BROWN TROUT PREDATION IN SILVER CREEK

A MASTERS THESIS BY RICHARD WILKISON

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FISH COMMUNITY STRUCTURE AND BROWN TROUT PREDATION IN UPPER SILVER CREEK, IDAHO

by

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ABSTRACT

A 15-year old brown trout population in upper Silver Creek, a high desert spring creek in southcentral Idaho, negatively impacted a productive rainbow trout population. Population estimates of rainbow and brown trout at five sites were compared with earlier estimates to evaluate changes in the two populations over the period from 1976 to 1992. Population data indicated the presence of an expanding brown trout population and an accumulation of many large individuals. Brown trout biomass in 1993 at five sites in upper Silver Creek increased significantly from 1986 values. Rainbow trout biomass over the same period remained relatively constant with the exception of a 71% decrease at a site where a 494% increase in brown trout biomass occurred.

Stomach contents were collected seasonally from brown trout, primarily > 300 mm, during 1993-1994 from three sites located within the same sections where population data had been gathered. Brown trout < 300 mm consumed only invertebrates. With increasing size, brown trout included a greater percentage of fish in their diet, and fish larger than 500 mm rarely consumed invertebrates. Salmonids comprised the largest proportion of the daily ration of prey fishes (grams dry weight). Brown trout mainly selected rainbow trout, brook trout and mountain whitefish as prey.

Conspecifics were consumed in a lower proportion than their abundance in the environment. Brown trout predation was estimated to account for the removal of 12,700 rainbow trout and 2,745 brown trout per hectare annually from Silver Creek.

Population and diet evaluation results from Silver Creek underscore the potential for deleterious effects of introduced brown trout on sympatric native and nonnative species. These results also indicate a need for a clearer understanding of the role of brown trout in various types of fish communities and aquatic environments if they are to be successfully managed with sympatric fishes.

CHAPTER I:

CHANGES IN FISH COMMUNITY STRUCTURE IN UPPER SILVER CREEK, IDAHO, 15 YEARS AFTER THE INTRODUCTION OF BROWN TROUT

INTRODUCTION

The introduction of nonnative salmonids into waters in the western United States has been a common practice for nearly 100 years. Not until recently, however, have researchers begun to examine the effects of nonnative species introductions on resident native and other nonnative salmonids and, to a lesser extent, native nongame fishes. Because of the ease with which it was cultured in the hatchery, the rainbow trout (*Oncorhynchus mykiss*), a native of the western United States, was probably the most widely distributed of the salmonids during early introductions. The brown trout (*Salmo trutta*), a native of Europe, was first introduced into the United States in the late 1800's (Luton 1985; MacCrimmon and Marshall 1968). While it was not cultured and distributed as extensively as the rainbow trout during this early period, the brown trout was very successful in many areas where it was introduced (MacCrimmon and Marshall 1968). Since its introduction into the United States, the brown trout has been managed as a valuable sport fish and its range has expanded to include nearly every state with coldwater streams.

Today, however, the role of the brown trout in mixed-species salmonid fisheries is not well understood and its potential to negatively impact native salmonids, nonnative salmonids, and native nongame fishes is becoming a concern of fisheries biologists, conservationists, and anglers. There is some indication that brown trout may negatively impact sympatric brook trout (Morse and MacCrimmon 1986; Dewald and Wilzbach 1992; Fausch and White 1981; Waters 1983), cutthroat trout (Wang and White 1994), rainbow trout (Gatz et al. 1987; Hayes 1989) and other native game and nongame species (Garman and Nielsen 1982; Jackson and Williams 1980; Ault and White 1994; Townsend and Crowl 1991) through competition and/or predation. Several explanations have been proposed for the brown trout's ability to successfully compete with other species including: greater aggressiveness, lower vulnerability to predation and angling, higher growth rates and greater longevity, greater use of fish and other vertebrates as food, and possible differences in microhabitat use that increase survival in early life stages. Unfortunately, most of these explanations have not been examined thoroughly.

The relatively recent introduction of brown trout into Silver Creek, in south-central Idaho, provided a unique opportunity to examine the potential effects of brown trout on sympatric salmonids and native nongame fishes in streams. Silver Creek has for decades been recognized as a world-class rainbow trout fishery. Well known for its large, surface-feeding rainbow trout, abundant aquatic insects, and crystal clear spring water, Silver Creek is considered one of the top spring creeks in the world by anglers. Brown trout were not found in Silver Creek above the town of Picabo in a 1976-1977 fishery survey conducted by Idaho Fish and Game biologists (Thurow 1978). However, between 1978 and 1980, brown trout were released into the system by a local angler (Paul Todd, The Nature Conservancy, personal communication). In 1981, researchers from Idaho State University (ISU) collected a few adult brown trout while electrofishing in upper Silver Creek but did not observe any juveniles of the species. In 1986 and 1987, snorkeling by ISU researchers documented the presence of adults and a few juveniles well into upper Stalker, Mud, and Grove creeks, all tributaries to Silver Creek (Riehle et al. 1989).

