Logan River whirling disease study: factors affecting trout population dynamics, abundance, and distribution in the Logan River, Utah

by
Phaedra Budy
Assistant Professor
Assistant Coop Leader

Gary P. Thiede
Research Associate

Ernesto A. de la Hoz
Graduate Research Assistant

and

Shane Vatland
Research Assistant

USGS Utah Cooperative Fish and Wildlife Research Unit
Department of Aquatic, Watershed, and Earth Resources,
and Ecology Center
Utah State University
Logan, UT 84322-5290

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TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS	vi
EXECUTIVE SUMMARY	vii
INTRODUCTION	1
STUDY SITE	4
METHODS	4
Biological data	5
Fish sampling	5
Collection	5
Population estimates	5
Condition	6
Diet analysis	6
Whirling disease analysis	6
Fish Health Condition Assessment	7
Invertebrate sampling	7
Oligochaetes and *Tubifex tubifex* collection	7
Periphyton	7
Environmental variables	7
Discharge	8
Temperature	8
Substrate	8
Turbidity	8
Conductivity and pH	8
Nutrient sampling and analysis	8
Fish Movement	8
Creel Survey	9
Sentinel Fish Experiments	9
RESULTS	9
Biological data	9
Fish sampling	9
Franklin Basin	10
Red Banks	10
Forestry Camp	10
Twin Bridges	10

Third Dam …….. 11
Lower Logan ……..…….. 11
Temple Fork …….. 11
Right Hand Fork …….. 11
Condition ……... 12
Whirling disease analysis …….… 14
Cutthroat trout ……..……... 14
Brown trout …….……... 14
Other salmonids ……... 14
Fish Health Condition Assessment ……..……... 14
Oligochaete and *Tubifex tubifex* collection…..…….. 15
Periphyton……..…….. 15
Environmental variables……... 15
Discharge ……..……... 15
Temperature ……... 15
Substrate ……... 16
Turbidity…….. 16
Conductivity and pH …… 16
Nutrient sampling and analysis ……... 16
Fish Movement ……. 16
Creel Survey …… 17
Sentinel Fish Experiments …….. 18
DISCUSSION……. 19
FUTURE …….. 21
LITERATURE CITED …….. 23
APPENDICES ……... 49
Length-weight regressions ……. 49
2002 Creel survey …… 50

LIST OF TABLES

		Page
Table 1.	Population estimates (Fish/km) based on the modified Zippin depletion method. NA indicates that although a particular species was present at the site, insufficient catch precluded population estimation. SE designates one standard error……..	12
Table 2.	Comparison of number of fish by species per kilometer for five river sections. Numbers are based on reach-specific modified Zippin population estimates. Double dashes (--) indicate that no fish were captured or there was insufficient catch precluded a population estimate. All ages combined. Data prior to 2001 were taken from UDWR report 00-3……..	13
Table 3.	Number of trout tagged in the Logan River mainstem and two tributaries in 2002. Each trout was tagged with an individually-numbered, site-specifically colored tag. Double dash (--) indicates that no fish were captured or tagged at that site……	17
Table 4.	Catch and harvest estimates based on catch rate, angling hours, and number of anglers per day for creel survey conducted on the Logan River, June-August 2002……	18

LIST OF FIGURES

		Page
Figure 1.	Map of the Logan River and sample sites. Light gray squares in upper reaches indicate sites that tested negative for *M. cerebralis* in 1999. Dark squares tested positive in 1999. Circles indicate sites were whirling disease was detected in 2001……..	28
Figure 2.	Population estimates for cutthroat trout, brown trout, and mountain whitefish based on a modified Zippin depletion method, for six sites on the Logan River and tributaries (Temple Fork and Right Hand Fork), 2001-2002. Error bars represent 95% confidence intervals……..……	29
Figure 3.	Estimated number of cutthroat trout per kilometer in the Logan River and two tributaries, 1967-2002. Sample reaches were 200 m long in the mainstem and 100 m long in the tributaries. Error bars represent 95% confidence intervals……	30

Figure 4. Estimated number of brown trout per kilometer in the Logan River and two tributaries, 1967-2002. Sample reaches were 200 m long in the mainstem and 100 m long in the tributaries. Error bars represent 95% confidence intervals……. 31
Figure 5. Length frequency distributions by species for fish captured by electrofishing in Franklin Basin, 2002. The modified Zippin population estimate is shown as N, and 95% confidence intervals are in brackets. NA indicates that a population estimate was not possible……. 32
Figure 6. Length frequency distributions by species for fish captured by electrofishing at Red Banks, 2002. The modified Zippin population estimate is shown as N, and 95% confidence intervals are in brackets. NA indicates that a population estimate was not possible……. 32
Figure 7. Length frequency distributions by species for fish captured by electrofishing at Forestry Camp, 2002. The modified Zippin population estimate is shown as N, and 95% confidence intervals are in brackets……. 33
Figure 8. Length frequency distributions by species for fish captured by electrofishing at Twin Bridges, 2002. The modified Zippin population estimate is shown as N, and 95% confidence intervals are in brackets. ……... 33
Figure 9. Length frequency distributions by species for fish captured by electrofishing at Third Dam, 2002. The modified Zippin population estimate is shown as N, and 95% confidence intervals are in brackets……..……. 34
Figure 10. Length frequency distributions by species for fish captured by electrofishing at the Lower Logan site, 2002. The modified Zippin population estimate is shown as N, and 95% confidence intervals are in brackets……. 34
Figure 11. Length frequency distributions by species for fish captured by electrofishing at Temple Fork, 2002. The modified Zippin population estimate is shown as N, and 95% confidence intervals are in brackets…….…. 35
Figure 12. Length frequency distributions by species for fish captured by electrofishing at Right Hand Fork, 2002. The modified Zippin population estimate is shown as N, and 95% confidence intervals are in brackets…….……. 35

Figure 13. Condition (Fulton's K) of adult and subadult cutthroat trout (top panels) and brown trout (bottom panels) captured in the Logan River, 2001 and 2002. Error bars represent ± 1 SE…… 36
Figure 14. Condition (Fulton's K) of adult and subadult brown trout (top panels) and brown trout (bottom panels) captured in the Logan River, 2001 and 2002. Error bars represent ± 1 SE……. 37
Figure 15. Percentage of cutthroat trout (all ages combined) by sample site tested positive for *M. cerebralis* in the Logan River, 2001 and 2002, based on PCR testing. Sample sizes (n) are given above bars…… 38
Figure 16. Percentage of brown trout (all ages combined) by sample site tested positive for *M. cerebralis* in the Logan River, 2001 and 2002, based on PCR testing…….. 39
Figure 17. Total number of oligochaetes (left y-axis) sampled per time unit (10 minutes) by sampling site, and percentage of *Tubifex tubifex* (right y-axis) in each sample by site…….. 40
Figure 18. Periphyton biomass expressed in mg/m^2 of chlorophyll *a* at eight sites on the Logan River, 2001 and 2002. Boxes correspond to quartiles: bold line is the mean, narrow line is the median. Whiskers correspond to the 10th and 90th percentiles. Sample size (n) is the total number of rocks used for chlorophyll a extraction. Data from three transects at each site were combined…….…… 41
Figure 19. Monthly discharge measurements (cfs) at eight sites along the Logan River and two tributaries, 2001 and 2002……... 42
Figure 20. Average summer temperatures at eight sites along the Logan River, 2001 and 2002. Maximum and minimum temperatures are indicated for 2002……. 43
Figure 21. Average daily temperatures at seven sites along the Logan River and tributaries, 2001 and 2002. Shaded areas show ideal temperatures for TAM production, *T. tubifex* growth, and temperatures correlated with high *M. cerebralis* infection rates in Colorado streams…… 44
Figure 22. Substrate measurements in the Logan River, 2001 and 2002. Mean particle size (left y-axis) and percent fines (right y-axis) are shown by site……... 45
Figure 23. Average summer total nitrogen (mg/L; top panel) and average summer total phosphorous (μg/L; bottom panel) measured at six sites in the Logan River mainstem and two tributaries, 2001 and 2002……... 46

Figure 24. Number of anglers counted and interviewed within each sampling reach. Note that all anglers counted were not necessarily interviewed…….…. 47
Figure 25. Angler responses to a question regarding the desirability of mountain whitefish…….. 47
Figure 26. Angler responses to a question regarding fishing success…….. 48
Figure 27. Angler responses to a question regarding overall fishing trip satisfaction…… 48

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EXECUTIVE SUMMARY

During base flow conditions of 2001 and 2002, trout populations were sampled at eight sites ranging from Franklin Basin at high elevation to the Lower Logan site below the golf course. Population estimates were completed based on depletion techniques. Fish were weighed and measured, and condition was assessed. Subsamples of fish from each species and age group (adult or subadult) were tested for whirling disease using a polymerase chain reaction (PCR) technique. We sampled abiotic variables including temperature, conductivity, pH, turbidity, and substrate composition along with biotic variables including oligochaete density and composition, chlorophyll *a*, and nutrients (nitrogen and phosphorus) at each site.

In addition to our baseline monitoring and evaluation and as part of his Master's thesis, De la Hoz (2003) investigated the relationship between temperature, discharge, substrate size, nutrient concentration (nitrogen and phosphorous), periphyton (chlorophyll *a*), and the relative abundance of *Tubifex tubifex* to the distribution, and prevalence of *Myxobolus cerebralis* in wild salmonid populations and sentinel fish in the mainstem of the Logan River and two of its tributaries. De la Hoz also explored the suitability of these factors in the development of a simple predictive model relating potential increases in prevalence of *M. cerebralis* to differences or changes in environmental factors.

Trout density has not changed significantly over the duration of the study (initiated in 2001) and compared to previous evaluations. The number of cutthroat trout decreased slightly in 2002 compared to 2001, but not compared to previous years. These data suggest that thus far, trout in the Logan River are not experiencing population-level effects from the widespread presence of whirling disease throughout the drainage. Considering the maximum age of these trout, the higher susceptibility of juvenile fish, we would expect to see a time lag between the establishment of the parasite and any population decline. Thus, we strongly caution that it may be far to soon to see a population-level effect, especially considering the overall increase in prevalence of *M. cerebralis* and the potential for synergistic effects of life history and environmental conditions (both years of the study were very similar environmentally).

As observed in 2001, in 2002 whirling disease was widely distributed throughout the Logan River drainage and prevalence of *M. cerebralis* in trout has increased 10-25% since 2001. Right Hand Fork is the only site that remains "clean" and free of *M.*

cerebralis (this site is dominated 100% by brown trout). In sentinel fish, prevalence ranged from undetected at the upper-most site and the two tributaries, to 56% at an upper-elevation mainstem site (Forestry Camp). The parasite was not detected in sentinel fish at two sites (Franklin Basin and Temple Fork) where wild trout were infected. Despite this widespread prevalence, we observed very few fish with clinical signs that could be attributed to the effect of the parasite (*but see Discussion*). Fish condition (as Fulton's K), while highly variable, remains near 1 at most sites. However, we note that there is a significant decline in condition for most categories of trout, as we move from the upper elevation sites down to the site below the Lower Logan golf course (R^2 range from 0.42-0.71). This pattern is likely driven by increased temperatures and altered habitat conditions at the lowermost sites of the Logan River.

Abiotic and biotic variables were variable across sites within the river, but were similar for the two years of the study. *M. cerebralis* prevalence in cutthroat trout and brown trout (response variables) was related to two environmental factors (explanatory variables). The prevalence of *M. cerebralis* among cutthroat trout increased with increasing temperatures from high to low elevation sites, and the highest prevalence of the parasite was associated with temperatures around 12 °C. In addition, prevalence demonstrated a nonlinear relationship with discharge, with the highest prevalence, at a low elevation mainstem site (Third Dam). A similar pattern was observed for prevalence in brown trout in relation to temperature and discharge. Prevalence was not related to the other biotic factors (e.g., productivity) or abiotic factors (e.g., sedimentation) thought to be linked to oligochaete worms or the distribution of the worms themselves. However, the range of conditions both among sites within the Logan River and among years may not have provided an adequate range to evaluate these relationships fully. This limitation may have occurred despite the substantial difference in elevation and habitat use observed across our index sites and may also be an artifact of high within-site variability for some of the variables (e.g., chlorophyll). Nonetheless, the predictive relationship between prevalence and temperature and discharge explains a large proportion of the variance, is statistically significant, and is mechanistically and biologically explainable (De la Hoz 2003).

Our study was conducted to provide baseline information for the distribution and prevalence of *M. cerebralis* along the Logan River, and to assess potential relationships between environmental factors and the parasite. Annual monitoring is critical for detecting, understanding, and predicting the current and future impacts of *M. cerebralis* on Bonneville cutthroat trout. The understanding of the environmental variables that influence the distribution and prevalence of *M. cerebralis*, and the

mechanisms of its dispersal, is a tool that fishery biologists and managers could use to limit the spread of the parasite, and to develop plans to minimize potential negative effects on wild salmonid populations.

In addition to likely being one of the last remaining fisheries with intact habitat and a strong population of cutthroat trout, the Logan River provides a popular fishery for cutthroat trout. Our creel census revealed that the fishery gets consistent pressure and is fished by a wide variety of anglers. The great majority of the anglers ranked their fishing trip on the Logan as “Very satisfactory”, the highest possible category, demonstrating the popularity of this fishery for local recreation enthusiasts. In addition, most (94%) caught trout on the Logan River are released, further indicating a community commitment to the future sustainability of the resource.

INTRODUCTION

The Logan River, once considered one of the best trout streams in the region, still supports a popular fishery for stocked rainbow trout (*Oncorhynchus mykiss*), brook trout (*Salvelinus fontinalis*), brown trout (*Salmo trutta*), and the endemic Bonneville cutthroat trout (*O. clarki utah*). The decline in the population of the native cutthroat trout throughout the intermountain west is evident, and only a few populations remain However, the Bonneville cutthroat trout in the Logan River might be one of the strongest and largest metapopulations within their historic range (Thompson et al. 2000). In addition, there is no evidence within this watershed that non-native trout have expanded their populations within the past decades. Understanding the population dynamics and condition of the trout population, habitat quality, and the current and potential future effects of disease in the Logan River is critical for the effective management of this system (Lentsch et al. 1997).

Dynamics of fish populations are directly linked to the environmental characteristics of their habitat. Physical, chemical, and biological characteristics of the environment affect growth, survival, and birth rates. Further, salmonids use different habitats at different life stages and during different seasons (Bradford and Higgins 2000; Bonneau and Scarnechia 1997; Maki-Petays et al. 1996); therefore, it is necessary to expand habitat-population relationships to larger scales that encompass the various habitats used. Physical characteristics of habitat similarly affect the community structure and distribution of macroinvertebrate fauna and other biota. Hydrological and sedimentary networks within a drainage can explain, at least partially, the community organization of macroinvertebrate communities (Rice et al. 2001).

In addition to environmental variables, parasites and disease likely play an important role in determining fish population dynamics. The severity, prevalence, and impact of a given disease also depend on the interactions of several variables of the host, the pathogen, and environment (Reno 1998). Pathogens demand energy that the host would otherwise use for growth, survival, and reproduction (Minchella and Scott 1991). The occurrence of disease depends on the genetic characteristics, immunological, and nutritional conditions of the host, among other variables (Moffit et al. 1998). Diseases occur both in wild and cultured fish populations; however, while the effects of many diseases are known in cultured fish, less information is available for wild populations.

Myxobolus cerebralis, the parasite causative agent of whirling disease, has caused severe declines at the population level in some states such as Colorado and Montana (Nehring and Walker 1996; Vincent 1996; Baldwin et al 1998); however, fish

populations from other areas where fish have tested positive for whirling disease in other states (e.g., California) have not been significantly impacted. Fish samples for the Logan River have tested positive for whirling disease, but there is no evidence of population declines in this drainage at this time (Thompson et al. 2000, Budy et al. 2002).

Environmental factors also influence ecology of the tubificid oligochaete, *Tubifex tubifex*. These worms are necessary as intermediate hosts, to complete the *M. cerebralis* life cycle. Reynoldson (1987) experimented with the effects of temperature, oxygen, and substrate on growth rates of tubificid oligochaetes and demonstrated that the growth of *T. tubifex* occurs over a narrow temperature range (10-13 °C). On the other hand, his experiments indicated they tolerated extended periods of anoxia and showed no evidence of substrate quality affecting growth rates. Tubificid preference of substrate; however, has been significantly correlated with the abundance of heterotrophic aerobic bacteria, suggesting that biological components may be more important than physical or chemical properties on their substrate selection (McMurtry et al. 1983). In addition, increasing concentrations of nitrogen and phosphorous in the water as well as the proliferation of bacteria lead to increasing abundance of *T. tubifex* (Lestochova 1994). Further, tubificid worms show preference for a combination of silt-clay and leaf material, such that the associated microflora might offer concentrated bacterial food (Lazim and Learner 1987).

Within *T. tubifex* worms, *M. cerebralis* transforms to an actinosporean (triactinomyxon gyrosalmo or TAM), which can infect salmonids. El-Matbouli et al. (1999) showed experimentally that 15 °C is the optimal temperature for the production of TAMs in infected *T. tubifex*, lower temperatures (5-10 °C) apparently retard the development and maturation, but extend the period of spore production. In contrast, temperatures between 15 °C and 20 °C apparently accelerate the development of the parasite, increase the number of spores released, and decrease the period of release. Production of TAMs in natural systems may also be related to variables such as changing diel light cycle, water flows, and temperature or timing of worm infection (Arndt et al. 2001). Smith et al. (2001) found that TAM viability decreases as pH moves farther from neutral values. Other experiments revealed that neither water hardness nor low dissolved oxygen levels (0-0.5 mg/L for a period of 72 hours) had an effect on the viability of the spores at exposure times between 24 to 72 hours. However, in general, there is a limited understanding of the biological-ecological variables that influence host-pathogen relations. To understand the diseases and their possible impacts on fish populations, it is crucial to determine which of the variables are important, how to measure these variables, and how to interpret the results of such measurements (Hedrick 1998).

Numerous studies have focused on the biology of the parasite (Halliday 1976), the oligochaete host - *Tubifex tubifex* (Hedrick and El-Matbouli 2002), and on the effects of fish (MacConnell and Vincent 2002). Surprisingly fewer studies have been designed to identify and enhance the understanding of the environmental factors that may be associated to the distribution, prevalence, and infectivity of the parasite (Hiner and Moffitt 2002).

Myxobolus cerebralis was reported for the first time in Utah in 1991. Other test samples have also demonstrated the presence of another pathogen (*M. neurobius*) related to the whirling disease pathogen. Possible effects of *M. cerebralis* on the native trout population in the Logan River are not yet known, nor are the physical, chemical, and biological characteristics that might be linked to its dispersal, infectivity, and prevalence. While trout and salmon samples from many systems through the United States have tested positive for whirling disease, population level effects of the disease have been variable or unreported (Nehring and Walker 1996).

