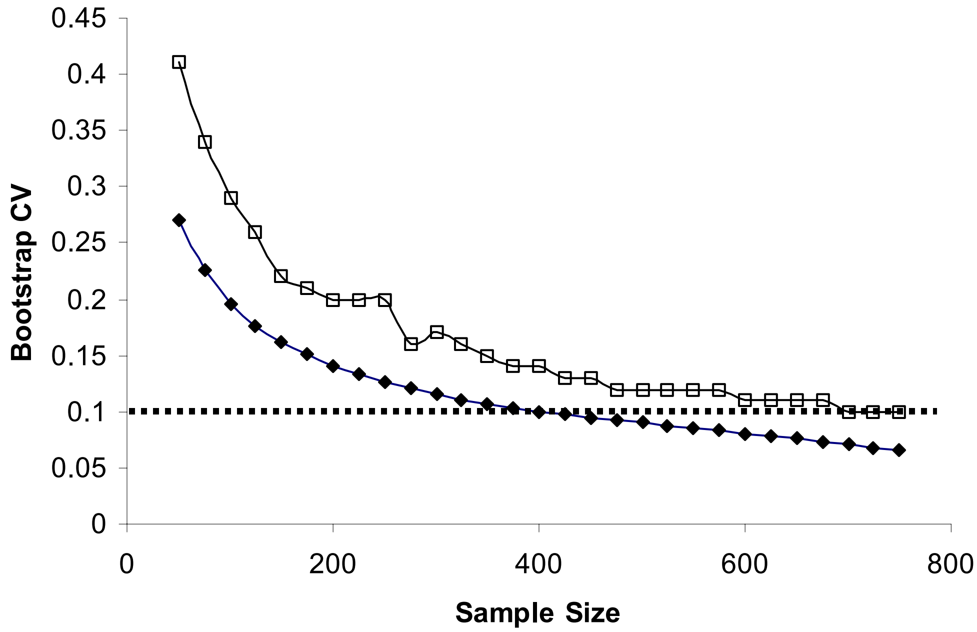

Figure 4. Bootstrapped trip coefficient of variation of brown trout EF CPE based on data from a single mainstem Colorado River trip (March, 2001, closed symbols) and multiple trips (EF data from 1991-2000, open symbols) Colorado River trip. Horizontal dashed line indicates approximate precision level for adequate long term monitoring power.

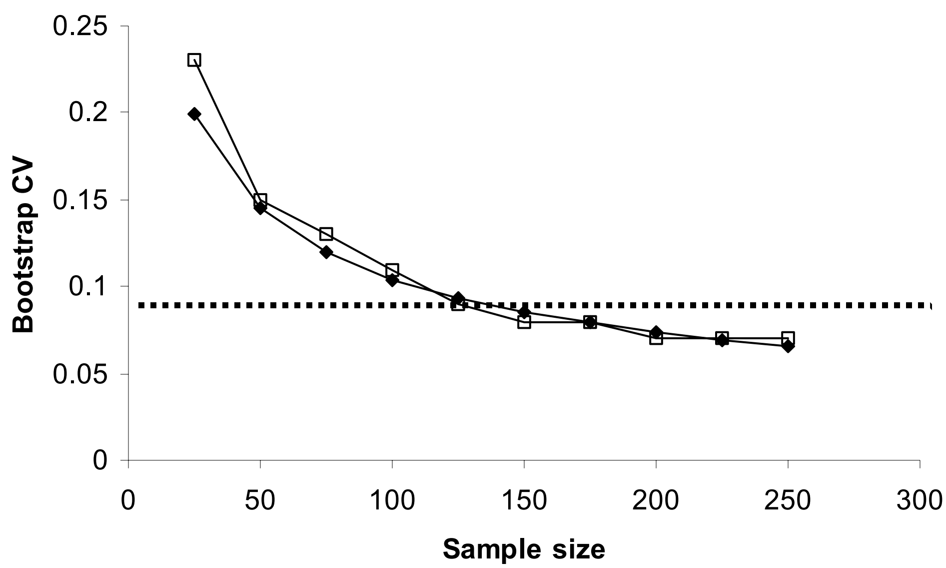

Figure 5. Bootstrapped sample coefficient of variation of rainbow trout CPE based on data from March, 2001mainstem Colorado River trip. Dashed line indicates approximate precision level for adequate long term monitoring power.

