Status of the Lee's Ferry Trout Fishery

2006 Annual Report

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2255 North Gemini Drive
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Cooperative Agreement No. 05WRAG0050 – Mod 2

April 2007

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EXECUTIVE SUMMARY

We present results of rainbow trout monitoring in the Lee's Ferry tailwater (Colorado River below Glen Canyon Dam, AZ) during 2006. We also describe modifications made to monitoring strategies and techniques which were implemented to improve long-term monitoring programs. Objectives and subsequent findings are as follows:

Objective 1: *Evaluate data from fixed and random transects to determine if data can be pooled thereby increasing power to detect trends in the rainbow trout population.*

Fixed sites provide long-term trend data for monitoring fish populations in the Lee's Ferry tailwater. Beginning in 2002, we implemented an augmented, serially alternating sampling design which incorporates random sites with the fixed sites to provide improved point estimates of fishery status. However, for statistical analyses it is unclear as to whether the two types of data can be combined for more powerful evaluation of long-term trends. To evaluate differences in means and variances of the two types of data, we compared catch per unit effort (CPE), relative condition (K_n) and size structure, (PSD; # fish ≥ 406 mm TL/# fish ≥ 305 mm TL)*100 from fixed and random sites during similar time periods using one-way analysis of variance (ANOVA; S. Urquhart, *personal communication*).

Objective 2: *Monitor the trout fishery in the Lee's Ferry reach to determine status and trends in abundance (CPE), population structure (size composition and proportional stock density, PSD), growth rate and relative condition (K_n).*

Data collected during 2006 indicate the Lee's Ferry fishery may be improving after a period of high densities and low fish condition that occurred from 1998 to 2001. Low relative abundance of all fish from 2006, particularly fish < 200 mm, appears to be leading to increases in PSD and growth. Relative condition in 2006 was the highest observed since 1996. Overrecruitment and density dependent growth from the past appear to be alleviated. However, resource limitation (i.e. food, space) and water quality (i.e. temperature, dissolved oxygen) now appear to be problematic. The New Zealand mudsnail has proliferated throughout the tailwater and has been known to restructure food webs. Drought conditions at Lake Powell have caused fluctuating cycles in the

amount of dissolved oxygen coming through Glen Canyon Dam. This was especially apparent during the fall of 2005 when DO levels reached the lower lethal limit for rainbow trout in the fishery and likely caused further deterioration of the aquatic foodbase.

Objective 3: *Determine the efficacy of using otolith information for growth analysis and to back-calculate lengths at age for comparison to historical length group assignment.*

We removed sagittal otoliths from the heads of rainbow trout that were sacrificed for the Arizona Game and Fish Department's diet analysis. Otolith back-calculated length at age and growth agreed well with the estimated growth from recaptured passive integrated transponder (PIT) tagged fish (2000-present). In addition, we used a modified Faban's technique to predict length at recapture and growth to better fit von Bertalanffy growth parameters to compare historical (1991-1999) and recent (2000-2006) growth trajectories. We estimated similar growth to age 2 for both time periods, however, we estimated faster growth during the historical time period. We attribute slower growth over recent years to a suite of factors which may include degradation of the aquatic foodbase likely caused by previously high densities of rainbow trout, the proliferation of the New Zealand mudsnail, and warmer water releases (and subsequent low dissolved oxygen levels) from Glen Canyon Dam, among others.

Low overall densities, size structure and increased condition indices support the conclusion that the system is in a recovery period. Water and foodbase quality will be essential to ensure the persistence of the Lee's Ferry trout populations. Dam management should seek to establish favorable conditions for attaining population size structure (i.e., PSD) and relative condition (K_n) objectives.

INTRODUCTION

The Arizona Game and Fish Department has been monitoring and performing research on trout in Glen Canyon since the mid 1960's. Rainbow trout (*Oncorhynchus mykiss;* RBT) were initially stocked in the Colorado River below Glen Canyon Dam (GCD) in 1964 and since that time, fish management efforts, dam operations, and flow regimes have interacted to influence the trout community (Arizona Game and Fish Department [AGFD] 1996; Persons et al. 1985; Marzolf 1991; Reger et al. 1995; McKinney and Persons 1999; McKinney et al. 1999 a, c, d). Impacts of regulated flow on rainbow trout in the Lee's Ferry tailwater has been a source of interest for resource managers and the public for several decades (Persons et al. 1985; Maddux et al. 1987; Reger et al. 1995, McKinney and Persons 1999, McKinney et al. 1999 a, d; McKinney et al. 2001 a; McKinney and Speas 2001). Understanding fish ecology in relation to dam operations is essential in order to integrate water, power, and fishery management goals.

Ecology of non-native rainbow trout in the Lee's Ferry tailwater (river mile [RM] -15 to RM 0; Figure 1) is strongly influenced by operations of Glen Canyon Dam (McKinney and Persons 1999, McKinney and Speas 2001; McKinney et al. 1999 b, c; McKinney et al. 2001 a, b). Rainbow trout in the tailwater provide a popular recreational fishery and coexist with native flannelmouth sucker (*Catostomus latipinnis*; FMS) and non-native common carp (*Cyprinus carpio*; CRP). From 1991 through 1997, higher mean and less variable releases from GCD favored high standing stocks of rainbow trout, but size-related changes occurred in relative condition and bioenergetics of fish (McKinney et al. 1999a; McKinney and Speas 2001). Small fish (< 305 mm) were strongly affected by low and variable releases from the dam, but not by biotic variables which allowed them to meet maintenance energy requirements. In contrast, large fish (≥ 305 mm) were not affected by flow variability but were strongly influenced by biotic factors (i.e. density-dependence) associated with degradation of the aquatic foodbase. Large fish rarely met maintenance energy requirements (McKinney and Speas 2001). Relative condition of large fish peaked in 1994 and then fell 10 % by 1997, whereas condition of small fish was generally stable between 1991 and 1997. From 1997 to 2000, Speas et al. (2004b) noted a marked reduction in year-to-year variance in catch-per-unit-effort (CPUE), relative condition (K_n) and proportional stock density (PSD; Speas et al. 2004b), likely caused by the impacts of increased densities on the foodbase in the mid 1990's.

Standardized monitoring of the trout fishery using electrofishing (EF; Sharber et al. 1994) at fixed sampling locations was initiated in 1991 and has provided data on response of the RBT population to dam operations (McKinney and Persons 1999; McKinney et al. 1999a, c, d; McKinney et al. 2001a). In recent years, the Grand Canyon Monitoring and Research Center (GCMRC) sponsored a series of protocol evaluation panels for external scientific review of Colorado River sampling protocols (http://www.gcmrc.gov/pep/troutPEP.htm). This scientific review panel recommended increasing the overall sample size through reduction in length of existing fixed transects and addition of randomly selected sites. Random components of this augmented, serially alternating sampling design (Urquhart et al. 1998) are intended to give representative estimates of fishery status, whereas fixed components ensure continuity with existing trend data. Increasing the number of sample transects per sampling occasion also provides increased statistical power to detect changes in fishery variables on a yearly time scale (Speas et al. 2004c).

In this report, we present results from fish monitoring activities in the Lee's Ferry tailwater during 2006. Our monitoring objectives have not changed since 2002 and include evaluating the status and trends in relative abundance (CPUE), population structure (size composition and PSD), growth rate, and relative condition (K_n) of rainbow trout. In 2006 we also collected otoliths from a subsample of rainbow trout to determine if they could be used to give accurate age estimates and to verify or reject age assignment based on length categories established in previous years. In this report we will compare and contrast data collected from fixed and random sites since 2002, and evaluate the existing serially alternating sampling design.

METHODS

Field Collections

We collected electrofishing (EF) samples in the Lee's Ferry tailwater (Figure 1) during April 4-6, June 26-28, and October 10-12, 2006. For all sample occasions we used two 16' Achilles inflatable boats outfitted for electrofishing, applying pulsed DC (~310 V, ~15 A; Sharber et al. 1994) to a 35-cm spherical electrode system. Sampling commenced shortly after dusk and persisted 5-7 hours per night. Daily river discharge at GCD ranged from ca. 7,000 to 12,000 cfs during April, 9,500 to 18,000 cfs during June, and 7,000 to 13,000 cfs during October (Figure 2).

During each monitoring survey, we electrofished 9 fixed and 27 random sites covering approximately 4 km of shoreline area (see Speas et al. 2004b). The 27 random transects were selected without replacement from strata containing the remaining sample units found in river kilometer (RK) 0.9 – 26.85. We stratified sample units in two ways: 1) by shoreline types / relative abundance combinations. This stratum was comprised of talus/cobble bar shorelines, which are characterized by the highest CPE values observed in 2001 (ca. 5.3 fish/min. EF; Speas et al. 2004b) and sand bar/cliff face shorelines characterized by the lowest CPE values from 2001 (ca. 3.6 fish/min EF; Speas et al. 2004b); and 2) longitudinally, as upper (RK 0.9 – 8.15), middle (RK 8.15 - 19.05) and lower (RK 19.05 – 26.85) subreaches of the tailwater below GCD. We selected specific shoreline types according to their availability (percentage of shoreline length) within river subreaches. Longitudinal stratification also allowed randomization while maintaining safety and logistical integrity (i.e., boats visit the same section of the river on each night) as well as among longitudinal gradients in fish density (Speas et al. 2004b).

