Status of the Lee's Ferry Trout Fishery

2003-2005 Annual Report

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TABLE OF CONTENTS

TABLE OF CONTENTS……………………………………………………………………..i

LIST OF TABLES……………………………………………………………………...ii

LIST OF FIGURES……………………………………………………………………iii

EXECUTIVE SUMMARY……………………………………………………………vi

INTRODUCTION……………………………………………………………………...1

METHODS……………………………………………………………………………..2

Field collections…………………………………………………………………...2

Data analysis…………………………………………………………………………4

Evaluation of data from fixed and random sites…………………………..4

Long term monitoring……………………………………………………..4

Effects of the Beach Habitat Building Flood……………………………...5

RESULTS………………………………………………………………………………5

Evaluation of data from fixed and random sites…………………………………..6

Long term monitoring……………………………………………………………..6

Effects of the Beach Habitat Building Flood……………………………………...8

DISCUSSION…………………………………………………………………………..8

ACKNOWLEDGEMENTS…………………………………………………………...11

LITERATURE CITED………………………………………………………………..12

LIST OF TABLES

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 2003 – November 2005). * denotes significance at the α = 0.05 level……………………………………...…………………………15

Table 2. Number of each species captured per trip by transect type at Lee's Ferry in 2003-2005. RBT = rainbow trout; SPD = speckled dace; BNT = brown trout; CRP = common carp; FMS = flannelmouth sucker; SMB = smallmouth bass; CCF = channel catfish……………..……………………………………………16

Table 3. Results of analysis of variance on rainbow trout (RBT) relative abundance (CPUE; catch per minute), and size structure (PSD; proportional stock density) by size class between November and December 2004 (before and after a Beach Habitat Building Flood, respectively), in the Lee's Ferry tailwater. Table includes data from both fixed and random transects. * denotes significance at the α = 0.05 level………………………………………………...……………………17

LIST OF FIGURES

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……….18

Figure 2. Mean daily discharge (cfs) from Glen Canyon Dam during 2003 (red line), 2004 (green line), and 2005 (blue line)………………………………………..19

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………………………………………………………….20

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………………………………………………………………..21

Figure 5. Lee's Ferry rainbow trout length frequency distribution during all sampling in 2003 (April, August, and November; left column), 2004 (April, July, and November; middle column), and 2005 (April, June, and November; right column). Data includes both fixed and random transects. Data from December 2004 was excluded from this analysis………………………………………………………22

Figure 6. Rainbow trout mean relative abundance (catch per minute) in the Lee's Ferry tailwater fishery, 1991-2005. Figure represents data from all size classes in both fixed and random transects. Data from December 2004 are excluded from this analysis. Bars represent ± 1 S.E. of the mean…………………………………...23

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, 1991-2005. Figure represents data from both fixed and random transects. Data from December 2004 were exluded from this analysis. Bars represent ± 1 S.E. of the mean……………………24

Figure 8. Mean angler catch-per-unit-effort (CPUE; catch per hour) of rainbow trout in the Lee's Ferry tailwater fishery, 1991-2005. Bars represent ± 1 S.E. of the mean…………………………………………………………………25

Figure 9. Rainbow trout mean proportional stock density ([# fish ≥ 406 mm TL / # fish ≥ 305 mm TL]*100; PSD) in the Lee's Ferry tailwater fishery, 1991-2005. Figure represents data from both fixed and random transects. Data from December 2004 were excluded from this analysis. Bars represent ± 1 S.E. of the mean………...26

Figure 10. Rainbow trout mean relative condition (K_n) in the Lee's Ferry tailwater fishery, 1991-2005. Figure represents data from all size classes in both fixed and random transects. Data from December 2004 were excluded from this analysis. Bars represent ± 1 S.E. of the mean……………………………………………...27

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, 1991-2005. Figure represents data from both fixed and random transects. Bars represent ± 1 S.E. of the mean……………………..28

Figure 12. Mean daily discharge from Glen Canyon Dam during November 2004, including the beach habitat building flood (BHBF; red line), and December 2004 (blue line), following the BHBF. Sampling the Lee's Ferry tailwater occurred prior to the BHBF during 11/01-11/03/2004, and following the BHBF during 12/06-12/08/2004……………………………………………………………...29

Figure 13. Mean rainbow trout relative abundance of all size classes (catch per minute; top panel) and mean proportional stock density ([# fish ≥ 406 mm TL / # fish ≥

405 mm TL]*100; bottom panel) before a Beach Habitat Building Flood (BHBF; November) and after the BHBF (December) in the Lee's Ferry tailwater, 2004. Bars represent 95% confidence intervals of the mean…………………………...30

Figure 14. Rainbow trout mean relative abundance for fish < 152 mm total length (TL; panel A), 152-304 mm TL (panel B), 305-405 mm TL (panel C), and > 405 mm TL (panel D), in the Lee's Ferry tailwater, November and December, 2004. Figure represents data from both fixed and random transects. Bars represent 95% confidence intervals of the mean. Note the scale difference on the y-axis on panel D……………………………………………………………………………….31

EXECUTIVE SUMMARY

We present results of rainbow trout monitoring in the Lee's Ferry tailwater (Colorado River below Glen Canyon Dam, AZ) during 2003-2005. 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 2003-2005 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 2003-2005, particularly fish < 200 mm, appears to be leading to increases in PSD and growth. Relative condition was higher during 2003-2005 than 1999-2001 and was similar to that observed in 1992 and 1997. 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 effects of a Beach Habitat Building Flood on rainbow trout dispersal and population indices.*

In response to concerns about deteriorating beaches in Grand Canyon, the Bureau of Reclamation conducted a Beach Habitat Building Flood (BHBF), designed to move sand from the thalweg and deposit it on the shores. Analyses indicated no significant dispersal of rainbow trout downstream of Lee's Ferry during this flood event. However, the flood appeared to cause a spatial redistribution of fish within the fishery. Larger fish were more vulnerable to our sampling (i.e. near shore) immediately following the flood, presumably due to the inundation of new terrestrial food resources. Flexibility in management objectives is needed to allow for maintenance of fish densities that will increase relative condition, growth and PSD over a range of flow regimes. Modifying flow regimes to limit rainbow trout recruitment should be evaluated as a means of making progress toward size structure, growth and condition objectives.

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 2003 to 2005. Herein we will compare and contrast data collected in fixed and random sites from 2003 to 2005, and evaluate the serially alternating sampling design. 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. We will also present observed changes in relative abundance and size structure, if any, following a Beach Habitat Building Flow (BHBF) that occurred in November 2004. This high flow event was designed to allocate sand from the river to the shorelines to improve existing beaches along the river.

METHODS

Field Collections

We collected electrofishing (EF) samples in the Lee's Ferry tailwater (Figure 1) three times per year during 2003 and 2005, and four times during 2004 (exact dates for specific trips are provided in Table 2). 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.

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 type / relative abundance combinations and 2) longitudinally. The shoreline type stratification 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). We selected specific shoreline types according to their availability (percentage of shoreline length) within river subreaches. The longitudinal stratification is by river mile, 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. 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 when conditions permitted accurate weight measurments.. 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 (400 Khz) 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), 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 RBT captured, removed their stomachs, clipped a pelvic fin, and extracted a muscle plug from the dorsal musculature. We also sacrificed RBT in 2003 and 2004, 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 (Makinster et al. 2007). 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 > 405 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 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.

Effects of the Beach Habitat Building Flood

We examined the impacts of the 3-day, 2004 BHBF on the traditional fishery indices (CPE and PSD). We used ANOVA to examine differences between before and after the flood event. Additional AVOVAs were used to determine if size-selective differences in CPE were seen prior to and following the flood.

RESULTS

Discharges from Glen Canyon Dam were seasonally variable during 2003-2005 (Figure 2). Flows during 2003 showed the typical pattern of the ROD regime with low fluctuating flows during the winter followed by spring flows fluctuating between 6,000 and 15,000 cfs daily. January through March flows during 2004 and 2005 were designed to suppress rainbow trout recruitment in the Colorado River and fluctuated between 5,000 and 20,000 cfs daily. Spring and summer flows during 2004-2005 followed the ROD regime. Water temperatures below Glen Canyon Dam were between 9-10ºC in April throughout 2003-2005, but water temperatures increased during latter parts of each year, particularly in the fall (Figure 3). Water temperatures were the warmest in November

2003 and 2004 and reached 13º and 15ºC, respectively. Drought conditions resulting in low lake levels at Lake Powell likely led to temperatures observed at Lee's Ferry in 2005 (Figure 3), which were the warmest observed on record. The warmest temperatures observed were about 16ºC and occurred in November 2005. During much of 2005 (July-November), water temperatures were about 5ºC warmer than the trend observed through 1988 to 2002 (Figure 3). These warmer temperatures likely caused additional effects on the rainbow trout population at Lee's Ferry such as increased energetic demands and changes to the foodbase. Dissolved oxygen below Glen Canyon Dam decreased as water temperatures increased during 2005 and reached the lower lethal limit for rainbow trout (November 2005 DO was below 4 mg/L; Figure 4).

