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Status and Trends of the Rainbow Trout Population in the Lees Ferry Reach of the Colorado River downstream from Glen Canyon Dam, Arizona, 1991–2009

Scientific Investigations Report 2011–5015

U.S. Department of the Interior
U.S. Geological Survey

Cover. Two anglers and a river guide fly fishing for rainbow trout (*Oncorhynchus mykiss*) at Lees Ferry, Arizona (Photograph courtesy of Rory Aikens, Arizona Game and Fish Department. Used with permission).

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Conversion Factors

[This report uses metric units for all measurements except for river flow, the standard measure of which is cubic feet per second (ft^3/s), and river mile (RM), which is used to describe distances along the Colorado River downstream of Glen Canyon Dam]

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows: °F= (1.8×°C) +32

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By Andrew S. Makinster,[1] William R. Persons,[2] and Luke A. Avery[1]

Abstract

The Lees Ferry reach of the Colorado River, a 25-kilometer segment of river located immediately downstream from Glen Canyon Dam, has contained a nonnative rainbow trout (*Oncorhynchus mykiss)* sport fishery since it was first stocked in 1964. The fishery has evolved over time in response to changes in dam operations and fish management. Long-term monitoring of the rainbow trout population downstream of Glen Canyon Dam is an essential component of the Glen Canyon Dam Adaptive Management Program. A standardized sampling design was implemented in 1991 and has changed several times in response to independent, external scientific-review recommendations and budget constraints. Population metrics (catch per unit effort, proportional stock density, and relative condition) were estimated from 1991 to 2009 by combining data collected at fixed sampling sites during this time period and at random sampling sites from 2002 to 2009. The validity of combining population metrics for data collected at fixed and random sites was confirmed by a one-way analysis of variance by fish-length class size.

Analysis of the rainbow trout population metrics from 1991 to 2009 showed that the abundance of rainbow trout increased from 1991 to 1997, following implementation of a more steady flow regime, but declined from about 2000 to 2007. Abundance in 2008 and 2009 was high compared to previous years, which was likely the result of increased early survival caused by improved habitat conditions following the 2008 high-flow experiment at Glen Canyon Dam. Proportional stock density declined between 1991 and 2006, reflecting increased natural reproduction and large numbers of small fish in samples. Since 2001, the proportional stock density has been relatively stable. Relative condition varied with size class of rainbow trout but has been relatively stable since 1991 for fish smaller than 152 millimeters (mm), except for a substantial decrease in 2009. Relative condition was more variable for larger size classes, and substantial decreases were observed for the 152–304-mm size class in 2009 and 305–405-mm size class in 2008 that persisted into 2009.

Introduction

Nonnative rainbow trout (*Oncorhynchus mykiss*) were initially stocked in 1964 in the Lees Ferry reach of the Colorado River in lower Glen Canyon downstream from Glen Canyon Dam (GCD; fig. 1). Since that time, fish management efforts, dam operations, and flow regimes (U.S. Department of the Interior, 1996) have affected this trout fishery (Marzolf, 1991; McKinney and others, 1999, 2001; McKinney and Speas, 2001; Korman, 2009; Korman and Campana, 2009; Korman and others, 2010). Effects of flow regulation on rainbow trout in the Lees Ferry reach have been a source of interest and debate for resource managers and the public for several decades (Maddux and others, unpub. report,1987;[1] McKinney and others, 1999, 2001; McKinney and Speas, 2001). Understanding how fish life histories are influenced by dam operations is essential to adaptively manage the water supply, hydroelectric power, and fishery, and meet other goals of the Glen Canyon Dam Adaptive Management Program (GCDAMP). Established in 1997, the GCDAMP is a Federal advisory committee chartered by the Department of the Interior to advise the Secretary of the Interior on the effects of GCD operations on downstream resources of the Colorado River.

Rainbow trout in the Lees Ferry reach constitute a popular recreational fishery and coexist with native flannelmouth sucker (*Catostomus latipinnis*) and nonnative common carp (*Cyprinus carpio*). Before 1991, the rainbow trout population was sustained by annual stocking (McKinney and others, 2001). Since that time, the population has been largely self sustaining; although, stocking continued through 1998. The rainbow trout population in the Lees Ferry reach

[1] Although the U.S. Geological Survey does not typically cite unpublished reports, this report makes reference to several unpublished reports to provide the reader with important background information. Copies of unpublished reports are available upon request by contacting the Center Director, U.S. Geological Survey, Southwest Biological Science Center, 2255 N. Gemini Drive, Flagstaff, AZ 86001.

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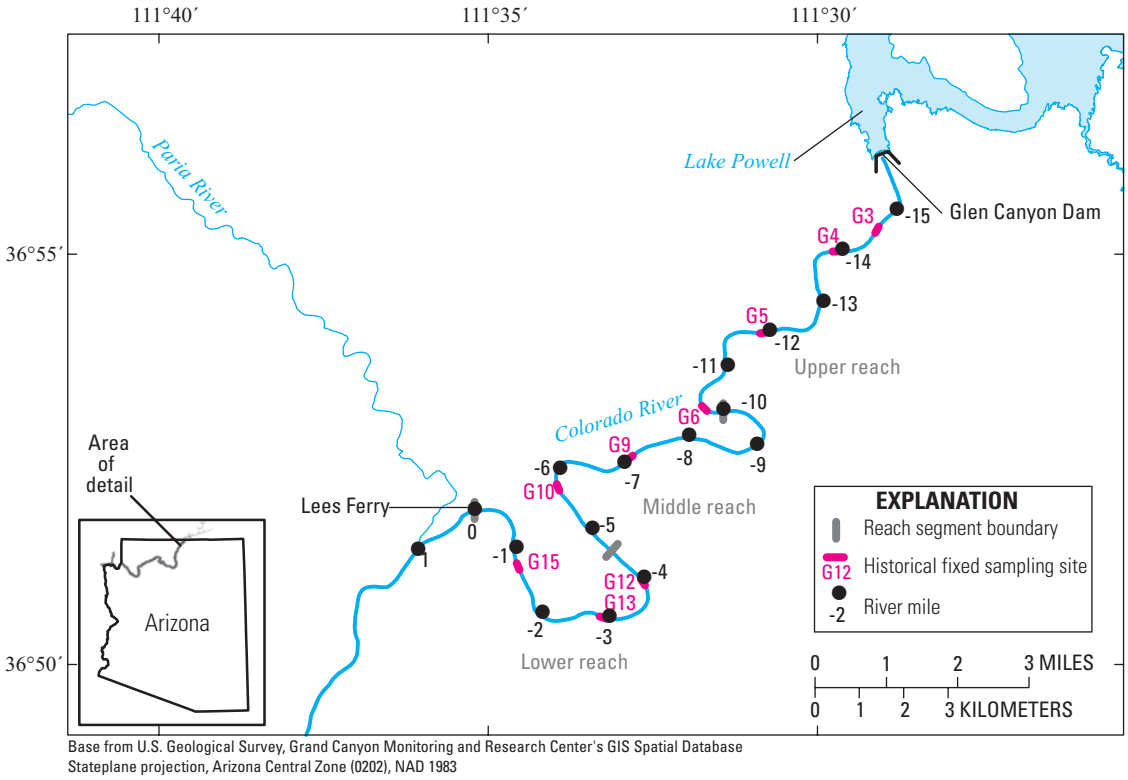

Figure 1. Location of the Lees Ferry reach of the Colorado River, which extends from Glen Canyon Dam at river mile (RM) -15.7 to Lees Ferry at RM 0. Locations of randomly selected electrofishing sampling sites (not shown) are distributed throughout the reach. Map credit: Thomas Gushue, U.S. Geological Survey.

has been monitored on a regular basis by the Arizona Game and Fish Department (AGFD) since 1991 as part of a cooperative agreement with the U.S. Geological Survey's (USGS) Grand Canyon Monitoring and Research Center (GCMRC). Data collected through these efforts were summarized annually in unpublished reports. The present study was initiated in 2010 to review, summarize, and interpret these previously unpublished data.

Purpose and Scope

The purpose of this report is to summarize rainbow trout monitoring in the Lees Ferry reach from 1991 through 2009, describing the results of (1) a comparison of rainbow trout data collected from two types of sampling sites (fixed and random) from June 2002 to November 2009 and (2) an evaluation of the status and trends of rainbow trout in the Lees Ferry reach from 1991 to 2009. Rainbow trout population variables evaluated for the study include catch per unit effort (CPUE), proportional stock density (PSD), and relative condition (K_n). Data from fixed and random sampling sites are statistically compared to determine whether they can be combined for analysis of population metrics. The CPUE data collected in 2008 and 2009 are described in relation to a 2008 high-flow experiment (HFE) at GCD.