We measured total length (TL; mm) for all fish captured and weight (g) for most fish captured. We sexed fish based on manual extrusion of gametes. At fixed transects, we implanted untagged RBT > 200 mm TL with 400 kHz passive integrated transponder (PIT) tags and clipped adipose fins of all salmonids receiving PIT tags to monitor tag loss. Untagged native species (i.e. FMS) > 150 mm TL were also implanted with 134.2 kHz PIT tags. This marking program is primarily intended to provide information on fish growth. We injected PIT tags ventrally into the fish body cavity with the insertion point immediately posterior to the pelvic fin.

A subsample of RBT, FMS, and CRP were sacrificed in the Lee's Ferry tailwater in 2006 for age and diet analysis (AGFD), foodbase analysis (Ted Kennedy, GCMRC, April and October only), and disease determination. For the age and diet analysis, we sacrificed 5 RBT from each fixed site varying in size from smallest to largest, removed their stomachs, and extracted sagittal otoliths. For the foodbase analysis, we sacrificed a subsample of the FMS and CRP captured, removed their stomachs, clipped a pelvic fin, and extracted a muscle plug from the dorsal musculature. We also sacrificed RBT in June 2006, removed and froze their heads, and shipped them to the AZ Game and Fish Department Fish Health Laboratory (Pinetop, AZ) to test for whirling disease. Additionally, whole RBT specimens were sacrificed, frozen, and shipped to Dr. Rebecca Cole of the U.S. Geological Survey Biological Resources Division (BRD; Madison, WI) for parasitological evaluations (Cole 2002). Unless sacrificed for BRD, whirling disease, diet and age analysis, or foodbase analysis, we released all fish alive at the location of capture.

Data Analysis

Evaluation of data from fixed and random sites

The role of fixed sites is primarily to provide long-term trend data to monitoring programs while data from random sites are the best point estimates of fishery status (Urquhart et al. 1998.) However, guidelines for statistical analyses of such data appear ambiguous as to whether the two types of data can be combined for more powerful (i.e. larger sample size) evaluation of long-term trends (S. Urquhart, *personal communication*). To evaluate differences in means and variances of the two types of data, we compared size-stratified data (CPE, K_n) and size structure (PSD) from fixed and random sites since the onset of the current sampling design in June 2002 using one-way analysis of variance (ANOVA; S. Urquhart, *personal communication*). We then used Levene's test of homogeneity of variance on site type (fixed vs. random) to test the null hypothesis that error variance in fixed and random sites are equal. If significant differences were not apparent, fixed and random site data were pooled to increase power for long-term trend detection. All statistical tests were considered significant at the $\alpha = 0.05$ level.

Long term monitoring

We computed CPE as fish captured per minute of EF, and indexed size structure of the catch by calculating PSD (Anderson and Nuemann 1996; McKinney et al. 1999a) as the ratio of "quality" sized fish to the sum of "quality" and "stock" sized fish, or

$$(\# \text{ fish} \geq 406 \text{ mm TL} / \# \text{ fish} \geq 305 \text{ mm TL})*100$$

Fish ≥ 406 mm have been protected from harvest by AGFD fishing regulations, and most fish ≥ 305 mm are sexually mature (McKinney et al. 1999a) and generally desired by Arizona anglers (Pringle 1994). We also computed CPE for the following length categories: < 152 mm TL, 152-304 mm TL, 305-405 mm TL and > 406 mm TL.

We determined relative condition factor (K_n; Le Cren 1951) as

$$K_n = W / W' * 100$$

where W′ is the standard weight relationship $e^{[(-4.6 + 2.856*LN(TL))]}$ incorporating all Lee's Ferry RBT length and weight data collected since 1991. We also determined relative weight (W_r; same equation as K_n; Anderson and Nuemann 1996) based on the standard weight equation developed by Simpkins and Hubert (University of Wyoming, unpublished data) for comparison to other rainbow trout fisheries across their range. We evaluated fishery data (CPE, K_n, PSD) from fixed EF sites by inspection of confidence intervals and means calculated for each year and by simple linear regression where trends appeared evident.

Age and growth evaluation

Sagittal otoliths were extracted from the heads of RBT sacrificed for diet analysis in 2006 by clipping the posterior base of the skull and opening the sacculus to expose the otoliths (Secor et al. 2001, 2002). Otoliths were then cleaned in alcohol and stored dry prior to reading. In the laboratory, otoliths were examined in whole view at 1.6x magnification for the presence of a nucleus and annuli. Two independent readers enumerated annuli, and discrepancies between readers were alleviated by repeated counts by both readers in tandem until agreement was achieved. Otoliths were then mounted on slides and images of each otolith were captured and analyzed using Capture Pro image analysis software. The number of visible annuli, the distance (mm) from the focus to each annuli, and the radial distance (mm) from the focus to the outer edge of the otolith was used to back-calculate mean length at age. Back-calculation of length at age for RBT was examined using the Fraser-Lee method given by the equation,

$$L_i = \frac{L_c - a}{S_c} S_i + a$$

where L_i was the back-calculated length of the fish at the i^{th} age, L_c was the length of fish at capture, S_c was the otolith radius at the time of capture, S_i was the radius of the annuli at the i^{th} age, and a was the intercept of the regression of fish length at capture on the otolith radius at capture (DeVries and Frie 1996). Rainbow trout ages were plotted against corresponding length to calculate mean length at age and growth for comparison to historical length-age relationships.

We compared historical (1991-1999) and recent (2000-2006) rainbow trout growth using Floy tag and PIT tag recapture information, respectively, as well as otolith information since 2004. Only fish at large for > 1 year were included in the recapture analysis to alleviate fish measurement error. Observed growth (using observed length at recapture) was determined by subtracting TL at the mark event from the TL at the recapture event divided by the time (days) at large between the two events. We then used a modified Faben's technique to predict length at recapture and growth to better fit von Bertalanffy growth parameters (Wang 1998; see Speas et al. 2004a, b). Data from both time periods were then regressed using linear regression to compute von Bertalanffy growth functions (theoretical maximum length [L_∞], Brody growth coefficient [K]). Mean length at age otolith data were plotted with data from both time periods to compare to recent PIT tag recapture information.

RESULTS

Flows from Glen Canyon Dam were seasonally variable in 2006 (Figure 2). From January through February 2006, flows ranged from about 9,500 to 18,000 cfs with a mean daily discharge of approximately 14,071 cfs. Spring flows followed normal ROD low monthly volumes in March-May, fluctuating between 6,000 and 15,000 cfs daily and hovering around 8,000 cfs on Sundays. High monthly volume flows began again in June and persisted through August, with daily fluctuations from 9,300 to 18,500 cfs. Lower fluctuating flows characterized September through November, with daily flows fluctuating between 6,500 and 12,500 cfs. December flows fluctuated between 9,500 to 17,000 cfs. Water temperatures below Glen Canyon Dam were between 9-10ºC in April and June, and about 12 ºC in October (Figure 3). Dissolved oxygen below Glen Canyon Dam was about 6.5 mg/L in April, peaked at about 8.0 mg/L in June, and was about 7.0 mg/L in October (Figure 4).

Whirling disease analyses were negative for all samples collected in 2006 (Jim Thompson, AGFD Fish Health Laboratory, personal communication). Results of parasitological evaluations (USGS-BRD, Madison, WI), GCMRC foodbase analyses for 2006, and AGFD diet analysis are incomplete at the time of submission of this report.

Evaluation of data from fixed and random sites

Analysis of size-stratified RBT data revealed no differences in CPE and PSD among fixed and random sites (Table 1), during similar temporal scales (June 2002 through October 2006). Differences were observed, however, in RBT K_n between both sites (Table 1), but these differences likely reflect associated large sample sizes and may not be biologically significant. Thus, data from both fixed and random sites were pooled to increase our ability to detect trends over time in Lee's Ferry RBT population indices.

Long term monitoring

A total of 1290 fish from 6 species were captured at Lee's Ferry in 2006. Rainbow trout were the most prevalent species captured (98%) followed by flannelmouth sucker (1%), common carp (1%), brown trout (*Salmo trutta*; 0.2%), channel catfish (0.08%), and walleye (*Sander vitreus*; 0.08%; see Table 2). The captured walleye during 2006 represents the first occurrence of this species in the Lee's Ferry tailwater since AGFD monitoring efforts dating from 1991. A total of 148 RBT were implanted with PIT tags and 13 PIT tagged fish were recaptured (1% recapture rate) during 2006 sampling. A total of 8 flannelmouth sucker were implanted with 134.2 kHz PIT tags; two of these fish were recaptured with 400 kHz tags and thus given new 134.2 kHz tags.

