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Statistical Evaluation of the Effects of Fall and Winter Flows on the Spring Condition of Rainbow and Brown Trout in the Green River Downstream of Flaming Gorge Dam

Environmental Science Division

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Statistical Evaluation of the Effects of Fall and Winter Flows on the Spring Condition of Rainbow and Brown Trout in the Green River Downstream of Flaming Gorge Dam

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for
Western Area Power Administration
Colorado River Storage Project Management Center

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Acronyms, Initialisms, and Abbreviations

BLH	brown trout at Little Hole
BTR	brown trout at Tailrace
N	sample size
P	probability
r_s	Spearman rank correlation coefficient
S	taxa richness
Reclamation	Bureau of Reclamation
RLH	rainbow trout at Little Hole
RTR	rainbow trout at Tailrace
SD	standard deviation
UDWR	Utah Division of Wildlife Resources
Western	Western Area Power Administration

Variables Used in the Analyses

cv_dmean	coefficient of variation of mean daily flows
hgt1000	total hours with flows >1,000 cfs
hgt2000	total hours with flows >2,000 cfs
hgt3000	total hours with flows >3,000 cfs
hgt4000	total hours with flows >4,000 cfs
L	length (mm)
mean_dcv	mean daily coefficient of variation in flow
mean_ddelta	mean change in flow between days (absolute values)
mean_ddelta (%)	mean change in flow between days (%)
mean_dmax	mean of maximum daily flow
mean_dmean	mean of mean daily flow
mean_dmin	mean of minimum daily flow
mean_drange	mean daily range of flows
mean_dskew	mean daily skewness of flow volumes
mean_hdelta	mean hourly change of flows (absolute values)
mean_hdelta (%)	mean hourly change of flows (%)
mean_mdelta	mean change in flow between months (absolute values)
mean_mdelta (%)	mean change in flow between months (%)
med_dmean	median of mean daily flow
range_dmean	range of mean daily flows
ratio WR	relative change in WR from fall to spring
skew_dmean	skewness of mean daily flows
W	weight (g)
WR	relative weight

Units of Measure

cfs	cubic foot (feet) per second
cm	centimeter(s)
CPUE	catch per unit effort (number of fish caught/h)
g	gram(s)
h	hour(s)
km	kilometers(s)
m	meter(s)
m^2	square meter(s)
m^3	cubic meter(s)
mm	millimeter(s)
s	second(s)

ACKNOWLEDGMENTS

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SUMMARY

Flaming Gorge Dam, a hydroelectric facility operated by the Bureau of Reclamation (Reclamation), is located on the Green River in Daggett County, northeastern Utah. In recent years, single peak releases each day or steady flows have been the operational pattern during the winter period. A double-peak pattern (two flow peaks each day) was implemented during the winter of 2006-2007 by Reclamation. Because there is no recent history of double-peaking at Flaming Gorge Dam, the potential effects of double-peaking operations on the body condition of trout in the dam's tailwater are not known.

A study plan was developed that identified research activities to evaluate potential effects from double-peaking operations during winter months. Along with other tasks, the study plan identified the need to conduct a statistical analysis of existing data on trout condition and macroinvertebrate abundance to evaluate potential effects of hydropower operations. This report presents the results of this analysis. We analyzed historical data to (1) describe temporal patterns and relationships among flows, benthic macroinvertebrate abundance, and condition of brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*) in the tailwaters of Flaming Gorge Dam and (2) to evaluate the degree to which flow characteristics (i.e., flow volumes and flow variability) and benthic macroinvertebrate abundance affect the condition of trout in this area. This information, together with further analyses of size-stratified trout data, may also serve as baseline data to which the effects of potential future double-peaking flows can be compared.

The condition (length, weight and/or relative weight) of rainbow trout (*Oncorhynchus mykiss*) at two sites in the Green River downstream of Flaming Gorge Dam (Tailrace and Little Hole) and weight of brown trout (*Salmo trutta*) at the Little Hole site has been decreasing since 1990 while the abundance of brown trout has been increasing at the two sites. At the same time, flow variability in the river has decreased and the abundance of total benthic macroinvertebrates at the Tailrace site has increased.

The condition of trout in spring (averaged across all sampled trout) was positively correlated with fall and winter flow variability (including within-day skewness, within-season skewness and/or change in flow between days) at both locations. No negative correlations between trout condition and any measure of flow variability were detected. The length and weight of rainbow trout at the Little Hole site were negatively correlated with increasing fall and winter flow volume. The condition of brown trout at Little Hole and the condition of brown and rainbow trout at Tailrace were not correlated with flow volume.

Macroinvertebrate variables during October were either positively correlated or not correlated with measures of trout condition at the Tailrace and Little Hole sites. With the exception of a positive correlation between taxa richness of macroinvertebrates in January and the relative weight of brown trout at Tailrace, the macroinvertebrate variables during January and April were either not correlated or negatively correlated with measures of trout condition.

We hypothesize that high flow variability increased drift by dislodging benthic macroinvertebrates, and that the drift, in turn, resulted in mostly lower densities of benthic macroinvertebrates, which benefited the trout by giving them more feeding opportunities. This

was supported by negative correlations between benthic macroinvertebrates and flow variability. Macroinvertebrate abundance (with the exception of ephemeropterans) was also negatively correlated with flow volume.

The change in trout condition from fall to spring, as measured by the ratio of spring to fall relative weight, was evaluated to determine their usefulness as a standardized index to control for the initial condition of the fish as they enter the winter period. The ratio values were less correlated with the fall condition values than the spring condition values and did not show the same relationships to flows, to macroinvertebrates, or across years as the above-mentioned spring relative weight values. We found that the condition ratio of rainbow trout at Tailrace was positively correlated with within-day flow variability but was not correlated with flow volume, between-day-, or within-season flow variability. The condition ratios of rainbow trout at Little Hole and of both trout species at Tailrace were not correlated to any of the measured flow variables. The condition ratios of both trout species were positively correlated with the abundance of January benthic macroinvertebrates at the Little Hole site and with January dipterans (brown trout) or total coleopterans (rainbow trout) at the Tailrace site.

The relationships among flows, macroinvertebrates, and trout condition were varied among species and locations. It is possible that additional relationships will be found when different size-classes of fish are analyzed separately. The relationships presented here do not necessarily indicate direct cause and effects (causality) and the high variability and low sample size yielded few strong and consistent patterns. Future analyses may yield additional insight into the relationship of trout condition to environmental variables.

STATISTICAL EVALUATION OF THE EFFECTS OF FALL AND WINTER FLOWS ON THE SPRING CONDITION OF RAINBOW AND BROWN TROUT IN THE GREEN RIVER DOWNSTREAM OF FLAMING GORGE DAM

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1 INTRODUCTION

Flow volume and flow patterns strongly affect the distribution, assemblage structure, and condition of native and nonnative fishes in regulated rivers (Gore 1996; Marchetti and Moyle 2001; Osmundson et al. 2002). These relationships are especially apparent downstream of some hydroelectric facilities, where natural flow regimes have been altered by changing the seasonal flow volumes, by introducing greater within-day variability in flows, by altering seasonal temperature regimes, and by changing the suspended sediment levels. In some cases, changes in water temperatures and turbidity have resulted in shifts from conditions suitable for supporting warmwater fish communities to conditions that favor the establishment of coldwater fish communities.

One such hydroelectric facility is Flaming Gorge Dam, which is located on the Green River (a tributary of the Colorado River) in Daggett County, northeastern Utah. Construction of the dam, which was completed in 1964, resulted in the formation of Flaming Gorge Reservoir, which has a surface elevation of approximately 1,840 m above sea level. Because of the hypolimnetic releases from the dam, the segment of the Green River located downstream has been transformed from a warmwater ecosystem to a coldwater ecosystem that supports a highly regarded trout fishery (Reclamation 2005). The dam has three turbines with a maximum combined release capacity of approximately 4,600 cfs (130 m^3/s). (The maximum combined release capacity is now about 4,200 cfs [119 m^3/s] following recent upgrades to the turbines.) Agreements between the Bureau of Reclamation (Reclamation) and the state of Utah have resulted in year-round minimum releases from Flaming Gorge Reservoir of 800 cfs (23 m^3/s) to maintain the trout fishery. In order to improve conditions for trout growth and survival during summer months, a selective water withdrawal structure was installed at the dam in 1978 that allows warmer epilimnetic water to be released through the turbines.

There have been various changes in typical operations at Flaming Gorge Dam over the years (Muth et al. 2000). Prior to 1984, Flaming Gorge Dam was primarily operated to match electrical power demands. This typically resulted in relatively high discharges during the winter and summer months and high within-day fluctuations in flow. Since 1984, the dam has been operated, in part, to increase and maintain the availability of nursery habitats for endangered fish that are present in sections of the Green River located approximately 150 km and further downstream from the dam. Additional flow and temperature recommendations to protect endangered fish and their habitats have been developed for the Green River downstream of

Flaming Gorge Dam since 1992 (USFWS 1992; Muth et al. 2000). A recent environmental impact statement (Reclamation 2005) and the associated Record of Decision (Reclamation 2006) resulted in additional changes in the operation of Flaming Gorge Dam to meet the flow recommendations proposed by Muth et al. (2000). These changes have resulted in higher spring peak flows, lower base flows from summer through winter, and moderation of within-day fluctuations, especially during summer and fall.

The ability to generate power on a schedule that more closely matches electrical demand increases the market value of the power produced. In recent years, single peak releases each day or steady flows have been the operational pattern instituted during the winter period. At the request of Western Area Power Administration (Western), a double-peaking release pattern at Flaming Gorge Dam that featured a peak in the morning and evening, and continued to meet flow requirements for endangered fish, was implemented during the winter of 2006–2007 by Reclamation. Because there is no recent history of double-peaking at Flaming Gorge Dam (except for a few weeks in October 1993), the potential effects of double-peaking operations on the condition of trout in the dam's tailwater are not known. However, because there are concerns that double-peaking operations could have negative effects on the growth, survival, and reproduction of trout, a study plan that identified research activities to evaluate potential effects from double-peaking operations during winter months was developed.

Along with other tasks, the study plan identified the need to conduct a statistical analysis of existing data on trout condition and macroinvertebrate abundance to evaluate potential effects of hydropower operations. This report presents the results of this analysis. We analyzed data collected since 1990 to (1) describe temporal patterns and relationships among flows, benthic macroinvertebrate abundance, and condition of brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*) in the tailwaters of Flaming Gorge Dam and (2) evaluate the degree to which flow characteristics (i.e., flow volumes and flow variability) and benthic macroinvertebrate abundance may affect the condition of trout in this area. The results summarize the relationships between flow and trout condition during a period when winter operations of Flaming Gorge Dam resulted in single daily peaks in flow. Due to the limited number of sampled years, however, the relationships that are identified in this report should be regarded only as potentially important relationships that warrant further examination once additional data have been collected. This information may also, together with analyses of size-stratified data, serve as baseline data to which the effects of potential future double-peaking flows can be compared.

Because fish in temperate zones typically experience a decline in condition over the winter due to colder water temperatures, reduced food supply, and behavioral changes, overwinter declines in condition following a winter with double-peaking operations would not be expected to be solely the result of a double-peaking effect. To compensate, we proposed two approaches: (1) comparison of spring body condition data in years that featured double-peaking to spring condition data from other years and (2) examination of the ratio of spring condition to fall condition over the period of record. The researchers hypothesized that the ratio would normalize condition data to more accurately reflect the effect of winter operations because it would be based on the starting condition of fish as they enter a particular winter. Such a ratio could be used to evaluate whether there is an incremental effect of double-peaking operations on the condition of overwintering fish. In this report, we explore the feasibility of using condition ratios by evaluating historic condition data.

We specifically evaluate the relationships among fall and winter flows, fall and winter macroinvertebrate abundance, and the condition of trout in the spring. Relationships between trout condition, flows, and macroinvertebrate abundance at other time periods will be evaluated in subsequent analyses.

The two sites for which fish and benthic macroinvertebrate data were available are known as Tailrace and Little Hole; both sites are approximately 1 km in length. The Tailrace site extends about 1 km downstream from the first boat ramp below the dam to the confluence of the Green River and Pipe Creek. This reach consists primarily of deeper runs, although there are some short riffle sections on either side of the thalweg. Macroinvertebrate samples associated with this site were collected just upstream from the Tailrace boat ramp (Vinson et al. 2006). The Little Hole reach extends downstream from the upstream-most Little Hole boat ramp to Grasshopper Island. This site consists of riffles, runs, and pools of various depths but has less run habitat than the Tailrace site. Samples of benthic macroinvertebrates for this site were collected just upstream from the Little Hole boat ramp (Vinson et al. 2006).

The report is divided into three parts. The first section presents and evaluates the temporal patterns found in existing data on fall and winter flows (1989–2006), macroinvertebrate abundance (1994–2006), and the body condition of trout in spring (1990–2006). The second portion of the report evaluates statistical relationships among variables derived from these data. The third portion of the report evaluates the potential use of a spring/fall body condition ratio as an index for evaluating the effect of overwinter flows on the condition of trout.

2 TEMPORAL PATTERNS IN FALL AND WINTER FLOWS, MACROINVERTEBRATE ABUNDANCE, AND TROUT CONDITION

This section provides an overview of the temporal relationships found in baseline data from 1990 through 2006 on trout condition, macroinvertebrate abundance, and flows in the tailwaters of Flaming Gorge Dam. This time period encompasses the years for which information is available for trout from spring and fall electrofishing surveys conducted by the Utah Division of Wildlife Resources (UDWR). Macroinvertebrate data are available from 1994 through 2006.

A variety of hydrologic conditions and ecological changes occurred in the study area over this time period. For example, there were (1) consecutive years of severe drought and years with moderately wet conditions; (2) annual operations with extended periods of steady base flows and with single-peak operations; (3) an influx of fine sediment to the river after the Mustang Ridge wildfire in 2002; (4) an invasion of the exotic New Zealand mud snail (*Potamopyrgus antipodarum*) starting in 2002; (5) large increases in wild-spawned brown trout, with a subsequent switch in numerical dominance from rainbow to brown trout; and (6) an increase in the numbers of anglers and fishing pressure. These changes are considered in the interpretation of results discussed in this report.

2.1 METHODS

Annual patterns for brown and rainbow trout size and body condition variables, abundance of macroinvertebrates, and selected aspects of the flow regime were summarized graphically and statistically evaluated for all relationships by testing the significance of nonparametric rank correlations (Spearman correlation coefficient, r_s). SAS statistical software (Version 9.1; SAS Institute Inc. 2002) was used to calculate flow variables from hourly flow data and to perform all statistical analyses. The sources and types of data used for analyses of trout, macroinvertebrates, and flows are summarized below.

2.1.1 Trout Data

All trout data evaluated in this report were provided by UDWR. Electrofishing surveys of trout in the Flaming Gorge tailwaters were conducted by UDWR personnel each fall and spring from 1990 through 2006, with the exception of the springs of 2003, 2004, and 2005. Data provided by UDWR for the analyses included summaries of abundance, lengths, weights, and calculated condition factor index for brown and rainbow trout segregated by sample collection location (Tailrace or Little Hole). Specifically, trout information used as dependent variables in our analyses included:

- Total length in spring (L, in mm);
- Weight in spring (W, in g);

- Relative weight in fall and spring (WR): $W/W_i \times 100$ where W_i = "standard weight" calculated from previously established species-specific length-weight regression equations (Murphy et al. 1991)

Catch per unit effort in spring (CPUE, in number of fish caught per hour) was used to test whether the lengths, weights, and relative weights were density dependent. CPUE data were not available for the spring of 1996 at the Little Hole site.

At the time that this report was prepared, the CPUE, lengths, weights, and relative weights of three different size-classes of trout in 100 mm bins (i.e., 200–299 mm, 300–399 mm, and ≥400 mm) were not available for analyses. The size-stratified data will be plotted here to illustrate trends, but will be further analyzed in a subsequent report.

2.1.2 Macroinvertebrate Data

Data pertaining to macroinvertebrate abundance in the Flaming Gorge tailwaters were provided by Dr. Mark Vinson at Utah State University (Appendix A). Macroinvertebrates were collected annually using Hess nets in riffle habitats located upstream of the Tailrace and Little Hole electrofishing sites in the months of January, April, July, and September or October (hereafter referred to as the October sample) from 1994–2006 (see Vinson et al. 2006 for a description of sampling protocol). The data consisted of mean values, reported as estimated densities (i.e., number of individuals/m^2), from eight pooled samples for each site and season. The dependent variables used in our analyses included estimated total macroinvertebrate densities and densities of organisms within selected taxonomic orders (Ephemeroptera, Amphipoda, Coleoptera, and Diptera) for specific time periods (Table 1). New Zealand mud snails first appeared at the sites in 2002 and were not included in our analysis because of the small number of observations. We only used macroinvertebrate data from the October, January, and April collections for the analyses in this report because it was assumed that the condition of trout in April is most likely affected by food availability during the period immediately preceding April. Since monitoring of macroinvertebrates did not start until 1994, the number of years for which such data were available (N = 10) is lower than the total number of years for which trout electrofishing data were available (N = 14).

2.1.3 Water Temperature Data

Hourly water temperature data from 1990–2006 were obtained from U.S. Geological Survey (USGS) gage near Greendale, Utah (0.8 km downstream of the dam, Station 092345000). The data for each overwinter period are plotted to illustrate trends over the examined years. The data were, however, too incomplete for a complete statistical analyses. Several of the years (11 out of 17) had missing data for one or several months in the overwinter periods (October-March).

TABLE 1 Benthic Macroinvertebrate Variables Used in the Analysis

Variables	Definition
Total macroinvertebrates	Mean number/m^2 of macroinvertebrates of all taxa in October [a], January, and April samples
Total taxa richness	Mean number of identified macroinvertebrate taxa in October [a], January, and April samples
Total ephemeropterans	Mean number/m^2 of ephemeropterans in October [a], January, and April samples
Total amphipods	Mean number/m^2 of amphipods in October [a], January, and April samples
Total coleopterans	Mean number/m^2 of coleopterans in October[a], January, and April samples
Total dipterans	Mean number/m^2 of dipterans in October [a], January, and April samples
Total NZ mud snails	Mean number/m^2 of New Zealand mud snails in October [a], January, and April samples
October macroinvertebrates	Mean number/m^2 of macroinvertebrates of all taxa in October samples[a]
October taxa richness	Mean number of identified macroinvertebrate taxa in October samples [a]
October ephemeropterans	Mean number/m^2 of ephemeropterans in October samples[a]
October amphipods	Mean number/m^2 of amphipods in October samples[a]
October coleopterans	Mean number/m^2 of coleopterans in October samples[a]
October dipterans	Mean number/m^2 of dipterans in October samples[a]
October NZ mud snails	Mean number/m^2 of New Zealand mud snails in October samples[a]
January macroinvertebrates	Mean number/m^2 of macroinvertebrates of all taxa in January samples
January taxa richness	Mean number of identified macroinvertebrate taxa in January samples
January ephemeropterans	Mean number/m^2 of ephemeropterans in January samples
January amphipods	Mean number/m^2 of amphipods in January samples
January coleopterans	Mean number/m^2 of coleopterans in January samples
January dipterans	Mean number/m^2 of dipterans in January samples
January NZ mud snails	Mean number/m^2 of New Zealand mud snails in January samples
April macroinvertebrates	Mean number/m^2 of macroinvertebrates of all taxa in April samples
April taxa richness	Mean number of identified macroinvertebrate taxa in April samples
April ephemeropterans	Mean number/m^2 of ephemeropterans in April samples
April amphipods	Mean number/m^2 of amphipods in April samples
April coleopterans	Mean number/m^2 of coleopterans in April samples
April dipterans	Mean number/m^2 of dipterans in April samples
April NZ mud snails	Mean number/m^2 of New Zealand mud snails in April samples

[a] Fall macroinvertebrate samples for most years were collected in October, but samples for 2001–2006 were collected in late September.

2.1.4 Flow Data

Data pertaining to water releases from Flaming Gorge Dam for 1989–2006 were provided by Western and were based on electrical generation data and non-power releases for those years. The values for 20 different flow variables were calculated with SAS statistical software for the fall through winter period (October through April) of each year by using hourly and daily mean flows (Appendix B). These variables were segregated into categories considered descriptive of various aspects of flow volume or flow variability (Table 2). In total, there were 8 variables used to evaluate flow volume and 12 variables used to evaluate flow variability. Variables describing aspects of flow variability were further divided according to whether they represented within-day variability (5 variables), between-day variability (2 variables), within-season variability (3 variables), or between-month variability (2 variables). Because it was anticipated that these variables would not be fully independent measures of flow conditions, correlations among the flow variables were also calculated (Appendix C).

2.2 RESULTS AND DISCUSSION

2.2.1 Trout Abundance, Length, Weight, and Condition

Trout CPUE, lengths (L), weights (W), and condition factor (WR) from 1990–2006 are presented in Figure 1. Rainbow trout are stocked into the Flaming Gorge tailwater each year. The number of rainbow trout stocked annually from 1990–2006 ranged from approximately 13,000 to 40,000 fish. Annual average lengths of the stocked fish ranged from 137 to 254 mm (Figure 2). Brown trout spawn successfully in the river, and recruitment for this species relies upon in-river production. Brown trout are not stocked in the Green River.

The number of brown trout captured during each electrofishing survey ranged from 31 to 401 at the Tailrace site and from 233 to 712 at the Little Hole site; the number of rainbow trout ranged from 298 to 869 at Tailrace and from 112 to 484 at Little Hole (Figure 3). During the survey period, rainbow trout were, on average, five times more abundant than brown trout at the Tailrace site, and brown trout were two times more abundant than rainbow trout at Little Hole (Figure 3). We did not evaluate data prior to 1990, but Modde et al. (1991) reported that trout densities at Tailrace from 1985–1988 exceeded those at Little Hole and that spring densities at Little Hole were more stable than at Tailrace. They also found that rainbow trout was the most abundant fish at both locations. However, the dominance of rainbow trout in electrofishing collections from Tailrace has decreased, since then, from being 23 times more abundant than brown trout in 1990 to being approximately equal in number in 2006 (Figures 1 and 3).

TABLE 2 Variables Used to Describe Flow Volume and Flow Variability in the Green River below Flaming Gorge Dam from October through April

Variable Category	Variable Name	Definition
Flow Volume		
	med_dmean	Median of mean daily flow
	mean_dmean	Mean of mean daily flow
	mean_dmin	Mean of minimum daily flow
	mean_dmax	Mean of maximum daily flow
	hgt1000	Total hours with flows >1,000 cfs
	hgt2000	Total hours with flows >2,000 cfs
	hgt3000	Total hours with flows >3,000 cfs
	hgt4000	Total hours with flows >4,000 cfs
Flow Variability		
Within-days	mean_hdelta	Mean hourly change of flows (absolute values)
	mean_hdelta (%)	Mean hourly change of flows (%)
	mean_drange	Mean daily range of flows
	mean_dcv	Mean daily coefficient of variation in flow
	mean_dskew	Mean daily skewness of flows
Between-days	mean_ddelta	Mean change in flow between days (absolute values)
	mean_ddelta (%)	Mean change in flow between days (%)
Within-season	range_dmean	Range of mean daily flows
	cv_dmean	Coefficient of variation of mean daily flows
	skew_dmean	Skewness of mean daily flows
Between-months	mean_mdelta	Mean change in flow between months (absolute values)
	mean_mdelta (%)	Mean change in flow between months (%)

Notes

Mean – a measure of central tendency calculated as the sum of the observed values divided by the number of observations.

Median – middle value of a group of numbers that have been arranged in order by size.

Range – difference between minimum and maximum values.

Coefficient of variation (CV) – ratio of the standard deviation to the mean.

Skewness – lack of symmetry in the data distribution for flows. Zero skewness has median equal to the mean. Positive skewness has median lower than the mean (i.e., the distribution is skewed to the right and has a longer right tail than expected for a normal distribution). This would suggest that there are more hours or days with low flows. A data distribution with a negative skewness has a median value greater than the mean (i.e., the distribution is skewed to the left and has a longer left tail). A negatively skewed distribution for flow data would indicate there were more hours or days with high flows.

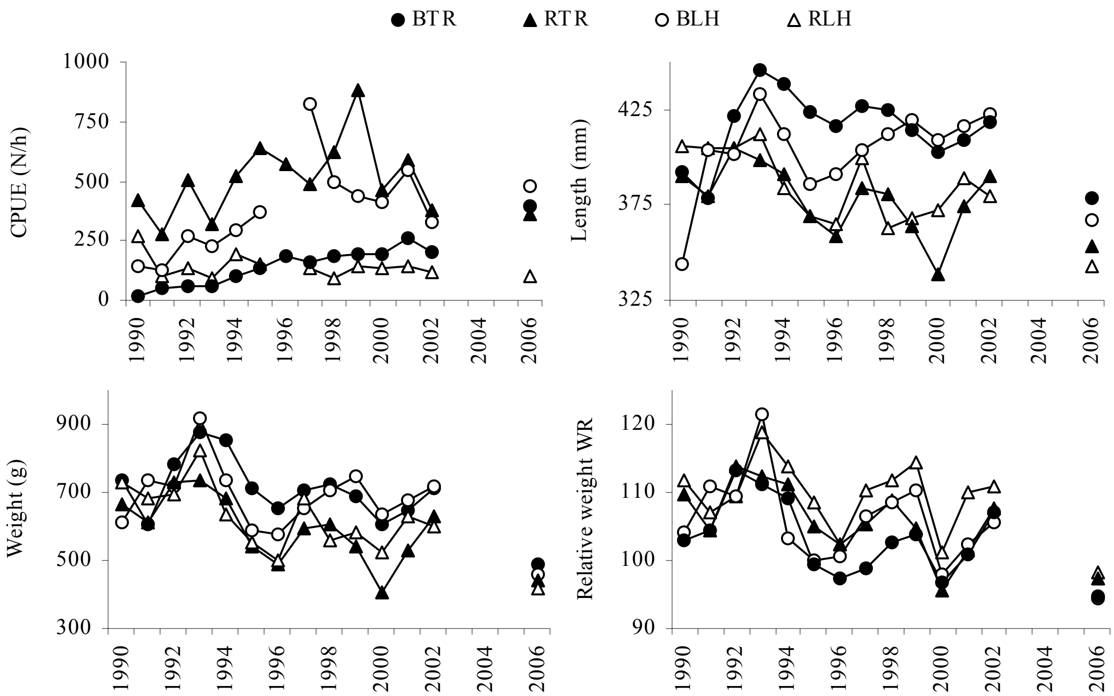

FIGURE 1 Mean Abundance (CPUE), Lengths, Weights, and Relative Weight of Trout from the Flaming Gorge Tailwater (BTR = brown trout at Tailrace, BLH = brown trout at Little Hole, RTR = rainbow trout at Tailrace, RLH = rainbow trout at Little Hole)

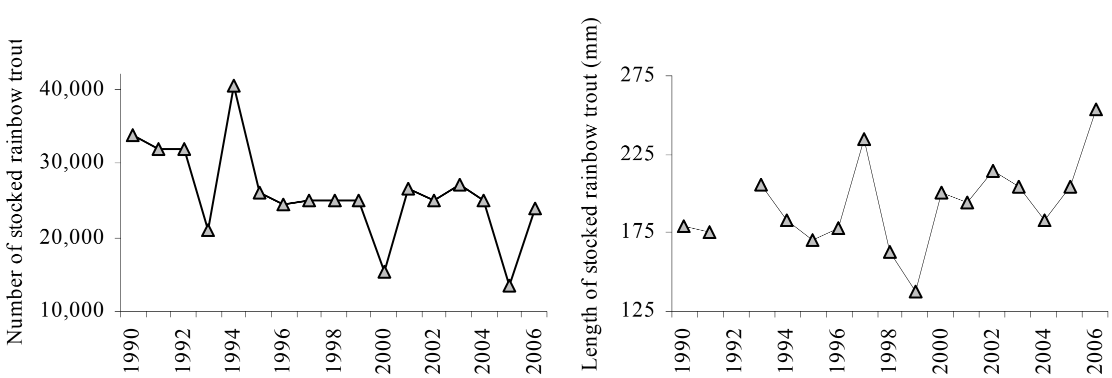

FIGURE 2 Numbers and Mean Length of Rainbow Trout Stocked in the Flaming Gorge Tailwater, 1990–2006

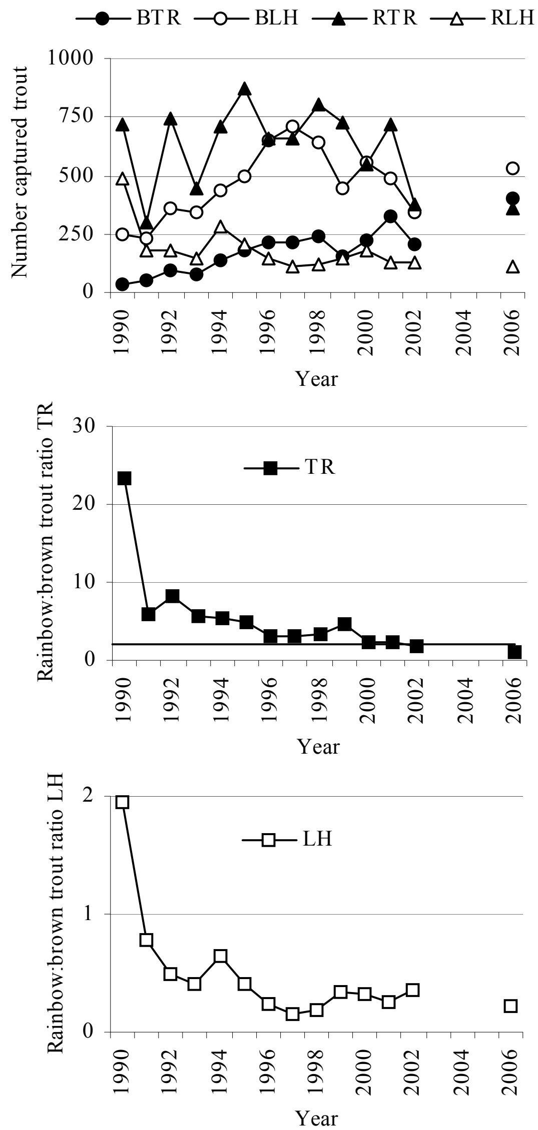

FIGURE 3 Numbers and Relative Abundance of Rainbow Trout and Brown Trout Captured at the Tailrace and Little Hole Sites (BTR = brown trout at Tailrace, BLH = brown trout at Little Hole, RTR = rainbow trout at Tailrace, RLH = rainbow trout at Little Hole)

The abundance of brown trout increased over the years at both locations (Figure 4). Values of L, W, and/or WR tended to decrease over the study period for rainbow trout at both locations, possibly as the result of a shift in the size distribution within the populations. The relative abundance of large rainbow trout (>400 mm) decreased from 20–71% of the fish captured during the 1990-2002 period to less than 10% during in the last year (Figure 5). Large brown trout (≥400 mm) decreased from 37-91% of the fish captured to less than 25% during the same time period. The shift in size was from predominantly large fish to intermediate-sized fish (300–400 mm) and it appears that the shift mostly occurred after 2002 (Figure 5). This analysis, however, does not separate stocked from the wild-spawned rainbow trout.

