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

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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EXECUTIVE SUMMARY

Trout populations were sampled at eight sites from ranging from Franklin Basin at high elevation down to the Lower Logan below the golf course, during base flow conditions of 2001. Population estimates were completed based on depletion techniques. Fish were weighed and measured and condition was estimated. Diet analyses were performed on stomachs; fish prey preference was estimated using electivity indices. Subsamples of fish from each species and age group (adult or subadult) were tested for whirling disease using PCR techniques. Abiotic variables including temperature, conductivity, pH, turbidity, and substrate composition and biotic variables including invertebrate density and composition, chlorophyll *a*, and nutrients (nitrogen and phosphorus) were sampled at each site. These variables were related to the prevalence and infection level of whirling disease observed in trout where appropriate.

Population estimates, based on depletion techniques, indicate that cutthroat populations are strong with the greatest number of cutthroat trout observed in Franklin basin, and none observed below Third Dam. Brown trout abundance was inversely related to cutthroat trout abundance with the greatest numbers observed below the golf course (Lower Logan) and none observed at Franklin Basin. Overall, abundance has increased 34% for cutthroat trout and about 300% for brown trout, since surveys completed by the UDWR in 1999. Cutthroat trout condition was generally fair to good with Fulton's K values > 1 observed at most sites. In contrast, brown trout condition was much poorer with values < 1 observed at the Lower Logan site and in both of the tributaries.

Whirling disease tests indicated that whirling disease has spread widely throughout the river since the last survey in 1999. Cutthroat trout tested > 50% positive at all sites from Red banks down to Third Dam. Upper elevation sites also tested positive, but with lower percentage of positive infection. Brown trout also tested positive at the Lower Logan but negative in the tributaries. These results indicate that whirling disease has spread up the Logan River and into the upper tributaries. Further, cutthroat sub adults generally showed greater infectivity relative to adults, consistent with the known greater sensitivity at earlier life stages. The combination of life history and low temperature may protect cutthroat in some areas. Despite the widespread detection of whirling disease throughout the Logan River, we observed no clinical signs of whirling disease on

any trout species sampled. It is too early to determine whether there is a population level effect of whirling disease in the Logan River (only two years of testing data).

Abiotic and biotic variables may affect both the levels of infectivity of a disease as well as the effect that disease has on an individual and/or the population. In the Logan River, minimum and maximum summers temperatures range from approximately 6 to 20 °C. The highest temperatures were observed below the golf course at the Lower Logan site (> 19 °C) and the lowest temperatures were observed at the highest elevation site, Franklin Basin. These high and low temperature extremes may limit TAM maturation and the spore release period and further, may determine the length of the *T. tubifex* growth period.

T. tubifex site preference and abundance has been shown to be related to the productivity of the environment (e.g., bacterial abundance and the concentrations of nitrogen and phosphorous) in the environment. Chlorophyll *a* data showed a pattern that roughly corresponds the degree of whirling disease infectivity, which may suggest that the more productive sites provide more suitable or preferred habitat for tubifex worms. Nutrient analyses (to be completed this year) will also contribute to our understanding of the effects of nitrogen and phosphorous on *T. tubifex* distribution.

Invertebrate density varied little across sites; however these measures of invertebrate density are highly sensitive to spatial and temporal variability. In contrast, the composition of the invertebrate fauna varied considerably from high elevation to low elevation. Ephemeropterans (mayflies) and organic matter were the primary components of adult and subadult cutthroat trout diets. Electivity indices indicate that cutthroat trout prefer odonates (dragonflies and damselflies) and ephemeropterans at high to mid elevation sites, and dipterans (black fly larvae) at low elevation sites. While dipterans made up a substantial proportion of the available invertebrate prey items at most sites, they were selected by cutthroat trout only at the Third Dam site. The modified environment of the dams, variation in species (within Diptera), or prey behavior may explain this difference.

The inverse relationship of cutthroat and brown trout and the small degree of spatial overlap suggests that these two fishes segregate spatially with cutthroat trout at higher elevation sites and brown trout at low elevation sites. Diet analyses demonstrated a high degree of overlap in prey items between brown and cutthroat trout. At the only site where they overlap, Twin Bridges, these two

species had similar diets. Whether the observed separation between cutthroat and brown trout in the Logan River is to due competition (interactive segregation) or differences in the physical preference and tolerance ranges (selective segregation) is unknown and may warrant some consideration in the future.

INTRODUCTION

Various studies of fish populations in the Logan River in northern Utah have been conducted over the past five decades (Thoreson 1949; Pechacek 1950; Matthews 1966; Twedt 1973; Hidelbrand 1998; Thompson et al. 2000), mostly to assess the effects of increasing fishing pressure and habitat deterioration. 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 (Benke 1992). 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 dynamics and condition of the trout population, habitat quality, and the current and potential 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 the 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 1996; 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).

The different responses of trout populations to *M. cerebralis* suggest the importance of other factors as contributing to year-class declines in whirling disease positive environments (Modin, 1998; Schisler et al. 2000). Infectious agents cause a disease of the host when the environmental conditions are favorable, when there are additional stresses, and sufficient interactions between these factors (Hedrick 1998; Lafferty and Kuris 1999). In addition, susceptibility to the disease is an important factor to consider when planning sampling in order to avoid bias towards sampling just survivors of more tolerant species. Rainbow trout are more susceptible to death from infection by *M. cerebralis* due to its higher infection levels and severity of lesions compared to brown trout, cutthroat trout, and other salmonids (Baldwin et al. 1998). Also, it is important to consider the presence of mountain whitefish (*Prosopium williamsoni*) in the Logan River as this species was reported infected with *M. cerebralis* in various drainages in Montana (Baldwin et al. 1998).

Environmental factors also influence ecology of the tubuficid oligochaete, *Tubifex tubifex*. These worms are necessary as intermediate hosts to complete the whirling disease 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). Also, 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). In addition, 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° and 20° 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 form 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).

Whirling disease in Utah- Whirling disease was reported for the first time in Utah in 1991. Examinations from various sites led to the discovery of new occurrences of whirling disease in Utah. Samples from the Little Bear River tested positive for whirling disease, as did samples from a commercial aquaculture facility in Wayne County (Wilson 1993). In 1994, samples from Porcupine Reservoir also tested positive for whirling disease; representing a significant increase in the prevalence of the disease in the population of kokanee salmon (*O. nerka*) since the beginning of a monitoring program that started in 1996 (Wilson et al. 1998). Preliminary results from whirling disease samples indicated that it was present in the Logan River (Montgomery et al. 2001). 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, as 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 started a long-term monitoring program of the fish community at eight sites, from the upper headwaters of the Logan River (Franklin Basin) down 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 will consider different physical (e.g., flow, temperature, substrate), chemical (e.g., concentrations of phosphorous and nitrogen), and biological (e.g., invertebrates) factors associated with fish abundance and distribution, as well as the presence and virulence of whirling disease and its transmission from one area to another.

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 the trout populations. In this later aspect, we focus on the relationships between environmental factors (e.g., temperature, flow, sediment, water quality) and the presence, infectivity, and prevalence of whirling disease. We will also attempt to determine which environmental factors limit the distribution and abundance of *T. tubifex*.

We separated the study into two components. The biological component addresses (1) the food web structure including measurements of chlorophyll concentrations in the periphyton, (2) the study of the invertebrate community, (3) the assessment of the abundance and distribution of trout populations and oligochaete worms, and (4) 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, based on a yearly average, is approximately 2.6 cubic feet per second (0.07 m^3/sec). At the Right Hand Fork tributary discharge reaches its maximum value (3.5 cfs), while the lowest (1.3 cfs) is observed below the First dam (Thoreson 1949).

Predominant game fish include stocked rainbow trout (including albino strains), brook trout, brown trout, and endemic Bonneville cutthroat trout. Non-game fish include mountain whitefish, carp (*Cyprinus carpio*), mountain sucker (*Catostomus platyrhuncus*), 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 subadult and adult fish using PCR techniques.
3) Analyze the food web structure by examining gut contents, and electivity indices.
4) Relate dietary information to fish and invertebrate abundance and distribution.
5) Determine oligochaete density and distribution.
6) 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.
7) Relate these biotic and abiotic variables to fish and invertebrate distribution and abundance, and distribution and presence of whirling disease.
8) Determine whirling disease infection rates and the intensity of the infection among sentinel fish exposed in the field.

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. The settings on the electrofishing equipment varied depending on the stream conductivity. However, to obtain comparable data to previous surveys, settings will be similar to those used by the UDWR personnel (pulse: 70 Hz, frequency: 4 ms, and voltage: 400 V). Effort will be 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, 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, whirling disease, and future stable isotope analyses.

Population estimates- Population estimates were calculated by two removal methods: a depletion estimate and a modified Zippin depletion estimate. A reach-specific 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 = 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 ($\pm$ 2 standard errors $\sim$ 95% confidence intervals) 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.

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

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

$$\text{Standard error (SE)} = [C_1 * C_2 / (C_1 - C_2)^2] * (C_1 + C_2)^{½}$$

Condition- Length-weight relationships and condition factor (Fulton's K = W * 100,000 / L^3) were calculated for cutthroat and brown trout (adults and subadults) for each site, and then compared within and across sites.

Diet analysis- To better understand the factors related to fish abundance and distribution in the drainage, stomach contents of sampled fish were analyzed. Stomachs were removed from the same fish used for PCR whirling disease analyses. Stomachs were removed and preserved in 10% buffered formalin. Before the samples were examined in detail, they were rinsed with water and preserved in 70% ethanol (Bowen 1996). Stomach contents were identified to species of prey fish (when possible), whereas terrestrial invertebrates were classified explicitly. Aquatic invertebrates in stomachs were identified to order (e.g., Trichoptera, Plecoptera, Ephemeroptera). Prey fish were counted and weighed (blot-dry wet weights to nearest 0.01 g), while invertebrate prey were weighed *en masse* by classification. Intact prey fish were measured to the nearest mm (backbone and standard length). Percent composition by weight was calculated as recommended by Bowen (1996).

Prey selection- To relate fish diets to food availability and determine prey selectivity by each fish species, we calculated two different electivity indices at sites where sufficient data existed (Franklin Basin, Forestry Camp, and Third Dam).

Chesson's alpha (α) is defined as:

$$\alpha_i = (r_i / p_i) / \sum (r_i / p_i)$$

where, r_i is the proportion of items of food type i in the diet and p_i is the proportion of items of food type i in the environment. Random feeding is a function of the number of

food items, 1/n. The index varies between 0 and 1. Values above 1/n designate preferred prey items and values below 1/n signify avoided items.

Strauss's linear index (*L*) is defined as:

$$L = r_i - p_i$$

Values of zero imply random feeding, while preference and avoidance vary from +1 to –1, respectively.

Whirling disease analyses

Fish heads from each specimen were removed, frozen, and tested for whirling disease following the polymerase chain reaction method (PCR; Andree et. al. 1998). For mountain whitefish, the caudal peduncle was tested. PCR samples were processed by Pisces-Molecular LLC (Boulder, Colorado).

Invertebrate sampling

Aquatic invertebrates were sampled with a kick net or surber sampler and washed through a 500-µm screen to remove fine sediments. Samples were placed in buckets and non-benthic macroinvertebrates were removed, the remainder of each sample was retained and preserved with ethanol for later lab identification. An additional sample of the predominant herbivore and predator species was collected and frozen immediately for future stable isotope analyses.

To minimize cost and duplication of effort, the results from invertebrate samples enumerated, identified, and summarized by the USU Bug Lab (Mark Vinson, unpublished data) were used for this report. These data represent from 3 to 12 samples averaged for each site (n = 8) in years 1997-2000.

Periphyton

Rocks were collected randomly from a riffle zone at each site by walking through a transect perpendicular to the shoreline. Ten rocks were collected from three transects (3 replicates). Collected rocks were placed in plastic bags (whirl-packs), stored in a cooler in the field, and kept in a refrigerator in the laboratory prior to extraction of chlorophyll and fluorometric analyses. Chlorophyll *a* was extracted within 24 hours of collection. The surface dimensions of each rock were estimated based on the shape of the rock and multiple measurements at each axis.

A known volume of 100% methanol was added to the previously frozen rocks held in sealed plastic bags. Chlorophyll *a* pigment was extracted in the dark for 24 hours at room temperature. From the extract, two 6 mL aliquots per sample were analyzed fluorometrically (Holm-Hansen and Riemann 1978).

Environmental variables

Sampling of river water for physical and chemical characteristics was conducted generally 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 (Optic Stow Away) set in streams. Temperature was also recorded with a hand-held thermometer before and after electrofishing at each site.

Substrate- Substrate particles 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) and total phosphorous (TP) was digested simultaneously (Valderrama 1991); separate aliquots were taken for the determination of nitrate (Nydahl 1978) and soluble reactive phosphorous (Valderrama 1991). Two replicates of each sample and two spikes were processed for quality assurance and quality control.

Sentinel Fish Experiment

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 for 21 days and returned to the lab and held in site-specific aquaria in 15° C, pathogen-free water for 4 months. Three cages at each site held 90 fish. Exposures were conducted at three sites. Franklin Basin, the uppermost site, was used as control as it previously tested negative for whirling diseases. The sites at Temple Fork and Twin Bridges represented low to highly infected locations, respectively based on preliminary whirling disease tests in 1999 (Thompson et al. 2000). PCR analyses were conducted on all surviving fish. Age of fish was reported in Celsius temperature units (CTU). Physical and chemical variables (discharge, turbidity, conductivity, pH,) were measured weekly at exposure (cage) sites; temperature was recorded hourly using temperature loggers.

RESULTS

Biological data

Fish sampling

Bonneville cutthroat trout, brown trout, rainbow trout, brook trout, and mountain whitefish were sampled during stream surveys in the Logan River drainage in summer 2001. We also captured sculpin at most sites and carp at the lower-most elevation. 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); similar estimates were obtained using a regular depletion estimate for each of these species (Figure 3). The following summaries by site are from the modified Zippin depletion population estimates (estimate $\pm$ 1 standard error).

Franklin Basin- Population estimates indicate that Franklin Basin had the highest cutthroat trout abundance of all sampled sites (1768 ± 149 fish/km; Figure 2). Using three-pass electroshocking, we captured 177 cutthroat trout ranging from 60 to 350 mm TL demonstrating two strong age classes with modes at 140 mm and 240 mm (Figure 4). The current size distribution was similar to the 1999 survey (Thompson et al. 2000). A small number of brook trout (45 ± 15 fish/km) were also captured at this site: four were between 140 and 150 mm and one was 280 mm (Figure 5).

Red Banks- The cutthroat trout population estimate at this site was 1626 ± 42 fish/km (Figure 2). Most of the fish captured were cutthroat trout (n = 325) in three possible age classes with modal lengths of 100 mm, 160 mm, and 250 mm (Figure 6); similar to sizes captured in the 1999 survey (Thompson et al. 2000). The brown trout population was estimated at 40 ± 69 fish/km. All eight brown trout captured were greater than 200 mm. Only two brook trout (~ 300 mm) and one whitefish (~ 500 mm) were captured at Red Banks (Figure 6). Due to the small number of fish captured, population estimates were not calculated for these two species.

Forestry Camp- We captured 348 cutthroat trout at this location providing a population estimate of 1742 ± 62 fish/km (Figure 2). Length frequency histograms indicate four potential age classes with modes at 30 mm, 105 mm, 170 mm, and 250 mm (Figure 6). We captured more age-0 cutthroat trout; however, size frequencies were similar to the 1999 survey (Thompson et al. 2000). Only one brown trout (~ 260 mm) and one whitefish (~ 400 mm) were captured at Forestry Camp (Figure 7). Catches of brown trout and whitefish were equally as low in the 1999 survey (Thompson et al. 2000).

Twin Bridges- Brown trout (413 ± 85 fish/km) were slightly more abundant than cutthroat trout (394 ± 363 fish/km) at this site (Figure 2). We captured 83 brown trout of four apparent age classes with modes at 60 mm, 150 mm, and 240 mm, and 350 mm (Figure 8). It appears that modal length has increased since the 1999 survey (1999 modes roughly at 50 mm, 120 mm, 220 mm, and 310 mm; Thompson et al. 2000). Seventy-nine cutthroat trout were captured with modes at 110 mm, and 250 mm. We captured one cutthroat measuring 410 mm. Whitefish were either very small or very large; five were approximately 90 mm and 6 were larger than 400 mm (Figure 8). We estimated 56 ± 6 whitefish/km at Twin Bridges (Table 1).

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.

Site	Species	Fish/km	SE
Franklin Basin	Cutthroat	1768	149
	Brook	45	15
Forestry Camp	Cutthroat	1742	62
	Brown	NA	NA
	Whitefish	NA	NA
Red Banks	Cutthroat	1626	42
	Brown	40	69
	Brook	NA	NA

Site	Species	Fish/km	SE
	Whitefish	NA	NA
Twin Bridges	Cutthroat	394	363
	Brown	413	85
	Whitefish	56	6
Third Dam	Cutthroat	49	24
	Brown	2126	377
	Rainbow	35	0
	Whitefish	90	0
Lower Logan	Brown	1557	931
	Whitefish	269	109
Temple Fork	Cutthroat	171	3
	Brown	2124	63
Right Hand Fork	Brown	2700	116

Third Dam- Third Dam was the only site where rainbow trout were captured (n = 7): two were 130 mm and five were ~ 310 mm (Figure 9). Brown trout were very abundant (2126 ± 377 fish/km) at this location, whereas abundance estimates of cutthroat trout (49 ± 24 fish/km), rainbow trout (35 fish/km), and whitefish (90 fish/km) were much lower (Table 1). We captured 425 brown trout in four possible age classes with modes at 60 mm, 150 mm, 230 mm, and 310 mm (Figure 9). Nine cutthroat trout were captured: eight ranged between 90 and 150 mm, and one was ~ 330 mm. Eighteen whitefish were collected: one was 170 mm, 12 ranged between 310 and 360 mm, and five were approximately 420 mm (Figure 9).

Lower Logan- Brown trout dominated this section of the river (1557 ± 931 fish/km; Figure 2), 311 were captured in three possible age classes with modes at 70 mm, 160 mm and 240 mm. Thirty-three brown trout were larger than 280 mm, including one which was ~ 520 mm. Whitefish were less abundant (269 ± 109 fish/km), only 54 were collected: 37 were less than 110 mm and 33 were larger than 270 mm (Figure 10).

Temple Fork- In this tributary, we captured 212 brown trout, providing a population estimate of 2124 ± 63 fish/km (Figure 2). More than 40% were less than 100 mm, and six ranged from 140 to 340 mm. As in past surveys (1983 and 1999; Thompson et al. 2000), age-0 brown trout were the most abundant age class. The abundance of cutthroat trout was low (171 ± 3 fish/km; Figure 3). Captured cutthroat trout ranged from 90 to 329 mm (Figure 11). No brook or rainbow trout were captured as in past surveys.

Right Hand Fork- Only brown trout were captured (n = 270) at this site (Table 1). The brown trout population was estimated at 2700 ± 116 fish/km (Figure 2). There appeared to be at four possible age classes with modal lengths at 70 mm, 110 mm,

160 mm, and 210 mm (Figure 12). We captured substantially more age-0 brown trout during our survey compared to past surveys. Cutthroat trout were not captured as in past surveys (Thompson et al. 2000).

Overall, since 1999, cutthroat trout population estimates increased 28% at Forestry Camp and 78% at Twin Bridges. However, a slight decrease (12%) was observed at Temple Fork. We observed a 50% increase at Red Banks and 30% at Franklin Basin (Figure 13). The population of brown trout increased 62% at Twin Bridges, and 647% at Temple Fork. Previous surveys reported the presence of brown trout at Forestry Camp; however, no brown trout were caught at this site during our survey (Figure 14). The population of whitefish at Twin Bridges decreased 77% since 1999. No whitefish were captured at Forestry Camp, although whitefish were present in 1991 and 1999 (Table 2).

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 dashed 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 (Thompson et al. 2000).

Franklin Basin	Number per kilometer			
	Cutthroat	Brown	Whitefish	Rainbow
1991	634	--	--	--
1999	1359	--	--	--
2001	1768	--	--	--

Twin Bridge	Number per kilometer			
	Cutthroat	Brown	Whitefish	Rainbow
1991	199	236	68	50
1999	86	155	54	--
2001	727	170	12	--

Red Banks	Number per kilometer			
	Cutthroat	Brown	Whitefish	Rainbow

1991	1125	12	19	6
1999	1083	--	--	--
2001	1626	40	--	--

Forestry Camp	Number per kilometer			
	Cutthroat	Brown	Whitefish	Rainbow
1991	1858	12	6	--
1999	1361	5	25	--
2001	1742	--	--	--

Temple Fork	Number per kilometer			
	Cutthroat	Brown	Whitefish	Rainbow
1967	50	56	--	--
1999	194	284	--	--
2001	171	2124	--	--

Condition- Condition factor (Fulton's K $\pm$ 1 SE) for subadult cutthroat trout (≤ 150 mm) ranged from 0.9 (± 0.04) at Third Dam to 1.3 (± 0.15) at Forestry Camp. Similar fish condition was observed at Franklin Basin (1.06 ± 0.03) and Twin Bridges (1.06 ± 0.15). Adults from the same species exhibited similar condition at all sites: 1.09 ± 0.12 at Franklin Basin, 1 ± 0.01 at Red Banks, 1.03 ± 0.04 at Forestry Camp, and 1.1 ± 0.04 at Twin Bridges (Figure 14). Variation in condition across sites for brown trout was higher than for cutthroat trout. Condition of subadult brown trout ranged from 0.96 (± 0.24) at Lower Logan to 1.34 (± 0.3) at Twin Bridges. We observed no difference in subadult brown trout condition among the tributaries: 1.02 ± 0.03 at Temple Fork and 0.92 ± 0.24 at Right Hand Fork. Adult brown trout condition was 1.1 ± 0.04 at Twin Bridges, 1.1 ± 0.05 at Third Dam, and 0.93 at Lower Logan. Adult brown trout from the tributaries exhibited similar condition: 0.9 ± 0.02 and 0.94 ± 0.02 at Temple Fork and Right Hand Fork, respectively (Figure 15).

