Ecology of rainbow trout in the Lee's Ferry fishery below Glen Canyon Dam, Arizona

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INTRODUCTION

Closure of Glen Canyon (GCD) in 1963 impounded the Colorado River near the Arizona-Utah border and formed a large, meromictic reservoir (Lake Powell) and significantly altered the hydrology, limnology and aquatic ecology of the downstream riverine environment. Numerous authors have compared pre- and post-dam hydrology (Dawdy 1991), sediment transport (Andrews 1991), limnology (Stanford and Ward 1991) and aquatic biology (Blinn and Cole 1991) of the Colorado River below GCD and discussed operations of the hydroelectric power facility (Hughes 1991, Ingram et al. 1991). Daily, monthly and yearly flows below GCD since closure of the facility in 1963 have differed from pre-dam conditions (Andrews 1991, Hughes 1991, Patten 1991, Stanford and Ward 1991, U. S. Department of Interior [USDI] 1995). Although releases from the dam and flow regimes between 1963 to 1998 varied, mean daily flows have exceeded power plant capacity (852 m^3s^{-1}) only about three percent of the time (vs. 18% pre-dam) and have been less than 142 m^3s^{-1} about 10% of the time (vs. 16% pre-dam). Daily variations in flow have increased during much of the post-dam period (USDI 1995). Implementation of an interim flow regime in 1991 resulted in more stable discharges from the dam, and higher steady flows were maintained during mid-1995 to early 1996 and from late 1996 to present (USDI 1995).

Non-native rainbow trout (*Oncorhynchus mykiss*) were first introduced in 1964 (Stone 1964) into the Lee's Ferry reach, a 26 km tailwater immediately below GCD. Following introductions of benthic macroflora (*Cladophora glomerata*) and macrofauna (e.g., *Gammarus lacustris*, chironomids, gastropods) into the tailwater during 1966-1969 (Stone and Queenan 1967, Stone and Rathbun 1968, 1969, Maddux et al. 1987), the fishery achieved a "trophy"

status by about 1977 (Reger et al. 1989). However, the fishery historically has undergone dramatic changes in angler use and trout abundance, body condition, population structure and spawning success (McKinney and Persons 1998). Operations of GCD are relevant to ecology of the non-native rainbow trout and the aquatic food base in the Lee's Ferry reach (Blinn et al. 1995, McKinney and Persons 1998), but variables potentially influencing the trout fishery are poorly understood.

The present report reflects preliminary quantitative analyses of influences of dam operations and other abiotic and biotic variables on the rainbow trout recreational fishery in the tailwater. Specifically, we sought to determine if releases from GCD, the aquatic food base and water quality variables influenced spatial and temporal differences in measurements of the rainbow trout community during 1991-1997. Studies were conducted to meet the following objectives provided by Glen Canyon Monitoring and Research Center (Cooperative Agreement No. 1425-97-FC-40-20810):

OBJECTIVE 1 (Research)--Synthesize existing information (published and unpublished data) on the Glen Canyon/Lee's Ferry trout fishery and determine the fishery's likely response (growth, reproduction, recruitment, population structure, size and distribution) to dam operations.

This OBJECTIVE was addressed in a previous report (McKinney and Persons 1998).

OBJECTIVE 2 (Monitoring)--Monitor the trout fishery in Lee's Ferry to determine population size, structure, distribution, reproductive success, growth and overall recruitment to reproductive size in response to dam operations.

OBJECTIVE 3 (Research)--Develop methods for estimating the proportion of natural

reproductive success in combination with stocking quantities and rates to determine desired levels of recruitment balanced against the carrying capacity for a range of dam operations.

OBJECTIVES 4, 5 (Research)--Develop evaluation criteria for and measure and assess the health and condition of the rainbow trout population and evaluate health and condition factors in relation to changes in the aquatic food base and nutrient levels and dam operations.

STUDY AREA

Glen Canyon Dam impounds the Colorado River in north-central Arizona near the Arizona-Utah border and forms Lake Powell, a 653 km^2 meromictic reservoir of a high desert oligotrophic system. Hypolimnetic releases from the reservoir are clear and cold-stenothermic within the tailwater immediately below GCD (Stanford and Ward 1991, Stevens et al. 1997). The Lee's Ferry reach extends between the dam (river kilometer [RK] -25.5) and Lee's Ferry (RK 0), is confined within a narrow, deeply-incised canyon and has no perennially-flowing tributaries. Non-native rainbow trout are the predominate fish in the tailwater reach but coexist with much lower densities of native flannelmouth sucker (*Catostomus latipinnis*) (McKinney et al. 1998) and non-native common carp (*Cyprinus carpio*) (personal observations). Releases from GCD during investigations ranged from 142 to 1,278 m^3s^{-1}, but flows generally did not exceed about 625 m^3s^{-1}.

METHODS

Field collections

Rainbow trout

We captured rainbow trout between dusk and dawn 2-4 times per year by single-pass electrofishing (EF) at fifteen (1991-1996) or nine (1997-1998) standardized transects (ca. 33

min/transect). We used a complex pattern of pulsed direct current, applying 215 volts and maintaining a 15 ampere output to a 30 cm stainless steel anode system (Sharber et al. 1994). Fish were measured to the nearest mm total length (TL), weighed to the nearest g and released unless collected for analysis of food habits.