The weight of brown trout was negatively correlated with its CPUE at the Tailrace site (Figure 6) and the length and weight of rainbow trout at both locations were negatively correlated with the combined abundance of both trout species (Figure 7). Relative weights of rainbow trout and brown trout were not significantly correlated with the density of trout. The length and numbers of capture trout were not correlated with the length or number of stocked rainbow trout ($r_s < 0.36$, Spearman rank correlation, $P \geq 0.05$).

Although the trout variables related to size and body condition exhibited similar patterns over the years for both species and both sample locations (especially W and WR; Figure 1), they were not similar enough to justify pooling the data (on the basis of repeated measures analysis of variance [ANOVA] in which year was used as the repeated measure and location and trout species were used as treatment effects). For example, from 1990–2006, the average WR of rainbow trout and brown trout in spring was 3.5 and 2.3 units higher at the Little Hole site than at the Tailrace site. Moreover, rainbow trout were, on average, 6 cm longer and 30 g heavier at Little Hole than at Tailrace, whereas brown trout were 12 cm longer and 22 g heavier at the Tailrace site. Therefore, the data were analyzed separately for each trout species and for each sample location.

In this report, we use mean condition data, pooled across all size-groups. As mentioned previously, size-specific relationships will be examined in a subsequent report using disaggregated data.

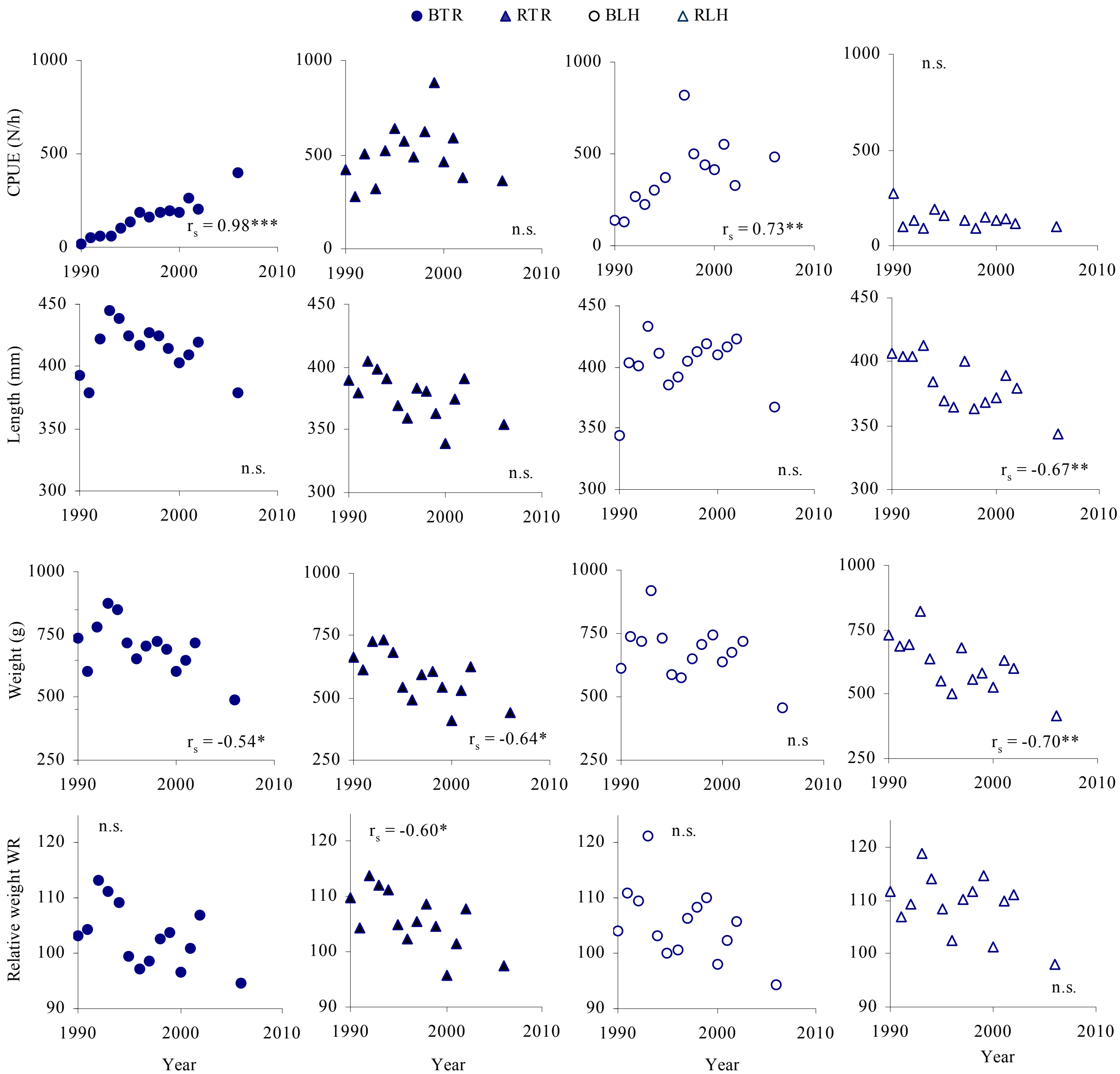

FIGURE 4 Relationships between Trout Variables and Years, 1990–2006 (Plots include rank correlation coefficients for statistically significant relationships; asterisks denote level of the significance: * *P* < 0.05, ** *P* < 0.01, * *P* < 0.001, n.s. *P* > 0.05; BTR = brown trout at Tailrace, BLH = brown trout at Little Hole, RTR = rainbow trout at Tailrace, RLH = rainbow trout at Little Hole)**

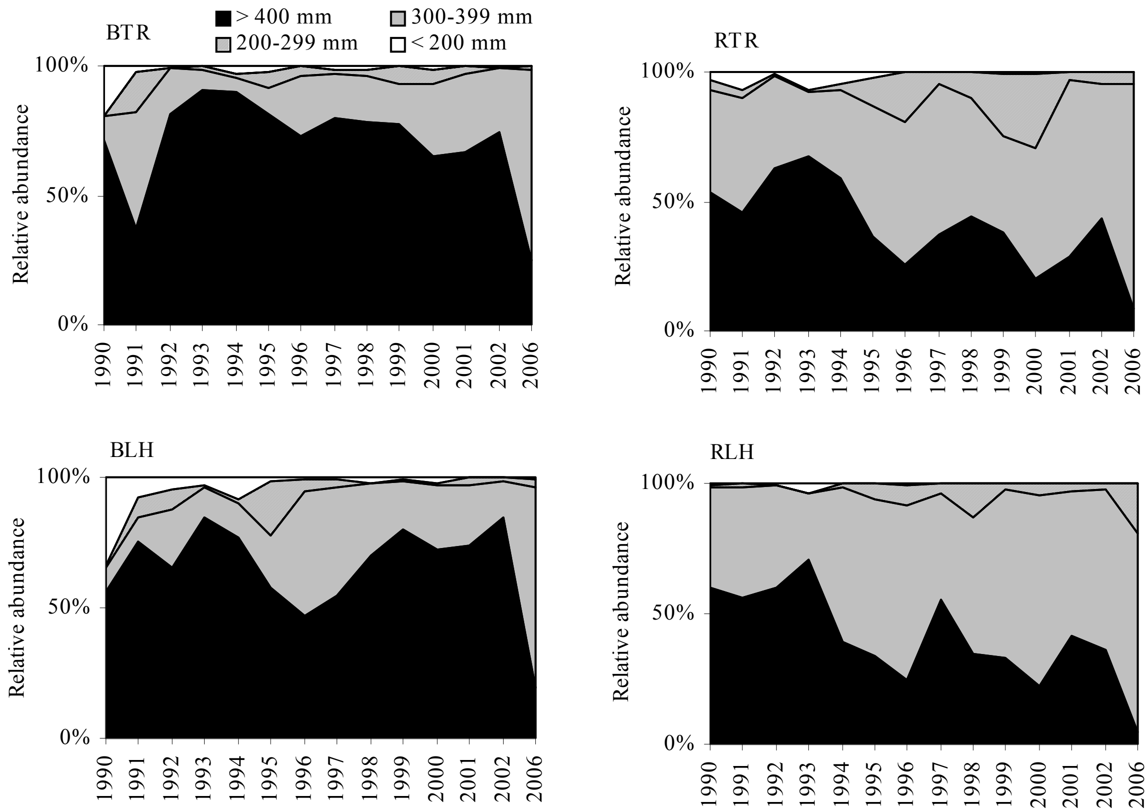

FIGURE 5 Relative Spring Abundance of Trout in Different Size-Classes (<200 mm, 200–299 mm, 300–399 mm, and ≥400 mm), 1990–2006 (No data were collected 2003–2005. BTR = brown trout at Tailrace, BLH = brown trout at Little Hole, RTR = rainbow trout at Tailrace, RLH = rainbow trout at Little Hole)

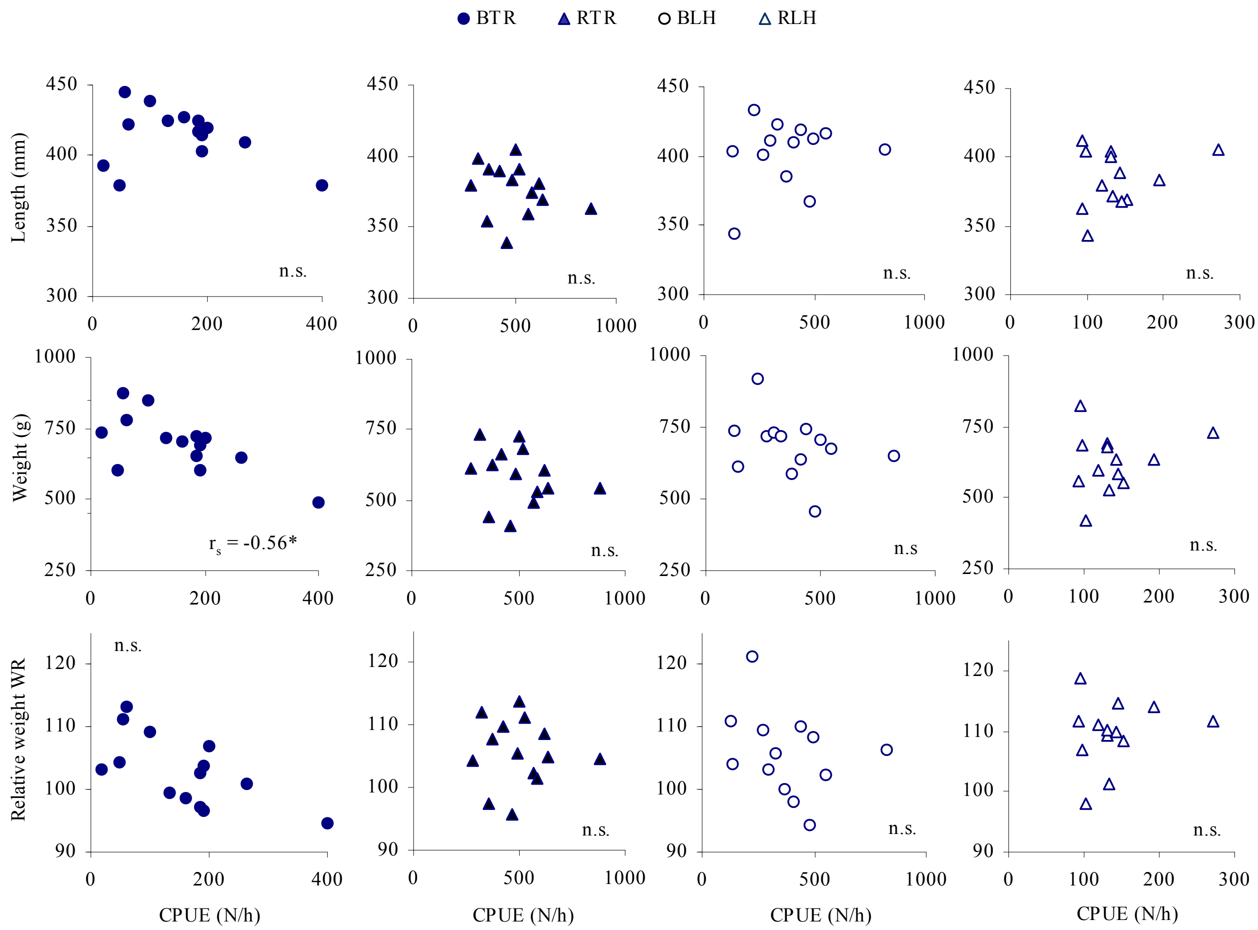

FIGURE 6 Relationships between Trout Condition and Trout Abundance (CPUE), 1990–2006 (Plots include rank correlation coefficients for statistically significant relationships; asterisks denote level of the significance: * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$, n.s. $P > 0.05$; BTR = brown trout at Tailrace, BLH = brown trout at Little Hole, RTR = rainbow trout at Tailrace, RLH = rainbow trout at Little Hole)

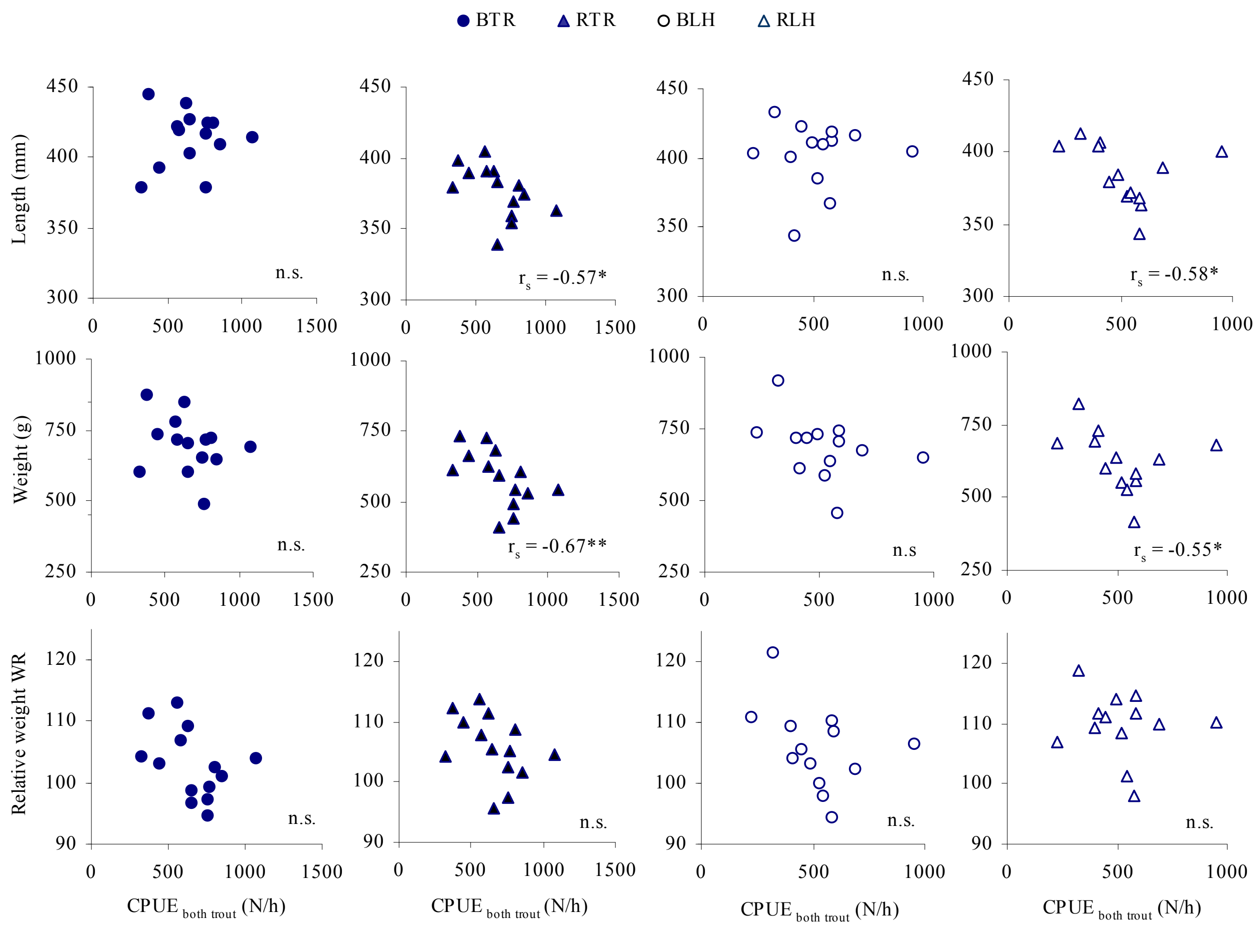

FIGURE 7 Relationships between Trout Variables and Trout Abundance of Both Trout Species Combined (CPUE $_{both\ trout}$), 1990–2006 (Plots include rank correlation coefficients for statistically significant relationships; asterisks denote level of the significance: * *P* < 0.05, ** *P* < 0.01, * *P* < 0.001, n.s. *P* > 0.05; BTR = brown trout at Tailrace, BLH = brown trout at Little Hole, RTR = rainbow trout at Tailrace, RLH = rainbow trout at Little Hole)**

2.2.2 Benthic Macroinvertebrate Abundance

The total abundance of benthic macroinvertebrates over all seasons combined (i.e., January, April, July, and October) was, on average, 40% higher at Tailrace (14,739 ± 7,294/m^2; mean ± SD) than at Little Hole (10,516 ± 4,064/m^2; Figure A.1), whereas macroinvertebrate taxa richness was, on average, higher at Little Hole (mean number of taxa ± SD: 10 ± 3) than at Tailrace (mean number of taxa ± SD: 7 ± 2). The majority of macroinvertebrates collected were amphipods (63% and 60% at Tailrace and Little Hole, respectively) and dipterans (33% and 26%), followed by ephemeropterans (3% and 7%) and coleopterans (0% and 2%). New Zealand mud snails began to appear at Little Hole in 2002; they peaked in 2002–2005 (640/m^2 in April 2002), but have since decreased in abundance (72/m^2 in April 2006; Figure A.1).

Total macroinvertebrate abundance (all taxa) during the fall and winter (mean of October, January, and April densities) ranged from 9,152/m^2 in 1998 to 25,981/m^2 in 2004 at Tailrace and from 6,676/m^2 in 1999 to 14,829/m^2 in 2003 at Little Hole (Figure 8). These densities are similar to or slightly higher than densities reported in other tailwaters (e.g., 4,000–16,000/m^2 in the South Fork Boise River in Idaho; White and Wade 1980). Total macroinvertebrate densities have increased over the years at Tailrace (Figure 8; $r_s = 0.66$), mainly attributable to an increase in the abundance of amphipods and dipterans (the most abundant taxon) in the January and/or April samples over those years. Although there was no statistically significant trend in total macroinvertebrate abundance at Little Hole, measured densities peaked in 1996 and 2001–2003. This peak was partly a reflection of elevated densities of dipterans in April 2002 (e.g., 9,289/m^2, Figure A.1). Taxa richness increased over the years at the Little Hole site decreased slightly in April at the Tailrace site (Figure 8).

2.2.3 Water Temperature

From the available data, we could not determine whether water temperatures in the fall and winter changed over the studied period (Figure 9). There is no reason, however, to presume that wintertime water temperatures would differ by much from year-to-year since water is intentionally withdrawn from the hypolimnion of the reservoir where water temperature is relatively constant during that period.

2.2.4 Flow Volume and Variability

The overall mean flow during the fall and winter periods of water years[1] 1989–2006 was 1,500 ± 700 cfs (mean_dmean ± SD), with high volumes in 1996–2000 (mean_dmean >2,000 cfs) and small volumes in 1990, 1991, 1993, and 2001–2005 (mean_dmean < 1,000 cfs, Figure 10, Figure B.1). The same pattern was observed in median (med_dmean), minimum (mean_dmin), maximum (mean_dmax) flows and in the number of hours with flows above

[1] A water year begins on October 1 and ends on September 30 of the following year. The number designation for the year is the standard calendar year designation of the January through September period of the water year.

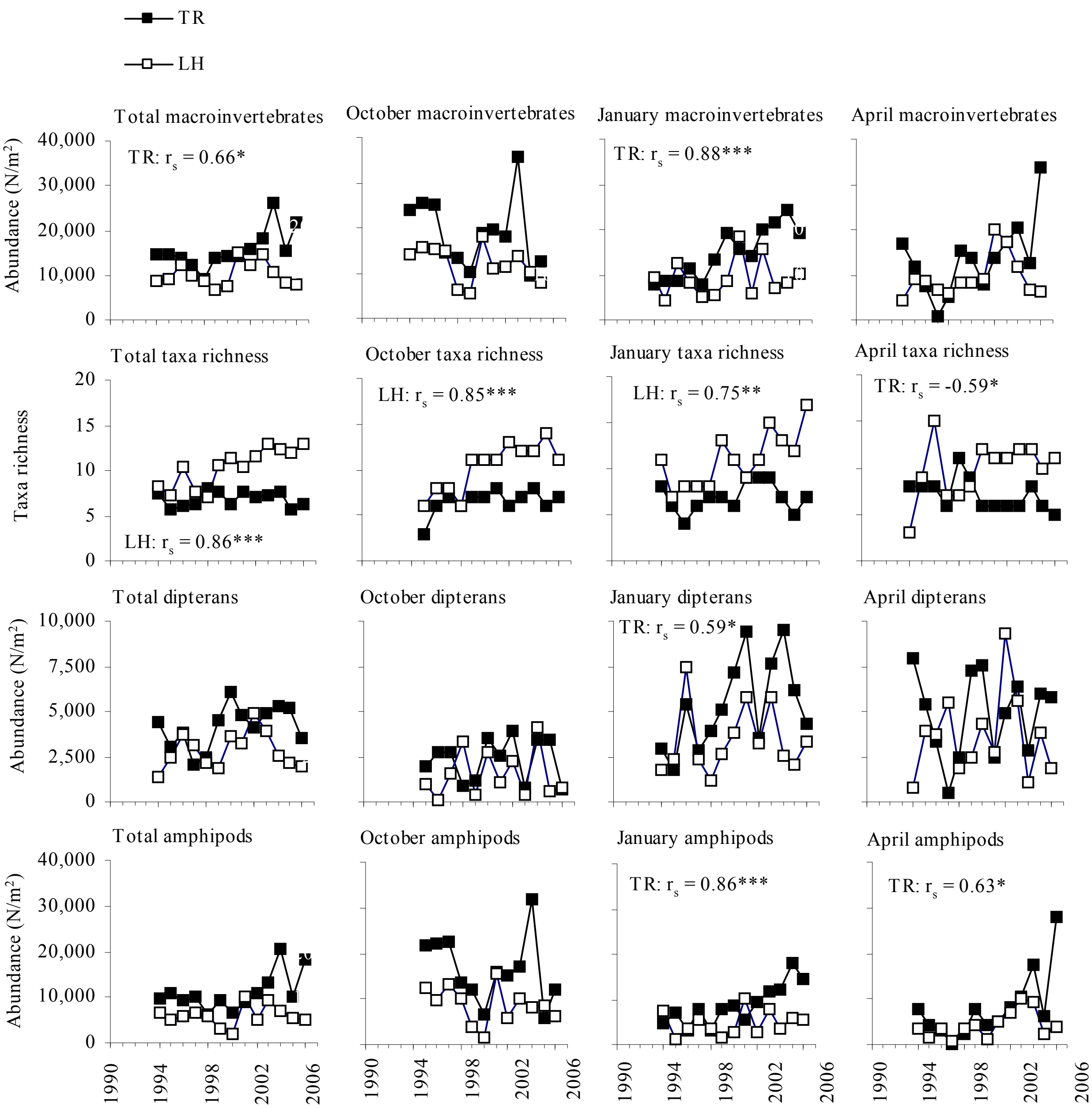

FIGURE 8 Benthic Macroinvertebrate Abundance in the Flaming Gorge Tailwater, 1994–2006 (See Table 1 for variable descriptions. Rank correlation coefficients are shown for statistically significant relationships; asterisks denote level of the significance: * *P* < 0.05, ** *P* < 0.01, * *P* < 0.001; TR = Tailrace, LH = Little Hole)**

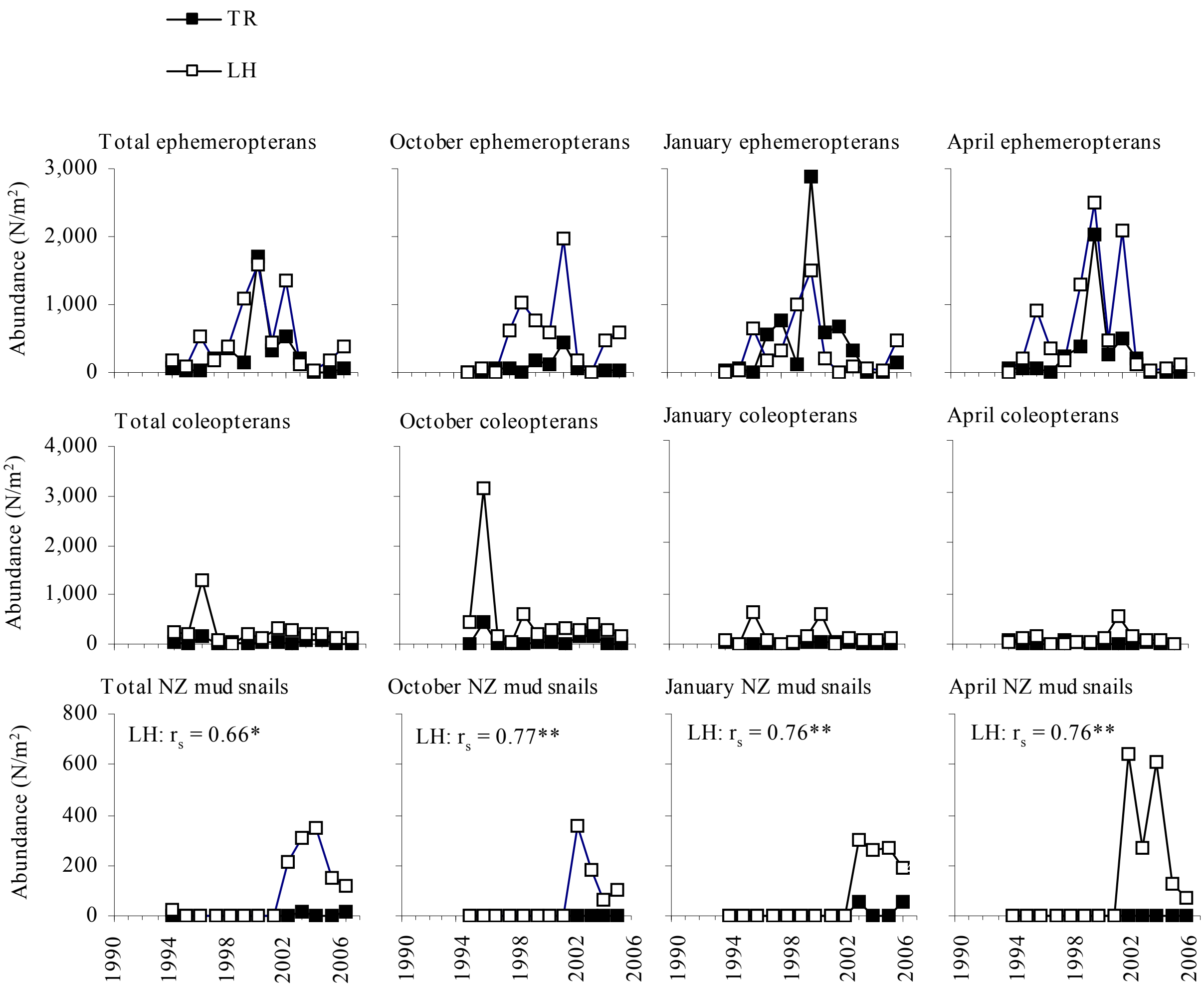

FIGURE 8 (Cont.)