Diet analysis- Fish consumed a variety of macroinvertebrates from several taxa: Ephemeroptera, Plecoptera, Trichoptera, Coleoptera, Diptera, Odonata, Chironomidae, Oligochaeta, Megaloptera, and Hirudinea. Fish also consumed various items such as organic and inorganic matter, seeds, nematodes, terrestrial invertebrates (including beetles, crickets, and ants), amphipods, gastropods, and leeches. A few brown trout and cutthroat trout diets contained fish (including sculpin).

Cutthroat trout diets varied little by site and were principally composed of mayflies (Ephemeroptera) and organic matter (Figure 16). Fish were only included in diets at Red Banks and Twin Bridges (Figure 16). Adult cutthroat trout included fewer prey items in their diets than did subadults, as seen in data from Franklin Basin (Figure 17).

Brown trout included more prey in their diets than cutthroat trout. Brown trout diets varied by site (Figure 18). Brown trout consumed fish throughout the mainstem, except at Forestry Camp; however, only two brown trout were captured at Forestry Camp (Figure 18). At all sites, organic matter represented at least 20% of all diets. As with cutthroat trout, mayflies were an important component of brown trout diets at most sites and for adults and subadults (Figure 19).

Diets of other fish sampled were less diverse likely due to low sample sizes and limited distribution. Rainbow trout diets were dominated by organic matter, midges (Chirnomidae), black fly larvae (Diptera), and stoneflies (Plecoptera) at Third Dam (Figure 20). Brook trout primarily consumed organic matter and mayflies (Figure 21). Organic matter composed at least 50% of mountain whitefish diets (Figure 22).

Prey selection- Food selectivity by cutthroat trout varied greatly by site and slightly by index used. According to Chesson's alpha, cutthroat trout preferred odonates at Franklin Basin, yet preferred mayflies (Ephemeroptera) when using Strauss's linear index (Table 3). Both indices demonstrated that mayflies were selected by cutthroat trout at Forestry Camp and dipterans were selected at Third Dam.

Whirling disease analyses

Cutthroat trout- Clinical signs of whirling disease such as black tail or deformities were not observed at any of our sites on any of the species collected. However, PCR assays for *Myxobolus cerebralis* indicated the parasite was present in all mainstem reaches sampled and at one of the tributaries, Temple Fork. The parasite was not detected at Red Banks and Franklin Basin until the current 2001 survey (Figure 1). Despite the widespread distribution of *M. cerebralis*, the prevalence of infection on cutthroat trout varied greatly, ranging from 5% at the headwaters to 100% at Third Dam. At Temple Fork, 30% of the cutthroat trout (n = 13) tested positive (Figure 23). Interestingly, while all adults tested from Temple Fork were infected (n = 13), juvenile cutthroat trout from the same location tested negative for *M. cerebralis* (Figure 24). More than 50% of the samples from Red Banks (n = 18), Forestry Camp (n = 17), and Twin Bridges (n = 19) also tested positive for *M. cerebralis.*

Table 3. Feeding selectivity by cutthroat trout on invertebrate prey at three sites in the Logan River calculated using Chesson's alpha and Strauss's linear index. Using Chesson's alpha, neutral selection or random feeding = 1/n = 0.125. Using Strauss's linear index, zero equals neutral selection or random feeding. Highest preferences are highlighted in bold.

Species	Franklin Basin	Forestry Camp	Third Dam
Chesson's alpha			
Ephemeroptera	0.000910	**0.700854**	0.103783
Plecoptera	0.000373	0.000000	0.148259
Trichoptera	0.002378	0.266891	0.061775
Coleoptera	0.000000	0.015338	0.123539
Diptera	0.000002	0.005414	**0.546016**
Odonata	**0.995080**	0.000001	0.000002
Chironomidae	0.000010	0.011504	0.016632
Oligochaeta	0.001247	0.000000	0.000002
Strauss's linear index			
Ephemeroptera	**0.464786**	**0.532374**	-0.136344
Plecoptera	0.002687	-0.020834	-0.016865
Trichoptera	0.116632	0.137174	-0.066772
Coleoptera	-0.040817	-0.027878	-0.004530
Diptera	-0.294197	-0.340674	**0.472321**
Odonata	0.002866	-0.000001	-0.000001
Chironomidae	-0.277685	-0.248910	-0.247809
Oligochaeta	0.025728	-0.031251	-0.000001

Brown trout- M. cerebralis was not detected in brown trout from Temple Fork (n = 5) or Right Hand Fork (n = 10), whereas 60% (n = 10) tested positive at Lower Logan (Figure 25). Samples of brown trout from Red Banks, Twin Bridges, and Third Dam have not been tested.

Other salmonids- M. cerebralis was not detected in brook trout from Franklin Basin (n = 4) or Red Banks (n = 2). Whitefish from Twin Bridges (n = 6) and Third Dam (n = 4) also tested negative for *M. cerebralis*. However, *M. cerebralis* was detected in 75% of the rainbow trout samples (n = 4) from Third Dam. Whitefish samples from Red Banks and Lower Logan have not been tested for *M. cerebralis*.

Environmental variables

Discharge- Lowest discharge recorded from May thru September was 0.06 cfs (0.17 m^3/sec) during June in an Upper Franklin Basin reach, whereas the highest was recorded at Twin Bridges in July (81 cfs or 2.3 m^3/sec). Base flow discharge was higher at the mid-elevation sections of the river in relation to the headwaters, lower sections, and the tributaries (Figure 26).

Temperature- Summer temperatures at most sites were close to or within the ideal range (10 to 13 °C) for growth of *T. tubifex,* the secondary host for *M. cerebralis*. Temperatures at the Lower Logan section were above this range (Figure 27). Mid-summer temperatures at Forestry Camp and Twin Bridges approached the ideal 15 °C for triactinomyxon (TAM) production. On the other hand, temperatures between 13 and 17 °C have been correlated to higher *M. cerebralis* infection rates in other studies. Our data show that only mid-summer temperatures at Forestry Camp and Twin Bridges, 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 27).

Substrates- Mean particle size ranged from less than 50 mm to ~300 mm, decreasing from high to lower elevations of the mainstem. Mean particle size in the tributaries was less than 50 mm (Figure 28). Percent fines, measured as sediments less than 10 mm, ranged from 0% at Red Banks to 10% at Forestry Camp; higher percentages were observed in the tributaries, particularly at Temple Fork (24%; Figure 28). 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. It is possible that measurement methods biased these results; therefore pebble counts will be repeated during summer 2002.

Turbidity- The highest turbidity values were recorded during May, ranging from 1.5 NTU at Twin Bridges and Right Hand Fork to 2.8 NTU at Franklin Basin. Values rarely exceeded 1 NTU across all sites during the summer, except for Lower Logan were turbidity reached 2.7 NTU in September (Figure 29).

Conductivity and pH- Water conductivity ranged from 125 µS at Franklin Basin in May, to 504 µS at Lower Logan in August. Conductivity increased throughout the summer, particularly at the uppermost sites (Franklin Basin, Red Banks, and Forestry Camp) and at Lower Logan (Figure 29). pH levels did not vary significantly along the Logan

River. Across all sites pH values were slightly higher than neutral, ranging from 7.71 to 8.82 (Figure 29).

Periphyton

The periphyton biomasses at mainstem sites, as indicated by chlorophyll *a* concentrations, varied greatly across sites. Chlorophyll *a* ranged from 48 mg/m^2 at Red Banks to 192 mg/m^2 at Third Dam. Chlorophyll *a* concentrations at Franklin Basin, Twin Bridges, and Lower Logan were 58 mg/m^2, 62 mg/m^2, and 92 mg/m^2, respectively; higher concentrations were found at Forestry Camp (119 mg/m^2). Chlorophyll *a* at Temple Fork (194 mg/m^2) was higher than at Right Hand Fork (12 mg/m^2; Figure 30).

Invertebrate sampling

Franklin Basin- Collectors-gatherers were predominant (67%) at this site (Figure 31). Ephemeroptera (28%), Diptera (29%), and Chironomidae (28%) were the major taxonomic groups observed; only 1% of the invertebrates were oligochaetes (Figure 31).

Forestry Camp- Similar to Franklin Basin, most invertebrates (65%) at Forestry Camp were collectors-gatherers (Figure 32). Diptera (33%) and Ephemeroptera (26%) were the most abundant invertebrate groups. Oligochaetes represented 3% of the invertebrate community at this site (Figure 32).

Twin Bridges- Forty seven percent of the invertebrates were collectors-gatherers at Twin Bridges (Figure 33). The abundance of invertebrates was evenly distributed among five major taxonomic groups: Ephemeroptera (16%), Trichoptera (16%), Diptera (25%), Chironomidae (21%), and Coleoptera (11%). No oligochaetes were observed at this site (Figure 33).

Third Dam- Over 50% of the invertebrates at this site were collectors-gatherers, and close to one fourth of the total community were scrapers (Figure 34). Taxonomic groups were represented mainly by the orders Diptera (31%), Ephemeroptera (25%), and Chironomidae (25%). No oligochaetes were reported at this site (Figure 34).

Lower Logan- Invertebrates at this site were mainly collectors-gatherers (73%); 14% were shredders (Figure 35). Two orders dominated the invertebrate community, Diptera (40%) and Chironomidae (39%). Oligochaetes represented only 1% (Figure 35).

Temple Fork- Collectors-gatherers represented 62% of the invertebrates; 26% were scrapers (Figure 36). Ephemeropterans represented 47% of the total taxa composition, 18% were Diptera, 16% were Chironomidae, and 10% were Trichoptera. No oligochaetes were observed (Figure 36).

Right Hand Fork- The highest percentage of predators (35%) was present at this site; scrapers represented 30% and collectors-gatherers 27% (Figure 37). Two orders dominated the taxa composition, Trichoptera (36%) and Plecoptera (28%). Dipterans represented 14%, and only 1% were oligochaetes (Figure 37).

Sentinel Cage Experiments

Survival was poor for cutthroat trout in sentinel cages. PCR analysis indicated that all fish tested negative for whirling disease at Franklin Basin (n = 16) and Temple Fork (n = 23). At Twin Bridges (n = 4), 50% of sentinel fish tested negative, 25% were positive, and 25% were triple positive (Figure 38).

DISCUSSION

Trout populations were sampled at eight sites from ranging from Franklin Basin at high elevation down to the Lower Logan below the golf course, during base flow conditions of 2001. These sites represent the range of natural and anthropogenic habitat present in the Logan River. Population estimates, based on depletion techniques, indicated that cutthroat trout populations were strong with the greatest number of cutthroat trout observed in Franklin Basin, and none observed below Third Dam. Brown trout abundance was inversely related to cutthroat trout abundance with the greatest numbers observed below the golf course (Lower Logan) and none observed at Franklin Basin. Population estimates of trout species for 2001, compared to previous surveys, demonstrate that both cutthroat and brown trout have strong populations throughout their range in the Logan River. Overall, abundance has increased roughly 34% for cutthroat trout about 300% for brown trout, since surveys completed by the UDWR in 1999. Brook trout were observed only in very low numbers at high elevation sites, and rainbow trout were only caught at Third Dam in 2001. Also, mountain whitefish abundance has decreased since prior surveys. The similarity between depletion estimates and modified Zippin estimates indicates that capture probability is not declining with subsequent electroshocker passes and suggests these fish are not learning to avoid the electroshocker, the preferred scenario for a robust population estimate (Krebs 1999).

Size frequency data for cutthroat trout demonstrate two to three size (age) classes at most sites with the greatest proportion of the adults ranging from approximately 220 to 290 mm. For brown trout, there appear to be three to four size or age classes at most sites with the larger adults generally ranging from approximately 240 to 350 mm. Age classes should be verified in the future with scale or otoliths analyses and/or marking. Cutthroat trout condition was generally fair to good with Fulton's K values > 1 observed at most sites. In contrast, brown trout condition was much poorer with values < 1 observed at the Lower Logan site and in both of the tributaries. Brown trout in both Temple Fork and Right Hand Fork were obviously in poor condition, at the time of sampling, with long skinny bodies and large heads. This pattern suggests that there may be a greater abundance of brown trout in the tributaries than can be supported by the available food supply, or possibly temperature or another factor is limiting growth (McCormick et al. 1972). The poor condition of brown trout observed below the golf course (Lower Logan site) may be due to a combination of warm temperatures and high turbidity in August and September (Cherry et al. 1976; Sweka and Hartman 2001).

Whirling disease tests indicated that whirling disease has spread widely throughout the river since the last survey in 1999 (Figure 1). Cutthroat trout tested > 50% positive at all sites from Red Banks down to Third Dam. Brown trout also tested positive at the Lower Logan, but negative in the tributaries. The positive tests for brown trout are somewhat surprising given that they are generally thought to be much less susceptible to whirling disease, compared to other trout species (Baldwin et al. 1999). These results indicate that whirling disease has spread up the Logan River and into the upper tributaries (the Lower Logan was not tested previous to 2001). Further, cutthroat trout subadults generally showed greater infectivity relative to adults, consistent with the known greater sensitivity at earlier life stages (Hoffman et al. 1962). The combination of life history and low temperature may protect cutthroat trout in some areas (e.g., Franklin Basin). For example, the less susceptible adults may migrate up into the tributary areas to spawn, and juveniles may thus rear in tributaries that are too cold for TAM production, before migrating back to the more highly infected mainstem at larger sizes, after the most critical period for infection has passed.

Despite the widespread detection of whirling disease throughout the Logan River, we observed no clinical signs of whirling disease on any trout species sampled. The overall increase in abundance of trout populations, since the 1999 survey, suggests that trout in the Logan River are not experiencing population level effects of whirling disease at this time. However, with only two nearly continuous years of abundance data for most of these sites, and given the age structure of these populations (may live

up to 6 years old and spawn repeatedly), it is far too early to say with certainty there is no population effect of whirling disease. Further, disease may impact individuals or populations indirectly through reduced growth, ability to compete for food resources effectively, increased predation risk, or compensatory mortality (Minchella and Scott 1991).

Abiotic and biotic variables may affect both the levels of infectivity of a disease as well as the effect that disease has on an individuals and/or the population (Reno 1998). In the Logan River, minimum and maximum summer temperatures ranged from approximately 6 to 20 °C. The highest temperatures were observed below the golf course at the Lower Logan site (> 19 °C) and the lowest temperatures were observed at the highest elevation site, Franklin Basin. These high and low temperature extremes may limit TAM maturation and the spore release period (El-Matbouli et al. 1999) and further, may determine the length of the *T. tubifex* growth period (Reynoldson 1987). In addition, turbidity remained high throughout the summer at the Lower Logan site (and declined over time at the other sites), which may provide a better food base for tubifex worms. Neither conductivity nor pH varied significantly across sites.

T. tubifex site preference and abundance has been shown to be related to the productivity of the environment (e.g., bacterial abundance and the concentrations of nitrogen and phosphorous in the environment). Chlorophyll *a* represents an index of primary productivity. These data showed a pattern that roughly corresponds to the degree of whirling disease infectivity, which may suggest that the more productive sites provided more suitable or preferred habitat for tubifex worms. Nutrient analyses (to be completed this year) will also contribute to our understanding of the effects of nitrogen and phosphorous on the distribution and abundance of *T. tubifex*.

Aquatic invertebrate data do not differentiate among taxa within Oligochaeta; however, these data indicated that oligochaete abundance was greatest at Franklin Basin and generally declined with elevation. There was a slightly higher abundance of oligochaetes observed at the Lower Logan site, however, relative to other mid-elevation sites. As noted above, the higher turbidity and sedimentation at the Lower Logan site may provide better habitat for oligochaete (and thus tubifex) worms. However, there were very low densities of oligochaetes observed in the tributaries, where the percent fines was the greatest. These sites may have more suitable substrate but may be too nutrient limited to support high densities of oligochaetes.

Invertebrate density varied little across sites; however, these measures of invertebrate density were highly sensitive to spatial and temporal variability (M. Vinson, personal

communication). In contrast, the composition of the invertebrate fauna varied considerably from high elevation to low elevation. Ephemeroptera (mayflies) and organic matter were the primary components of adult and subadult cutthroat trout diets. Electivity indices (Chesson's alpha and Strauss's linear) indicated that cutthroat trout preferred Odonates (dragonflies and damselflies) and Ephemeroptera at high to mid elevation sites, and Diptera (black fly larvae) at low elevation sites. While Diptera made up a substantial proportion of the available invertebrate prey items at most sites, they were selected by cutthroat trout only at the Third Dam site. The modified environment of the dams or variation in species (within Diptera) or prey behavior may explain this difference.

The inverse relationship of cutthroat and brown trout and the small degree of spatial overlap suggests that these two fishes segregate spatially with cutthroat trout at higher elevation sites and brown trout at low elevation sites. Diet analyses demonstrated a high degree of overlap in prey items between brown and cutthroat trout. At the only site where they overlap, Twin Bridges, these two species had similar diets and both included fish prey. For competition to be occurring however, not only must there be dietary overlap, there must also be a limiting resource (Fausch 1988). As noted above, total invertebrate density varied little across sites; however, more preferred and energetically profitable species may differ. Cutthroat trout are typically thought to have cooler temperature preferences with upper lethal temperatures around 18 to 20 °C (Vigg and Koch 1980), whereas brown trout generally have a wider and warmer range of temperature tolerance (upper lethal temperature 23 °C), possibly contributing to the segregation we observed (Fry 1947; Cherry et al. 1977; Vigg and Koch 1980). Whether the observed separation between cutthroat and brown trout in the Logan River was to due competition (interactive segregation) or differences in the physical preference and tolerance ranges (selective segregation) is unknown and may warrant some consideration in the future (Bohn and Amundsen 2001).

FUTURE

Baseline monitoring of trout populations and the impacts of whirling disease as described above will continue into 2002. Fat indices will also be determined on a subsample of fish from each site according to UDWR protocol. Spore digest analysis did not occur in 2001; however, a subsample of fish from 2001 will be analyzed by the UDWR Fisheries Experiment Station using the spore digestion technique. This approach will allow us to compare and corroborate results from the PCR technique and the spore digestion technique.

In order to better understand fish movement between whirling disease 'hot spots' and 'clean areas', we will mark the predominant trout species (~200 of each species) at each site with site-specifically colored (n = 8), individually numbered Floy T-bar tags. Tagged fish will be recovered from anglers (via creel census and mail and phone returns) and from the annual electroshocking survey in late summer. A creel census will be completed in order to collect tags and inform anglers about our study as well as to quantify fishing pressure and angler satisfaction. Creel surveying will occur 4-5 days per week throughout the summer with sampled days chosen systematically to represent all the days of the week, with at least one weekend day sampled every week. Informative signs will be placed at the major fishing areas. Floy tags will also be imprinted with the USU Fish Ecology Lab phone number. In addition to fish movement data, an important variable for understanding the spread of whirling disease, tagging will also provide an independent mark and recapture population estimate to verify the electroshocking estimates and survival.

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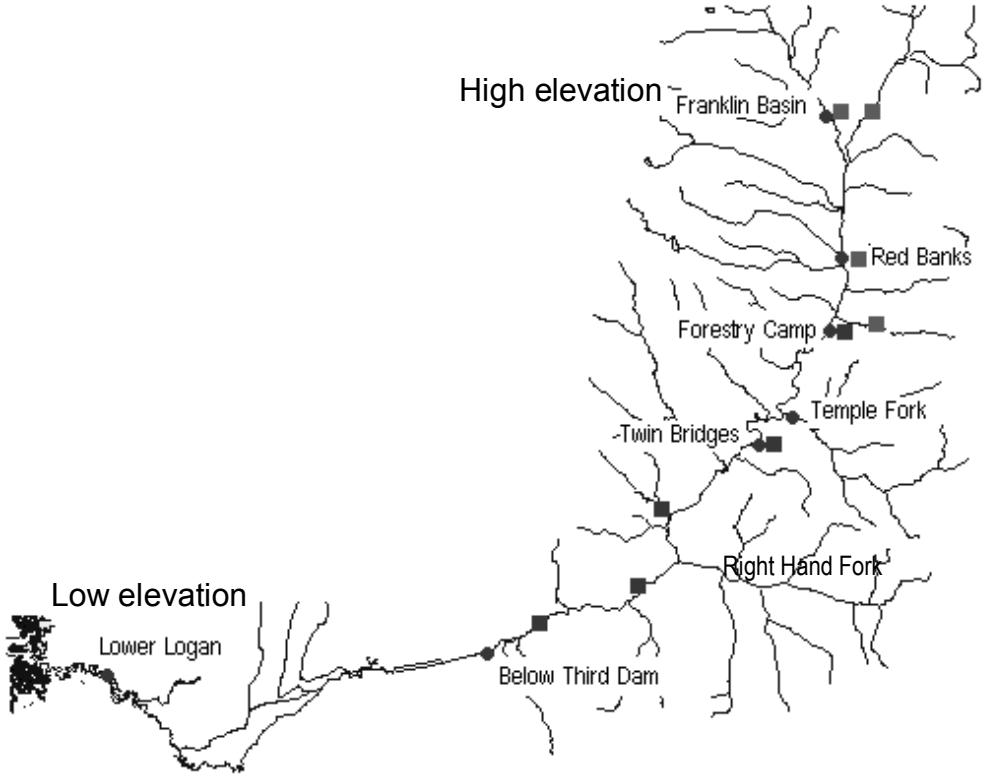


Figure 1. Map of the Logan River and sample sites. Light gray squares in upper reaches indicate sites that tested negative for *M. cerebralis* in 1999. Dark squares tested positive in 1999. Circles indicate sites were whirling disease was detected in 2001.