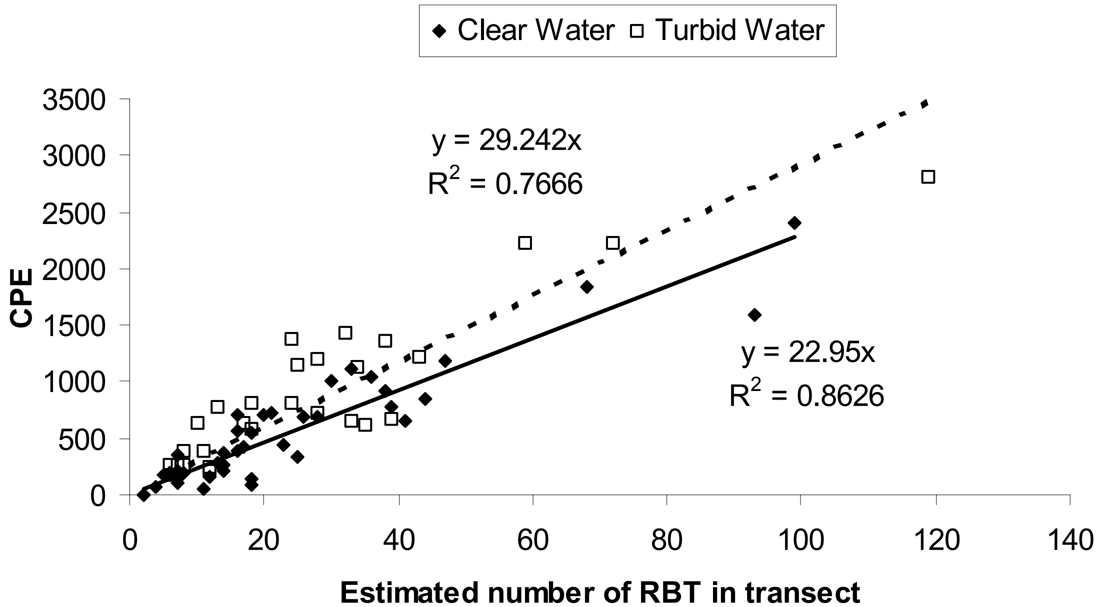

Figure 6. Relationship between estimated number of rainbow trout (from depletion EF) in sampling transect (x axis) to observed CPE (y axis) for data collected during clear (solid symbols and line) and turbid (open symbols, dashed line) water conditions during March 2001.