Description of Study Area

Glen Canyon Dam impounds the Colorado River in north-central Arizona near the Arizona-Utah border (fig. 1). The Lees Ferry reach of the river is known as a tailwater fishery because it occurs downstream from a large dam where deepwater discharge provides cool water that allows coldwater species like rainbow trout to survive. Water temperatures range from 9˚C to 15˚C at the foot of the dam (Voichick and Wright, 2007). The Lees Ferry reach is confined within a narrow, deeply incised canyon and has no perennially flowing tributaries.

Flow Regimes

Between 1988 and 1994, annual mean water releases from GCD were approximately 10,600 ft^3/s, increasing to approximately 21,200 ft^3/s in 1997. Daily water releases commonly fluctuated from less than 1,500 ft^3/s to more than 17,000 ft^3/s from 1988 to 1991; minimum daily flows approached 3,000 ft^3/s (McKinney and others, 2001). After mid-1991, minimum releases from the dam were 5,000 ft^3/s, and mean daily fluctuations in flows declined by more than 50 percent. HFEs were conducted in 1996, 2004, and 2008. These HFEs were relatively short-duration (3–7 days) releases that exceeded the powerplant capacity (31,500 ft^3/s).

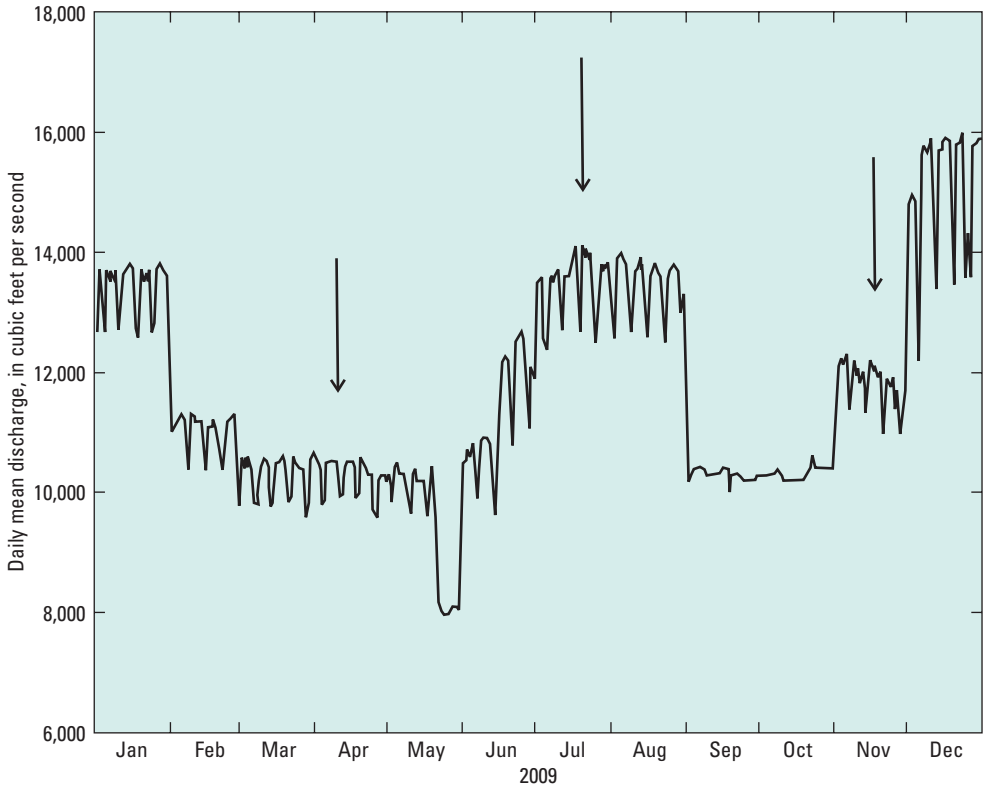

Figure 2. Daily mean discharge released from Glen Canyon Dam during 2009. Arrows denote electrofishing sampling events.

Discharges from GCD were seasonally variable during 2009 (fig. 2). Dam releases also fluctuated daily throughout 2009, with the exception of a short period in May and the entire months of September and October. As part of a 5-year steady-flows experiment that got underway in the fall of 2008, flows were held steady at about 10,000 ft^3/s in September and October 2009. This experiment was initiated to try and raise nearshore Colorado River water temperatures in the vicinity of the confluence of the Little Colorado River to benefit the endangered humpback chub (*Gila cypha*; U.S. Department of the Interior, 2008). This experiment is proposed to end in 2012, and ongoing research is investigating the effects of fall steady flows on rainbow trout and humpback chub.

Previous Investigations

Electrofishing has been used to sample the fish community in the Lees Ferry reach since the early 1980s (Maddux and others, unpub. report, 1987). Standardized monitoring of the trout fishery using electrofishing was initiated in 1991 and was used through 2009 to provide data to evaluate responses of the rainbow trout population to dam operations (McKinney and others, 2001). From 1991 through 1997, higher mean and less variable water discharge from GCD favored increased densities of rainbow trout, but changes occurred in the relative condition (a measure of the weight-to-length relationship) and bioenergetics (energy flow through living systems) of the population (McKinney and others, 2001; McKinney and Speas, 2001). Rainbow trout less than 305 mm in length were strongly affected by low and variable water discharge from the dam but not by biological variables; therefore, these trout were able to meet energy requirements for growth. In contrast, rainbow trout longer than 305 mm were not affected by flow variability, but their growth and condition were strongly influenced by biological factors associated with changes in quantity and quality of the aquatic food resources. Since the early 1990s, large trout have rarely met energy requirements for growth (McKinney and Speas, 2001).

In recent years, the GCMRC sponsored two protocol evaluation panels (PEPs) to provide independent, external scientific reviews of Colorado River monitoring protocols (Anders and others, unpub. report, 2001; Bradford and others, unpub. report, 2009). The PEP that convened in 2000 recommended increasing the overall number of electrofishing samples by reducing the length of river sampled at existing fixed sampling sites by three-fourths and adding random sampling sites throughout the Lees Ferry reach. These recommendations were implemented in 2002. Random sampling is intended to give representative estimates of the rainbow trout population status, whereas sampling at fixed sites ensures continuity with historical data (Urquhart and others, 1998). The increased number of sampling sites provides increased statistical power to detect changes in rainbow trout population variables on a yearly timescale (Speas and others, unpub. report, 2004).

River Mile Naming Convention in Study Area

The term *river mile* (RM) is used to describe distance along the Colorado River in the study area. The use of this term has historical precedent and provides a reproducible method for describing locations. Lees Ferry (fig. 1) is considered the reference point, RM 0, with mileage measured from both upstream and downstream locations. Locations upstream from Lees Ferry in Glen Canyon Dam National Recreation Area are assigned negative river mile designations; thus, GCD is located at RM -15.7.

Methods of Investigation

Historical information about the rainbow trout population in the Lees Ferry reach, collected using electrofishing and creel surveys, or angler exit interviews, was compiled, documented, and analyzed to determine how characteristics of the population changed over time.

Data Compilation

The rainbow trout population in the Lees Ferry reach has been sampled by the AGFD since 1984 and documented in unpublished AGFD annual reports. The GCMRC transferred the data collected by the AGFD to a Microsoft®Access fish database maintained by the GCMRC. Data analyzed in this study (1991–2009) were downloaded from the fish database and imported into SPSS software (SPSS Inc., Chicago, Ill.) for analysis. The data were filtered to exclude samples not collected using standard electrofishing methods, checked for errors, and coded for inclusion in analyses in this study. Data collected before 1991 were not included in this study because they were not collected in a consistent manner. The entire GCMRC fish database for the Colorado River downstream of GCD contains approximately 750,000 individual fish capture records, and, of this total, approximately 63,500 records were analyzed for this study for fish captured in the Lees Ferry reach during 1991–2009.

Rainbow Trout Sampling

From 1991 to 2009, rainbow trout were sampled in the Lees Ferry reach using electrofishing to collect fish two to four times per year. Information for each captured fish was recorded before it was released. Before 2002, sampling sites were selected on the basis of longitudinal (along-river) stratification, whereby the Lees Ferry reach was divided into lower (RM 0 to -4.5), middle (RM -4.5 to -10.0), and upper (RM -10.0 to -15.7) subreaches. Starting in 2002, sampling sites have also been selected on the basis of shoreline habitat stratification. These habitats include talus/cobble-bar and sandbar/cliff-face shorelines.

Electrofishing

The electrofishing equipment used to sample rainbow trout from 1991 to 2009 was operated from boats and consisted of a system that applied pulsed direct current (~310 V, ~15 A; Sharber and others, 1994) to a 356-mm spherical electrode system. Sampling typically commenced shortly after dusk and was conducted 5 to 7 hours per night when daily dam releases, and thus flows, were typically at a minimum. Over the years, two different boat types were used to conduct the sampling, but the electrofishing system configurations remained the same.

Capture probabilities (defined as the number of fish captured divided by the number of fish available to be captured) during electrofishing were unlikely to be affected between sampling events by water temperature, discharge, and turbidity because sampling conditions were generally similar from year to year. Therefore, it has been assumed that CPUE, expressed as the number of fish captured per minute of electrofishing, is a valid surrogate for rainbow trout population size.