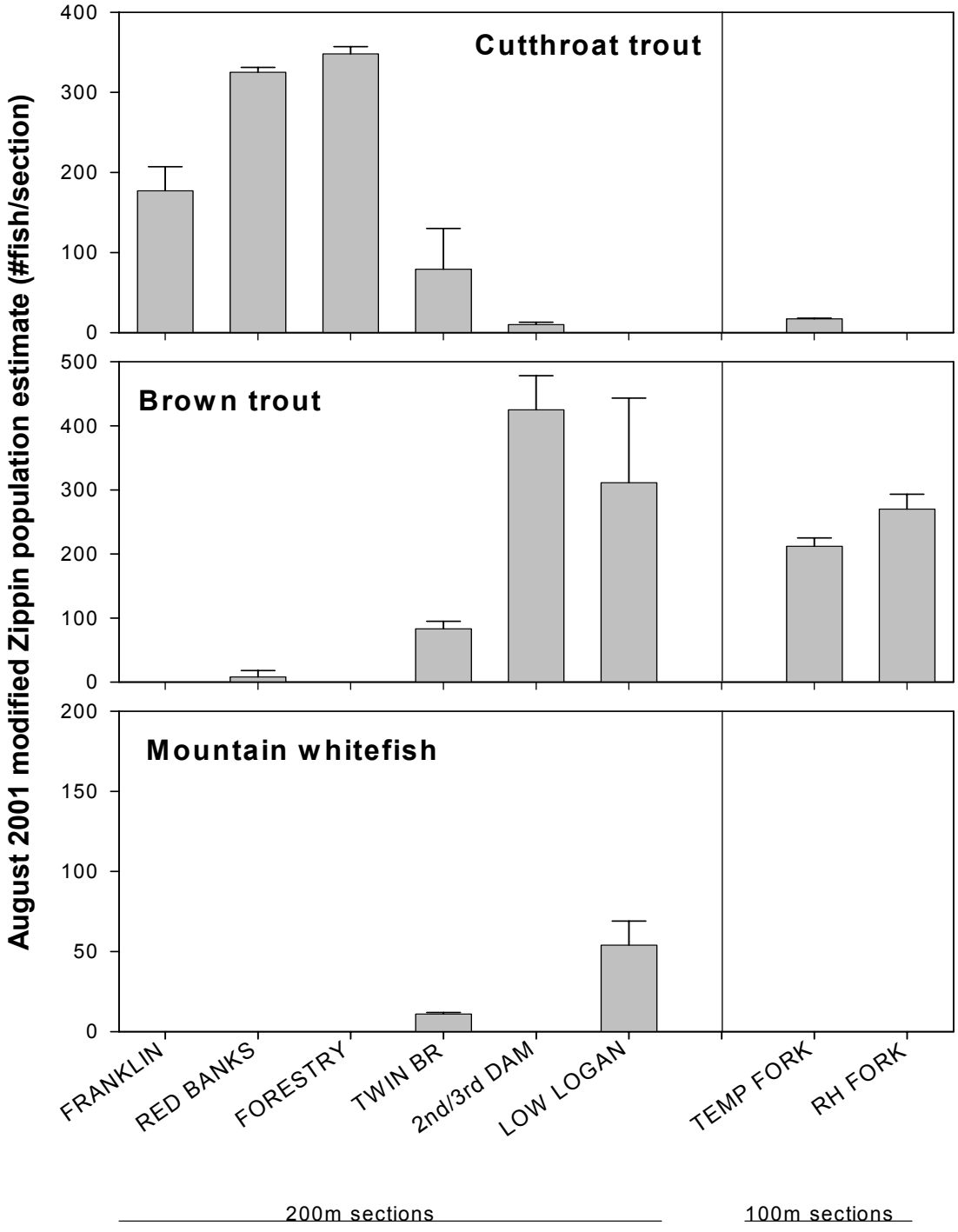


Figure 2. Population estimates for cutthroat trout, brown trout, and mountain whitefish based on a modified Zippin depletion method, for six sites on the Logan River and tributaries (Temple Fork and Right Hand Fork), August 2001. Error bars represent one standard error.

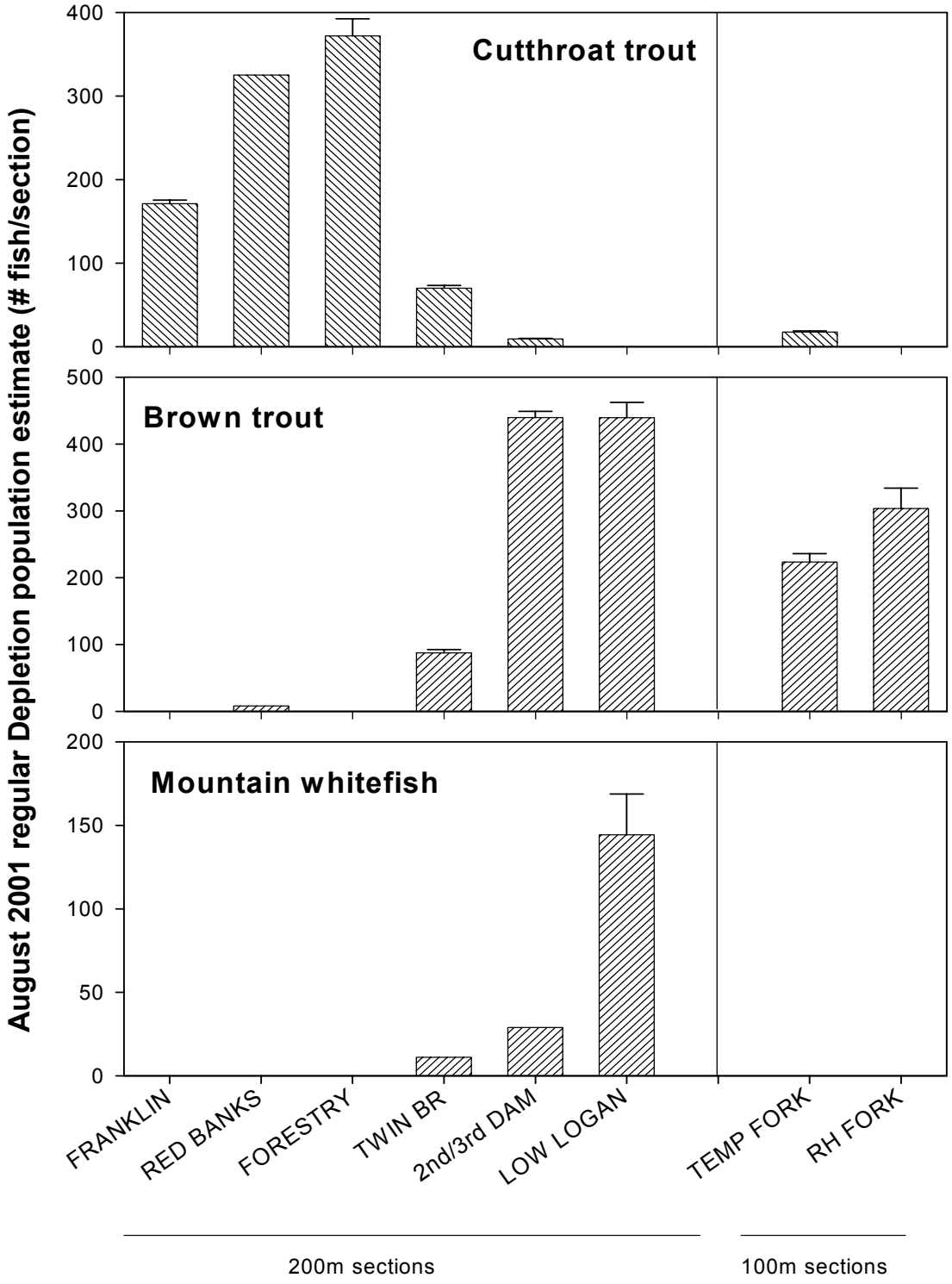


Figure 3. Population estimates for cutthroat trout, brown trout, and mountain whitefish based on a depletion method, Logan River and two tributaries, August 2001. Error bars represent one standard error.

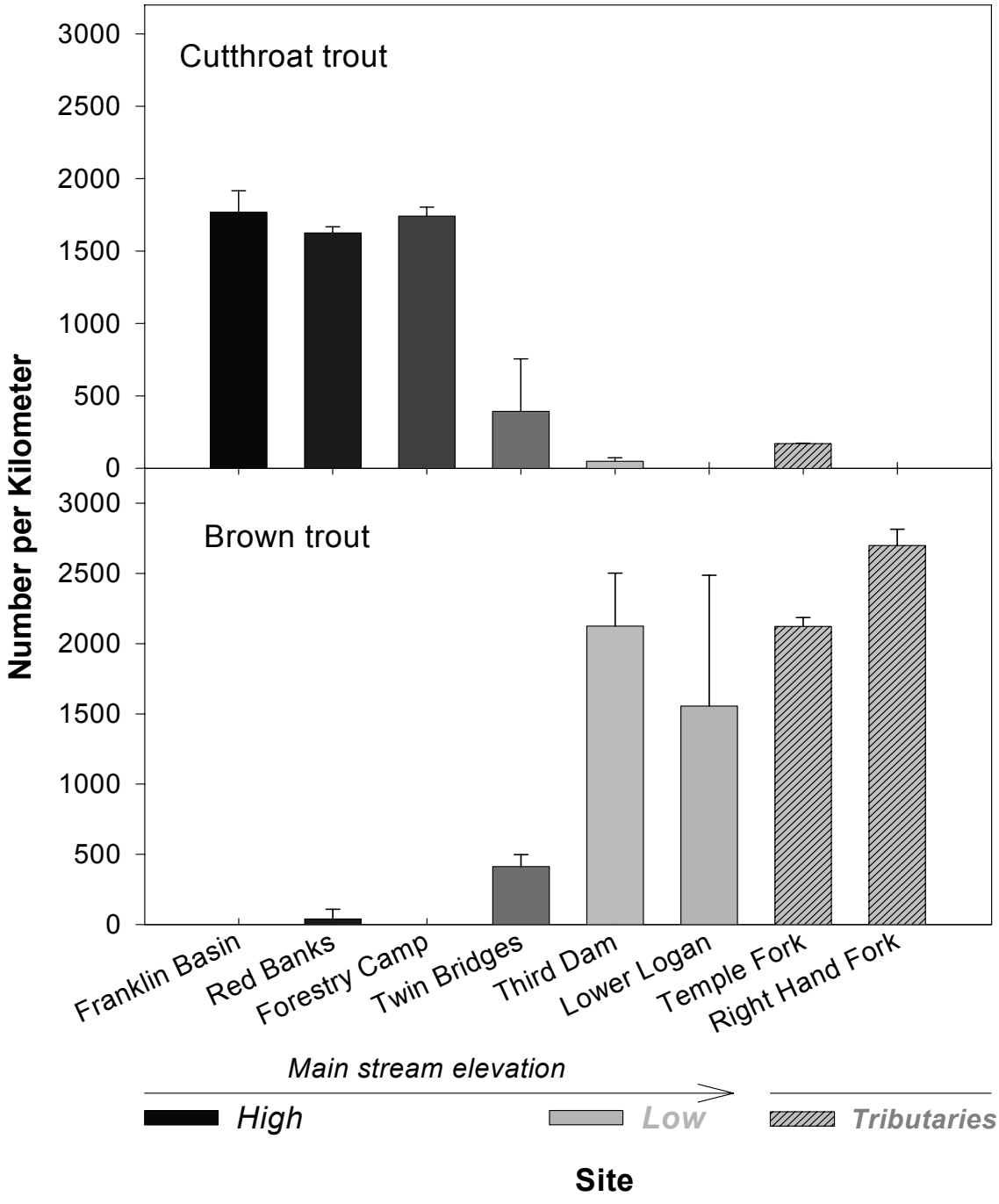


Figure 4. Estimated number of fish per kilometer for cutthroat trout (top) and brown trout (bottom), Logan River and two tributaries, August 2001. Sample reaches were 200 m long in the mainstem and 100 m long in the tributaries. Error bars represent one standard error.

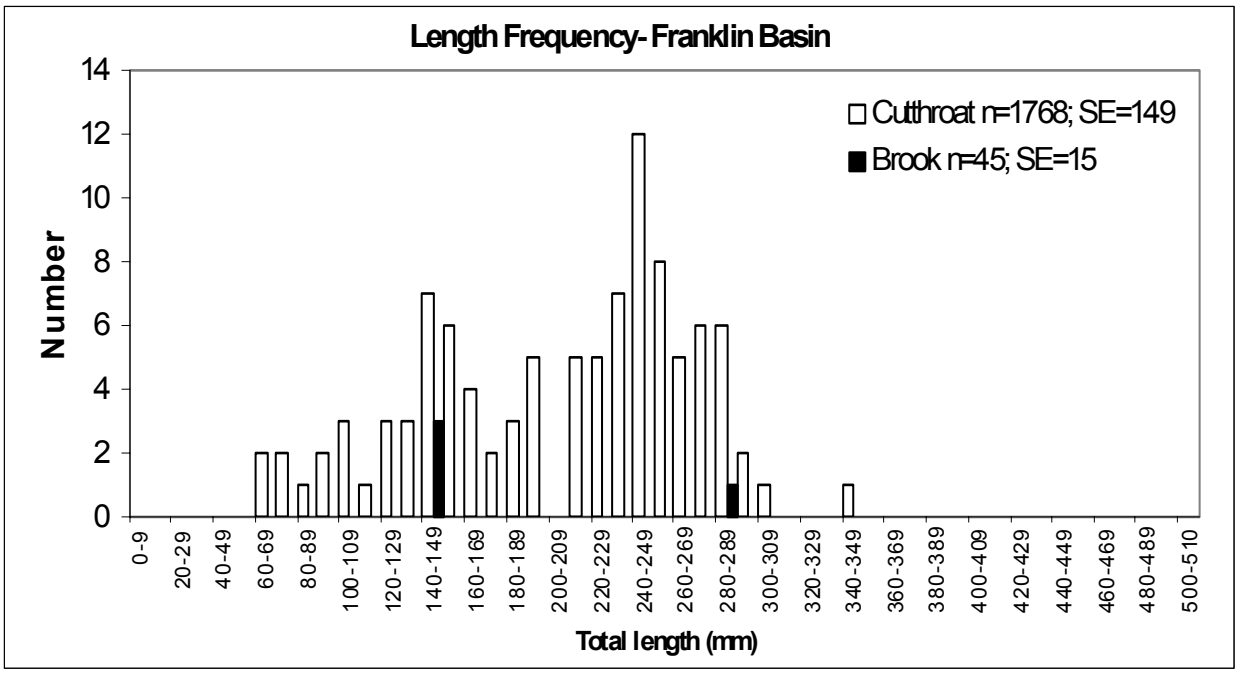


Figure 5. Length frequency distributions for cutthroat trout and brook trout captured by electrofishing in Franklin Basin, August 2001. The modified Zippin population estimate is shown as n, and SE equals one standard error.

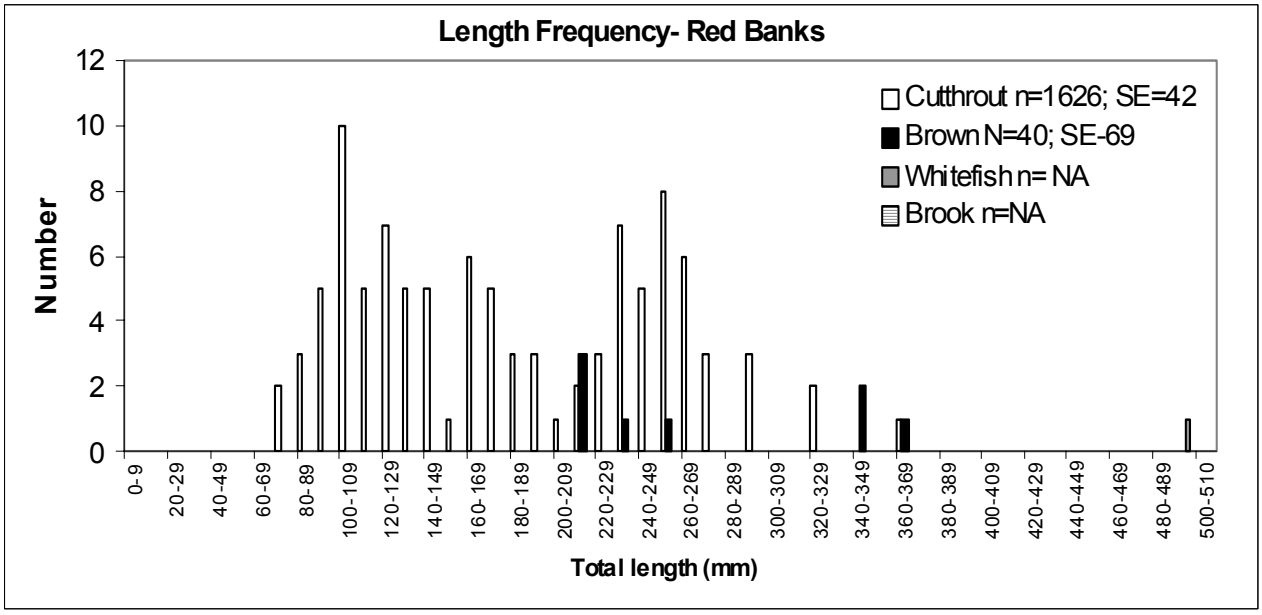


Figure 6. Length frequency distributions for cutthroat trout, brown trout, mountain whitefish, and brook trout captured by electrofishing at Red Banks, August 2001. The modified Zippin population estimate is shown as n, and SE equals one standard error. NA indicates that a population estimate was not possible.

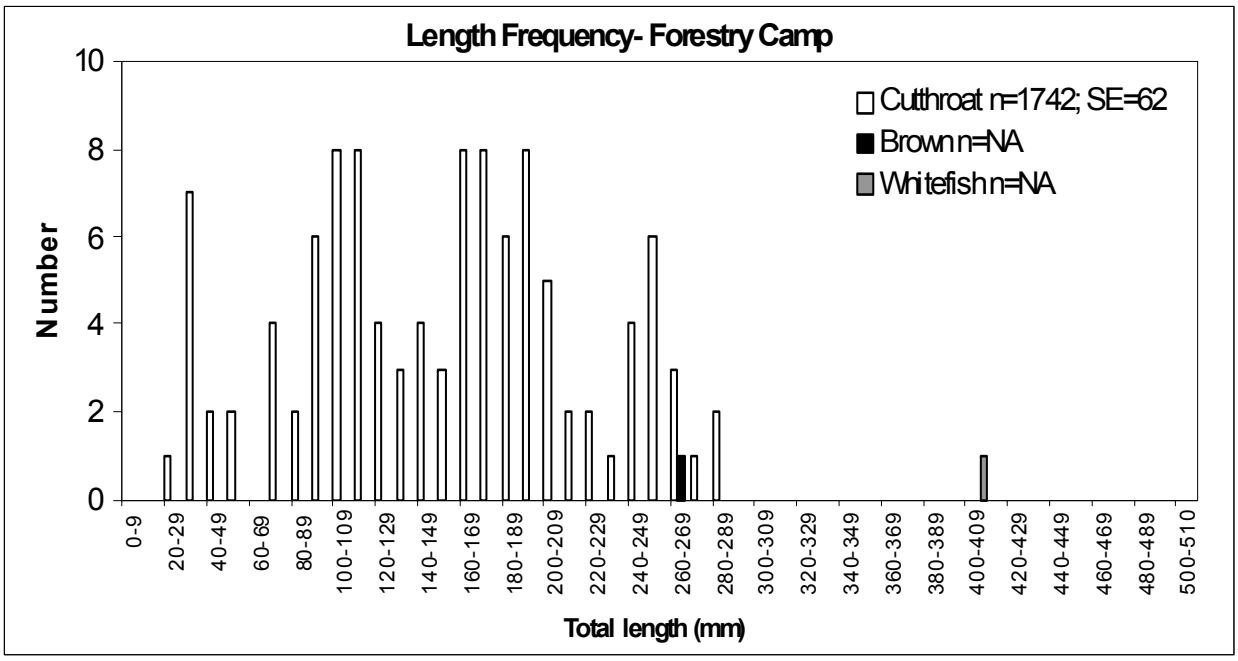


Figure 7. Length frequency distributions for cutthroat trout, brown trout, and mountain whitefish captured by electrofishing at Forestry Camp, August 2001. The modified Zippin population estimate is shown as n, and SE equals one standard error. NA indicates that a population estimate was not possible.