Whirling disease analyses were negative for all samples collected during 2003-2005 (Jim Thompson, AGFD Fish Health Laboratory, personal communication). Results of parasitological evaluations (USGS-BRD, Madison, WI), GCMRC foodbase analyses, 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 fixed and random 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 in Lee's Ferry RBT population indices.

Long term monitoring

A total of 7,211 fish from 7 species were captured at Lee's Ferry during 2003-2005 (Table 2). Rainbow trout were the most prevalent species captured (99%) followed by common carp (0.5%), flannelmouth sucker (0.3%), brown trout (*Salmo trutta*; 0.2%), channel catfish (0.01%), smallmouth bass (*Micropterus dolomieu*; 0.08%), and speckled dace (*Rhinichthys osculus*; see Table 2). The captured smallmouth bass during 2003 represents the first occurrence of this species in the Lee's Ferry tailwater since AGFD monitoring efforts dating from 1991. A total of 983 RBT were implanted with PIT tags and 74 PIT tagged fish were recaptured (8% recapture rate) during 2003-2005 sampling.

A total of 15 flannelmouth sucker were implanted with 134.2 kHz PIT tags; 5 of these fish were recaptured with 400 kHz tags and thus given new 134.2 kHz tags. A total of 39 CRP were PIT tagged with no recaptures. The mean total length of RBT captured during 2003-2005 was 263 ± 1.60 mm, 229 ± 1.97 mm, and 255 ± 2.24 mm, respectively (mean ± 1 S.E.).

Length frequency analysis shows a RBT distribution skewed towards larger fish in 2003-2005 with the majority of fish captured > 200 mm TL (Figure 5, top row). Relatively few fish were captured < 150 mm TL throughout all years and sampling events, with the exception of November 2004. Sampling effort in November 2005, however, showed a more typical bimodal distribution with about 45% of fish captured comprising a mode < 150 mm TL and about 40% of fish captured comprising a mode between 250 and 350 mm TL (Figure 5, lower right panel).

Overall, the CPE of RBT at Lee's Ferry continued its decline since 2000 (Figure 6). Rainbow trout CPE for all sampling and sizes during 2003-2005 was 3.43 ± 0.30, 2.68 ± 0.22, and 1.95 ± 0.18 fish per minute of electrofishing, respectively (mean ± 1 S.E.), which is similar to the densities of RBT in the mid to late 1990's. This overall decrease in density is largely attributable to the dramatic 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 has also decreased since 2002, and estimated densities for this size class in 2004 and 2005 are similar to those seen in 1996 and 1997 (Figure 7, panel B). Density of RBT in the 305 to 405 mm TL size class increased from 2002 to 2003 and has generally declined since (Figure 7, panel C). Estimated CPE of RBT > 406 mm TL in 2005 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) is similar to the trends 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 but estimates from 2004 and 2005 were significantly higher than 2003 as evidenced by the lack of overlap in confidence intervals. Angler catch rates in 2004 and 2005 were about 0.77 ± 0.04 and 0.68 ± 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 2004 and 2005 was the lowest recorded for the fishery since monitoring began in 1991 (Figure 9). The PSD in recent years (2001-2005) has remained relatively stable but is significantly lower than that observed in 2000. Proportional stock density during the period of this study was 3.62 ± 0.80, 4.10 ± 0.91, and 2.81 ± 0.70 (Figure 9).

Rainbow trout K_n for all sizes of fish was significantly lower in 2004 and 2005 than that observed in 2003, but was not likely observable by anglers (i.e. very small differences due to large sample sizes; Figure 10). Mean K_n in 2003-2005 was 80.97 ± 0.47, 79.61 ± 0.29, and 78.87 ± 0.31, respectively, and was similar to trout condition in 1998. Size-stratified analysis of K_n showed decreases in trout condition during 2004-2005 compared to 2003 in the < 152 mm TL and 305-405 mm TL size classes as evidenced by the lack of overlapping standard errors (Figure 11, panels A and C, respectively). Increasing trends in rainbow trout condition for all sizes classes but > 405 mm TL were observed in 2003 versus 2002 (Figure 11).

Effects of the Beach Habitat Building Flood

The BHBF occurred in November 2004, and consisted of discharges around 43,000 cfs that lasted for a period of about 3 days (Figure 12). Rainbow trout CPE of all size classes before and after the November 2004 BHBF was not statistically significant (2.82 ± 0.94 and 3.09 ± 0.94 fish per minute, respectively, $P > 0.05$; Figure 13). However, significantly more rainbow trout > 405 mm TL were captured following the flood ($P = 0.001$; Table 3), but such trends were not apparent for the other size classes (Figure 14). Rainbow trout size structure was significantly higher following the BHBF (Table 3), and was the third largest recorded since 2000.

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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. 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 (2003 through 2005) 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 (Makinster et al. 2007). For example, anglers likely will not recognize the 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. Although relative condition did not increase in 2004-2005, we expect food availability to increase given the currently low densities of rainbow trout. 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 increased during 2004-2005 compared to 2003. Length frequency analysis suggests relatively high densities of rainbow trout > 250 mm TL during 2005. Lower overall densities currently found in the fishery should allow these fish to reach sizes more vulnerable to angling. Also, November 2004 and 2005 data show a more typical bimodal population distribution that was not observed in 2003. 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 limited our ability to monitor growth and led us to use an additional method to determine growth rates and approximate ages of rainbow trout at Lee's Ferry (Makinster 2007). We collected otoliths from rainbow trout from 2004 and 2005 and reported the results in Makinster et al. (2007). 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 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.

The Beach Habitat Building Flood that occurred in 2004 did not lead to substantial effects on the rainbow trout population at Lee's Ferry. Our ability to detect significant differences prior to and following the flood were strengthened by sampling the exact same sites before and after the flood. Relative abundance of all size classes of fish did not differ before and after the flood. Our size-selective analysis showed similar estimates of relative abundance for all size classes but the largest fish following the flood.

This suggests this relatively high flow event did not cause substantial downstream displacement of any sized fish from Lee's Ferry. The higher relative abundance of rainbow trout > 405 mm TL following the flood is a likely function of our large sample sizes and biologically does not appear to be significant. However, we found a larger rainbow trout size structure following the flood. We suspect the flood caused a spatial redistribution of fish within, rather than downstream, the Lee's Ferry tailwater. We hypothesize that large fish in the thalweg prior to the flood likely moved toward the shoreline during and after the flood to exploit the additional food resources (Maddux et al. 1997; McKinney et al. 1999a,b,d; 2001a). As such, these fish likely became more vulnerable to our sampling. Additionally, small fish (< 200 mm TL) typically found near shore were likely competively displaced to other areas within the fishery, outside of our sampling areas.

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LITERATURE CITED

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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 2003 – November 2005). * 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	0.58 (0.09)	0.96 (0.15)	0.82 (0.13)	0.03 (0.01)
Random	0.47 (0.05)	1.20 (0.09)	1.08 (0.08)	0.05 (0.01)
F	1.11	1.99	2.82	1.64
DF	1, 302	1, 302	1, 302	1, 302
***P*-value**	0.29	0.16	0.09	0.20
Condition				
Mean K_n (S.E.)				
Fixed	82.50 (0.92)	80.82 (0.48)	74.62 (0.56)	74.09 (3.67)
Random	83.02 (0.58)	82.39 (0.32)	76.77 (0.33)	74.13 (2.36)
F	0.23	7.33	11.01	0.00
DF	1, 600	1, 1582	1, 1368	1, 56
***P*-value**	0.63	0.007*	0.01*	0.99

	Entire fishery
Size structure	
Mean PSD (S.E.)	
Fixed	3.00 (0.92)
Random	3.68 (0.54)
F	0.41
DF	1, 277
***P*-value**	0.52

Table 2. Number of each species captured per trip by transect type at Lee's Ferry in 2003-2005. RBT = rainbow trout; SPD = speckled dace; BNT = brown trout; CRP = common carp; FMS = flannelmouth sucker; SMB = smallmouth bass; CCF = channel catfish.