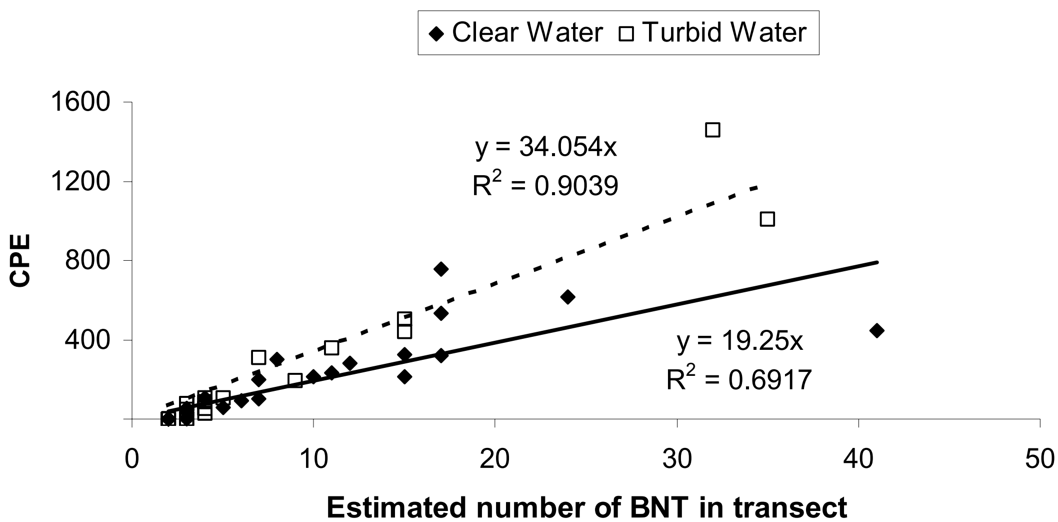

Figure 7. Relationship between estimated number of brown trout (from depletion EF) in sampling transect (x axis) to observed CPE (y axis) for data collected during clear (solid symbols and line) and turbid (open symbols, dashed line) water conditions during March 2001.

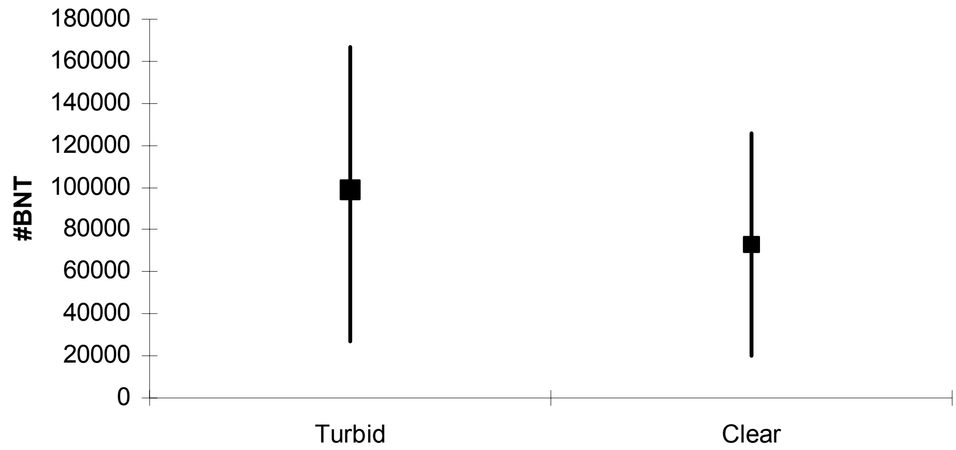

Figure 8. Population estimates (RM 20-221) for brown trout derived from depletion data collected under turbid (August and September, 2000, N=93) and clear (June, July and September, 2000, N=222) water clarity conditions. Bars indicate 95% confidence intervals of the estimates.

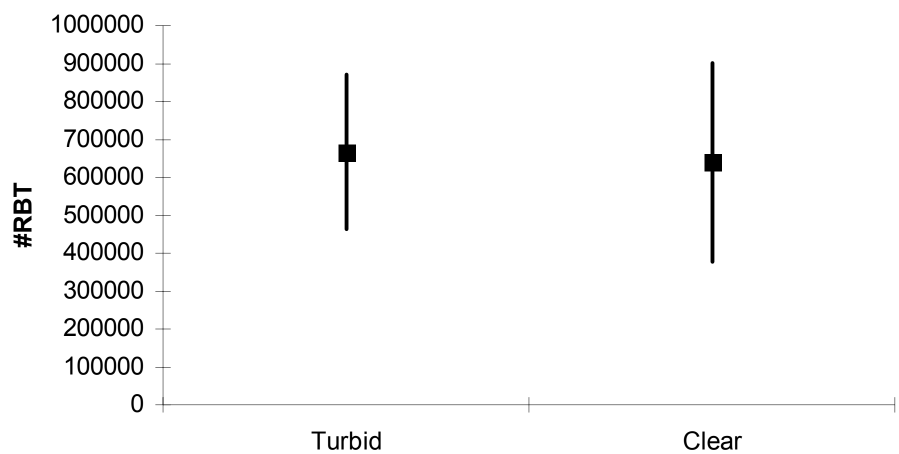

Figure 9. Population estimates (RM 20-221) for rainbow trout derived from depletion data collected under turbid (August and September, 2000, N=93) and clear (June, July and September, 2000, N=222) water clarity conditions. Bars indicate 95% confidence intervals of the estimates.