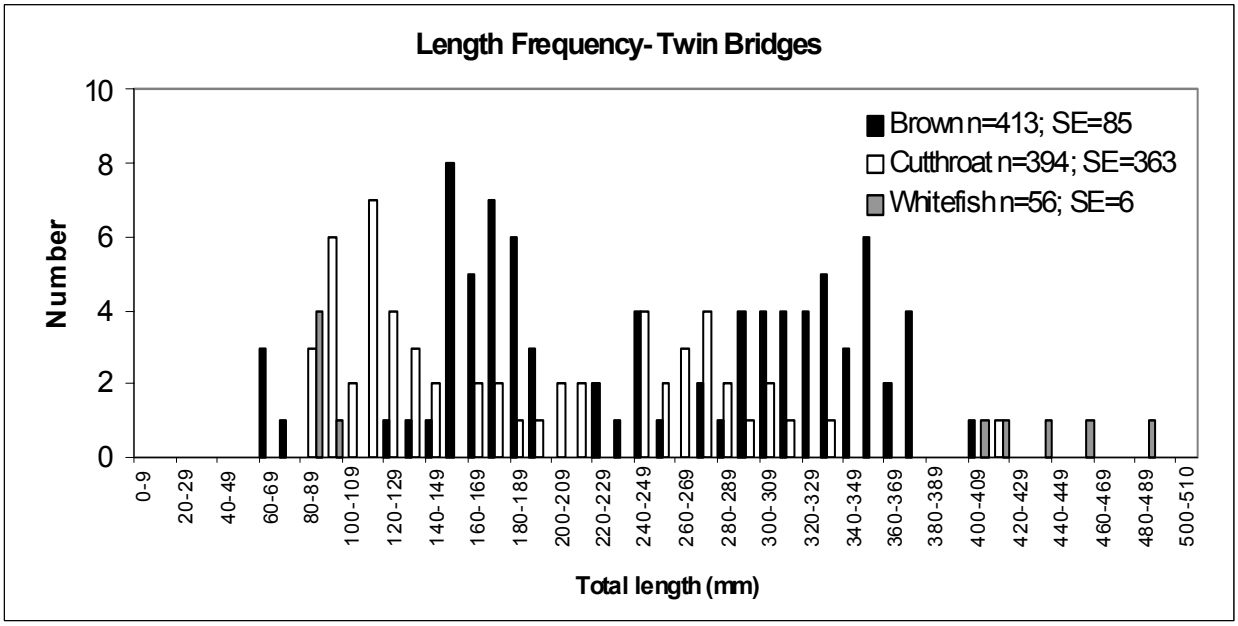


Figure 8. Length frequency distributions for cutthroat trout, brown trout, and mountain whitefish captured by electrofishing at Twin Bridges, August 2001. The modified Zippin population estimate is shown as n, and SE equals one standard error.

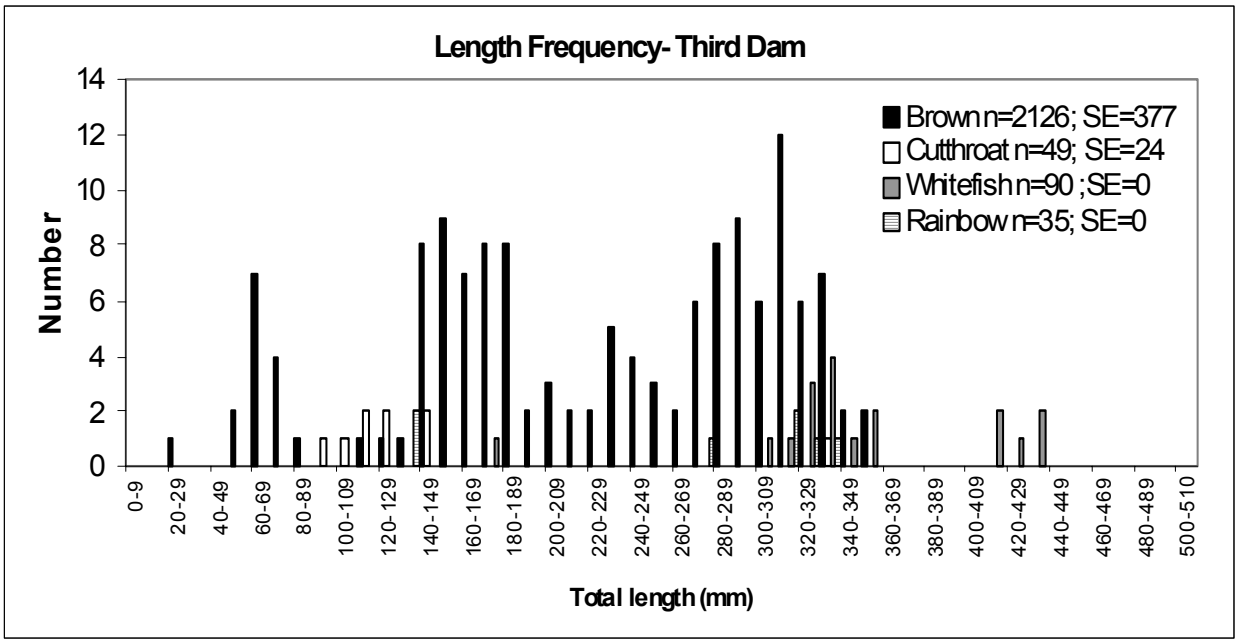
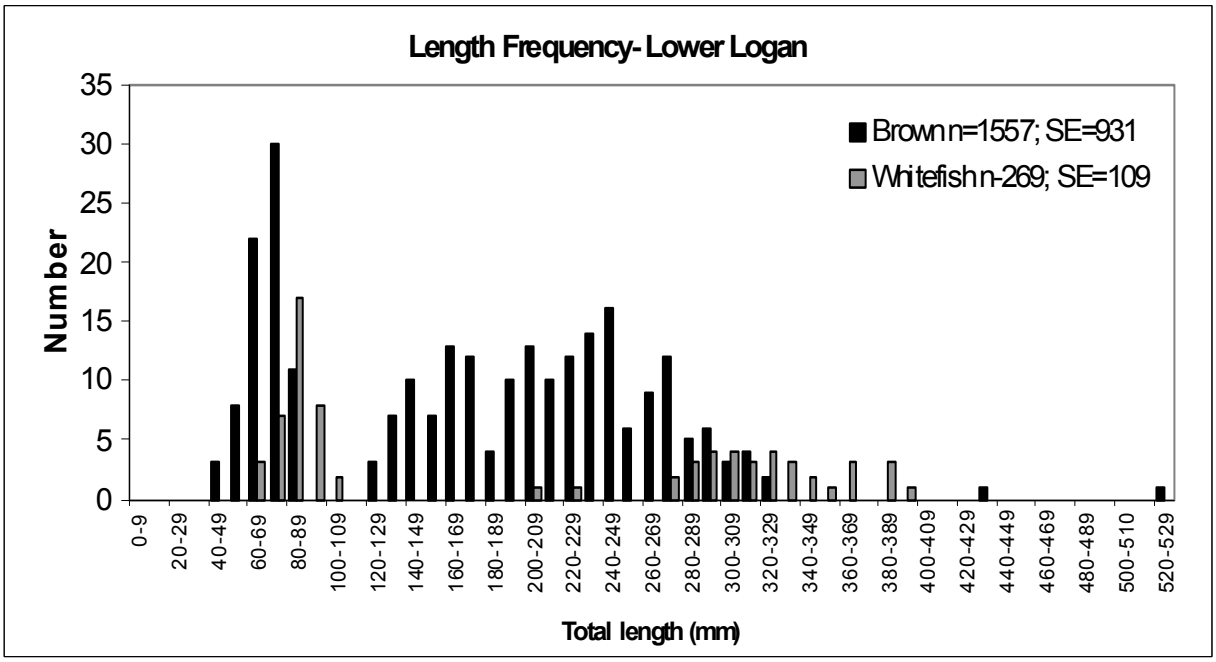


Figure 9. Length frequency distributions for cutthroat trout, brown trout, mountain whitefish, and rainbow trout captured by electrofishing at Third Dam, August 2001. The modified Zippin population estimate is shown as n, and SE equals one standard error. NA indicates that a population estimate was not possible.

Figure 10. Length frequency distributions for brown trout and mountain whitefish



captured by electrofishing at Lower Logan, August 2001. The modified Zippin population estimate is shown as n, and SE equals one standard error. NA indicates that a population estimate was not possible.

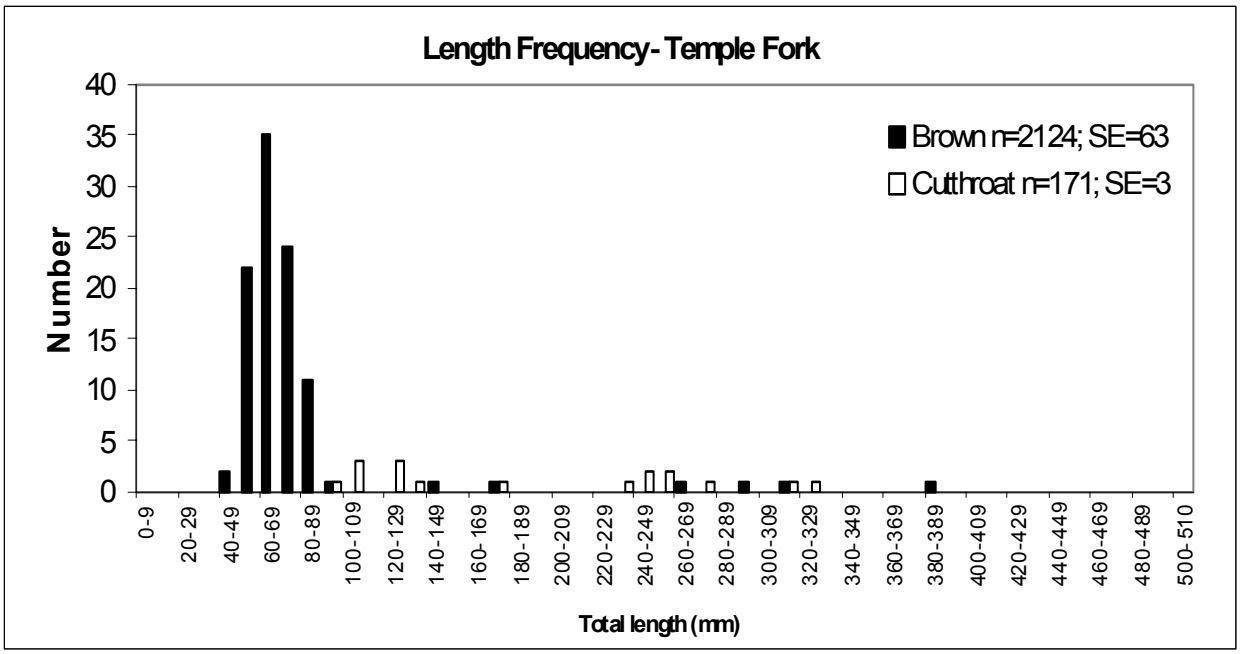


Figure 11. Length frequency distributions for cutthroat trout and brown trout captured by electrofishing at Temple Fork, August 2001. The modified Zippin population estimate is shown as n, and SE equals one standard error.

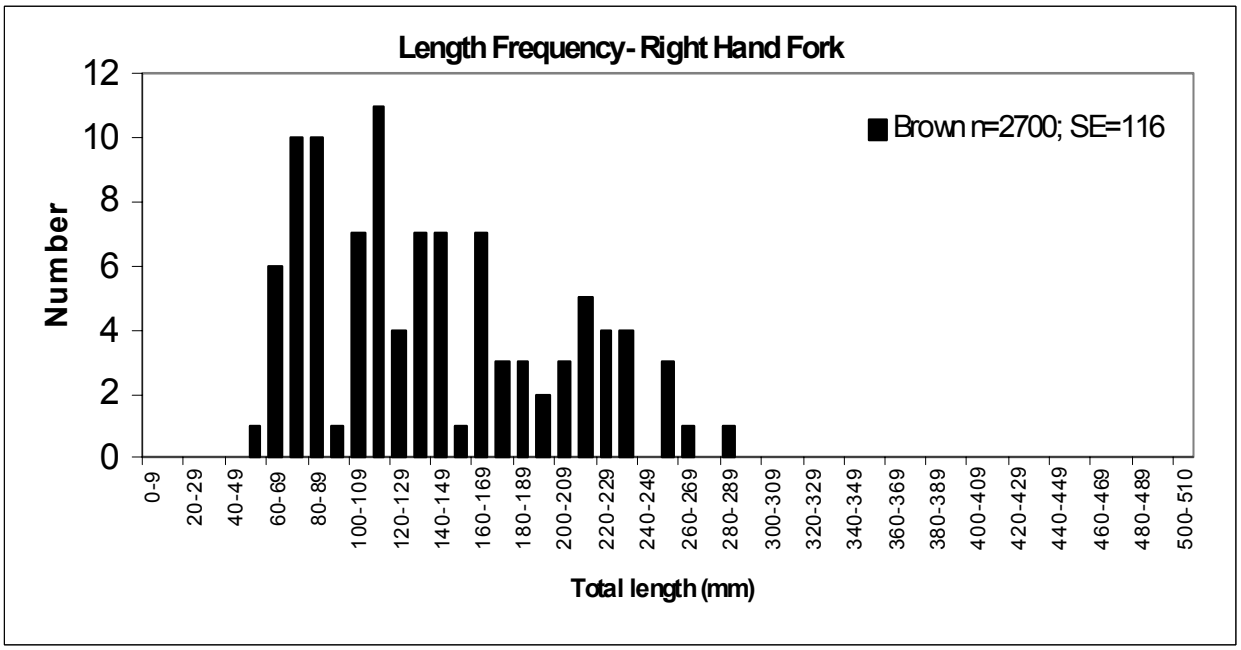


Figure 12. Length frequency distributions for brown trout captured by electrofishing at Right Hand Fork, August 2001. The modified Zippin population estimate is shown as n, and SE equals one standard error.

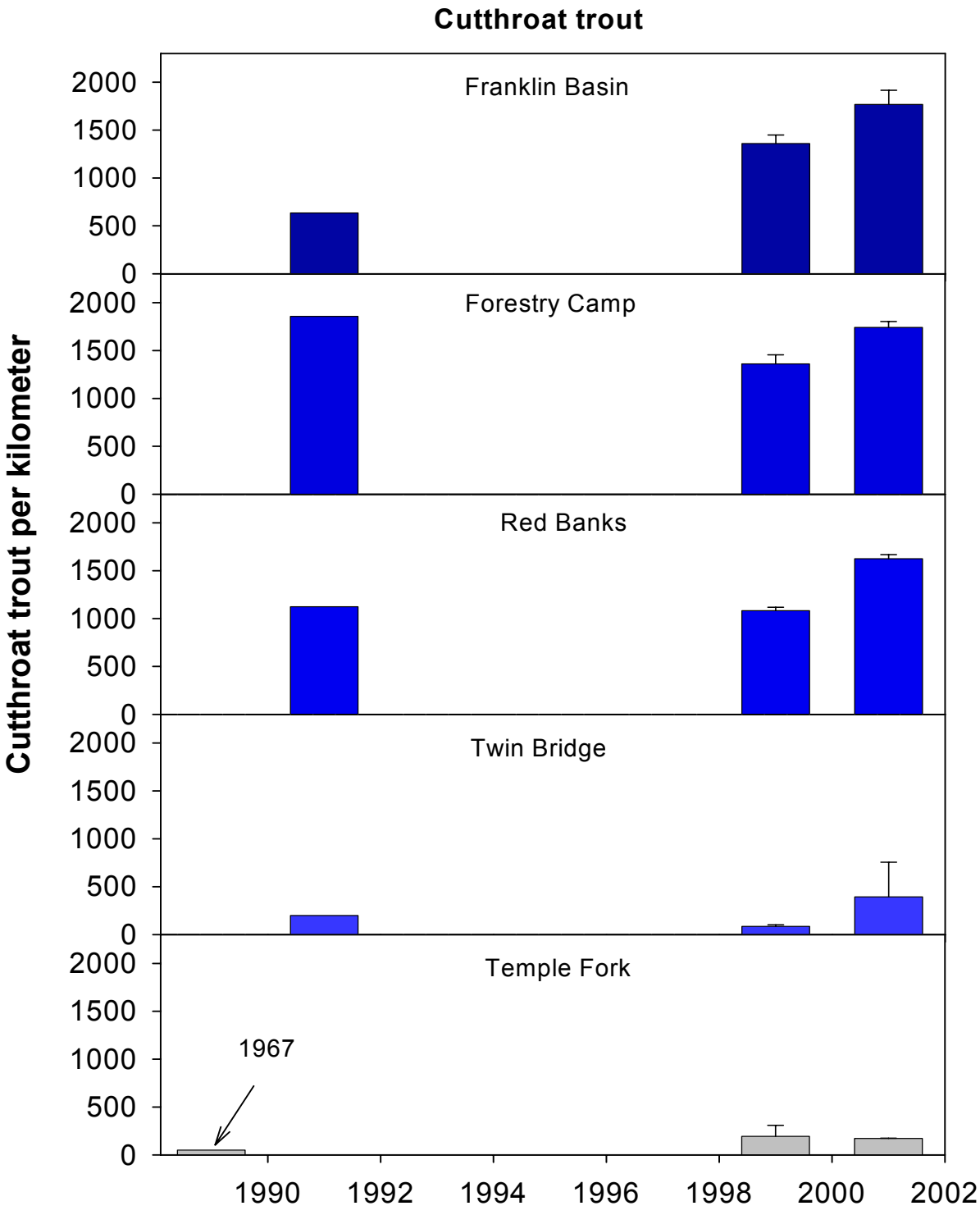


Figure 13. Abundance of cutthroat trout per kilometer for several sites from past studies (Thompson et al. 2000) and the current 2001 study. No information was available from 1992 to 1998. Error bars represent one standard error.

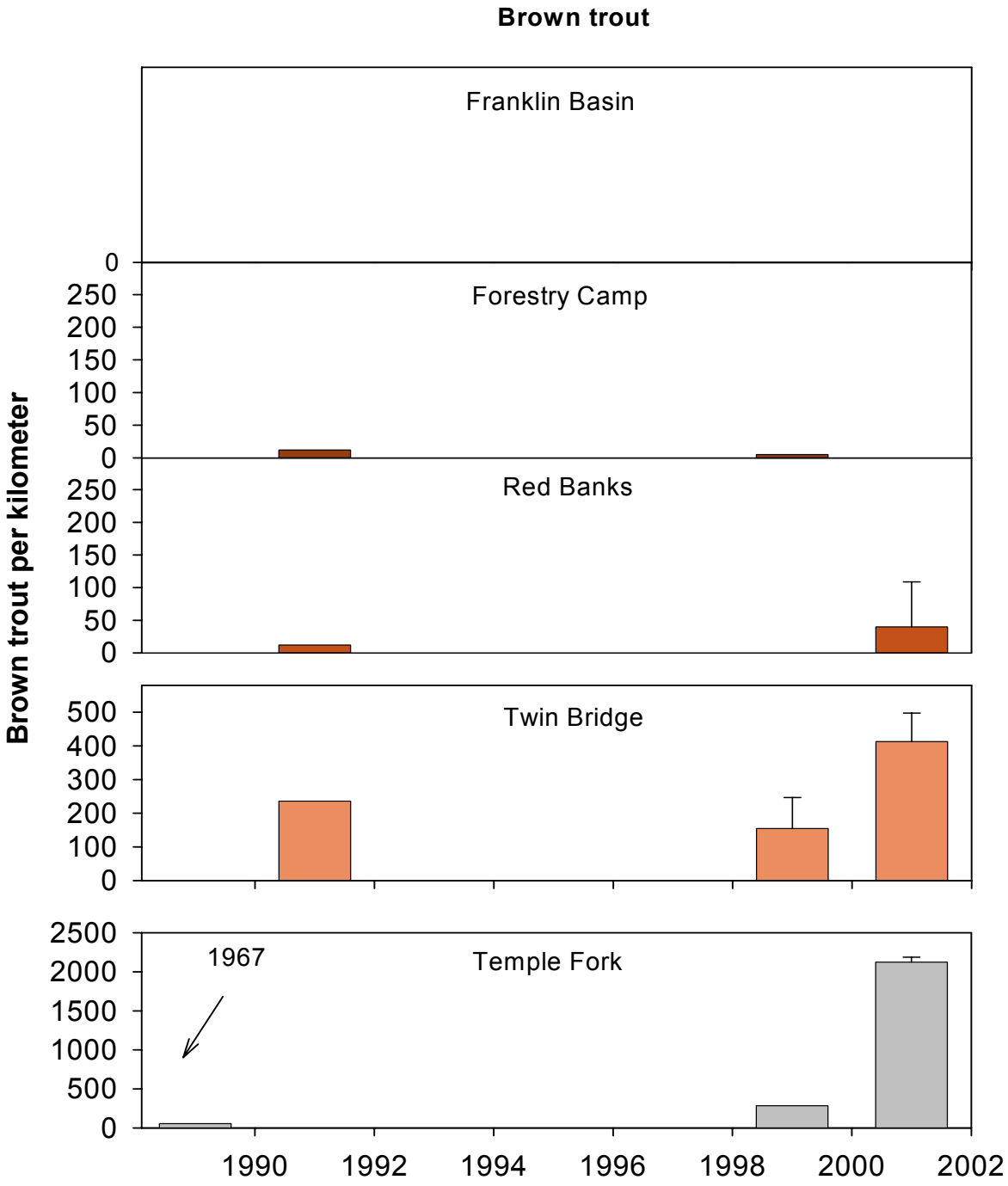


Figure 14. Abundance of brown trout per kilometer for several sites from past studies (Thompson et al. 2000) and the current 2001 study. No information was available from 1992 to 1998. Error bars represent one standard error.