Year	Trip ID	Transect type	Total catch						
			RBT	SPD	BNT	CRP	FMS	SMB	CCF
2003	LF20030428	Fixed	229				1	1	
	04/28–04/30/2003	Random	848			5			
		Total	***1077***			***5***	***1***	***1***	
	LF20030804	Fixed	267		1	1			
	08/04-08/06/2003	Random	496		1	1			
		Total	***763***		***2***	***2***			
	LF20031103	Fixed	218			8	4		
	11/03-11/05/2003	Random	591		2	4	8		
		Total	***809***		***2***	***12***	***12***		
2004	LF20040426	Fixed	171		2				
	04/26-04/28/2004	Random	305			1			
		Total	***476***		***2***	***1***			
	LF20040712	Fixed	230			2			
	07/12-07/14/2004	Random	577		1	2	1		
		Total	***807***		***1***	***4***	***1***		
	LF20041101	Fixed	248			2			
	11/01-11/03/2004	Random	581	1		7			
		Total	***829***	***1***		***9***			
	LF20041206	Fixed	177						
	12/06-12/08/2004	Random	627		1	1			
		Total	***804***		***1***	***1***			
2005	LF20050404	Fixed	79				2		
	04/04-04/06/2005	Random	262		2		1		
		Total	***341***		***2***		***3***		
	LF20050628	Fixed	197			2	1		
	06/28-06/30/2005	Random	487		1	2			1
		Total	***684***		***1***	***4***	***1***		***1***
	LF20051128	Fixed	168				1		
	11/28-11/30/2005	Random	377		2	1	2		
		Total	***545***		***2***	***1***	***3***		
	Grand total		**7135**	**1**	**13**	**39**	**21**	**1**	**1**
	Percent of catch (%)		**99**	**0.01**	**0.2**	**0.5**	**0.3**	**0.01**	**0.01**

Table 3. Results of analysis of variance on rainbow trout (RBT) relative abundance (CPUE; catch per minute), and size structure (PSD; proportional stock density) by size class between November and December 2004 (before and after a Beach Habitat Building Flood, respectively), in the Lee's Ferry tailwater. Table includes data from both fixed and random transects. * denotes significance at the α = 0.05 level.

Parameter	RBT Size class (mm)			
	< 152 mm	**152 – 304 mm**	**305 – 405 mm**	**> 405 mm**
Abundance				
Mean CPUE (S.E.)				
November	1.55 (0.24)	0.62 (0.16)	0.64 (0.26)	0.01 (0.01)
December	1.08 (0.24)	0.82 (0.16)	1.10 (0.15)	0.08 (0.01)
F	1.95	0.79	3.29	12.71
DF	1, 70	1, 70	1, 70	1, 70
***P*-value**	0.17	0.38	0.07	0.001*
	Entire fishery			
Size structure				
Mean PSD (S.E.)				
November	2.22 (1.47)			
December	7.91 (1.49)			
F	7.38			
DF	1, 57			
***P*-value**	0.009*			

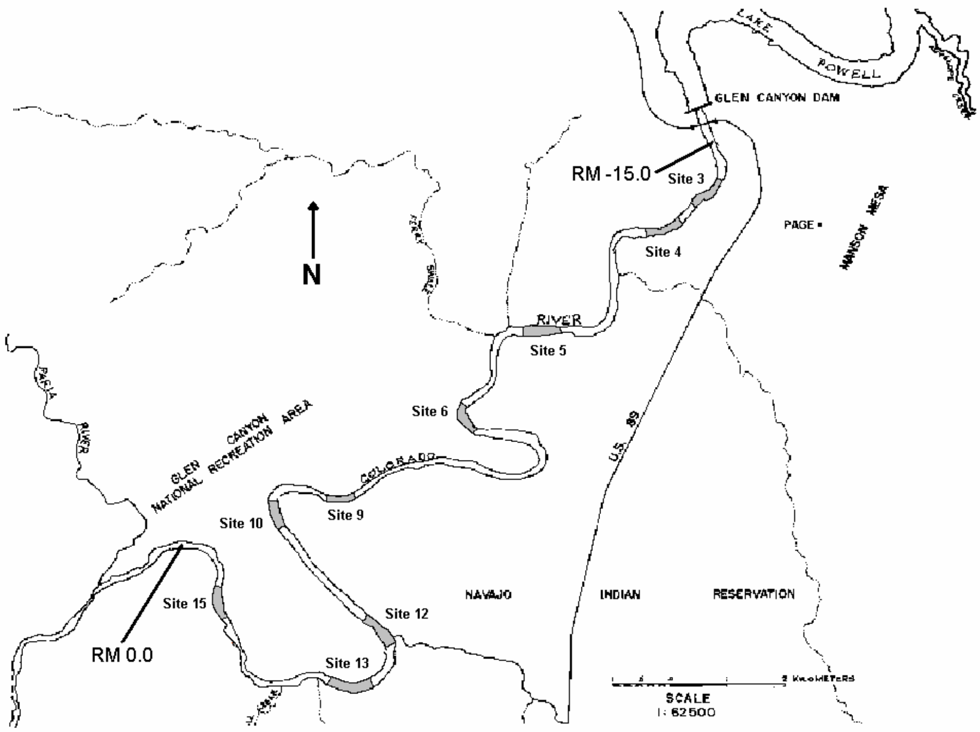

Figure 1. Map showing the Lee's Ferry tailwater fishery below Glen Canyon Dam, on the Colorado River, Arizona. Fixed sampling locations are shaded gray.

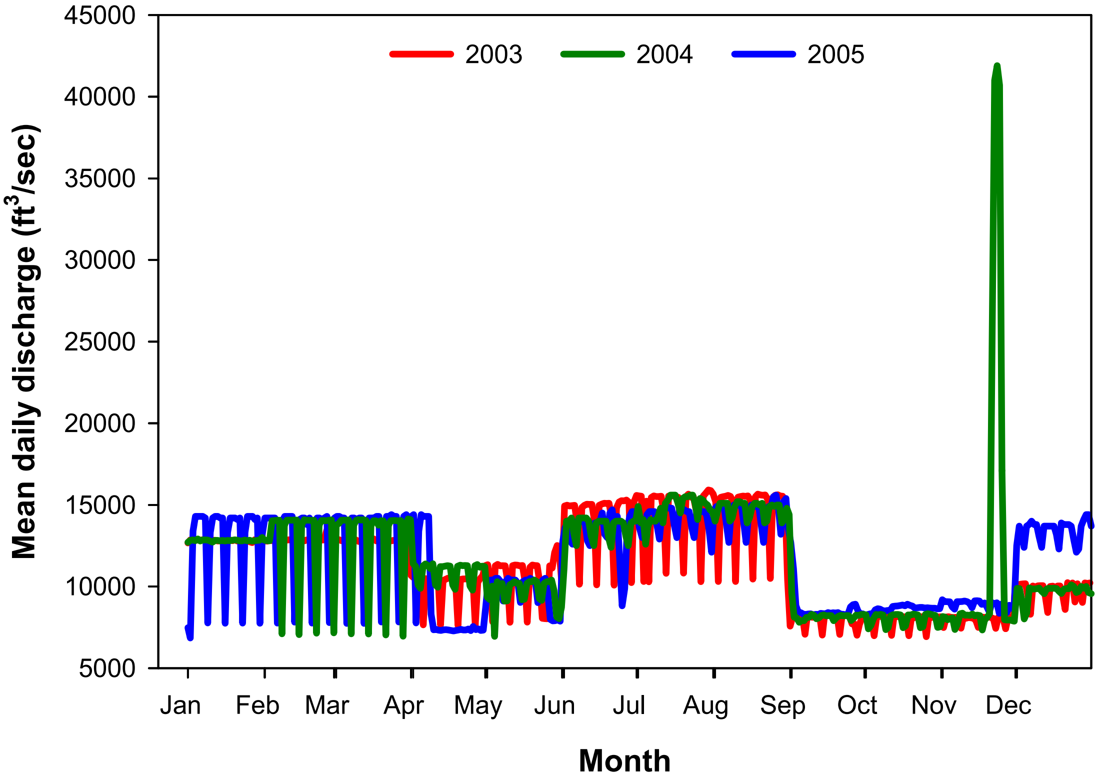

Figure 2. Mean daily discharge (cfs) from Glen Canyon Dam during 2003 (red line), 2004 (green line), and 2005 (blue line).