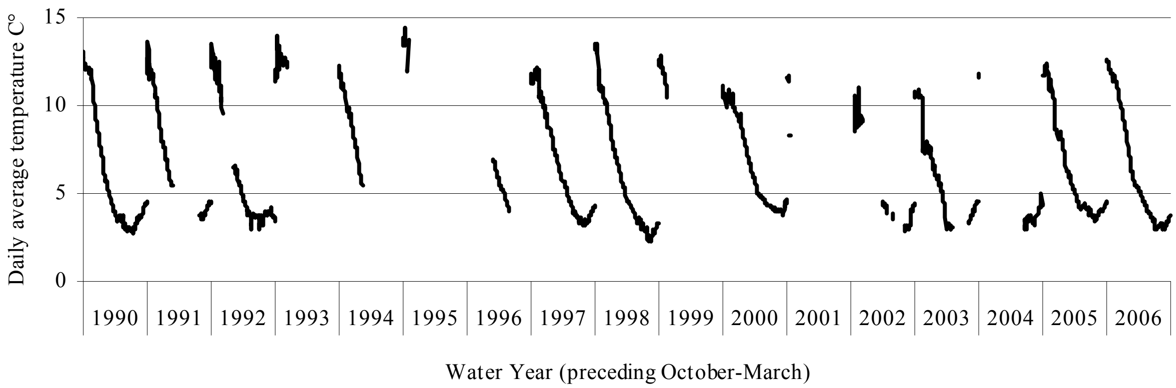

FIGURE 9 Water Temperature from October through March of Each Water Year, 1990-2006, at the Greendale Gage Downstream of Flaming Gorge Dam

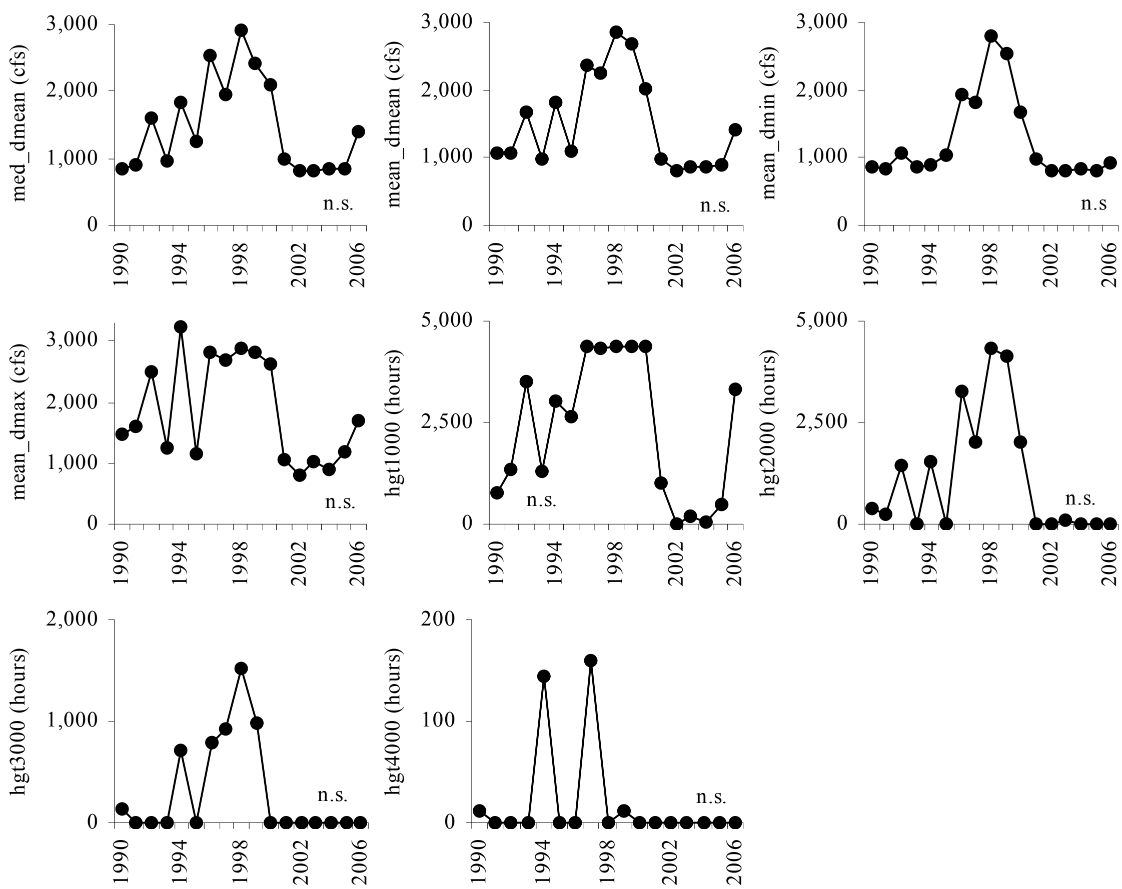

FIGURE 10 Variables Representing Flow Volume from October through March of Each Water Year, 1990–2006 (See Table 2 for variable descriptions. Plots include rank correlation coefficients for statistically significant relationships; asterisks indicate the significance level: * *P* < 0.05, ** *P* < 0.01, * *P* < 0.001, n.s. *P* > 0.05)**

1,000 cfs (hgt1000), 2,000 cfs (hgt2000), and 3,000 cfs (hgt3000) but not in the number of hours with flows above 4,000 cfs (Figure 10).

The overall mean within-day flow variability, measured as the within-day range of flows (mean_drange), during the fall and winter was 600 ± 600 cfs (mean_drange ± SD), with high values in 1992 and 1994 water years (mean_drange 1,400 and 2,350 cfs, respectively) and low values (<500 cfs) in 1993, 1995, 1998, 1999, and 2001–2005 water years (Figure 11). The same pattern was observed for the hourly change in flow (mean_hdelta and mean_hdelta%) and within-day coefficient of variation (mean_dcv). The hourly change in flow showed a statistically significant decrease over the years ($P < 0.05$, Spearman rank correlation). Daily skewness (mean_dskew) was high (>1.0; due to daily peaks of short duration) during the fall and winter periods of the 1991, 1993, and 2005 water years and was low (<-0.5) in the 1998 and 2006 water years (in 1998, this was due to stable high flows with a few low values, and in 2006, this was due to daily peaks of long duration, Figure 11 and Figure B.1).

Examples of hydrographs that resulted in positive and negative values of daily skewness are presented in Figure 12. (Also note that a stable flow with a few high values also results in a positive skewness and that a stable flow with a few low values results in a negative skewness.)

Between-day flow variability (mean_ddelta), measured as the changes in mean daily flows between consecutive days during the fall and winter period, was less than 200 cfs in all years and averaged 50 ± 50 cfs (overall mean ± SD). The highest values of between-day flow changes occurred during 1990 to 1992 and 1994 and decreased significantly over the years (Figure 13a, Figure B.2). The change in daily mean flow within entire fall and winter periods (range_dmean) ranged from 50 cfs in 2002 to almost 3,000 cfs in 1997 and decreased over the years (Figure 13b). The coefficient of variation in mean daily flows during overwinter periods (cv_dmean) also decreased over the years – exceeded 25% in 1990, 1992, 1994, and 1997 and was less than 10% in 2000–2002 and 2004–2006 (Figure 13b). Skewness of daily means (skew_dmean) was particularly high in 1993, 2003, and 2004 because there were a few days with high mean flows (Figure B.2). Changes in flows between consecutive months (mean_mdelta, a measure of between-month flow variability) decrease over the years and were, on average, less than 550 cfs, with the highest measured values in 1992 and 1994–1998 (Figure 13c).

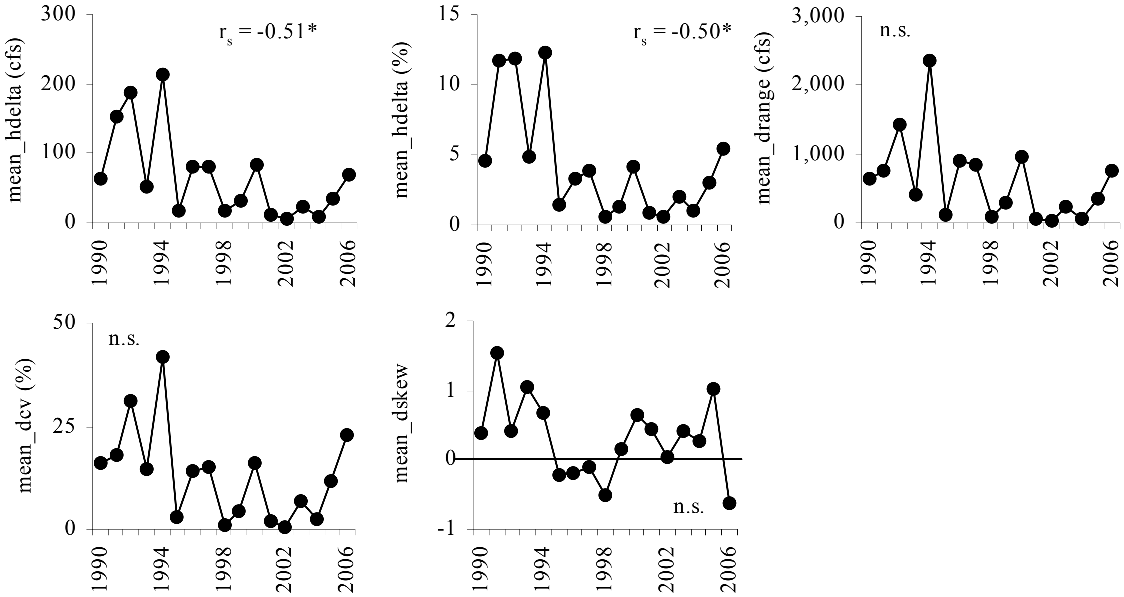

FIGURE 11 Variables Representing within-Day Flow Variability from October through March of Each Water Year, 1990–2006 (See Table 2 for variable descriptions. Plots include rank correlation coefficients for statistically significant relationships; asterisks indicate the significance level: * *P* < 0.05, ** *P* < 0.01, * *P* < 0.001, n.s. *P* > 0.05)**

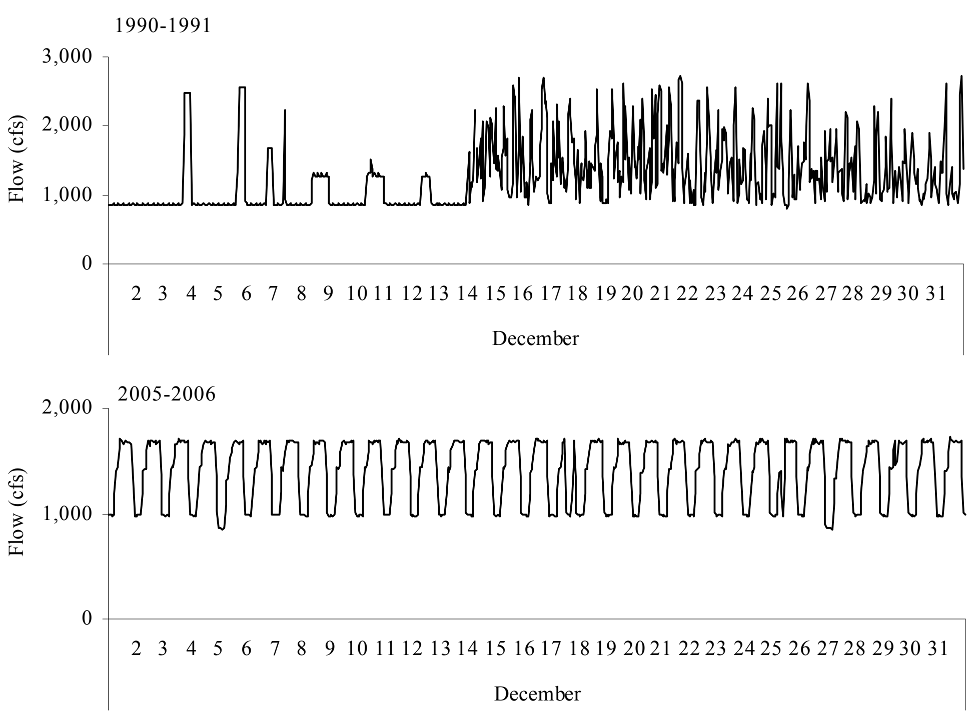

FIGURE 12 Examples of Flows Resulting in High Values of Positive Daily Skewness (mean_dskew) in 1991 and Negative Daily Skewness in 2006

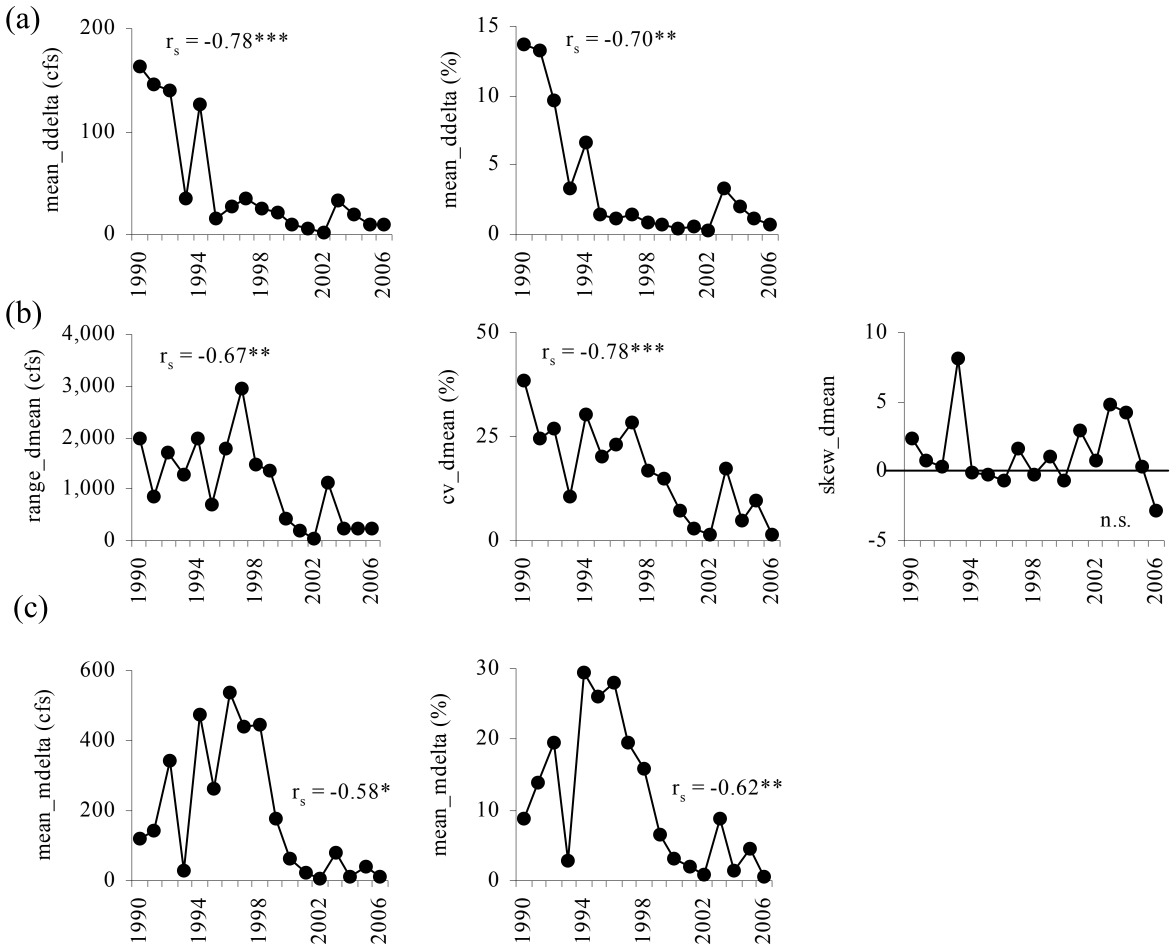

FIGURE 13 Variables Representing (a) between-Day Variability, (b) within-Season Variability, and (c) between-Month Variability from October through March of Each Water Year, 1990–2006 (See Table 2 for variable descriptions. Plots include rank correlation coefficients for statistically significant relationships; asterisks indicate the significance level: * *P* < 0.05, ** *P* < 0.01, * *P* < 0.001, n.s. *P* > 0.05)**

3 RELATIONSHIPS AMONG FLOWS, MACROINVERTEBRATE ABUNDANCE, AND TROUT CONDITION IN SPRING

Flows can affect the composition, abundance, distribution, growth, survival, and reproduction of riverine fishes (e.g., Resh et al. 1988; Power et al. 1995; Marchetti and Moyle 2001; Bonvechio and Allen 2005; de la Hoz and Budy 2005). Increased flow, for example, could result in a reduction in the activity of fish to compensate for increased energy-costs of swimming (Kemp et al. 2006) or cause fish to move to slower-flowing and shallower habitats (Gillette et al. 2006). Flows may also influence the availability of food because macroinvertebrate drift can be strongly affected by changing flows (e.g., catastrophic drift), particularly after long periods of stable discharge (Brittain and Eikeland 1988), thereby affecting food availability. In addition, increased water levels may increase the amount of spawning habitat and the availability of food resources for fish by inundating shoreline vegetation.

In this section, we present the statistical evaluations of the relationships between (1) trout condition in the spring and flows in the fall and winter; (2) trout condition and the abundance of benthic macroinvertebrates; and (3) benthic macroinvertebrate abundance and fall and winter flows.

3.1 METHODS

The effects of flows on trout condition, the effects of macroinvertebrates on trout condition, and the effects of flows on the abundance and taxa richness of benthic macroinvertebrates were explored by examining bivariate relationships. The years for which data were available for these evaluations are shown in Table 3.

The significance of relationships among flows, abundance of macroinvertebrates, and trout condition were examined with nonparametric rank correlation (Spearman correlation coefficient, r_s) using SAS statistical software (Version 9.1; SAS Institute Inc. 2002). Because of the exploratory nature of these analyses, the critical alpha for statistical significance was not adjusted for the number of analyses but was set at 0.05. The significance level of each relationship is provided in each figure (* for $P < 0.05$, ** for $P < 0.01$, and *** for $P < 0.001$). Due to the exploratory nature of this study and low sample size (N = 10–17 years), the relationships that are identified in this report should be regarded only as potentially important relationships that warrant further examination once additional data have been collected.

TABLE 3 Summary of Years for Which Data Were Available for Statistical Evaluations

	Variables			Bivariate Tests		
Year	Trout	Flow	Macro-invertebrates	Flows × Trout	Macro-invertebrates × Trout	Flows × Macro-invertebrates
1990	×	×		×		
1991	×	×		×		
1992	×	×		×		
1993	×	×		×		
1994	×	×	×	×	×	×
1995	×	×	×	×	×	×
1996	×	×	×	×	×	×
1997	×	×	×	×	×	×
1998	×	×	×	×	×	×
1999	×	×	×	×	×	×
2000	×	×	×	×	×	×
2001	×	×	×	×	×	×
2002	×	×	×	×	×	×
2003		×	×			×
2004		×	×			×
2005		×	×			×
2006	×	×	×	×	×	×
Number of years	14	17	13	14	10	13

3.2 RESULTS

3.2.1 Relationships Between Trout Abundance and Condition and Flow

Values of L and W for rainbow trout at Little Hole were negatively correlated with flow volume (Figure 14 and Table 4) whereas values of WR were positively correlated with the number of hours with flows above 3,000 cfs (hgt3000). Values of WR for brown trout at Tailrace and values of W and/or L for both trout species at Little Hole were positively correlated with within-day variability (mean_dskew, Figure 15 and Table 4). Daily short-duration peaks result in a high positive value of mean_dskew, whereas daily long duration peaks result in a low negative value. Days with identical maximum and minimum flows can have very different values of skewness. The condition of rainbow trout at both locations (W and WR at Tailrace; and L and W at Little Hole) was positively correlated with increasing between-day variability (mean_ddelta and mean_ddelta%; Figure 16 and Table 4).

Rainbow trout L and W at Tailrace; brown trout W and WR at Little Hole; and rainbow trout L, W and WR at Little Hole were positively correlated with one of the within-season flow variability variables (skew_dmean; Figure 17 and Table 4) but not with any of the variables representing between-month flow variability. Skewness is a measure of erratic flows, but its ecological relationship with some of the trout condition variables evaluated in this study is uncertain because a high skewness can result from one single peak. For example, 1993 had a high value of skew_dmean and the highest or second highest measured trout condition, whereas 2005–2006 had low value and the lowest measured trout condition. A closer look at the mean daily flow in 1993 (Figure B.2), when the highest measured trout condition was recorded, reveals that the high skew_dmean value resulted from a single peak in March, while flows during the remainder of the period were stable. It is not clear why such a flow pattern would be more favorable to trout in 1993 than in similarly stable years from 2000–2006.

TABLE 4 Summary of Statistically Significant Correlations between Trout Variables and Year, CPUE, and Flow Variables[a]

Variable	Definition	Correlations between Year and Flow Variable	Trout Variables Correlated with Year, CPUE and Flow Variables			
			Brown Trout at Tailrace	Rainbow Trout at Tailrace	Brown Trout at Little Hole	Rainbow Trout at Little Hole
Year	1990-2006	N/A	+++CPUE, -W	-W, -WR	+CPUE	--L, --W
Trout Abundance						
CPUE	Catch per unit effort (N/h)	N/A	-W	None	None	None
$CPUE_{both\ trout}$	Catch per unit effort of both trout species combined (N/h)	N/A	None	-L, --W	None	-L, -W
Flow Volume						
med_dmean	Median of mean daily flow	None	None	None	None	-L
mean_dmean	Mean of mean daily flow	None	None	None	None	-L
mean_dmin	Mean of minimum daily flow	None	None	None	None	None
mean_dmax	Mean of maximum daily flow	None	None	None	None	None
hgt1000	Total hours with flows >1,000 cfs	None	None	None	None	-L, -W
hgt2000	Total hours with flows >2,000 cfs	None	None	None	None	None
hgt3000	Total hours with flows >3,000 cfs	None	None	None	None	+WR
hgt4000	Total hours with flows >4,000 cfs	None	None	None	None	None
Within-Day Flow Variability						
mean_hdelta	Mean hourly change of flows (absolute values)	-	None	None	None	None
mean_hdelta (%)	Mean hourly change of flows (% of daily)	-	None	None	None	None
mean_drange	Mean daily range of flows	None	None	None	None	None
mean_dcv	Mean daily coefficient of variation in flow	None	None	None	None	None
mean_dskew	Mean daily skewness of flows	None	+WR	None	++W	++L, +W
Between-Day Flow Variability						
mean_ddelta	Mean change in flow between days (absolute values)	---	None	+W, +WR	None	+L, +W
mean_ddelta (%)	Mean change in flow between days (% of daily)	--	None	+W, +WR	None	+L, ++W

Table 4 (Cont.)

Variable	Definition	Correlations between Year and Flow Variable	Trout Variables Correlated with Year, CPUE and Flow Variables			
			Brown Trout at Tailrace	Rainbow Trout at Tailrace	Brown Trout at Little Hole	Rainbow Trout at Little Hole
Within-Season Flow Variability						
range_dmean	Range of mean daily flows	--	None	None	None	None
cv_dmean	Coefficient of variation of mean daily flows	---	None	None	None	None
skew_dmean	Skewness of mean daily flows	None	None	+L, +W	+W, +WR	++L, +++W, ++WR
Between-Month Flow Variability						
mean_mdelta	Mean change in flow between months (absolute values)	-	None	None	None	None
mean_mdelta (%)	Mean change in flow between months (%)	--	None	None	None	None

[a] The sign (+ or –) preceding a variable indicates whether the correlation is positive or negative. The significance of the relationship is indicated by the number of signs shown (1: $P < 0.05$, 2: $P < 0.01$, 3: $P < 0.001$). N/A = test not applicable, CPUE = catch per unit effort, L = length, W = weight, WR = relative weight.