The mean total length of RBT captured during 2006 was 267 ± 3.10 mm (mean ± 1 S.E.). This was significantly greater than the mean of all RBT captured in 2005 (255 ± 2.79 mm; $P = 0.007$) and is similar to the largest mean annual total length measured on record in 1992 (265 ± 2.08 mm) and 2003 (263 ± 2.14 mm).

Length frequency analysis shows a RBT distribution skewed towards larger fish in 2006 with the majority of fish captured being between 300 and 400 mm TL (Figure 5, panel A). Relatively few fish were captured < 150 mm TL during 2006, especially in April and June (Figure 5, panels B and C). Sampling effort in October, however, showed a more typical bimodal distribution with about 30% of fish captured comprising a mode < 150 mm TL and about 60% of fish captured comprising a mode between 250 and 350 mm TL (Figure 5, panel D).

Overall, the CPE of RBT at Lee's Ferry continued its decline since 2000 (Figure 6). Rainbow trout CPE for all sampling in 2006 was 1.47 ± 0.14 fish per minute of electrofishing (mean ± 1 S.E.), which is similar to the densities of RBT in 1992 and 1993. This overall decrease in density is largely attributable to the drastic decrease in numbers of RBT < 152 mm TL since 2001 (Figure 7, panel A). Density of RBT in the 152 to 304 mm TL size class also decreased from 2005 to 2006, and is similar to densities for this size class from 1994 to 1995 (Figure 7, panel B). Density of RBT in the 305 to 405 mm TL size class has generally declined since 2001 and is similar to densities found in 1991, 1996, and 2005 (Figure 7, panel C). Estimated CPE of RBT > 406 mm TL in 2006 was the lowest recorded since 1991 and has shown a declining trend since 2003 (Figure 7, panel D).

Angler CPE from creel surveys (AGFD Region 2, unpublished data) reflected the trend seen in the electrofishing CPE data for 305-405 mm TL RBT since 1991 (Figure 8). Catch rates since 2002 were substantially lower than those observed from 1996 to 2001 and have declined precipitously since 2004. Angler catch rates in 2006 were about 0.58 ± 0.03 fish per angler hour and were similar to those observed in 1994.

As indicated by the declining trend in abundance of RBT greater than 305 mm TL since 2003, PSD in 2006 was the lowest recorded for the fishery since monitoring began in 1991 (Figure 9). Proportional stock density in 2006 was 1.00 ± 0.46 (mean ± 1 S.E.) which was most similar to PSD observed in 2005 (2.81 ± 0.70).

Rainbow trout K_n for all sizes of fish was greater in 2006 than that observed in 2005 (Figure 10). Mean K_n in 2006 was 82.48 ± 0.30, and was similar to trout condition in 1995 and 1996. Size-stratified analysis of K_n did not show increases in trout condition since 2005 in the < 152 mm TL and > 406 mm TL size classes as evidenced by overlapping standard errors (Figure 11, panels A and D, respectively). Increasing trends in trout condition were observed, however, in the 152 -304 mm TL and the 305 – 405 mm TL size classes (Figure 11, panels B and C, respectively).

Age and growth evaluation

A total of 164 RBT otoliths were removed and examined and ages of those analyzed ranged between 0 and 5 years. Percent contributions of each age of trout analyzed and corresponding mean TL at each age are given in Table 3.

Comparison of historical (1991-1999; Floy tag) and recent (2000-2006; PIT tag) modeled recapture information for RBT growth suggested different growth trajectories for the two time periods. Growth was relatively similar among the two periods for fish up to 2 years old, but faster growth to ages 3 and above was seen in historical versus recent data (Figure 12). For example, model predictions showed RBT from 1991 to 1999 reached 3 years of age around 336 mm TL, whereas RBT from 2000 to 2006 reached a similar age around 291 mm TL. Estimates of L_∞ and K also differed between historical and recent periods with L_∞ values of 446 mm and 355 mm and K values of 0.46 and 0.57, respectively. Mean TL at age from back-calculated RBT otolith data showed similar growth trajectories to recent modeled recapture data (up to age 5; Figure 12), suggesting a validation of our growth model for current conditions in the fishery.

DISCUSSION

The GCMRC-sponsored protocol evaluation panel suggested increasing overall sample size in the Lee's Ferry tailwater by reducing the length of fixed electrofishing transects and incorporating randomly selected transects. We initiated this augmented, serially alternating sampling regime (Urquhart et al. 1998) in June 2002, where fixed transects served to ensure comparison with historical data and random transects provided representative estimates of fishery status. Our analysis of fixed and random transects over similar temporal scales (June 2002 through October 2006) showed no differences in size-stratified estimates of relative abundance and size structure. Differences were observed in size-stratified relative condition among fixed and random transects. However, we believe these differences likely reflect our large sample sizes and biologically may not be significant. For example, anglers likely will not recognize minor differences in relative condition for rainbow trout most vulnerable to angling (i.e. 305-405 mm TL). Thus, we pooled data from both fixed and random transects to increase our ability to detect rainbow trout population trends over time (Speas et al. 2004c). While our analysis of this data consisted of relatively simple statistics (ANOVA; S. Urquhart, *personal communication*), we recognize the potential for more robust statistical analysis of this data. We hope additional input from future protocol evaluation panels will help with this issue.

Overall catch rates of rainbow trout at Lee's Ferry have declined since 2000. This likely represents a decline in overall abundance of the rainbow trout population which may be due to a suite of interacting factors including declining abundance of fish < 152 mm TL, low dissolved oxygen in 2005, and changes in the foodbase (i.e. New Zealand mudsnail, *Potamopyrgus antipodarum*). Redd counts at Lee's Ferry have declined by orders of magnitude since 2004 (J. Korman, *personal communication*), suggesting limited larval rainbow trout production in recent years. The low relative condition observed from 2002 to 2005 further suggests mature rainbow trout were unable to meet maintenance energy requirements needed to spawn (McKinney and Speas 2001). During the fall of 2005, dissolved oxygen approached the lower lethal limit for rainbow trout (below 4 mg/L) for about a 3-week period which likely caused further declines in abundance. The New Zealand mudsnail was first detected in Lee's Ferry in 1995 and has been known to restructure food webs in other systems (Hall et al. 2006). However, the absence of baseline foodbase data limits our ability to relate rainbow trout population dynamics to mudsnail presence.

Current conditions of the fishery, however, suggest the rainbow trout population is relieved of the density-dependent constraints seen in previous years (1997-2000; Speas et al. 2004a, b). The relative abundance of mature rainbow trout currently is similar to the low densities observed in the early 1990's. As a likely result of decreases in overall rainbow trout relative abundance, relative condition increased significantly from 2005 to 2006. This, coupled with current high compensatory survival of rainbow trout fry (J. Korman, *personal communication*), suggests successful spawn and recruitment for the fishery in the near future. The size structure of the fishery currently is the lowest observed on record. However, given current low rainbow trout densities, we expect size structure, relative condition, and growth to increase.

Creel results confirm the changes seen in the electrofishing trends. Angler catch rates in 2006 were the lowest observed since 1994. However, length frequency analysis suggests high densities of rainbow trout > 250 mm TL during 2006. Lower densities currently found in the fishery should allow these fish to reach sizes more vulnerable to angling. Also, October data suggests a successful spawn occurred in early 2006. The effects of lower densities should cause growth rates and size structure to increase thus producing larger, more vulnerable fish for anglers in the near future.

The low recapture rate of PIT-carrying rainbow trout led us to use an additional method to determine growth rates and approximate ages of rainbow trout at Lee's Ferry. We collected otoliths from rainbow trout from 2004 to 2006 to determine age of fish and to back-calculate growth rates between/among years and cohorts. Despite concerns that the stenothermic environment would not yield good annulus deposition, the otoliths were readable. Analysis of otoliths collected indicates rainbow trout currently at Lee's Ferry are taking longer to reach maturity than historical (prior to 2000) recapture data previously indicated. Also, given current conditions, it may take 5 years or more for rainbow trout to reach quality size (> 405 mm TL). Again, with current low densities we believe growth will increase allowing for successful spawn and recruitment and an increased proportion of the population vulnerable to angling. Due to our confidence in determining age and growth using otoliths, we have incorporated otolith removal and analysis into our long-term protocol for the Lee's Ferry fishery.

Our model comparing historical (1991-1999) and recent (2000-2006) growth from recapture data suggests showed differing growth trajectories between the two time periods. We suspect the faster historical growth is highly influenced by lower rainbow trout densities in the early 1990's, prior to the density-dependent effects likely caused by the regimented flow regime (mid to late 1990's; McKinney and Speas 2001; Speas et al. 2004a,b). However, current estimates of relative abundance (2004-2006) are similar to those seen in the early 1990's suggesting growth should be similar. Temperatures in Lee's Ferry since 2003 have been about 2ºC warmer from June through December than 1991 to 2002, suggesting higher daily energetic demands for the population currently.