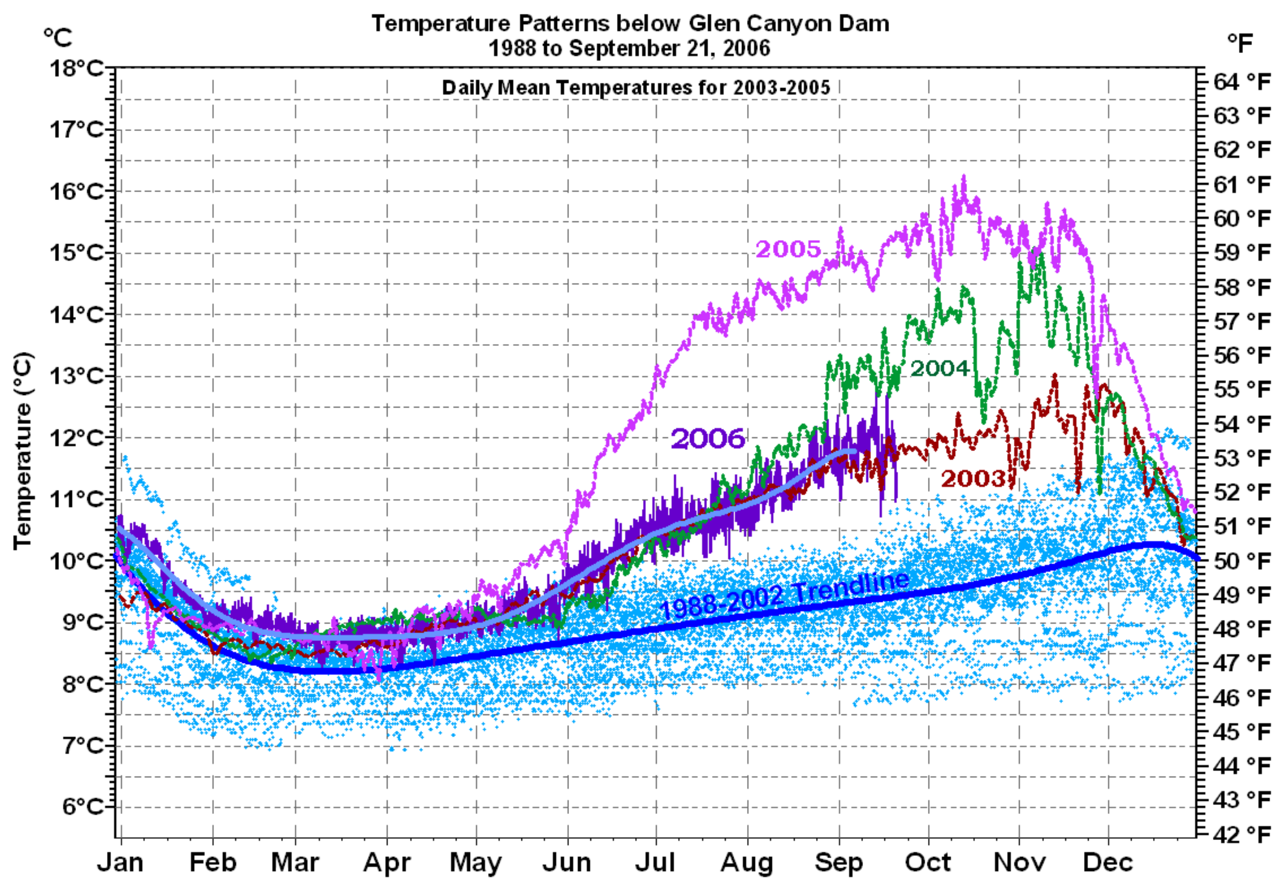

Figure 3. Daily temperatures below Glen Canyon Dam from 1988-2002 (blue line), 2003 (red line), 2004 (green line), 2005 (pink line), and 2006 (purple line). Figure courtesy of Susan Hueftle, USGS, Grand Canyon Monitoring and Research Center, Flagstaff, AZ.

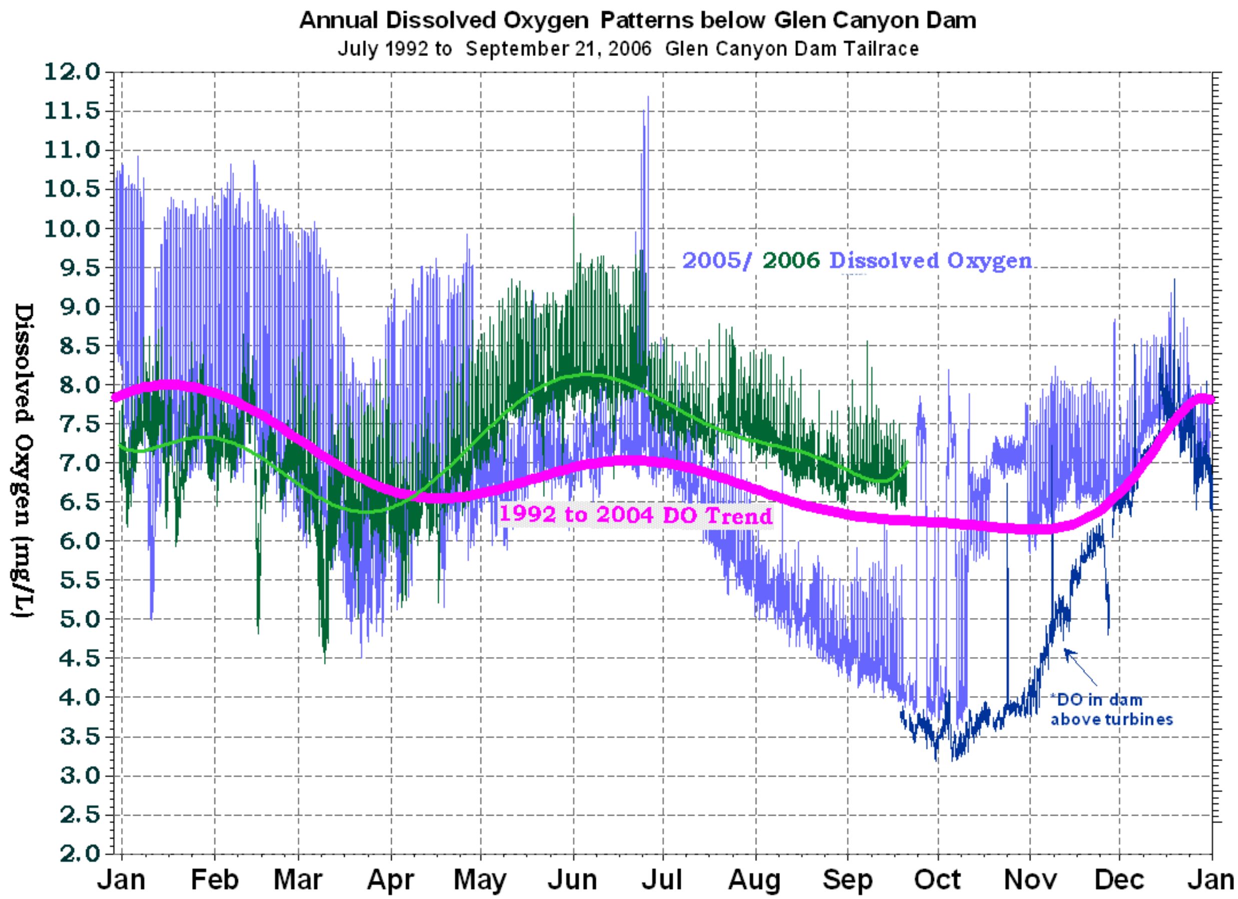

Figure 4. Daily dissolved oxygen (mg/L) below Glen Canyon Dam from 1992-2004 (pink line), 2005 (blue line), and 2006 (green line). Figure courtesy of Susan Hueftle, USGS, Grand Canyon Monitoring and Research Center, Flagstaff, AZ.