1991–96

Fifteen fixed sampling sites were established along the 25-km Lees Ferry reach beginning in November 1991. These sites were relatively uniformly distributed along the Lees Ferry reach, so that the lower, middle, and upper subreaches each contained five fixed sites. The sites were sampled by electroshocking a reach about 610 m in length at each site for approximately 2,000 seconds. The electrofishing system was operated from a 6-m flat-bottomed aluminum boat.

1997–2001

Starting in April 1997, to eliminate redundancy in habitat types and reduce the cost of monitoring the Lees Ferry reach, 6 of the 15 sites that had been sampled since 1991 were removed from the sampling design. Of the six sites eliminated, half represented locations with high densities of rainbow trout and half represented locations with low densities. The remaining nine fixed sites were sampled during this period using the same methods and equipment used from 1991 to 1996, except that in 2001 a 5-m inflatable boat was used in addition to the 6-m aluminum boat. Comparisons showed no differences in catch rate between the two boat types (Speas and others, unpub. report, 2004).

2002–9

On the basis of the recommendations made by the PEP that convened in 2000, sampling was conducted at 9 historical fixed sites and 27 random sites from 2002 to 2009. Initially, the study area was stratified by Lees Ferry subreach and shoreline habitat within subreaches to ensure representation of the lower, middle, and upper subreaches and talus/cobble-bar and sandbar/cliff-face shorelines in each sampling event. For each sampling event, 27 sites were selected randomly (9 sites per

stratum) without replacement (sites sampled previously were excluded). Again following the recommendations of the PEP, the river length sampled at each of the fixed sites was reduced from about 610 to 150 m, and the duration of electroshocking was reduced from approximately 2,000 to 500 seconds (Speas and others, unpub. report, 2004). The sampled river length and electroshocking duration were the same for fixed and random sites. The total length of river sampled for each sampling event was approximately 5.6 km or about 10 percent of the available shoreline. All sites were sampled using the same methods and equipment used from 1991 to 2001, except that the electrofishing system was operated from a 5-m inflatable boat starting in 2002.

Data Collection and Fish Handling

Total length (TL) was measured for all fish, and weight was measured when conditions permitted accurate measurements. The sex of captured fish was determined on the basis of manual extrusion of gametes. Starting in 2007, individually numbered Floy FD-68B external anchor tags (Floy Tag Company, Seattle, Wash.) were inserted into rainbow trout longer than 200-mm TL that were captured at the random sampling sites. In 2009, previously untagged rainbow trout longer than 152-mm TL captured at the fixed sampling sites were implanted with 400-kHz passive integrated transponder (PIT) tags. That same year, standard ISO 134.2-kHz PIT tags were implanted in previously untagged flannelmouth sucker and brown trout (*Salmo trutta*) longer than 152-mm TL, consistent with Grand Canyon fish-handling protocols (Ward and Hangsleben, unpub. report, 2009). The 400-kHz tags were used in this study because they were surplus tags no longer used in other Colorado River studies. Both PIT tag types are full duplex, 12-mm tags. The adipose fins of the PIT-tagged rainbow and brown trout were clipped so that tag loss could be monitored. The tagging program is primarily intended to provide information in future years on fish movement and growth, because tagged fish are measured each time they are recaptured.

Subsamples of rainbow trout were sacrificed once per year during 2000 and 2002–6 (N=60–110 for each sampling event) and tested for whirling disease at the AGFD Pinetop Fish Health Laboratory. Tests used the modified polymerase chain reaction method. Starting in 2007, subsamples of rainbow trout continued to be sacrificed once per year, but they were tested for whirling disease at the Washington Animal Disease Diagnostic Laboratory at Washington State University.

Creel Surveys

Creel surveys have been conducted by the AGFD since about 1977. In 2009, creel surveys were conducted during 6 random weekdays and 4 weekend days per month. As part of a creel survey, personnel recorded the number of fish caught and kept by anglers, the species, the number of hours fished per angler, and other information. In this study, angler CPUE was calculated as the number of fish caught per hour fished. Historical creel survey data for the Lees Ferry reach are maintained by AGFD and GCMRC.

Data Analysis

Rainbow trout data collected in the Lees Ferry reach from 1991 to 2009 were evaluated by analyzing the status and trends of selected population metrics. Before conducting a trend analysis, however, it was necessary to determine if data collected at fixed and random sampling sites could be combined and analyzed as one dataset.

Rainbow Trout Population Metrics

CPUE, a surrogate measure of the size of the rainbow trout population in the Lees Ferry reach, was defined in this study as the number of rainbow trout captured per minute of electrofishing. The CPUE was computed for four fish-length size classes: less than 152 mm, 152 mm to less than 305 mm, 305 to less than 405 mm, and equal to or more than 405 mm. For ease of discussion, these size classes are referred to hereafter as <152 mm, 152–305 mm, 305–405 mm, and >405 mm. As this report may be of interest to members of the general public who are more familiar with English units, the following equivalents are provided for the size classes:

Size class	
in millimeters	**in inches**
<152	<6
152 to <305	6 to <12
305 to <405	12 to <16
≥405	≥16

The size structure of the rainbow trout population in the Lees Ferry reach was described by calculating proportional stock density (PSD; Anderson and Nuemann, 1996) as the ratio of "quality-sized" fish (defined as longer than 405 mm) to the sum of quality- and "stock-sized" fish (defined as longer than 305 mm). The PSD (in percent) is computed as

$$PSD = \left(\frac{RBT_Q}{RBT_S}\right) \times 100, \quad (1)$$

where RBT_Q is the number of rainbow trout longer than 405 mm, and RBT_S is the number of rainbow trout longer than 305 mm. Rainbow trout longer than 405 mm have been protected from harvest by AGFD fishing regulations; most rainbow trout longer than 305 mm are sexually mature and generally desired by anglers (Todd Pringle, Arizona Game and Fish Department, written commun., 2004).

The relative condition (K_n; Le Cren, 1951) of individual rainbow trout was computed according to

$$K_n = \left(\frac{W}{W'}\right) \times 100, \quad (2)$$

where K_n is expressed as a percentage, W is the weight (grams) of the fish, and W' (grams) is the standard weight relationship $W' = 10^{[(-4.6 + 2.856 * \log_{10}(TL))]}$ estimated from a linear regression of rainbow trout length (TL in equation 2 is in millimeters) versus weight (grams) for data collected in the Lees Ferry reach since 1991. The relative condition was computed for the four fish-length size classes defined earlier.

Comparison of Data from Fixed and Random Sampling Sites

The primary role of fixed sampling sites is to provide data that can be used to identify long-term trends in fish populations; the primary role of random sampling sites is to provide data that can be used to assess the status of fish populations at particular times (Urquhart and others, 1998). Guidelines for statistical analyses of data from fixed and random sites are unclear as to whether the two types of data can be combined for more powerful (that is, larger sample sizes to reduce variance in estimators) evaluations of long-term trends (N.S. Urquhart, Colorado State University, written commun., 2002). In this study, it is assumed that if data collected at fixed sites have means and variances similar to those of data collected at random sites, then the two types of data may be combined for long-term trend analysis.

To evaluate differences in means and variances of the two types of data, population metrics (CPUE, PSD, and K_n) estimated from data collected at fixed and random sites in the Lees Ferry reach from June 2002 to November 2009 were compared using one-way analysis of variance (ANOVA). The CPUE data were log-transformed to correct for unequal variances. Levene's test of homogeneity of variance was used to test the null hypothesis that error variances of fixed and random site data were equal. No statistically significant (α=0.05) differences in CPUE and PSD were detected among fixed and random sites (table 1). Differences were observed in K_n for the 152–305-mm and 305–405-mm size classes. These differences were very small (1–4 percent), however, and attributed to the large sample sizes (more than 800 length and weight measurements for each size class). The differences in K_n are not believed to be biologically significant. On the basis of the results of the ANOVA, all population metrics estimated from data collected from 1991 to 2009, whether from fixed or random sites, were combined into one dataset and analyzed to determine the status and trends of the rainbow trout population in the Lees Ferry reach.

Table 1. One-way analysis of variance (ANOVA) results of rainbow trout population metrics estimated from data collected at fixed and random sampling sites in the Lees Ferry reach, June 2002–November 2009.