Further, the New Zealand mudsnail was not discovered in the tailwater until 1995, and literature suggests this invasive species has dominated secondary production in other systems (Hall et al. 2006). Both increased temperature and establishment of the New Zealand mudsnail serve as possible explanations for the differences observed between historical and recent growth.

ACKNOWLEDGEMENTS

Grand Canyon Monitoring and Research Center provided funding for the present studies. We wish to thank GCMRC personnel Stuart Reider, Peter Weiss, and Steve Jones for all their hard work driving boats in the field and keeping clean, legible data. We also thank Carol Fritzinger for coordinating trip schedules and equipment. Numerous Game and Fish personnel volunteered their time to collect this data, and to them our thanks are due. We thank David Ward, Clay Nelson, and Brian Clark for reviewing earlier drafts of this report.

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Table 1. Results of analysis of variance on rainbow trout (RBT) relative abundance (CPUE; catch per minute), relative condition (K_n), and size structure (PSD; proportional stock density) by size class between fixed and random transects in the Lee's Ferry tailwater fishery. Data represent similar time frames for each transect type (June 2002 – October 2006). * denotes significance at the α = 0.05 level.

	RBT Size class (mm)			
Parameter	**< 152 mm**	**152 – 304 mm**	**305 – 405 mm**	**> 405 mm**
Abundance				
Mean CPUE (S.E.)				
Fixed	0.57 (0.08)	1.17 (0.16)	0.80 (0.10)	0.03 (0.01)
Random	0.47 (0.05)	1.27 (0.09)	0.91 (0.06)	0.04 (0.01)
F	1.04	0.27	0.92	0.41
DF	1, 354	1, 354	1, 354	1, 354
***P*-value**	0.31	0.61	0.34	0.52
Condition				
Mean K_n (S.E.)				
Fixed	81.06 (0.77)	80.54 (0.38)	75.48 (0.50)	73.76 (3.63)
Random	83.09 (0.51)	82.56 (0.23)	76.80 (0.30)	75.29 (2.24)
F	4.79	20.86	5.18	0.13
DF	1, 723	1, 2800	1, 1830	1, 67
***P*-value**	0.03*	< 0.001*	0.02*	0.72
	Entire fishery			
Size structure				
Mean PSD (S.E.)				
Fixed	2.14 (0.70)			
Random	2.64 (0.40)			
F	0.38			
DF	1, 324			
***P*-value**	0.54			

Table 2. Number of each species captured per trip by transect type at Lee's Ferry in 2006. RBT = rainbow trout; BNT = brown trout; CRP = common carp; FMS = flannelmouth sucker; WAL = walleye; CCF = channel catfish.

Trip ID	Date	Transect type	Total catch					
			RBT	BNT	CRP	FMS	WAL	CCF
LF20060404	4/04 – 4/06	Fixed	81			2		
		Random	212	2		1		
		Total	**293**	**2**		**3**		
LF20060626	6/26 – 6/28	Fixed	117		1	1	1	
		Random	453					1
		Total	**570**		**1**	**1**	**1**	**1**
LF20061010	10/10 – 10/12	Fixed	102		5	1		
		Random	302		2	6		
		Total	**404**		**7**	**7**		
Grand total			**1267**	**2**	**8**	**11**	**1**	**1**
Percent of catch (%)			**98**	**0.2**	**1**	**1**	**0.08**	**0.08**

Table 3. Mean back-calculated total length (TL, mm), total number of back-calculations, and percent contribution of ages of rainbow trout derived from otoliths in the Lee's Ferry tailwater fishery, 2004-2006. Standard error of the mean is given in parenthesis.

	Age (years)					
	0	**1**	**2**	**3**	**4**	**5**
Mean back-calculated TL		168.5 (2.7)	239.2 (3.9)	293.8 (5.5)	310.7 (9.8)	337.7 (28.3)
N	6	159	118	65	17	6
% contribution	4%	25%	32%	29%	7%	4%

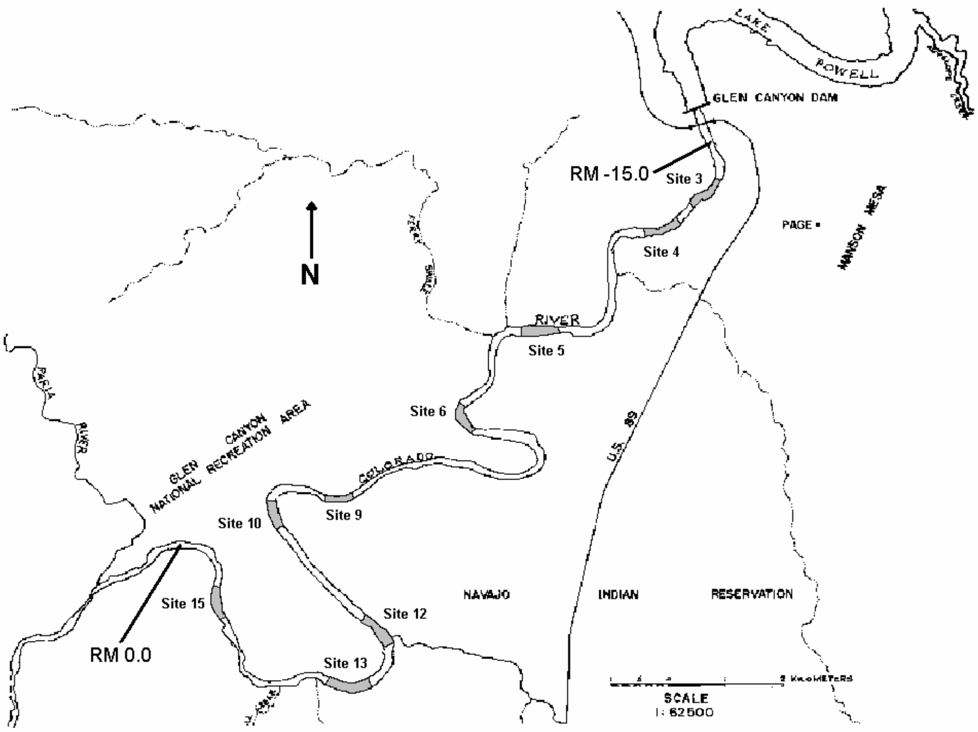

Figure 1. Map showing the Lee's Ferry tailwater fishery below Glen Canyon Dam, on the Colorado River, Arizona. Fixed sampling locations are shaded gray.

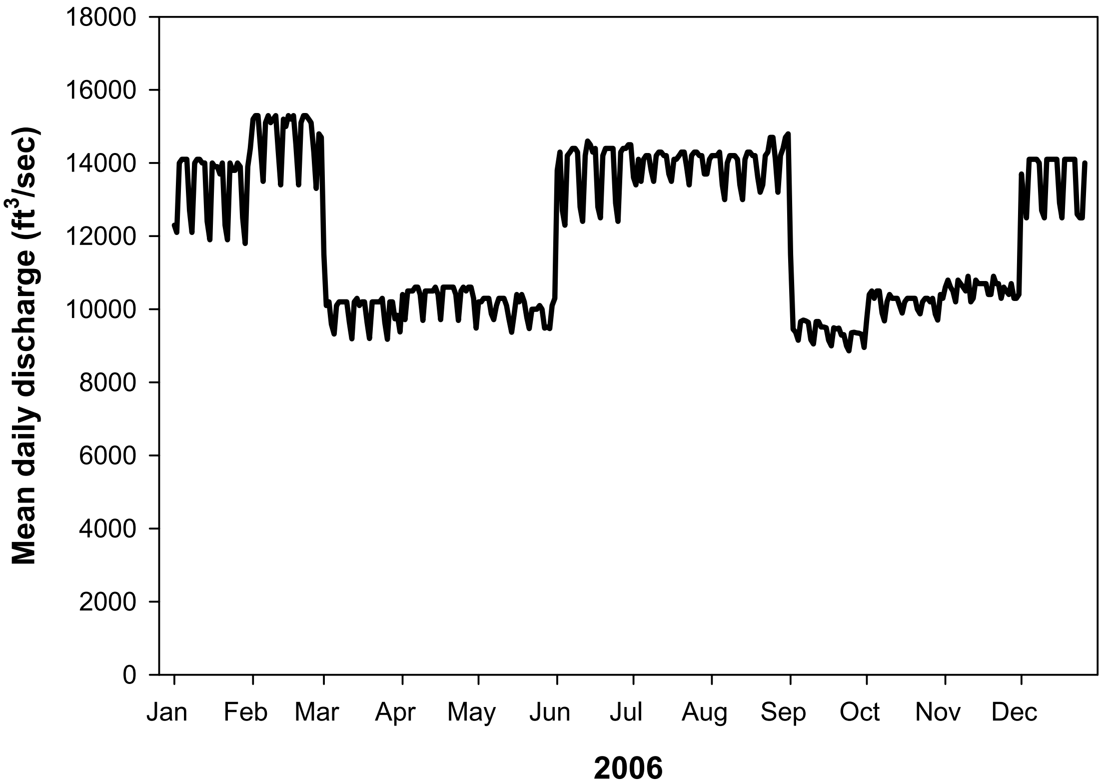

Figure 2. Mean daily discharge (cfs) from Glen Canyon Dam during 2006.