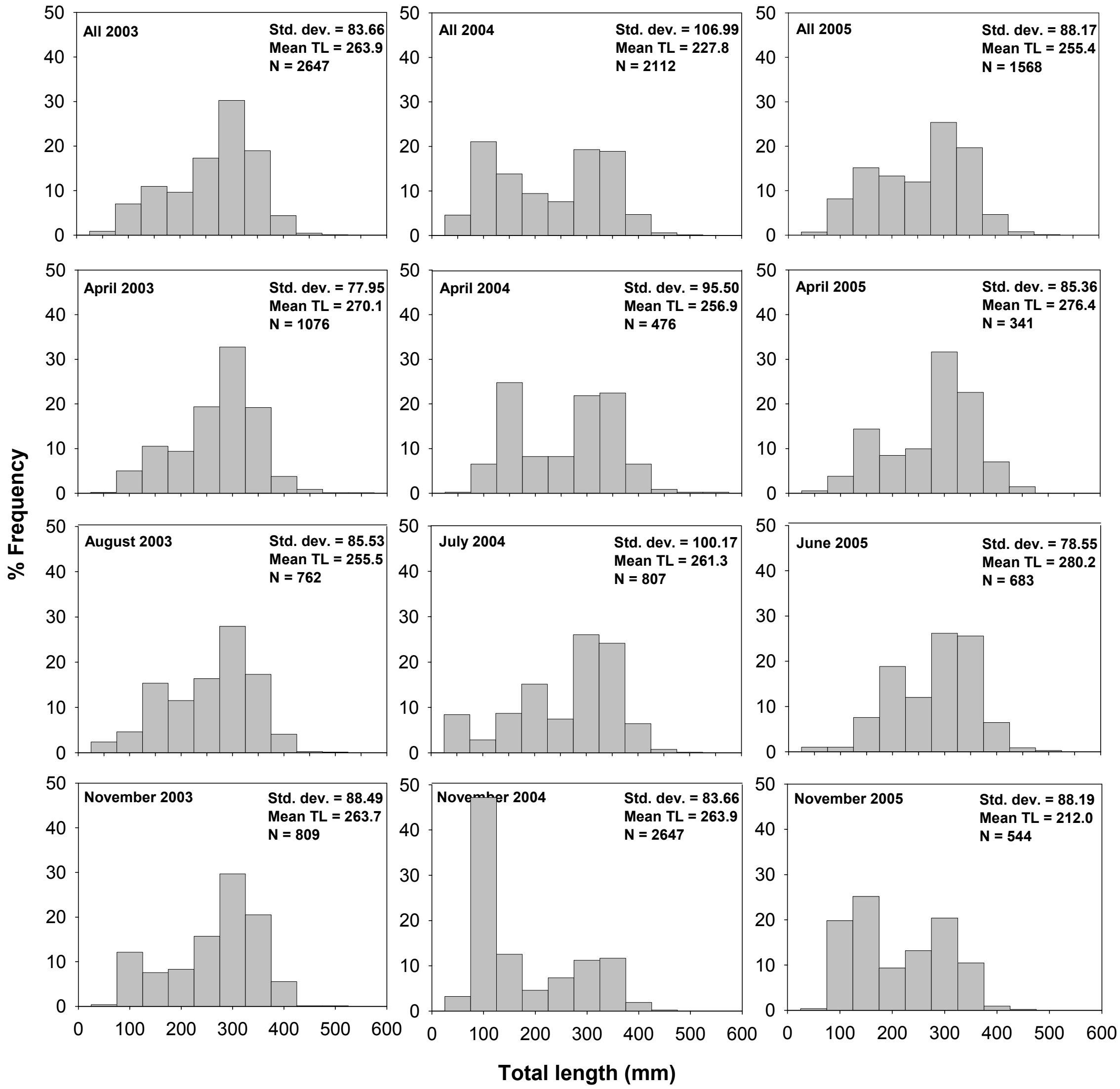

Figure 5. Lee's Ferry rainbow trout length frequency distribution during all sampling in 2003 (April, August, and November; left column), 2004 (April, July, and November; middle column), and 2005 (April, June, and November; right column). Data includes both fixed and random transects. Data from December 2004 (following a Beach Habitat Building Flood) was excluded from this analysis.

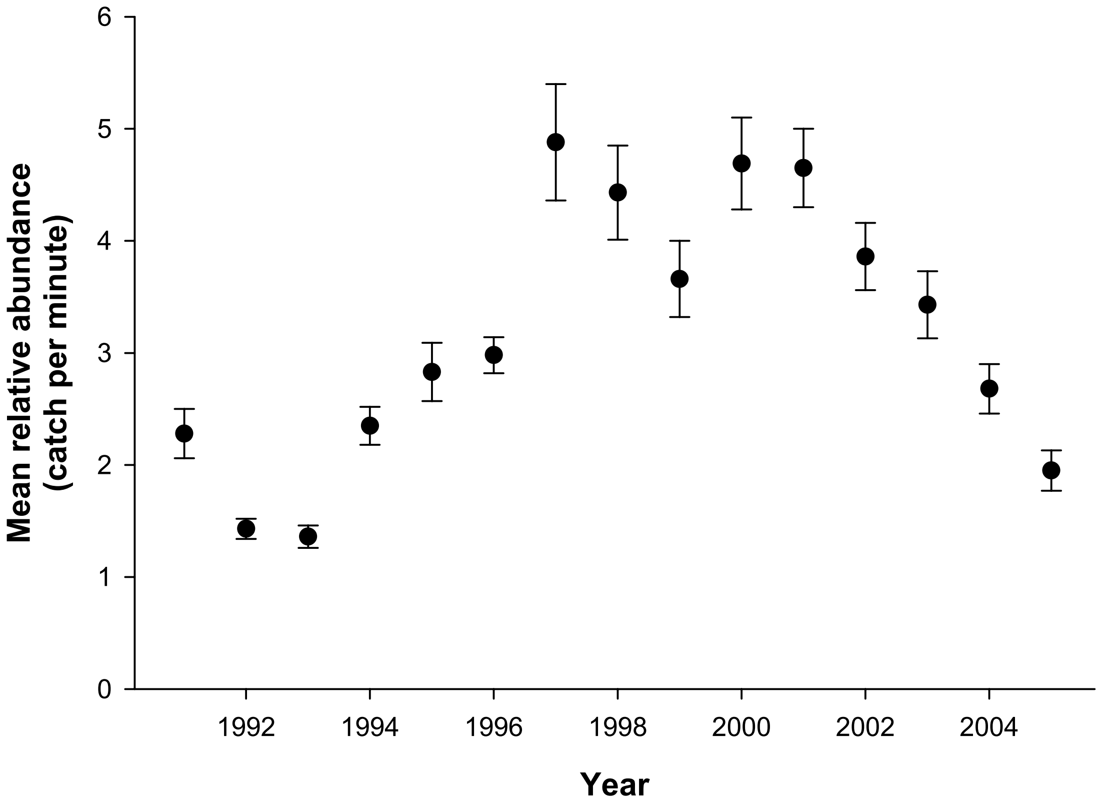

Figure 6. Rainbow trout mean relative abundance (catch per minute) in the Lee's Ferry tailwater fishery, 1991-2005. Figure represents data from all size classes in both fixed and random transects. Data from December 2004 (following a Beach Habitat Building Flood) are excluded from this analysis. Bars represent ± 1 S.E. of the mean.