Population estimates

Mark-recapture

Three standardized electrofishing transects were stratified by location in the reach (RM [river mile] -10.5, RM -7.5 and RM -4.1) and sampled following the above procedures during July 9-12, 1998 to estimate population size following mark-recapture procedures. No fish were collected for food habits analyses, and trout $\geq$150 mm TL were implanted with passive integrated transponder (PIT) tags during the first three nights of EF, and presence/absence of PIT tags was recorded on nights 2-4.

Hydroacoustics

We conducted preliminary testing of hydroacoustic technology during daylight (15:30 h - 18:00 h) March 18, 1998 to determine potential applicability in assessing rainbow trout population size and structural indices in the Lee's Ferry reach. Conditions were cool, sunny and windy, and releases from GCD were about 568 m^3s^{-1}. Gordon Mueller (U. S. Geological Survey) provided equipment and conducted the survey, which started at RK -25 and proceeded downstream following approximately mid-channel to Lee's Ferry. Acoustic data were collected continuously at an estimated speed between 4-6 mph on a BioSonic's dual beam scientific echosounder, model DT-5000. The system operates on 430 kHz and uses a 6.5 and 15 degree transducer. Data were collected at a -60 dB threshold which under ideal conditions would allow

detection of targets ≥1.6 cm. Five data files were created for subsequent analysis and consisted of a total 36,000 acoustic pings or samples. Gordon Mueller and AGFD tentatively will conduct a second hydroacoustic survey between dusk and dawn during Labor Day 1998, when reduced steady flows are expected.

Benthic macroinvertebrates, periphyton, macrophytes

We sampled benthic macroinvertebrates (Hess sampler 0.09 m^2; 1 mm mesh), periphyton (0.415 cm^2 template; Angradi and Kubly 1993) and submerged macrophytes (Hess sampler 0.09 m^2; 1 mm mesh) at lowest possible flow level in the nearshore wetted zone monthly (1991-1994) or quarterly (1995-1997) on standardized transects associated with cobble bar and fine-sediment habitats. Periphyton and macrophyte samples for mass analyses were held on ice for transport to the laboratory. Zoobenthic samples were preserved at collection using 10% formalin.

Organic drift

Joe Shannon and Dean Blinn (Northern Arizona University) provided AGFD with unpublished results of their drift studies conducted at Lee's Ferry during 1991-1997. Collection of drift data by Joe Shannon and Dean Blinn followed established procedures (Shannon et al. 1996). We (AGFD) also collected drift samples monthly during May 1993 to July 1994 about 250 m above Lee's Ferry over 24 h periods coincident with low, rising, high and falling phases of the daily hydrograph. We depth-integrated samples by towing (minimal boat speed) and slowly raising and lowering a metered (flow meter attached centrally in net mouth) net while traversing a standardized transect normal to direction of river flow. We attached a 6.8 kg "fish" on a 1 m drop chain attached 0.6 m in front of the net.

Water quality

Susan Hueftle and Bill Vernieu (Glen Canyon Monitoring and Research Center) allowed use of their water quality data collected from dam penstocks and at Lee's Ferry (Hueftle and Vernieu 1998) to determine relationships between trout and water quality variables.

Dam operations

Hourly and daily releases from GCD were obtained from U. S. Bureau of Reclamation unpublished data for hypolimnetic discharges measured at dam penstocks (elevation 1,058 m). Michael D. Yard (GCMRC) provided a model to determine wetted perimeter of the Lee's Ferry reach as a function of discharge from the dam.

Laboratory procedures

Stomach contents of trout were identified to the lowest practical taxonomic level and measured to the nearest mL using volumetric displacement. Dry weights (DW) for *Gammarus lacustris* and chironomids collected during 1997-1998 was regressed on volume (mL) of each taxon in trout stomachs to develop a standard curve which then was used to estimate DW of these items in trout stomachs for 1991-1998. We also incorporated conversions of volume and DM for total and specific macroinvertebrates in trout stomachs (Cummins and Wuychek 1971, Angradi and Griffith 1990, Ensign et al. 1990, Blinn et al. 1995, Weiland and Hayward 1997, Hayward and Weiland 1998) to obtain energy estimates. We calculated relative stomach volume (RGV = total volume of stomach contents (mL or DM)/TL) for total contents and RGV for predominant food items and computed percent composition by volume of dominant ingested items.

Benthic macroinvertebrate (numbers of each taxonomic group), periphyton and macrophyte densities were calculated per unit area of substrate sampled. Ash free dry masses

(AFDW) of periphyton and macrophytes were determined by loss on ignition (100^0 C 24 h; 550^0 C 2 h). We identified organic matter in the drift to the lowest practical taxonomic level. Macroinvertebrates collected in the drift were counted by taxon and further estimated using volumetric displacement, and plant material was quantified by volumetric displacement and AFDW.

Analytical procedures

We computed condition indices for trout $\geq$100 mm using relative condition factor [$Kn = [W/10^{(-4.6 + 2.856 Log10 (L))} \times 100]$), Fulton's condition factor [$K = (W/L^3) \times 100{,}000$] and relative weight (Wr; Simpkins and Hubert 1996). Relative length-related bias was compared using analysis of covariance (ANCOVA). Ponderal indices for all fish combined were plotted against TL, and slopes were compared using an F test (Littel et al. 1991). Variance/mean ratios of Log_{10} wet weight by 10 mm increments stabilized at about 100 mm TL, so only fish equal to or greater than this length were incorporated in condition factor analyses.