[Abbreviations: mm, millimeters; CPUE, catch per unit effort; S.E., standard error; <, less than; K_n, relative condition; DF, degrees of freedom; *P*-value, probability value; PSD, proportional stock density; *, denotes significance at α=0.05]

Parameter	Size class of rainbow trout			
	<152 mm	152 to <305 mm	305 to <405 mm	≥405 mm
Abundance				
Mean CPUE (2 S.E.)				
Fixed sampling sites	1.04 (0.14)	0.84 (0.10)	0.66 (0.06)	0.03 (0.01)
Random sampling sites	0.95 (0.08)	1.00 (0.06)	0.77 (0.04)	0.04 (0.01)
F ratio	0.36	2.20	2.20	2.85
DF (numerator, denominator)	1, 805	1, 805	1, 805	1, 805
P-value	0.55	0.14	0.14	0.09
Condition				
Mean K_n (2 S.E.)				
Fixed sampling sites	80.25 (0.61)	80.85 (0.28)	76.27 (0.35)	75.25 (2.16)
Random sampling sites	81.62 (0.38)	82.65 (0.17)	78.13 (0.21)	77.71 (1.17)
F ratio	3.64	31.29	20.68	1.00
DF (numerator, denominator)	1, 975	1, 4750	1, 3536	1, 178
P-value	0.06	< 0.0001*	< 0.0001*	0.32
	All size classes			
Size structure				
Mean PSD (2 S.E.)				
Fixed sampling sites	3.51 (0.79)			
Random sampling sites	4.21 (0.46)			
F ratio	0.58			
DF (numerator, denominator)	1, 707			
P-value	0.45			

Status and Trends of Rainbow Trout Population

The status and trends of the rainbow trout population in the Lees Ferry reach were evaluated by analyzing trout population metrics computed from data collected at fixed and random sampling sites from 1991 to 2009. These metrics included the annual mean CPUE, PSD, and K_n. Detailed results for fish data collected in 2009 are presented in appendix 1, including length frequency distributions and tag recapture information.

Catch per Unit Effort

In this study, CPUE for rainbow trout was used as a surrogate measure of the abundance, or population size, of the species. Between 1991 and 2009, the mean CPUE for rainbow trout ranged from 1.3 to 4.8 fish per minute (fig. 3). The CPUE increased from 1991 to 1997, following implementation of a more steady flow regime, but declined from about 2000 to 2007. The substantial increase in CPUE in 2008 and 2009 was likely the result of the effects of the March 2008 HFE. During this HFE, large volumes of water (41,500 ft^3/s) were released from GCD for 60 hours to restore sandbars and fulfill other objectives identified by the GCDAMP (for details, see Melis and others, 2010). The high CPUE in 2008 is largely attributable to increased catch of rainbow trout shorter than 152 mm (fig. 4*A*). The CPUE increase in 2009 is partially the result of increased catch of rainbow trout shorter than 152 mm as well as increased catch of trout in the 152–305-mm size class (fig. 4*A–B*). The latter represents the 2008 cohort as well as the 2009 cohort. The CPUE of rainbow trout in the 305–405-mm size class declined slightly from 2003 to 2008 but appeared to stabilize in 2009 (fig. 4*C*). The CPUE of rainbow trout longer than 405 mm has remained low since 2000 (fig. 4*D*).

On the basis of creel survey results, the general trends in the mean angler CPUE for rainbow trout (fig. 5) resemble the trends in the mean electrofishing CPUE for rainbow trout in the 152–305-mm and 305–405-mm size classes from 1991 to 2009 (fig. 4*B–C*). Trends in mean angler CPUE (fig. 5) likely differ from the mean electrofishing CPUE for the combined size classes (fig. 3) owing to the prevalence of small rainbow trout captured during electrofishing surveys, especially in 2008 and 2009, which anglers do not catch. Angler catch rates declined substantially in 2002, and catch rates have only fluctuated slightly since then. Mean angler CPUE increased in 2009, probably because of the recruitment of the 2008 cohort into the more catchable 152–305-mm size class.

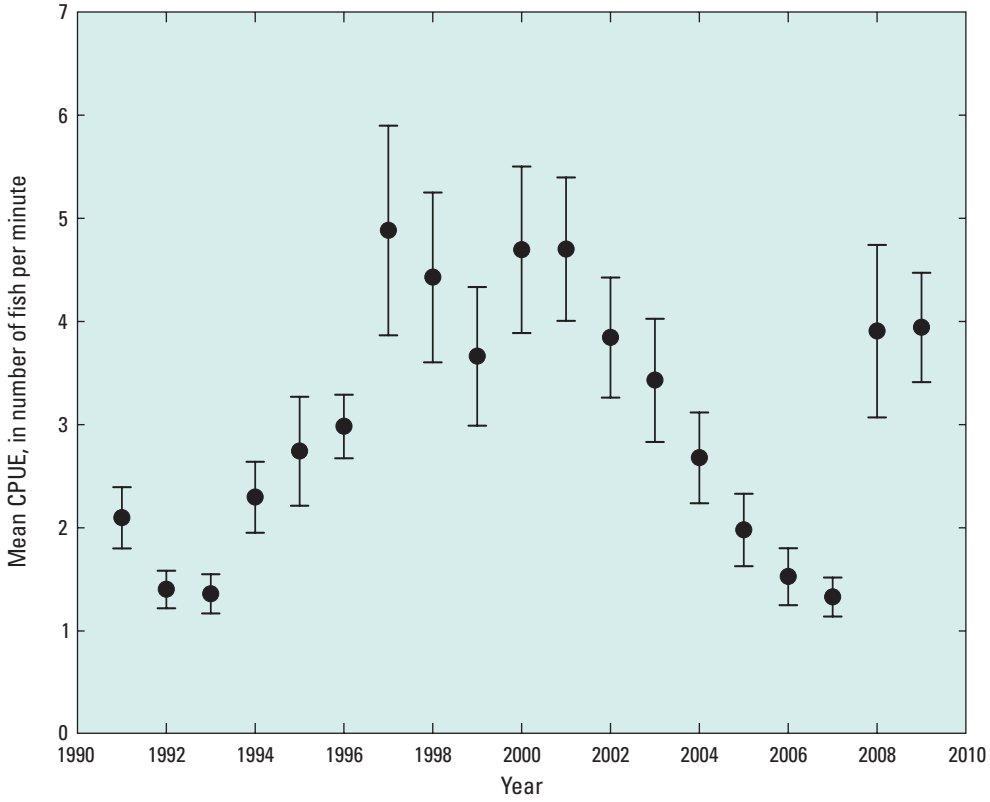

Figure 3. Mean catch per unit effort (CPUE) of rainbow trout captured during electrofishing surveys in the Lees Ferry reach, 1991–2009. The data shown are from all size classes and were collected at both fixed and random sampling sites. Bars represent ±2 standard errors of the mean, which are close approximations to 95-percent confidence intervals.