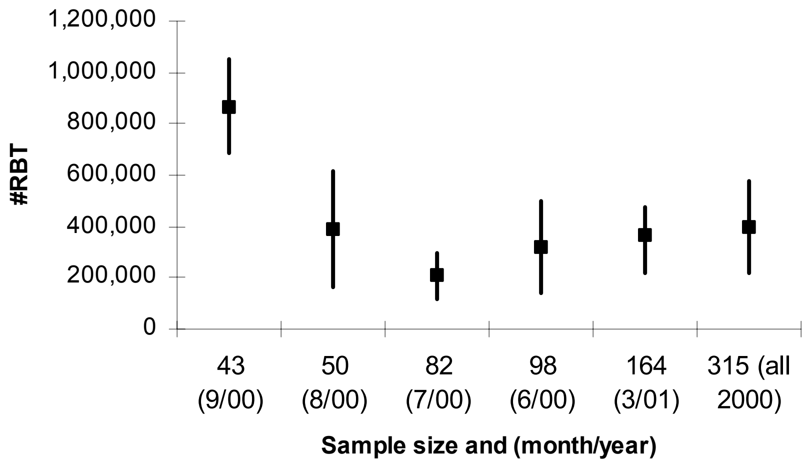

Figure 10. Estimated RBT population size (RM 39-196) in relation to sample size. X-axis values in parentheses are trip dates (month/year), and bars indicate upper and lower 95% confidence intervals.

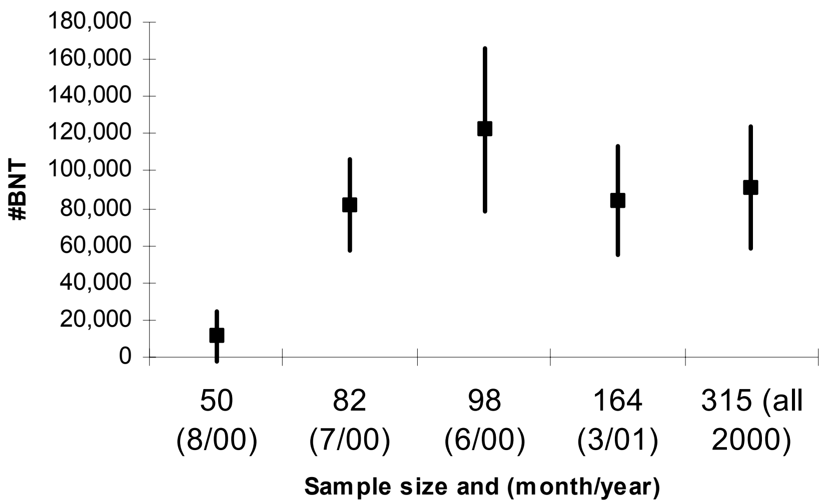

Figure 11. Estimated BNT population size (RM 39-160) in relation to sample size. X-axis values in parentheses are trip dates (month/year), and bars indicate upper and lower 95% confidence intervals.