We compared annual, location and seasonal means for periphyton and macrophytes (AFDW) and for benthic macroinvertebrate densities using the Kruskal-Wallis test (K-W). Mean trout catch rates, relative condition factor and size (length, weight) for years and seasons (winter = December-February; spring = March-May; summer = June-August; fall = September-November) were compared using analysis of variance (ANOVA). Data for CPUE and kg/min EF were kurtotic and were transformed, respectively, using Log_{10} and square root. Sampling locations were treated as random variables and incorporated into the error term (main effect x location) using the RANDOM and TEST statements in the SAS GLM procedure (Littel et al. 1991). Duncan's Multiple Range test was used for multiple comparisons where parametric

statistical procedures indicated significant treatment effects in the absence of significant interaction effect ($\alpha = 0.05$ for all statistical tests).

Trout RGV data were highly skewed, and we used K-W tests to determine annual and seasonal differences for trout food habit variables with respect to length categories and origin of fish (stocked, wild-spawned). Frequencies of empty stomachs observed throughout the study period with respect to length categories and fish origin were analyzed using a chi-square test of independence for trout among seasons were tested using Spearman Rank Order correlations. Sample sizes permitted chi-square analyses of seasonal but not yearly differences in frequencies of empty stomachs for all fish combined. Trends in frequencies of empty stomachs among years were tested using Spearman Rank Order correlations. Frequency of occurrence for stomach content data were analyzed only for fish with ingested food items, while frequency of empty stomachs were calculated as percent of all fish.

We calculated proportional stock density (PSD; Anderson and Neumann 1996) for trout captured by EF during all trips. Calculations were based on the number of fish within or exceeding a present slot limit (trophy size) divided by the number trout greater than minimal size "desired by fishermen" (Reger et al. 1995). Log-transformed data were used to evaluate regressions of PSD against CPUE, Kn and Kg/min.

We compared yearly and seasonal means for periphyton and macrophytes (AFDW) and benthic macroinvertebrate densities using the Kruskal-Wallis test (K-W).

We used Spearman's Rank Order Correlations to explore predictor effects on response variables for rainbow trout. Due to temporal variability in sampling periods, benthic, drift and trout data were categorized by season and year for these analyses.

Bioenergetics

We presently are working on an energy model for rainbow trout in the Lee's Ferry reach, based on food habits data and incorporating variables for trout consumption (Cummins and Wuychek 1971, Elliott 1975, Boisclair and Leggett 1988, Storebakken and Austreng 1988, Angradi and Griffith 1990, Ensign et al. 1990, Rand et al. 1993, Bowen et al. 1995, Filbert and Hawkins 1995, H_roux and Magnan 1996, Weiland and Hayward 1997, Hayward and Weiland 1998).

We selected prey taxa according to their percent stomach content by volume and by estimated caloric densities for inclusion in bioenergetic and consumption models. *Cladophora glomerata*, *G. lacustris* and total chironomidae together accounted for more than 90% of trout stomach content over the six year study period. Due to minimal energetic value to trout, *C. glomerata* was eliminated from consumption estimates (Angradi 1994, Weiland and Hayward 1997). Dry weights for *G. lacustris* were predicted from unpublished volume-dry weight regressions developed by Arizona Game and Fish Department and assigned caloric densities developed by Blinn et al. (1995).

Total chironomid dry weights were estimated by multiplying their volumes times the specific gravity constant (1.05; Filbert and Hawkins 1995). Dry weight was determined by converting wet weight. We assumed that invertebrate DW was 10% of wet weight (Cummins and Wuychek 1971, Hewett and Kraft 1993).

Daily dry food weight (C_{24}) and energy intake were estimated assuming that feeding rates were constant over a 24 h period (Storebakken and Austreng 1988, Ensign et al. 1990, Boisclair and Leggett 1988). Mean gastric evacuation rate (GER) for *Salmo trutta* fed *Gammarus* sp. At

9.8^0C (Elliott 1972) was used for calculation of C_{24}. A separate C_{24} estimate was made using GER for rainbow trout fed chiromonidae (Hayward and Weiland 1998). Maintenance ration (MR; mg DW/day) was calculated using Elliot's (1975) estimation for rainbow trout at 10^0C. Maximum consumption rates (Cmax) were calculated using equations from Elliot (1972) for *S. trutta* fed *Gammarus* sp. and, in a separate analysis, for rainbow trout fed chironomidae (Weiland and Hayward 1997, Hayward and Weiland 1998). We plan to simulate rainbow trout growth based on observed consumption by using a bioenergetics model (Hewett and Johnson 1992). Population estimates

Hydroacoustics: There are two methods of acoustically estimating fish densities, echo integration and echo counting. The DT-5000 analysis program calculates fish densities using echo integration and examines total reflective energy measured from all targets (and noise) divided by energy received by an average size fish. This approach is best suited for environments containing large numbers of fish, and the procedure is inaccurate in noisy, shallow waters that have low fish densities.

The dual-beam system used measures the reflected energy returned by an underwater target by triangulation. Signal strength of a target return is directly proportionate to size and is indicative of its reflective characteristics (size and composition) and depth. Thus, we can estimate fish size by measuring echo strength. Echo counting greatly reduces biases associated with noise or large non-fish targets, was employed in present studies, and the procedure measures fish density by dividing the number of fish detected by the total area or volume sampled. Echogram editing is best accomplished on small data files having high resolution, and the five files for this study were subdivided into 36 segments (1,000 pings) for analysis. Fish

densities were calculated for each of the 36 segments by taking the number of targets detected (pings), estimating the detection area (m^2) of the echosounder beam based on average depth of the river and converting values to numbers of fish detected per hectare for each of the 1,000 ping segments. Resulting values were corrected to 415 ha (estimated surface of the Lee's Ferry reach at discharges from the dam of ca. 142 m^3s^{-1}).