To evaluate population changes and the potential effects of whirling disease, we initiated (2001) a long-term monitoring program of the fish community at eight sites, from the upper headwaters of the Logan River (Franklin Basin) to the lower Logan River (Logan River golf course area; Figure 1). Survey locations were chosen to maximize information on trout distribution and capture the range of physical habitat characteristics observed in the Logan River drainage. Most selected sites were previously sampled by the Utah Division of Wildlife Resources (UDWR; *see* Thompson et al. 2000). This allowed us to compare and contrast our results to data from previous surveys. In addition, we considered different physical (e.g., flow, temperature, substrate), chemical (e.g., concentrations of phosphorous and nitrogen), and biological (e.g., productivity) factors associated with fish abundance and distribution, as well as the presence and prevalence of *M. cerebralis* along the stream.

The objectives of this study are to assess the current status of trout populations in the Logan River, evaluate possible environmental factors affecting these populations, and learn more about the presence of *M. cerebralis* in the system and its possible implications for trout populations. In this later aspect, we focus on the relationships between environmental factors (e.g., temperature, flow, sediment) and the prevalence of whirling disease.

We separated the study into two components. The biological component addresses (1) the indices of productivity including measurements of chlorophyll concentrations in the periphyton, (2) the assessment of the abundance and distribution of trout populations and oligochaete worms, and (3) the prevalence of whirling disease. A second abiotic

component includes the measurement of relevant physical and chemical variables including nutrients, flow, turbidity, substrate, temperature, pH, and conductivity.

STUDY SITE

The headwaters of the Logan River are located in the southeastern corner of Franklin County, Idaho (Figure 1). The river runs southwest entering the state of Utah in the northeast corner of Cache County at an approximate elevation of 2600 m. The two largest tributaries are the Franklin Basin branch and the Beaver Creek branch, the first one being the largest; they join approximately 2 km south of Beaver Mountain, about 10 km south of the Idaho state line. The stream then runs through Logan Canyon for 64 km to reach the city of Logan, dropping to an elevation of approximately 1370 m at the eastern city limits (Thoreson 1949).

The gradient on the main stream varies from 7-32 m per km, and the higher gradient of the tributaries reach 75 m per km in Spawn Creek, making them predominantly white-water streams. Riffles and swift channels are common while pools are sparse. Boulders and rubble are common in the stream bottom of higher gradient sections; gravel beds and sand occur in areas of lower gradient or not exposed to the stream current, solid bedrock is also common. Impoundments are heavily silted as a result of natural erosion. The average discharge at the mouth of the canyon is 247 cfs (7 m^3/s; Sigler 1951).

Predominant game fish include native Bonneville cutthroat trout, brown trout, stocked rainbow trout (including albino strains), brook trout, and mountain whitefish. Non-game fish include carp (*Cyprinus carpio*), mountain sucker (*Catostomus platyrhyncus*), and mottled sculpin (*Cottus bairdi*).

METHODS

To meet the general objectives, we used the following methodologies:

1) Use depletion electroshocking methods to sample salmonids, and estimate population abundance and distribution.
2) Evaluate all fish sampled for external signs of whirling disease, examine the retained subsample of subadult and adult fish following a Health Condition Assessment and using PCR analysis.
3) Determine oligochaete density and distribution.

4) Measure relevant physical and chemical variables such as discharge, temperature, substrate, turbidity, conductivity, pH, and nutrient (nitrogen and phosphorous) concentrations that may determine and limit the distribution of worms and spores over spatial and temporal scales.
5) Relate these biotic and abiotic variables to fish and invertebrate distribution and abundance, and distribution and presence of *M. cerebralis*.
6) Determine whirling disease infection rates and the intensity of the infection among sentinel fish exposed in the field.
7) Determine degree of fish movement between whirling disease "hot spots" and "clean areas" by marking and recapturing trout.
8) Assess the Logan River fishery based on a roving creel census and tag recaptures both from surveys and from anglers.

Biological data

Fish sampling

Collection- Fish collection was conducted during base flow conditions using a three-pass depletion technique. Block nets were placed at the lower and upper end of each stream section (100 m sections in the headwaters and tributaries, 200 m in the mainstem). The settings on the electrofishing equipment varied depending on the stream conductivity. Effort was recorded as the time spent fishing per fixed distance, as suggested by Reynolds (1996). For smaller streams, a backpack mounted electrofishing unit was used. For the larger mainstream surveys, a canoe-mounted electrofishing unit was used. Captured fish were anesthetized with a dose of MS-222. Lengths (mm total length, TL) and weights (g) were recorded and in addition, fish were checked for external signs of whirling disease (e.g., black tail, deformities of the jaw or spine). When more than one hundred fish of any species were captured, lengths and weights were recorded only for the first hundred (Reynolds 1996). When possible, 20 subadults and 10 adults from each species were kept. These fish were euthanized using a lethal dose of MS-222 and placed on ice in labeled bags after lengths and weights were measured. These fish were used for diet, health condition assessment, whirling disease, and potential future stable isotope analyses.

Population estimates- Population estimates were calculated by two removal methods: a linear 3-pass depletion estimate and a modified Zippin depletion estimate. A reach-specific linear 3-pass depletion population estimate for each fish species was determined using a standard linear regression, where the x-intercept (when $y = 0$) equals the population estimate.

$$N = x + (y / -c)$$

Where,
N = population estimate, also is equals the intercept on the y-axis when x = 0,
x = cumulative catch,
y = catch per effort,
c = slope of the regression line (catchability).

For comparison purposes, a modified Zippin multiple-pass depletion formula (Zippin 1958) was used to estimate the population (± 95% confidence intervals, CI) of cutthroat trout, brown trout, and mountain whitefish for each site where sufficient fish were caught. A modified Zippin depletion estimate was used by UDWR in previous surveys. In future years, we will quantify the relationship between the Zippin estimate and linear 3-pass depletion estimate, adjust previous UDWR estimates accordingly, and present only the 3-pass estimates, which have greater precision.

$$N = C_1^2 / C_1 - C_2$$

Where,
N = estimated fish population,
C_1 = number of fish captured in first pass, and
C_2 = number of fish captured in second pass.

$$\text{Standard error (SE)} = [C_1 * C_2 / (C_1 - C_2)^2] * (C_1 + C_2)^{1/2}$$

$$95\%\ CI = 2 * (SE)$$

Condition- Length-weight relationships (by species, both years combined; Appendix 1) and condition factor (Fulton's $K = W * 100{,}000 / L^3$) were calculated for cutthroat and brown trout (adults and subadults based on length frequency data) for each site, and then compared within and across sites.

Diet analysis- Stomach contents of sampled fish were taken and preserved. Due to a lack of funding, diet analysis was not conducted in 2002.

Whirling disease analyses

For cutthroat and brown trout, fish heads from each specimen were removed, frozen, and tested for prevalence of *Myxobolus cerebralis* following the polymerase chain

reaction method (PCR; Andree et. al. 1998). PCR samples were processed by Pisces-Molecular LLC (Boulder, Colorado).

Fish Health Condition Assessment

The same subsampled fish taken for PCR analysis were also assessed for health and condition using procedures outlined by Goede (1988, 1991). One technician conducted this profile for the entire sampling period.

Invertebrate sampling

No invertebrate sampling or analysis was conducted in 2002 due to a lack of funding.

Oligochaete and *Tubifex tubifex* collection

The distribution of tubificid worms is controlled by their preference for fine sediments (Sauter and Gude 1996) and its nutrient concentrations (Lestochova 1994). Semi-quantitative samples (fixed-time samples) were collected to compare proportions of tubificid worms within oligochaete communities across different sites. Oligochaetes were collected during summer from habitats with soft, fine sediments using a kick net. Oligochaete samples consisted of a 10-minute fixed-time sample. Samples were washed using a 500 μm mesh screen, sorted, and preserved in 70% ethanol.

Periphyton

Chlorophyll *a,* extracted from periphyton was used as an index of productivity. In summer 2002, three to five unpolished tiles (30 x 30 cm) were individually deployed across a riffle at each sampling site. Tiles where retrieved after six weeks, placed in plastic bags, stored in a cooler in the field, and frozen in the laboratory until chlorophyll *a* was extracted in methanol. Chlorophyll a was extracted in the dark for 24 h at room temperature. From the extract, three 6 ml aliquots were analyzed fluorometrically (Holm-Hansen and Riemann 1978). Chlorophyll *a* concentrations were expressed in mg/m^2.

Environmental variables

Sampling of river water for physical and chemical characteristics was generally conducted monthly through autumn.

Discharge- Discharge was calculated from the current velocity cross-sectionally measured, at 10-20 equally spaced sites, using an electromagnetic flow meter (Marsh-McBirney Flow Mate 2000).

Temperature- Temperature at each site was recorded hourly using temperature loggers (Onset Stow Away) set in streams.

Substrate- Substrate particles and percent fines were collected randomly from a riffle zone at each site by walking through a transect perpendicular to the shoreline. Particle size was measured and classified using Wolman pebble counts.

Turbidity- Water samples were taken in a 50 mL polyethylene bottle. Turbidity was measured *in situ* with a turbidity meter (LaMotte model 2020) after the sample had reached equilibrium with air temperature. Values were reported in NTUs (nephelometric turbidity units).

Conductivity and pH- The water electrical conductance and pH were measured with an Oakton model 10 pH/Conductivity/°C meter. Conductivity values were recorded as µS/cm at 20° C. Temperature was recorded concurrently.

Nutrient sampling and analysis- Water samples were collected in sample bottles that were first acid washed with 1 N HCl and rinsed three times with stream water. Samples were stored in an ice cooler in the field and frozen in the lab. Total nitrogen (TN) was analyzed by high temperature catalytic oxidation (HTCO) and total phosphorous (TP) was analyzed using the standard ascorbic acid.

Fish Movement

In order to better understand fish movement between whirling disease “hot spots” and “clean areas”, we marked trout species (target = 200 of each species) at each site with different colored site-specific Floy T-bar tags. Tagged fish were and will continue to be recovered from anglers (creel census and mail and phone returns) and from the annual electroshocking survey in late summer. Informative signs were placed at the major fishing areas. The USU Fish Ecology Lab’s phone number (435-797-3380) was also imprinted on the fish tags.

In addition to fish movement data, a potentially important variable for understanding the spread of *M. cerebralis*, tagging will also provide an independent mark-recapture population estimate to verify the electroshocking estimates and allow us to estimate

survival (after the first complete year). Tagging data will also allow us to determine growth from recaptured fish.

Creel Survey

During summer 2002, we utilized a roving creel survey in order to collect tags and inform anglers about this study as well as to quantify fishing pressure and angler satisfaction. The survey was conducted from 10 June to 3 August 2002 on the Logan River and two of its tributaries, Right Hand Fork and Temple Fork during three randomly selected days per week including one weekend day. Anglers were interviewed at eight defined reaches on 21 separate days. The start times for surveys would either be at 07:00 or 09:00 hours, and the site where the surveys began and route direction (upstream or downstream) varied systematically based on random assignments. The sample time at each site consisted of 45 minutes in which the sampler would look for any anglers at the site and interview them. Of the 93 anglers counted in the survey, 75 were interviewed. The interviews provided a variety of information ranging from estimates of fishing effort and catch to general opinions on the fishery (see Appendix 2 for survey).

Sentinel Fish Experiments

To assess infection rates and intensities among sentinel fish, whirling disease-free hatchery-reared cutthroat trout fry (Bear Lake strain; 1 to 9 weeks post hatch) were exposed in the field and returned to the lab and held in aquaria (n = 9) in 10-12 °C, pathogen-free water for 3 months. Three cages at each site held 90 fish. Exposures were conducted at three sites: Franklin Basin, Temple Fork, and Twin Bridges. PCR analyses were conducted on surviving fish. Physical and chemical variables were measured weekly at exposure (cage) sites; temperature was recorded hourly using temperature loggers. This component of the study is described in greater detail in Ernesto de la Hoz's Masters thesis (De la Hoz 2003).

RESULTS

Biological data

<u>Fish sampling</u>

Bonneville cutthroat trout, brown trout, rainbow trout, brook trout, and mountain whitefish were sampled during stream surveys in the Logan River drainage in summer 2002. We also captured sculpin at most sites and carp at the lower-most site. Based

on modified Zippin depletion population estimates, abundance and distribution of cutthroat trout, brown trout and whitefish varied in the Logan River (Figure 2, Table 1). Numbers of cutthroat trout per km decreased slightly at some sights and increased slightly at other sites from the 2001 survey, but were at or near 1999 survey levels (Figure 3). Numbers of brown trout per km increased or decreased depending on site compared to 2001 surveys, but was higher than the 1999 estimates (Figure 4). The following summaries by site are from the modified Zippin depletion population estimates or regular depletion estimates (estimate ± 95% confidence intervals).

Franklin Basin- Population estimates indicated that Franklin Basin had high cutthroat trout abundance (1037 ± 98 fish/km; Table 1). Using three-pass electroshocking, we captured 101 cutthroat trout ranging from 10 to 320 mm TL demonstrating four age classes: less than 50 mm, 60-120 mm, 130-200 mm, and greater than 210 mm (Figure 5). In 2002, there appeared to be more distinct age classes, and we captured more smaller cutthroat trout. Only three brook trout were captured at this site, precluding a population estimate (Figure 5).

Red Banks- The cutthroat trout population estimate was highest at this site: 1883 ± 58 fish/km (Table 1). Most of the fish captured were cutthroat trout (n = 99) in four possible age classes: less than 10 mm, 80-140 mm, 150-240 mm, and 250-330 mm (Figure 6). Only three brown trout were captured, all less than 230 mm. One brook trout (~ 110 mm) was caught. Due to the small number of fish captured, population estimates were not calculated for these two species.

Forestry Camp- We captured 98 cutthroat trout at this location providing a population estimate of 1442 ± 6240 fish/km (Table 1). Length frequency histograms indicate four potential age classes with modes at 30 mm, 105 mm, 170 mm, and 250 mm (Figure 7), virtually identical to last year's data (Budy et al. 2002). Eleven brown trout in two age classes were captured, providing a population estimate of 56 ± 2 fish/km (Table 1). Only one whitefish (~ 490 mm) was caught (Figure 7). Catches of brown trout and whitefish were equally as low in the past surveys (Budy et al. 2002, Thompson et al. 2000).

Twin Bridges- Brown trout (506 ± 58 fish/km) were more abundant than cutthroat trout (203 ± 20 fish/km) at this site (Table 1). We captured 86 brown trout of five apparent age classes with modes at 60 mm, 170 mm, and 250 mm, 320 mm, and 360 mm (Figure 8). Forty cutthroat trout were captured in four likely age classes with modes at 110 mm, 145 mm, 200 mm, and 240 mm. Only one whitefish was taken (Figure 8).

Third Dam- As in 2001, Third Dam was the only site where rainbow trout were captured (n = 3 in 2002): ranging from 180-250 mm (Figure 9). Brown trout were abundant (1302 ± 48 fish/km) at this location, whereas abundance estimates of cutthroat trout (82 ± 46 fish/km), and whitefish (178 ± 12 fish/km) were much lower (Table 1). We captured 70 brown trout in four possible age classes with modes at 60 mm, 160 mm, 230 mm, and 320 mm (Figure 9). Twelve cutthroat trout were captured: ranging from 100-300 mm. Thirty-one whitefish were collected: two were juveniles (60-80 mm), the remainder ranged from 260-450 mm (Figure 9). Whitefish catch and abundance nearly doubled in 2002, since the 2001 survey (Budy et al. 2002).

Lower Logan- Brown trout dominated this section of the river (864 ± 56 fish/km; Table 1), as 100 were captured in three possible age classes with modes at 60 mm, 160 mm and 250 mm. Whitefish were less abundant (560 ± 376 fish/km), only 57 were collected: 45 were smaller than 110 mm (Figure 10). While brown trout abundance was half that of 2001 estimates, whitefish abundance doubled (Budy et al. 2002)

Temple Fork- In this tributary, we captured 100 brown trout, providing a population estimate of 733 ± 543 fish/km (Table 1), nearly one-third the 2001 estimates (Budy et al. 2002). More than 40% were less than 80 mm. As in past surveys, age-0 brown trout were the most abundant age class. The abundance of cutthroat trout increased in 2002 (542 ± 212 fish/km; Figure 11); double that of 2001 estimates (Budy et al. 2002). The 47 captured cutthroat trout ranged from 70 to 330 mm (Figure 11).

Right Hand Fork- As in 2001, only brown trout were captured (n = 100 in 2002) at this site (Table 1). The brown trout population was estimated at 3517 ± 126 fish/km (Figure 12), up from 2001 (Budy et al. 2002). There appeared to be six possible age classes with modal lengths at 60 mm, 130 mm, 190 mm, and 220 mm (Figure 12). Also, one brown trout less than 10 mm and one approximately 410 mm were captured. Cutthroat trout were not captured as in past surveys (Budy et al. 2002, Thompson et al. 2000).

Overall, since the 2001 survey, cutthroat trout population estimates have decreased slightly. However, we estimated increased cutthroat trout abundance at Red Banks, Third Dam, and Temple Fork. The population of brown trout increased at Forestry Camp, Twin Bridges, and Right Hand Fork. The population of whitefish increased at Third Dam and Lower Logan, but decreased at other sample sites. In general, since 1991, cutthroat and brown trout abundances have increased at most sites (Table 2).

Table 1. Population estimates (Fish/km) and 95% confidence intervals (CI) based on the modified Zippin depletion method. NA indicates that although a particular species was present at the site, insufficient catch precluded population estimation. An asterisk (*) indicates estimates based on a linear 3-pass depletion method.

Site	Species	2001		2002	
		Fish/km	95% CI	Fish/km	95% CI
Franklin Basin	Cutthroat	1768	297	1037	98
	Brook	45	30	NA	NA
Red Banks	Cutthroat	1626	84	1883	58
	Brown	40	139	NA	NA
	Brook	NA	NA	5	NA
	Whitefish	NA	NA	NA	NA
Forestry Camp	Cutthroat	1742	123	1442	40
	Brown	NA	NA	56	2
	Whitefish	NA	NA	5	NA
Twin Bridges	Cutthroat	394	727	203	20
	Brown	413	170	506	58
	Whitefish	56	12	5	NA
Third Dam	Cutthroat	49	48	82	46
	Brown	2126	754	1302	48
	Whitefish	35	NA	5	NA
	Rainbow	90	NA	178	12
Lower Logan	Brown	1557	1862	864	56
	Whitefish	269	219	560	376
Temple Fork	Cutthroat	210*	122*	542*	212*
	Brown	2120*	808*	733*	546*
Right Hand Fork	Brown	2700	232	3517	126

Condition- Condition factor (Fulton's K $\pm$ 1 SE) for subadult cutthroat trout (≤ 150 mm; based on length frequency data) ranged from 0.87 (± 0.02) at Temple Fork to 1.11 (± 0.06) at Franklin Basin (Figure 13). Condition of subadult cutthroat trout appeared to be negatively correlated with elevation (location) of site in the mainstem (R^2 = 0.42, *df* = 8, *p* = 0.06). For example, subadults at Franklin Basin had higher condition than subadults at Third Dam. Adult cutthroat trout exhibited slightly lower condition than subadults: a low of 0.79 ± 0.05 at Franklin Basin and a high of 1.08 ± 0.05 at Twin Bridges (Figure 13). Contrary to subadults, condition of adult cutthroat trout was

lower at Franklin Basin than at Twin Bridges; however, this relationship was weak (R^2 = 0.35, *df* = 7, *p* = 0.12).