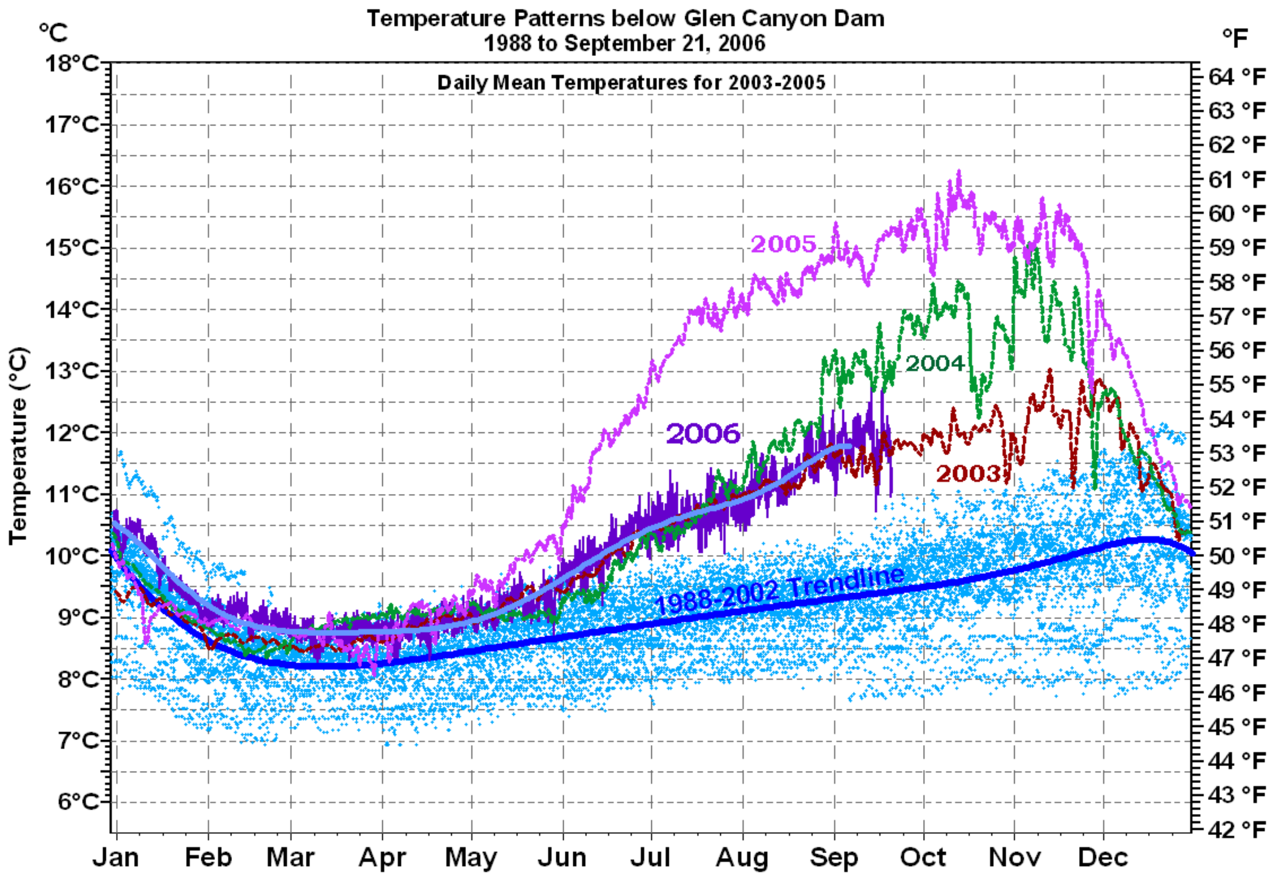

Figure 3. Daily temperatures below Glen Canyon Dam from 1988-2002 (blue line), 2003 (red line), 2004 (green line), 2005 (pink line), and 2006 (purple line). Figure courtesy of Susan Hueftle, USGS, Grand Canyon Monitoring and Research Center, Flagstaff, AZ.

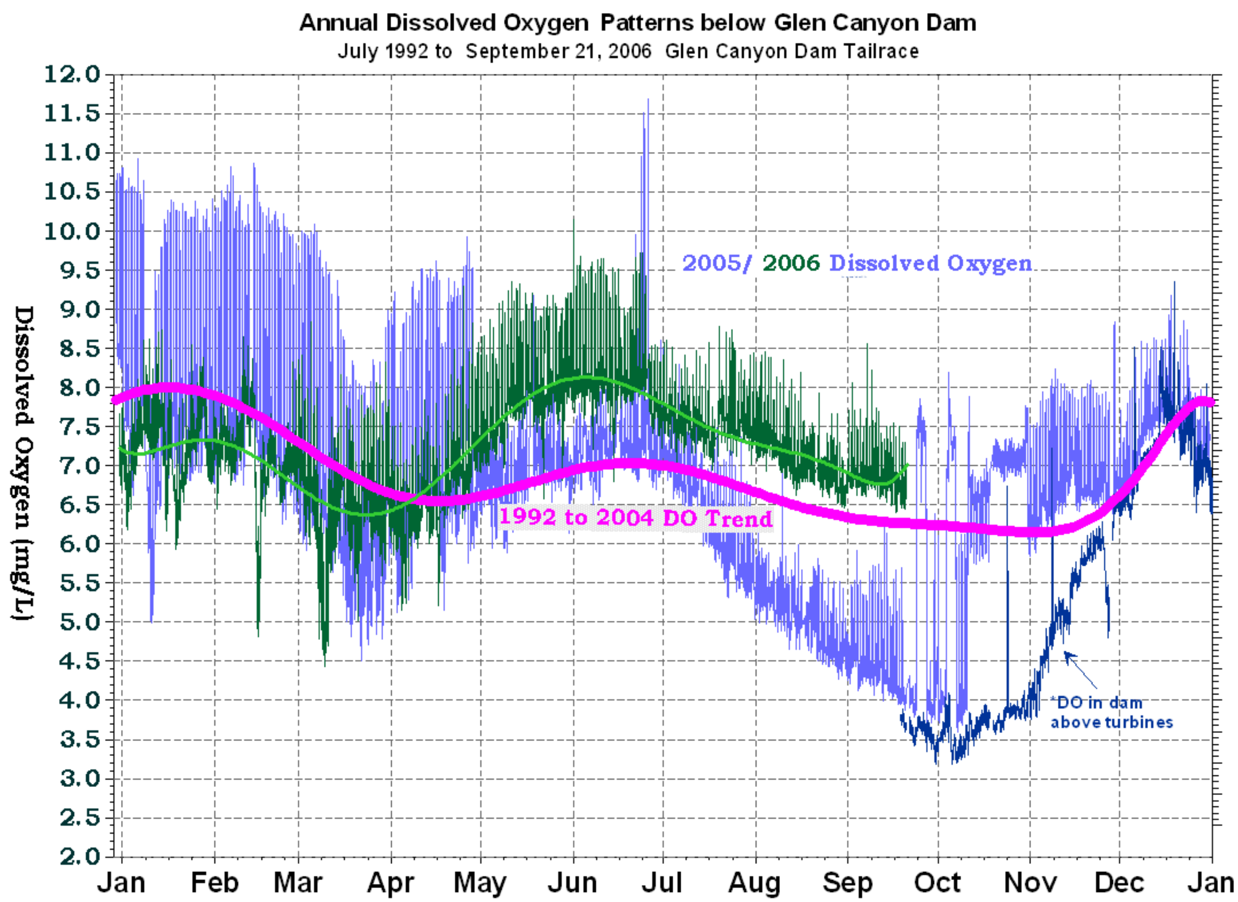

Figure 4. Daily dissolved oxygen (mg/L) below Glen Canyon Dam from 1992-2004 (pink line), 2005 (blue line), and 2006 (green line). Figure courtesy of Susan Hueftle, USGS, Grand Canyon Monitoring and Research Center, Flagstaff, AZ.