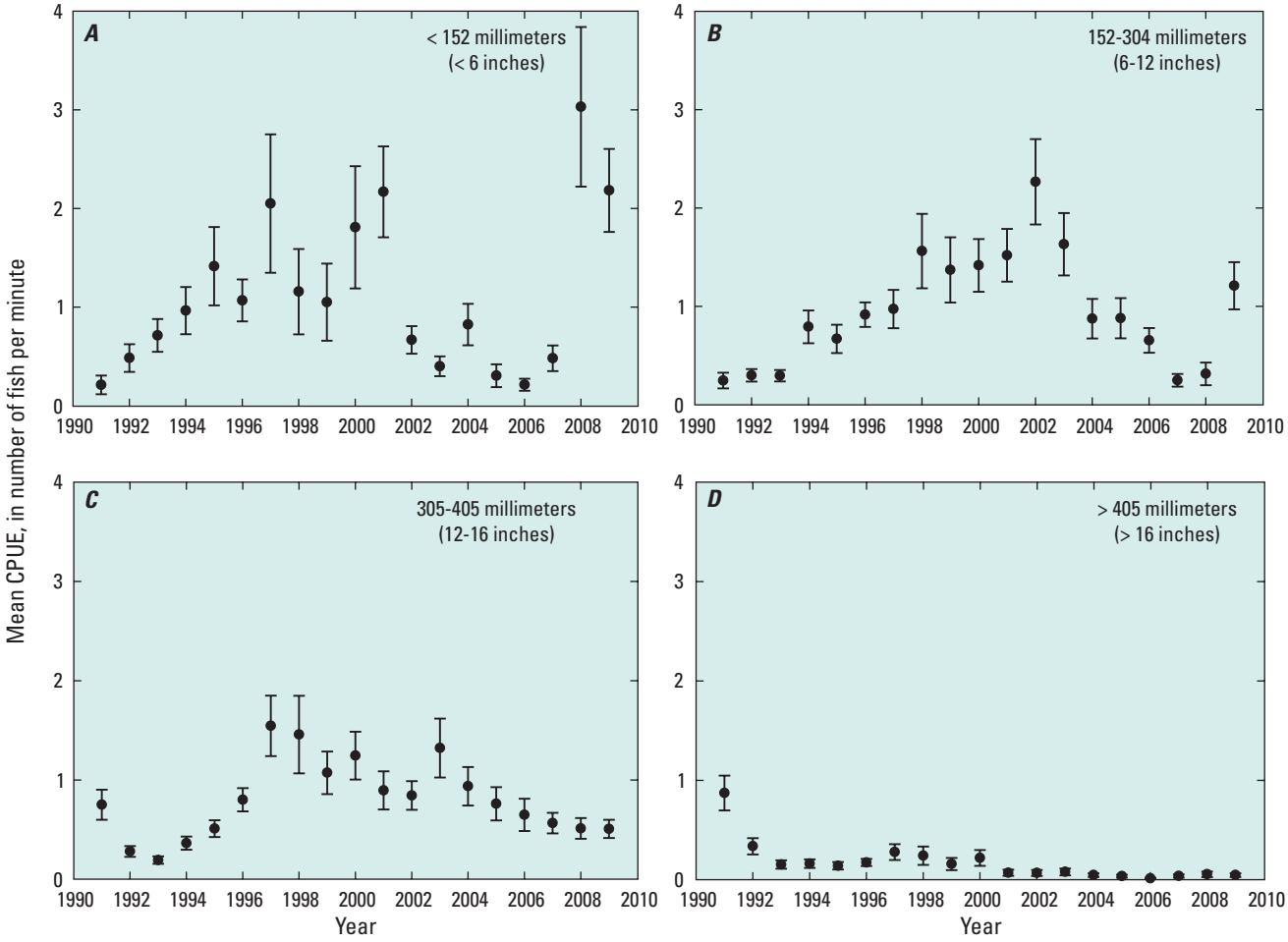

Figure 4. Mean catch per unit effort (CPUE) of rainbow trout for fish of size class: *A*, <152 millimeters (mm), *B*, 152–305 mm, *C*, 305–405 mm, and *D*, >405 mm captured during electrofishing surveys in the Lees Ferry reach, 1991–2009. The data shown were collected at both fixed and random sampling sites. Bars represent ±2 standard errors of the mean, which are close approximations to 95-percent confidence intervals.

Proportional Stock Density

Mean PSD is a numerical descriptor of the size structure of the rainbow trout population. A low PSD means that the population has a high proportion of small fish, and a high PSD means the opposite. The mean PSD shows a decreasing trend between 1991 and 2006 (fig. 6) as the proportion of small fish in the population increased. In recent years (2001–9), the mean PSD has remained relatively stable, but it is substantially lower than in 2000.

Relative Condition

The mean K_n of rainbow trout is a measure of the weight-length relationship (or "plumpness") of the rainbow trout population. The mean K_n of the population (fig. 7) and the mean CPUE (fig. 3) generally have an inverse relationship, which is especially apparent in a comparison of the mean K_n and mean CPUE of the 305–405-mm size classes (figs 8*C* and 4*C*, respectively). The mean K_n for the size class <152 mm has remained relatively constant since 1990, with a substantial decrease in 2009. A similar substantial decrease in mean K_n occurred in the larger (152–305 mm) size class (fig. 8*B*). For the 152–305-mm size class, the substantial decrease in mean K_n started in 2008 and persisted in 2009 (fig. 8*C*). The decrease in mean K_n that coincides with the increase in mean CPUE indicates that after the 2008 HFE a relatively large number of small fish were less plump than in previous years.

Effects of 2008 High-Flow Experiment

The increase in abundance of the rainbow trout population in the Lees Ferry reach in 2008–9 appears related to the HFE conducted in the spring of 2008. The relatively high CPUE in 2008 and 2009 (fig. 3) was because of high catches of small fish in 2008 and 2009 (fig. 4),

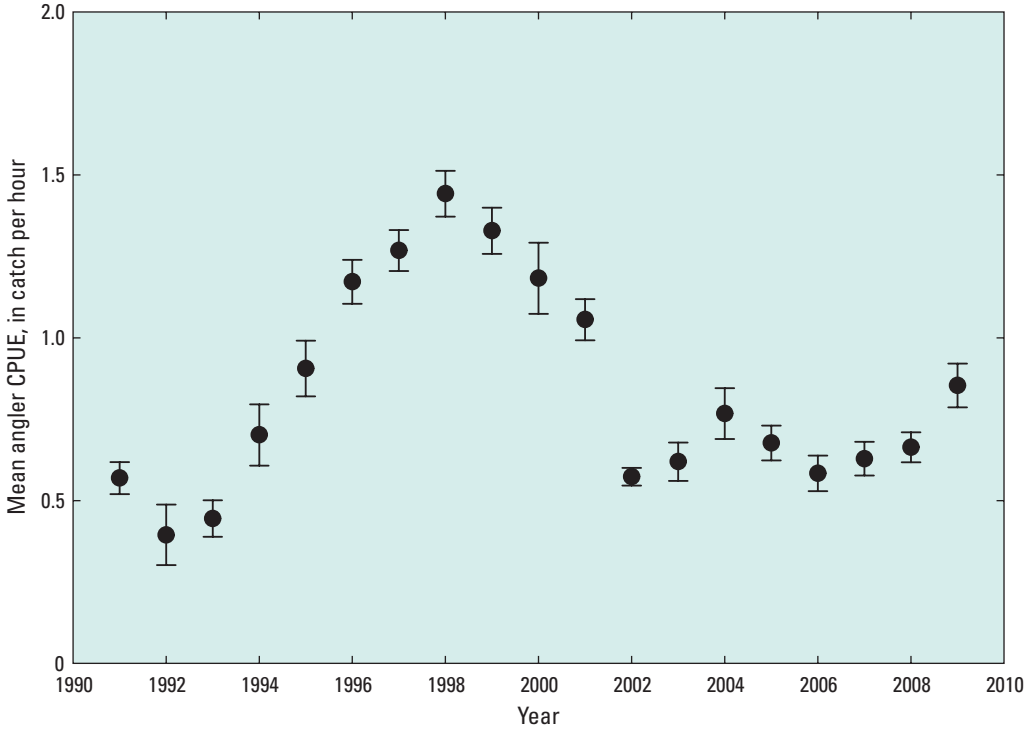

Figure 5. Mean angler catch per unit effort (CPUE) of rainbow trout in the Lees Ferry reach, 1991–2009. Bars represent ±2 standard errors of the mean, which are close approximations to 95-percent confidence intervals.

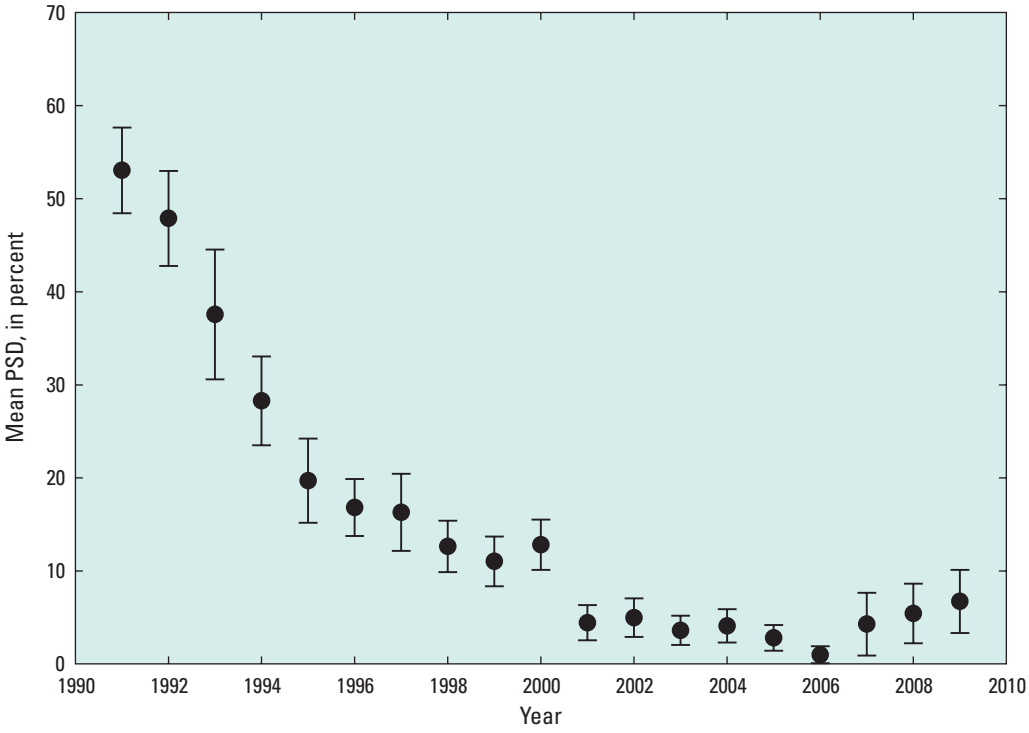

Figure 6. Mean proportional stock density (PSD) of rainbow trout in the Lees Ferry reach, 1991–2009. PSD is defined in equation 1 in the text. The data shown were collected at fixed and random sampling sites. Bars represent ±2 standard errors of the mean, which are close approximations to 95-percent confidence intervals.