Table 2. Comparison of number of fish by species per kilometer for five river sections. Numbers are based on reach-specific modified Zippin population estimates. Double dashes (--) indicate that no fish were captured or insufficient catch precluded a population estimate. All ages combined. An asterisk (*) indicates estimates based on linear 3-pass depletion methods. Data prior to 2001 were taken from UDWR report 00-3 (Thompson et al. 2000).

		Population estimate (fish per km)			
		Species			
Site	**Year**	**Cutthroat**	**Brown**	**Whitefish**	**Rainbow**
Franklin Basin	1991	634	--	--	--
	1999	1359	--	--	--
	2001	1768	--	--	--
	2002	1037	--	--	--
Red Banks	1991	1125	12	19	6
	1999	1083	--	--	--
	2001	1626	40	--	--
	2002	1883	--	--	--
Forestry Camp	1991	1858	12	6	--
	1999	1361	5	25	--
	2001	1742	--	--	--
	2002	1442	56	5	--
Twin Bridges	1991	199	236	68	50
	1999	86	155	54	--
	2001	394	413	56	--
	2002	203	506	5	--
Temple Fork	1967	50	56	--	--
	1999	194	284	--	--
	2001	210*	2120*	--	--
	2002	542*	733*	--	--

Variation in condition across size classes for brown trout was lower as compared to cutthroat trout. Condition of subadult brown trout ranged from 0.93 (± 0.02) at Lower Logan to 1.25 (± 0.14) at Temple Fork (Figure 14). Condition of subadult brown trout was negatively correlated with site elevation (R^2 = 0.70, *df* = 6, *p* = 0.02). Subadults

captured at Forestry Camp had much better condition than those sampled at the Lower Logan site. Adult brown trout condition ranged from 0.91 ± 0.02 at Lower Logan to 1.10 ± 0.04 at Twin Bridges. Adult brown trout from the tributaries and mainstem exhibited similar condition. As with subadults, condition of adults in the middle reaches of the mainstem had significantly better condition than brown trout at the Lower Logan site ($R^2 = 0.71$, $df = 5$, $p = 0.03$).

Whirling disease analyses

Cutthroat trout- Clinical signs of whirling disease such as black tail or deformities were observed in very few fish. However, PCR assays for *M. cerebralis* indicated the parasite was present in all mainstem reaches sampled and in one of the tributaries, Temple Fork. Despite the widespread distribution of *M. cerebralis*, the prevalence of infection on cutthroat trout varied greatly, ranging from 18% at the headwaters to 85% at Third Dam (Figure 15). At Temple Fork, 50% of the cutthroat trout (n = 19) tested positive (Figure 15), up from 30% in 2001 (Budy et al. 2002). More than 70% of the samples from Red Banks (n = 20), Forestry Camp (n = 20), and Twin Bridges (n = 19) also tested positive for *M. cerebralis*, an average increase of approximately 10% over last year.

Brown trout- M. cerebralis was not detected in brown trout from Right Hand Fork (n = 10), although for the first time, *M. cerebralis* was detected in brown trout from Temple Fork (10% positive in 11 fish; Figure 16). Over 80% (n = 19) tested positive at Lower Logan and samples from Twin Bridges (35%) and Third Dam (65%) tested positive (Figure 16). On average, prevalence of *M. cerebralis* in brown trout increased 25% in study reaches.

Other salmonids- Prevalence of *M. cerebralis* was not tested in rainbow trout, mountain whitefish, or brook trout due to lack of funding. Samples that were taken are being held at the Fish Ecology Lab at Utah State University and will be analyzed in the next fiscal year.

Fish Health Condition Assessment

Health and condition (as based on UDWR HCP assessment) was assessed on 54 cutthroat trout, 53 brown trout, three rainbow trout, and three brook trout collected from 27 July to 8 August 2002. Good “clear” eyes were observed in all fish. Only one instance of a gill abnormality was observed in a 313 mm cutthroat trout. Mineral deposits were observed in the pseudobranchs (located dorsally and anterior to the gills) of 22 (41% of sampled) cutthroat trout. Thirteen (24%) cutthroat trout displayed

hemorrhaging of the thymus. All but three fish had fat deposits around the pyloric ceca. Red coloration of the spleen was observed in 22% of cutthroat trout and 43% of brown trout, while granular appearance of the spleen was observed in only one brown trout. Sixteen percent of fish had slight inflammations in the hindgut. Kidneys in all sampled fish were normal. Twenty-four percent of fish had normal livers. Bladders were empty in 45% of fish. Nineteen percent of sampled fish were immature, 45% were females, and 36% were males. No fish displayed active erosion of fins, and only one fish, a brown trout, had a slightly shortened opercle.

Oligochaete and *Tubifex tubifex* collection

Total oligochaetes captured over a 10-minute interval varied greatly by site (Figure 17). No oligochaetes were found at Third Dam or Lower Logan, while the greatest numbers were sampled at Forestry Camp (over 900 worms per 10-minute sampling interval). *T. tubifex* were found at all sample sites, and percent of *T. tubifex* in samples varied greatly by site (Figure 17). Percent of *T. tubifex* in samples was almost 90% at Forestry Camp, but was less than 15% at all other sampled sites.

Periphyton

Periphyton biomass, as indicated by chlorophyll *a* concentrations, varied little across mainstem sites. Chlorophyll *a* ranged from approximately 75 mg/m^2 at Franklin Basin to 90 mg/m^2 at Lower Logan (Figure 18). In the tributaries, chlorophyll *a* at Right Hand Fork (approximately 95 mg/m^2) was higher than at Temple Fork (75 mg/m^2; Figure 18).

Environmental variables

Discharge- Flows in 2002 were slightly higher in than in 2001 (Figure 19). Lowest discharge recorded from May thru September was 5.7 cfs (0.2 m^3/sec; 18 September) at Right Hand Fork, whereas the highest flow was recorded at Twin Bridges (3 July; 102.1 cfs or 2.9 m^3/sec). These data follow the same trends as in 2001 (Budy et al. 2002). Base flow discharge was higher at the mid-elevation sections of the river in relation to the headwaters, lower sections, and the tributaries (Figure 19).

Temperature- Average summer temperatures were coolest in the highest elevation site (Franklin Basin) and warmest at the lowermost site (Lower Logan; Figure 20). Summer (June-September) temperatures at most sites (except for Franklin Basin) were close to or within the ideal range (10 to 13 °C) for growth of *T. tubifex,* the secondary host for *M. cerebralis*. As in 2001, temperatures at the Lower Logan site were above this range (Figure 20). Mid-summer temperatures at Twin Bridges and

Third Dam approached the ideal 15 °C for triactinomyxon (TAM) production. On the other hand, temperatures between 13 and 17 °C have been correlated with higher *M. cerebralis* infection rates in other studies. Our data indicate that only mid-summer temperatures at Forestry Camp, Twin Bridges, and Third Dam, and early and late summer temperatures at Lower Logan fell within this category. Temperatures at Franklin Basin were generally below ideal for TAM production, *T. tubifex* growth, and the temperature range that has been correlated to high infection rates (Figure 21).

Substrate- Mean particle size ranged from less than 50 mm to ~250 mm, decreasing from high to lower elevations of the mainstem. (Figure 22). Mean particle size in the tributaries was approximately 100 mm (Figure 22). Percent fines, measured as sediments less than 10 mm, ranged from less than 5% at Third Dam to nearly 15% at Franklin Basin, Red Banks, and Forestry Camp; higher percentages were observed in the tributaries, particularly at Temple Fork (30%; Figure 22). As was the case in 2001, these findings are not consistent with expected results; that is, a higher percent fines at the lower-most site, and mid sections of the mainstem and the tributaries.

Turbidity- Turbidity varied from 0.15 NTUs at Right Hand Fork during May up to 2.4 NTUs at the Lower Logan site in July.

Conductivity and pH- Water conductivity ranged from a low of 216 µS/cm at Franklin Basin up to 423 µS/cm at Right Hand Fork in May 2002. pH levels did not vary much along the Logan River, persisting between 8.5 and 9.5.

Nutrient sampling and analysis- Total dissolved nitrogen (TN) varied by site (Figure 23). The Lower Logan site had the highest summer 2002 average TN levels (0.27 $\pm$ 0.08; mg/L $\pm$ 1 SD), followed closely by levels in one of the tributaries, Right Hand Fork (0.22 $\pm$ 0.01). Levels and trends were similar in 2001 and 2002 (Figure 23). Total phosphorous (TP) levels varied little by site, and TP in the mainstem were similar to TP in the tributaries in both 2001 and 2002 (Figure 23). Total phosphorous ranged from 16 $\pm$ 3.5 (µg/L $\pm$ 1 SD) at Third Dam up to 29 $\pm$ 9.4 at Lower Logan.

Fish Movement

In the mainstem and two tributaries, we tagged 680 cutthroat trout and 846 brown trout with site-specifically colored, individually-numbered Floy T-bar tags (Table 3). Preliminary data reveal that up to 30% of tagged fish were recaptured at the original tagging location (Note: fish were not tagged until mid summer).

Although several fish were recaptured by anglers and through the annual sampling, it is premature to draw conclusions from this limited movement data. Sufficient movement information should be available to quantify movement at the end of the 2003 field season.

Table 3. Number of trout tagged in the Logan River mainstem and two tributaries in 2002. Each trout was tagged with an individually numbered, site-specifically colored tag. Double dash (--) indicates that no fish were captured or tagged at that site.

		Number of fish tagged	
Site	**Tag color**	**Cutthroat trout**	**Brown trout**
Franklin Basin	Green	129	--
Red Banks	Red	216	--
Forestry Camp	Yellow	212	--
Twin Bridges	Blue	23	89
Third Dam	Purple	--	186
Lower Logan	Gray	--	205
Temple Fork	Orange	100	103
Right Hand Fork	White	--	263

Creel Survey

The number of anglers interviewed ranged greatly by site (Figure 24). Our sample site at Forestry Camp received the highest fishing pressure, while Third Dam had the fewest anglers. Overall catch rate was 0.53 fish per angling hour (Table 4). The weekday catch rate was higher than the weekend catch rate, likely because experienced, dedicated anglers fished regardless of day, and weekends attract anglers of all skill levels (Table 4). The average angler was 36 years old, the youngest angler was age 4, while the eldest angler interviewed was 73 years old. Ninety-three percent of anglers were male. Fly-fishing was the predominant fishing method (89.3%), followed by spinning rods (artificial lures; 5.3%), bait fishing (2.7%), or a combination of tackles (2.7%). Species of fish targeted ranged from “anything” (36%), “all trout” (32%), “cutthroat trout” (26%), “brown trout” (3%), “whitefish” (1%), and “rainbow trout” (1%). Desirability of whitefish ranged greatly (Figure 25). While fishing success was mixed (Figure 26), overall trip satisfaction was “very satisfactory” (highest rating) for 75% of interviewed anglers (Figure 27).

Anglers caught and reported via telephone thirteen study-tagged fish. The creel clerk caught 217 fish, of which 15 were study-tagged.

Table 4. Catch and harvest estimates based on catch rate, angling hours, and number of anglers per day for creel survey conducted on the Logan River, June-August 2002. Adjusted estimates are based on a stratified sampling design.

Parameter	Raw	Adjusted
Overall		
Catch rate (fish/angling hr)	0.53	0.53
Average angler hours (angling hrs/angler)	4:40	4:40
Anglers per day	4.43	13.29
Daily catch (fish/day)	11.05	33.15
Weekday		
Catch rate (fish/angling hr)	0.67	0.67
Average angler hours (angling hrs/angler)	3:58	3:58
Anglers per day	3.38	10.15
Daily catch (fish/day)	9.00	26.99
Weekend		
Catch rate (fish/angling hr)	0.44	0.44
Average angler hours (angling hrs/angler)	5:19	5:19
Anglers per day	6.13	18.38
Daily catch (fish/day)	14.33	42.99
Weekly		
Based on overall catch (fish/wk)	77.35	232.06
Based on weekday-weekend catch (fish/wk)	73.63	220.90
Percent released	94	94
Weekly harvest (fish kept/wk) based on overall catch	4.36	13.07

Sentinel Fish Experiments

The parasite was not detected in sentinel fish at two sites (Franklin Basin, Temple Fork) where wild trout were infected. In sentinel fish, prevalence ranged from undetected at the upper-most site and the two tributaries, to 56 % at an upper-elevation mainstem site (Forestry Camp). Results from sentinel cage experiments are outlined in detail in De la Hoz (2003).

DISCUSSION

Trout density in the Logan River, based on depletion electroshocking population estimates, has not changed significantly over the duration of the study (initiated in 2001) and compared to previous evaluations. The number of cutthroat trout decreased slightly in 2002 compared to 2001, but not compared to previous years. These data suggest that thus far, trout in the Logan River are not experiencing population level effect from the widespread presence of *Myxobolus cerebralis* throughout the drainage.

Despite the lack of observed population decline, we caution that it may be far to soon to see a population-level effect. In the Logan River and similar western riverine systems, cutthroat trout typically live to 3 years with age of first reproduction at age-1 for males and age-2 for females (Fleener 1951), and brown trout typically live 8 years (Sigler 1951). Thus given that whirling disease typically has its greatest effect on juvenile fish, it could take many years to first observe a population-level effect. In the Logan River, we estimate that whirling disease became firmly established between 1998 and 2001. If any population-level effect of the disease were to occur, it might not emerge until 2007. Staggered broods could dampen any population-level decline that may occur; we observe substantial overlap in ages in the Logan River (*see* Figures 5-12).

As observed in the 2001 study, in 2002 *M. cerebralis* was widely distributed throughout the Logan River drainage and has increased 10 to 25% overall since 2001. Prevalence ranged from a high near 80% at our Third Dam site to a 0% in Right Hand Fork, the only site that remains “clean” and free of *M. cerebralis*. Despite this widespread prevalence, we observe very few fish with clinical signs (i.e., deformities, black tail) of whirling disease and fish condition, while highly variable, remains near 1 at most sites. The paucity of clinical signs in wild and sentinel fish suggest that the abundance of TAMs along the Logan River is low. Spore concentration (dose) is directly related to the development of clinical signs of whirling disease and its severity (Markiw 1992). However, other factors such as fish age (Markiw 1992), size (Thompson and Nehring 1999 Thompson et al. 1999), species (Hedrick et al. 1999, Sollid et al. 2002, Vincent 2002), and environmental factors at the time of the exposure may also influence the susceptibility of fish to the disease.

Abiotic and biotic variables continue to be variable across sites within the river. We continue to see the highest discharge at the mid-elevation sites, the lowest temperatures in Franklin Basin (headwaters), and the highest temperatures at the

Lower Logan, below the golf course. Temperatures at the Lower Logan site (maximum of 18 °C) are close to the upper limit for cutthroat trout (LT50 = 24.2 °C, lethal limits 16-26 °C; Johnstone and Rahel 2003), but are within the range considered positive for brown trout growth and survival (3.8-19.5 °C; thermal maximum at 28.96; Armour 1994). Productivity, as estimated from chlorophyll a data, is highly variable within site, likely masking any large-scale differences in productivity across sites. Oligochaete abundance was greatest at a mid-elevation site and did not appear to be related to substrate type (e.g., percent fines). Nutrient levels were highest at the Lower Logan site, likely as a result of anthropogenic nutrient input as the Logan River travels through town and past the golf course. Despite the variability across sites, environmental conditions observed in 2002 were extremely similar to 2001.

In addition to these baseline whirling disease data and population assessments, we (De la Hoz 2003) also evaluated the relationship between key biotic and abiotic factors. These factors may be hypothetically linked to the spread and impact of the disease through various mechanisms and components of the pathogen life cycle. Our data thus far demonstrate that in the Logan River, the prevalence of *M. cerebralis* in cutthroat and brown trout could be predicted based on site-specific discharge and temperature (De la Hoz 2003). In this system, prevalence does not appear to be related to either biotic factors (e.g., productivity) or abiotic factors (e.g., sedimentation) thought to be linked to oligochaete worms or the distribution of the worms themselves. We note however, that the range of conditions both among sites within the Logan and among years may not have provided an adequate range to evaluate these relationships fully. This limitation may have occurred despite the substantial difference in elevation and habitat use observed across our index sites and was likely affected by the similarity in environmental conditions observed across the two years of data collected so far. Nonetheless, the predictive relationship between prevalence and temperature and discharge explains a large proportion of the variance, is statistically significant, and makes sense biologically (De la Hoz 2003).

This range of observed temperatures and discharge across sites likely explains, in part, the allopatric pattern of cutthroat trout presence in the headwaters and brown trout presence in the lower elevations, with almost no overlap. Little is known about the interactions of introduced trout and native cutthroat trout in the Logan River. However, spatial segregation, as observed between cutthroat and brown trout in the Logan River, is thought to be a common response to competition or resource overlap (Schoener 1974). In the Logan River, brown trout completely dominate Right Hand Fork, a cold tributary likely occupied by cutthroat historically. As noted above, all areas of the Logan River except Right Hand Fork now test positive for *M. cerebralis* with varying levels of prevalence. This anomaly, as well as the varying degree of

prevalence across the other Logan river sites, is likely a result of the combined effects of dominant fish species, temperature, productivity, and discharge (De la Hoz 2003).

The Logan River provides a popular fishery for cutthroat trout and likely one of the last remaining fisheries with habitat intact and a strong population of cutthroat. Our creel census revealed that the fishery gets consistent pressure and is fished by a wide variety of anglers. For example, our youngest angler questioned was 4 years old; the oldest was 73 years old. The fishery was dominated by male anglers fishing on weekends; however, there were a few female anglers and a lesser but consistent set of weekday anglers as well. The great majority of the anglers ranked their fishing trip on the Logan as "Very satisfactory", the highest possible category, demonstrating the popularity of this fishery for local recreation enthusiasts. In addition, most (94%) caught trout on the Logan are released, further indicating a community commitment to the future sustainability of the resource.

Potential threats to cutthroat in the Logan River include the effects of *M. cerebralis*, habitat degradation, and the potential for negative effects from interactions with introduced fishes (e.g., brown trout). These interactions remain unknown but may include competition, predation, and the combined effects of differences in susceptibility to *M. cerebralis* and habitat occupation (see also Chapter 2, De la Hoz 2003). Continued monitoring and upcoming research will facilitate our understanding of these complex mechanisms and aide in protecting these native fish.

FUTURE

Given the complete and consistent distribution of *Myxobolus cerebralis* throughout the Logan River, in 2003 we propose to spot check key index sites for whirling disease and move the remaining resources into evaluating species that have not been fully evaluated in previous years. In fiscal year 2003, we propose to run PCR analyses on mountain whitefish collected in 2001 and 2002 and brown trout that were not analyzed in 2001 from two sites (currently frozen). These analyses are important in order to track the spread and prevalence of the disease and as whitefish carry whirling disease and appear to be potentially declining (although the time series is too limited for strong conclusions regarding population trend). Further, in order to attempt to better understand the extent of the distribution of whirling disease in the Logan River, in 2003 we will also run PCR on 2-3 new tributaries not previously sampled.