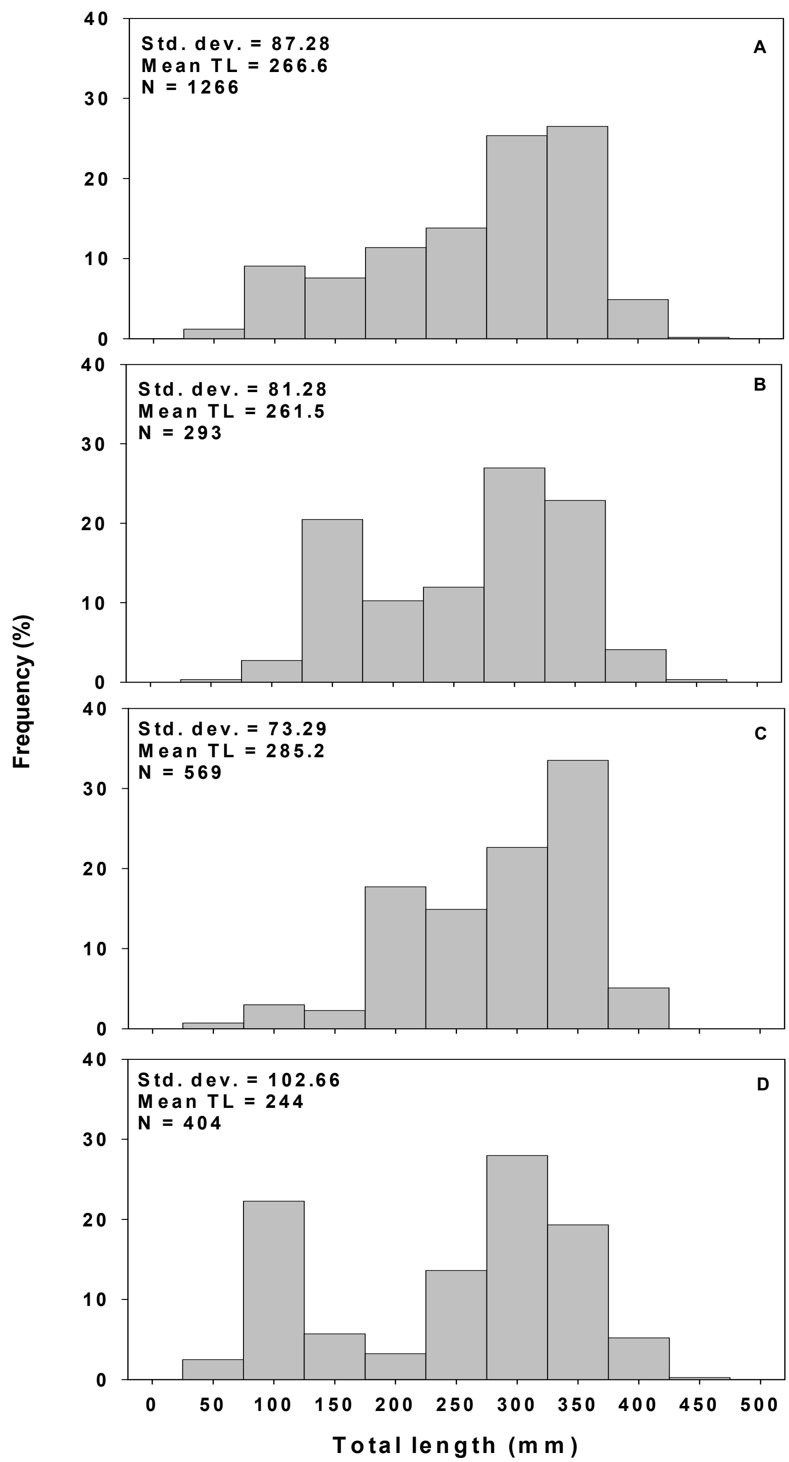

Figure 5. Lee's Ferry rainbow trout length frequency distribution during all sampling in 2006 (A), April 2006 (B), June 2006 (C), and October 2006 (D). Data includes both fixed and random transects.

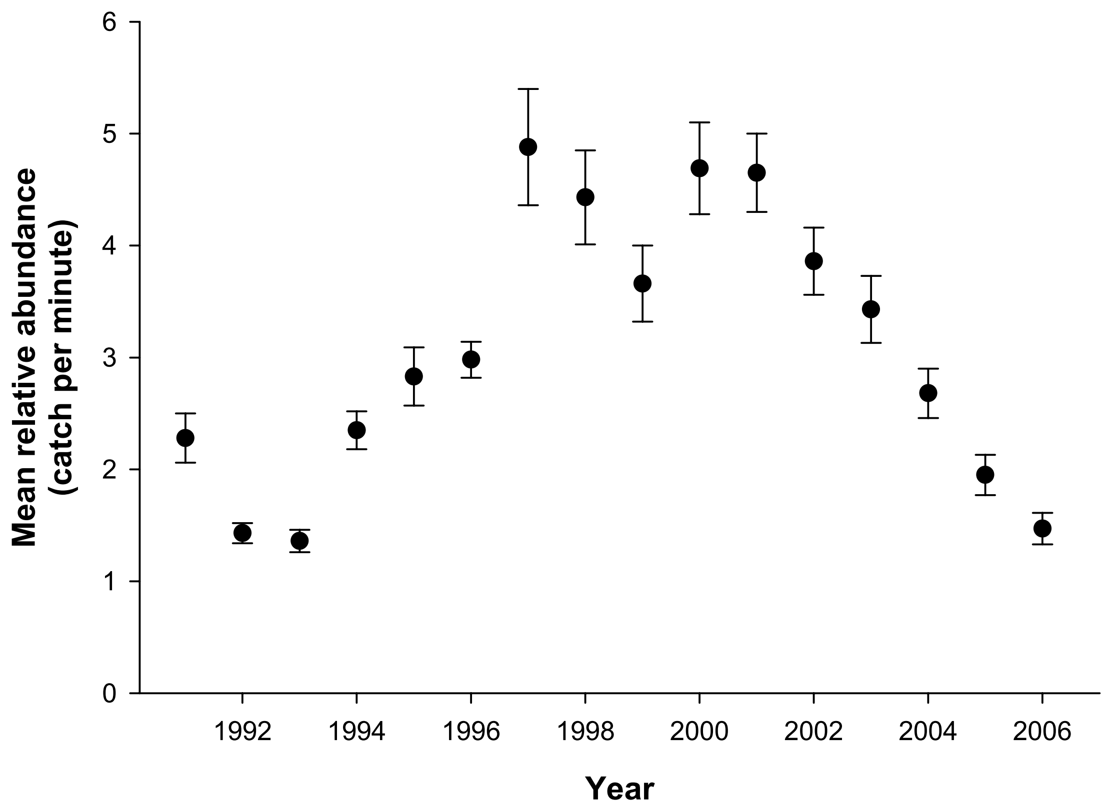

Figure 6. Rainbow trout mean relative abundance (catch per minute) in the Lee's Ferry tailwater fishery, 1991-2006. Figure represents data from all size classes in both fixed and random transects. Bars represent ± 1 S.E. of the mean.

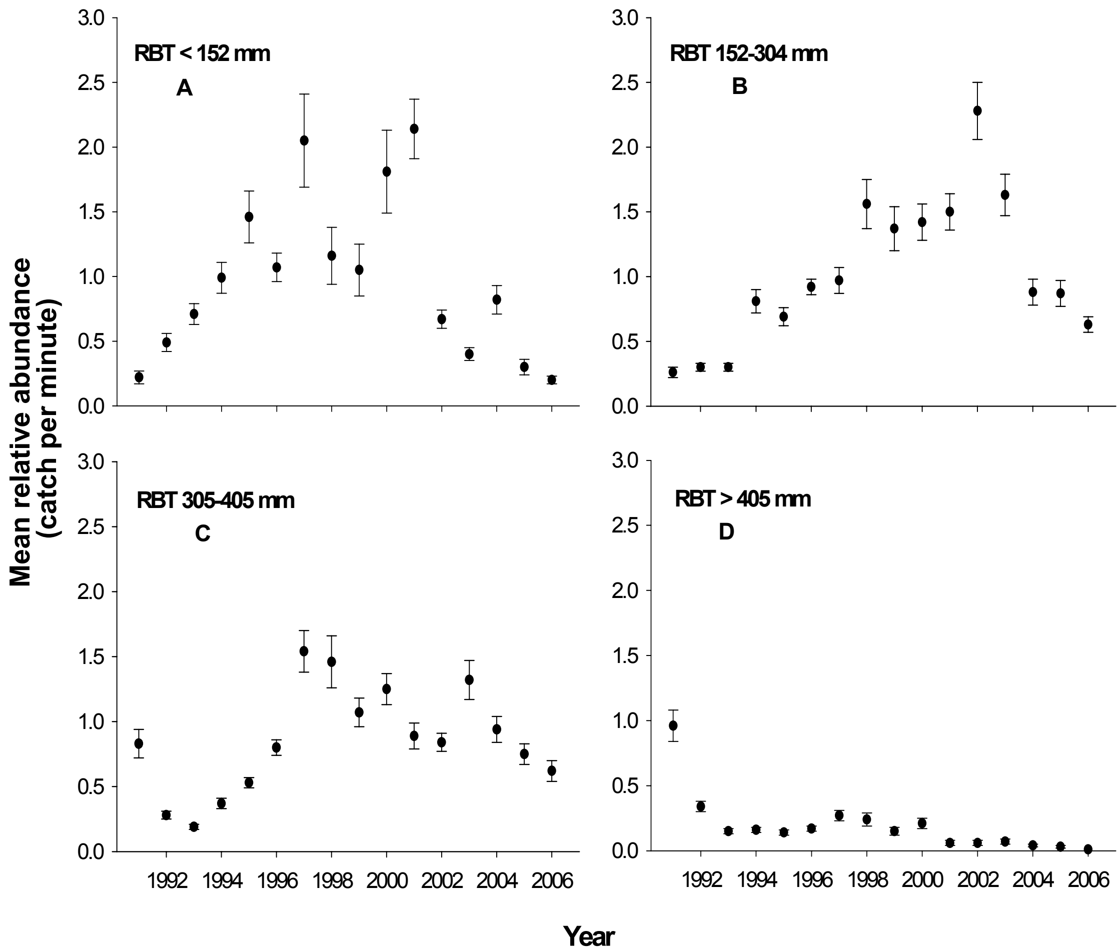

Figure 7. Rainbow trout mean relative abundance (catch per minute) for fish < 152 mm total length (TL; A), 152-304 mm TL (B), 305-405 mm TL (C), and > 405 mm TL (D) in the Lee's Ferry tailwater fishery, 1991-2006. Figure represents data from both fixed and random transects. Bars represent ± 1 S.E. of the mean.