While data were collected at a threshold of -60 dB, target recognition during the analysis phase was set at -40 dB to identify targets larger than 16 cm. We believe that this setting removed the majority of non-fish targets that were suspended in the water column. Unfortunately, this procedure also eliminated any fish <16 cm.

Mark-recapture:

Analytical procedures are pending.

RESULTS

Rainbow trout

CPUE

Catch-per-minute for all trout combined differed among locations, years and seasons ($P<0.001$). Although effects of location on CPUE were significant for year and season ($P<0.001$), no interactions were statistically significant, indicating that CPUE at all sites changed comparably over years and seasons.

Catch rates for all trout declined from 1991-1992-1993, stabilized at a higher level in 1994-1996, then increased in 1997. Seasonally, CPUE for all fish was greatest in summer and fall and declined to a minimum in winter. Effects of year, location and season were significant

(P<0.001) for trout <152 mm, with no significant interactions. The CPUE was lowest during 1991-1993, increased through 1997 and was lowest in winter, intermediate in spring and highest in summer and fall for this size class. The CPUE for fish 152-304 mm was lowest during 1991-1993, increased during 1994-1997 (P<0.001) and was lowest in winter, intermediate in spring and fall, and highest during summer (P<0.001). The CPUE for fish 305-405 mm differed by year and location (P<0.001), but not season, and interaction effects were not statistically significant. Catch rate for trout in this size category declined from 1991-1993, then increased 1994-1997. Season, year and location significantly (P<0.001) influenced CPUE for trout 406-558 mm, and interactions were insignificant. The CPUE was highest in 1991, declined to a stable level in 1993-1996, then increased in 1997. Seasonal CPUE was greatest in winter and stable other periods for this size class.

Catch rates for stocked and wild-spawned trout differed among years and location, but only stocked fish differed among seasons (P<0.05). There were no statistically significant interaction effects. For all stocked and wild-spawned fish, CPUE was lowest in 1992-1993. Catch rate for stocked fish increased (P<0.001) and was stable during 1994-1997, whereas that of wild-spawned trout generally increased over that time period. Catch-per-minute of stocked trout was greatest (P<0.03) in spring through fall.

The CPUE for stocked trout <152 mm differed among years (P<0.02) and seasons (P<0.001) but not among locations, and there were no significant interaction effects. The CPUE was highest during 1992-1994 and declined to a stable level in 1995-1997. The index was lowest in winter, intermediate in spring and fall and highest in summer. In contrast, the CPUE for wild-spawned fish <152 mm was stable and lowest during 1992-1994, then increased to a

maximum in 1997, seasonal effects were statistically insignificant, and location effects were significant.

(P<0.001).

Stocked fish 152-304 mm differed in CPUE among years and location (P<0.001) but not among seasons, and interaction effects were statistically insignificant. The CPUE increased from 1992-1993 levels during 1994-1996 but declined in 1997. Among wild-spawned trout 152-304 mm, CPUE differed among years and locations (P<0.001) and seasons (P<0.005). Catch-per-minute for wild-spawned fish was lowest in 1992-1993, gradually increased to a maximum in 1997, and was lowest during fall and winter, highest in spring and summer. Stocked fish 305-405 mm differed in CPUE among years (P<0.001) but not among locations or seasons. The CPUE was lowest in 1993, intermediated in 1994 and stable and highest in 1995-1997. Catch-per-minute for wild-spawned trout 305-405 mm differed among years and locations (P≤0.001) and seasons (P<0.05). The CPUE was lowest in 1992-1993 and increased from 1994 through 1997. Seasonally, CPUE was lowest in spring and winter, highest in summer and fall. In contrast, CPUE for stocked fish 406-558 mm did not differ among years or season, and there were no statistically significant interaction effects, but the location effect during seasons differed significantly (P<0.0.01). Wild-spawned trout 406-558 mm differed among years and locations (P<0.001), but not among seasons, although location effect differed seasonally (P<001). The CPUE was stable from 1992 to 1995 but increased during 1996 and 1997.

Trout in size classes <152 mm, 152-304 mm, 305-405 mm and 406-558 mm comprised 39.0%, 25.0%,23.0% and 12.0%, respectively, of the total sample for all trout combined. Analyses by 50 mm increments provided comparable results, except that they indicated

stockpiling of smaller fish within the slot (slot limit: 406-558 mm; percentages of total catch all trout: 400-449 mm = 9.4%; 450-499 mm = 3.5%; 500-550 mm = 0.6%). Proportional composition of fish <152 mm increased about fourfold between 1991-1993 then remained generally stable through 1997 but exhibited yearly variability. Trout 152-304 mm increased proportionally during 1991-1994 but trended lower in 1995-1997. Fish 305-405 mm declined in proportion from 1991 to 1993 then increased about threefold by 1997, returning to 1991 levels. Trout 406-558 mm declined proportionally in 1991-1994, when composition stabilized through 1997.

Seasonally, percent composition of trout <152 mm tended to be highest in summer and fall, lowest in winter, but seasonal trends differed from this for other size classes. Composition of fish 152-304 mm was highest in summer, and trout 305-405 mm did not differ in percent composition among seasons. Percent composition of trout 406-558 mm was greatest in winter, lowest in summer and fall.