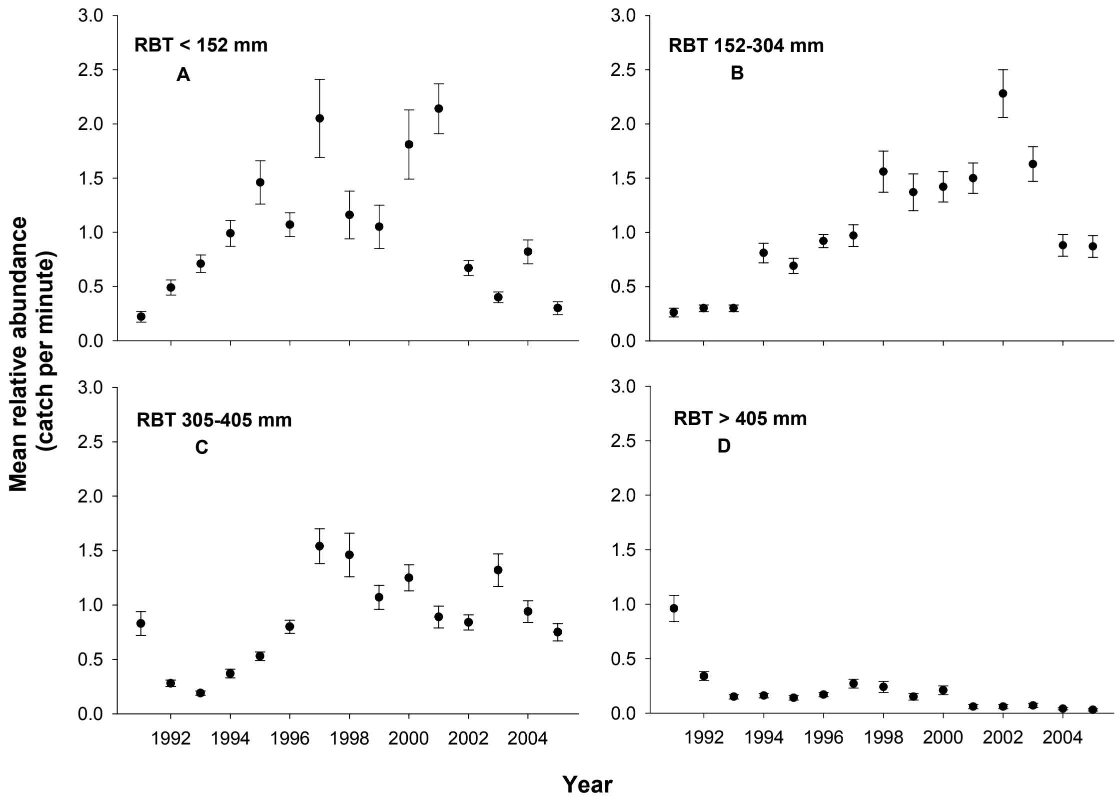

Figure 7. Rainbow trout mean relative abundance (catch per minute) for fish < 152 mm total length (TL; A), 152-304 mm TL (B), 305-405 mm TL (C), and > 405 mm TL (D) in the Lee's Ferry tailwater fishery, 1991-2005. Figure represents data from both fixed and random transects. Data from December 2004 (following a Beach Habitat Building Flood) were excluded from this analysis. Bars represent ± 1 S.E. of the mean.

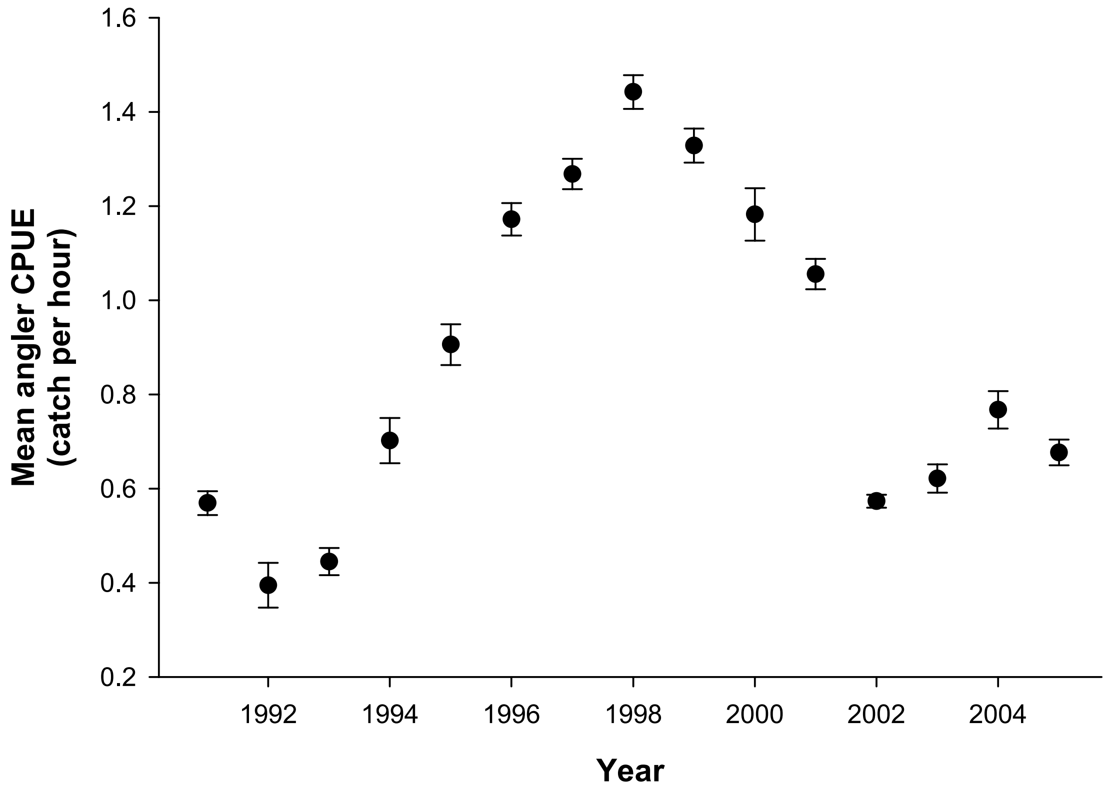

Figure 8. Mean angler catch-per-unit-effort (CPUE; catch per hour) of rainbow trout in the Lee's Ferry tailwater fishery, 1991-2005. Bars represent ± 1 S.E. of the mean.

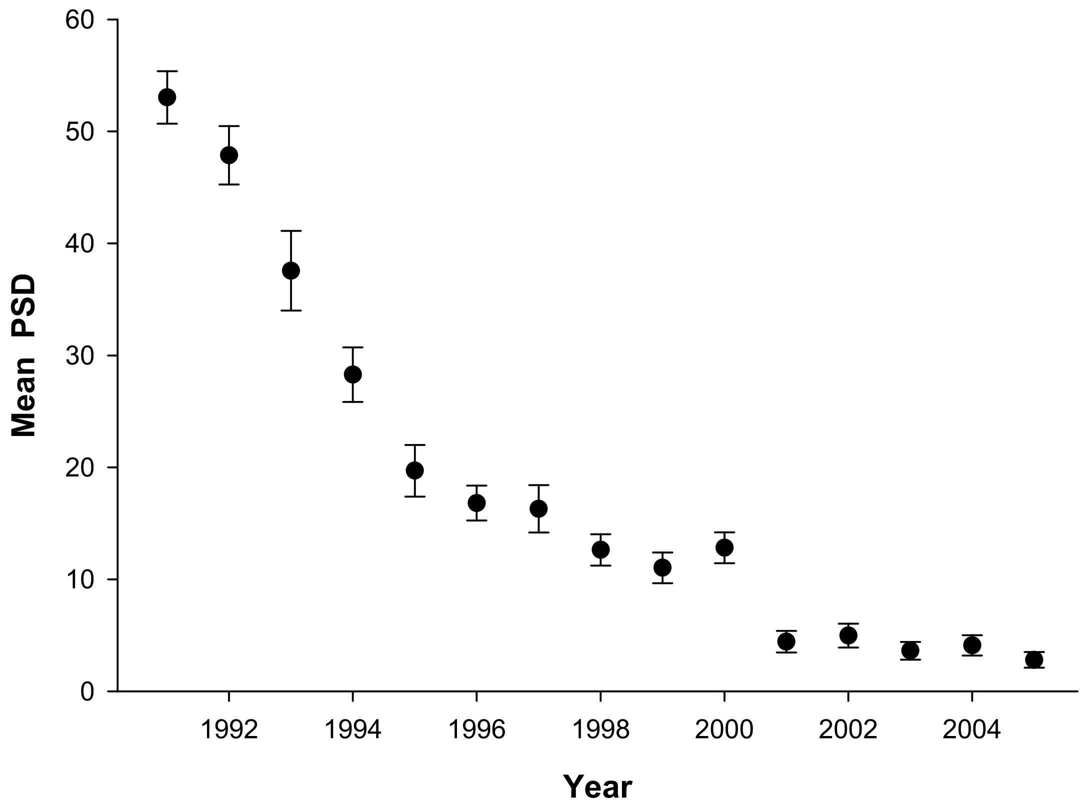

Figure 9. Rainbow trout mean proportional stock density ([# fish ≥ 406 mm TL / # fish ≥ 305 mm TL]*100; PSD) in the Lee's Ferry tailwater fishery, 1991-2005. Figure represents data from both fixed and random transects. Data from December 2004 were excluded from this analysis. Bars represent ± 1 S.E. of the mean.