As native cutthroat trout and introduced brown trout are both abundant in the Logan River, understanding their interactions may be important for understanding and

preserving the native Bonneville cutthroat trout. In other systems, brown trout consistently out compete *Oncorhynchus* species like rainbow and cutthroat trout. In the Logan River, brown trout generally occupy lower elevation sites, and cutthroat trout generally occupy upper elevation sites with little overlap. However, both species do co-occur at intermediate sites and in some tributaries. It is also important to note that brown trout dominate the only remaining main tributary that has consistently tested negative for prevalence of *Myxobolus cerebralis*, Right Hand Fork. In 2003, utilizing funds provided by a CURI grant through Utah State University, we propose to do some common garden experiments with brown and cutthroat trout in three sites, a cutthroat trout only site (Franklin Basin), a brown trout only site (Third Dam), and a cutthroat-brown trout site (Temple Fork) to attempt to understand interactions between these two species.

Analyses of gut contents on sampled fish from these sites will be complimentary to these common garden experiments, and stomach contents will be compared to the distribution of invertebrates and other fish species (via electivity indices). Stomachs will be removed and analyzed from the same 30 fish used for whirling disease analyses described above. In addition, we propose to run stable isotopes on a small subset of fish (using tissue from the same 30 fish from whirling disease analyses above), invertebrates, and periphyton samples. Isotope analyses will include N15/N14 and C13/C12 ratios and will be prepared by Fish Ecology Lab technicians and run by the USU Biotechnology Laboratory. Isotopes describe seasonal or longer-term diet information, whereas stomach analyses provide short-term diet information and are an important corroboration for isotopes. Diet information (isotopes and stomach contents) will be used in combination with invertebrate samples to evaluate food web structure, fish distribution and inter-specific interactions, and habitat effects on both fish and whirling disease distribution.

In 2003, population estimates using mark-recapture techniques will be possible based on fish tagged in 2002 and subsequently recaptured in the annual census in 2003. Tagged fish will also be recovered from anglers (via mail and phone returns). Informative signs were placed in 2002 and will be updated and replaced in 2003 at the major fishing areas. To gain more robust population-level information, we will begin collecting scale samples and aging a subsample of trout captured in the Logan River, in order to determine age structure of trout populations and to determine brood effects of whirling disease.

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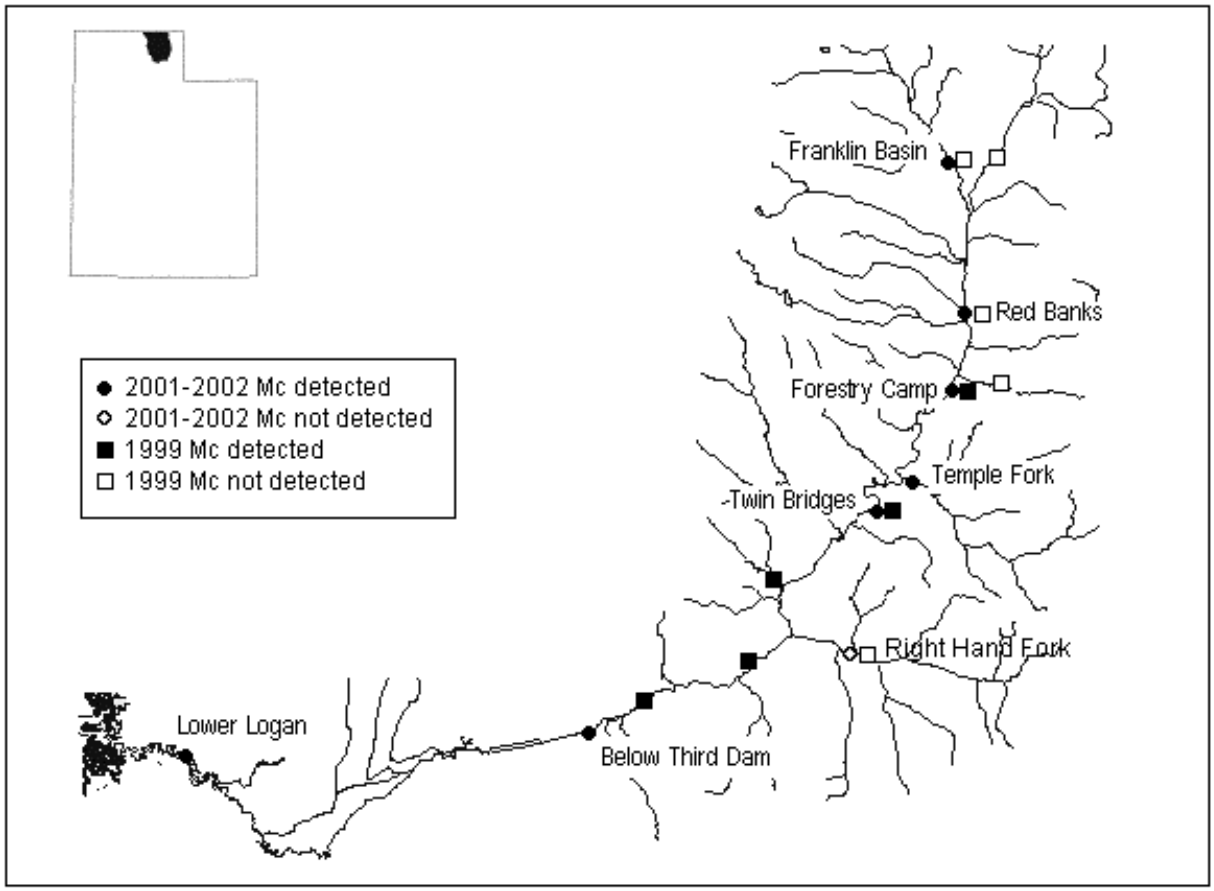


Figure 1. Map of the Logan River and sample sites. Locations and dates when *Myxobolus cerebralis* was detected in trout are indicated.

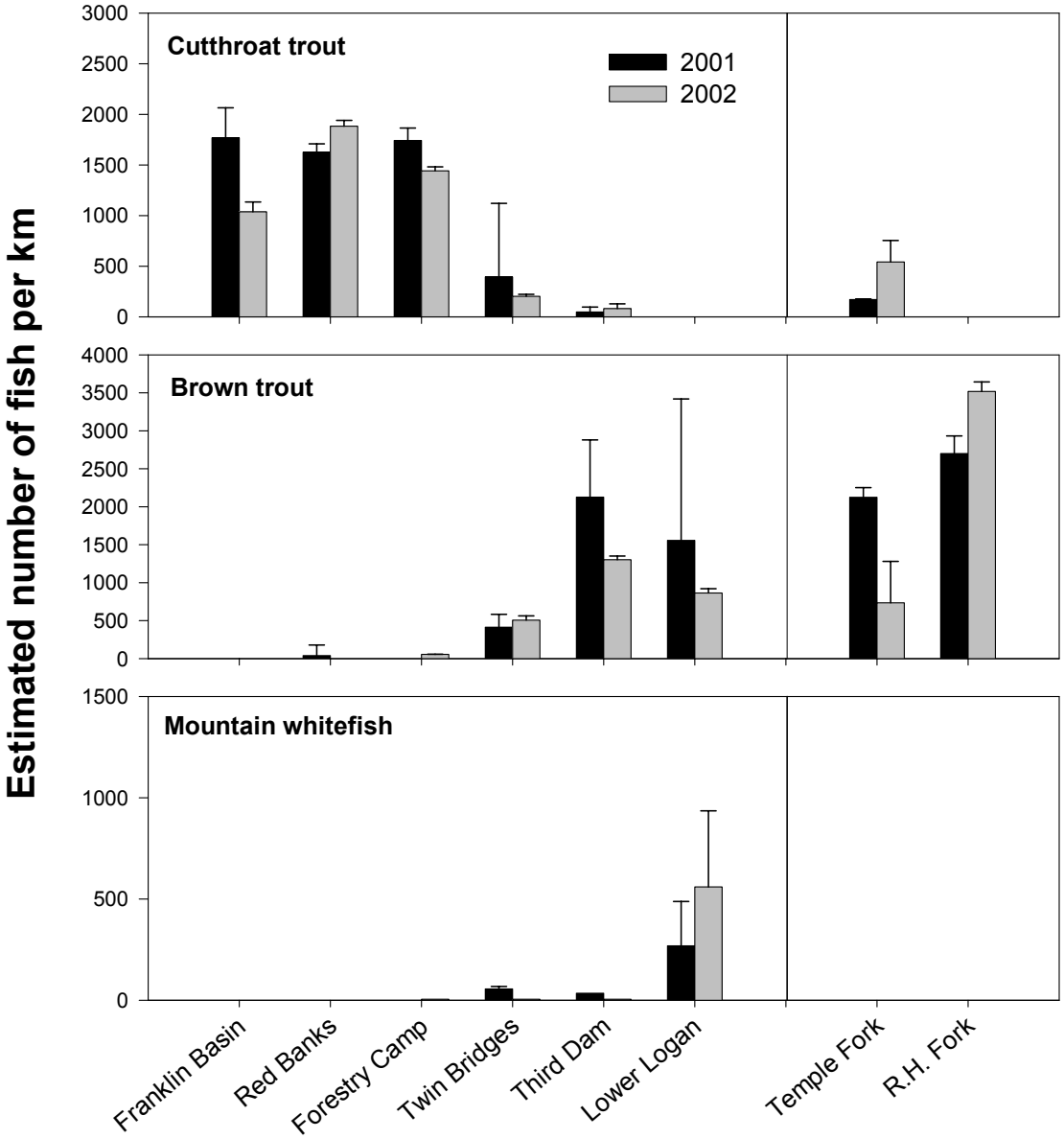


Figure 2. Population estimates for cutthroat trout, brown trout, and mountain whitefish based on a modified Zippin depletion method, for six sites on the Logan River and tributaries (Temple Fork and Right Hand Fork), 2001-2002. Error bars represent 95% confidence intervals.

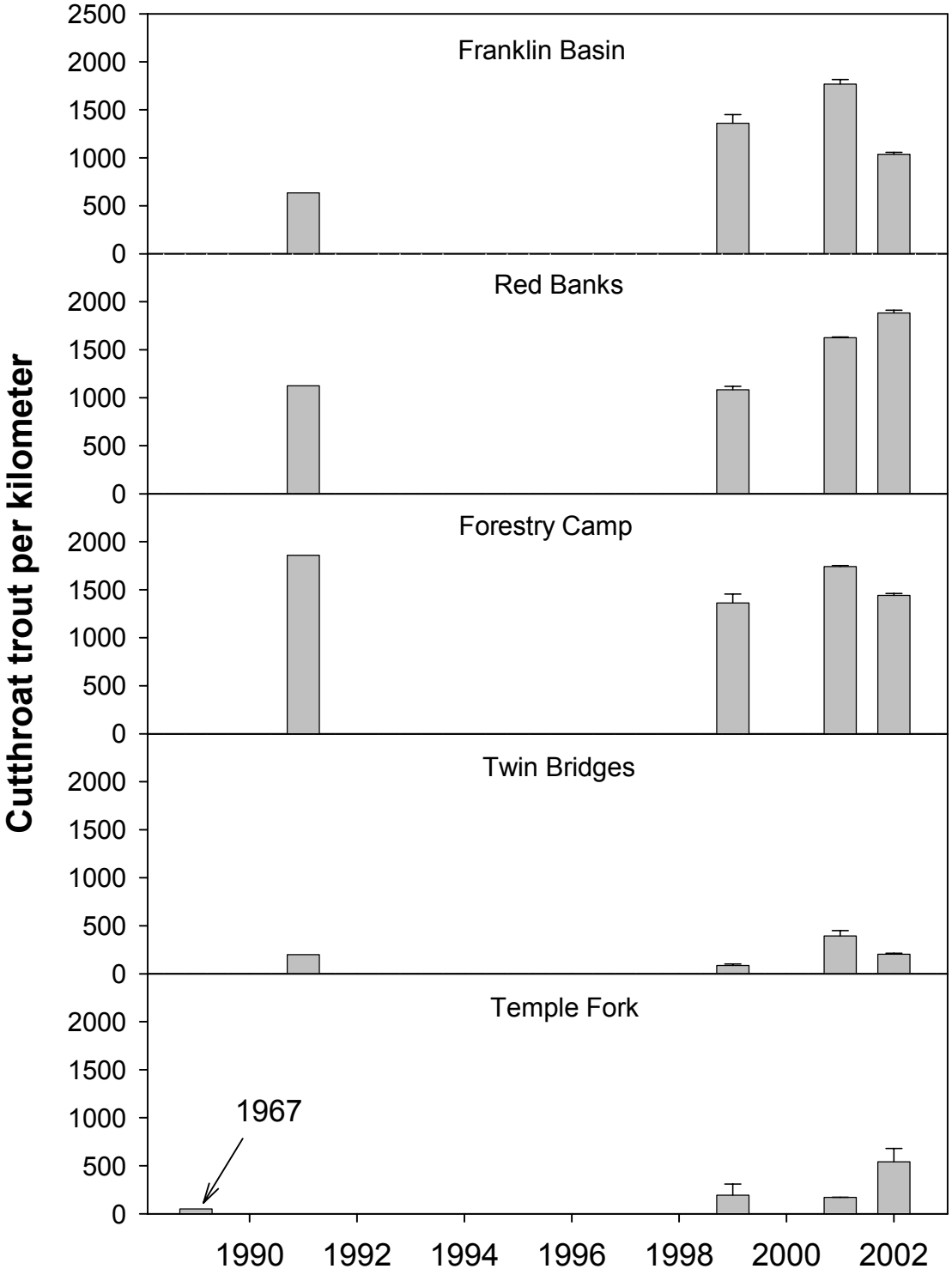


Figure 3. Population estimates for cutthroat trout based on a modified Zippin depletion method, for four sites on the Logan River and a tributary (Temple Fork), 1967-2002. Error bars represent 95% confidence intervals.

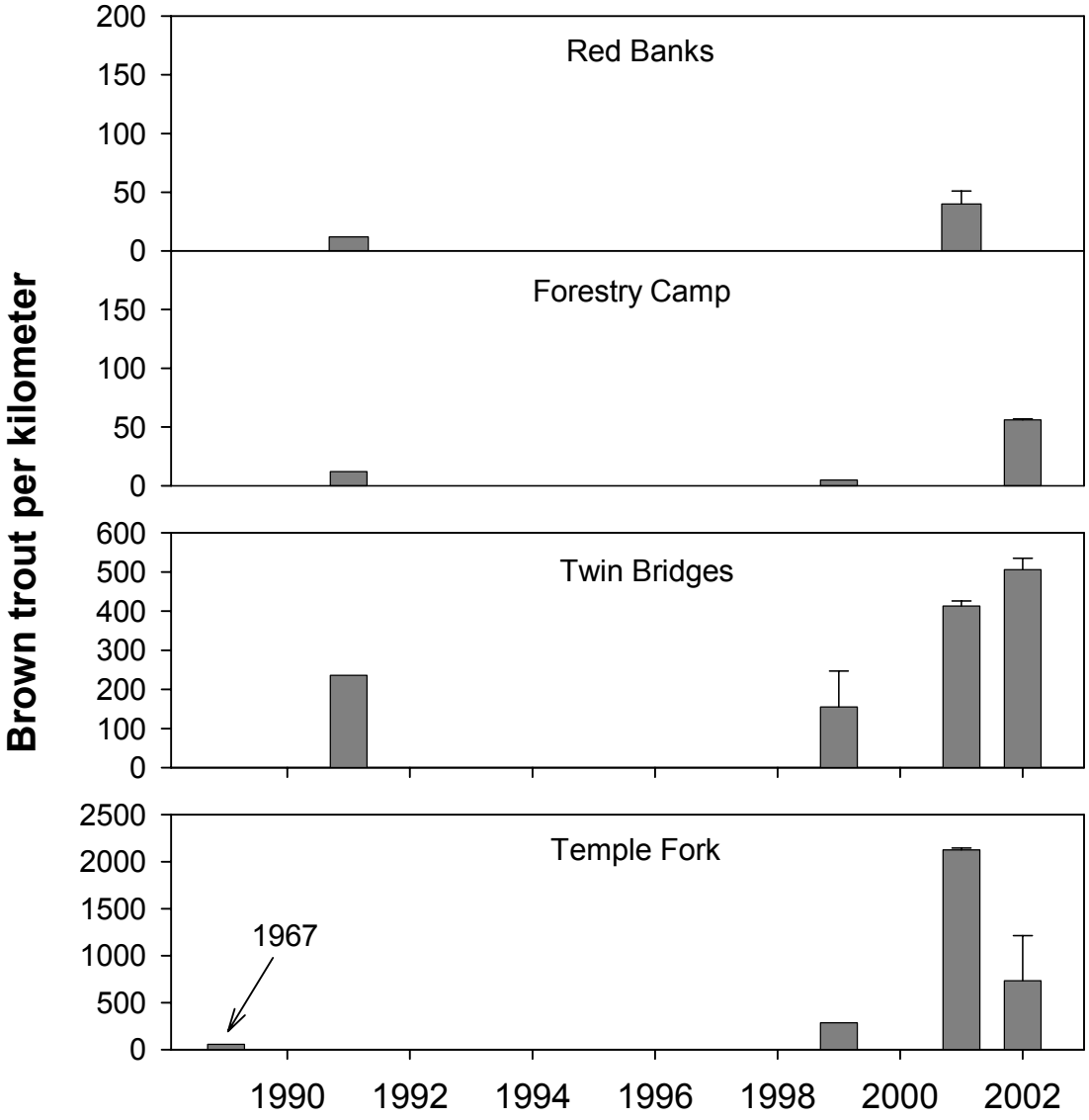


Figure 4. Population estimates for brown trout based on a modified Zippin depletion method, for three sites on the Logan River and a tributary (Temple Fork), 1967-2002. Error bars represent 95% confidence intervals.