Biomass/minute electrofishing

Mass-per-minute (Kg/min) for all fish captured by EF differed among years and location ($P<0.001$) but not among seasons, and interaction effects were statistically insignificant. Mass-per-minute was highest and comparable in 1991 and 1997, declined in 1992-1993, then increased from 1994 to 1997. Mass catch rate for stocked fish 100-152 mm differed among years ($P<0.001$) and location within years ($P<0.05$) and among seasons ($P<0.001$), but not among locations for seasons, and interaction effects were statistically insignificant. Kilograms/minute were stable and highest during 1992-1994 but declined in 1995-1997. Kilograms-per-minute of wild-spawned trout 100-152 mm differed among years and location ($P<0.001$) and seasons

(P<0.02). Mass was lowest in 1992-1993, then increased in 1994, was greatest in 1995-1997, and was lowest in winter and greatest in summer.

Mass of all fish 152-304 mm differed among years, locations and season (P<0.001), and interaction effects were not statistically significant. Mass increased from 1991-1993 lows to intermediate levels in 1994-1995, increased again in 1996-1997 and was lowest in winter, greatest in summer. Mass of stocked trout 152-304 mm differed among years and location for years (P<0.001), but effects of season and interaction were not statistically significant. Mass was lowest in 1992-1993, increased to higher, stable levels during 1994-1997. Mass of wild-spawned fish of this size class differed among years and location (P<0.001) and season (P<0.05), and interaction effect was statistically insignificant. Kilogram/minute was lowest in 1992-1993, increased during 1994-1995 and again in each of 1996 and 1997 and tended to be lowest in fall through spring of each year.

Mass of all trout 305-405 mm differed among years and location (P<0.001), but seasonal and interaction effects were statistically insignificant. Mass decreased from 1991 to 1992-1993, increased in 1994 and 1995, then remained stable through 1997. Mass of stocked trout in this size category differed among years (P<0.001) but not among locations or seasons, and interaction effects were not statistically significant. Mass of wild-spawned fish 305-405 mm differed among years, location and season (P<0.01), and interaction effects were statistically insignificant. Mass increased steadily from 1992 to 1997 and was highest in summer and fall. Biomass catch-per-minute for all trout 406-558 mm differed among years, location and season (P<0.001), and interaction effects were not statistically significant. Mass declined from 1991 to 1992 and again to stable levels in 1993-1996, then increased in 1997. Mass of fish captured in

this size class was greatest in winter, lowest in fall and summer. Stocked trout 406-558 mm did not differ among years (1994-1997) or season, and location effect was significant ($P<0.02$) only seasonally. Mass of wild-spawned fish for this size class differed among years and locations ($P<0.001$) but not seasons, and interaction effects were statistically insignificant. Mass was lower in 1992-1993 than during stable levels in 1994-1997.

Relative condition factor

Relative condition index (Kn) was selected for analyses, since slope of Kn on TL ($\beta = -0.0158$) differed significantly ($P<0.001$) from, and was less than slopes for K ($\beta = -0.0722$) and Wr ($\beta = -0.0752$). Use of Fulton's K for trout likely is associated with weight/length biases unless specific criteria are met (Bolger and Connolly 1989, Hubert et al. 1994, Anderson and Neumann 1996), while Wr is generally more applicable for comparisons among different fisheries, rather than within a fishery (Murphy et al. 1990, Liao et al. 1995, Simpkins and Hubert 1996). Relative condition factor for all trout captured differed among years, locations and seasons ($P<0.001$), and interaction effects were statistically insignificant. Condition was lowest in 1991, increased each year from 1992-1994 and declined in 1995-1996 and again in 1997. Seasonally, Kn was lowest in winter, highest in summer. Stocked fish differed among years ($P<0.001$) but not by location among years. The index also varied with location in seasonal comparisons ($P<0.05$) but did not differ among seasons, and interaction effects between location and year and season were statistically insignificant. The index was higher and stable in 1992-1994, declined in 1995-1996 and again in 1997. In contrast, Kn for wild-spawned fish differed among years and location ($P<0.001$) and season ($P<0.02$), but interaction effects also were statistically insignificant. The index declined in 1996 and 1997 from previous levels and was

greatest in summer and generally stable other seasons.

The Kn for all trout 100-152 mm did not differ significantly among years, location or season. Condition of fish 152-304 mm differed among years and location ($P<0.001$) and season ($P<0.02$). Condition increased from 1991 levels during 1992-1995 but declined in 1996 and in 1997, and the index was higher in summer and fall than in spring and winter. Condition of fish 305-405 mm differed among years, location and season ($P<0.001$), and interaction effects were not statistically different. The index increased from 1991 to 1992 and in 1993-1994 but declined in 1995-1996 and in 1997 and was higher in summer than other seasons. Condition of all trout 406-558 mm differed among year and location ($P<0.001$) but not among seasons, and interaction effects were statistically insignificant.

The condition index for stocked fish 100-152 mm differed significantly only among years ($P<0.001$). Condition increased over previous levels in 1995-1996 but declined to previous levels in 1997. However, condition of wild-spawned fish for this size class did not differ significantly among years, location or season. Condition for stocked trout 152-304 mm differed among years ($P<0.01$) but not among seasons or locations by year, although location effect was significant for season ($P<0.05$). Condition of wild-spawned fish 152-304 mm differed among years ($P<0.001$) and location ($P<0.02$) but not among seasons, and interaction effects were statistically insignificant. Stocked trout 305-405 mm differed in condition among years and locations ($P<0.01$) but not among seasons, and interaction effects were not statistically significant. Among wild-spawned fish in this size class, condition differed among years and locations ($P<0.001$) but not among seasons, and interaction effects were not statistically significant. The condition index for this size class increased from 1992 to a higher, stable level

in 1993-1996, then declined in 1997.