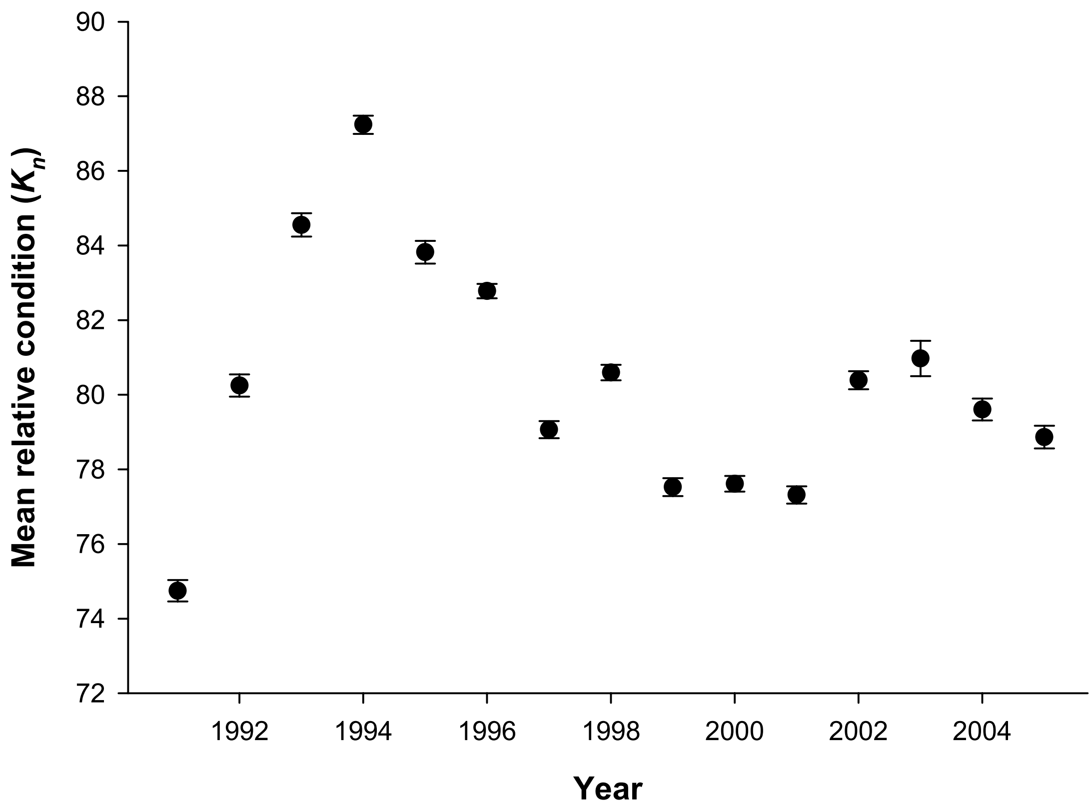

Figure 10. Rainbow trout mean relative condition (K_n) in the Lee's Ferry tailwater fishery, 1991-2005. Figure represents data from all size classes in both fixed and random transects. Data from December 2004 were excluded from this analysis. Bars represent ± 1 S.E. of the mean.

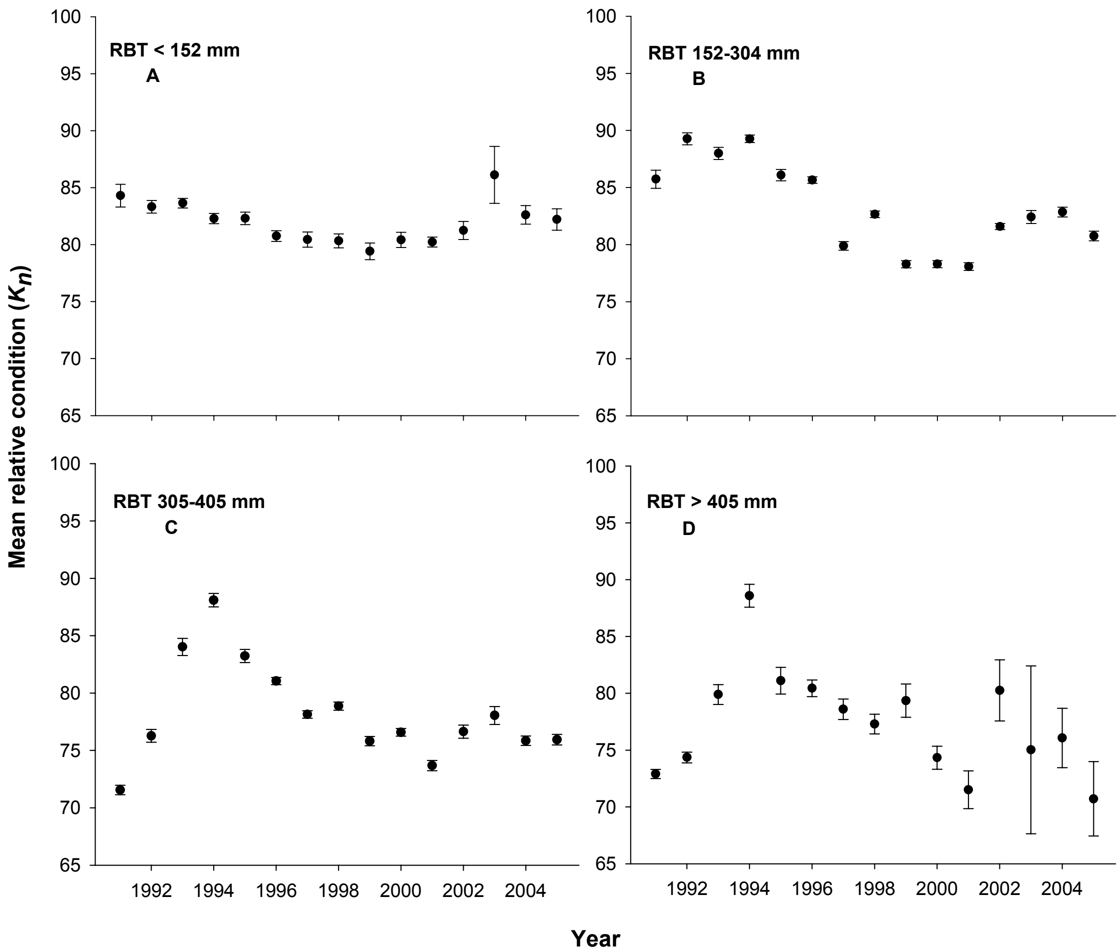

Figure 11. Rainbow trout mean relative condition (K_n) for fish < 152 mm total length (TL; A), 152-304 mm TL (B), 305-405 mm TL (C), and > 405 mm TL (D) in the Lee's Ferry tailwater fishery, 1991-2005. Figure represents data from both fixed and random transects. Bars represent ± 1 S.E. of the mean.

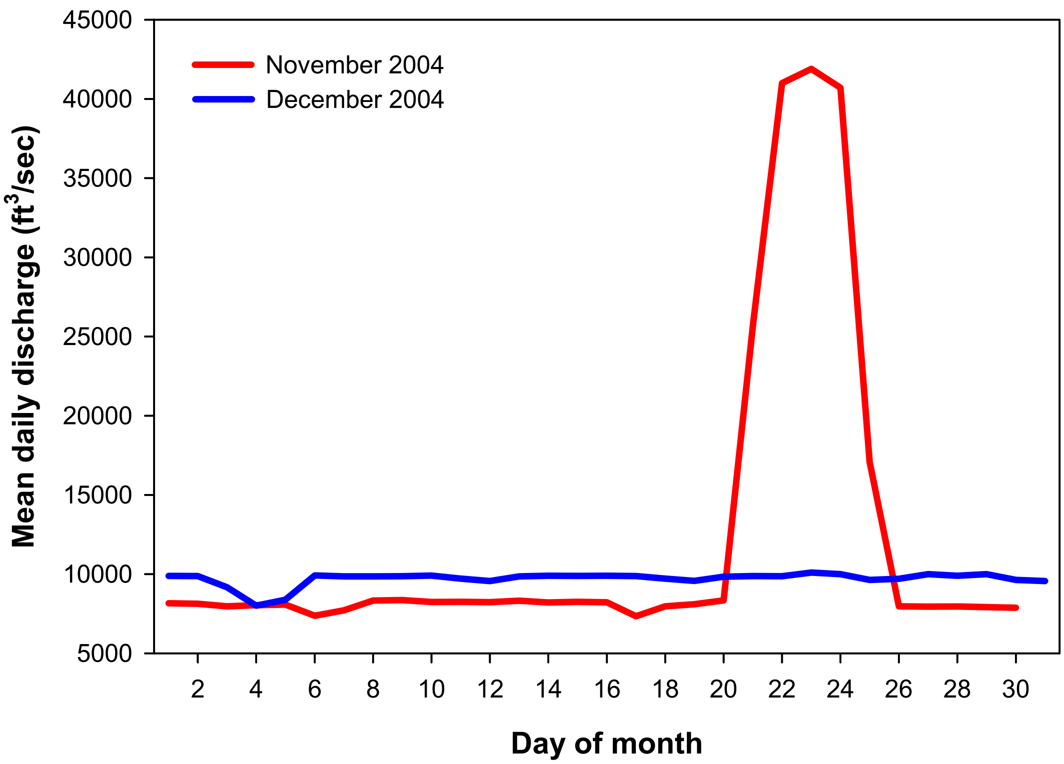

Figure 12. Mean daily discharge from Glen Canyon Dam during November 2004, including the beach habitat building flood (BHBF; red line), and December 2004 (blue line), following the BHBF. Sampling the Lee's Ferry tailwater occurred prior to the BHBF during 11/01-11/03/2004, and following the BHBF during 12/06-12/08/2004.