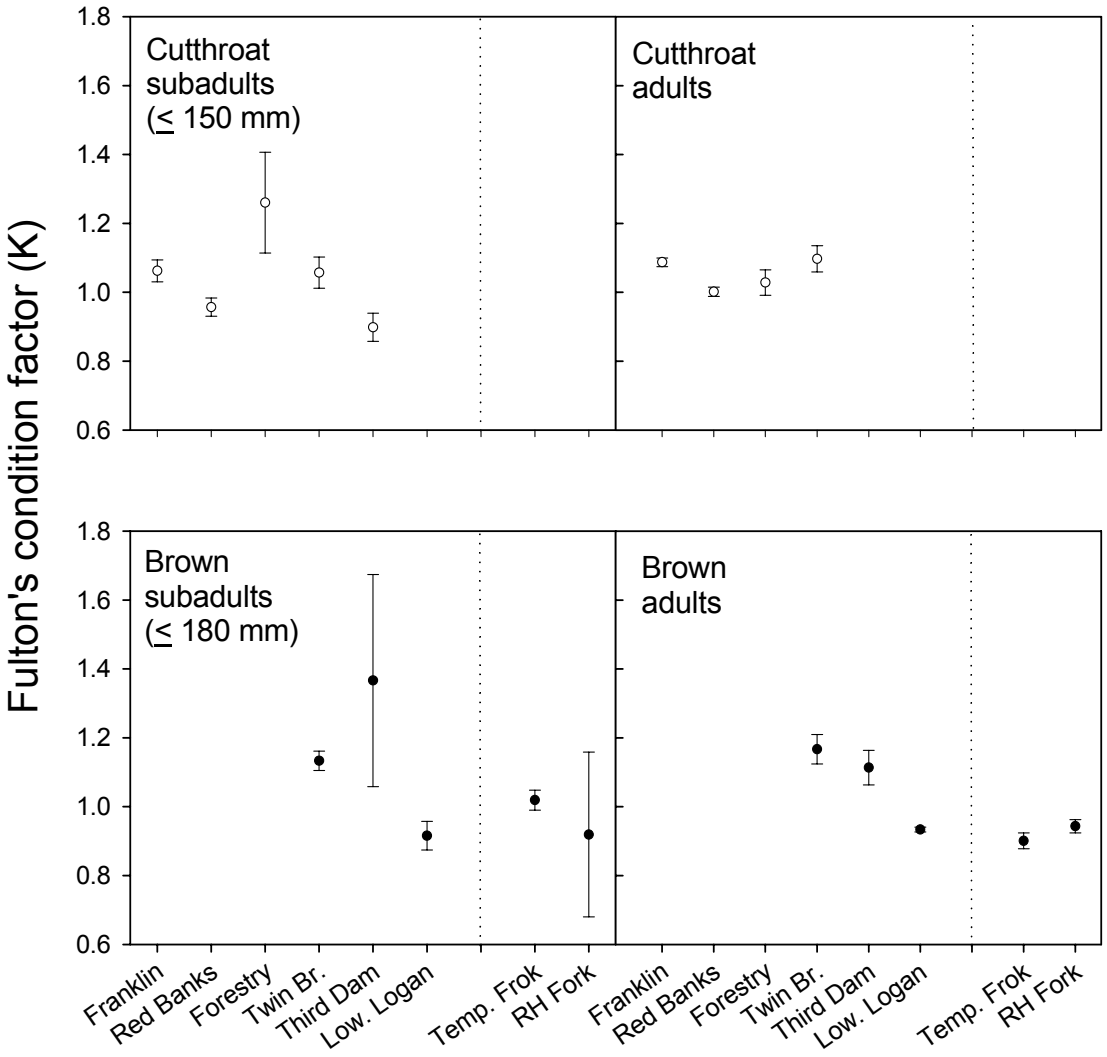


Figure 15. Condition (Fulton's K) of adult and subadult cutthroat trout (top panels) and brown trout (bottom panels) captured in the Logan River, August 2001. Error bars represent ± 1 SE.

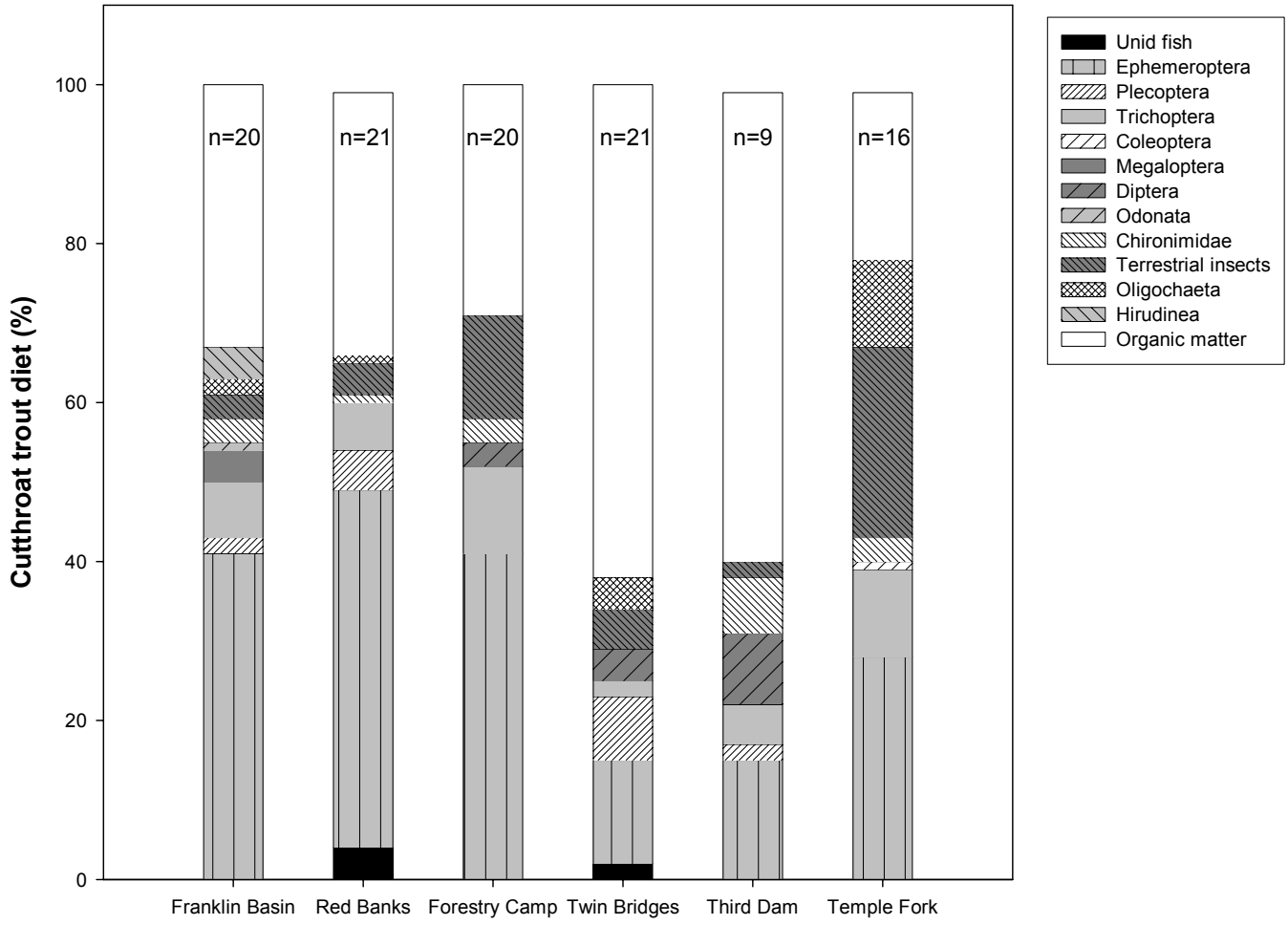


Figure 16. Percent composition by wet weight of prey in cutthroat trout diets caught in the Logan River and tributaries, August 2001. Sample size (n) is given on bars.

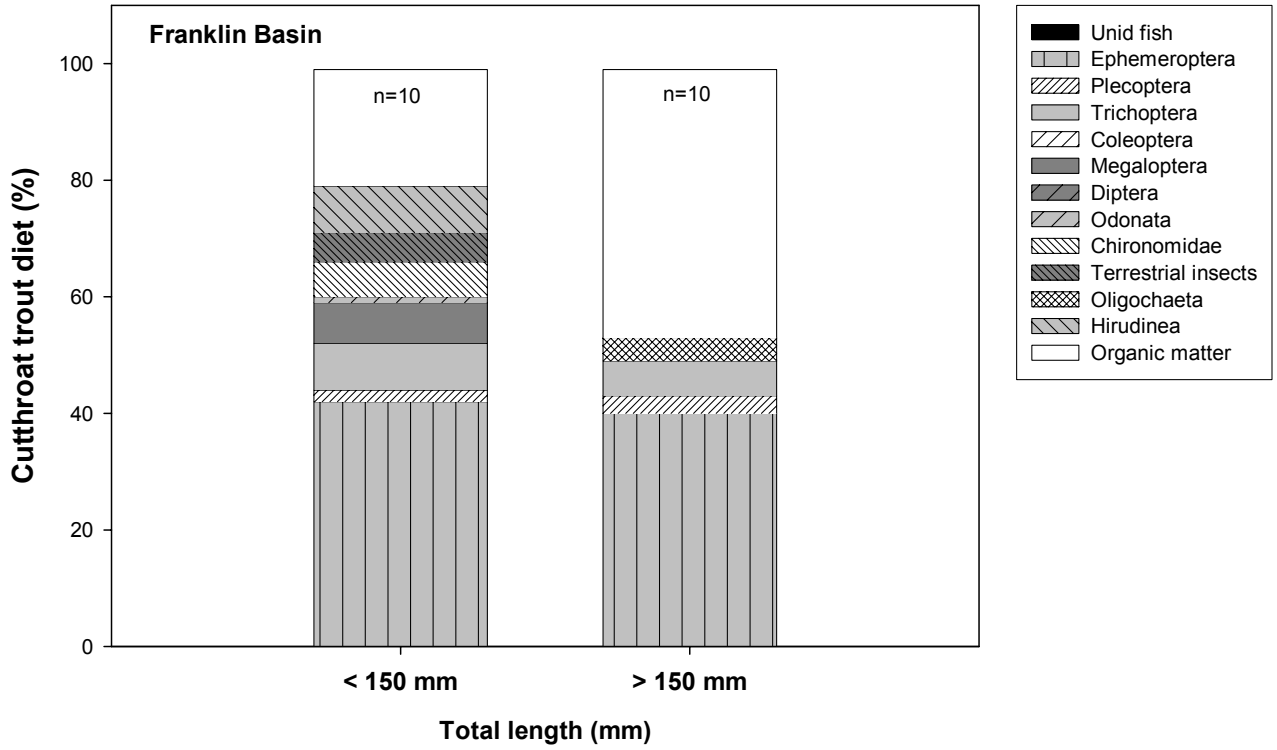


Figure 17. Percent composition by wet weight of prey in diets of adult and subadult cutthroat trout sampled at Franklin Basin, August 2001. Sample size (n) is given on bars.

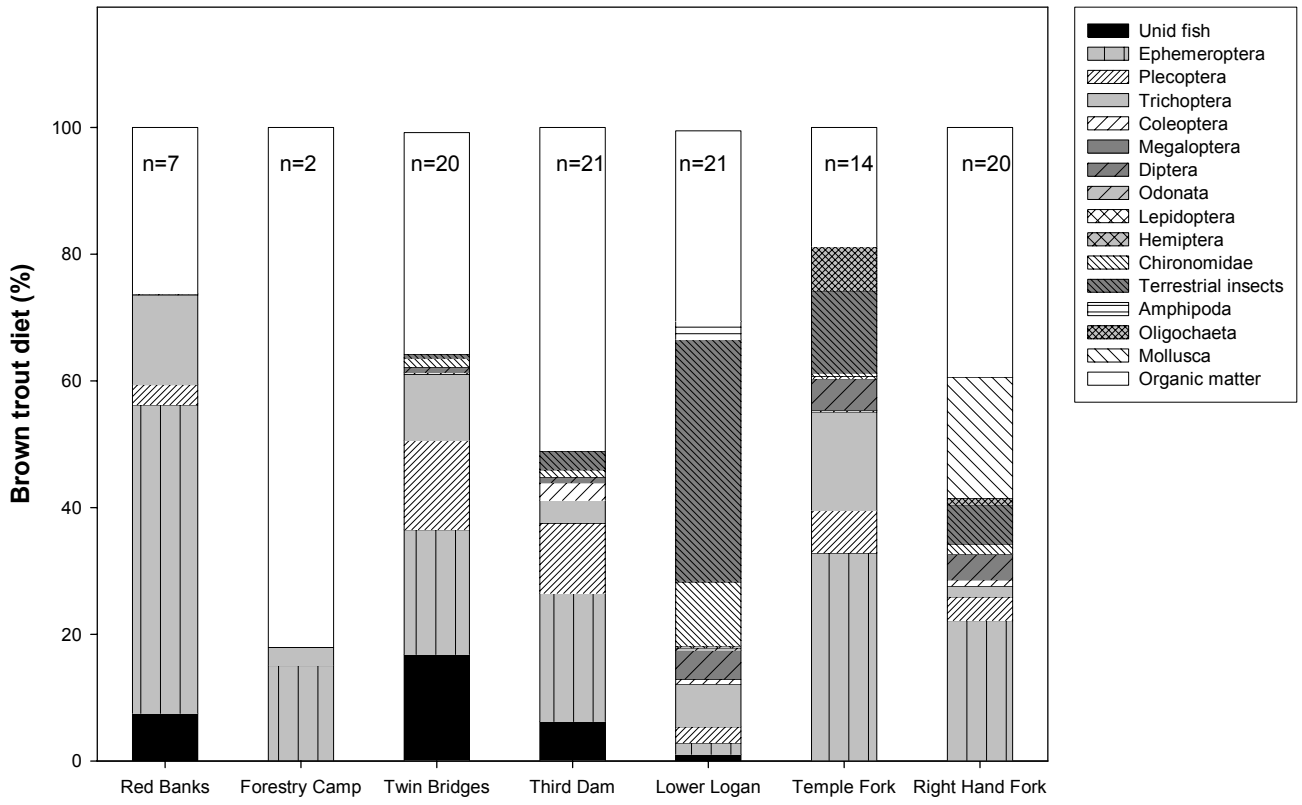


Figure 18. Percent composition by wet weight of prey in brown trout diets caught in the Logan River and tributaries, August 2001. Sample size (n) is given on bars.

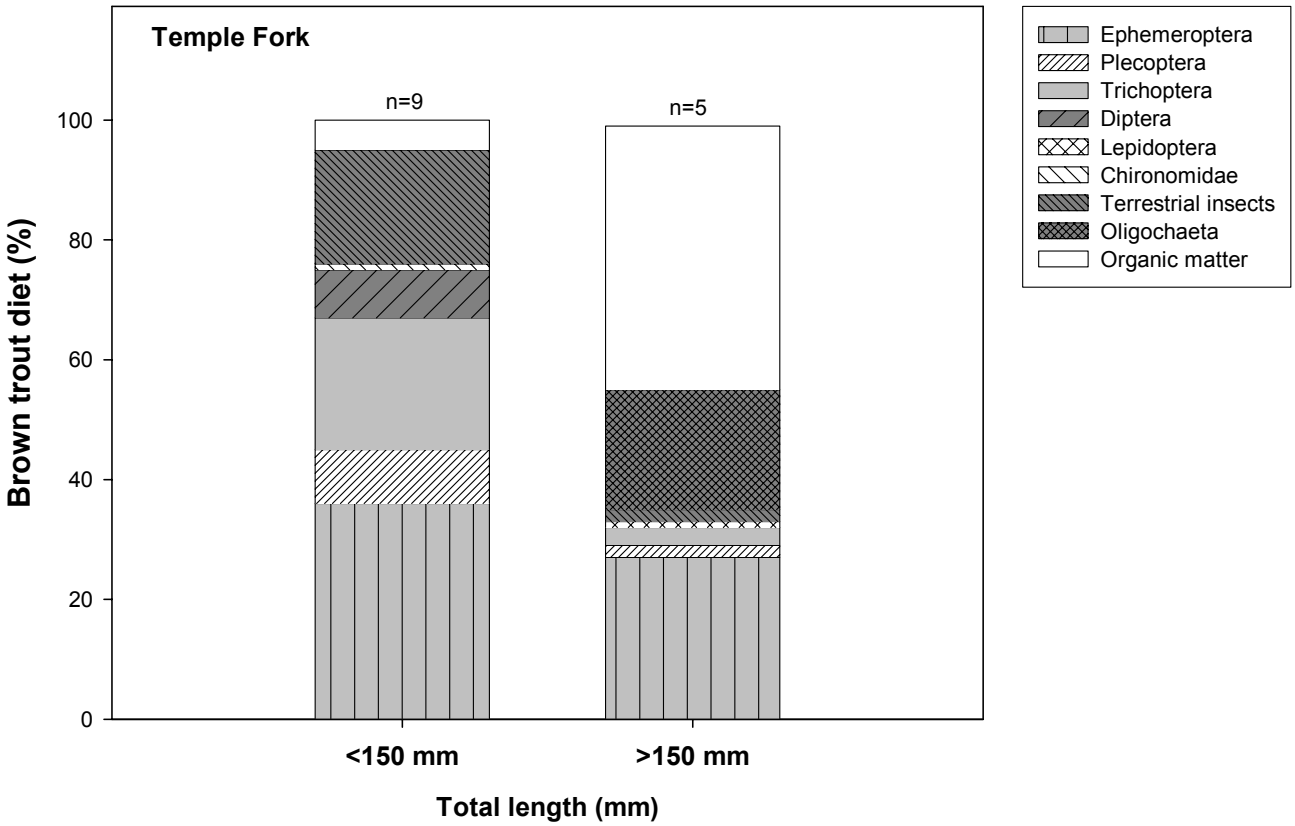


Figure 19. Percent composition by wet weight of prey in diets of adult and subadult brown trout caught at Temple Fork, August 2001. Sample size (n) is given on bars.

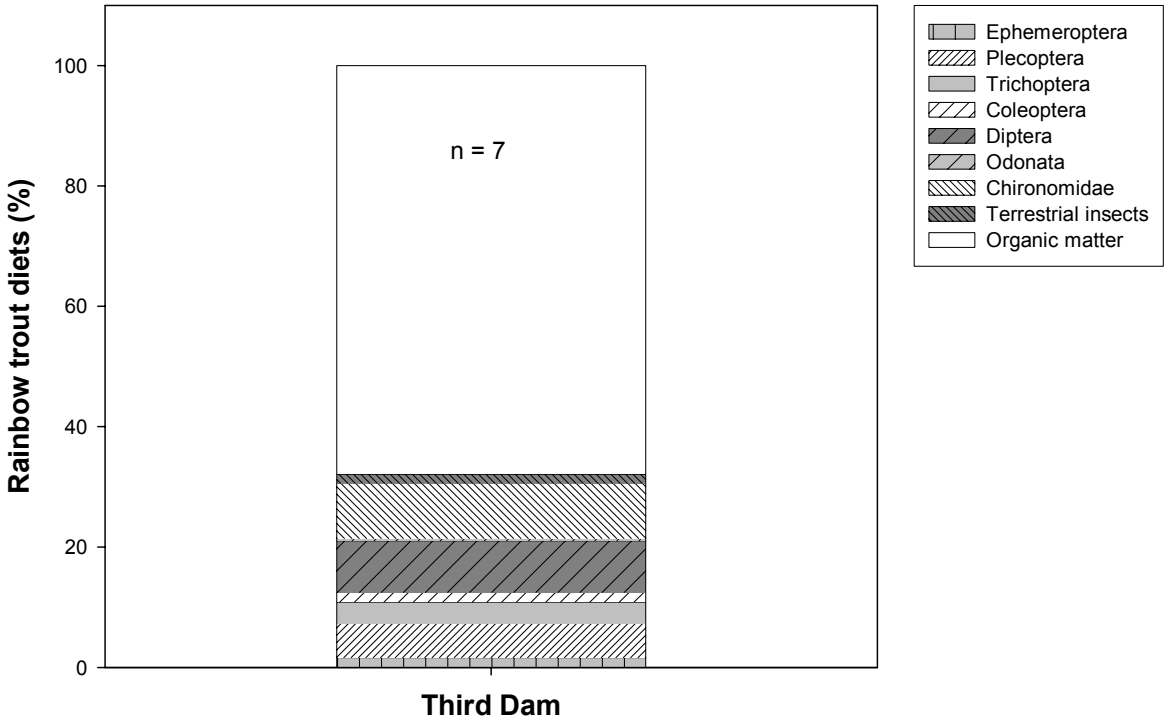


Figure 20. Percent composition by wet weight of prey in rainbow trout diets caught at Third Dam in August 2001. Sample size (n) is given on bar.

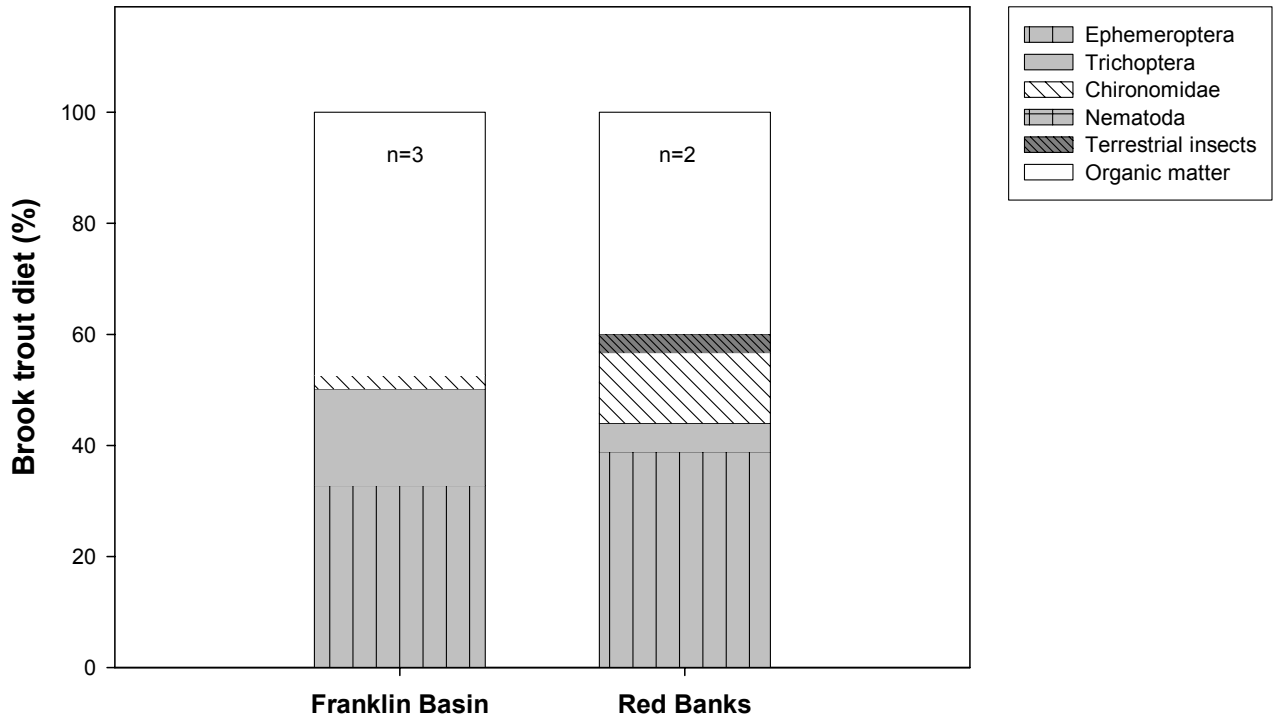


Figure 21. Percent composition by wet weight of prey in brook trout diets caught at Franklin Basin and Red Banks in August 2001. Sample size (n) is given on bars.