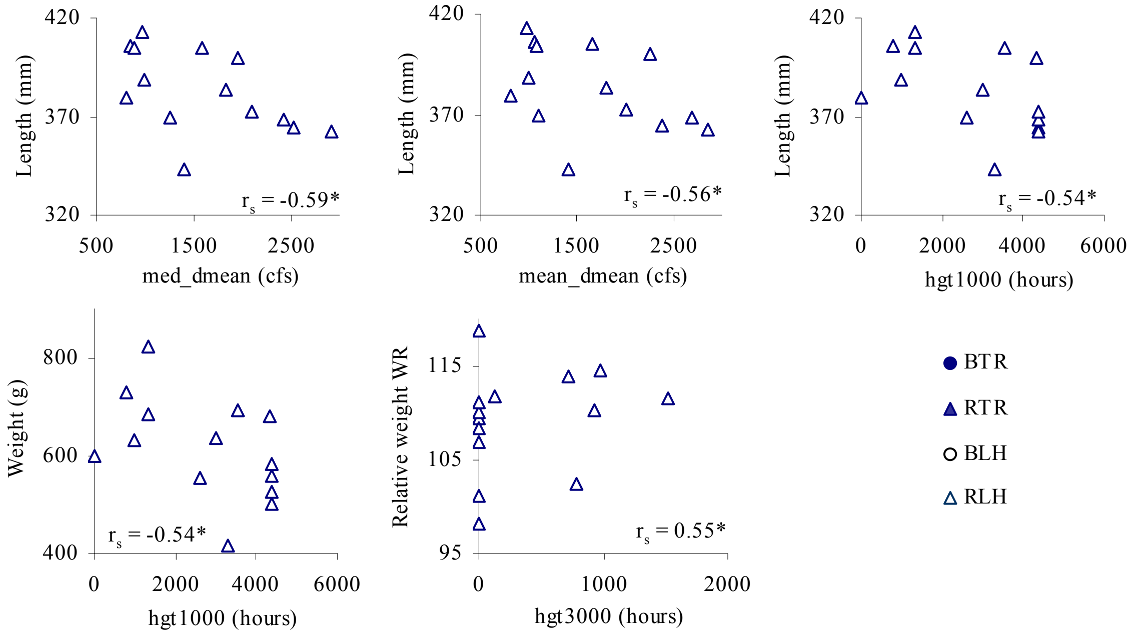

FIGURE 14 Statistically Significant Relationships between Trout and Flow Volume Variables, 1990–2006 (Plots include Spearman rank correlation coefficients; asterisks denote level of significance: * *P* < 0.05, ** *P* < 0.01, and * *P* < 0.001; BTR = brown trout at Tailrace, BLH = brown trout at Little Hole, RTR = rainbow trout at Tailrace, RLH = rainbow trout at Little Hole)**

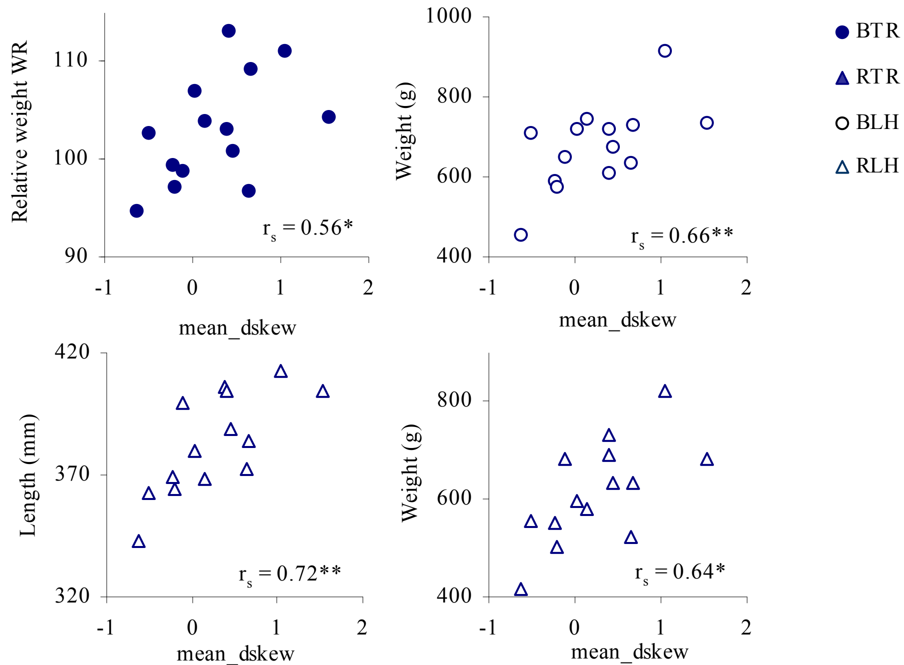

FIGURE 15 Statistically Significant Relationships between Trout and within-Day Flow Variability Variables, 1990–2006 (Plots include rank correlation coefficients; asterisks denote level of significance: * *P* < 0.05, ** *P* < 0.01, and * *P* < 0.001; BTR = brown trout at Tailrace, BLH = brown trout at Little Hole, RTR = rainbow trout at Tailrace, RLH = rainbow trout at Little Hole)**

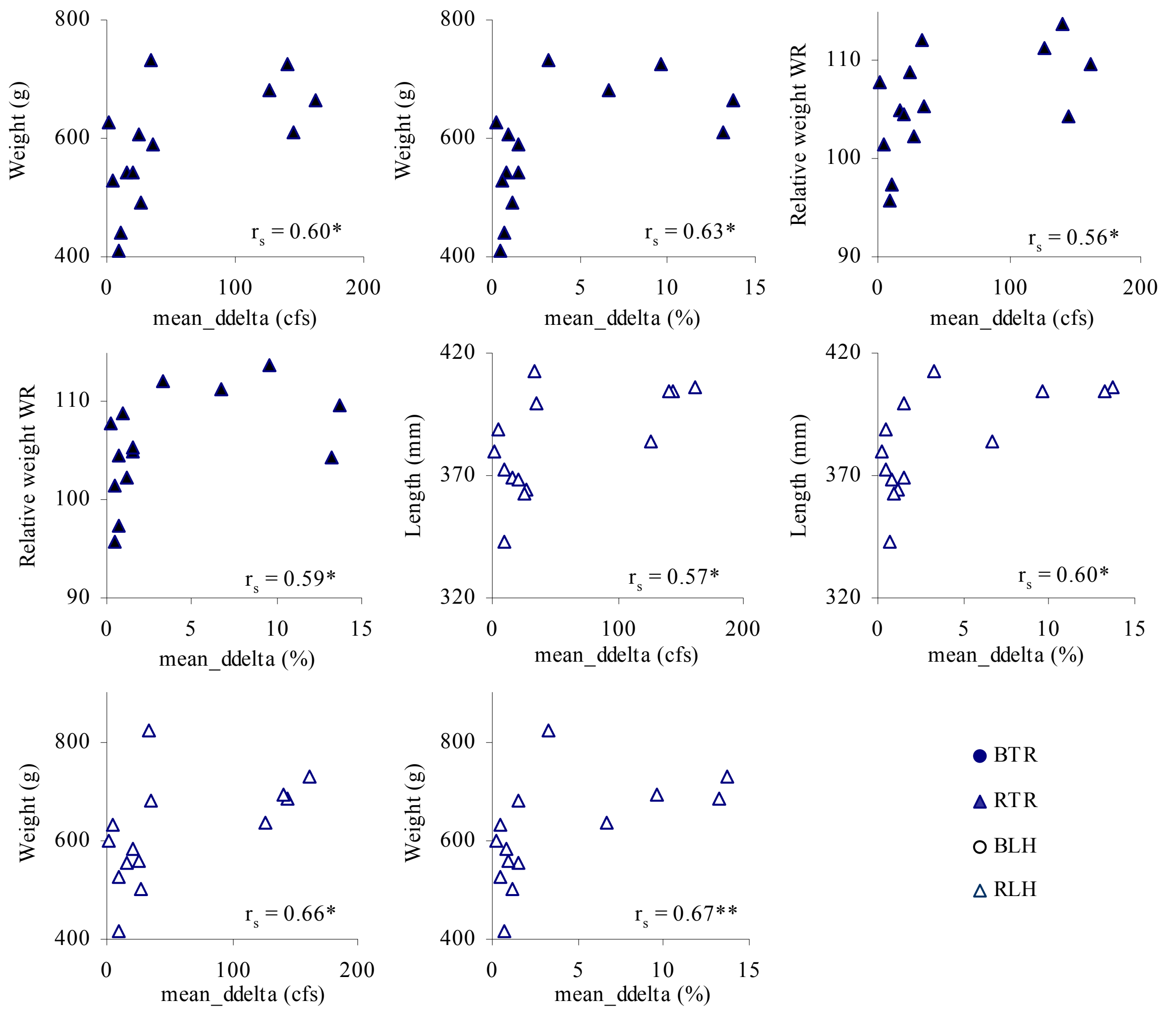

FIGURE 16 Statistically Significant Relationships between Trout and between-Day Flow Variability Variables, 1990–2006 (Plots include rank correlation coefficients; asterisks denote level of significance: * *P* < 0.05, ** *P* < 0.01, and * *P* < 0.001; BTR = brown trout at Tailrace, BLH = brown trout at Little Hole, RTR = rainbow trout at Tailrace, RLH = rainbow trout at Little Hole)**

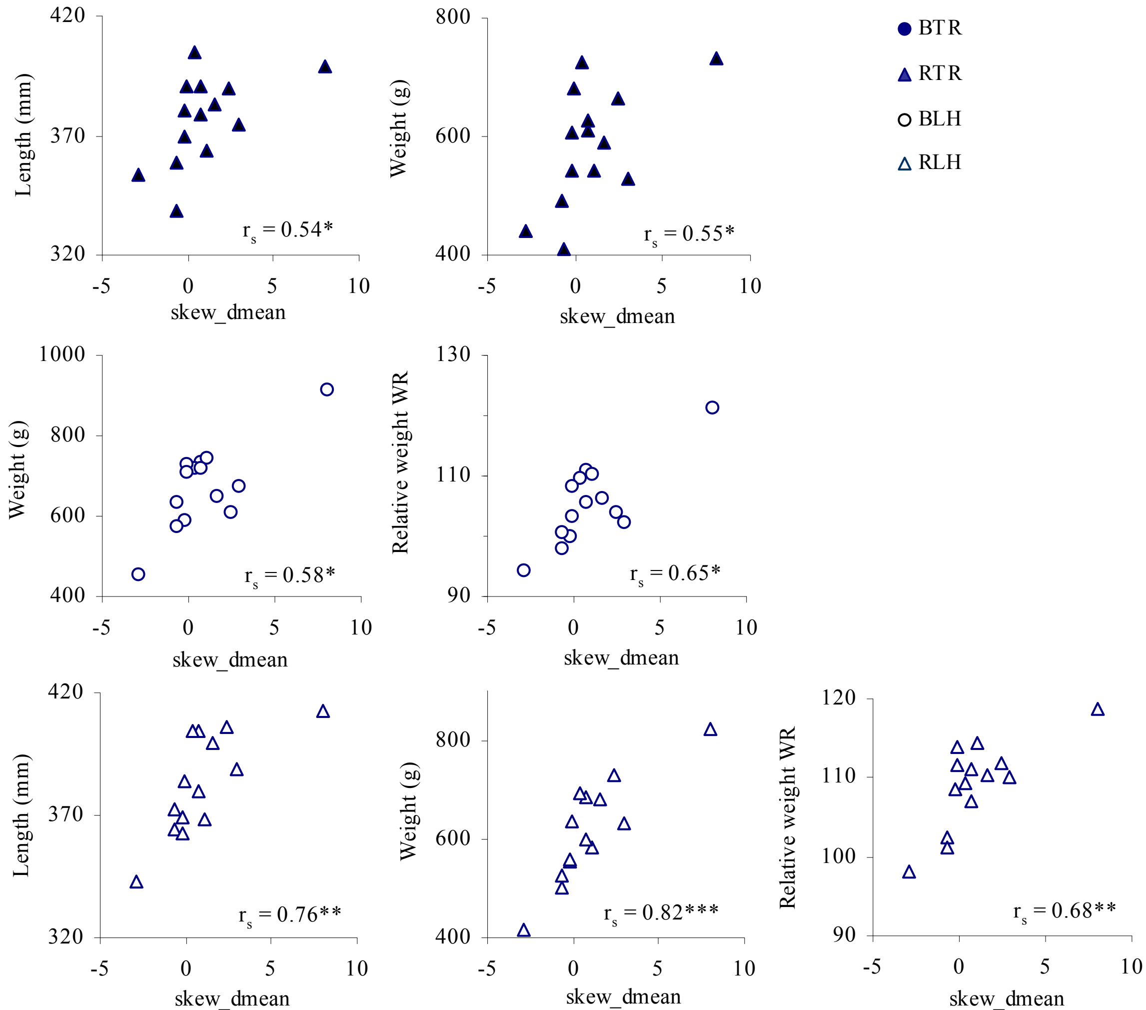

FIGURE 17 Statistically Significant Relationships between Trout and within-Season Flow Variability Variables, 1990–2006 (Plots include rank correlation coefficients; asterisks denote level of significance: * *P* < 0.05, ** *P* < 0.01, and * *P* < 0.001; BTR = brown trout at Tailrace, BLH = brown trout at Little Hole, RTR = rainbow trout at Tailrace, RLH = rainbow trout at Little Hole)**

3.2.2 Relationships between Macroinvertebrate Abundance and Trout Abundance and Condition

Brown trout L at Tailrace was negatively correlated with the abundance of macroinvertebrates and dipterans in January and was positively correlated with the abundance of macroinvertebrates and amphipods in October (Table 5 and Figure 18). Brown trout W at Tailrace was negatively correlated with January abundance of macroinvertebrates and dipterans while brown trout WR was positively correlated with January taxa richness. Rainbow trout WR at Tailrace was negatively correlated with January macroinvertebrates and dipterans. At Little Hole, brown trout L and W were positively correlated with October ephemeropterans. Rainbow trout W at Little Hole was negatively correlated with April taxa richness and rainbow trout WR was negatively correlated with January dipterans and April taxa richness.

3.2.3 Relationships between Macroinvertebrate Abundance and Flow

At Tailrace, January abundances of total macroinvertebrates and amphipods were negatively correlated with flow volume in the fall and April abundance of amphipods was negatively correlated with flow volume in the winter (Table 6, Figures 19 and 20). April taxa richness at Tailrace was positively correlated with flow volume in winter. At Little Hole, there were no negative correlations detected between January abundances and flow volume in the fall, but January ephemeropteran abundance was positively correlated with fall flow volume. April abundances of total macroinvertebrates, coleopterans, and amphipods and taxa richness at Little Hole were negatively correlated with flow volume in the winter.

January macroinvertebrate abundance at Tailrace and April macroinvertebrate and coleopteran abundances at Little Hole were negatively correlated with within-day flow variability during the fall and winter periods, respectively (mean_hdelta and mean_drange, Table 6, Figure 21a). January macroinvertebrate abundance values at Little Hole and April abundance values at Tailrace were not correlated with within-day flow variability.

At Tailrace, negative correlations were detected between macroinvertebrate abundance and between-day, within-season, and between-month variability: (1) January macroinvertebrate abundance vs. fall mean_ddelta, range_dmean, and mean_mdelta; (2) January amphipod abundance vs. fall mean_ddelta, range_dmean, cv_dmean, and mean_mdelta; (3) January dipteran abundance vs. fall mean_ddelta, range_dmean, and mean_mdelta; (4) April amphipod abundance vs. winter mean_mdelta; and (5) April ephemeropteran abundance vs. winter mean_ddelta (%) (Table 6, Figures 21b and 22). At Little Hole, ephemeropterans was the only macroinvertebrate taxa that were correlated with any of these variables (April ephemeropteran abundance was negatively correlated with winter mean_ddelta (%) [Figure 21b]). Taxa richness at Little Hole was negatively correlated with fall cv_dmean and mean_mdelta (Figure 22).

TABLE 5 Summary of Statistically Significant Correlations between Trout and Macroinvertebrate Variables[a]

	Trout Variables Correlated with Macroinvertebrate Variables			
Macroinvertebrate Variable	Brown Trout at Tailrace	Rainbow Trout at Tailrace	Brown Trout at Little Hole	Rainbow Trout at Little Hole
Total macroinvertebrates	None	None	None	None
Total taxa richness	None	None	None	None
Total ephemeropterans	None	None	None	None
Total amphipods	None	None	None	None
Total coleopterans	None	None	None	None
Total dipterans	None	None	None	None
October macroinvertebrates	+L	None	None	None
October taxa richness	None	None	None	None
October ephemeropterans	None	None	++L, +W	None
October amphipods	+L	None	None	None
October coleopterans	None	None	None	None
October dipterans	None	None	None	None
January macroinvertebrates	--L, --W	--WR	None	None
January taxa richness	+WR	None	None	None
January ephemeropterans	None	None	None	None
January amphipods	None	None	None	None
January coleopterans	None	None	None	None
January dipterans	-L, -W	-WR	None	-WR
April macroinvertebrates	None	None	None	None
April taxa richness	None	None	None	-W, -WR
April ephemeropterans	None	None	None	None
April amphipods	None	None	None	None
April coleopterans	None	None	None	None
April dipterans	None	None	None	None

[a] The sign (+ or –) preceding a variable indicates whether the correlation is positive or negative. The significance of the relationship is indicated by the number of signs shown (1: $P < 0.05$, 2: $P < 0.01$, 3: $P < 0.001$). L = length, W = weight, WR = relative weight.

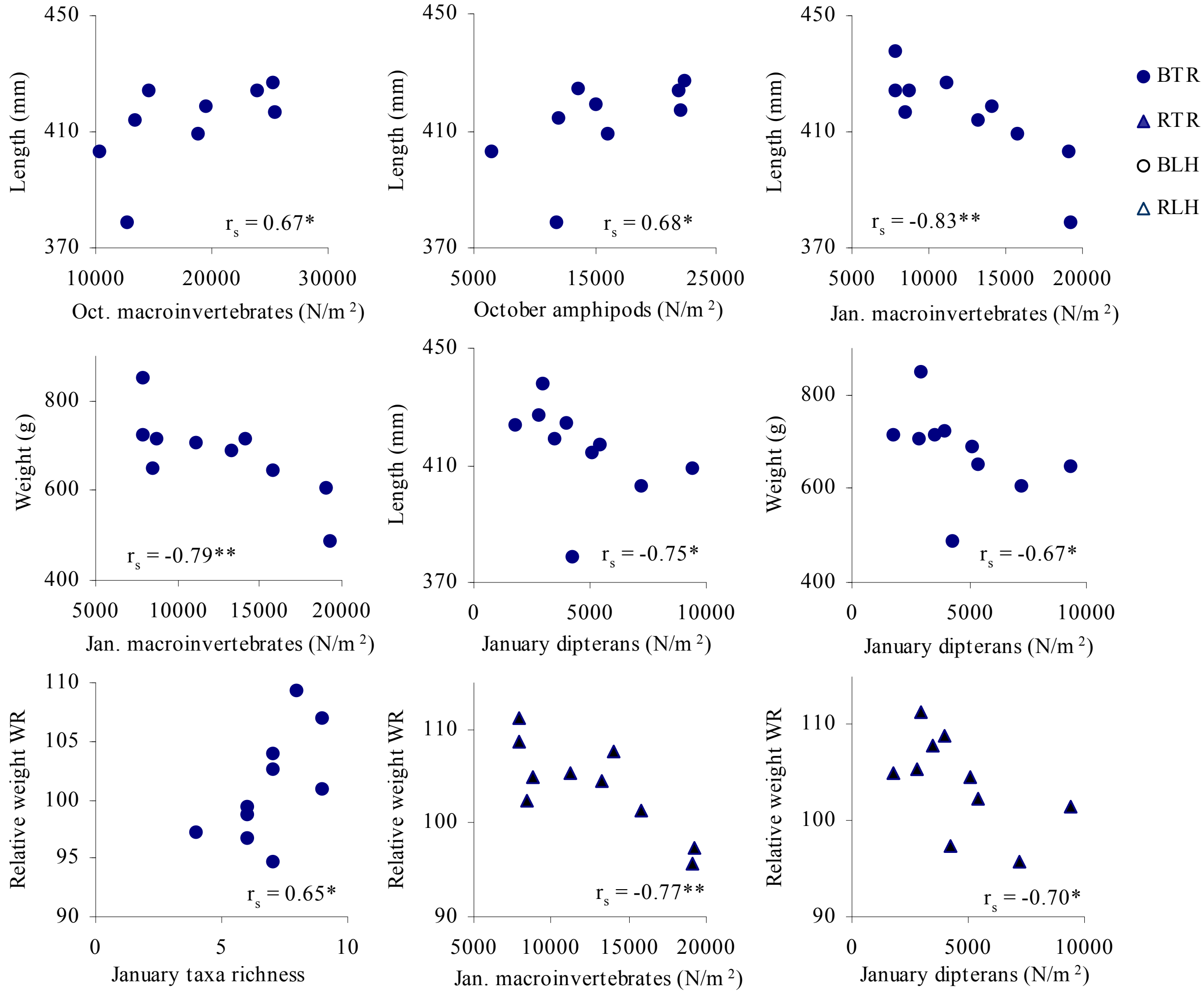

FIGURE 18 Statistically Significant Relationships between Trout and Macroinvertebrate Variables, 1994-2006 (Plots include rank correlation coefficients; asterisks denote level of significance: * *P* < 0.05, ** *P* < 0.01, and * *P* < 0.001; BTR = brown trout at Tailrace, BLH = brown trout at Little Hole, RTR = rainbow trout at Tailrace, RLH = rainbow trout at Little Hole)**

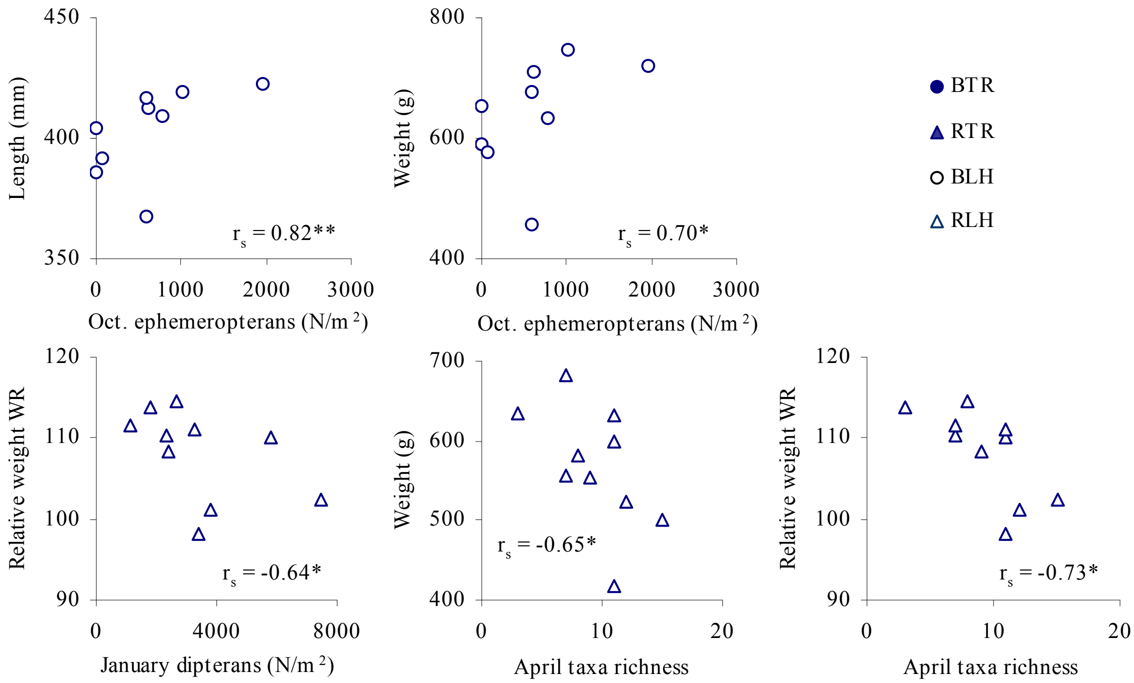

FIGURE 18 (Cont.)

TABLE 6 Summary of Statistically Significant Correlations between Macroinvertebrate and Flow Variables[a]

		Macroinvertebrate Variables Correlated with Year and Flow Variables			
Variable	Definition	Tailrace in January[b]	Tailrace in April[c]	Little Hole in January[b]	Little Hole in April[c]
Year	1994-2006	+++Total, +++Amph, +Dipt	+Amph	++S, ++NZ	++NZ
Volume					
med_dmean	Median of mean daily flow	--Total, --Amph	-Amph	+Eph	--Total, --Col, -Amph
mean_dmean	Mean of mean daily flow	-Total, -Amph	-Amph	+Eph	-Total, -Col
mean_dmin	Mean of minimum daily flow	-Total, -Amph	--Amph	++Eph	-Col
mean_dmax	Mean of maximum daily flow	--Total, --Amph	None	None	--Total, -Col
hgt1000	Total hours with flows >1,000 cfs	-Total	-Amph	++Eph	-Total, -Amph
hgt2000	Total hours with flows >2,000 cfs	-Total, -Amph	+S	+Eph	None
hgt3000	Total hours with flows >3,000 cfs	---Total, --Amph	+S	None	-Total, -S
hgt4000	Total hours with flows >4,000 cfs	None	None	None	-S
Within-Day Variability					
mean_hdelta	Mean hourly change of flows (absolute values)	-Total	None	None	--Total, -Col
mean_hdelta (%)	Mean hourly change of flows (% of daily)	None	None	None	None
mean_drange	Mean daily range of flows	None	None	None	-Total, -Col
mean_dcv	Mean daily coefficient of variation in flow	None	None	None	None
mean_dskew	Mean daily skewness of flows	None	None	None	None
Between-Day Variability					
mean_ddelta	Mean change in flow between days (absolute values)	---Total, --Amph, -Dipt	None	None	None
mean_ddelta (%)	Mean change in flow between days (% of daily)	-Total, -Amph, -Dipt	-Eph	None	--Eph
Within-Season Variability					
range_dmean	Range of mean daily flows	---Total, --Amph, -Dipt	None	None	None
cv_dmean	Coefficient of variation of mean daily flows	--Total, ---Amph	None	-S	None
skew_dmean	Skewness of mean daily flows	None	None	None	none
Between-Month Variability					
mean_mdelta	Mean change in flow between months (absolute values)	---Total, --Amph, -Dipt	-Amph	--S	-S
mean_mdelta (%)	Mean change in flow between months (%)	--Total, --Amph	None	--S	None

[a] The sign (+ or –) preceding a variable indicates whether the correlation is positive or negative. The significance of the relationship is indicated by the number of signs shown (1: $P < 0.05$, 2: $P < 0.01$, 3: $P < 0.001$). S = taxa richness, Total = total macroinvertebrates, Eph = ephemeropterans, Amph = amphipods, Dipt = dipterans, Col = coleopterans, NZ = New Zealand mud snail (not tested against flow).