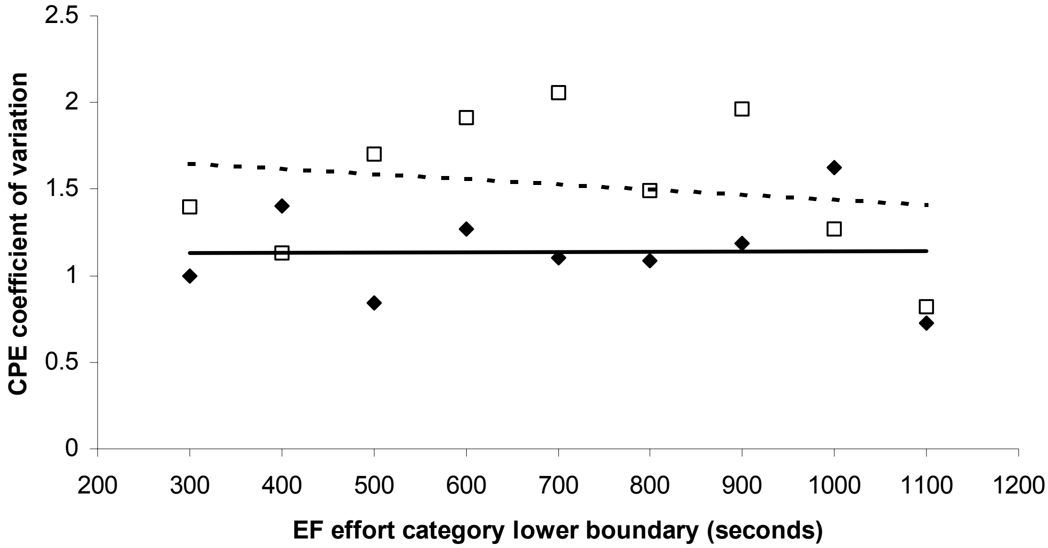

Figure 12. Electrofishing sample coefficient of variation (CV) as a function of EF duration for rainbow trout (solid symbols and line) and brown trout (open symbols, dashed line). Neither relationship is significant. Data are from Colorado River in Grand Canyon, 2000.

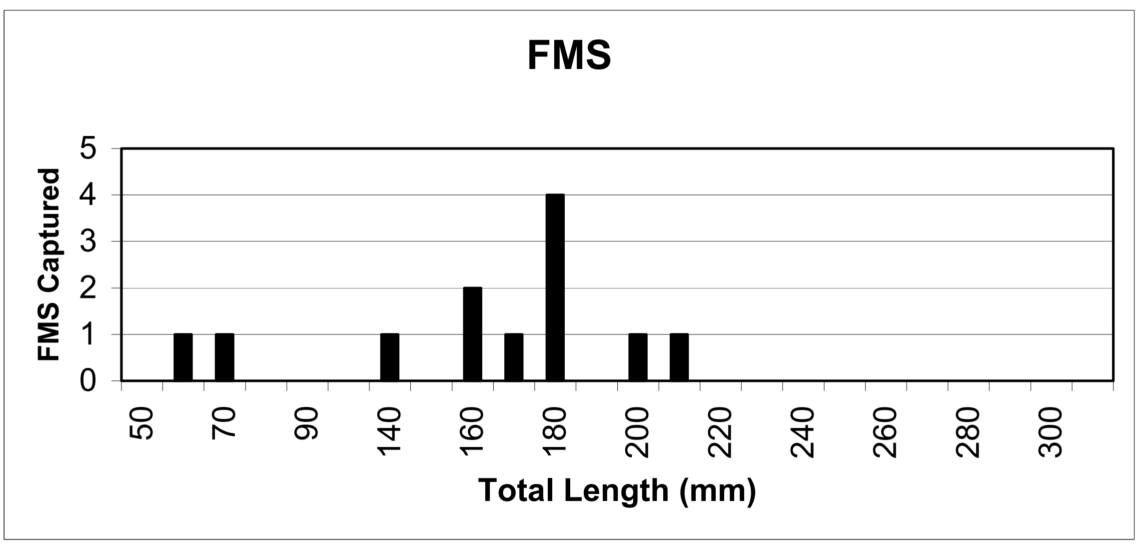

Figure 13. Number of FMS captured by length (mm) in Kanab Creek (April 17-20, 2002).

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