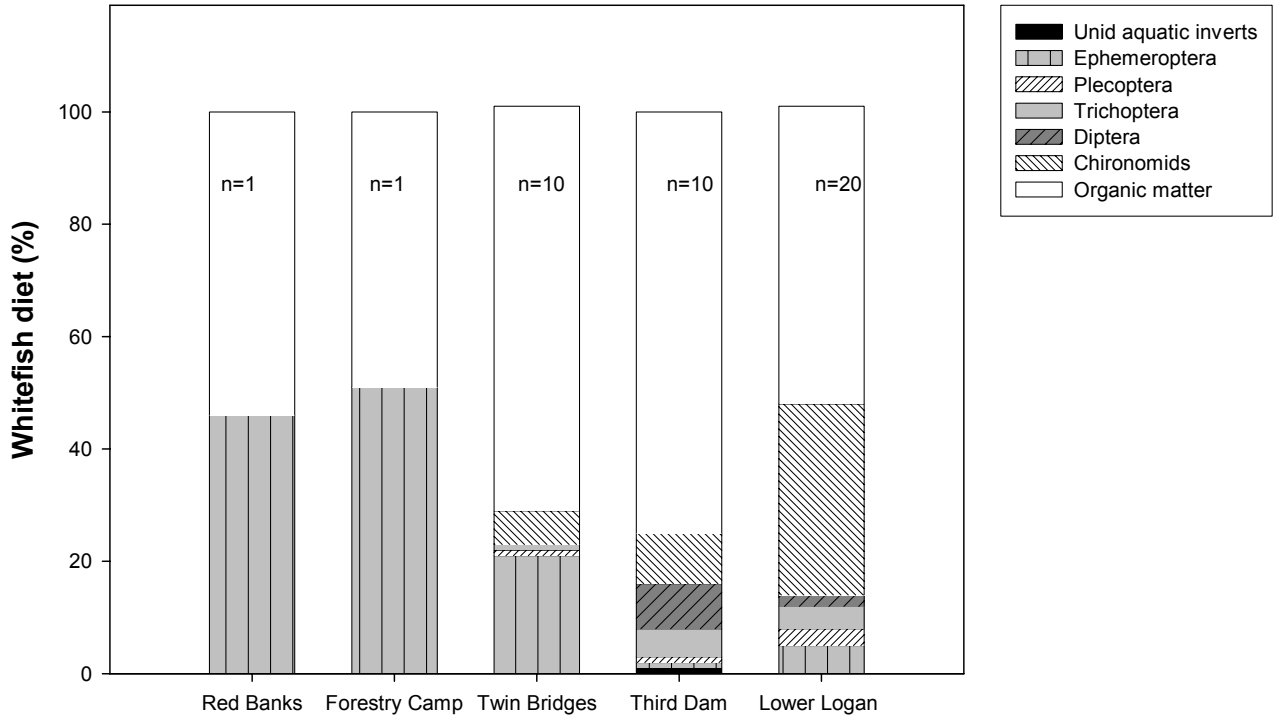


Figure 22. Percent composition by wet weight of prey in mountain whitefish diets caught in the Logan River in August 2001. Sample size (n) is given on bars.

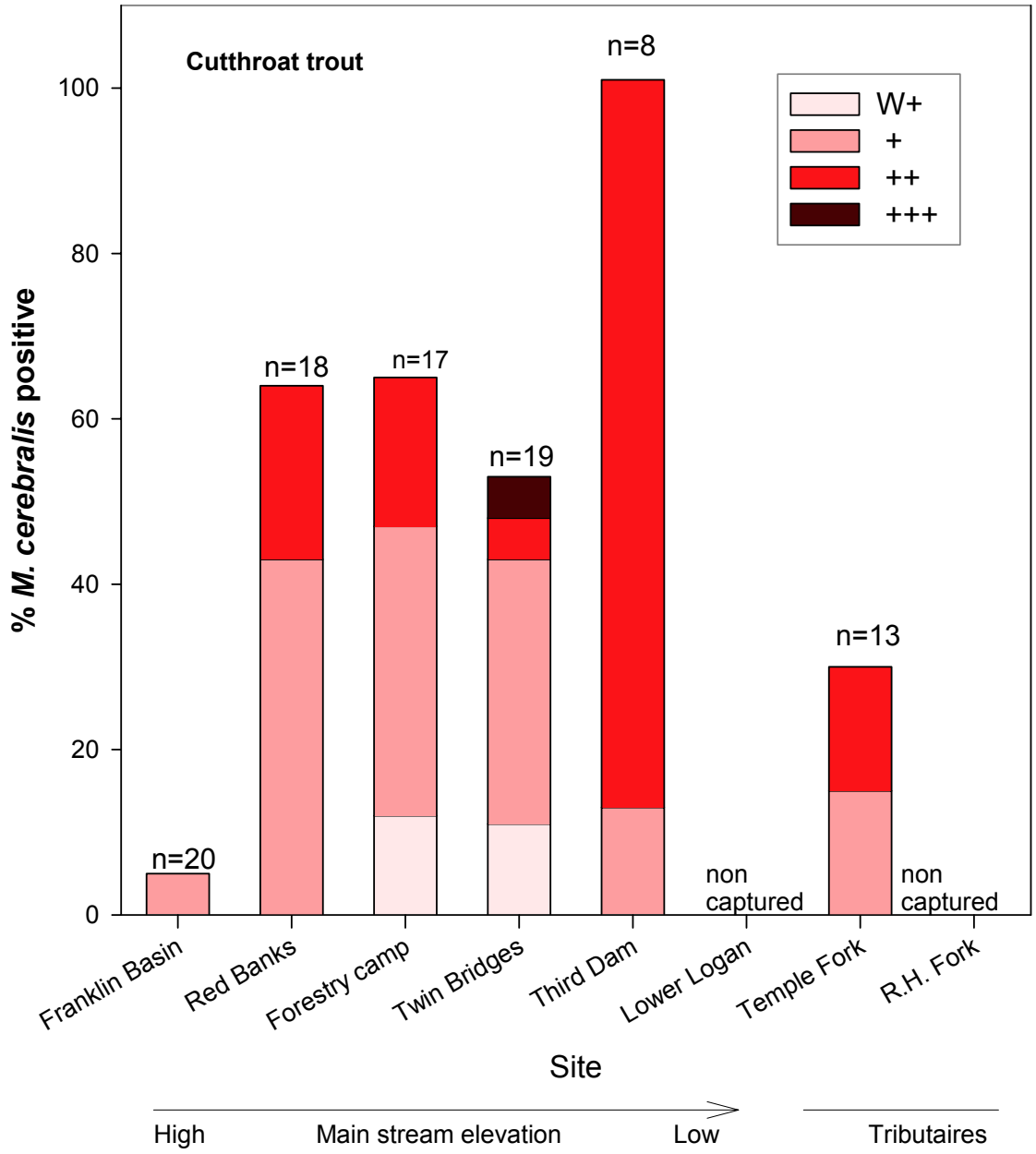


Figure 23. Percentage of cutthroat trout (all ages combined) by sample site tested positive for *M. cerebralis* in the Logan River, August 2001. Based on PCR testing, scores are shown as weak positive (W+), positive (+), strong positive (++), and very strong positive (+++). Sample sizes (n) are given above bars.

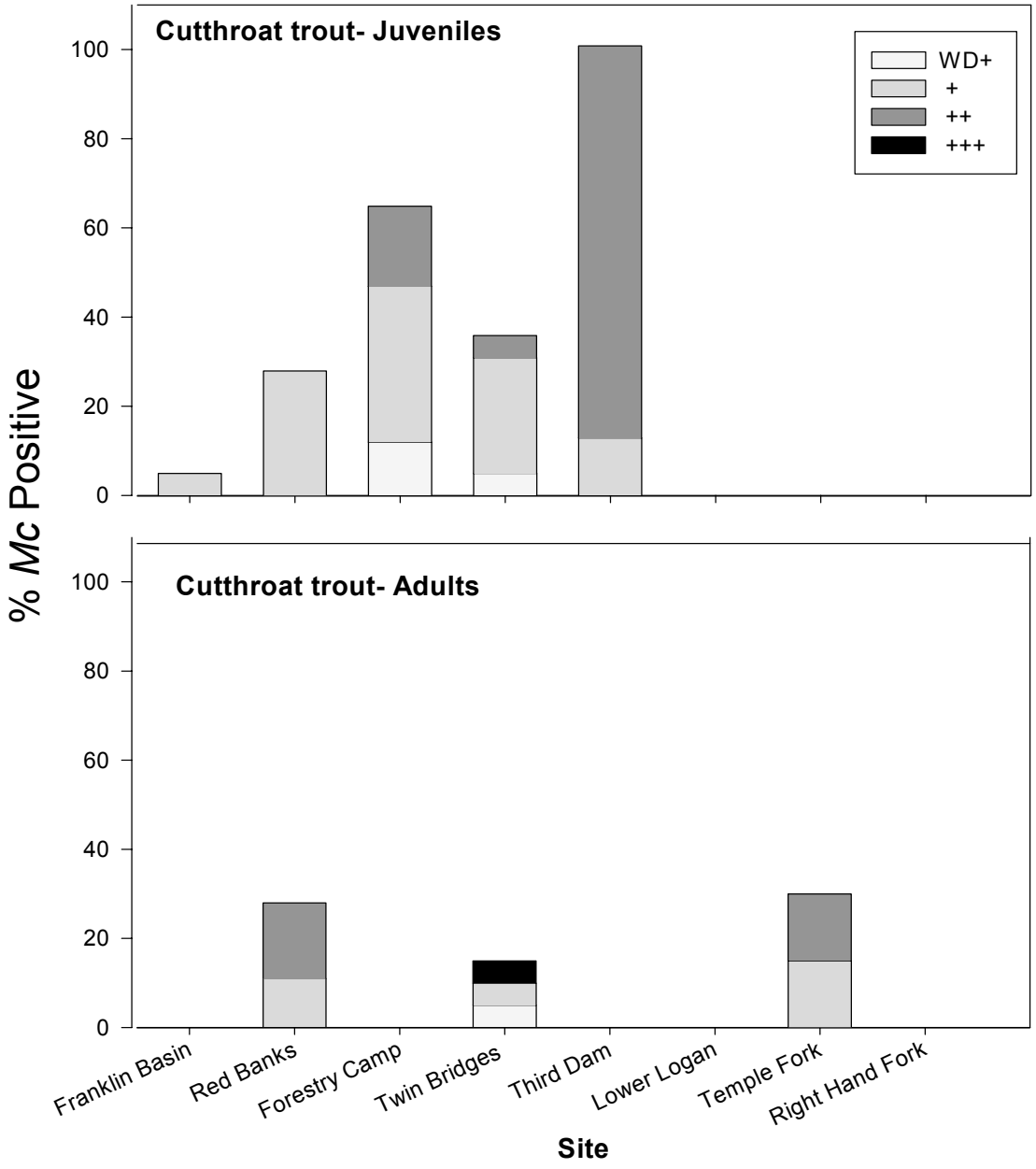


Figure 24. Percentage of cutthroat trout (subadults and adults) by sample site tested positive for *M. cerebralis* in the Logan River, August 2001. Based on PCR testing, scores are shown as weak positive (W+), positive (+), strong positive (++), and very strong positive (+++).

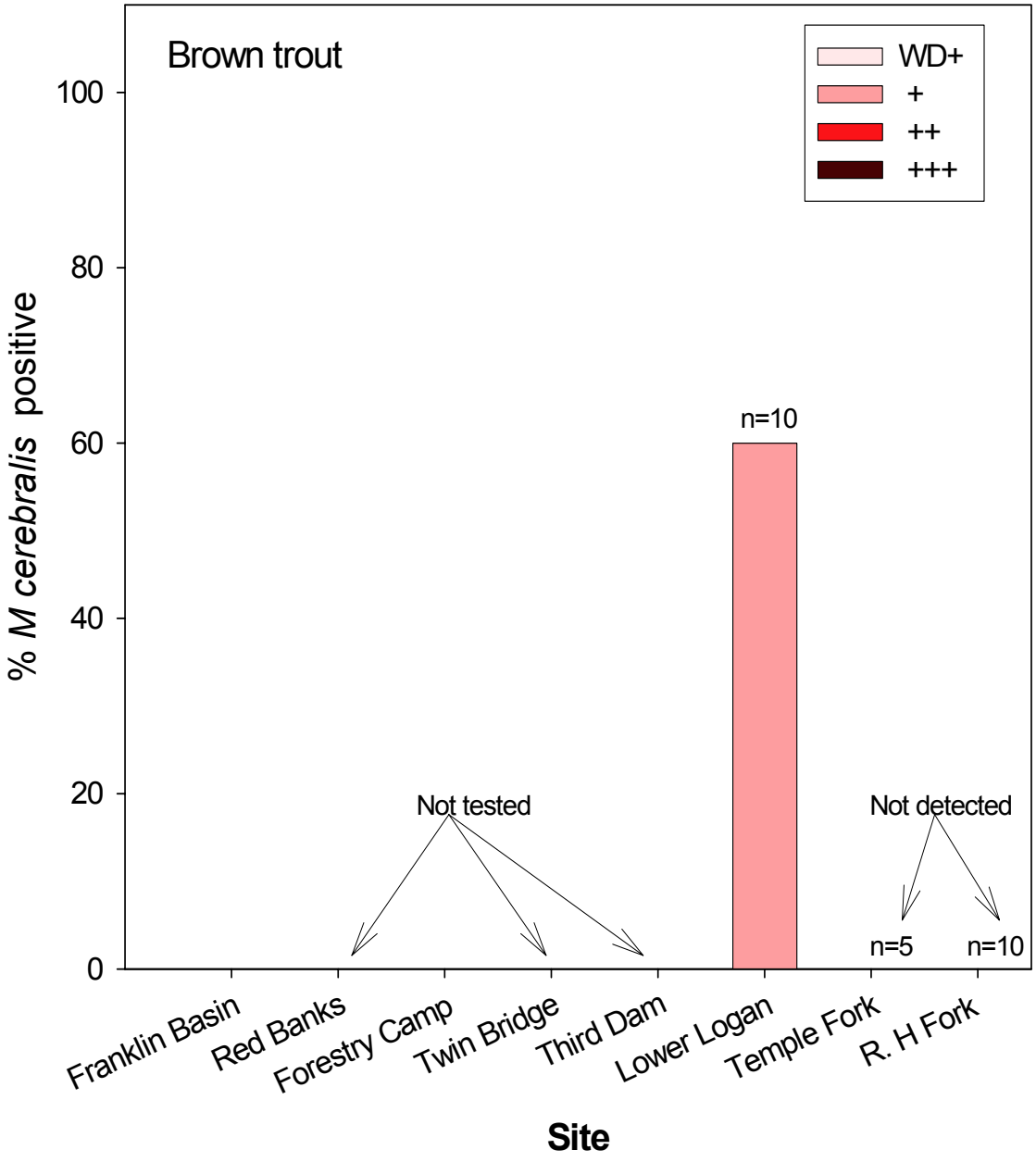


Figure 25. Percentage of brown trout (all ages combined) by sample site tested positive for *M. cerebralis* in the Logan River, August 2001. Based on PCR testing, scores are shown as weak positive (W+), positive (+), strong positive (++), and very strong positive (+++). Sample size (n) is given above bars. Brown trout were not captured at Franklin Basin or Forestry Camp.

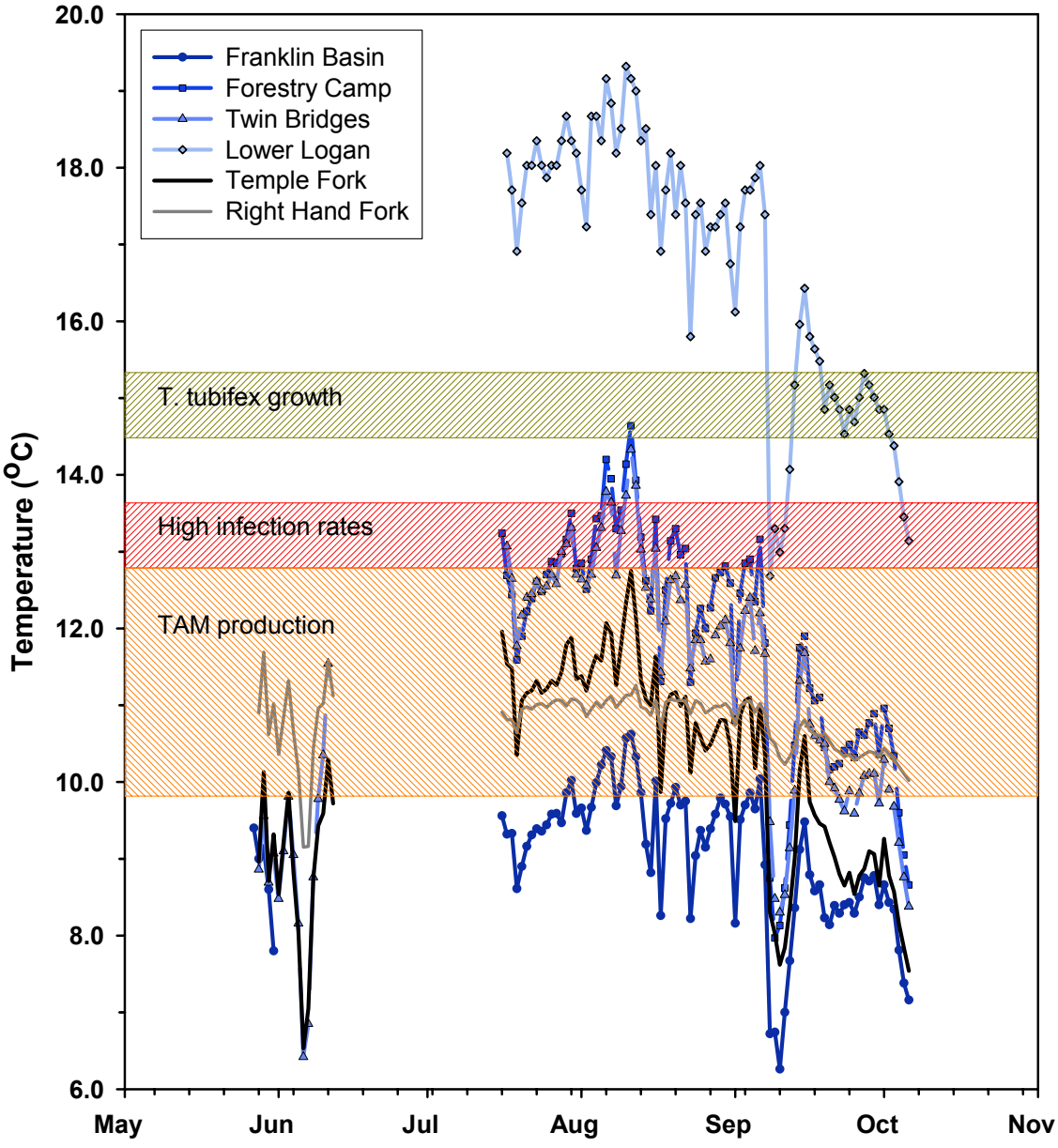


Figure 26. Average daily temperatures at six sites along the Logan River, June to October 2001. Shaded areas show ideal temperatures for TAM production, *T. tubifex* growth, and temperatures correlated with high *M. cerebralis* infection rates in Colorado streams.