[b] Correlated with flows in preceding fall (October–December)

[c] Correlated with flows in preceding winter (January–March)

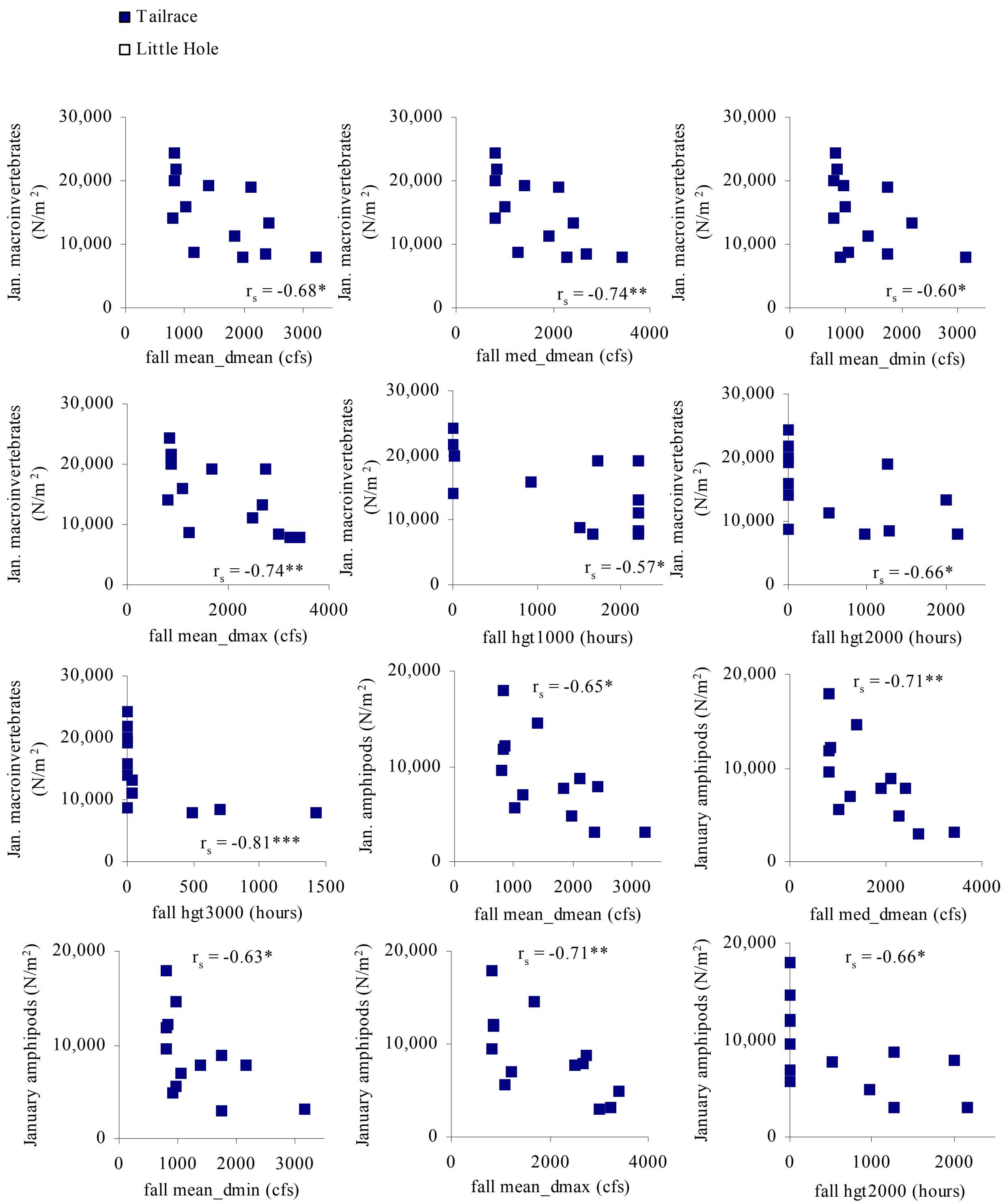

FIGURE 19 Statistically Significant Relationships between Macroinvertebrate Variables and Fall Flow Volume, 1994–2006 (Plots include rank correlation coefficients; asterisks denote level of significance: * *P* < 0.05, ** *P* < 0.01, and * *P* < 0.001)**

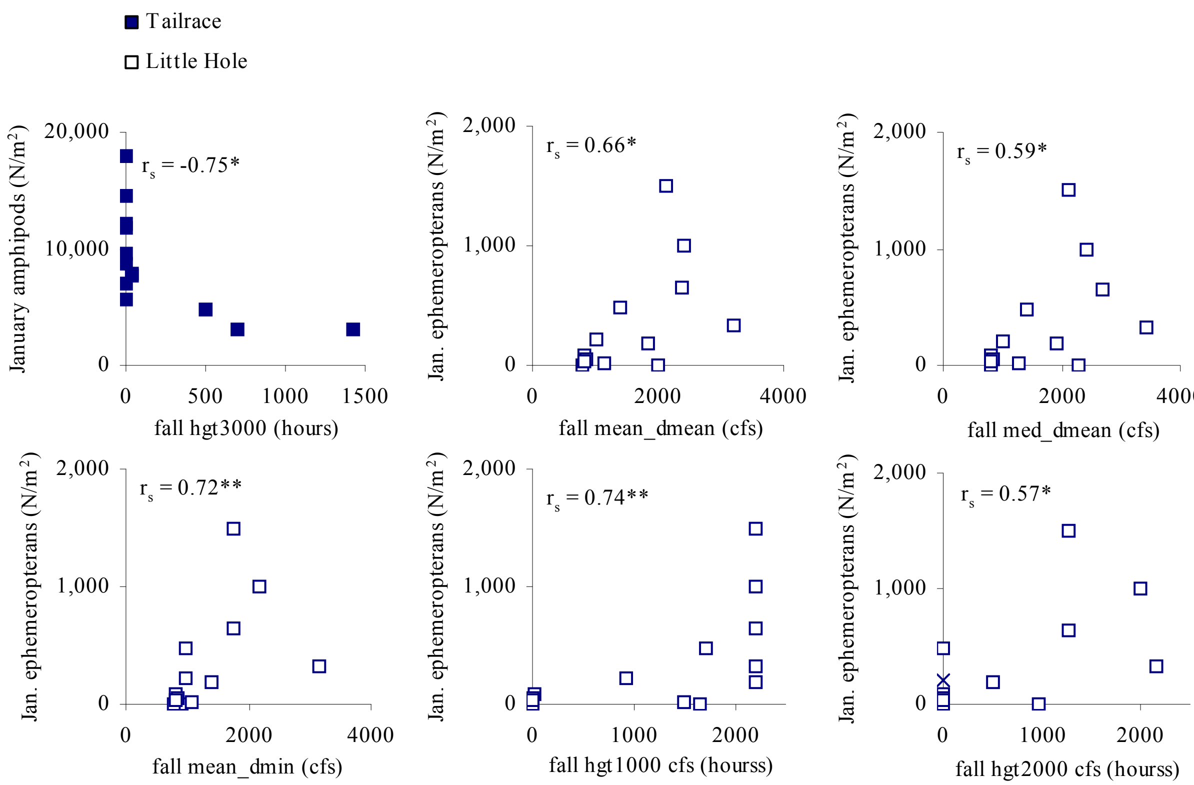

FIGURE 19 (Cont.)

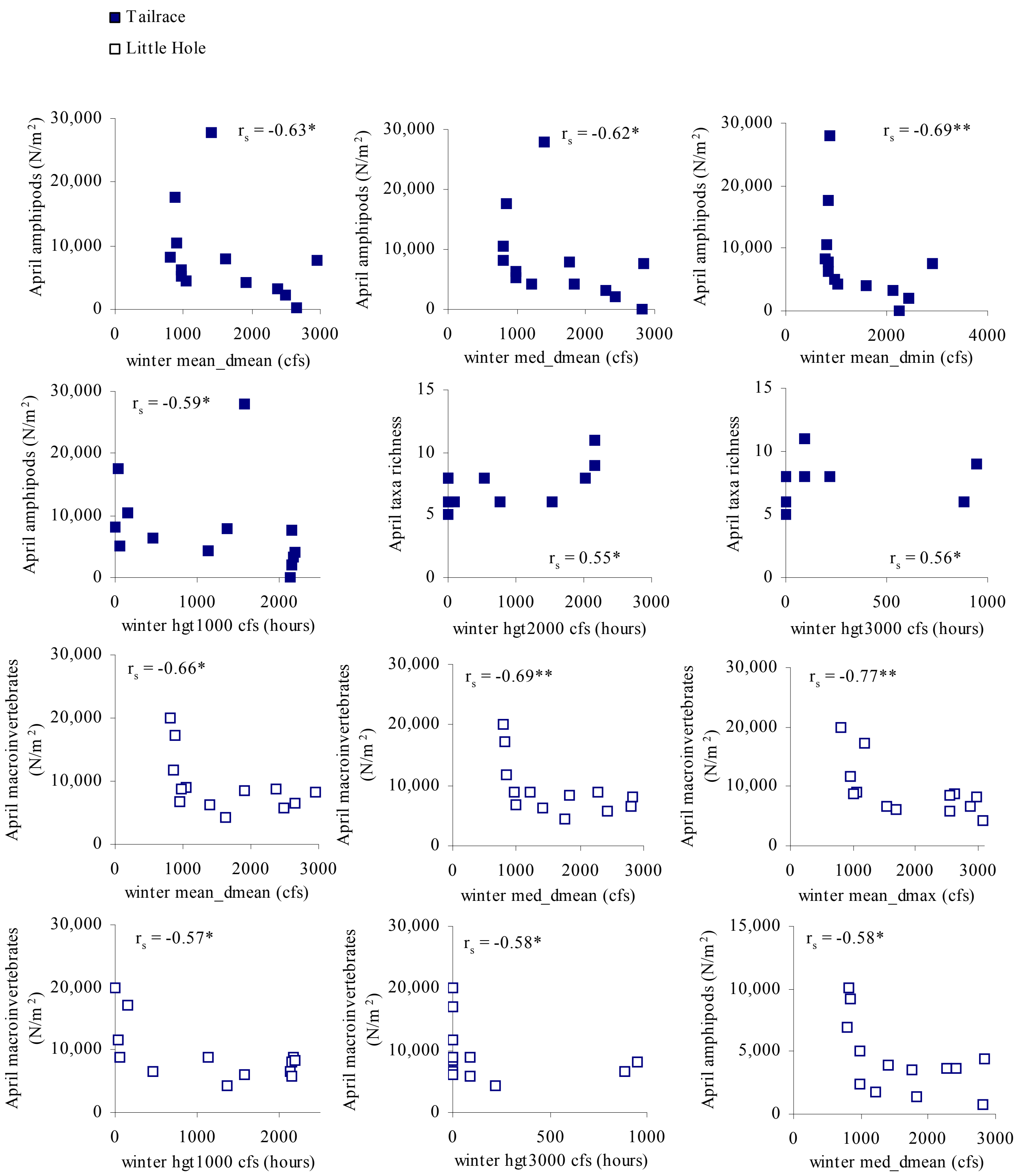

FIGURE 20 Statistically Significant Relationships between Macroinvertebrate Variables and Winter Flow Volume, 1994–2006 (Plots include rank correlation coefficients; asterisks denote level of significance: * *P* < 0.05, ** *P* < 0.01, and * *P* < 0.001)**

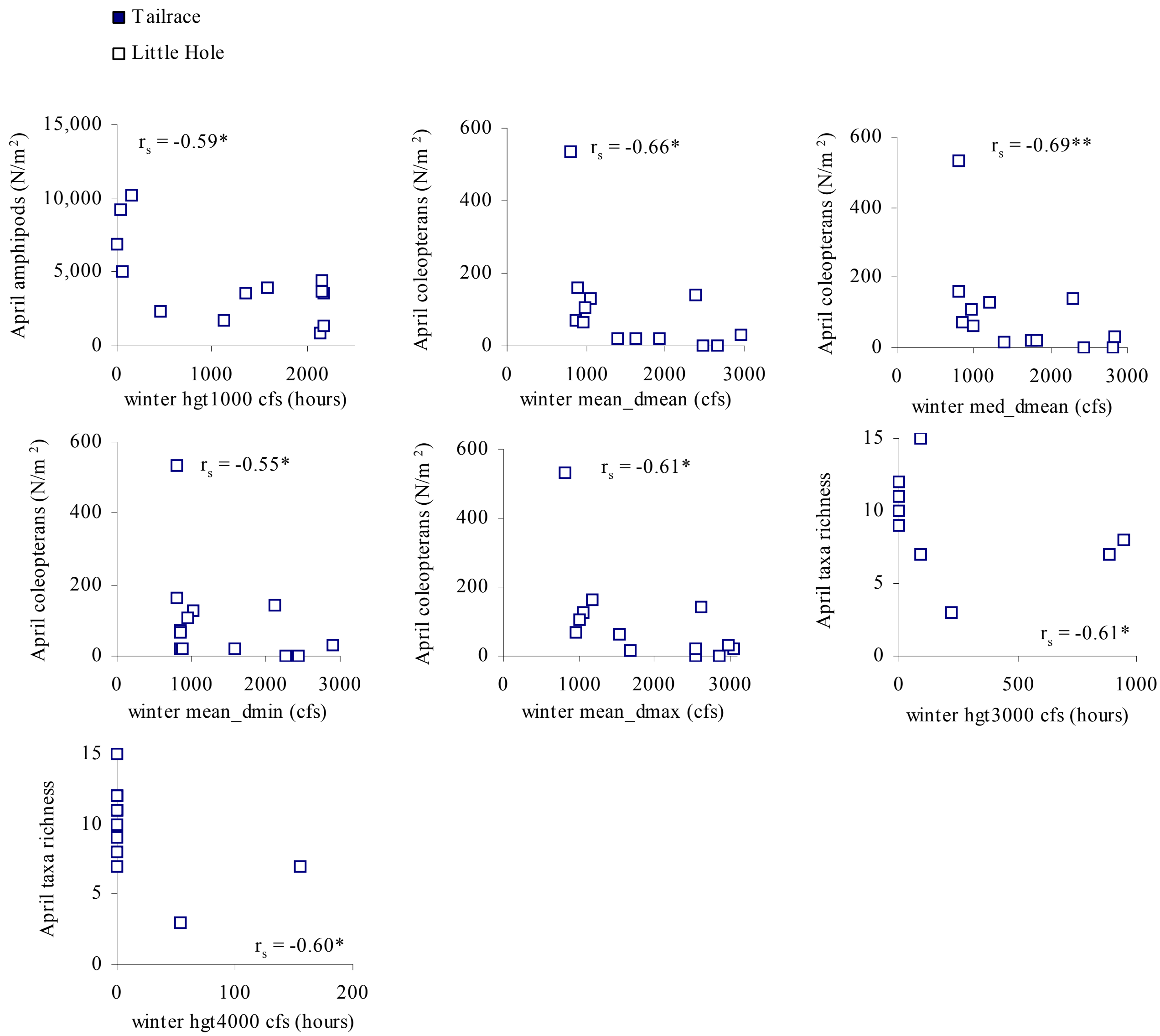

FIGURE 20 (Cont.)

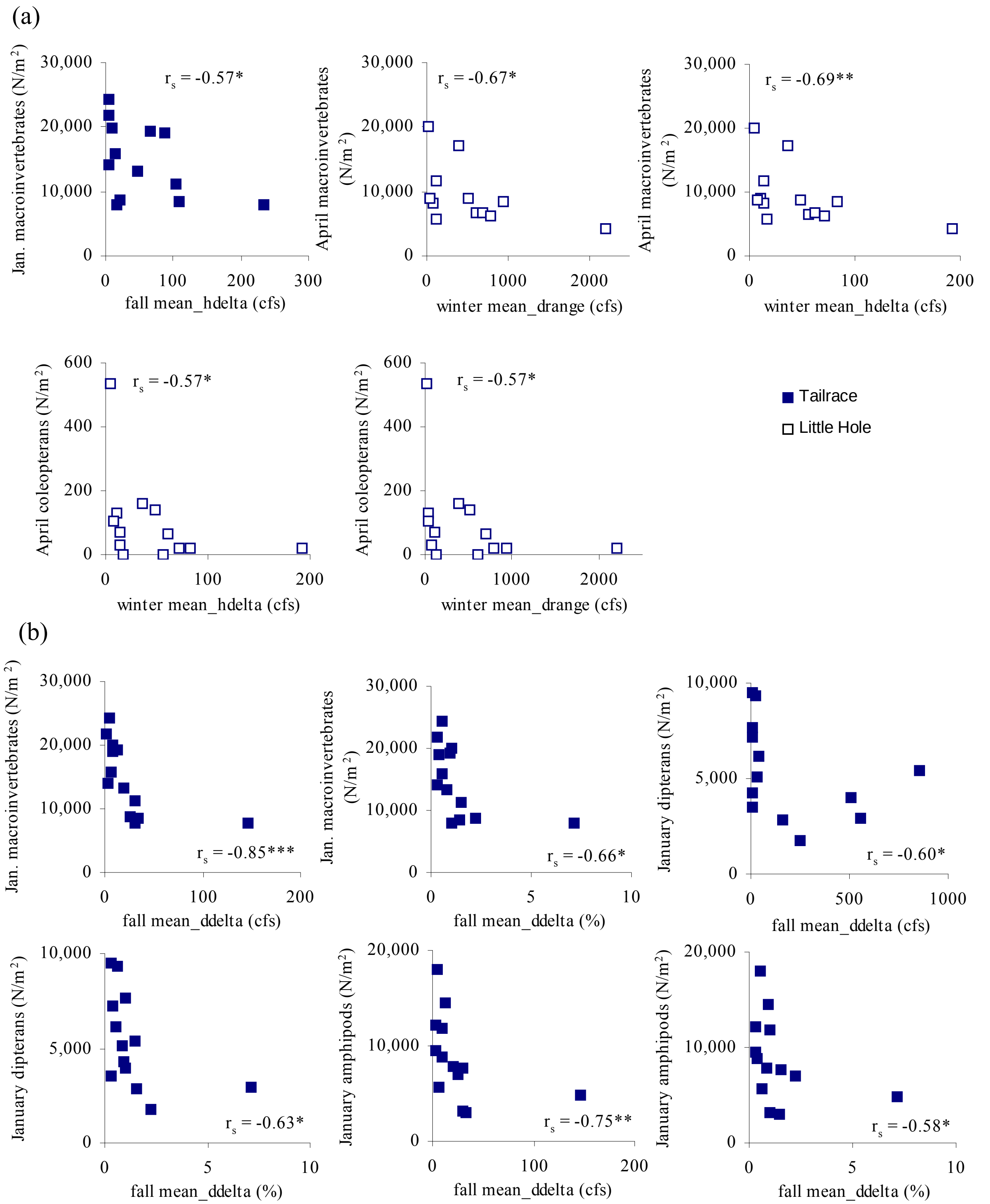

FIGURE 21 Statistically Significant Relationships between Macroinvertebrate Variables and (a) within-Day Variability, and (b) between-Day Variability of Fall and Winter Flows, 1994–2006 (Plots include rank correlation coefficients; asterisks denote level of significance: * *P* < 0.05, ** *P* < 0.01, and * *P* < 0.001)**

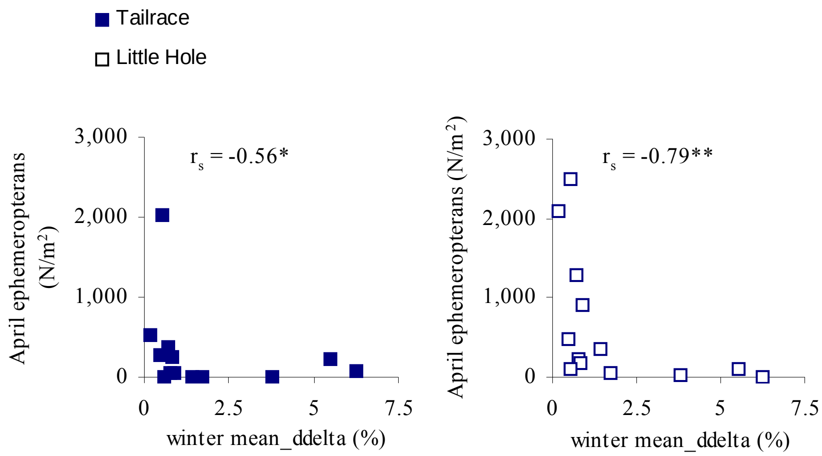

FIGURE 21 (Cont.)

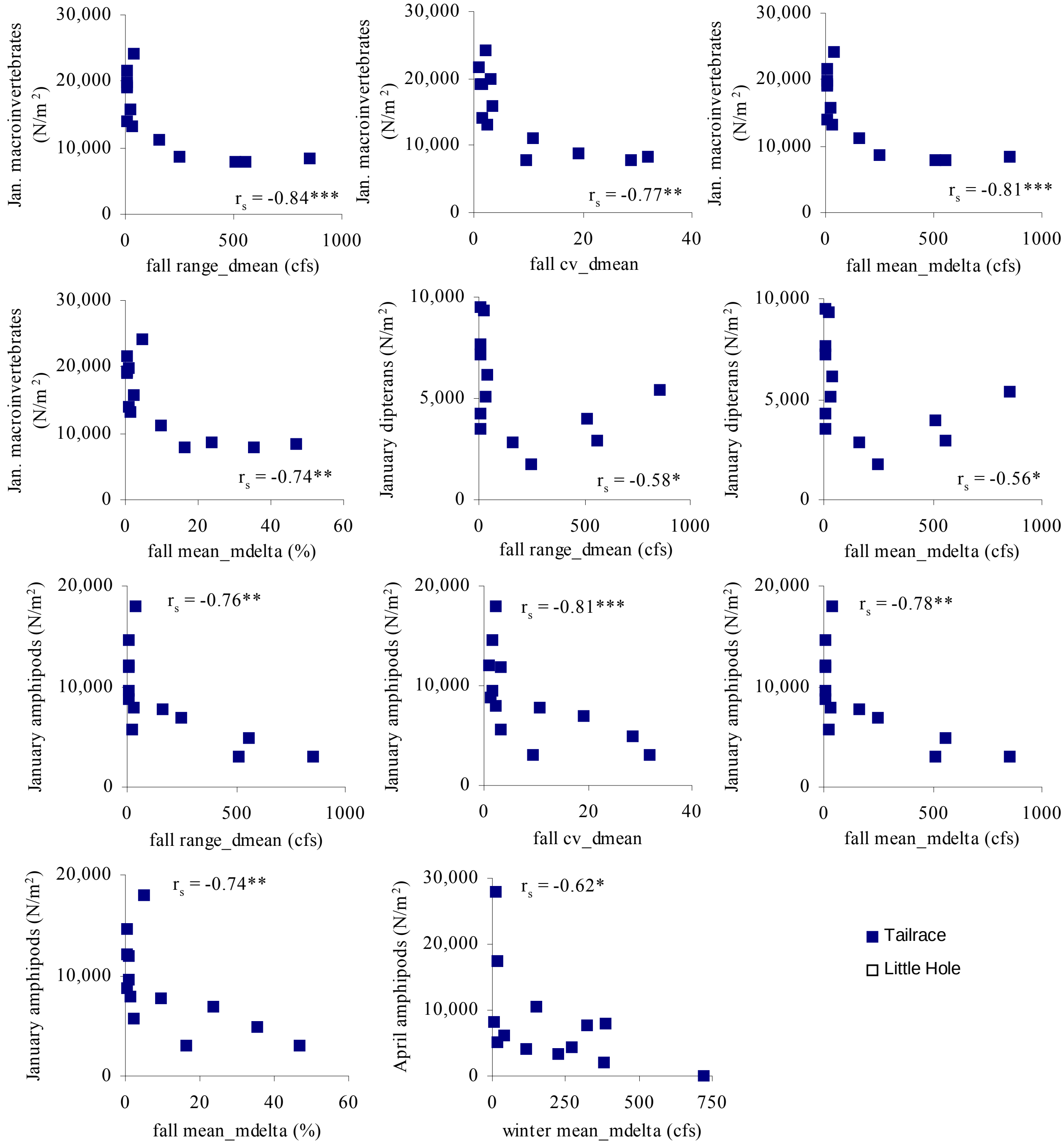

FIGURE 22 Statistically Significant Relationships between Macroinvertebrate Variables and within-Season and between-Month Variability of Fall and Winter Flows, 1994–2006 (Plots include rank correlation coefficients; asterisks denote level of significance: * *P* < 0.05, ** *P* < 0.01, and * *P* < 0.001)**

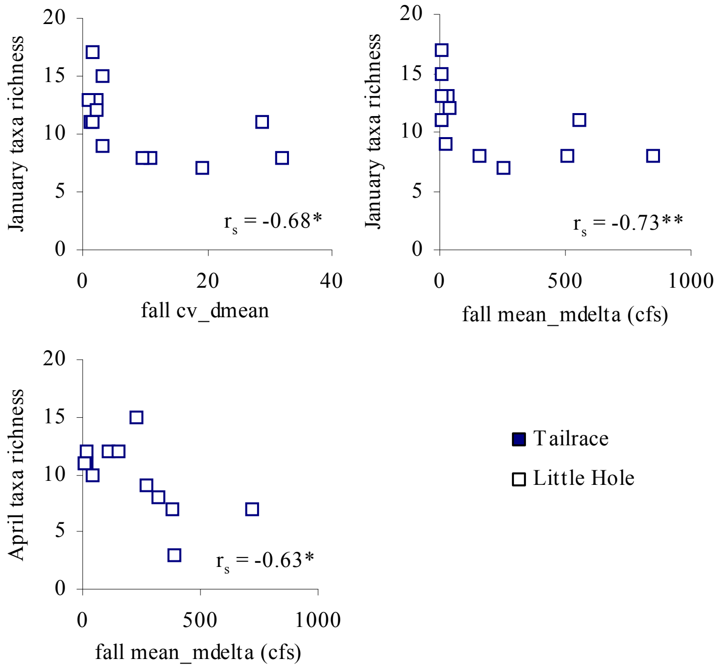

FIGURE 22 (Cont.)

3.3 DISCUSSION

Most of the significant relationships detected between variables were species- or location-dependent. Some of the relationships appeared to be relatively weak, and some apparently were statistically significant only because of the influence of one or two data points. Several patterns emerged, however.

Flow volume

The length and weight of rainbow trout at Little Hole appeared to be higher in years with lower fall and winter flow volumes. It should be noted, however, that the relative weight of rainbow trout at Tailrace was positively correlated with the number of hours in which flows were above 3,000 cfs, possibly as a result of an increase in habitat availability (e.g., more low-velocity shoreline habitat). The negative correlation between the length of rainbow trout and flow volume at Little Hole suggests that increasing flows affected the composition of the population of rainbow trout because length is unlikely to change directly in response to fall and winter flows. It is possible that increasing flow volume might have affected habitat availability and/or habitat quality. Habitat availability for rainbow trout has been shown to decrease in the tailwater sections of the Green River with increasing flows, except for the Tailrace site, where the habitat availability increased (review in Modde et al. 1991). Increased flow volume may also reduce the availability of algae and moss in downstream reaches as a result of scouring. Algae and moss are a substantial diet component for rainbow trout at the Tailrace site (Filbert 1991) and Vinson, Dinger and Baker (2006) found that the biomass of aquatic plants dropped considerably after above powerplant capacity flows in 1997, 1999 and 2005, from which it took 6 months for the plants to recover. In addition, the abundance of benthic macroinvertebrates at the Tailrace and Little Hole sites was negatively correlated with flow volume.

Flow variability

The condition of trout in spring appeared to be higher in years with higher within-day, between-day or within-season flow variability in the fall and winter periods (Table 4). Skewness in daily flow has been reported to be one of the most suitable measures of erratic water releases in different river systems (Olden and Poff 2003), and it may be particularly important for examining the effects of daily flow regimes on fish assemblages below hydroelectric dams (Kinsolving and Bain 1993). We found that trout condition (L, W, or WR) was positively correlated with within-season skewness (skew_dmean) at both locations. We also found that trout condition was positively correlated with within-day skewness (mean_dskew). Daily short-duration peaks result in a high positive value of mean_dskew, whereas daily long-duration peaks result in a low negative value. Days with identical maximum and minimum flows can have very different values of skewness. The relationship between trout condition and mean_dskew suggests that short-duration peaks improve trout condition (possibly by increasing the availability of drift) relative to stable flows or long-duration peaks. We hypothesize that the positive correlations between flow variability and condition of the trout could result from an increased availability of food, which occurs as variable flows dislodge benthic macroinvertebrates into the drift.

High flow variability may not affect energy-related condition and behavior in trout (e.g., as shown by Flodmark et al. 2006), but it may strongly affect the abundance of benthic invertebrates and the occurrence of drift (e.g., White and Wade 1980; Imbert and Perry 2000). The trout in the Green River below Flaming Gorge Dam are reported to feed both on the benthos and on drift (Filbert 1991), and fish may regulate benthic densities when drift is low (review in Dahl and Greenberg 1996) or when turbidity is high (such as after the Mustang Ridge wildfire in 2002). It is possible that the negative correlation between flow variability and the abundance of benthic macroinvertebrates, the positive correlation between flow variability (within-day, between-day, and within-season) and trout condition, and the negative correlation between the January abundance of benthic macroinvertebrates and trout, could be explained by flow-induced dislodgement of macroinvertebrates into the water column, which increases food availability for the trout (measured as increased condition) but, at the same time, decreases the abundance of benthic macroinvertebrates. Years with high daily skewness may have resulted in higher levels of drift downstream of Flaming Gorge Dam when compared with years with low daily skewness. We have no direct evidence that drift in the Green River tailwater increased in years with high flow variability, but White and Wade (1980) found that increased flow variability in a regulated river in Idaho (South Fork Boise River) resulted in episodically increased drift of benthic chironomids and ephemeropterans and a decrease of the density of some benthic taxa. The link between trout and its prey could not, however, be supported by the direct correlations between trout condition variables and the abundance of benthic macroinvertebrates in the Little Hole and Tailrace sites because these included both positive (some trout condition variables versus January macroinvertebrates), negative (some trout condition variables versus October macroinvertebrates), and uncorrelated relationships (Table 5).