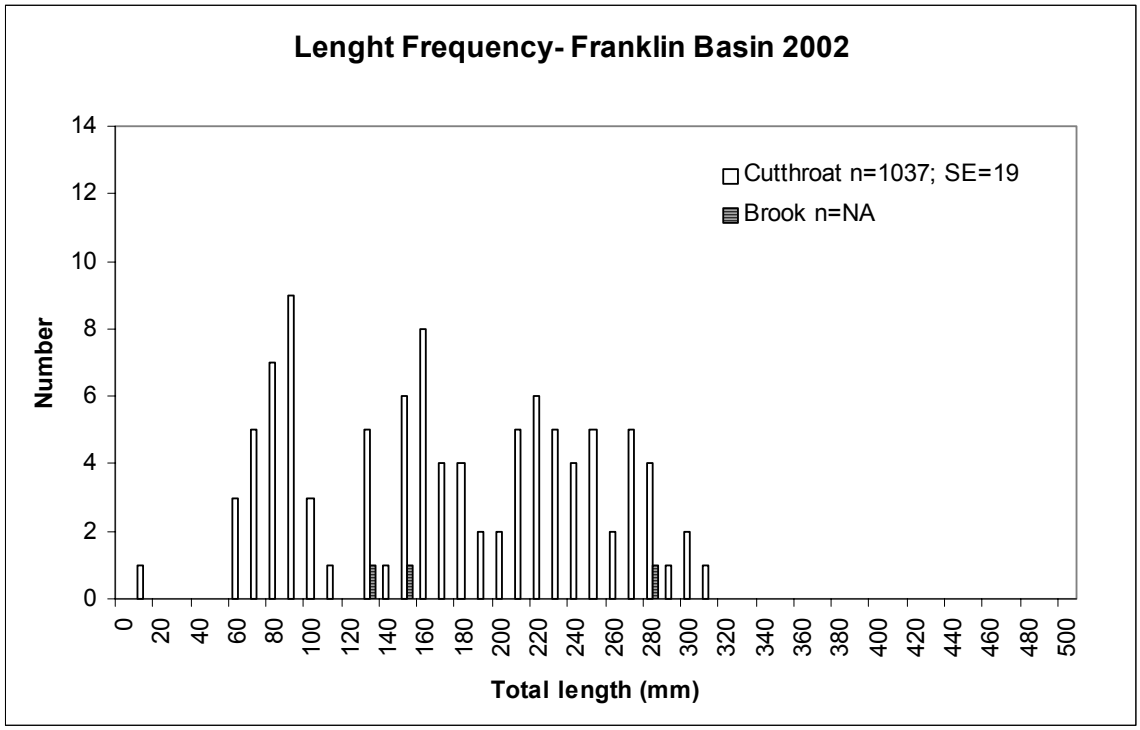


Figure 5. Length frequency distributions by species for fish captured by electrofishing at Franklin Basin, 2002. The modified Zippin population estimate is shown as N, and SE is given. NA indicates that a population estimate was not possible.

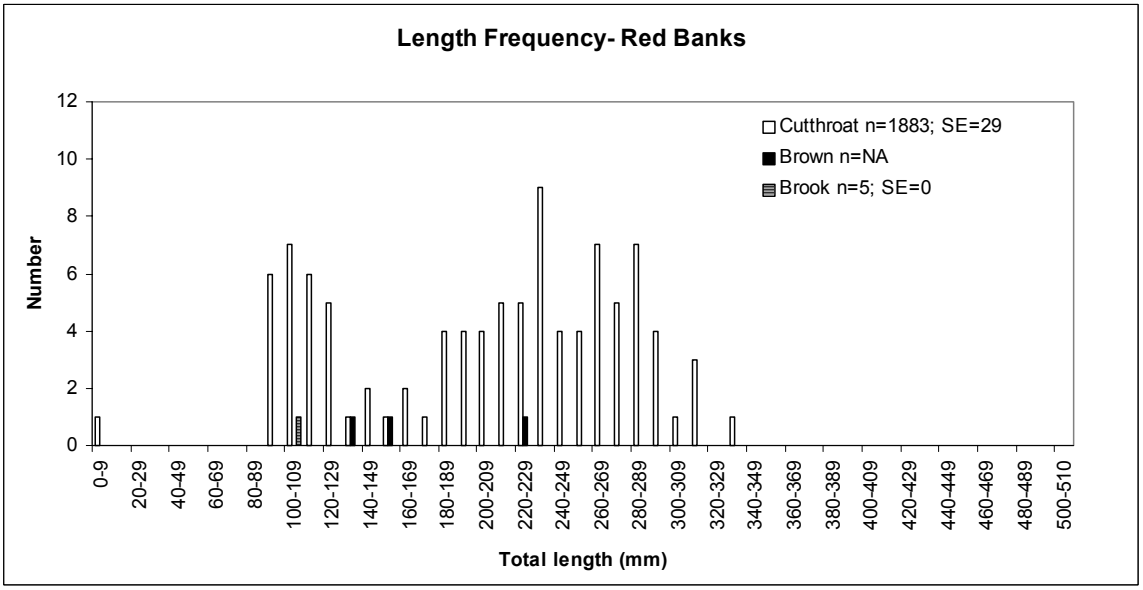


Figure 6. Length frequency distributions by species for fish captured by electrofishing at Red Banks, 2002. The modified Zippin population estimate is shown as N, and SE is given. NA indicates that a population estimate was not possible.

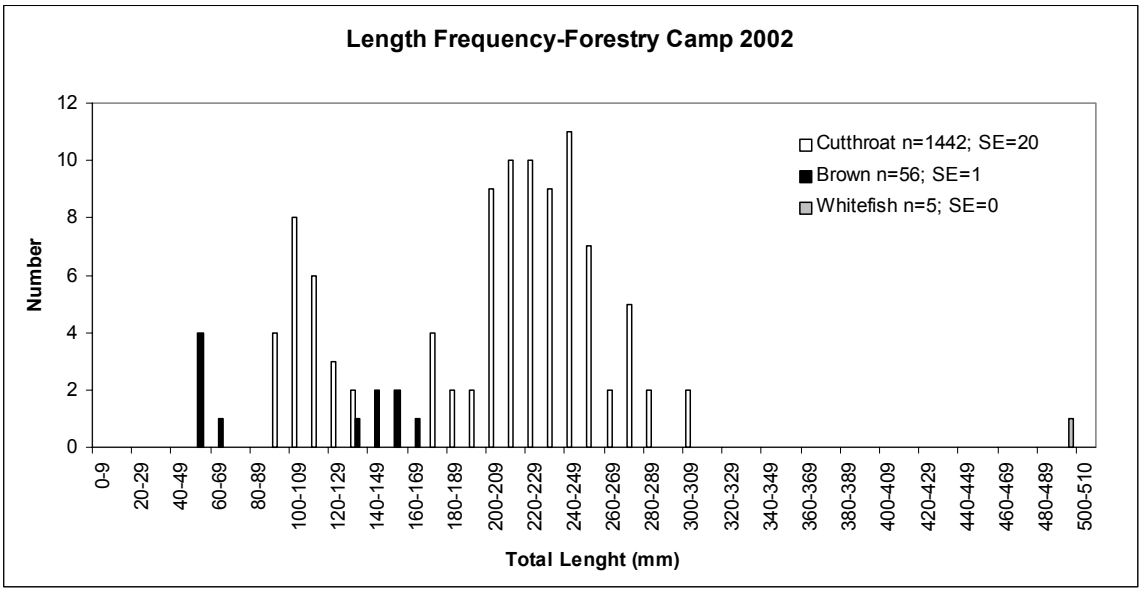


Figure 7. Length frequency distributions by species for fish captured by electrofishing at Forestry Camp, 2002. The modified Zippin population estimate is shown as N, and SE is given.

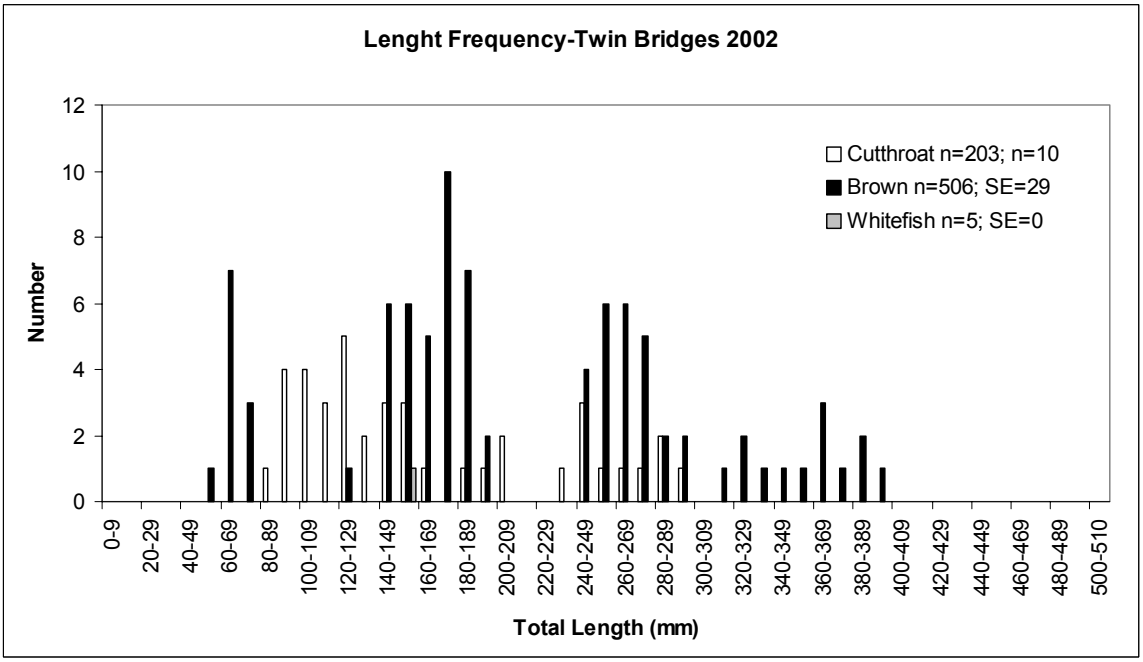


Figure 8. Length frequency distributions by species for fish captured by electrofishing at Twin Bridges, 2002. The modified Zippin population estimate is shown as N, and SE is given.

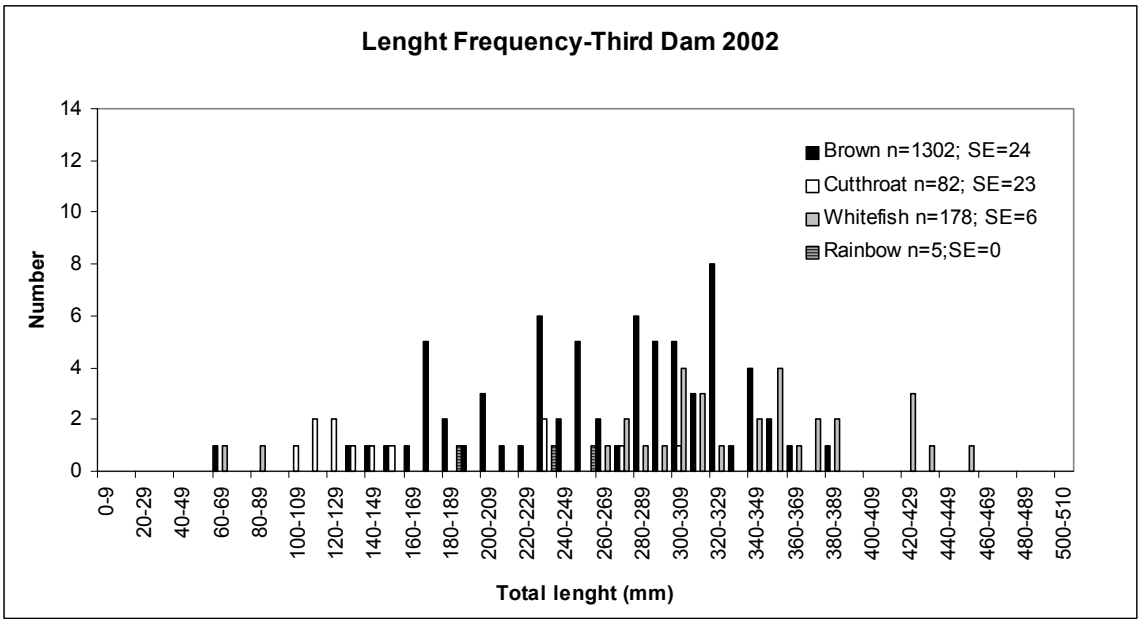


Figure 9. Length frequency distributions by species for fish captured by electrofishing at Third Dam, 2002. The modified Zippin population estimate is shown as N, and SE is given.

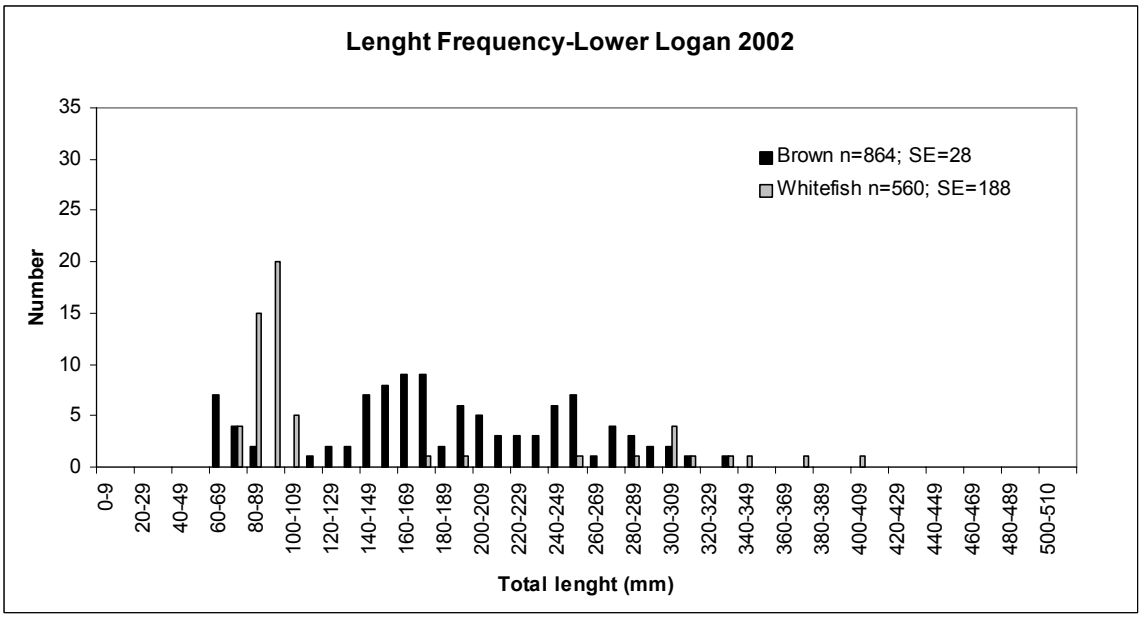


Figure 10. Length frequency distributions by species for fish captured by electrofishing in Lower Logan, 2002. The modified Zippin population estimate is shown as N, and SE is given.

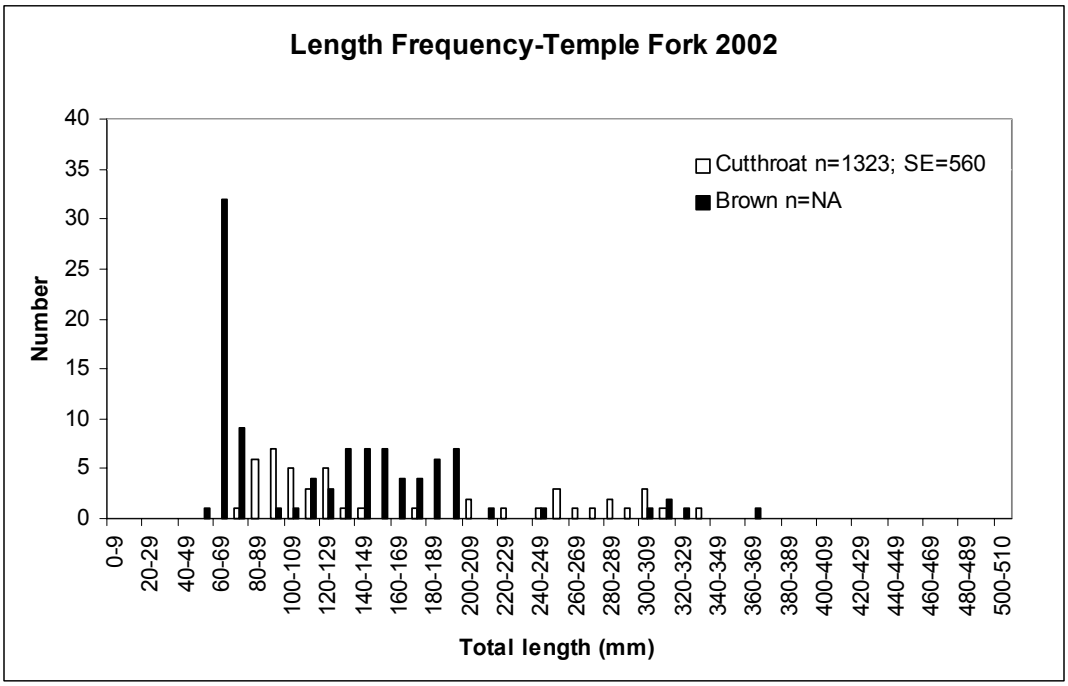


Figure 11. Length frequency distributions by species for fish captured by electrofishing in the Temple Fork tributary, 2002. The modified Zippin population estimate is shown as N, and SE is given.

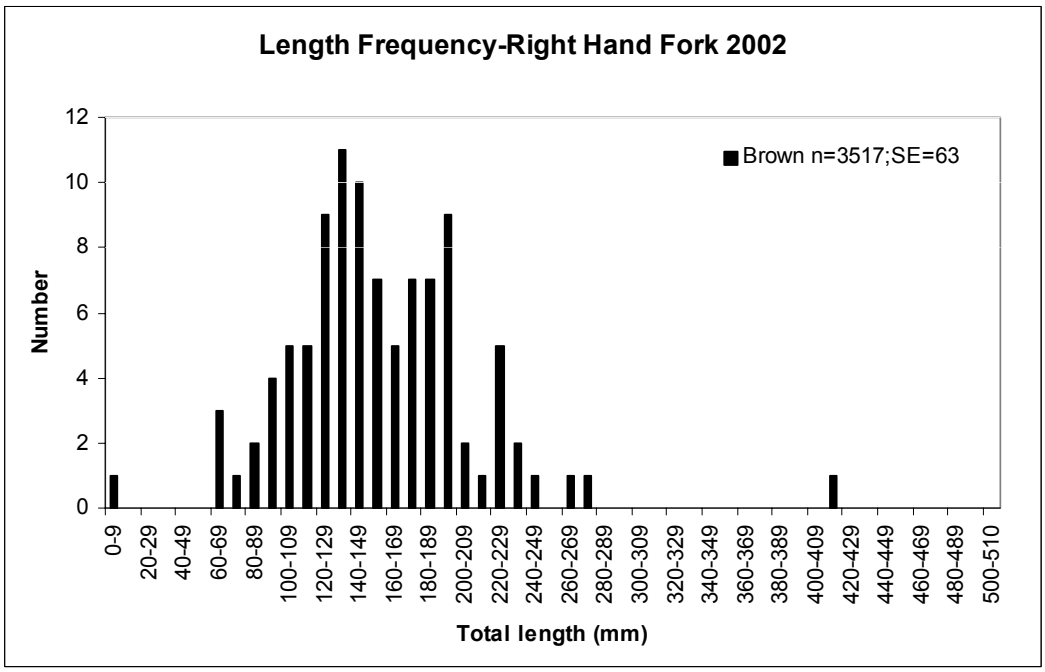


Figure 12. Length frequency distributions by species for fish captured by electrofishing in the Right Hand Fork tributary, 2002. The modified Zippin population estimate is shown as N, and SE is given.