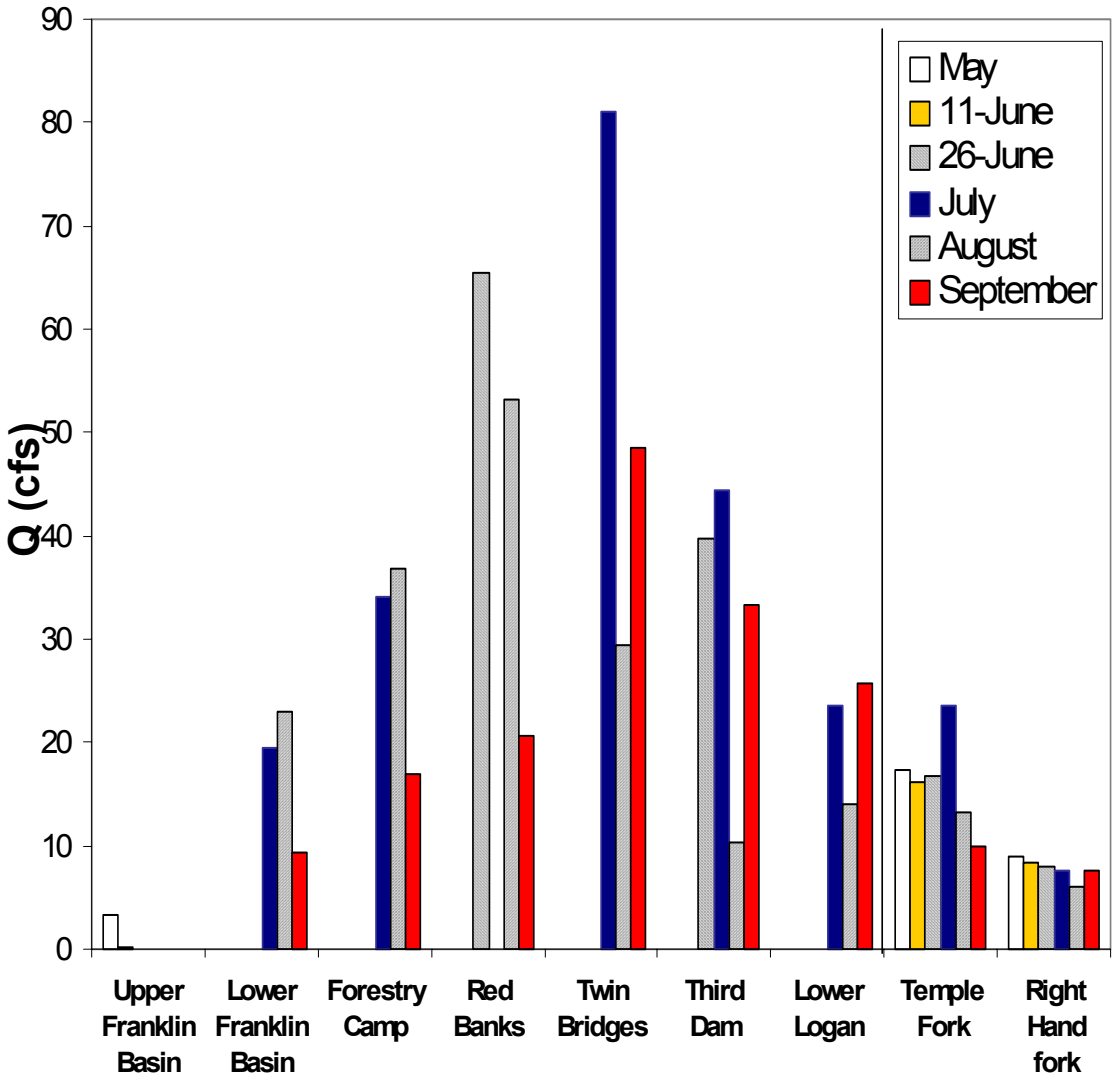


Figure 27. Monthly discharge measurements (Q in cfs) at seven sites along the Logan River and two tributaries, May to September 2001.

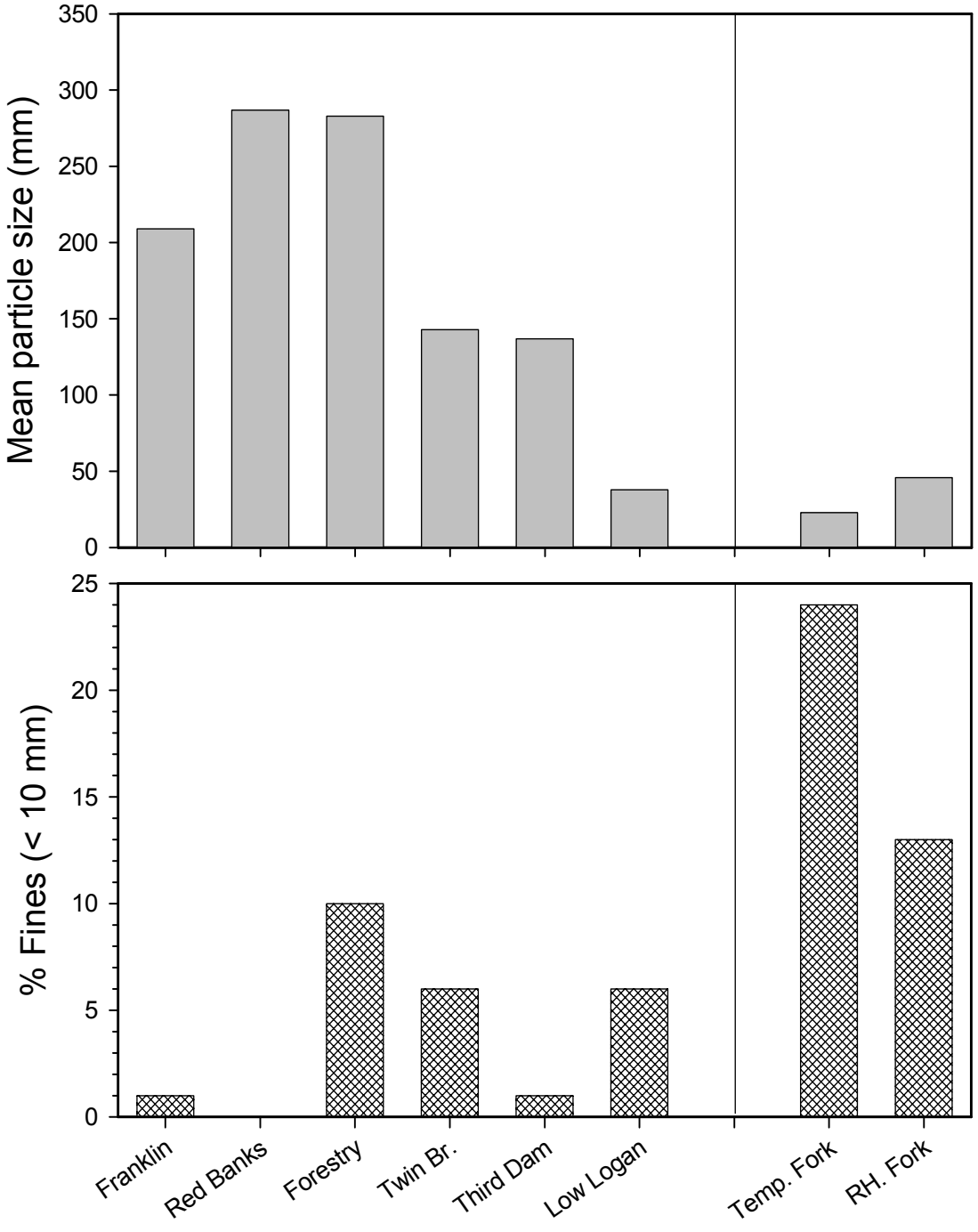


Figure 28. Substrates measurements in the Logan River and tributaries, summer 2001. Mean particle size (top panel) and percent fines (bottom panel) are shown by site.

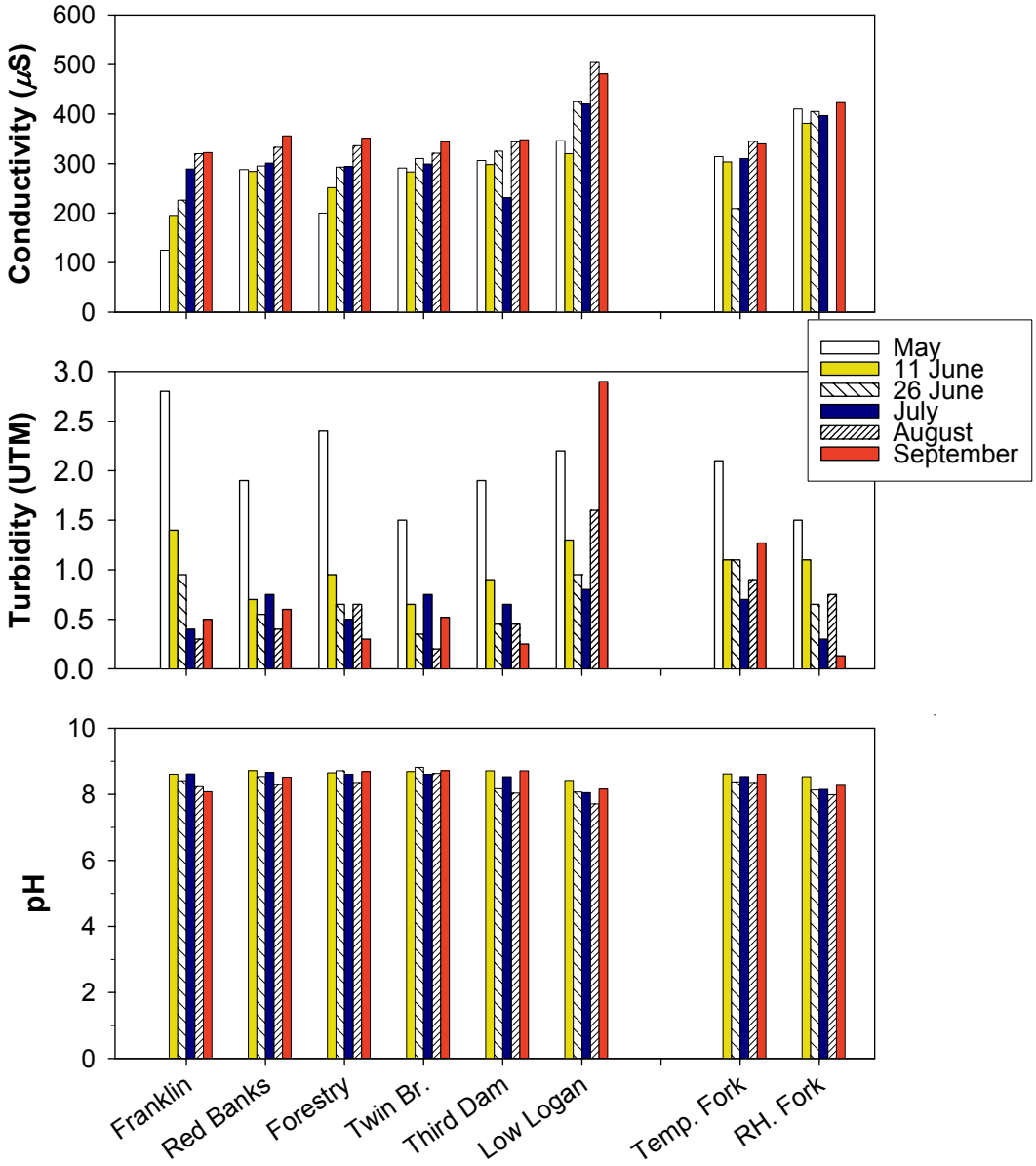


Figure 29. Conductivity (top panel), turbidity (middle panel), and pH (bottom panel) measured monthly at eight sites on the Logan River, May to September 2001.

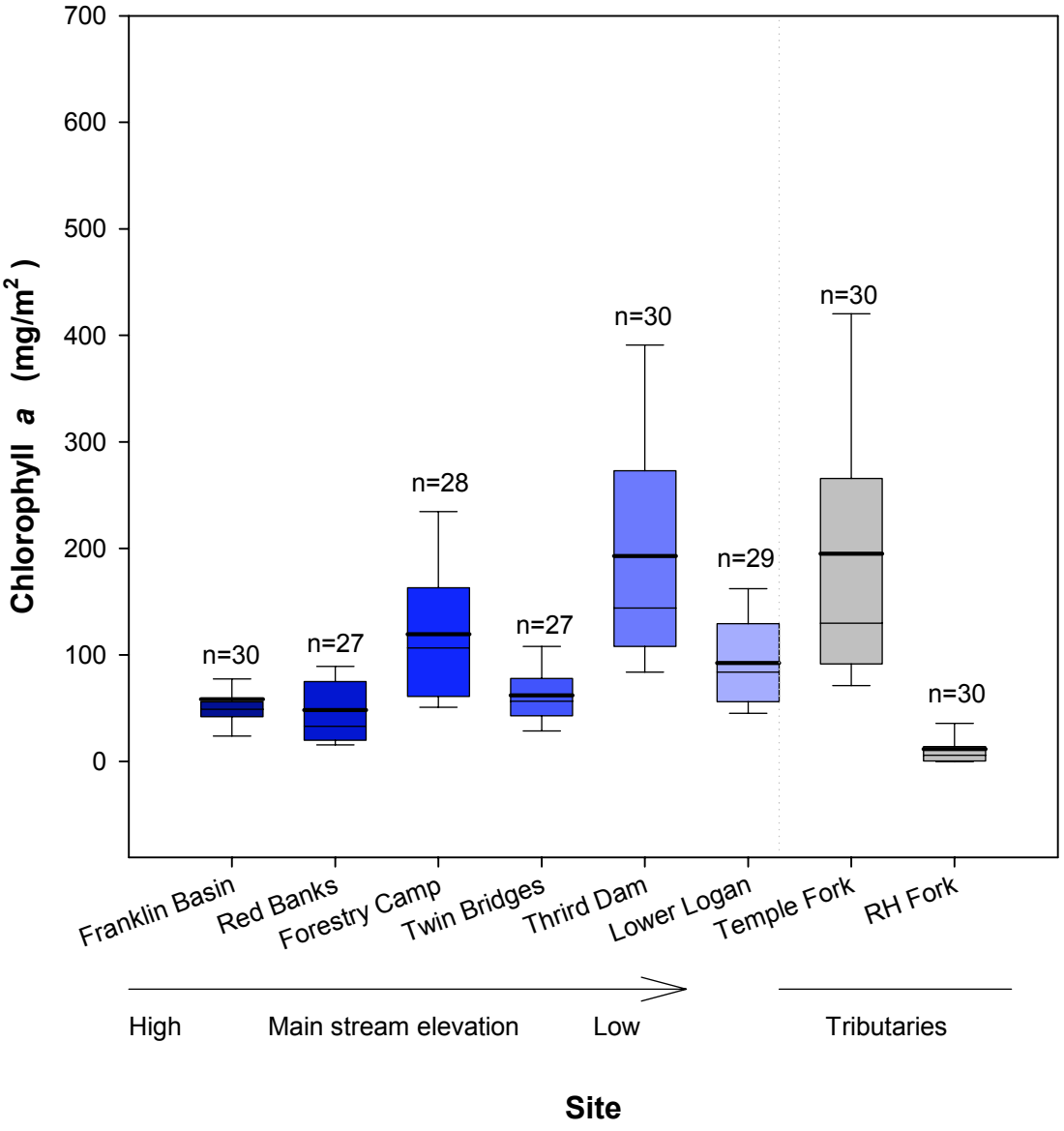


Figure 30. Periphyton biomass expressed in mg/m^2 of chlorophyll *a* at sites on the Logan River and tributaries, summer 2001. Boxes correspond to quartiles: bold line is the mean, narrow line is the median. Whiskers correspond to the 10th and 90th percentiles. Sample size (n) is the total number of rocks used for chlorophyll a extraction. Data from three transects at each site were combined.

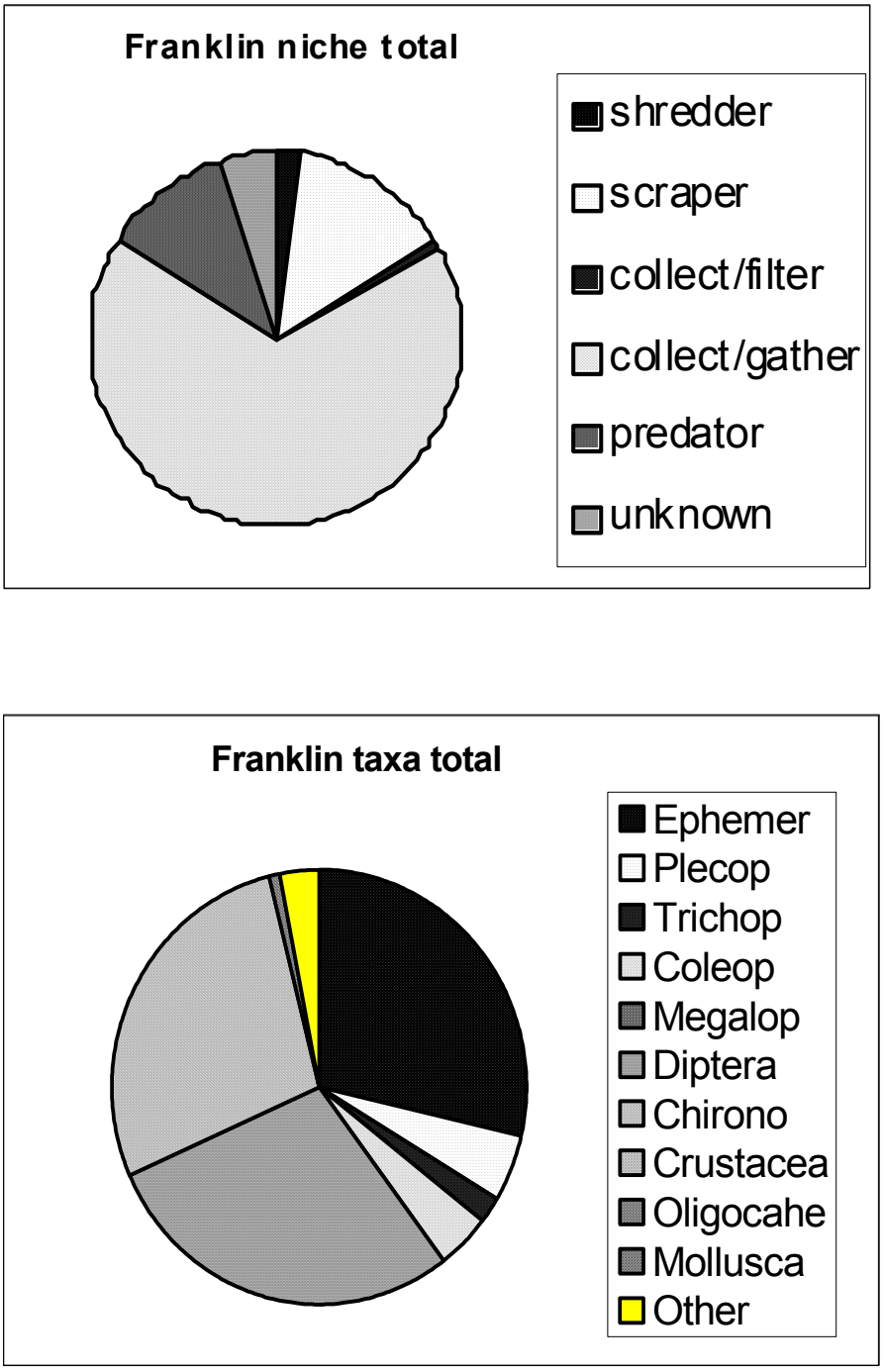
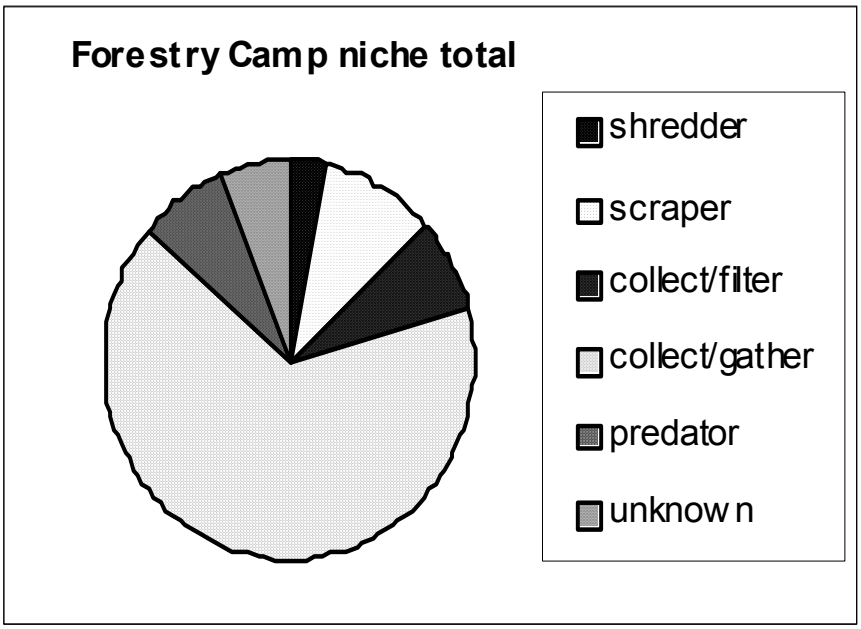


Figure 31. Invertebrates sampled at Franklin Basin in the Logan River, 1996-2000 (M. Vinson, unpublished data). Pie charts represent percent composition by niche (top pie) and percent composition by taxa (bottom pie).