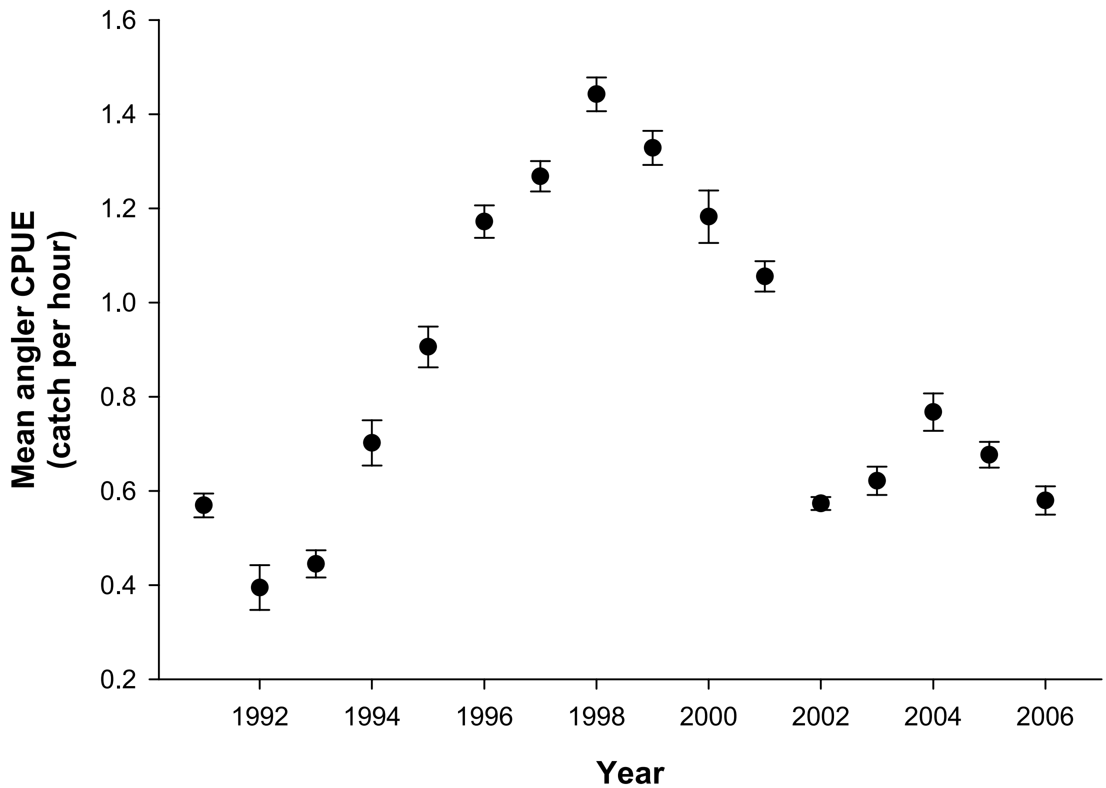

Figure 8. Mean angler catch-per-unit-effort (CPUE; catch per hour) of rainbow trout in the Lee's Ferry tailwater fishery, 1991-2006. Bars represent ± 1 S.E. of the mean.

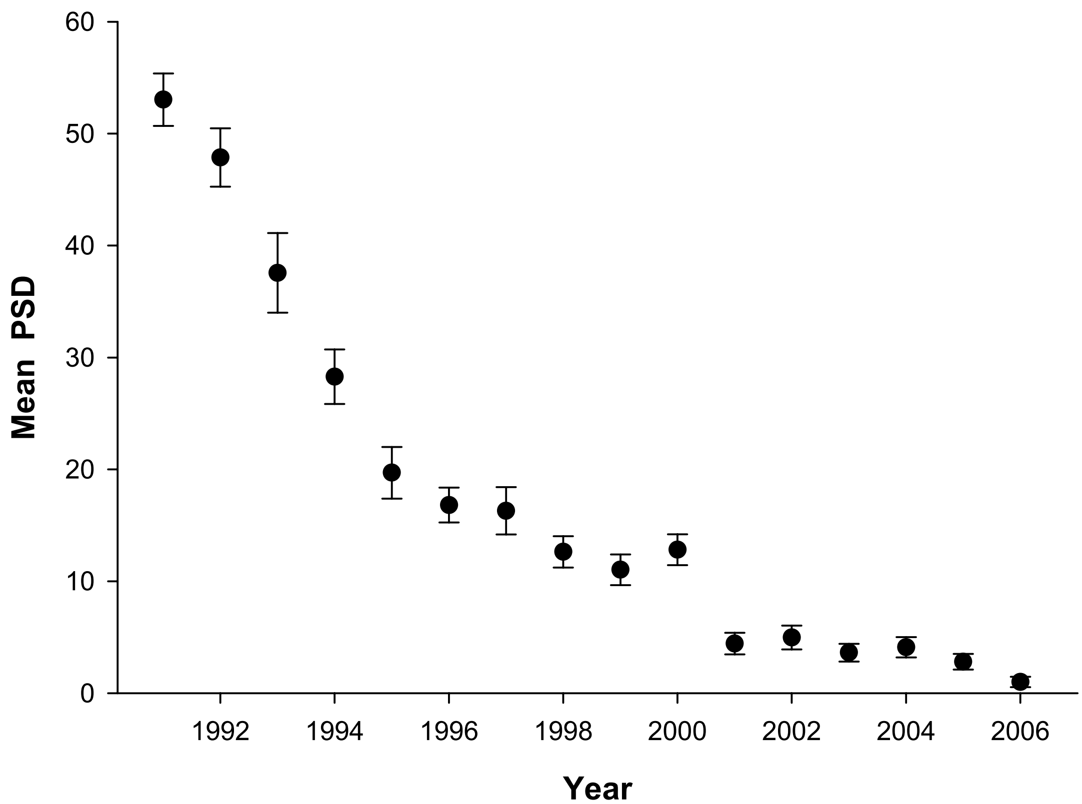

Figure 9. Rainbow trout mean proportional stock density (PSD) in the Lee's Ferry tailwater fishery, 1991-2006. Figure represents data from both fixed and random transects. Bars represent ± 1 S.E. of the mean.