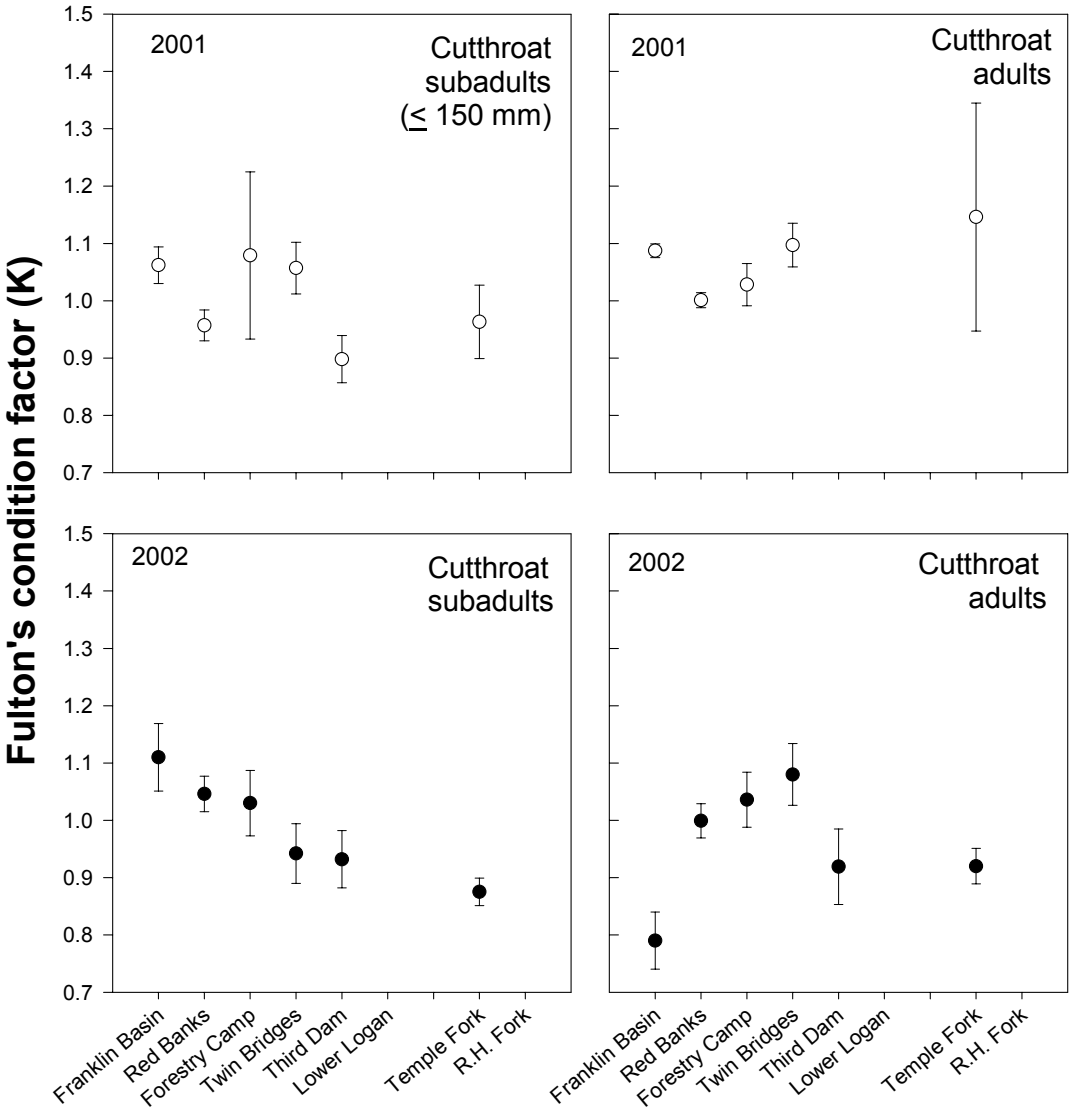


Figure 13. Condition (Fulton's K) of adult and subadult cutthroat trout captured in the Logan River, 2001 (top panels) and 2002 (bottom panels). Error bars represent ± 1 SE.

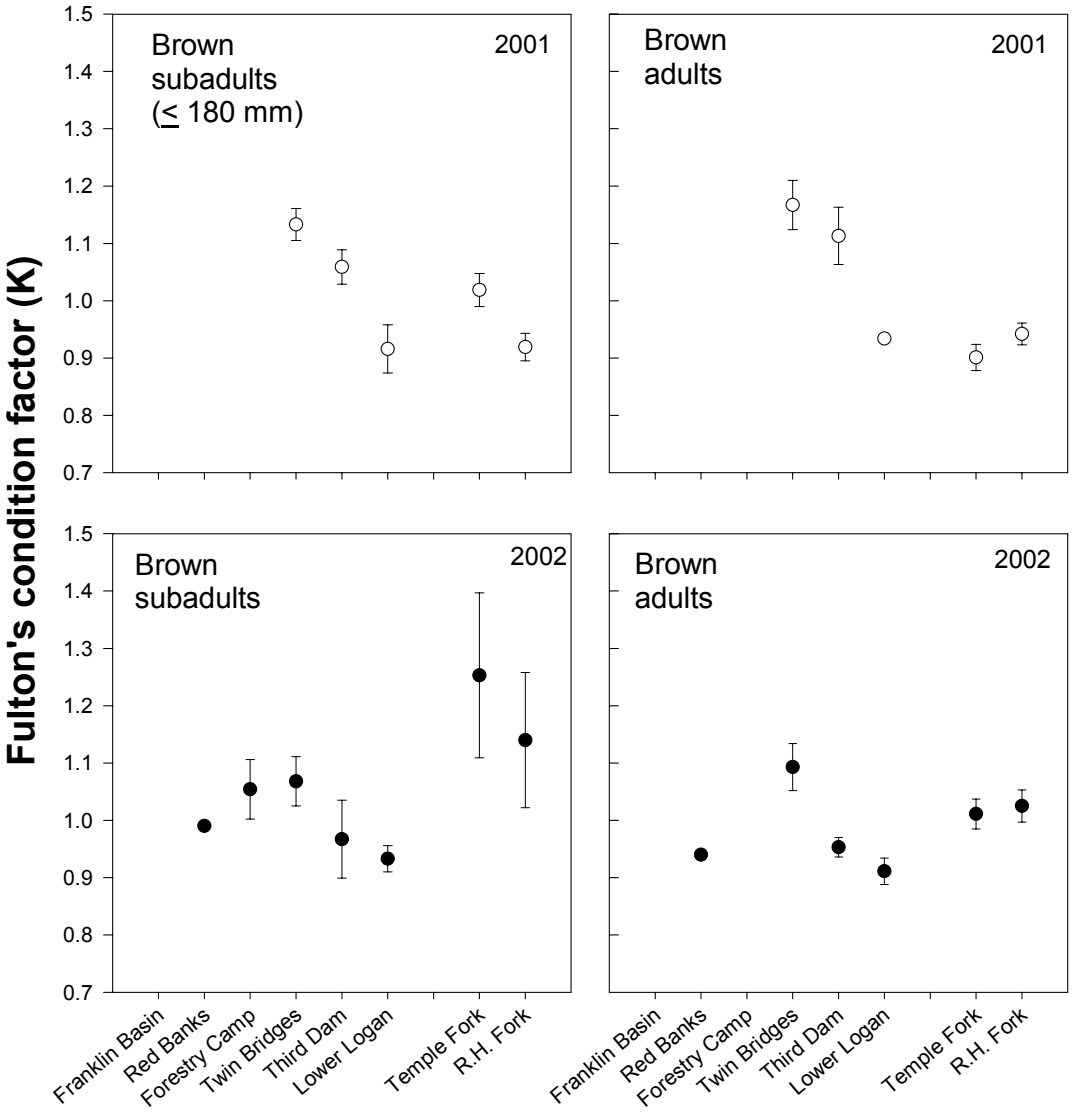


Figure 14. Condition (Fulton's K) of adult and subadult brown trout captured in the Logan River, 2001 (top panels) and 2002 (bottom panels). Error bars represent ± 1 SE.

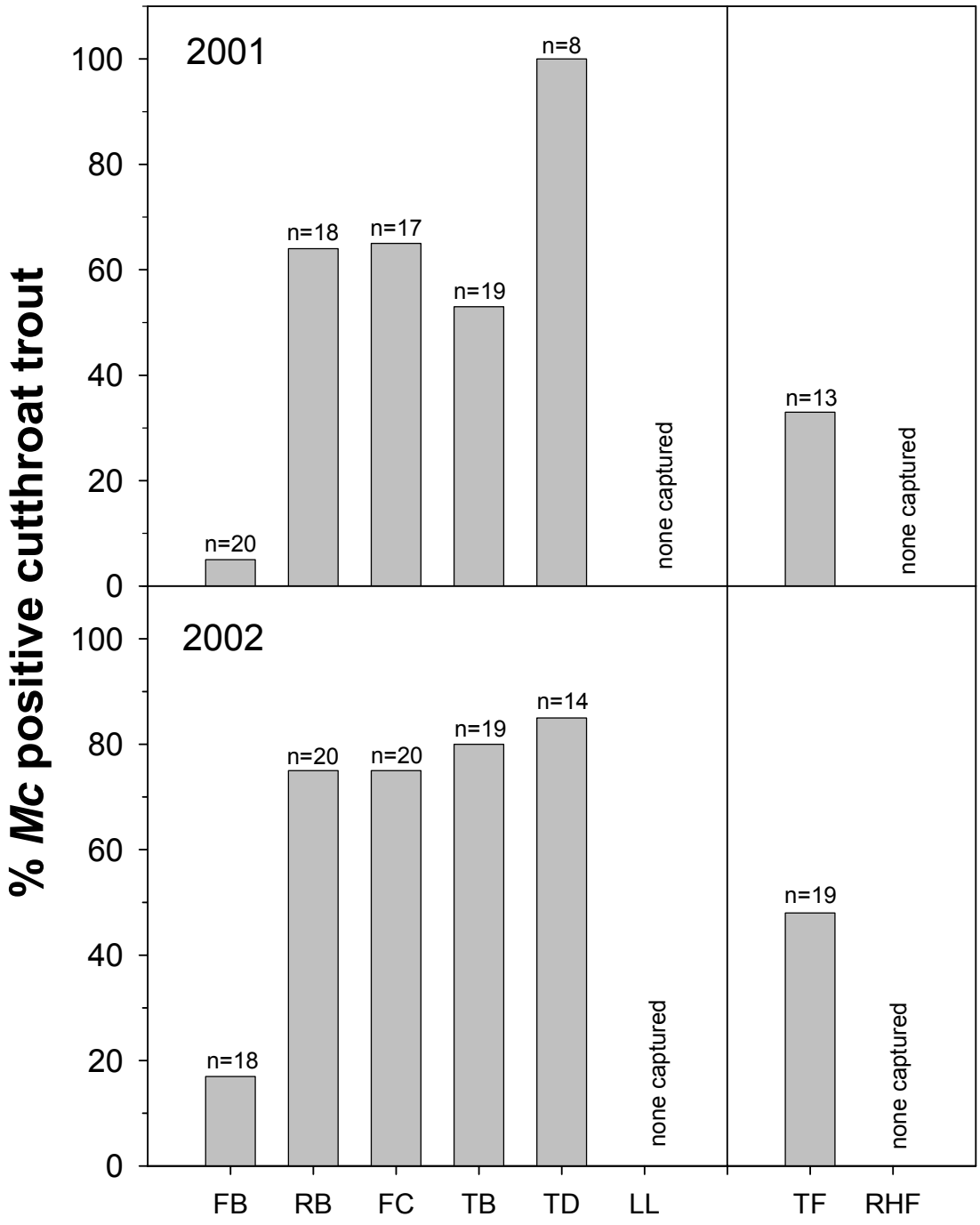


Figure 15. Percentage of cutthroat trout (all ages combined) by sample site tested positive for *M. cerebralis* in the Logan River, 2001 and 2002, based on PCR testing. Sample sizes (n) are given above bars. FB=Franklin Basin, RB=Red Banks, FC=Forestry Camp, TB=Twin Bridges, TD=Third Dam, LL=Lower Logan, TF=Temple Fork, RHF=Right Hand Fork.

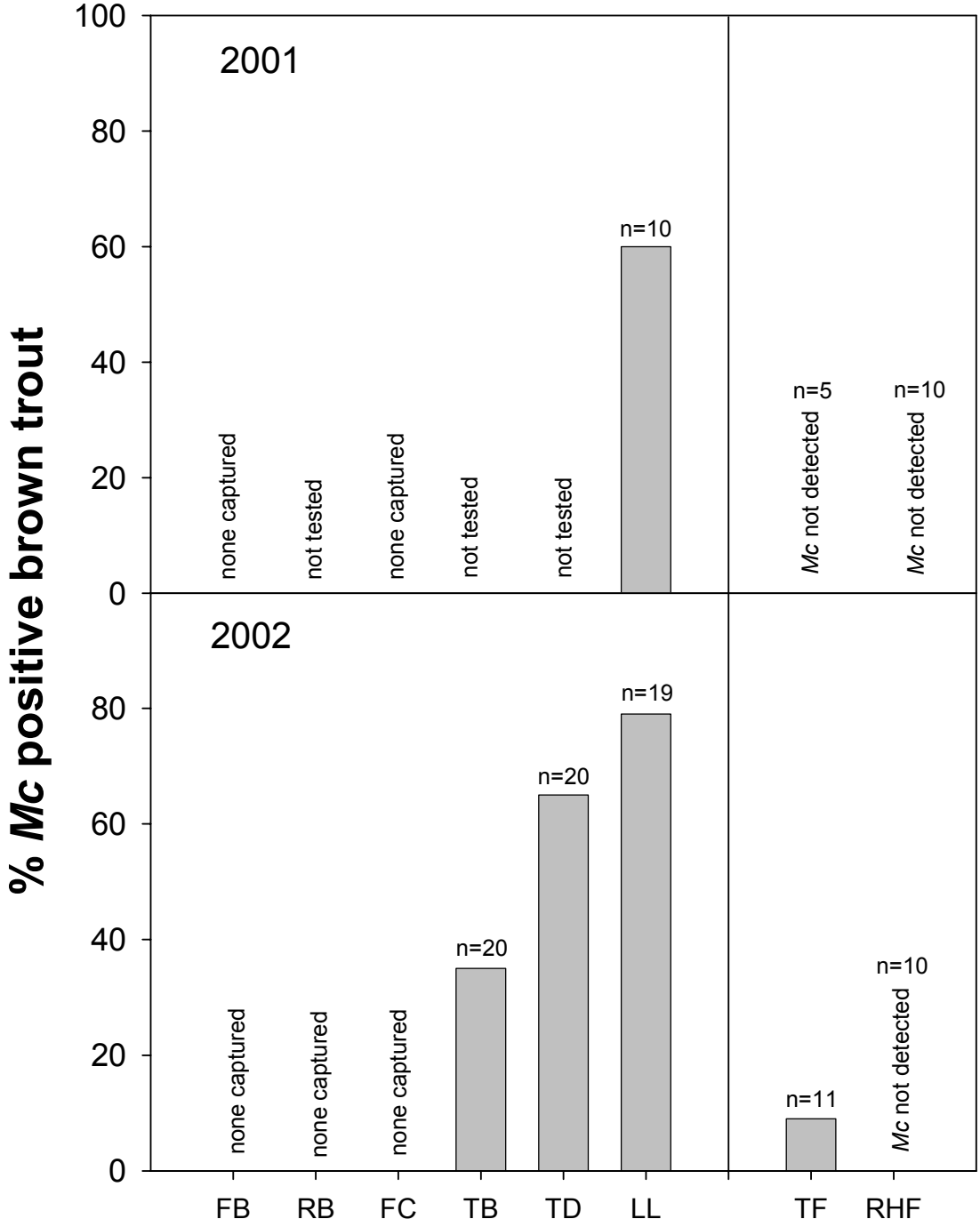


Figure 16. Percentage of brown trout (all ages combined) by sample site tested positive for *M. cerebralis* in the Logan River, 2001 and 2002, based on PCR testing. Sample sizes (n) are given above bars.

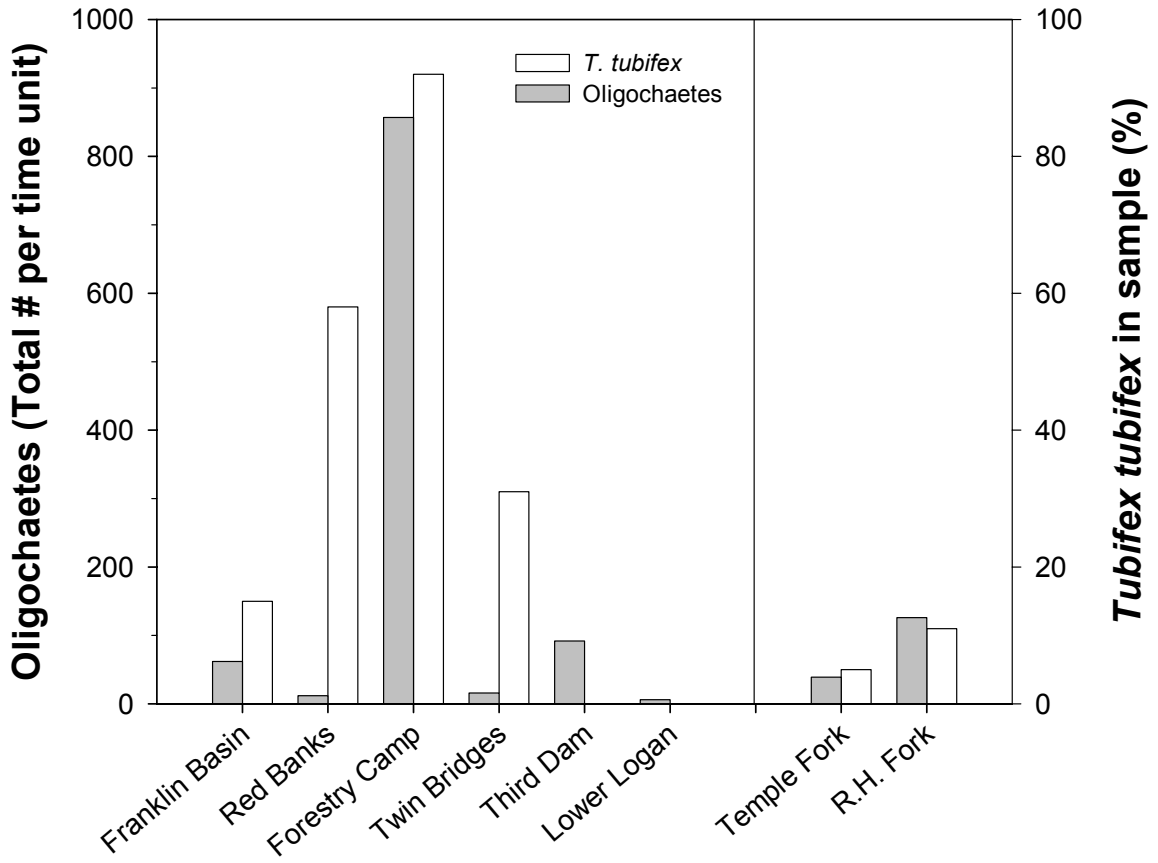


Figure 17. Total number of oligochaetes (left y-axis) sampled per time unit (10 minutes) by sampling site, and percentage of *Tubifex tubifex* (right y-axis) in each sample by site.