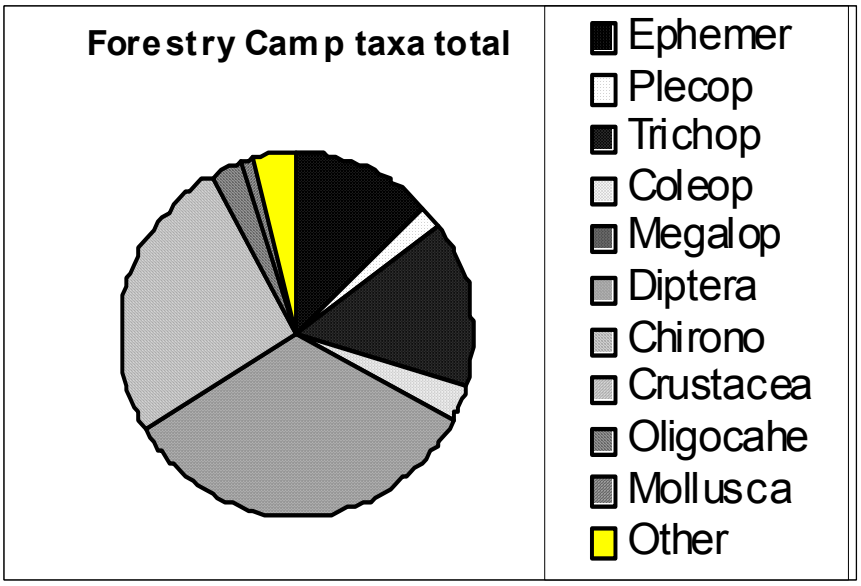
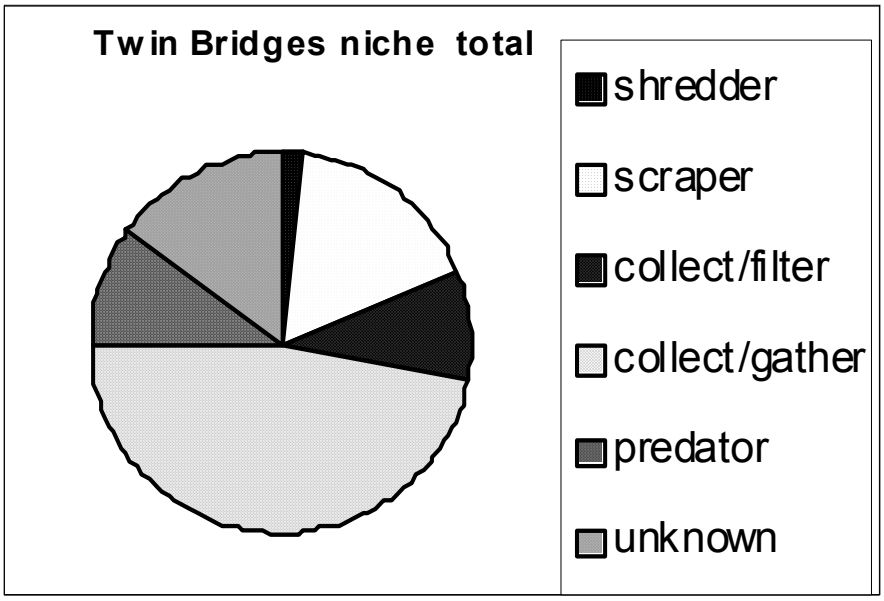


Figure 32. Invertebrates sampled at Forestry Camp in the Logan River, 1996-2000 (M. Vinson, unpublished data). Pie charts represent percent composition by niche (top pie) and percent composition by taxa (bottom pie).



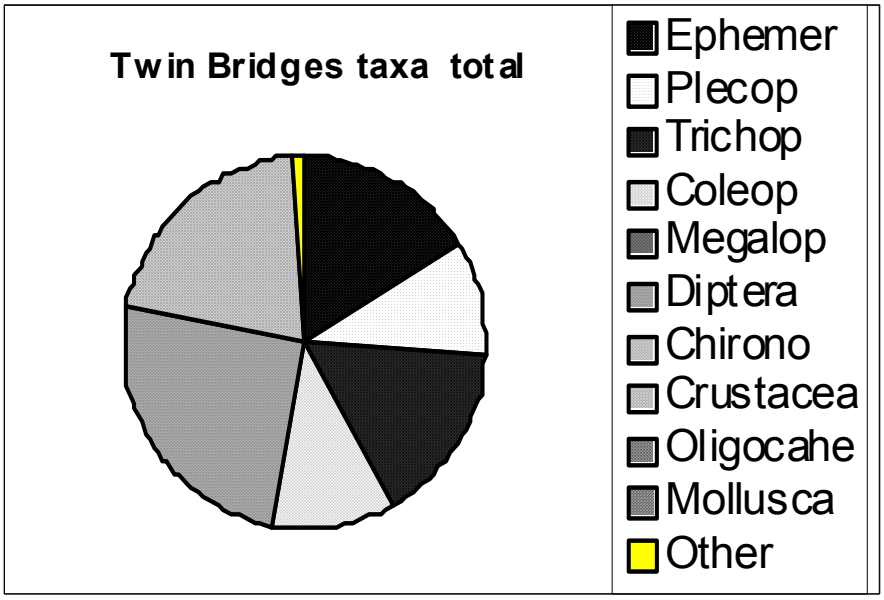
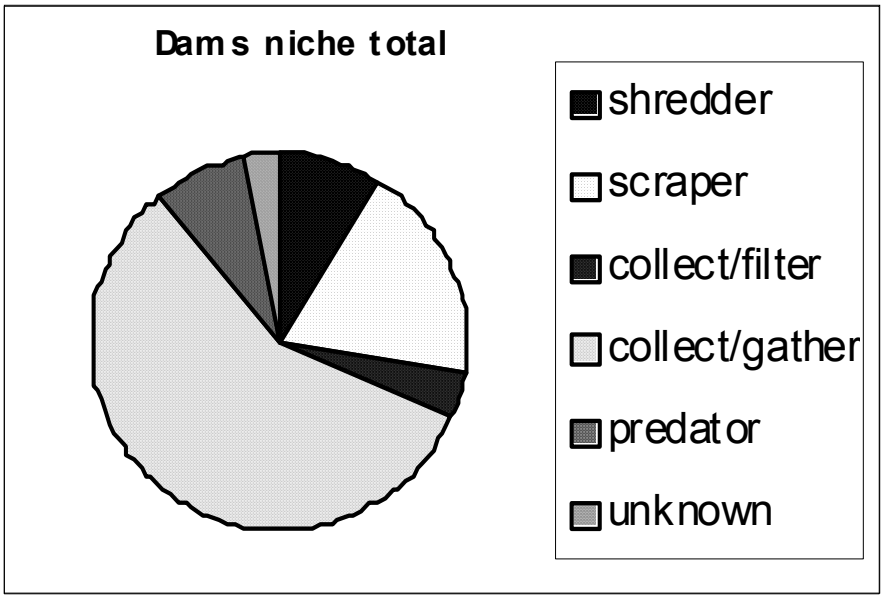


Figure 33. Invertebrates sampled at Twin Bridges in the Logan River, 1996-2000 (M. Vinson, unpublished data). Pie charts represent percent composition by niche (top pie) and percent composition by taxa (bottom pie).



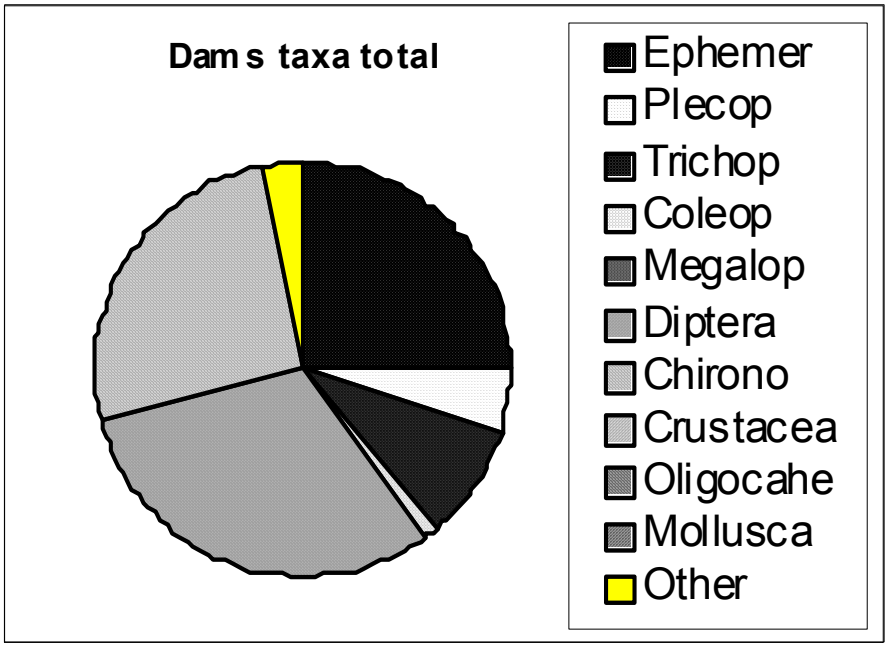
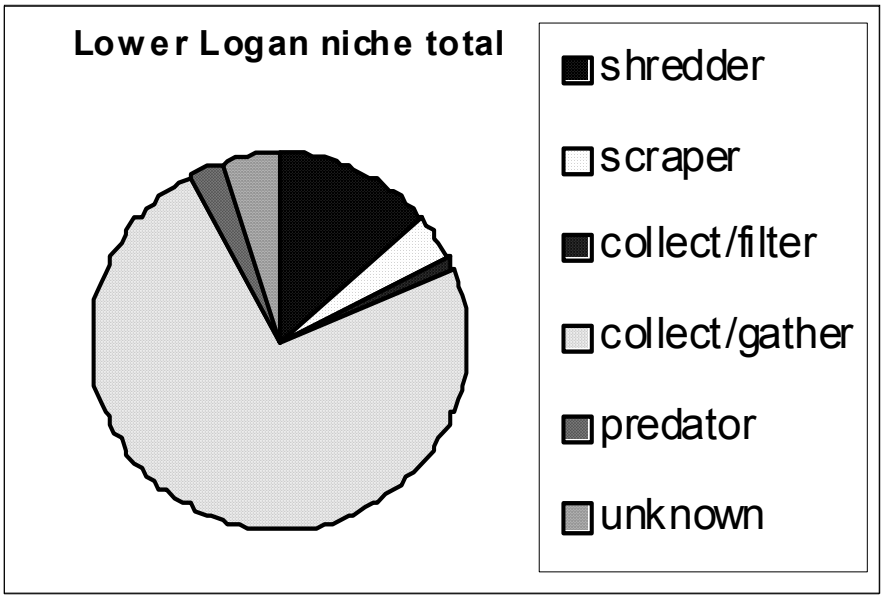


Figure 34. Invertebrates sampled at Second and Third dams in the Logan River, 1996-2000 (M. Vinson, unpublished data). Pie charts represent percent composition by niche (top pie) and percent composition by taxa (bottom pie).



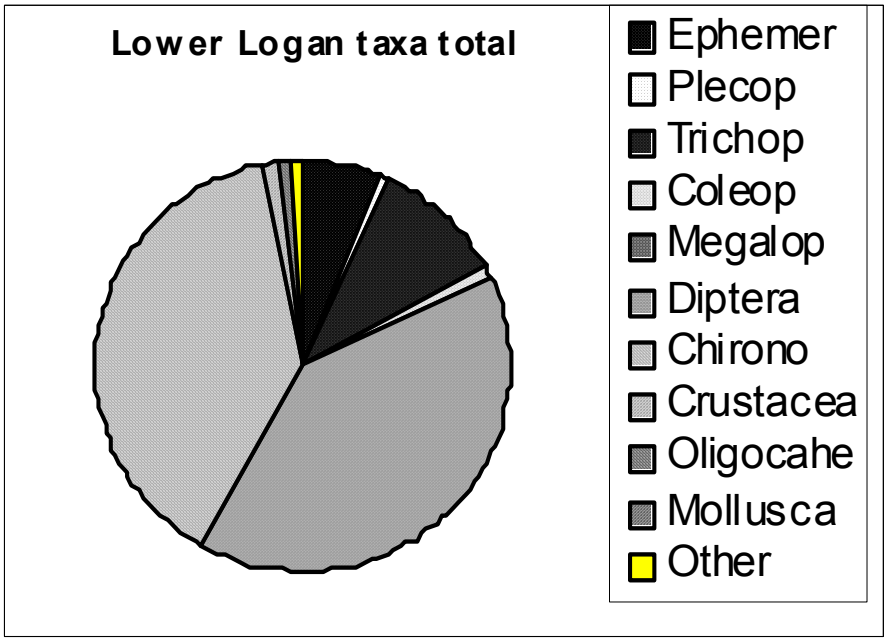
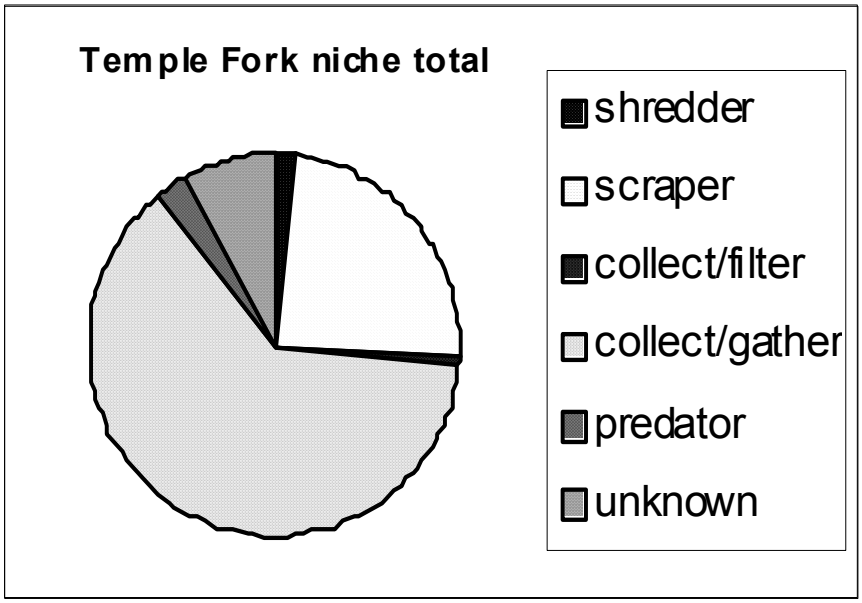


Figure 35. Invertebrates sampled at the Lower Logan site in the Logan River, 1996-2000 (M. Vinson, unpublished data). Pie charts represent percent composition by niche (top pie) and percent composition by taxa (bottom pie).



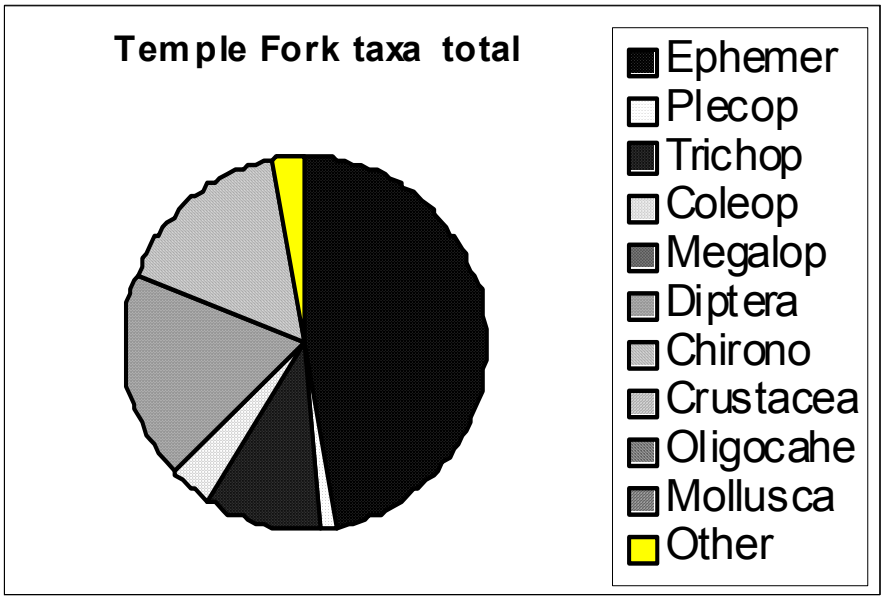
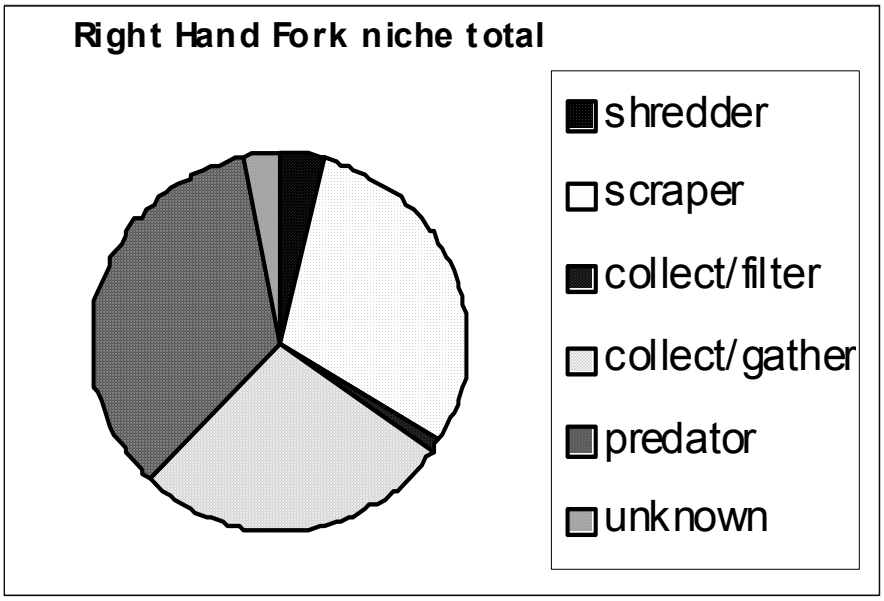


Figure 36. Invertebrates sampled at Temple Fork, a tributary to the Logan River, 1996-2000 (M. Vinson, unpublished data). Pie charts represent percent composition by niche (top pie) and percent composition by taxa (bottom pie).



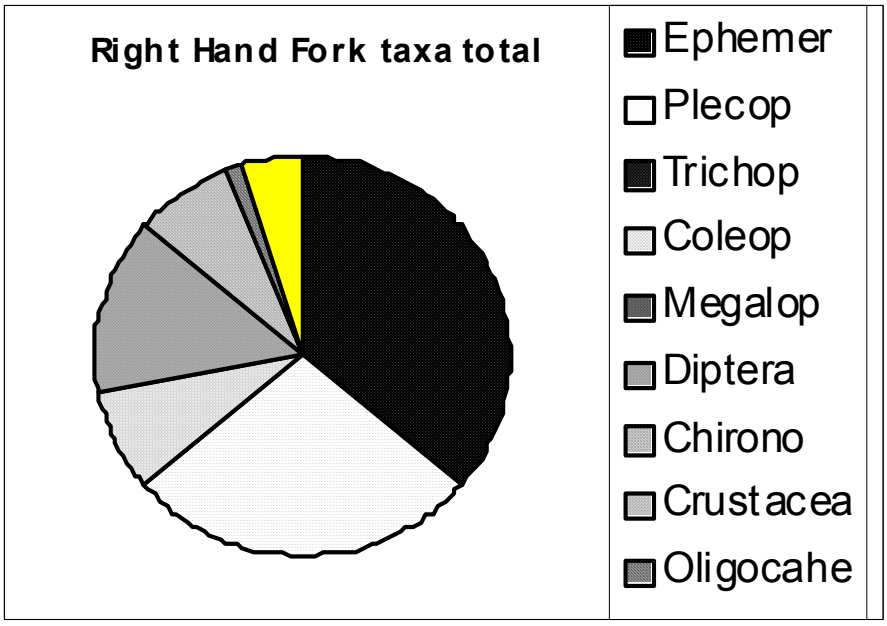


Figure 37. Invertebrates sampled at Right Hand Fork, a tributary to the Logan River, 1996-2000 (M. Vinson, unpublished data). Pie charts represent percent composition by niche (top pie) and percent composition by taxa (bottom pie).

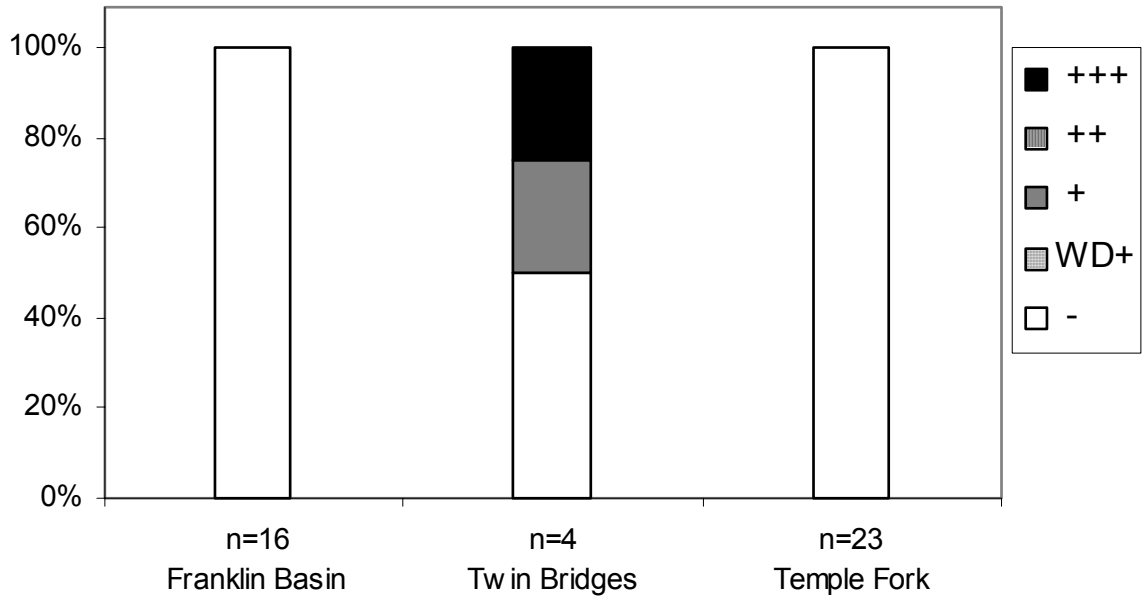


Figure 38. Percentage of cutthroat trout tested positive for *M. cerebralis* in sentinel cages at three sites in the Logan River, August 2001. Based on PCR testing, scores are shown as weak positive (W+), positive (+), strong positive (++), and very strong positive (+++). Sample size (n) is given.