Alternatively, if trout predation regulates the density of benthic macroinvertebrates, the negative correlation between the January abundance of macroinvertebrates and dipterans and the length of brown trout at the Tailrace site could result from an increase in predation pressure or shift in prey preference as the size structure changed within the trout population over the years evaluated. For example, the January abundance of amphipods increased at this site as the proportion of large trout decreased. Amphipods are, according to stomach content analyses by Filbert (1991), a preferred prey of large trout in the Green River during winter, and they are also the most abundant invertebrate taxa at the Tailrace site (average 63% of total abundance). Filbert and Hawkins (1995) also found that the condition and gut fullness of rainbow trout increased with increasing food availability and temperature in the Green River which suggests that these trout may be food-limited. Vinson et al. (2006) examined gut contents of trout in the Green River between 1998 and 2005, and found that gut fullness was relatively stable throughout the study period but that gut contents varied among the years and reflected prey availability in the river – the dominant prey taxa were amphipods, chironomids and ephemeropterans. They also found that the trout preferred ephemeropterans, gastropods, non-chironomid/simulid dipterans, terrestrial insects, *Gammarus* (brown trout) and *Potamogyrus* (brown trout), and avoided coleopterans, the amphipod *Hyalella* and chironomids.

Our results suggest that a reduction in flow variability may lead to an increase of the standing crop of benthic macroinvertebrates and to a decrease in the length, weight or relative weight of trout. It is possible that decreases in flow fluctuations during the falls and winters of the second half of the study period (Figures 11 and 13) might have contributed to the shift from rainbow trout to brown trout at Tailrace (Figure 3). Large flow fluctuations before and during the spawning period in October may have disrupted spawning and hindered the reproductive success of brown trout during the first half of the study period (e.g., Nelson 1986). It should be noted, however, that the length and weight of rainbow trout at the Tailrace and Little Hole sites and the weight of brown trout at the Tailrace site also were negatively correlated with the CPUE of trout (the CPUE of brown trout increased and the condition of trout decreased while the flow variability in the river decreased over the studied period). The cause and effects of these relationships are not clear.

The results presented here do not distinguish between individual and population responses in the trout—the observed relationships could result from differential survival, where fish entering the winter in poor condition could die before spring sampling (e.g., Simpkins and Hubert 2000). The pooled data in our study may have concealed some important size-specific relationships because McKinney et al. (2001) found that rainbow trout smaller than 305 mm were more strongly affected by flow volume, flow variation, and water temperature than larger trout in the tailwater of Glen Canyon Dam. Further, McKinney and Speas (2001) found that intermediate-size and large rainbow trout below Glen Canyon Dam were more food-limited than smaller trout because they tended to feed more on nutrient-poor food such as algae. We recommend additional analyses be conducted that explicitly consider in greater detail the potential effects on different size-classes.

4 USE OF SPRING TO FALL CONDITION RATIOS AS AN INDEX OF THE EFFECT OF FALL AND WINTER FLOW CONDITIONS ON TROUT

Fish typically experience a decline in condition over the winter because of colder water temperatures, reduced food supply, and behavioral changes. Any decline in condition over winter would not be solely the result of overwinter conditions in flow and food availability but would also depend on the initial condition of the fish when the winter period began. To compensate for the lack of information on this factor, we proposed examining the use of the ratio of spring condition to fall condition as an index of overwinter flow effects. Since the ratio is based on the condition of fish at the beginning of winter, the ratio could provide a better measure of the effects of overwinter flows on the trout in spring. This section evaluates whether such condition ratios (1) are independent of the fall values and (2) can be used to detect otherwise undetected relationships of trout condition to flows and macroinvertebrate abundance.

4.1 METHODS

Ratios were calculated by dividing the relative weight in the spring with the relative weight in the previous fall (ratio WR). Ratios could not be calculated for 1990 because fall condition values were not available for 1989. Ratios could also not be calculated for the period from 2003 to 2005 because spring sampling was not conducted in those years. Thus, the overall number of years for which ratios could be calculated was 13 (1991–2002 and 2006). The ratios were analyzed in the same manner as presented for spring condition factors (L, W, and WR) in Section 2. Plots of all statistically significant (on the basis of Spearman rank correlation analyses) bivariate relationships are presented in this section.

4.2 RESULTS AND DISCUSSION

In contrast to the spring condition values, the condition ratios did not show any obvious decline or increase over the years (Figure 23). Condition ratios were often negatively correlated to the fall condition values (Figure 24), suggesting that years with high condition in the fall showed a greater drop in condition over the winter when compared with years that started with low condition (i.e., the slope of the relationship of spring condition to fall condition was <1.0; Figure 25). It is possible that the low slopes reflect changes within the sampled population. For example, smaller fish, although usually in relatively good condition, may have lower survivorship than fish in relatively poor condition (often larger fish). When the ratios are correlated with the starting condition of the fish, their values do not solely reflect the effects of environmental or biotic influences. It is possible that the ratios would have been uncorrelated with the fall values if the ratios could have been calculated from individual trout instead of from average condition in fall and spring. Nonetheless, the correlations of condition ratios to fall condition values were usually lower ($-0.76 < r_s < -0.18$) than the corresponding correlations between the spring condition and fall condition.

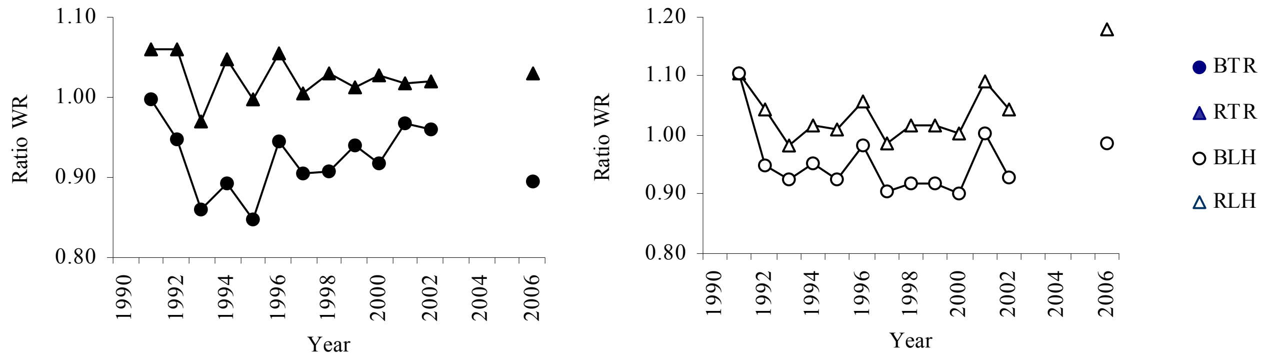

FIGURE 23 Temporal Patterns in Ratio WR of Brown and Rainbow Trout at the Tailrace and Little Hole Sites, 1991–2006

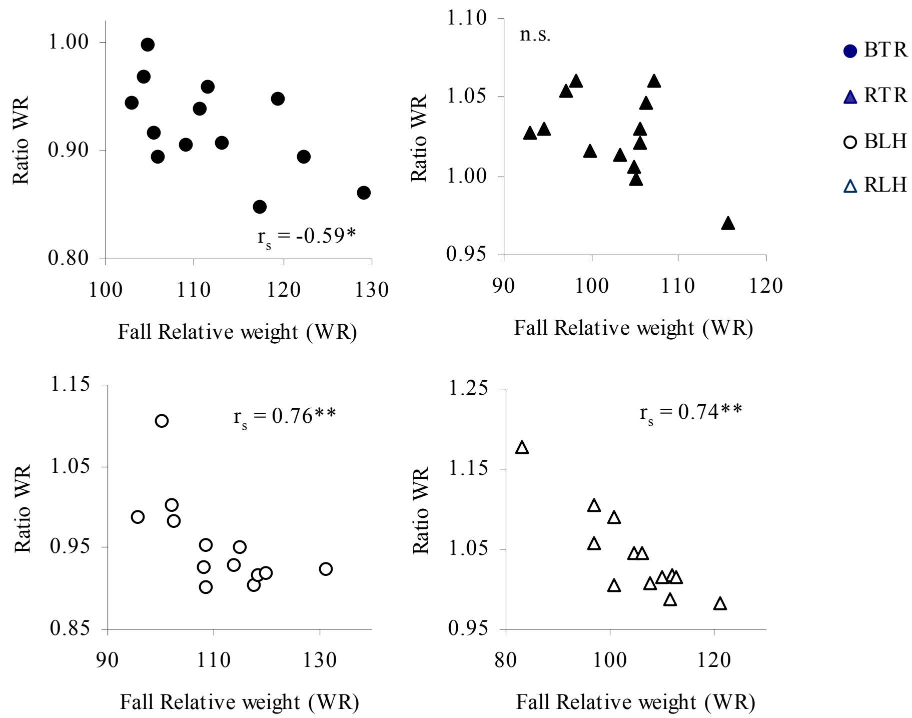

FIGURE 24 Relationships between Condition Ratios and Fall Values of WR, 1991–2006 (Plots include rank correlation coefficients for significant relationships; asterisks denote level of significance: * *P* < 0.05, ** *P* < 0.01, * *P* < 0.001, and n.s. *P* > 0.05; BTR = brown trout at Tailrace, BLH = brown trout at Little Hole, RTR = rainbow trout at Tailrace, RLH = rainbow trout at Little Hole)**

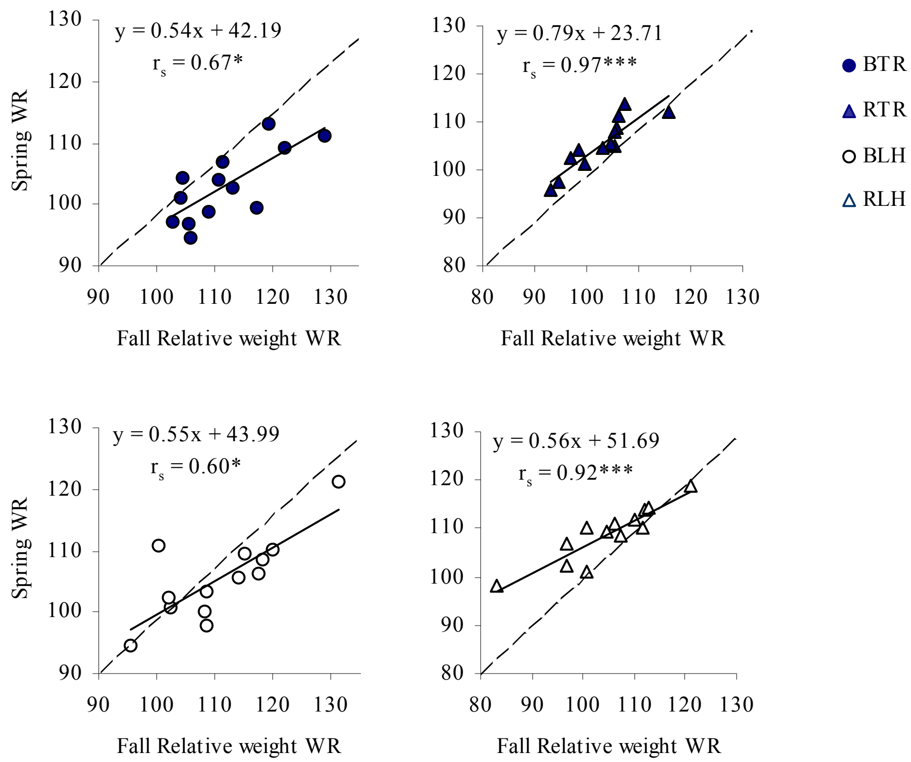

FIGURE 25 Relationships between Spring and Fall Values of WR, 1991–2006 (Plots include rank correlation coefficients, the best-fit regression line [solid line], and the line with slope of 1 and y-intercept of 0 [dashed line]; asterisks denote level of significance: * *P* < 0.05, ** *P* < 0.01, and * *P* < 0.001; BTR = brown trout at Tailrace, BLH = brown trout at Little Hole, RTR = rainbow trout at Tailrace, RLH = rainbow trout at Little Hole.)**

($0.60 < r_s < 0.97$, Table 7), which suggests that using the ratios could be comparable to or better than using the spring values alone to evaluate the effects of overwinter conditions on the trout. Although the spring to fall ratios may not be independent of the fall values, they could be used to find patterns that were undetected when the spring values alone were used.

The analyses showed that the ratios, in contrast to the spring values of rainbow trout at Little Hole, were not affected by flow volume (Table 8). While the spring values of rainbow trout at Tailrace showed no correlations with within-day variability, the ratio was positively correlated to mean_hdelta (Figure 26). In contrast to the spring condition values, condition ratios were not correlated with between-day variability or within-season variability. Similar to the spring condition values, condition ratios were not correlated with between-month variability.

TABLE 7 Spearman Rank Correlation Coefficients for Spring and Fall Trout Condition Variables[a]

	Spring and Ratio Values Correlated with Fall and Spring Values			
Variables	Brown Trout at Tailrace	Rainbow Trout at Tailrace	Brown Trout at Little Hole	Rainbow Trout at Little Hole
Spring L vs. Fall L	0.90***	0.81***	0.82***	0.43
Spring W vs. Fall W	0.89***	0.94***	0.64*	0.54
Spring WR vs. Fall WR	0.67*	0.97***	0.60*	0.92***
Ratio WR vs. Fall WR	–0.59*	–0.18	–0.76**	–0.74**
Ratio WR vs. Spring WR	0.14	-0.03	-0.08	-0.49

[a] Asterisks denote level of significance, i.e., * $P < 0.05$, ** $P < 0.01$, and *** $P < 0.001$.

In contrast to the negative correlations between spring condition and macroinvertebrate abundance in January, the condition ratio of brown trout at Tailrace was positively correlated with January dipterans, the condition ratio of brown trout at Little Hole was positively correlated with January macroinvertebrates, and the condition ratio of rainbow trout at Little Hole was positively correlated with January macroinvertebrates and April amphipods (Table 9, Figure 27). In contrast to the positive correlations between spring condition of brown trout and October macroinvertebrate abundance, the condition ratio of brown trout was not correlated with October macroinvertebrates. In addition, the condition of rainbow trout at Tailrace was positively correlated with total coleopterans (Table 9, Figure 27).

The difference between the relationships of condition ratios to macroinvertebrate abundance when compared with the relationships of spring condition values to macroinvertebrate abundance is problematic. We suggest that a thorough evaluation of disaggregated trout condition data (to evaluate size-specific relationships) as well as drift experiments be conducted to help elucidate important relationships and mechanisms.

TABLE 8 Summary of Statistically Significant Correlations between Condition Ratios and Year and Flow Variables[a]

		Trout Variables Correlated with Year and Flow Variables			
Variable	Definition	Brown Trout at Tailrace	Rainbow Trout at Tailrace	Brown Trout at Little Hole	Rainbow Trout at Little Hole
Year	1990-2006	None	None	None	None
Volume					
med_dmean	Median of mean daily flow	None	None	None	None
mean_dmean	Mean of mean daily flow	None	None	None	None
mean_dmin	Mean of minimum daily flow	None	None	None	None
mean_dmax	Mean of maximum daily flow	None	None	None	None
hgt1000	Total hours with flows >1,000 cfs	None	None	None	None
hgt2000	Total hours with flows >2,000 cfs	None	None	None	None
hgt3000	Total hours with flows >3,000 cfs	None	None	None	None
hgt4000	Total hours with flows >4,000 cfs	None	None	None	None
Within-Day Variability					
mean_hdelta	Mean hourly change of flows (absolute values)	None	+ratio WR	None	None
mean_hdelta (%)	Mean hourly change of flows (% of daily)	None	None	None	None
mean_drange	Mean daily range of flows	None	None	None	None
mean_dcv	Mean daily coefficient of variation in flow	None	None	None	None
mean_dskew	Mean daily skewness of flows	None	None	None	None
Between-Day Variability					
mean_ddelta	Mean change in flow between days (absolute values)	None	None	None	None
mean_ddelta (%)	Mean change in flow between days (% of daily)	None	None	None	None
Within-Season Variability					
range_dmean	Range of mean daily flows	None	None	None	None
cv_dmean	Coefficient of variation of mean daily flows	None	None	None	None
skew_dmean	Skewness of mean daily flows	None	None	None	None
Between-Month Variability					
mean_mdelta	Mean change in flow between months (absolute values)	None	None	None	None
mean_mdelta (%)	Mean change in flow between months (%)	None	None	None	None

[a] The sign (+ or –) preceding a variable indicates whether the correlation is positive or negative. The significance of the relationship is indicated by the number of signs shown (1: $P < 0.05$, 2: $P < 0.01$, 3: $P < 0.001$). Ratio WR = relative change in relative weight from fall to spring,

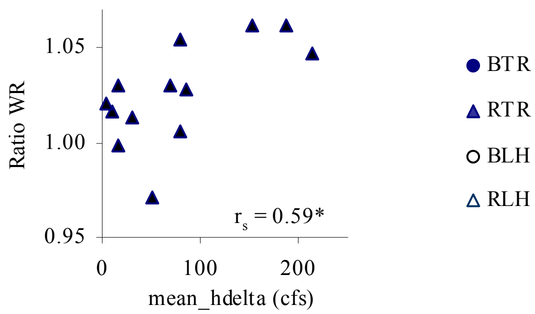

FIGURE 26 Statistically Significant Relationship between Trout Condition Ratios and within-Day Flow Variability, 1991–2006 (Plot include rank correlation coefficient; asterisks denote level of significance: * *P* < 0.05, ** *P* < 0.01, and * *P* < 0.001; BTR = brown trout at Tailrace, BLH = brown trout at Little Hole, RTR = rainbow trout at Tailrace, RLH = rainbow trout at Little Hole)**

TABLE 9 Summary of Statistically Significant Correlations between Trout Condition Ratios and Macroinvertebrate Variables[a]

	Trout Variables Correlated with Macroinvertebrate Variables			
Macroinvertebrate Variable	Brown Trout at Tailrace	Rainbow Trout at Tailrace	Brown Trout at Little Hole	Rainbow Trout at Little Hole
Total macroinvertebrates	None	None	None	None
Total taxa richness	None	None	None	None
Total ephemeropterans	None	None	None	None
Total amphipods	None	None	None	None
Total coleopterans	None	+ratio WR	None	None
Total dipterans	None	None	None	None
October macroinvertebrates	None	None	None	None
October taxa richness	None	None	None	None
October ephemeropterans	None	None	None	None
October amphipods	None	None	None	None
October coleopterans	None	None	None	None
October dipterans	None	None	None	None
January macroinvertebrates	None	None	+ratio WR	+ratio WR
January taxa richness	None	None	None	None
January ephemeropterans	None	None	None	None
January amphipods	None	None	None	None
January coleopterans	None	None	None	None
January dipterans	+ratio WR	None	None	None
April macroinvertebrates	None	None	None	None
April taxa richness	None	None	None	None
April ephemeropterans	None	None	None	None
April amphipods	None	None	None	+ratio WR
April coleopterans	None	None	None	None
April dipterans	None	None	None	None

[a] The sign (+ or –) preceding a variable indicates whether the correlation is positive or negative. The significance of the relationship is indicated by the number of signs shown (1: $P < 0.05$, 2: $P < 0.01$, 3: $P < 0.001$). Ratio WR = relative change in relative weight from fall to spring.

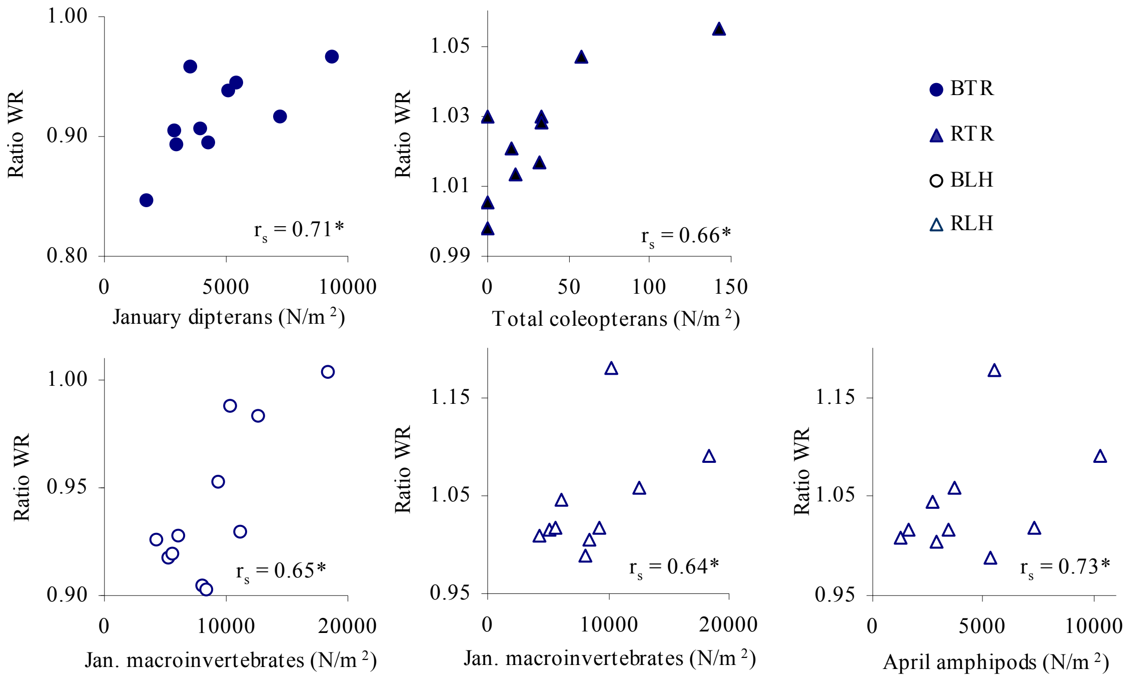

FIGURE 27 Statistically Significant Relationships between Trout Condition Ratios and Macroinvertebrate Abundance, 1994–2006 (Plots include rank correlation coefficients; asterisks denote level of significance: * *P* < 0.05, ** *P* < 0.01, and * *P* < 0.001; BTR = brown trout at Tailrace, BLH = brown trout at Little Hole, RTR = rainbow trout at Tailrace, RLH = rainbow trout at Little Hole)**

5 CONCLUSIONS

In this report, we statistically evaluated historical data to determine relationships among trout condition in the spring, macroinvertebrate abundance, and flows from Flaming Gorge Dam during the fall and winter months. The evaluations were made to help better understand the influence of flow magnitude and flow variability on trout and the aquatic food base as part of a larger evaluation to study the effects of future implementation of a double-peaking release pattern. The evaluations identified a number of significant relationships at both the Tailrace and Little Hole sites. In many cases, however, these relationships were site- and species-specific.

The length and weight of rainbow trout at Little Hole were found to be negatively correlated with flow volume. The condition, length, and weight of rainbow trout at Tailrace and brown trout at both sites were not significantly correlated with flow volume. This differential response to flow volume depending on location and trout species may be explained by differences in habitat characteristics in different sections of the tailwater. High-resolution habitat data recently collected at both sites could provide insight into these site-specific differences and will enable evaluation of habitat availability at different flows. Benthic macroinvertebrates were primarily negatively correlated with increased flow volume. The abundance of benthic macroinvertebrates at the Tailrace site in January (total abundance and abundance of amphipods) and April (abundance of amphipods) was negatively correlated with flow volumes for the preceding three-month time period. Similarly, total macroinvertebrate abundance and amphipod abundance at the Little Hole site in April was negatively correlated with flow volume for the immediately preceding three-month time period.

In general, measures of spring trout condition were positively correlated with increased flow variability. No negative correlations between trout condition and any measure of flow variability were detected. Macroinvertebrate densities were generally either not correlated or negatively correlated with flow variability. We hypothesize that increasing flow variability increases the loss of macroinvertebrates on substrates as they are dislodged and transported downstream in the drift. Data are needed on the effects of flow and flow variability on drift rates to enable testing of this hypothesis.

Because trout condition would be expected to be affected by declines in food availability, we also used available data to examine relationships between benthic macroinvertebrate abundance and variables representing trout condition. The abundance of macroinvertebrates during October was positively correlated with length of brown trout at the Tailrace site and with length and weight of brown trout at the Little Hole site. The measures of macroinvertebrate abundance during January and April and trout condition variables were either negatively or not significantly correlated. The interpretation of these results is not clear. It is possible that when fish are in good condition it is because they have been feeding heavily enough to reduce macroinvertebrate densities in spring. The positive correlation between trout condition and flow variability and the negative correlation between macroinvertebrates and flow variability support the hypothesis that variable flows reduce standing crops of benthic macroinvertebrates by forcing these organisms into the drift, where they are more available to feeding trout. Data are needed on the benthic and drift foraging rates of trout and effects on the standing crop of benthic macroinvertebrates to enable testing of these hypotheses.

We found that in years with higher fall condition values, the ratio of spring to fall trout condition was lower. In other words, the loss of condition overwinter was higher if fall condition was relatively good. Thus, the ratios of spring condition to fall condition (ratio WR) were correlated with the starting condition in the fall. We hypothesize that differential growth and/or survival among different size-classes of trout could be partly responsible for this correlation. Whereas there were indications that the length and weight of rainbow trout at Little Hole in the spring was negatively correlated with fall and winter flow volume, the condition ratios were not significantly correlated with flow volume. With the exception of a positive correlation between condition ratio of rainbow trout at Tailrace and within-day flow variability, condition ratios were not correlated with any measures of within-day and between-day variability, in contrast to the relationships identified between trout condition and spring condition alone. There was no significant relationship between spring condition ratios and between-month variability, similar to the relationships identified between trout condition and spring condition alone. Relationships between condition ratios and the abundance of benthic macroinvertebrates tended to be positively correlated, in contrast to the negative relationships identified when spring condition alone was compared to benthic macroinvertebrate abundance in January. Future evaluations should attempt to explain these sometimes conflicting results by evaluating disaggregated data and the condition factors of individual fish.

Because of the many potential interactions among flows, macroinvertebrates (abundance in benthos versus drift), and trout (density-dependent condition, size distribution, prey preference of each size-class of each trout species, and location), the interpretation of significant relationships is not straightforward. The analysis and interpretation of results are further complicated by the significant changes that have occurred during the study period (e.g., changes in hydrologic condition, increased fishing pressure, and large influx of sediment, and New Zealand mud snails; see introduction to Section 2).

It should also be recognized that some of the significant relationships could be spurious, result from individual outlying values, or result from sampling errors. The correlation analyses were derived from relatively few data points ($N = 10$ to 14), and the data include a gap between 2003 and 2005 when no trout were collected. The small sample size limits confidence in the results. Because of the exploratory nature of the analyses in this study, the critical alpha value for rejecting hypotheses was not adjusted to the number of tests made (e.g., no Bonferroni corrections). Therefore, the relationships that are identified in this report should be regarded only as potentially important relationships that warrant further examination once additional data have been collected.

Our results are based on averaged data for trout lengths and weights for each sample year, and they disregard the variability around the mean values (i.e., all regression and correlation analyses are calculated from average length, weight, and relative weight of rainbow and brown trout for each year). We recommend that many of these relationships be reexamined by using the individual measures for fish collected during electrofishing surveys. This reexamination would allow the variability of the data to be taken into account. It would also allow consideration of differences in responses among size-classes of trout to be analyzed.