Condition of stocked trout 406-558 mm differed among years ($P<0.001$) but not among locations or seasons. Relative condition factor was available for comparatively few stocked fish in this size group but was greatest during 1994 and declined to stable levels 1995-1997. Among wild-spawned trout 406-558 mm, sample size was larger, and condition differed among years and locations ($P<0.01$) but not among seasons, and year x location interaction was statistically significant ($P<0.05$). Condition for this size class increased from 1992 to a stable level during 1994-1996, then declined in 1997.

Population size estimates

Mark-recapture

Data are being entered for the July 9-12, 1998 electrofishing.

Hydroacoustics

The echosounder functioned normally during the March 18, 1998 sampling trip and showed a great deal of material within the water column. A large number of targets was detected which likely included air bubbles and suspended vegetation and debris. Our observations suggested the majority of this material was fragmented vegetation and small bubbles entrained by the river's turbulence. We observed fragments of *Cladophora glomerata*, *Potamogeton* sp. and other debris in the water column. Data analysis detected 33 targets larger than 16 cm, out of 36,000 pings recorded. Reflective energy ranged from -20 to -38 dB, which encompasses a size range between 160 mm and 1,500 mm. Eleven targets had an energy value of >-25 dB. If these were fish, they would have to have been longer than 900 mm, indicating the targets were not fish. These reflective signatures must have resulted from reflective energy anomalies from large

boulders or vegetation. These 11 targets were dropped from the data base, reducing the total number of targets believed to be fish to 22.

Fish densities were highly variable, ranging from 0 to 154 fish/ha. Based on the average fish density of 16.8/h, the pelagic zone that we surveyed and analyzed contained an estimated 6,970 fish >16 cm, representing fish found at depths >3 m but at a minimum of 0.3 m above substrata.

Proportional stock densities

Proportional stock density differed among years and seasons ($P<0.001$), and interaction effect was statistically insignificant. The index declined significantly from 1991-1992 through 1994, then declined to a stable level during 1995-1997. Seasonally, PSD was highest in winter, lowest in summer and fall. Coefficients of determination for regressions of Log_{10}(PSD) on Log_{10} (CPUE) and Log_{10}(Kn) were significant (0.54, 0.61, respectively; $P<0.001$) but not for Log_{10} (Kg/min). Log_{10} transformed Kn varied as a negative parabolic function of Log_{10}(PSD), whereas Log_{10}(CPUE) varied as a negative linear function of Log_{10}(PSD).

Food habits

Total RGV all trout combined differed among years ($P<0.01$) and seasons ($P< 0.001$). Total RGV declined from 1991-1992 to 1993, then increased through 1997. The pattern of change in total RGV between 1991-1997 reflected increases in *Gammarus* and *Cladophora* in diets. Total RGV for all trout combined was highest in summer. Size classes >152 mm tended to follow this pattern of seasonal change, which was due primarily to seasonal increases in ingested *Gammarus* ($P<0.001$) and *Cladophora* ($P< 0.001$). However, ingestion of chironomids ($P<0.001$) and gastropods ($P<0.01$), respectively, was highest in spring and fall.

Total RGV and RGVs for *Gammarus* ($P<0.05$), gastropods, *Cladophora* and total chironomids ($P<0.05$ all taxa) differed by size classes of trout among years and seasons. Significant year-to-year and seasonal trends were apparent primarily for trout 305 mm-405 mm. Total RGV for this size class increased by year ($P<0.01$), as did RGVs for *Gammarus* ($P<0.001$), gastropods ($P<0.02$) and *Cladophora* ($P<0.05$). Total RGVs for other size classes did not vary by year, nor did RGVs for most taxa.

In general, all size classes of trout followed comparable seasonal patterns of greater total RGV. However, individual taxa differed in seasonal patterns of consumption by trout. As with yearly trend data, trout 305-405 mm exhibited the most consistent seasonal changes in diet. Total RGV ($P<0.001$) and the RGVs for *Gammarus* ($P<0.01$) and *Cladophora* ($P<0.001$) for this length class peaked in summer, while RGVs for chironomids peaked in spring ($P<0.001$), and gastropods peaked during summer-fall ($P<0.05$).

No differences were observed in frequency of empty stomachs among size classes. Frequencies of empty stomachs differed between stocked and wild-spawned fish only for trout 305-400 mm TL, where wild-spawned fish had proportionately fewer empty stomachs ($P = 0.021$). Percent empty stomachs for all trout combined declined during 1992-1997. Percent empty stomachs for all trout combined was greater ($P<0.001$) in winter (35%) and fall (27 %), lower in summer (12 %) and spring (18 %), and individual length classes tended to follow similar patterns of seasonal change. About 22% of stomachs were empty over seasons and years for all trout combined.

Bioenergetics

Preliminary results indicate that energy intake by trout meets or exceeds minimum

metabolic requirements (MR) most frequently during spring to fall. Percentages of fish meeting or exceeding MR were greatest in 1992 and 1997. Percentage of maximum feeding rates also peaked in 1992 and 1997 and was greatest in summer. Other results are not presently available.

Benthos

Densities of *Gammarus* and gastropods declined between 1991 and 1997 ($P<0.001$). In contrast, densities of chironomids increased from 1991-1997 ($P<0.001$). Densities of *Gammarus* and gastropods are greatest in the fall ($P<0.001$), but chironomid densities are highest during spring-summer ($P<0.001$).