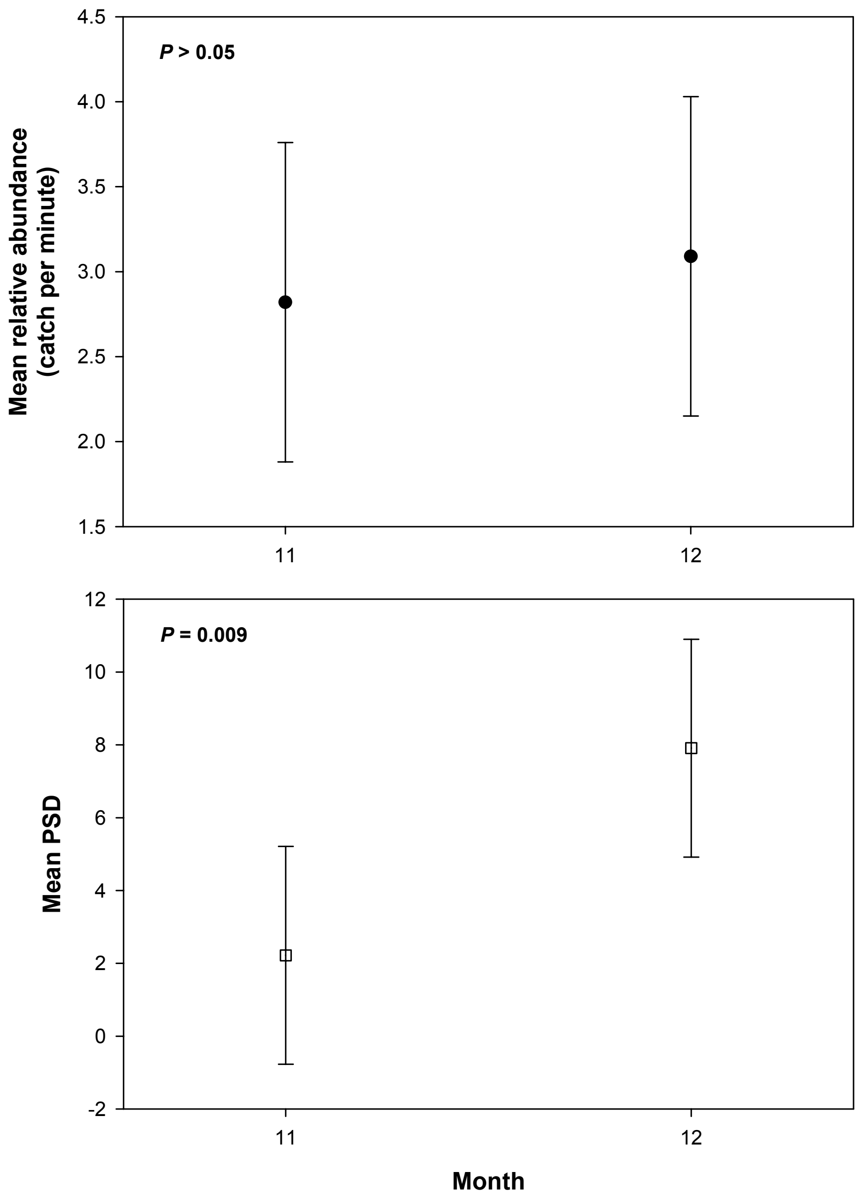

Figure 13. Mean rainbow trout relative abundance of all size classes (catch per minute; top panel) and mean proportional stock density ([# fish ≥ 406 mm TL / # fish ≥ 405 mm TL]*100; bottom panel) before a Beach Habitat Building Flood (BHBF; November) and after the BHBF (December) in the Lee's Ferry tailwater, 2004. Bars represent 95% confidence intervals of the mean.

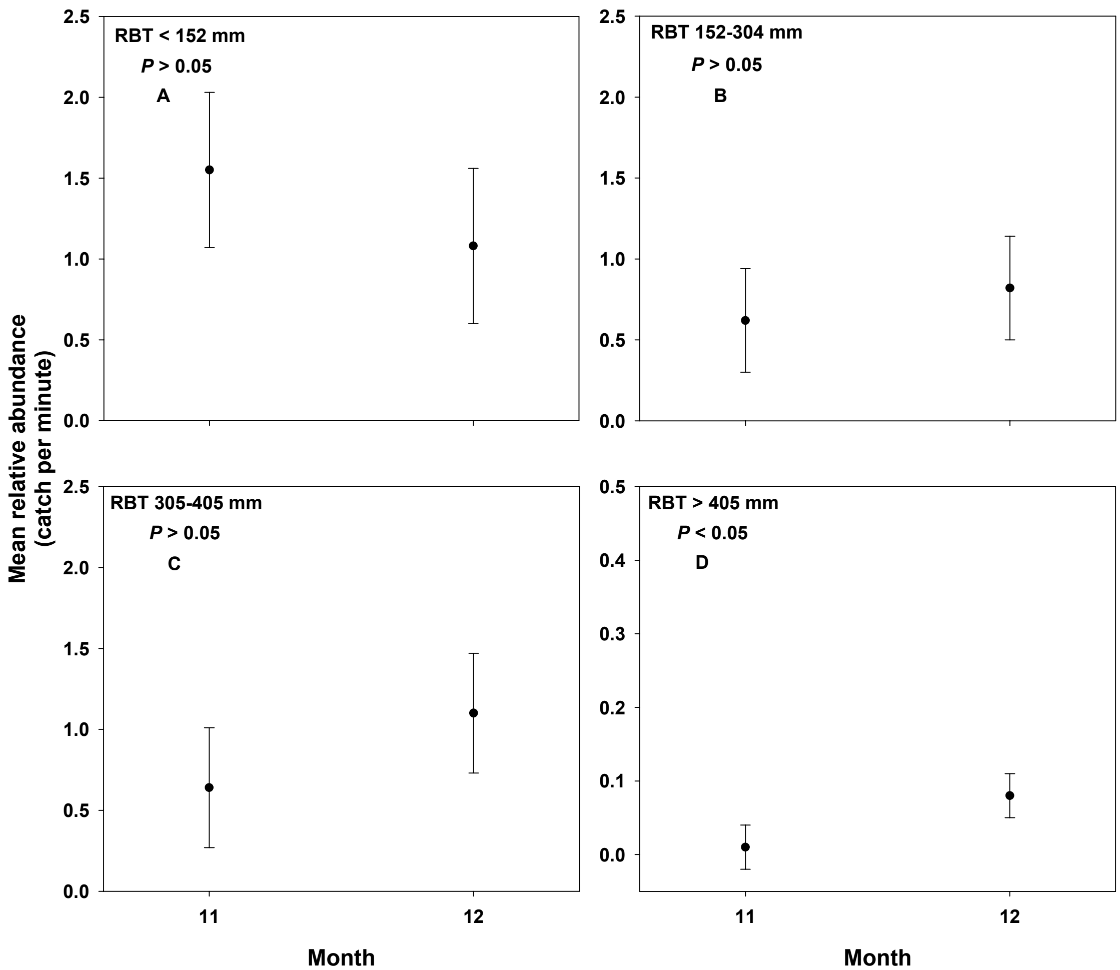

Figure 14. Rainbow trout mean relative abundance for fish < 152 mm total length (TL; panel A), 152-304 mm TL (panel B), 305-405 mm TL (panel C), and > 405 mm TL (panel D), in the Lee's Ferry tailwater, November and December, 2004 (prior to and following a Beach Habitat Building Flood). Figure represents data from both fixed and random transects. Bars represent 95% confidence intervals of the mean. Note the scale difference on the y-axis on panel D.