Moreover, this analysis only examined overwinter effects. Because the survival and condition of trout in the spring also depend on their condition at the beginning of winter, we suggest that the effects of flows on macroinvertebrate abundance and trout condition for other seasons of the year be examined as well.

Together with the size-stratified analyses of trout to be conducted, the evaluations made here serve as a baseline for future comparisons of relationships among trout condition, macroinvertebrate abundance, and flow parameters under a double-peaking flow regime. The significant relationships detected suggest future experimentation and hypothesis testing should focus on the effects of flow variability on macroinvertebrate standing crops, drift rates, and the feeding behavior of trout.

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APPENDIX A

SEASONAL ABUNDANCE AND TAXA RICHNESS OF MACROINVERTEBRATES IN THE GREEN RIVER DOWNSTREAM OF FLAMING GORGE DAM, 1994–2006

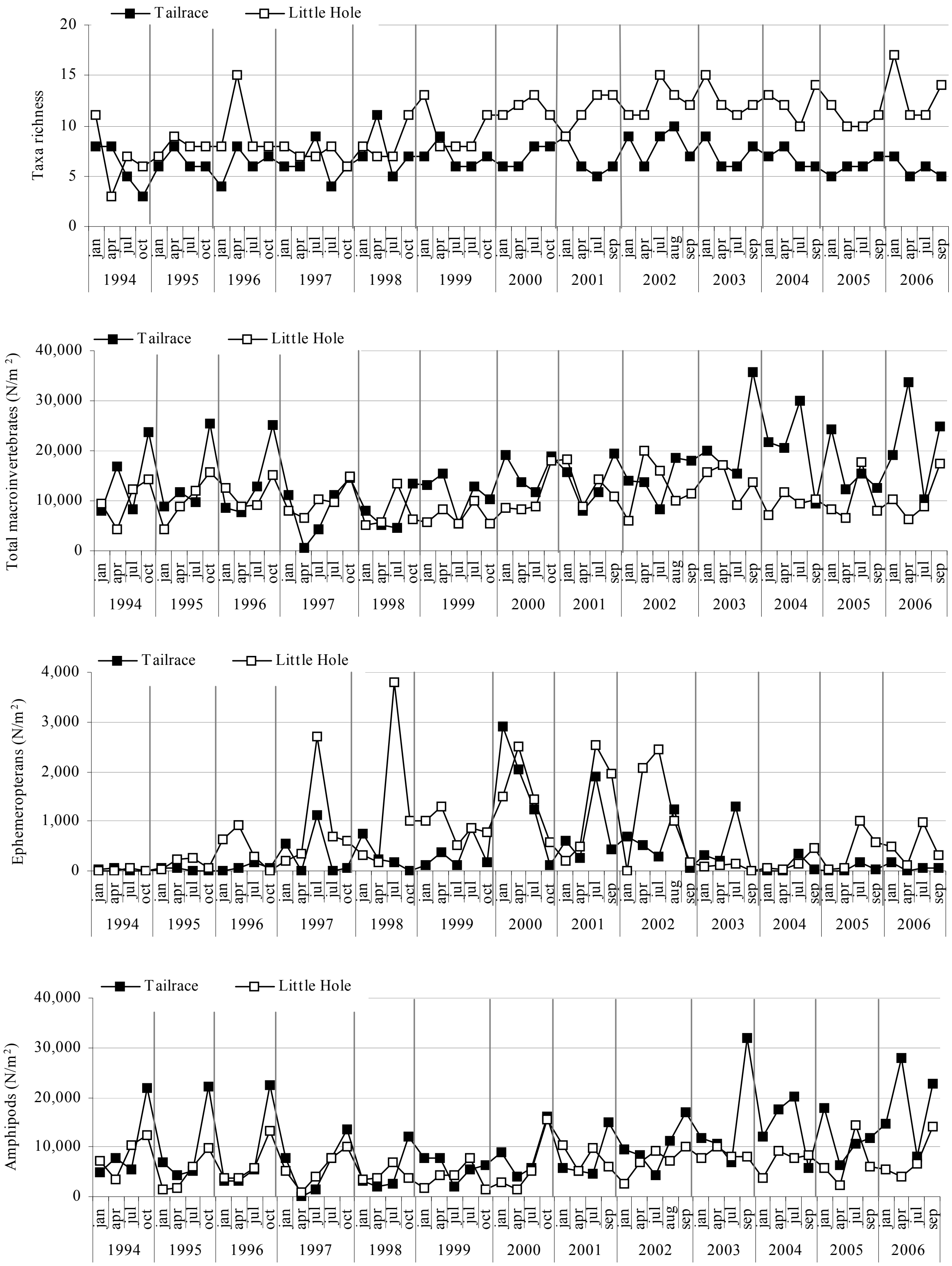


FIGURE A.1 Taxa Richness and Abundance of Benthic Macroinvertebrates at the Tailrace and Little Hole Sites, Green River, 1994–2006 (Source: M. Vinson, personal communication).

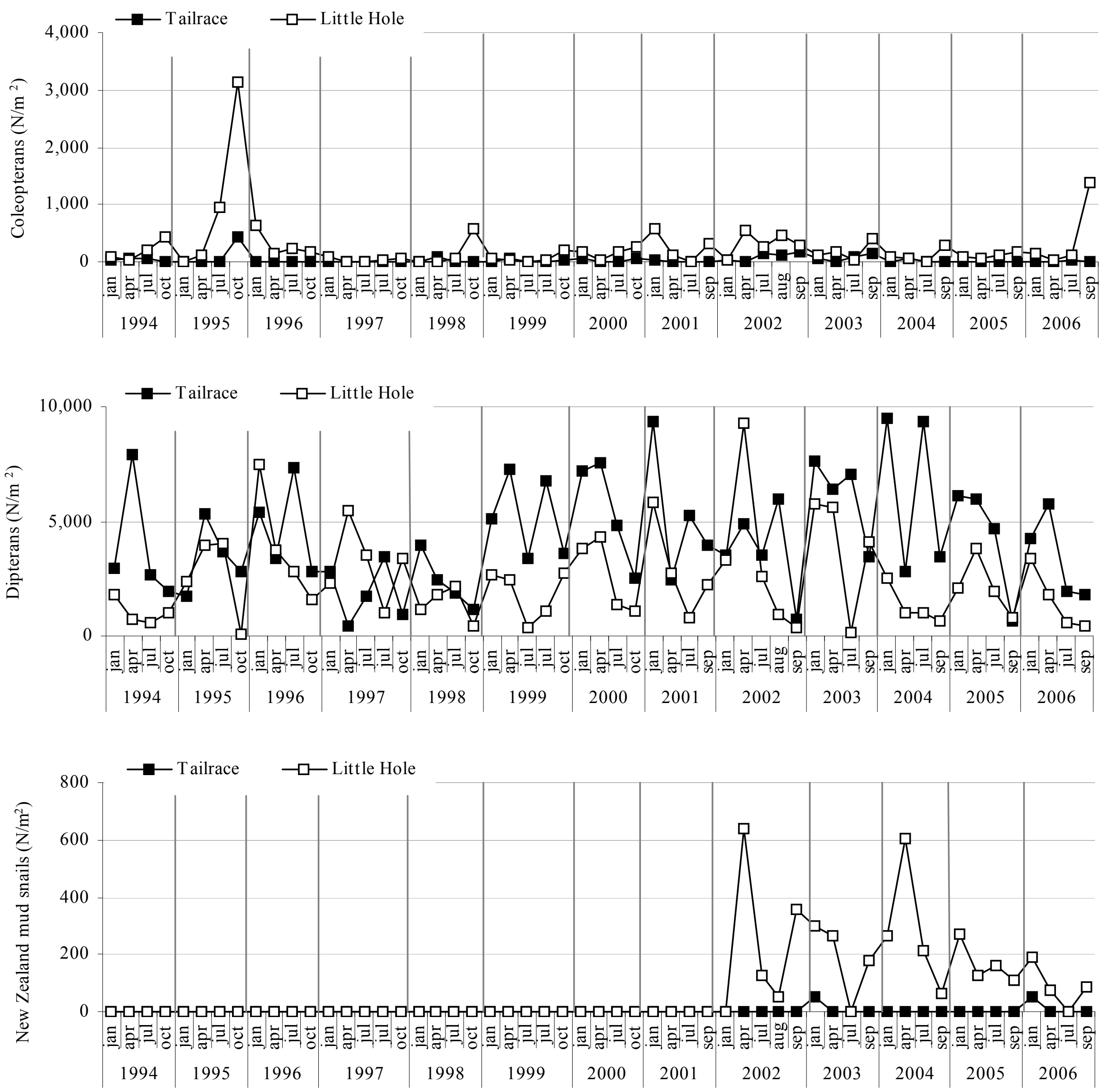


FIGURE A.1 (Cont.)

APPENDIX B

HOURLY AND DAILY FLOWS FROM OCTOBER THROUGH MARCH IN THE GREEN RIVER DOWNSTREAM OF FLAMING GORGE DAM, 1990–2006

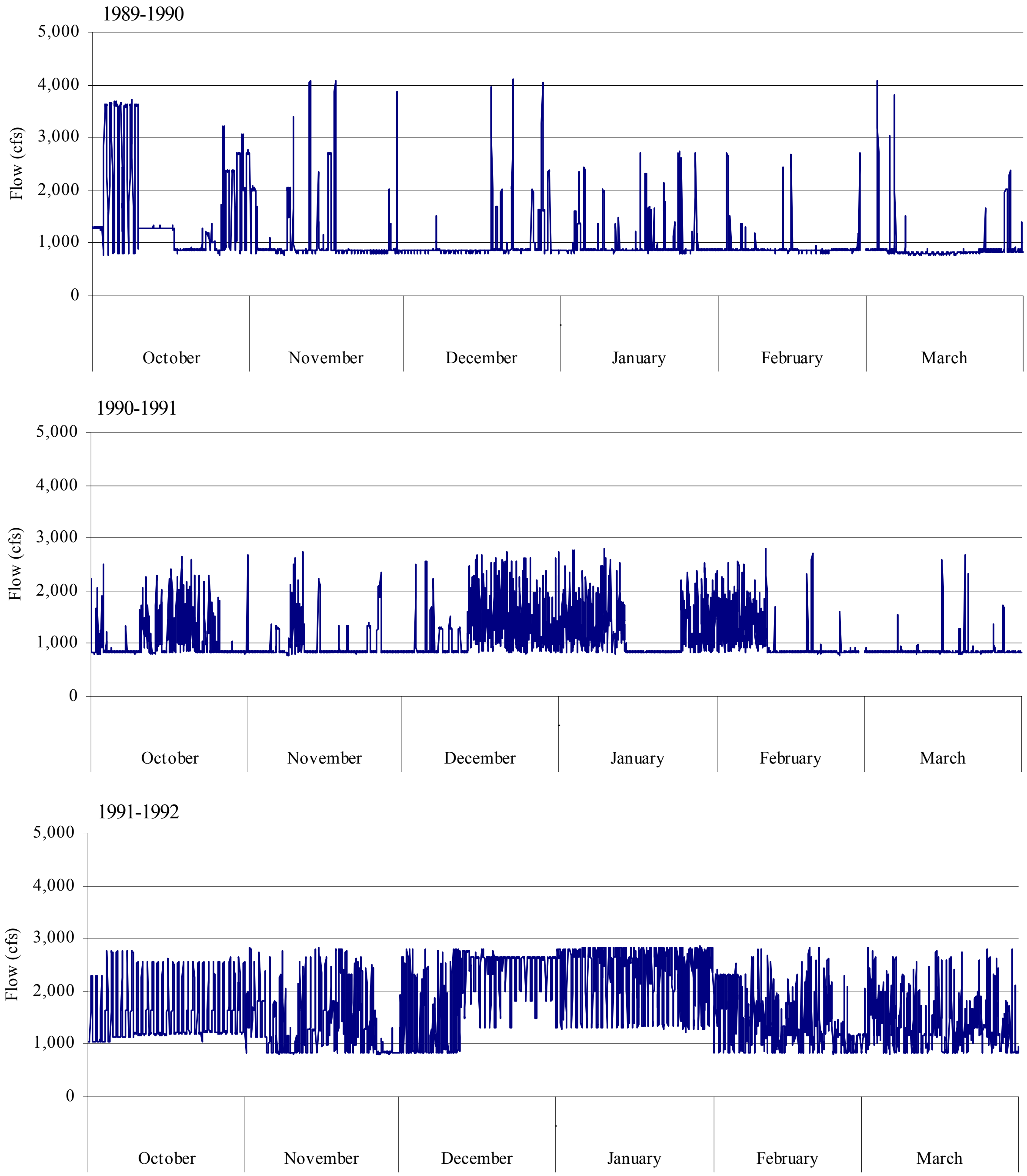
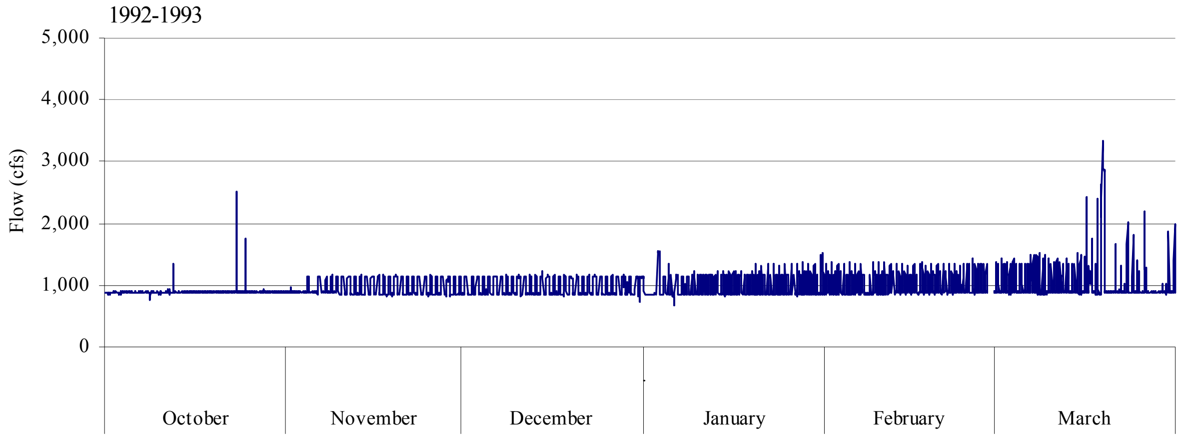
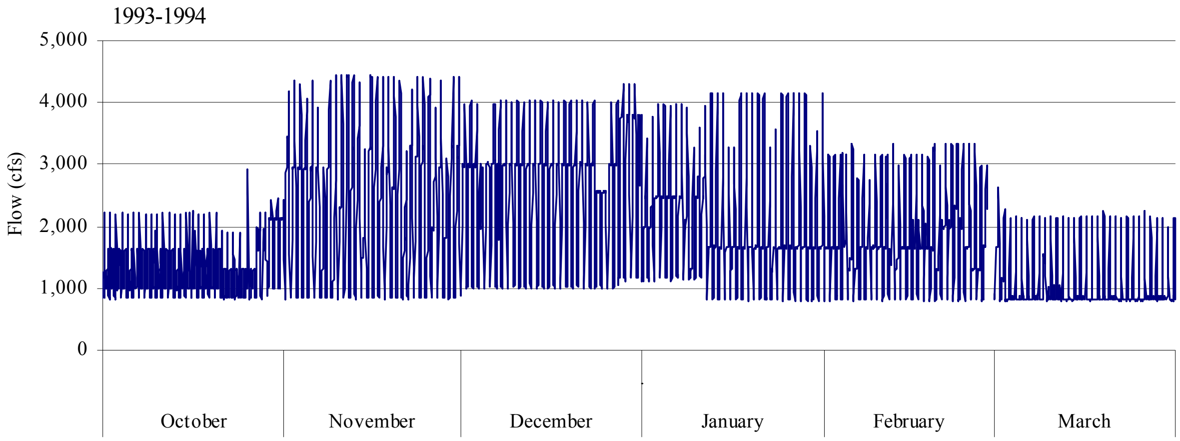


FIGURE B.1 Hourly Flows Downstream of Flaming Gorge Dam, Green River, from October through March, 1990–2006





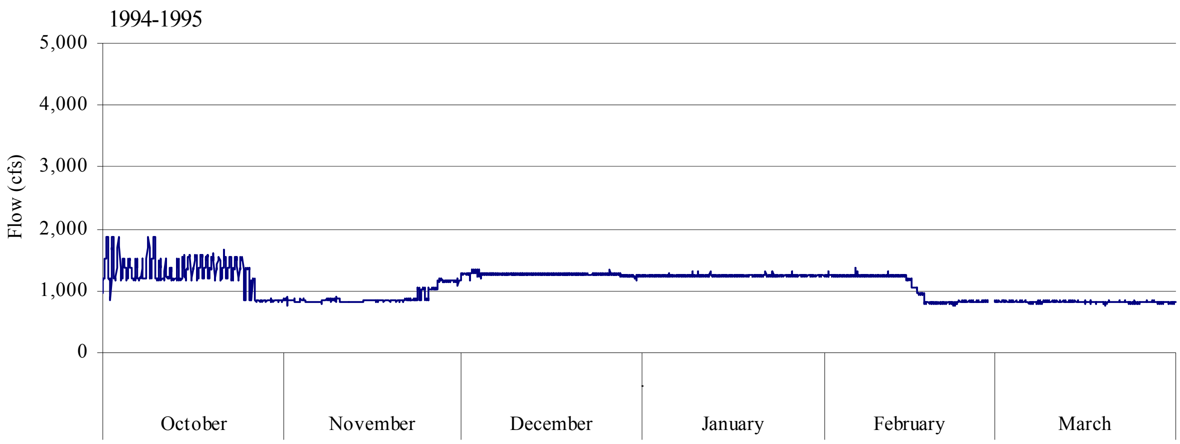


FIGURE B.1 (Cont.)

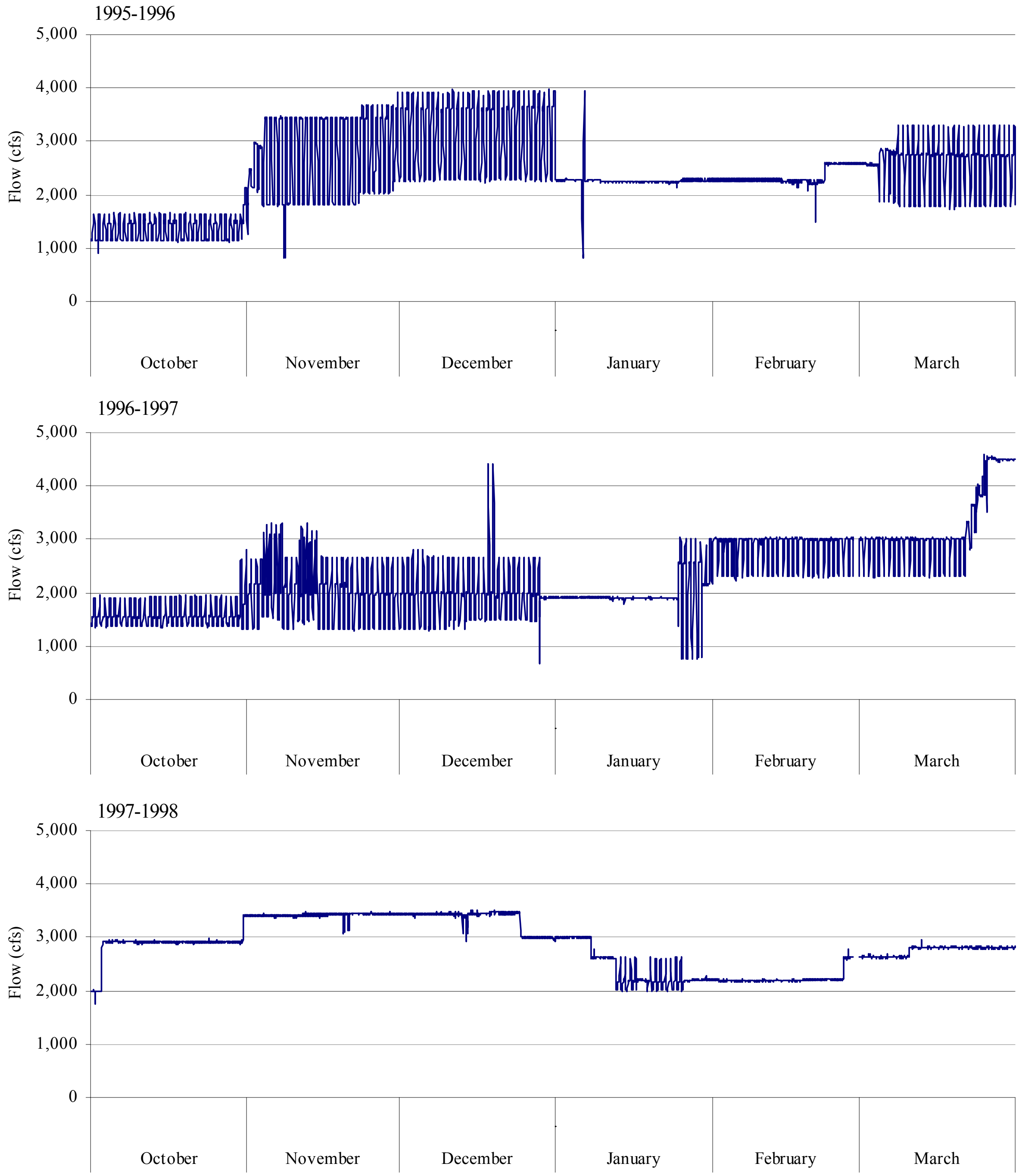


FIGURE B.1 (Cont.)

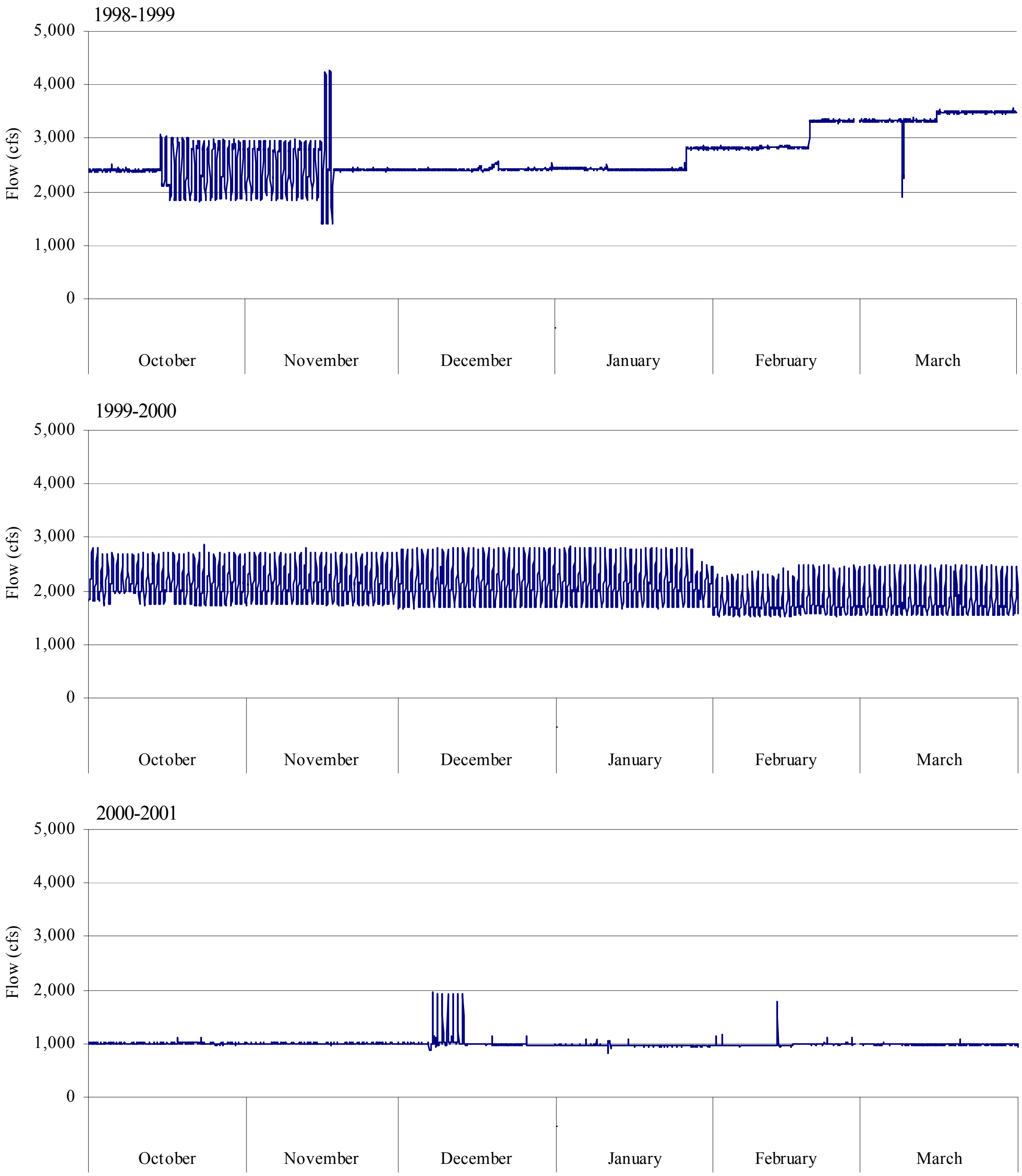


FIGURE B.1 (Cont.)

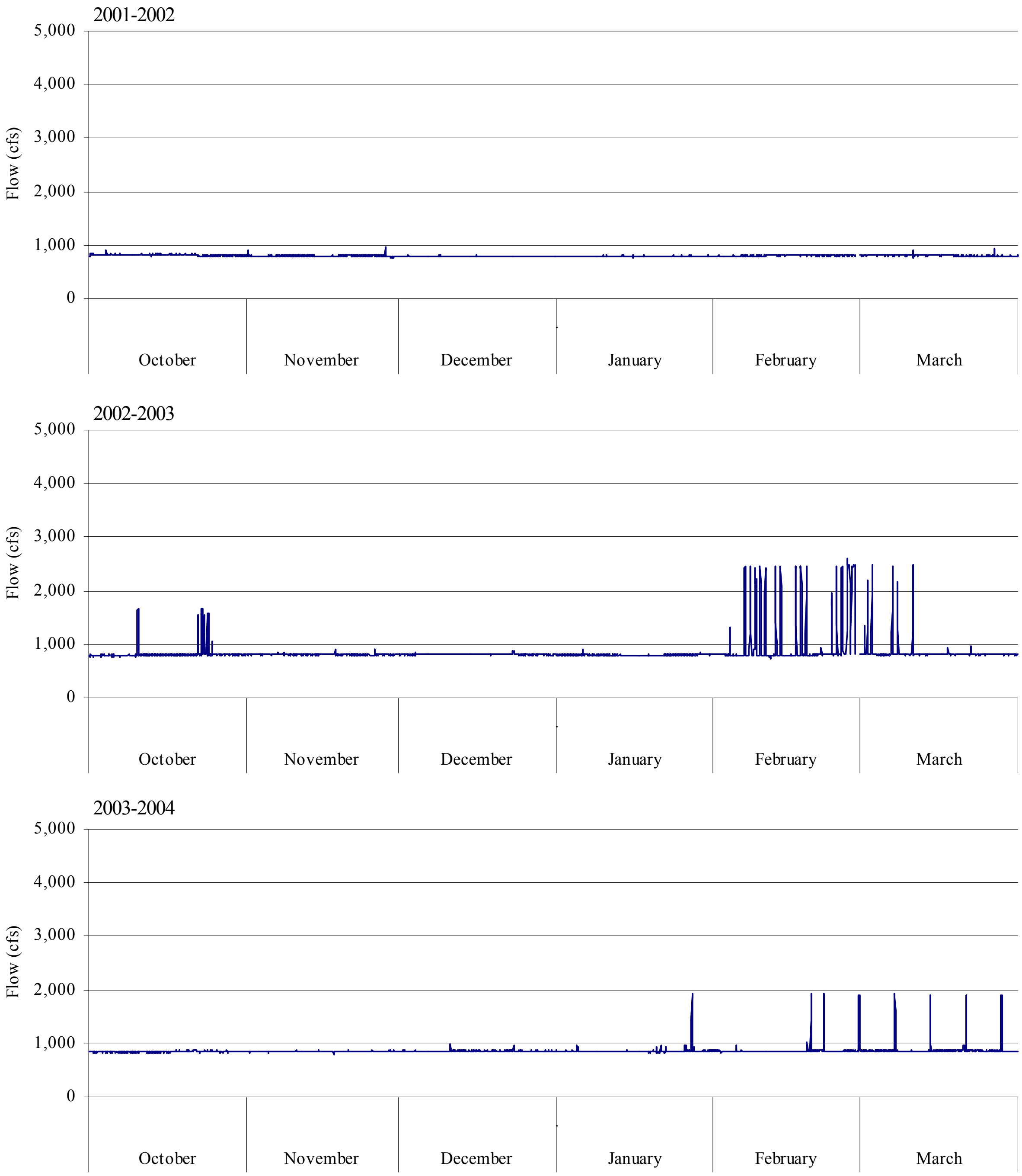


FIGURE B.1 (Cont.)