Periphyton mass differed among years and seasons ($P<0.001$). Periphyton mass declined from 1991 to about 1993 and remained stable until increasing in 1997. Periphyton mass was highest in summer ($P<0.001$). Mass of submerged macrophytes also differed among years and seasons ($P<0.001$) and was greater in 1995 than in 1994, 1996 or 1997 and was greater during winter to spring.

Drift

Drift concentrations of total plant matter and total macroinvertebrates increased at Lee's Ferry between about 1994 and 1997 ($P<0.05$). Concentrations of total macroinvertebrates and plant matter in the drift tended to be highest during spring-summer-fall.

Water quality

Analyses are pending.

Predictor and response variables

Due to the preliminary status of analyses, stated significance levels for this section indicate $\alpha = 0.05$. Releases from GCD significantly influenced CPUE and Kg/min for trout

captured by EF. Catch-per-minute for all fish combined differed in association with mean seasonal discharges, mean daily coefficient of variation in flows (CV) and mean daily minimum flows. Mean seasonal flows and minimum daily flows correlated positively with CPUE, while mean daily flow fluctuations and total hours $\leq$ 227 m^3s^{-1} during 1-2 seasons prior to EF correlated negatively with CPUE.

Catch-per-minute of trout < 152 mm, 152-304 mm and 305-405 mm TL correlated positively with mean and minimum daily flows during and 1-3 seasons prior to EF. In most cases, CPUE for the <152 mm and 152-305 mm TL size groups correlated negatively with total hours $\leq$ 227 m^3s^{-1}, mean daily flow fluctuations and CV during and/or in seasons prior to sampling. Catch-per-minute for the 305-405 mm TL size class usually was independent of flow fluctuations, while CPUE for fish 406-558 mm correlated positively with CV and mean maximum CV (CVmax) during seasons prior to sampling.

Trout mass (Kg/min) for all fish captured by EF correlated positively with mean daily discharges from the dam and mean CVmax 1-2 seasons prior to sampling but was independent of total hours per season $\leq$ 227 m^3s^{-1}. Mass of fish 100-152 mm TL correlated positively with mean daily and mean daily minimum flows during and prior to sampling but corresponded negatively with mean daily fluctuations in discharge, CV, CVmax and total hours < 227 m^3s^{-1} during and 1-2 seasons prior to sampling. Mass of fish 152-304 mm TL correlated positively with mean daily flows and mean daily minimum flows but correlated negatively with mean fluctuations in discharge, mean CV, mean CVmax and hours $\leq$227 m^3s^{-1} during and up to two seasons prior to sampling. Mass of trout 305-405 mm TL also correlated positively with mean daily flow and mean minimum daily flow. However, mass of fish 406-558 mm TL correlated

positively with mean CV two seasons prior to sampling.

Mean daily and mean minimum releases from the dam correlated positively with CPUE of naturally-spawned trout and negatively with Kn for both wild-spawned and stocked fish. In contrast, CV correlated negatively with CPUE but positively with Kn for wild-spawned and stocked fish. Total hours $\leq$227 m^3s^{-1} during the season prior to sampling correlated negatively with CPUE only for wild-spawned trout.

Catch- and Kg-per-minute of EF for all trout combined correlated negatively with *Gammarus* benthic densities. Trout mass and CPUE correlated positively with periphyton mass during all seasons. Condition of trout 152-302 mm TL was positively correlated with densities of *Gammarus*, gastropods and total invertebrates. Catch- and Kg-per-min of trout 305-405 mm TL were inversely correlated with benthic densities of *Gammarus* and gastropods. Catch- and Kg-per-minute of trout 406-558 mm TL were positively correlated with periphyton standing stocks.

Catch-per-minute for all fish combined and for all size classes correlated positively with trout mass but not with Kn, except that CPUE and Kn correlated negatively for fish 305-405 mm TL. In contrast, trout mass correlated negatively with Kn for all fish combined and for fish 305-405 mm TL.

Mean discharges from GCD and mean minimum flows correlated negatively with PSD. In contrast, mean daily fluctuations in flow, CV, CVmax and total hours $\leq$227 m^3s^{-1} during or previous to sampling correlated positively with PSD. We found no significant correlations between dam discharges and macroinvertebrate drift, or between trout Kn and macroinvertebrate benthic densities versus macroinvertebrate drift. However, CPUE of trout <152 mm TL

correlated positively with invertebrate drift. Invertebrate drift and total chironomid RGV correlated negatively for trout 152-304 mm TL. In contrast, invertebrate drift correlated positively with *Gammarus* RGV for trout 406-558 mm TL.

Relative condition factor of all trout correlated negatively with fluctuating discharges from GCD (CVmax). Condition of fish 152-305 mm TL correlated negatively with mean daily releases from the dam, and fish in the latter size category correlated negatively with CVmax. However, most negative correlations were found between condition of trout 305-405 and 406-558 mm TL and indices of flow variability (mean daily fluctuation, CV, CVmax and total hours $\leq$227 m^3s^{-1}) during or previous to sampling.

Relative stomach volume for all fish combined was negatively correlated with mean daily flows only for chironomid pupae two seasons prior to the period of EF sampling and was correlated positively only with *Cladophora* during the season when samples were taken. The RGV for gastropods correlated negatively with total hours $\leq$227 m^3s^{-1} and flow variation (CV and CVmax during sampling). Feeding by trout (% empty stomachs) correlated negatively with mean discharges during and one season prior to sampling and with mean minimum daily flows during sampling.