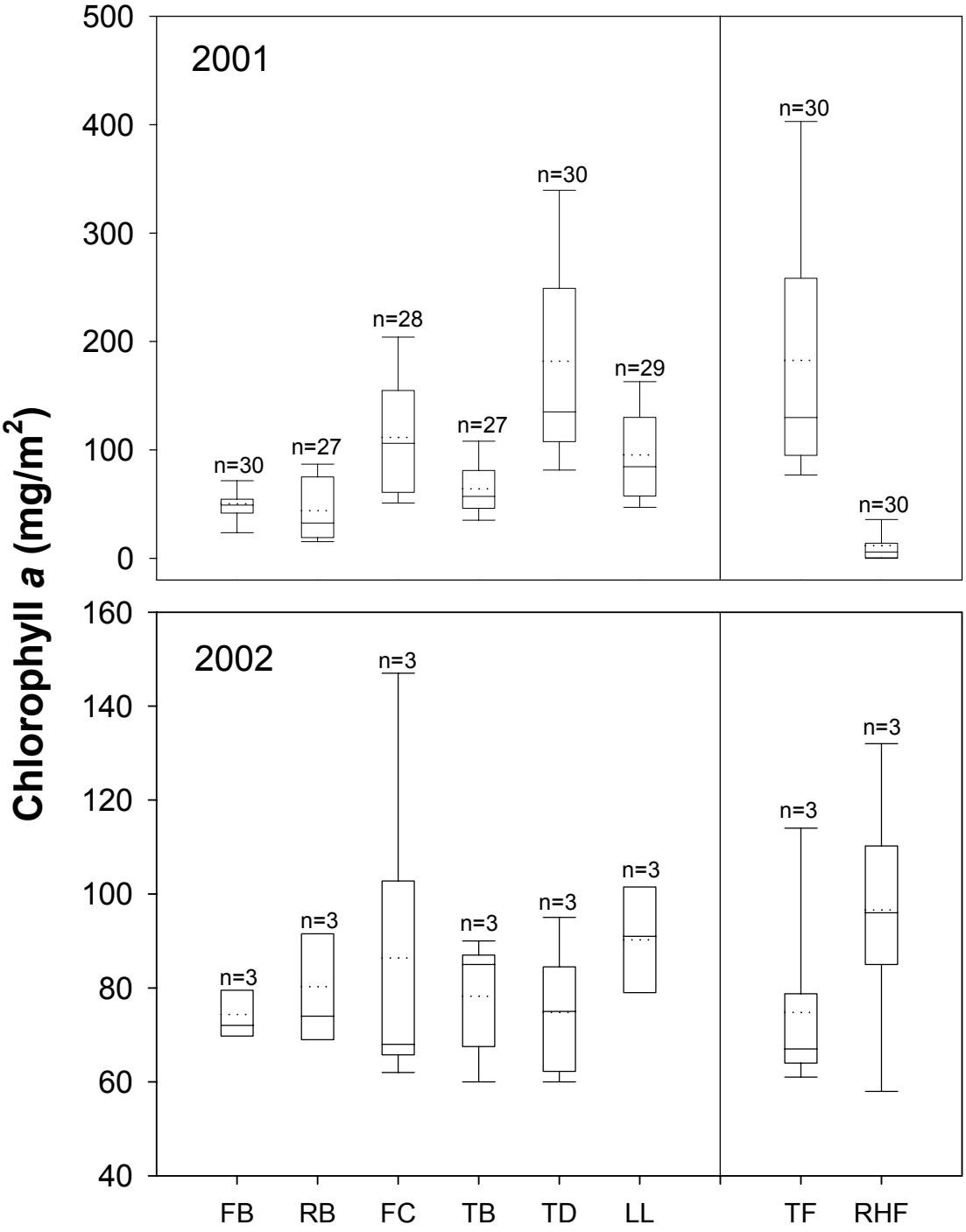


Figure 18. Periphyton biomass expressed in mg/m2 of chlorophyll a at eight sites on the Logan River, 2001 and 2002. Boxes correspond to quartiles: bold line is the mean, narrow line is the median. Whiskers correspond to the 10th and 90th percentiles. Sample size (n) is the total number of rocks (or tiles) used for chlorophyll a extraction. Data from three transects at each site were combined.

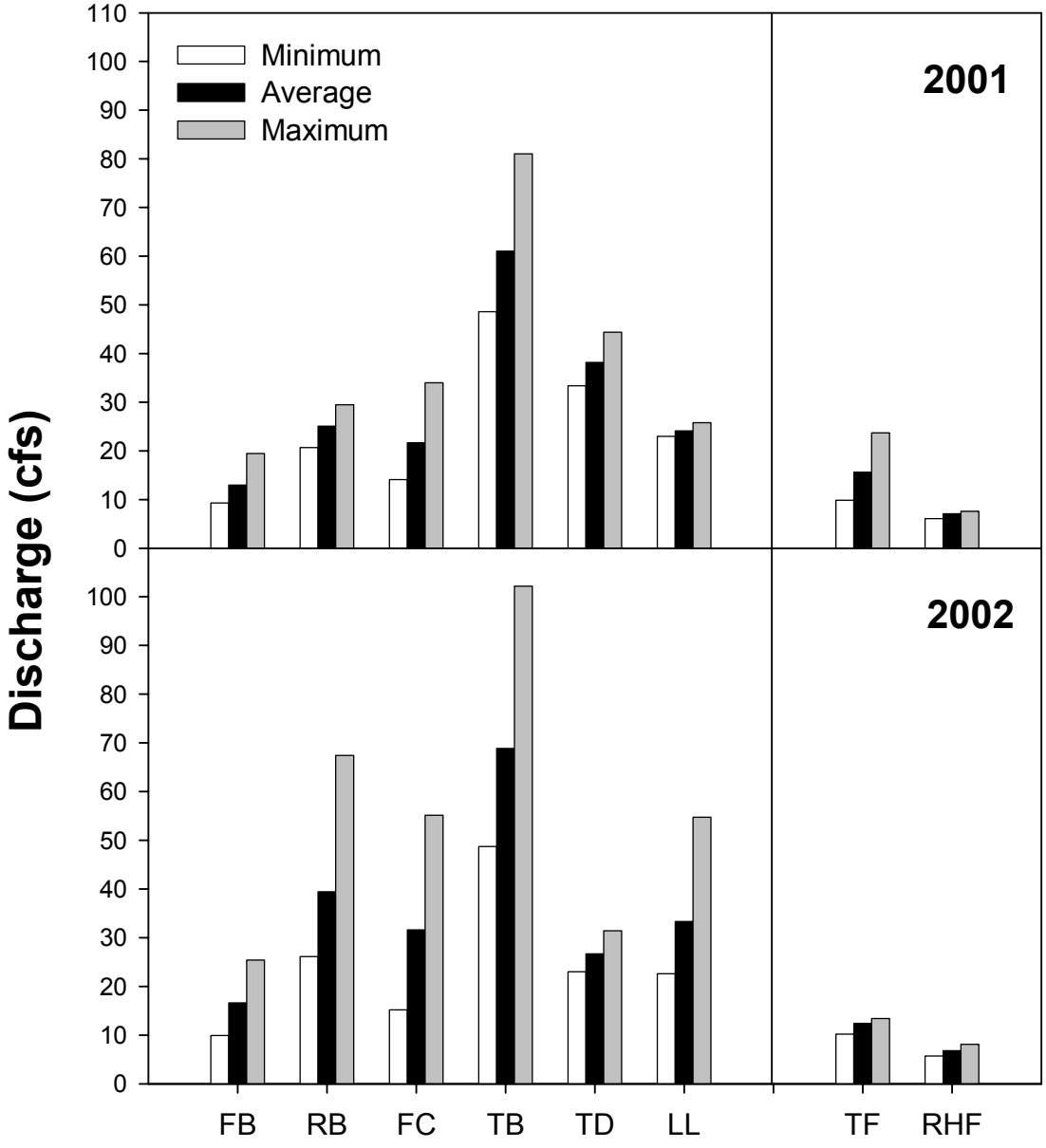


Figure 19. Monthly discharge measurements (cfs) at eight sites along the Logan River and two tributaries, 2001 and 2002.

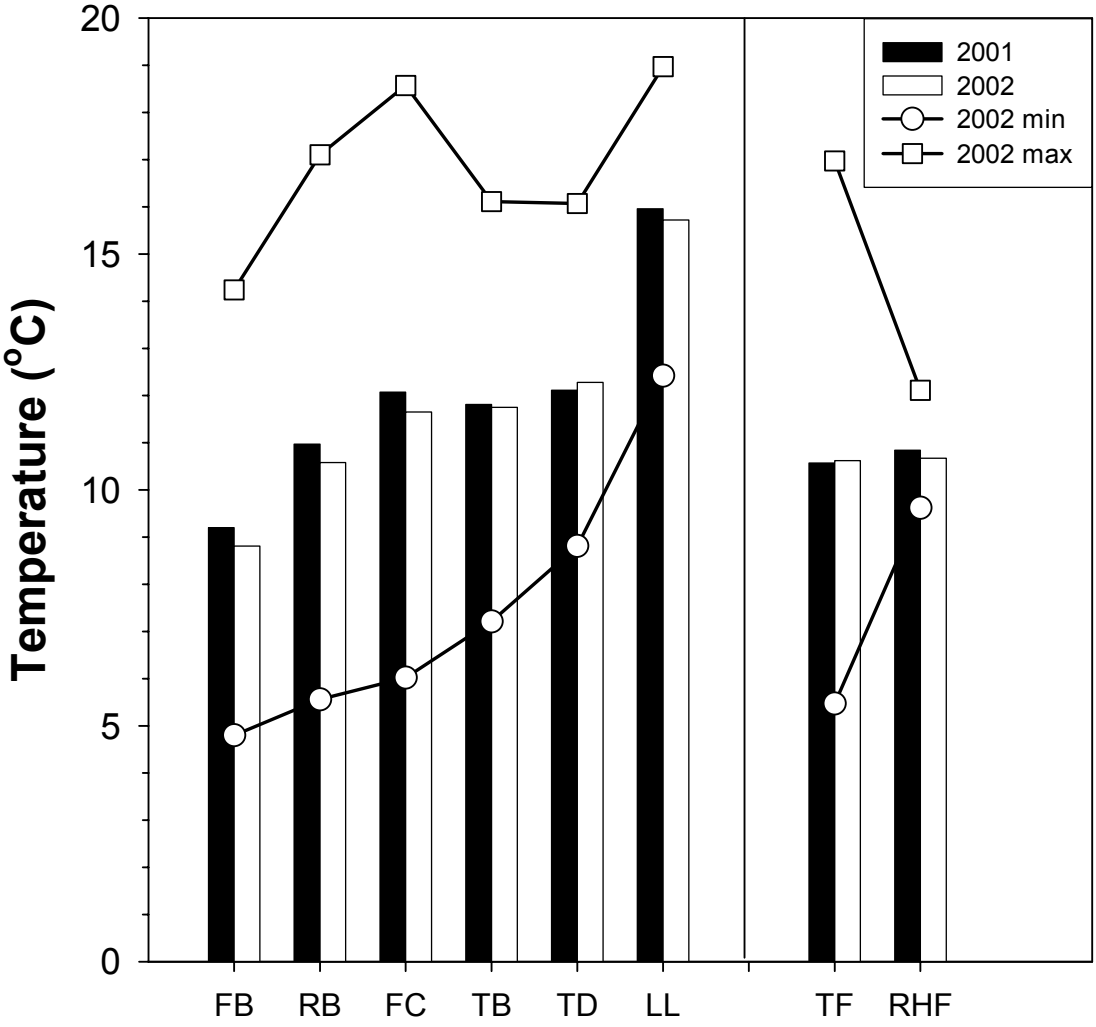


Figure 20. Average summer temperatures at eight sites along the Logan River, 2001 and 2002. Maximum and minimum temperatures are indicated for 2002.
FB = Franklin Basin, RB = Red Banks, FC = Forestry Camp, TB = Twin Bridges, TD = Third Dam, LL = Lower Logan, TF = Temple Fork, RHF = Right Hand Fork.

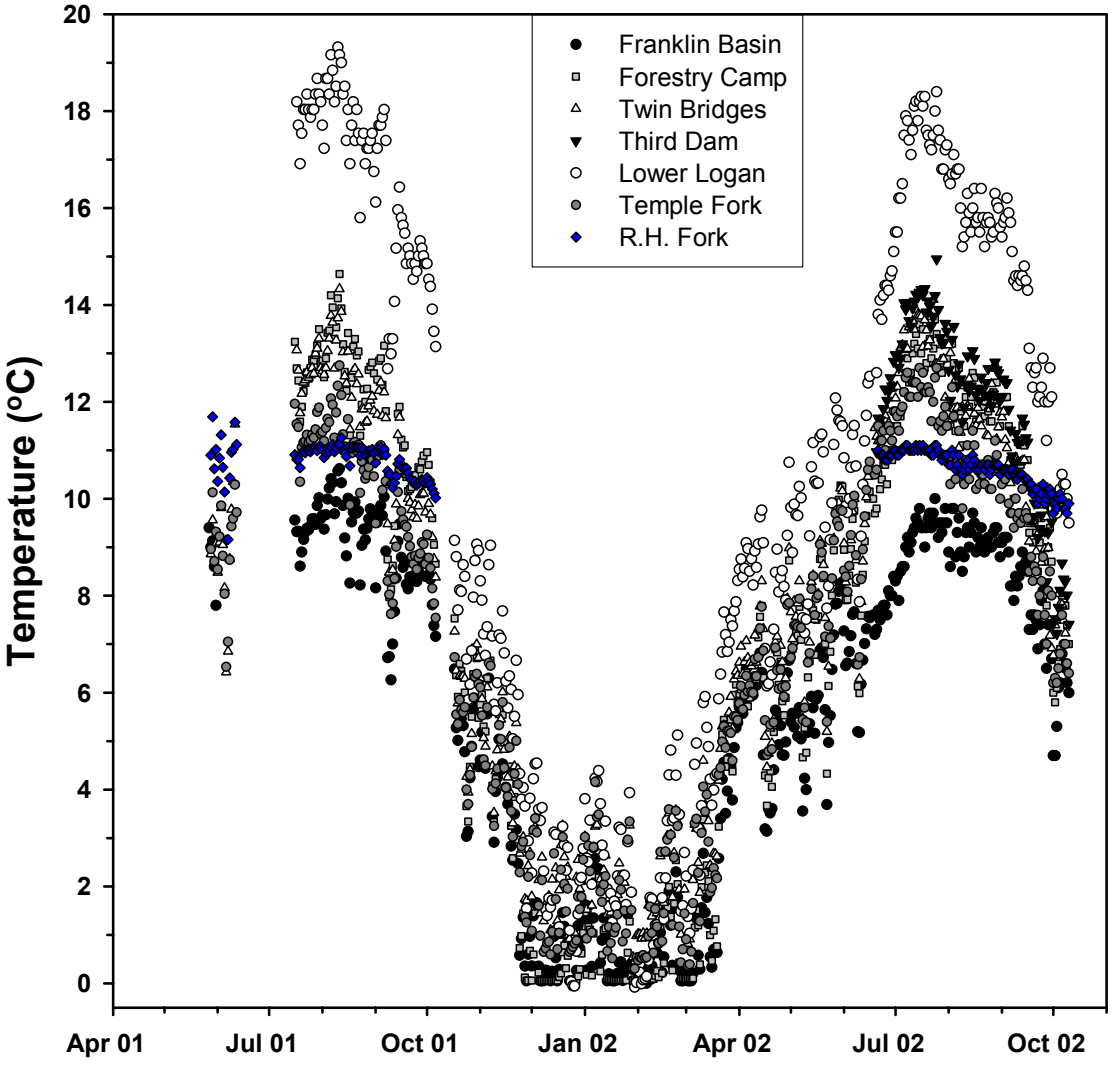


Figure 21. Average daily temperatures at five sites along the Logan River and two tributaries, June 2001 to October 2002. Shaded areas show ideal temperatures for TAM production, *T. tubifex* growth, and temperatures correlated with high *M. cerebralis* infection rates in Colorado streams.

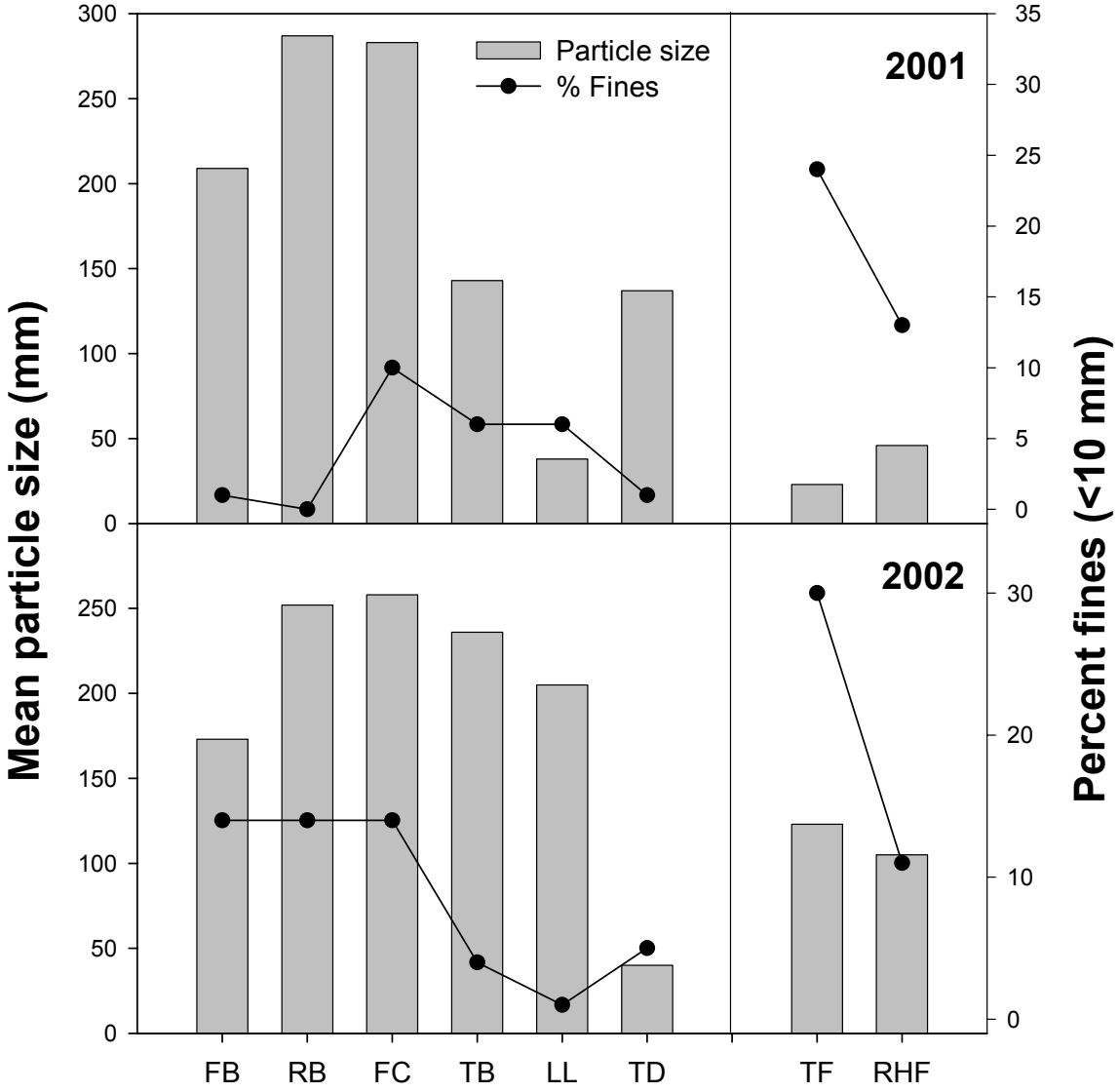


Figure 22. Substrate measurements in the Logan River and tributaries, summer 2001 and 2002. Mean particle size (gray bars; left y-axis) and percent fines (right y-axis) are shown by site. FB = Franklin Basin, RB = Red Banks, FC = Forestry Camp, TB = Twin Bridges, TD = Third Dam, LL = Lower Logan, TF = Temple Fork, RHF = Right Hand Fork.