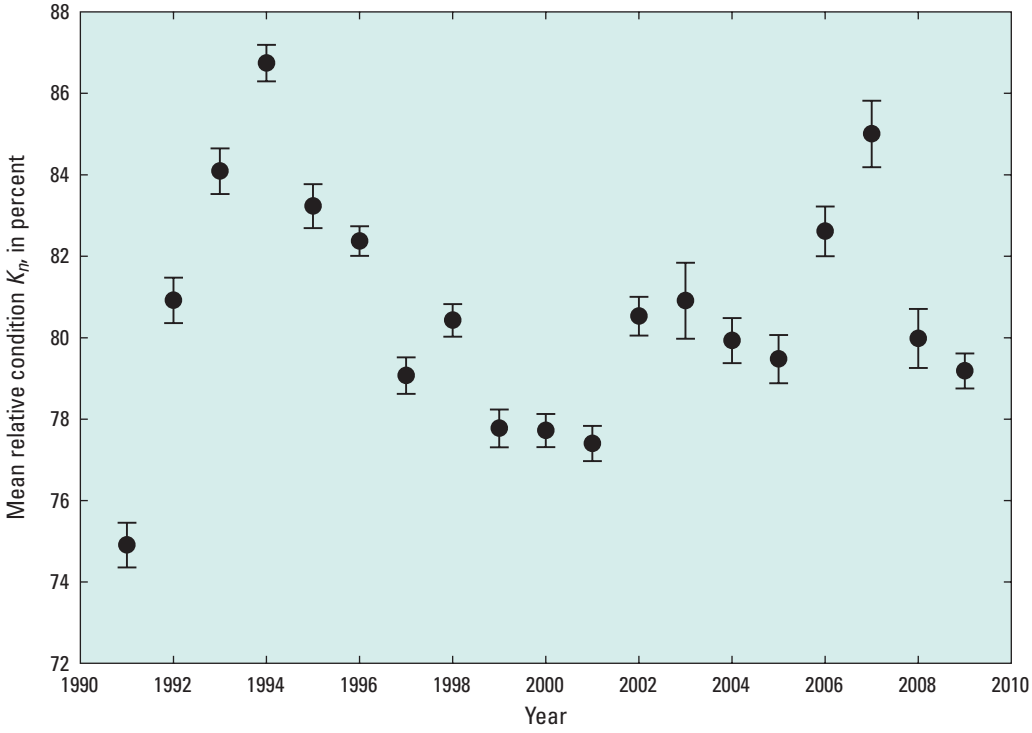

Figure 7. Mean relative condition (K_n) of rainbow trout in the Lees Ferry reach, 1991–2009. K_n is defined in equation 2 in the text. Data shown are from all size classes collected at both fixed and random sampling sites. Bars represent ±2 standard errors of the mean, which are close approximations to 95-percent confidence intervals.

particularly during October 2008 and July and November 2009 (appendix 1, fig. 1–1). Young-of-the-year rainbow trout (fish hatched within the past year) become vulnerable to standardized electrofishing during the fall when they have become sufficiently large (Korman and others, 2009). The high CPUEs of small fish in 2008 and 2009 appear to be related to a large increase in the survival of newly hatched fish during 2008 and 2009 associated with improved habitat conditions (Korman and others, 2010; Melis and others, 2010; Korman and others, 2011).

Rosi-Marshall and others (2010) reported that the 2008 HFE appeared to have restructured the aquatic food web, which could explain the changes in the rainbow trout population. For example, during the HFE, substantial scour of food resources occurred, and following the HFE, diatom production increased and the abundance of New Zealand mud snails (*Potamopyrgus antipodarum*) decreased (Rosi-Marshall and others, 2010). The decline in mud snails likely made food resources available to other secondary consumers, such as amphipods, chironomids, and gastropods, each of which are a food resource for rainbow trout; mud snails have been known to restructure food webs in other aquatic systems (Hall and others, 2006). In addition to improving food resources for rainbow trout, the HFE also would have removed fine sediment from gravel beds in the Lees Ferry reach, thereby improving the spawning habitat for the species (Gore and others, 1989).

Future Monitoring

Fixed and random sites have been sampled concurrently for 8 years (2002–9), and no statistically significant differences between the two site types have been found for most of the population metrics of interest. For this reason, the PEP that convened in 2009 recommended eliminating the fixed sampling sites and replacing them with additional random sampling sites. The PEP also recommended that power analyses be conducted to determine if the overall rainbow trout sampling effort could be reduced. Preliminary analyses indicate that a reduction in effort would not significantly affect the ability to monitor the rainbow trout population in the Lees Ferry reach.

Summary

Rainbow trout population metrics (CPUE, PSD, and K_n) computed from data collected at fixed and random sites from 2002 to 2009 were analyzed using one-way ANOVA by fish-length size class (<152 mm, 152–305 mm, 305–405 mm, and >405 mm). The purpose of the analysis was to determine if data from fixed and random sites could be combined into one dataset for a trend analysis. The analysis showed that there were no statistically significant differences, except for K_n for the 152–305-mm and 305–405-mm size classes. However, the differences were small and not believed to be biologically

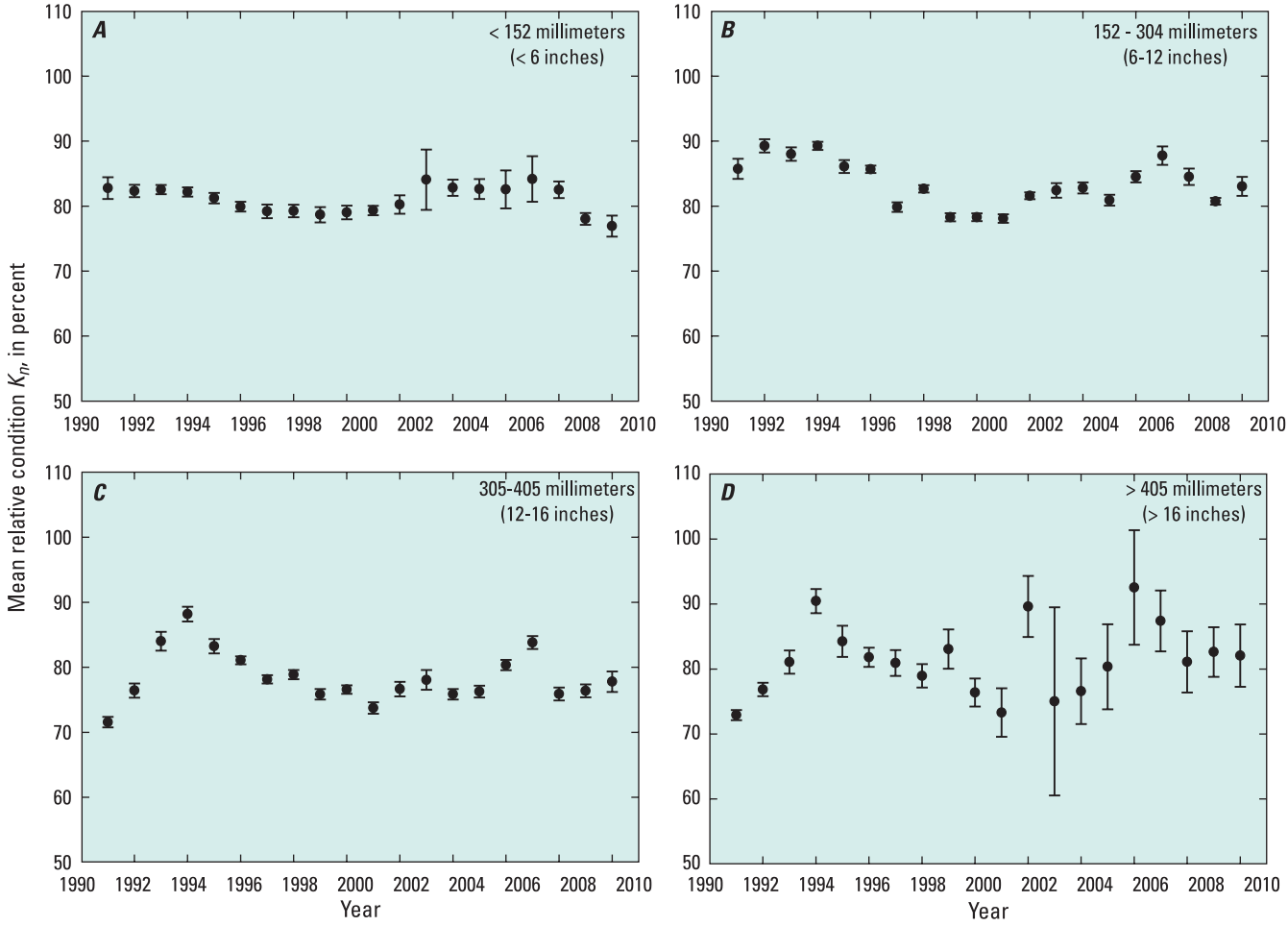

Figure 8. Mean relative condition (K_n) of rainbow trout for fish of size class *A*, <152 millimeters (mm), *B*, 152–305 mm, *C*, 305–405 mm, and *D*, >405 mm captured during electrofishing surveys in the Lees Ferry reach, 1991–2009. Data shown were collected at both fixed and random sampling sites. Bars represent ±2 standard errors of the mean, which are close approximations to 95-percent confidence intervals.

significant. On the basis of these results, it was determined that all population metrics estimated from data collected between 1991 and 2009 could be combined and analyzed as one dataset.