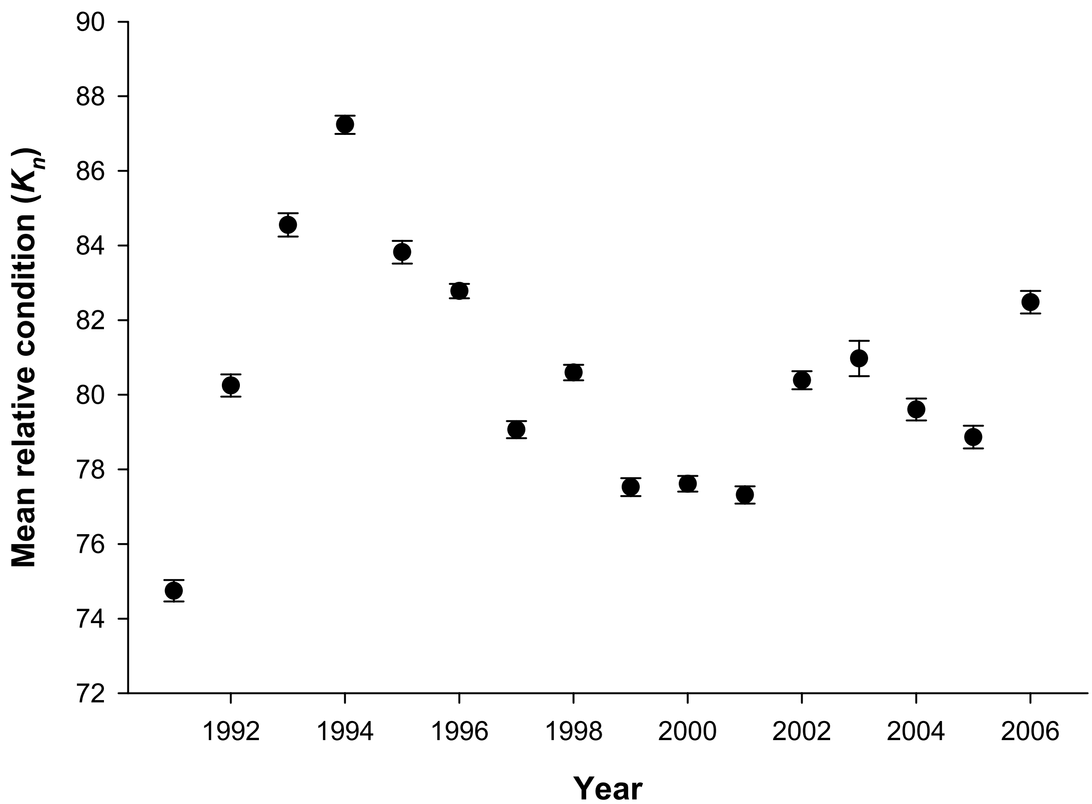

Figure 10. Rainbow trout mean relative condition (K_n) in the Lee's Ferry tailwater fishery, 1991-2006. Figure represents data from all size classes in both fixed and random transects. Bars represent ± 1 S.E. of the mean.

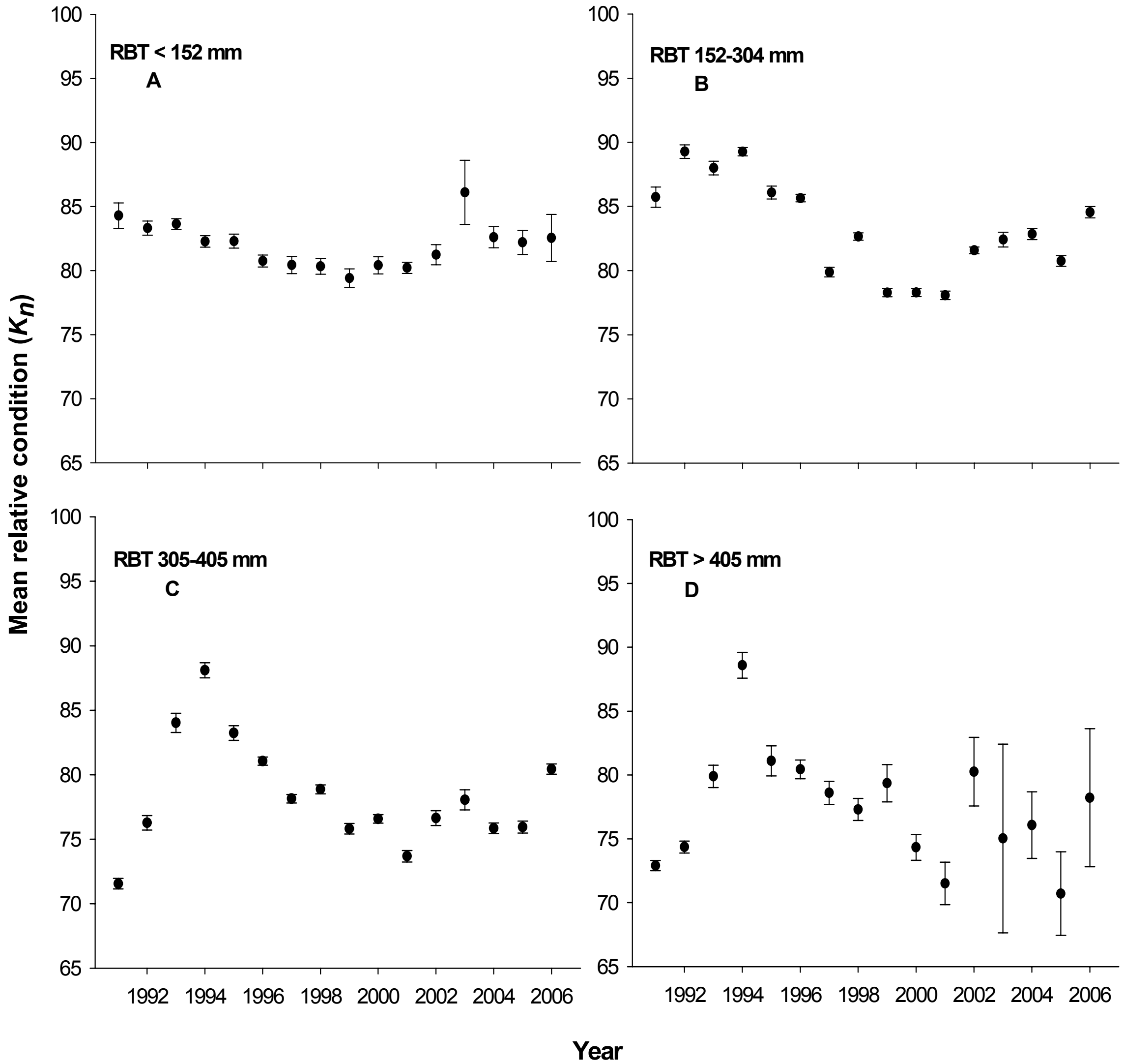

Figure 11. Rainbow trout mean relative condition (K_n) for fish < 152 mm total length (TL; A), 152-304 mm TL (B), 305-405 mm TL (C), and > 405 mm TL (D) in the Lee's Ferry tailwater fishery, 1991-2006. Figure represents data from both fixed and random transects. Bars represent ± 1 S.E. of the mean.

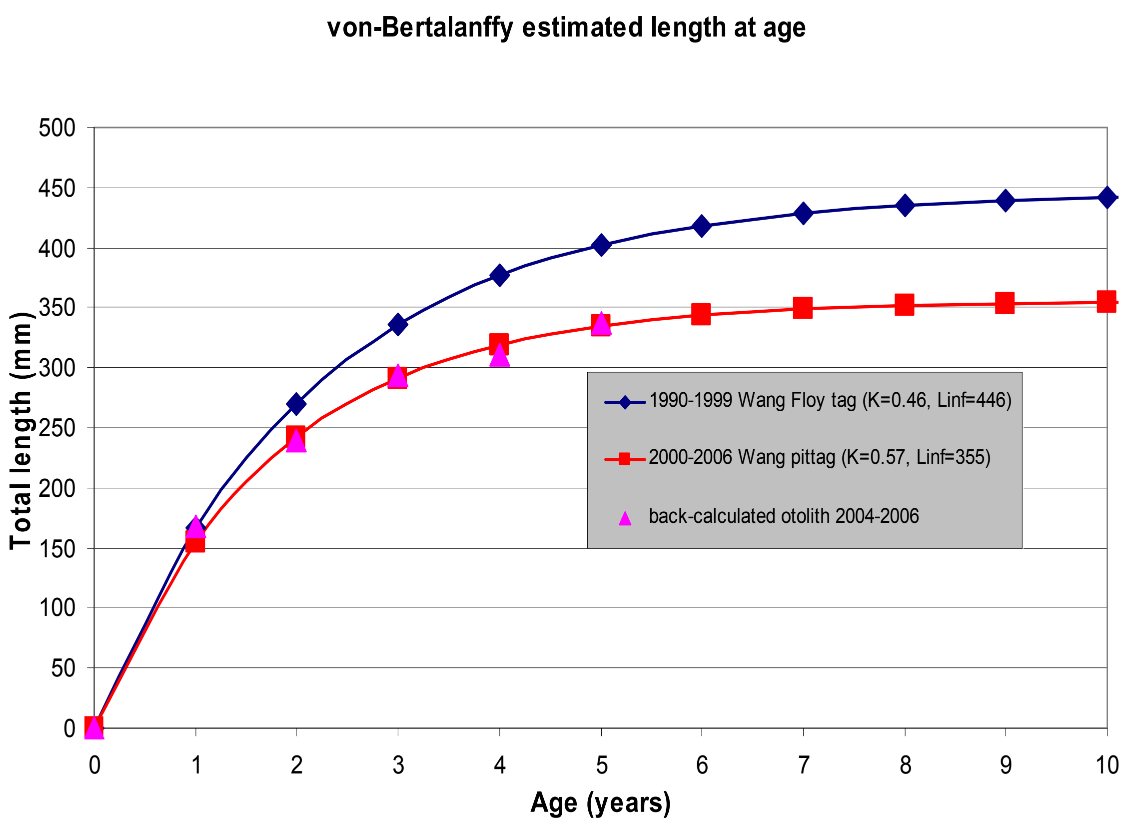

Figure 12. Modeled Lee's Ferry rainbow trout estimated length at age for fish captured during 1990-1999 (Floy tag recapture data; blue line), and 2000-2006 (pittag recapture data; red line). Pink triangles represent back-calculated lengths at age from otolith analysis (2004-2006).