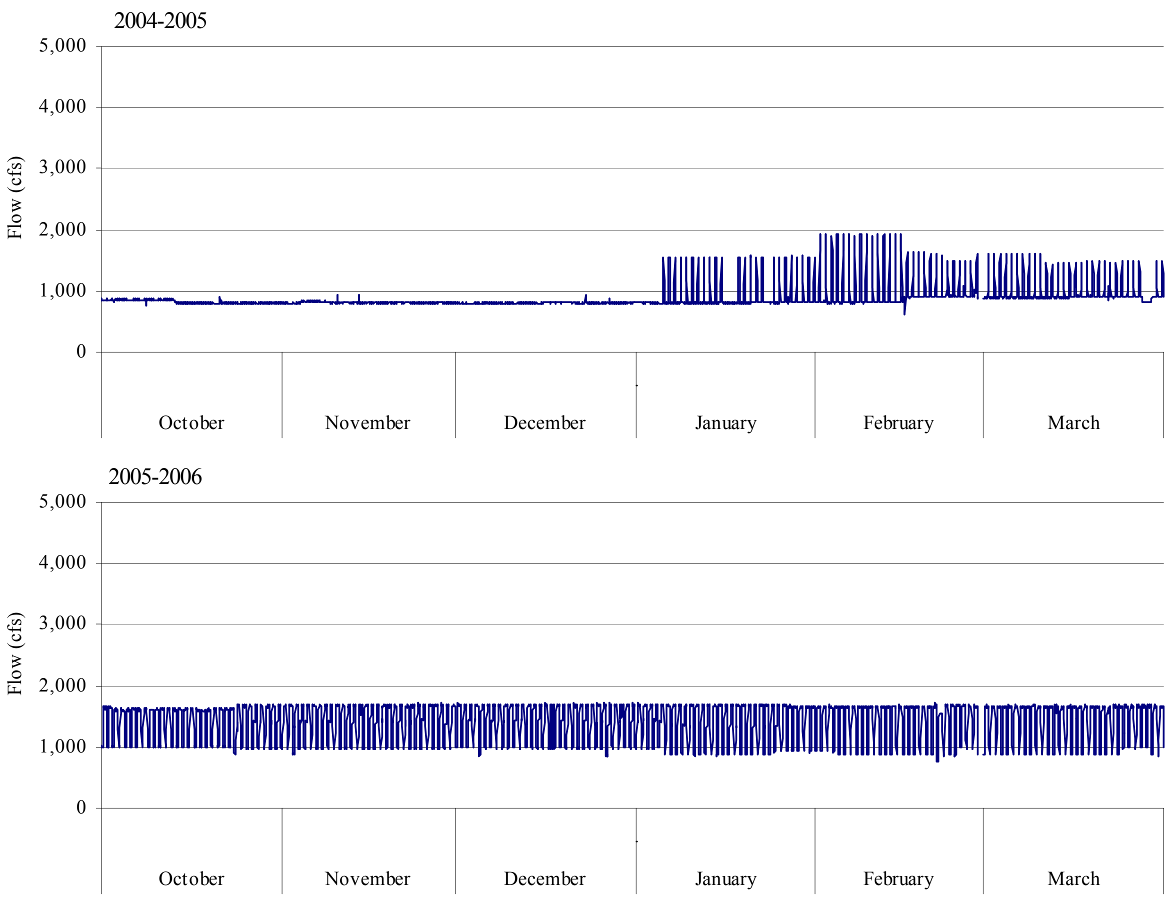


FIGURE B.1 (Cont.)

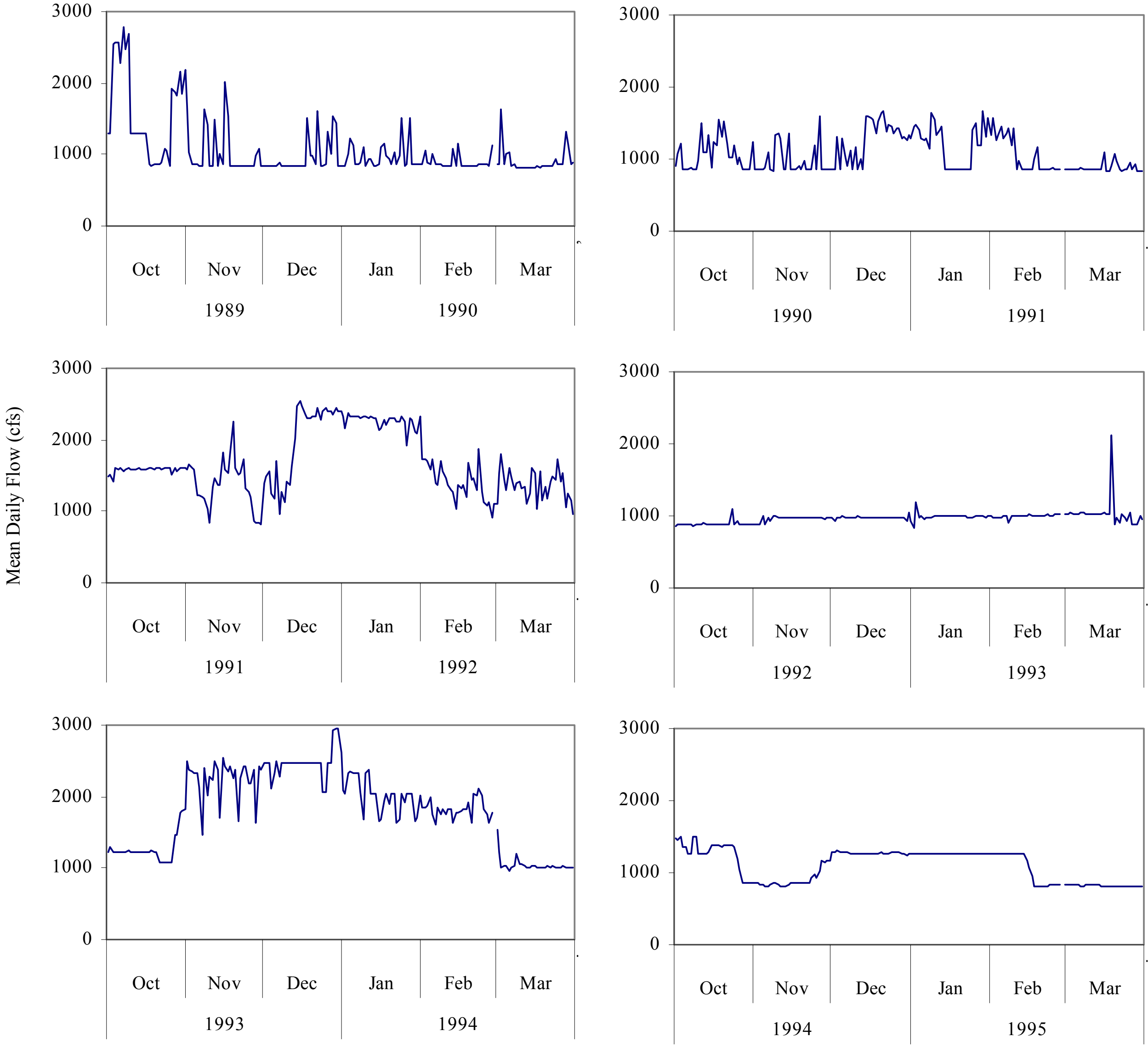
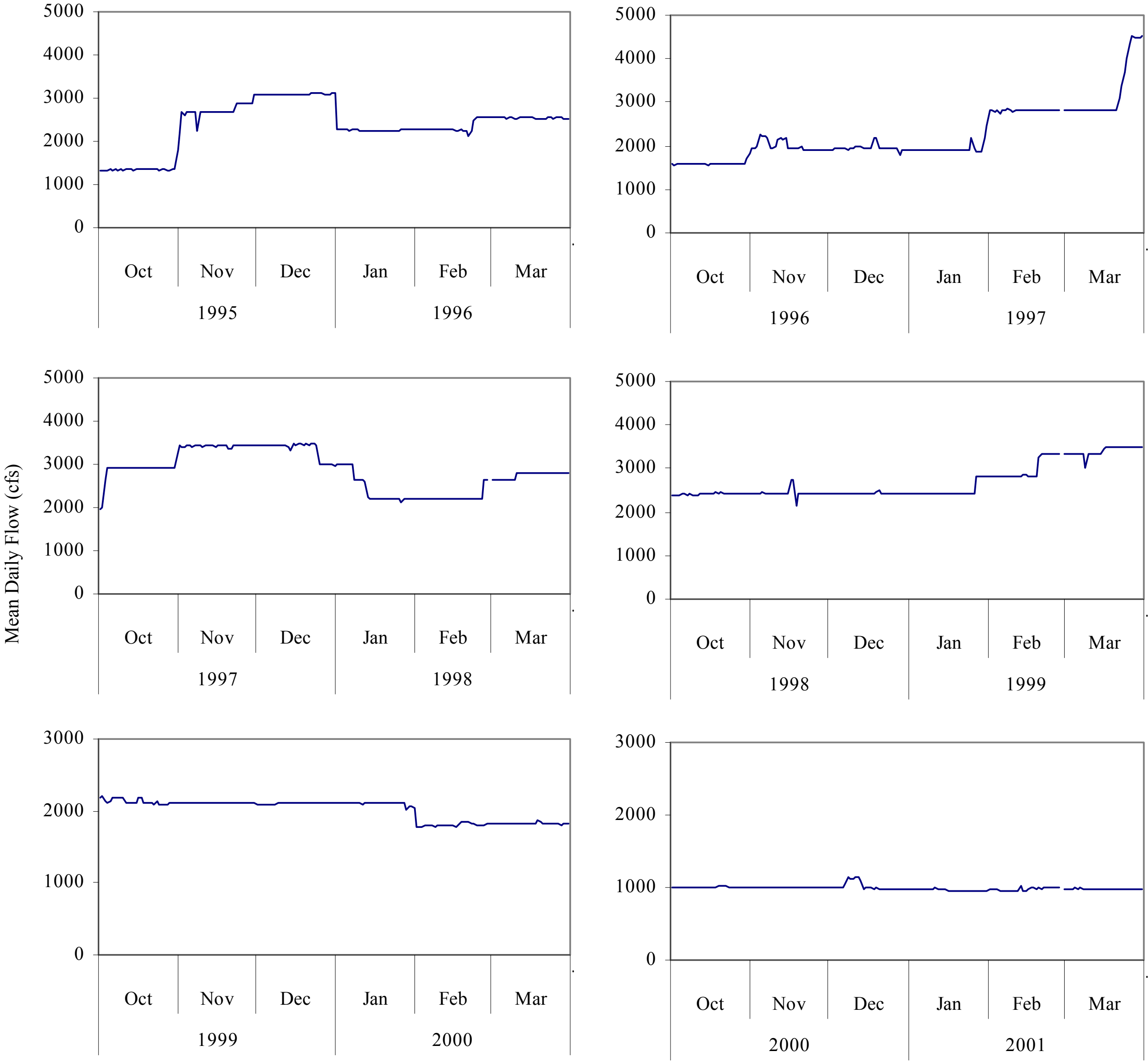


FIGURE B.2 Mean Daily Flow from October through March, 1990–2006



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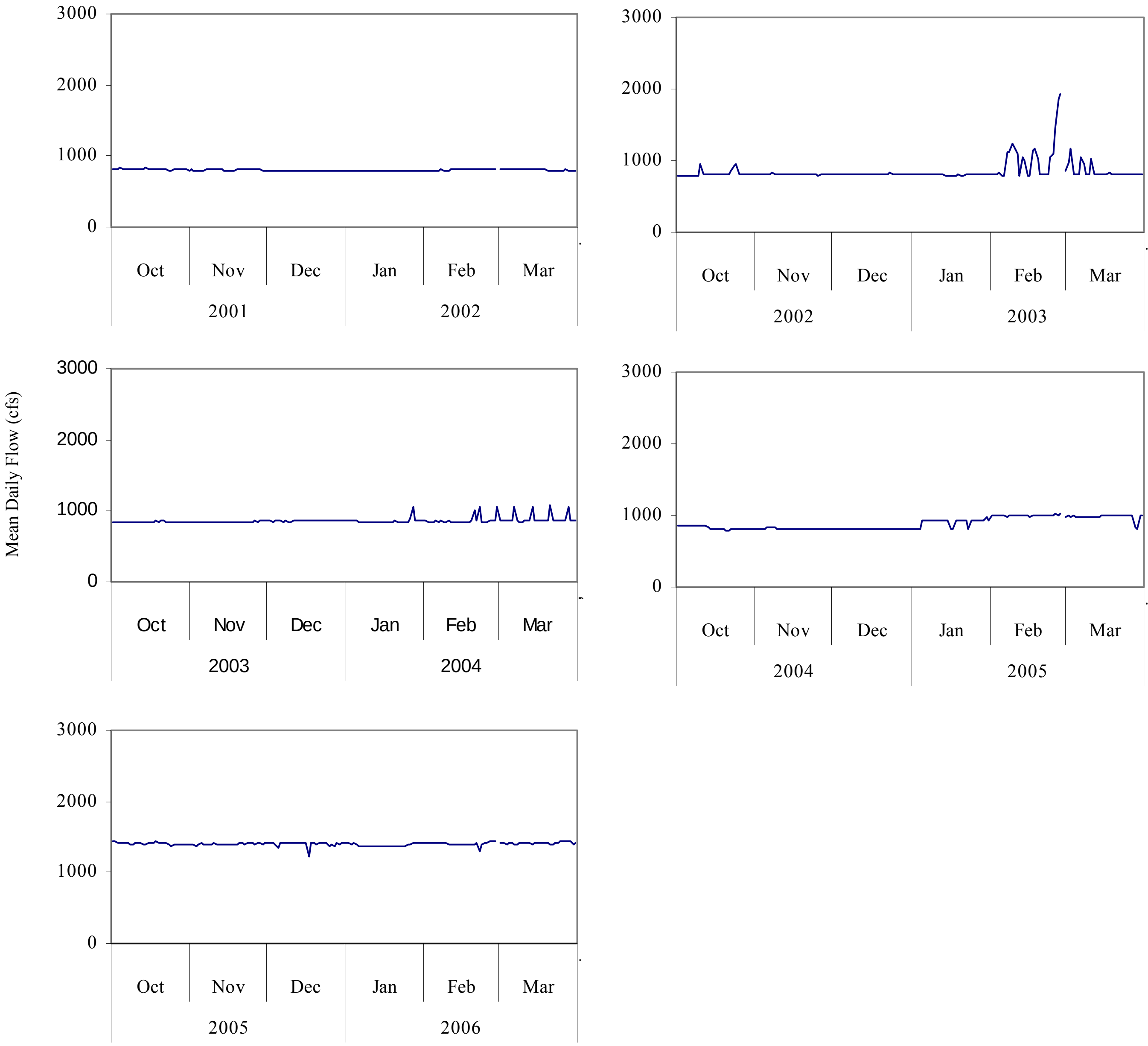

FIGURE B.2 (Cont.)

APPENDIX C

SPEARMAN RANK CORRELATIONS BETWEEN OCTOBER THROUGH MARCH FLOW VARIABLES IN THE GREEN RIVER DOWNSTREAM OF FLAMING GORGE DAM, 1990–2006

TABLE C.1 Spearman Rank Correlations (r_s) between October through March Flow Variables, 1990–2006[a]

Variable	Year	mean_dmean	med_dmean	mean_dmin	mean_dmax	sum_h1000	sum_h2000	sum_h3000	sum_h4000	mean_hdelta	mean_hdelta%	mean_drange	mean_dcv	mean_dskew	mean_ddelta	mean_ddelta%	cv_dmean	range_dmean	skew_dmean	mean_mdelta	mean_mdelta%
Year	1.00	-0.30	-0.24	-0.24	-0.36	-0.25	-0.42	-0.34	-0.32	**-0.51**	**-0.50**	-0.44	-0.42	-0.25	**-0.78**	**-0.70**	**-0.78**	**-0.67**	-0.09	**-0.58**	**-0.62**
mean_dmean	-0.30	1.00	**0.98**	**0.93**	**0.92**	**0.95**	**0.83**	**0.69**	0.38	0.48	0.14	**0.51**	0.27	-0.38	0.21	-0.11	0.38	**0.58**	**-0.54**	**0.74**	**0.53**
med_dmean	-0.24	**0.98**	1.00	**0.96**	**0.89**	**0.96**	**0.78**	**0.65**	0.27	0.43	0.10	**0.49**	0.22	-0.36	0.10	-0.20	0.27	**0.51**	**-0.54**	**0.69**	0.48
mean_dmin	-0.24	**0.93**	**0.96**	1.00	**0.76**	**0.91**	**0.72**	**0.62**	0.23	0.26	-0.04	0.33	0.06	-0.45	0.05	-0.23	0.23	0.46	-0.42	**0.63**	0.42
mean_dmax	-0.36	**0.92**	**0.89**	**0.76**	1.00	**0.86**	**0.85**	**0.73**	**0.49**	**0.66**	0.37	**0.67**	0.47	-0.15	0.38	0.06	**0.49**	**0.69**	-0.48	**0.75**	**0.56**
sum_h1000	-0.25	**0.95**	**0.96**	**0.91**	**0.86**	1.00	**0.77**	**0.52**	0.20	**0.54**	0.23	**0.60**	0.35	-0.29	0.11	-0.19	0.27	0.47	**-0.59**	**0.63**	0.45
sum_h2000	-0.42	**0.83**	**0.78**	**0.72**	**0.85**	**0.77**	1.00	**0.79**	0.46	0.48	0.12	0.47	0.22	-0.13	0.45	0.09	**0.54**	**0.76**	-0.19	**0.77**	**0.57**
sum_h3000	-0.34	**0.69**	**0.65**	**0.62**	**0.73**	**0.52**	**0.79**	1.00	**0.63**	0.17	-0.06	0.19	-0.02	-0.29	0.39	0.07	0.45	**0.74**	-0.02	**0.65**	0.44
sum_h4000	-0.32	0.38	0.27	0.23	**0.49**	0.20	0.46	**0.63**	1.00	0.34	0.25	0.34	0.30	-0.03	0.45	0.25	**0.58**	**0.67**	0.16	0.42	0.34
mean_hdelta	**-0.51**	0.48	0.43	0.26	**0.66**	**0.54**	0.48	0.17	0.34	1.00	**0.89**	**0.97**	**0.94**	0.32	**0.60**	0.44	**0.61**	**0.58**	-0.32	**0.51**	**0.50**
mean_hdelta%	**-0.50**	0.14	0.10	-0.04	0.37	0.23	0.12	-0.06	0.25	**0.89**	1.00	**0.87**	**0.98**	0.41	**0.61**	**0.59**	**0.51**	0.41	-0.15	0.24	0.30
mean_drange	-0.44	**0.51**	**0.49**	0.33	**0.67**	**0.60**	0.47	0.19	0.34	**0.97**	**0.87**	1.00	**0.92**	0.21	**0.50**	0.34	**0.56**	**0.58**	-0.40	**0.51**	**0.50**
mean_dcv	-0.42	0.27	0.22	0.06	0.47	0.35	0.22	-0.02	0.30	**0.94**	**0.98**	**0.92**	1.00	0.33	**0.56**	**0.50**	**0.51**	0.44	-0.25	0.28	0.31
mean_dskew	-0.25	-0.38	-0.36	-0.45	-0.15	-0.29	-0.13	-0.29	-0.03	0.32	0.41	0.21	0.33	1.00	0.26	0.38	0.11	-0.05	0.43	-0.15	-0.05
mean_ddelta	**-0.78**	0.21	0.10	0.05	0.38	0.11	0.45	0.39	0.45	**0.60**	**0.61**	**0.50**	**0.56**	0.26	1.00	**0.90**	**0.89**	**0.82**	0.27	**0.59**	**0.61**
mean_ddelta%	**-0.70**	-0.11	-0.20	-0.23	0.06	-0.19	0.09	0.07	0.25	0.44	**0.59**	0.34	**0.50**	0.38	**0.90**	1.00	**0.77**	**0.59**	0.36	0.38	**0.50**
cv_dmean	**-0.78**	0.38	0.27	0.23	**0.49**	0.27	**0.54**	0.45	**0.58**	**0.61**	**0.51**	**0.56**	**0.51**	0.11	**0.89**	**0.77**	1.00	**0.89**	0.03	**0.80**	**0.85**
range_dmean	**-0.67**	**0.58**	**0.51**	0.46	**0.69**	0.47	**0.76**	**0.74**	**0.67**	**0.58**	0.41	**0.58**	0.44	-0.05	**0.82**	**0.59**	**0.89**	1.00	0.03	**0.84**	**0.77**
skew_dmean	-0.09	**-0.54**	**-0.54**	-0.42	-0.48	**-0.59**	-0.19	-0.02	0.16	-0.32	-0.15	-0.40	-0.25	0.43	0.27	0.36	0.03	0.03	1.00	-0.31	-0.26
mean_mdelta	**-0.58**	**0.74**	**0.69**	**0.63**	**0.75**	**0.63**	**0.77**	**0.65**	0.42	**0.51**	0.24	**0.51**	0.28	-0.15	**0.59**	0.38	**0.80**	**0.84**	-0.31	1.00	**0.95**
mean_mdelta%	**-0.62**	**0.53**	0.48	0.42	**0.56**	0.45	**0.57**	0.44	0.34	**0.50**	0.30	**0.50**	0.31	-0.05	**0.61**	**0.50**	**0.85**	**0.77**	-0.26	**0.95**	1.00

[a] Statistically significant correlations ($P \leq 0.05$) are indicated in bold text.

APPENDIX D

SPEARMAN RANK CORRELATIONS BETWEEN TROUT AND FLOW VARIABLES IN THE GREEN RIVER DOWNSTREAM OF FLAMING GORGE DAM, 1990–2006

TABLE D.1 Spearman rank Correlations (r_s) between Trout Variables and Year and Flow, 1990–2006[a]

			Flow Volume								Within–Day Variability					Between–Day Variability		Within–Season Variability				
Species and Location	Trout Variable	Year	mean_dmean	med_dmean	mean_dmin	mean_dmax	sum_h1000	sum_h2000	sum_h3000	sum_h4000	mean_hdelta	mean_hdelta(%)	mean_drange	mean_dcv	mean_dskew	mean_ddelta	mean_ddelta (%)	range_dmean	cv_dmean	skew_dmean	mean_mdelta	mean_mdelta (%)
BTR	L	–0.15	0.14	0.24	0.21	0.24	0.06	0.22	0.42	0.24	–0.03	–0.06	0.04	–0.16	–0.02	0.09	0.13	0.41	0.20	0.17	0.44	0.43
	W	**–0.54**	–0.16	–0.15	–0.16	0.05	–0.31	0.09	0.31	0.27	0.02	0.16	0.01	0.01	0.20	0.45	0.50	0.48	0.43	0.39	0.28	0.36
	WR	–0.52	–0.35	–0.37	–0.4	–0.09	–0.45	–0.06	0.00	0.09	0.11	0.29	–0.04	0.11	**0.56**	0.42	0.47	0.17	0.25	0.52	0.03	0.13
	ratio WR	0.08	–0.14	–0.19	–0.09	–0.23	–0.12	0.01	–0.26	–0.26	–0.03	–0.17	–0.19	–0.16	0.27	–0.04	–0.16	–0.26	–0.14	0.21	–0.21	–0.23
RTR	L	–0.53	–0.37	–0.39	–0.4	–0.12	–0.5	–0.1	0.07	0.22	0.13	0.29	0.03	0.13	0.37	0.50	0.52	0.36	0.39	**0.54**	0.09	0.20
	W	**–0.65**	–0.35	–0.41	–0.44	–0.07	–0.49	–0.04	0.12	0.23	0.16	0.36	0.03	0.18	0.45	**0.60**	**0.63**	0.38	0.43	**0.55**	0.10	0.20
	WR	**–0.60**	–0.15	–0.19	–0.20	0.06	–0.32	0.09	0.27	0.28	0.12	0.25	0.06	0.11	0.20	**0.56**	**0.59**	0.51	0.49	0.40	0.28	0.35
	ratio WR	–0.25	0.19	0.15	–0.03	0.31	0.24	0.18	–0.17	–0.20	**0.60**	0.46	0.51	0.51	0.08	0.41	0.29	0.20	0.32	–0.46	0.30	0.28
BLH	L	0.31	–0.11	0.02	0.00	–0.03	–0.11	0.09	0.19	–0.03	–0.35	–0.37	–0.41	–0.45	0.36	–0.37	–0.42	–0.26	–0.45	0.45	–0.22	–0.33
	W	–0.29	–0.13	–0.13	–0.18	0.09	–0.19	0.14	0.16	0.14	0.10	0.16	–0.09	0.03	**0.66**	0.26	0.23	0.07	0.05	**0.58**	–0.01	–0.03
	WR	–0.47	–0.06	–0.13	–0.09	0.06	–0.17	0.25	0.32	0.14	0.05	0.07	–0.16	–0.06	0.43	0.49	0.42	0.27	0.23	**0.65**	0.10	0.04
	ratio WR	–0.13	–0.45	–0.47	–0.52	–0.32	–0.49	–0.50	–0.45	–0.30	0.08	0.30	–0.01	0.22	0.15	0.14	0.24	–0.24	–0.01	–0.05	–0.16	–0.06
RLH	L	**–0.67**	**–0.56**	**–0.59**	–0.53	–0.37	**–0.54**	–0.23	–0.19	0.20	0.25	0.44	0.13	0.28	**0.72**	**0.57**	**0.60**	0.25	0.42	**0.76**	–0.15	0.02
	W	**–0.70**	–0.45	–0.51	–0.46	–0.22	**–0.54**	–0.10	0.03	0.31	0.20	0.38	0.04	0.23	**0.64**	**0.66**	**0.67**	0.36	0.48	**0.82**	–0.04	0.06
	WR	–0.27	–0.09	–0.10	–0.09	0.11	–0.32	0.21	**0.55**	0.51	–0.23	–0.12	–0.28	–0.23	0.27	0.26	0.24	0.35	0.22	**0.68**	0.09	0.04
	ratio WR	0.15	–0.19	–0.23	–0.27	–0.17	–0.21	–0.32	–0.40	–0.32	0.06	0.16	–0.01	0.18	–0.09	–0.03	–0.03	–0.30	–0.14	–0.27	–0.19	–0.18

[a] Statistically significant correlations ($P \leq 0.05$) are indicated in bold text. L = length, W = weight, WR = relative weight, ratio WR = change in relative weight from fall to spring, BTR = brown trout at Tailrace, RTR = rainbow trout at Tailrace, BLH = brown trout at Little Hole, RLH = rainbow trout at Little Hole.

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