The mean CPUE for rainbow trout, a surrogate measure of its population size, increased from 1991 to 1997, following implementation of more steady releases from GCD, but declined from about 2000 to 2007. There was a significant increase in the mean CPUE in 2008 and 2009 that likely resulted from the March 2008 HFE. The high mean CPUEs in 2008 and 2009 are largely attributable to increased catch of small rainbow trout (<152 mm in 2008 and <305 mm in 2009). The mean PSD, a descriptor of the size structure of the rainbow trout population, shows a decreasing trend between 1991 and 2006, indicating that the proportion of small fish in the population increased. The mean PSD has remained relatively stable since 2001.

The mean K_n, a measure of the weight-length relationship, or plumpness, of fish in the rainbow trout population, remained relatively constant since 1991 for the size class <152 mm, except in 2009. In 2009, mean K_n declined substantially for the two smallest size classes (<152 mm and 152–305 mm) at the same time that the mean CPUE increased. Relative condition was more variable for larger size classes, and substantial decreases were observed for the 152–305-mm size class in 2009 and 305–405-mm size class in 2008 that persisted into 2009. This outcome indicates that after the 2008 HFE there were relatively large numbers of small rainbow trout that were less plump than in previous years. The high abundance of small rainbow trout in 2008 and 2009 were the result of improved survival of newly hatched fish. Survival improved because habitat conditions, in particular availability of food for rainbow trout in the form of drifting chironomids and simuliids, increased after the 2008 HFE.

For future monitoring of the rainbow trout population in the Lees Ferry reach, the second PEP that convened in 2009 recommended eliminating the nine remaining fixed sampling sites and replacing them with additional random sites. The PEP also recommended that power analyses be conducted to determine if overall rainbow trout sampling efforts can be reduced without loss of important information.

Acknowledgments

This work was funded by hydropower revenues provided by the Bureau of Reclamation as part of the Glen Canyon Dam Adaptive Management Program. We wish to thank the following staff and contractors of the USGS GCMRC for their hard work operating boats and keeping clean, legible data-collection field notes: Stuart Reider, Dave Foster, Scott Davis, Scott Perry, and Brett Starks. We also thank Carol Fritzinger, GCMRC Logistics Program Manager, for coordinating trip schedules and equipment. Numerous Arizona Game and Fish Department personnel volunteered their time to collect the data analyzed in this study, for which we thank them. Aaron Bunch (AGFD), Marijke van Heeswijk (USGS), and two anonymous reviewers provided suggestions that greatly improved the quality of this report.

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Appendix 1. Fish Sampling Results for 2009

A total of 3,747 fish from five species were captured in 2009 during standardized electrofishing sampling in the Lees Ferry reach (table 1–1). Rainbow trout (*Oncorhynchus mykiss*) were the most prevalent species captured (99 percent), followed by flannelmouth sucker (*Catostomus latipinnis*; 0.3 percent), common carp (*Cyprinus carpio*; 0.2 percent), brown trout (*Salmo trutta*; 0.1 percent), and green sunfish (*Lepomis cyanellus*; 0.03 percent). In 2009, the mean catch per unit effort (CPUE) for rainbow trout was 3.94±0.53 fish per minute of electrofishing (mean ±2 standard errors), the mean proportional stock density (PSD) was 6.7±3.4 percent, and the mean relative condition (K_n) was 79.1±0.44 percent. A total of 271 rainbow trout were implanted with passive integrated transponder (PIT) tags during sampling in 2009. In 2009, sampling also recaptured previously PIT-tagged fish, including 13 rainbow trout, 4 flannelmouth sucker, and 1 brown trout (table 1–2). A total of 761 rainbow trout were implanted with Floy anchor tags during sampling in 2009, and 4 fish were recaptured (table 1–2). A total of six common carp were implanted with Floy anchor tags but none were recaptured (table 1–2). The mean length of rainbow trout captured during 2009 was 165±2 mm.

A frequency analysis of the size of captured rainbow trout showed a bimodal distribution in April 2009, with the majority of fish shorter than 210 mm and longer than 321 mm (fig. 1–1). A large cohort of fish shorter than 100 mm was measured in July. This cohort persisted into November as a size class between 100 and 200 mm, indicating a relatively strong spawning event in the spring and good survival through summer and fall. The 2008 and 2009 spawning events both resulted in very strong fry survival, probably because of improvements in habitat conditions following the 2008 high-flow experiment (Korman, 2009; Korman and others, 2010).

During creel surveys in 2009, the Arizona Game and Fish Department contacted a total of 980 anglers during 342 interviews conducted near the Lees Ferry boat ramp (R.S. Rogers, Arizona Game and Fish Department, written commun., 2009). The data collected during these surveys showed that mean angler CPUE and effort were 0.9±0.07 fish per hour and 8.0±0.10 hours per day, respectively.

Rainbow trout samples collected in the Lees Ferry reach once per year in 2000 and from 2002 to 2009 for the purpose of checking for whirling disease tested negative in all years except 2007 (Jim Thompson, Arizona Game and Fish Department, written commun., 2009).

Table 1–1. Number of fish captured in the Lees Ferry reach by species and site type, 2009.

[Abbreviations: ID, identifier; RBT, rainbow trout (*Oncorhynchus mykiss*); BNT, brown trout (*Salmo trutta)*; CRP, common carp (*Cyprinus carpio*); FMS, flannelmouth sucker (*Catostomus latipinnis*); GSF, green sunfish (*Lepomis cyanellus)*]

Trip ID Date range	Site type	Number of fish captured				
		RBT	BNT	CRP	FMS	GSF
LF20090421	Fixed	267	2			
04/21–04/23/2009	Random	882	2	1	1	1
	Total	1,149	4	1	1	1
LF20090714	Fixed	396				
07/14–07/16/2009	Random	1,007	1		1	
	Total	1,403	1		1	
LF20091103	Fixed	432			1	
11/03–11/05/2009	Random	741		5	7	
	Total	1,173		5	8	
Grand total		3,725	5	6	10	1
Percent of catch (%)		99	0.1	0.2	0.3	0.03

Table 1–2. Instantaneous growth rate and related information of tagged fish recaptured in the Lees Ferry reach, 2009.

[Abbreviations: RM, river mile; mm, millimeter; mm/day, millimeter per day; PIT, passive integrated transponder; BNT, brown trout (*Salmo trutta)*; FMS, flannelmouth sucker (*Catostomus latipinnis*); RBT, rainbow trout (*Oncorhynchus mykiss*). Mark length and recapture length are provided in millimeters and instantaneous growth rate is provided in millimeters per day because actual measurements were made in millimeters]

Tag type	Species	Tag number	Date marked	Mark location (RM)	Date recaptured	Recapture location (RM)	Days out	Mark length (mm)	Recapture length (mm)	Distance moved (miles)	Instantaneous growth rate (mm/day)
PIT tag	BNT	3D9.1C2C9C8C5C	7/15/2008	-14.7	4/22/2009	-14.7	281	470	469	0	-0.004
	BNT	3D9.1C2C9C8C5C	7/15/2008	-14.7	7/15/2009	-13.45	365	470	476	1.25	0.016
	FMS	3D9.1BF198B9BD	3/23/2004	61.3	7/15/2009	-0.2	1,940	572	591	-6.5	0.010
	FMS	3D9.1C2C879BED	3/29/2008	57.4	11/3/2009	-3.3	585	428	464	-60.7	0.062
	FMS	5116736401	9/1/1997	-3	11/3/2009	-3.3	4,447	471	475	-0.3	0.001
	FMS	5116626257	12/5/1997	-12.5	11/4/2009	-12	4,353	511	550	0.5	0.009
	RBT	4360381E31	10/10/2006	-4	4/21/2009	-4	924	295	358	0	0.068
	RBT	433E702662	10/30/2008	-5.8	4/21/2009	-5.8	173	342	346	0	0.023
	RBT	436235376F	10/30/2008	-5.8	4/21/2009	-5.8	173	170	220	0	0.289
	RBT	436252606C	2/29/2008	-12	4/22/2009	-12	107	367	379	0	0.002
	RBT	43626D045F	7/15/2008	-14	7/15/2009	-14	365	364	373	0	0.025
	RBT	4364005264	10/11/2006	-14	7/15/2009	-14	1,008	315	395	0	0.079
	RBT	4364432272	4/23/2009	-10.25	7/16/2009	-10.25	84	194	237	0	0.512
	RBT	436600117D	7/15/2008	-14.7	7/15/2009	-14.7	365	354	363	0	0.025
	RBT	4364247A3A	7/16/2009	-10.25	11/5/2009	-10.3	113	158	209	-0.05	0.452
	RBT	436419783A	7/15/2008	-14.7	11/4/2009	-14.7	478	378	379	0	0.002
	RBT	4363017531	7/14/2009	-4	11/3/2009	-4	113	185	221	0	0.319
	RBT	43623C0C00	7/16/2008	-10.3	11/5/2009	-9.8	478	153	295	0.5	0.297
	RBT	4360290348	7/15/2009	-12	11/4/2009	-12	113	223	228	0	0.044
Floy tag	RBT	AGFD 1181	7/26/2007	-6.35	4/23/2009	-6.3	637	284	301	0.05	0.0267
	RBT	AGFD 0622	3/19/2008	-10.9	4/23/2009	-10.8	400	343	354	0.1	0.0275
	RBT	AGFD 1585	7/14/2009	-3.1	11/3/2009	-3.2	113	342	345	-0.1	0.0266
	RBT	AGFD 0565	7/15/2009	-12.9	11/4/2009	-13.2	113	350	350	-0.3	0.0000

Table 1–2. Instantaneous growth rate and related information of tagged fish recaptured in the Lees Ferry reach, 2009.