Total RGV for fish 152-304 mm TL correlated positively with mean daily flows but negatively with mean daily flow fluctuations during the season prior to sampling. The RGV for *Cladophora* correlated positively with mean and minimum daily flows but correlated negatively with mean daily flow fluctuations during the season of sampling. Gastropod RGV correlated negatively with CV and CVmax during the season prior to sampling and correlated negatively with total hours $\leq$227 m^3s^{-1} during all seasons. Percent empty stomachs correlated positively

with CVmax during two seasons prior to sampling.

Total RGV for trout 305-405 mm TL was negatively correlated with flow fluctuation variables (mean daily fluctuation, CV, CVmax and total hours $\leq$227 m^3s^{-1}) recorded up to two seasons prior to sampling, but was positively correlated with mean daily flows during the season prior to sampling. *Gammarus* RGV correlated negatively with mean daily fluctuations in flow. Gastropod RGV correlated negatively with the above flow fluctuation variables up to two seasons prior to sampling but correlated positively with mean daily flows during the season prior to sampling. Percent empty stomachs was negatively correlated with mean and mean minimum flows during sampling, and with mean flows during the season prior to sampling.

Total RGV for fish 406-558 mm TL correlated positively with CVmax during the sampling season. *Gammarus* RGV correlated positively with total hours/season $\leq$227 m^3s^{-1} during and two seasons prior to sampling, while RGV for gastropods correlated positively with total hours/season $\leq$227 m^3s^{-1} during the season of sampling. *Cladophora* RGV correlated positively with mean daily flow during and two seasons prior to sampling.

Catch- and Kg-per-minute for all fish combined correlated positively with RGV for *Cladophora*. Relative condition factor correlated negatively with *Gammarus* RGV. Catch and condition indices were independent of RGVs for trout 152-104 mm TL. Catch- and Kg-per-minute correlated positively with *Cladophora* RGV for trout 305-405 mm TL. No significant relationships existed between RGVs and CPUE or trout mass for fish 406-558 mm.

For all trout combined, RGVs for chironomid larvae, *Gammarus* and *Cladophora* correlated positively with total RGV, but only RGV for chironomid larvae correlated negatively with percent empty stomachs. Chironomid pupae RGV was inversely correlated with RGVs for

Gammarus and gastropods. The RGVs for chironomid pupae and larvae also correlated positively with *Cladophora* RGV for trout 152-304 mm TL. RGVs for *Gammarus* and gastropods were positively correlated, and RGVs for *Gammarus* and *Cladophora* correlated positively with total RGV for this size category. The RGVs for chironomid larvae and pupae were correlated positively for fish 305-405 mm TL, but only the RGV for larvae correlated positively with RGV for *Cladophora*. Total RGV correlated positively with RGVs for *Gammarus* and *Cladophora*. The RGVs of *Gammarus* and gastropods correlated positively for fish 406-558 mm TL, and RGV for *Cladophora* was positively correlated with total RGV.

Total RGVs for all fish combined correlated negatively with benthic densities of *Gammarus*. The RGVs of chironomid larvae and *Cladophora* correlated negatively with benthic densities of *Gammarus* and gastropods. Benthic densities of chironomids correlated positively with RGVs for chironomid larvae and *Cladophora*, but not with chironomid adults or pupae. *Gammarus* densities correlated positively, while chironomid pupae standing stocks correlated negatively, with percent empty stomachs.

Total RGVs for trout 152-304 mm TL correlated negatively with *Gammarus* and total invertebrate benthic densities. RGVs for *Cladophora* correlated negatively with benthic densities of *Gammarus* and gastropods, and RGVs for chironomid larvae and *Cladophora* correlated positively with chironomid benthic densities. RGVs for *Gammarus* and gastropods also correlated positively with periphyton mass.

Total RGVs for trout 305-405 mm TL corresponded negatively with *Gammarus* densities but positively with chironomid densities and periphyton mass. *Gammarus* and gastropod densities were negatively correlated with RGVs of chironomid larvae. *Gammarus* densities also

correlated negatively with RGV for *Cladophora.* In general, chironomid densities correlated positively with the RGV for their respective life stages and for *Cladophora*. The RGVs for *Cladophora*, correlated positively with periphyton mass.

The RGVs for trout 406-558 mm TL for chironomid larvae and *Cladophora* correlated positively with chironomid densities, and gastropod densities correlated positively with RGV for *Gammarus*. Chironomid density correlated positively with RGV for *Cladophora*, and the latter correlated negatively with *Gammarus* density.

Densities of benthic macroinvertebrates also generally were influenced by dam operations, but results were taxon-specific. *Gammarus* densities correlated negatively with mean flows and mean minimum daily flows during the season when samples were collected, and correlation was positive between amphipod densities and mean CV during the season prior to sampling. In contrast, chironomid densities exhibited no significant relationships with releases from GCD. Gastropods were more affected than other taxa by discharges from the dam. Gastropod densities correlated negatively with mean and mean minimum daily flows during and one season prior to sampling. However, snail densities correlated positively with CV during 1-2 seasons prior to sampling and with total hours $\leq$227 m^3s^{-1} during the sampling season. Macrophyte densities were unrelated to discharges from GCD, but periphyton correlated positively with mean CVmax two seasons prior to season of sampling.

Within benthic assemblages, densities of gastropods and *Gammarus* correlated positively with each other, and both taxa correlated negatively with chironomid pupae and periphyton standing stocks. Densities of chironomid larvae correlated positively with pupae densities, and both groups correlated positively with periphyton.

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