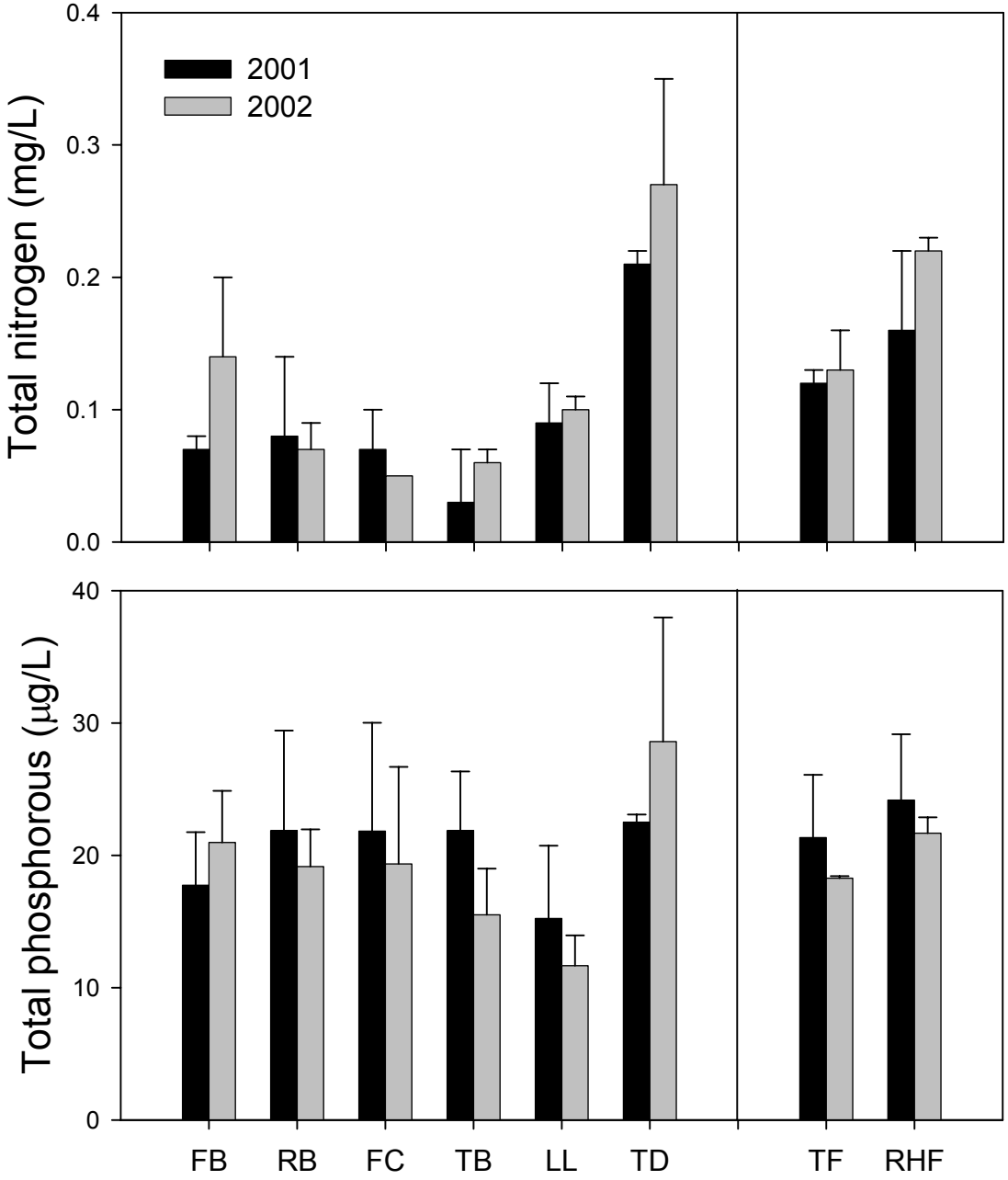


Figure 23. Average summer total nitrogen (mg/L; top panel) and average summer total phosphorous (μg/L; bottom panel) measured at six sites in the Logan River mainstem and two tributaries, 2001 (black bars) and 2002 (gray bars). FB = Franklin Basin, RB = Red Banks, FC = Forestry Camp, TB = Twin Bridges, TD = Third Dam, LL = Lower Logan, TF = Temple Fork, RHF = Right Hand Fork.

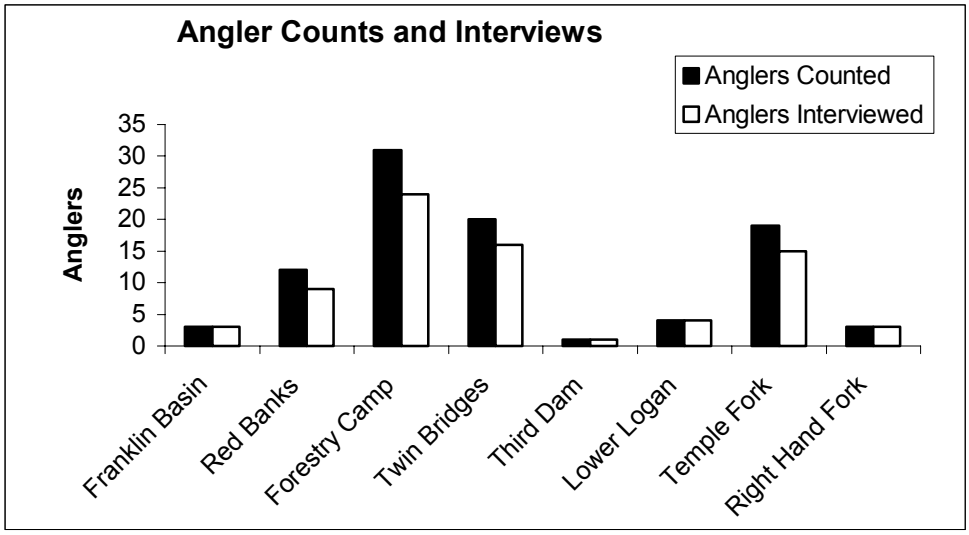


Figure 24. Number of anglers counted and interviewed within each sampling reach. Note that all anglers counted were not necessarily interviewed.

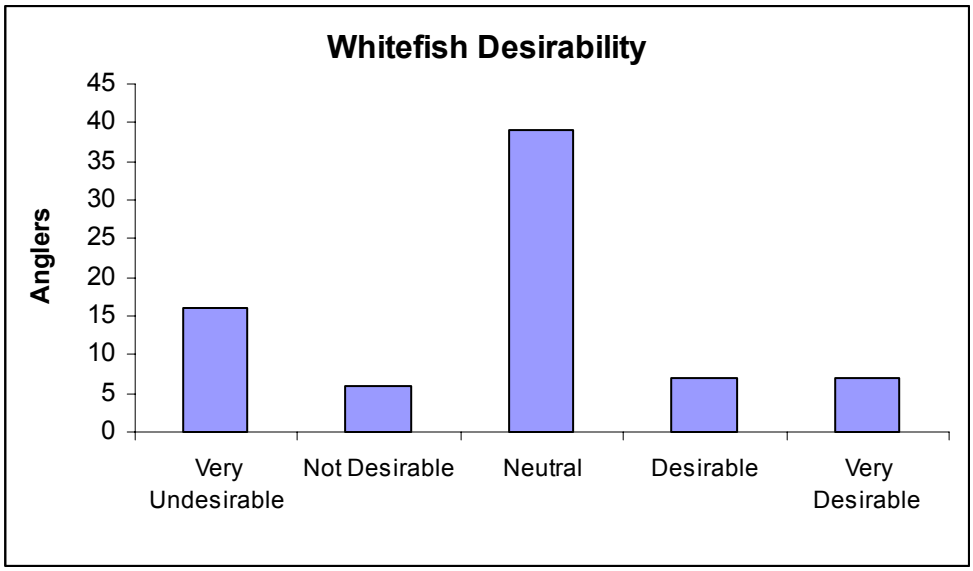


Figure 25. Angler responses to a question regarding the desirability of mountain whitefish.

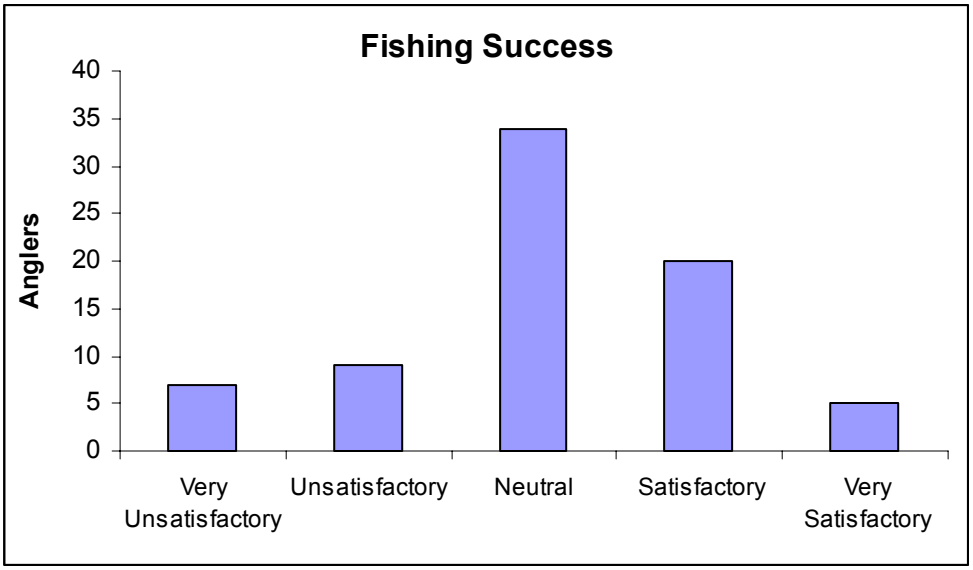


Figure 26. Angler responses to a question regarding fishing success.

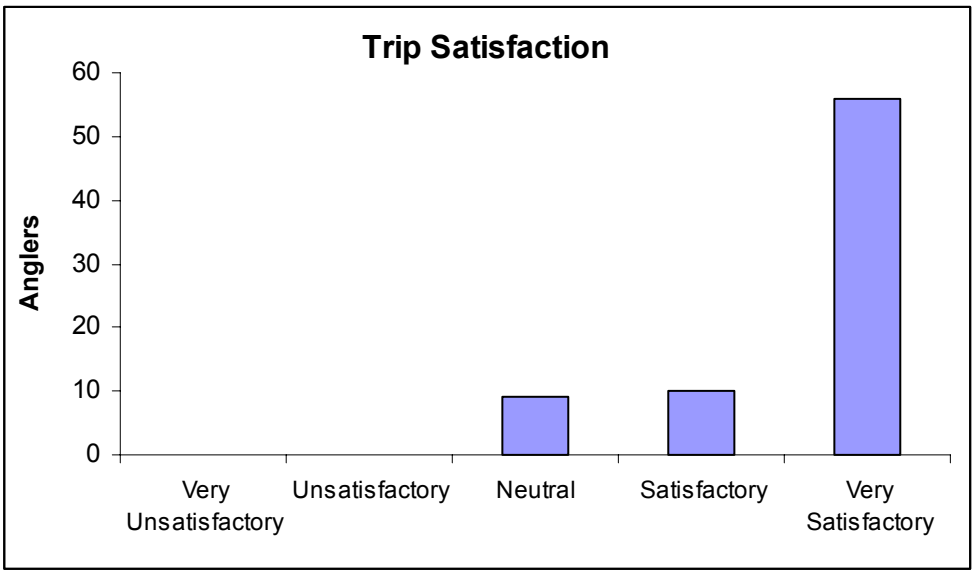
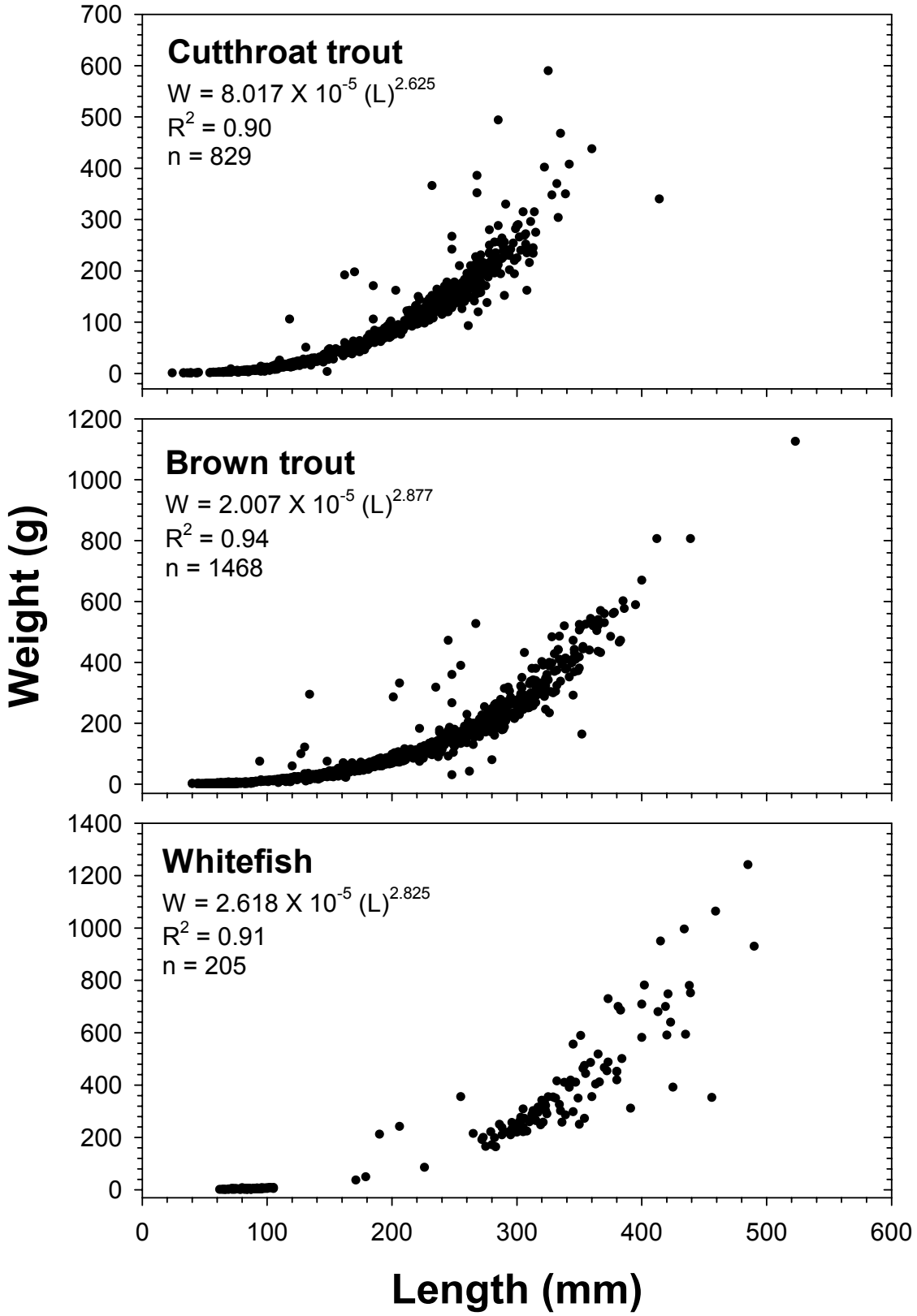


Figure 27. Angler responses to a question regarding overall fishing trip satisfaction.



Appendix Figure 1. Length-weight regression for cutthroat trout (top panel), brown trout (middle panel), and mountain whitefish (bottom panel) captured in the Logan River, 2001-2002. Regression equations are given along with sample size (n).

Logan River Creel Survey 2002

ate:	Interviewer:	Study sample site:
Sex: M F	Angler age?	Start interview time:
Primary fishing method: Fly fishing Spin fishing Bait fishing Other (specify)		
Actual fishing location:		

Good morning/afternoon. I'm doing a survey for Utah State University. We are conducting a study to examine fish movement and the spread of whirling disease in the Logan River. If you have 10 minutes, I'd like to ask you some questions about your fishing trip.

Q1. When did you start your fishing trip today? _____

Q2. When do you expect to finish your fishing trip today? _____

Q3. What species are you primarily fishing for today? (Rank them if more than one)
Cutthroat ____ Rainbow _____ Brown _____ Whitefish _____ Other (specify) _____

Q4. Do you have an opinion about whitefish? _____

What is it (circle)? Very desirable Desirable Neutral Not desirable Very undesirable

Q5. How many times do you fish the Logan River per year? _____

Q6. How many times do you fish here and other places per year? _____

I'd like you to respond to the following questions based on this scale (Very satisfied, satisfied, neutral, unsatisfied, very unsatisfied) and briefly tell me why you answered the way you did.

Q7. How would you rank your fishing success today (circle)? VS Satisf Neutral Unsat VUnsat

Why? _____

Q8. How would you rank your total trip satisfaction today (circle)? VS Satisf Neutral Unsat VUnsat

Why? _____

We've been tagging trout to investigate trout movement and the spread of whirling disease in the Logan River and tributaries. (Show them the tag and explain where on fish tag is located).

Q9. Did you catch any tagged fish today? _____. If yes, enter tagged fish info on ***RECAPTURE*** sheet.

If you caught any fish today and you allow me, I'd like to measure the catch.

Species	Kept	Released	Total		1	2	3	4	5
				Length (mm)					
				Weight (g)					
				Length					
				Weight					
				Length					
				Weight					
				Length					
				Weight					
				Length					
				Weight					

Time interview ended: _____ Comments: _____