[Abbreviations: RM, river mile; mm, millimeter; mm/day, millimeter per day; PIT, passive integrated transponder; BNT, brown trout (*Salmo trutta)*; FMS, flannelmouth sucker (*Catostomus latipinnis*); RBT, rainbow trout (*Oncorhynchus mykiss*). Mark length and recapture length are provided in millimeters and instantaneous growth rate is provided in millimeters per day because actual measurements were made in millimeters]

Tag type	Species	Tag number	Date marked	Mark location (RM)	Date recaptured	Recapture location (RM)	Days out	Mark length (mm)	Recapture length (mm)	Distance moved (miles)	Instantaneous growth rate (mm/day)
PIT tag	BNT	3D9.1C2C9C8C5C	7/15/2008	-14.7	4/22/2009	-14.7	281	470	469	0	-0.004
	BNT	3D9.1C2C9C8C5C	7/15/2008	-14.7	7/15/2009	-13.45	365	470	476	1.25	0.016
	FMS	3D9.1BF198B9BD	3/23/2004	61.3	7/15/2009	-0.2	1,940	572	591	-6.5	0.010
	FMS	3D9.1C2C879BED	3/29/2008	57.4	11/3/2009	-3.3	585	428	464	-60.7	0.062
	FMS	5116736401	9/1/1997	-3	11/3/2009	-3.3	4,447	471	475	-0.3	0.001
	FMS	5116626257	12/5/1997	-12.5	11/4/2009	-12	4,353	511	550	0.5	0.009
	RBT	4360381E31	10/10/2006	-4	4/21/2009	-4	924	295	358	0	0.068
	RBT	433E702662	10/30/2008	-5.8	4/21/2009	-5.8	173	342	346	0	0.023
	RBT	436235376F	10/30/2008	-5.8	4/21/2009	-5.8	173	170	220	0	0.289
	RBT	436252606C	2/29/2008	-12	4/22/2009	-12	107	367	379	0	0.002
	RBT	43626D045F	7/15/2008	-14	7/15/2009	-14	365	364	373	0	0.025
	RBT	4364005264	10/11/2006	-14	7/15/2009	-14	1,008	315	395	0	0.079
	RBT	4364432272	4/23/2009	-10.25	7/16/2009	-10.25	84	194	237	0	0.512
	RBT	436600117D	7/15/2008	-14.7	7/15/2009	-14.7	365	354	363	0	0.025
	RBT	4364247A3A	7/16/2009	-10.25	11/5/2009	-10.3	113	158	209	-0.05	0.452
	RBT	436419783A	7/15/2008	-14.7	11/4/2009	-14.7	478	378	379	0	0.002
	RBT	4363017531	7/14/2009	-4	11/3/2009	-4	113	185	221	0	0.319
	RBT	43623C0C00	7/16/2008	-10.3	11/5/2009	-9.8	478	153	295	0.5	0.297
	RBT	4360290348	7/15/2009	-12	11/4/2009	-12	113	223	228	0	0.044
Floy tag	RBT	AGFD 1181	7/26/2007	-6.35	4/23/2009	-6.3	637	284	301	0.05	0.0267
	RBT	AGFD 0622	3/19/2008	-10.9	4/23/2009	-10.8	400	343	354	0.1	0.0275
	RBT	AGFD 1585	7/14/2009	-3.1	11/3/2009	-3.2	113	342	345	-0.1	0.0266
	RBT	AGFD 0565	7/15/2009	-12.9	11/4/2009	-13.2	113	350	350	-0.3	0.0000

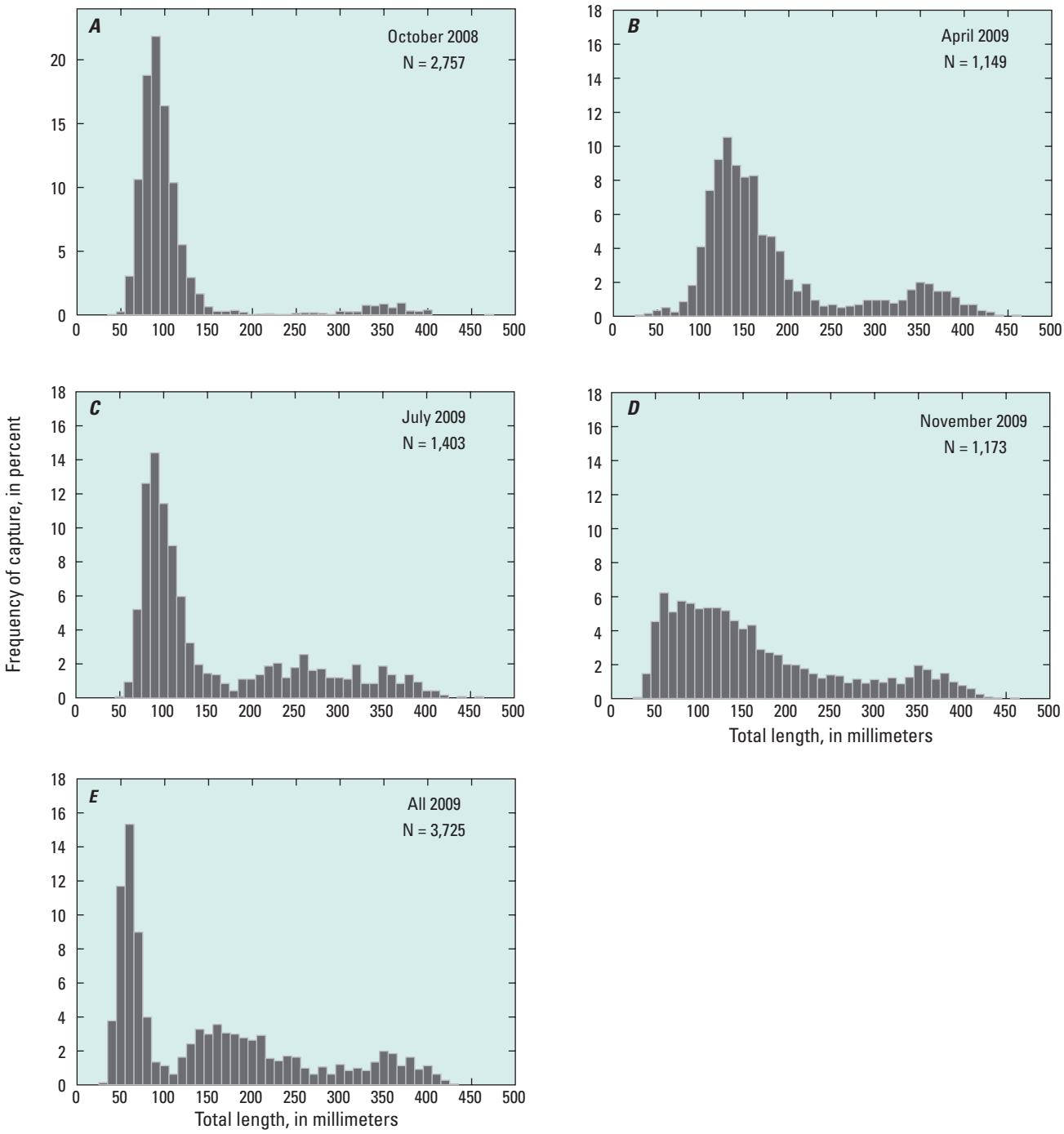

Figure 1-1. Frequency of capture in relation to size (total length) of rainbow trout captured in the Lees Ferry reach in *A*, October 2008, *B*, April 2009, *C*, July 2009, *D*, November 2009, and *E*, all three months, in 2009. Figure represents data collected at both fixed and random sampling sites.

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