Fish population sampling began in fall 1992 in a portion of upper Silver Creek to assess changes in the fish community that may have occurred since the 1976-1977 and 1986-1987 surveys. In particular, changes in the rainbow and brown trout populations were of primary interest. Data were collected on trout species abundance, density, and biomass and nongame fish species relative abundance in fall 1992 and summer 1993 to compare to earlier data. Specific objectives were to:

a. assess the relative abundance of game and nongame fish species in upper Silver Creek and evaluate whether changes have occurred by comparing to data collected by Thurow (1978),

b. evaluate the species and size composition and estimate the abundance, density, and biomass of salmonid species in upper Silver Creek and compare those data to data collected by Thurow (1978) and Riehle et al. (1989).

DESCRIPTION OF STUDY SITES

Silver Creek is a spring-fed stream situated between the Timmerman Hills and the Pioneer Mountains at the edge of a high elevation, cold desert on the northern edge of the Snake River plain in south central Idaho (Figure 1). Silver Creek is formed by the confluence of Grove and Stalker creeks and flows east for approximately 3 km before Loving Creek, the only major tributary, enters. From the confluence of Loving Creek, Silver Creek flows southeasterly for 42 km to its junction with the Little Wood River.

Peak discharge in Silver Creek occurs in late summer to early fall due to groundwater recharge and reduced irrigation of farm and pasture land. Mean monthly discharge for 1992 ranged from 2.0 m^3/sec in June to 4.0 m^3/sec in February (Figure 2). Discharge in 1993 ranged from 2.9 to 5.0 m^3/sec. Mean monthly discharge for 1976 and 1986 ranged from 3.6 to 7.1 m^3/sec and 3.5 to 6.8 m^3/sec, respectively

(Water Resources Data for Idaho, U.S. Geological Survey 1975-1993). In 1992-1993, specific conductance varied from 386 to 464 uS/cm, pH varied from 8.1 to 8.4, and total alkalinity ranged from 177 to 197 mg/l as calcium carbonate (Water Resources Data for Idaho, U.S. Geological Survey 1992-1993). In 1993 winter water temperatures ranged from 0.5 to 10.5 °C, while summer water temperatures varied from 7.5 to 21.5 °C.

In addition to rainbow trout and brown trout, game fish in Silver Creek include brook trout (*Salvelinus fontinalis*) and mountain whitefish (*Prosopium williamsoni*). Nongame species present consist of bridgelip sucker (*Catostomus columbianus*), redside shiner (*Richardsonius balteatus*), longnose dace (*Rhinichthys cataractae*), speckled dace (*Rhinichthys osculus*), Paiute sculpin (*Cottus beldingi*), and Wood River sculpin (*Cottus leiopomus*). Invertebrate densities estimated by Minshall and Manuel-Faler (unpublished data, 1982) were as high as 25,000 organisms/m^2 of stream bottom. Common predators of fish in Silver Creek include: Common Merganser (*Mergus merganser*), Forster's Tern (*Sterna forsteri*), Belted Kingfisher (*Ceryle alcyon*), Great Blue Heron (*Ardea herodias*), and mink (*Mustela vison*) (R. Wilkison, personal observation).

Riehle et al. (1989) electrofished seven sites in Silver Creek to obtain population data. Sampling in 1992-1993 was performed at five of these seven sites. I did not sample the Point of Rocks and Priest sites due to my primary interest in the fish community in the upper portion of Silver Creek. The five sites (Upper Stalker, Lower Stalker, Cabin, Kilpatrick, and Martin Bridge) sampled in 1986 and 1992-1993 were within sections that were electrofished during a 1976-1977 fishery survey (Thurow 1978). Four of the five electrofishing sites were located within The Nature Conservancy's (TNC) Silver Creek Preserve, two on Stalker Creek and two on Silver Creek. These sites were managed under a catch-and-release regulation by the Idaho Department of Fish and Game in 1986 and 1992-1993. The Martin Bridge site was located approximately 4 km downstream of the Silver Creek Preserve within Idaho Fish and Game Department property. This site was managed under statewide general regulations in 1986. In 1992-1993, the Martin Bridge area was managed with a two fish limit, none between 300 and 400 mm. Riehle et al. (1989) provided detailed descriptions of the site boundaries. Physical and biological characteristics of the electrofishing sites are summarized in Table 1. Sites ranged in length from 805 to 998 m and stream gradient was between 0.8 and 1.0 m/km.

The Stalker Creek electrofishing sites were dominated by silt substrate with some exposed gravel and marl. The dominant macrophytes were *Chara spp.* and *Potamogeton spp.* and the riparian zone contained dense stands of willow (*Salix spp.*) and birch (*Betula spp.*) mixed with sedges

(*Carex spp.*) and grasses (*Poa spp.*). Mean stream width at each site was approximately 9 m.

Gravel and marl substrate dominated the Cabin site at the upstream end and silt was most abundant at the downstream end. Aquatic macrophytes present at this site included *Chara spp.*, *Veronica spp.*, *Ranunculus spp.*, and *Potamogeton* spp. The riparian zone was considerably more open than the Stalker Creek sites with fewer willows and birches and more grasses and sedges.

The Kilpatrick site was 20 to 30 m wide at its upper end while the downstream end of the site included part of Kilpatrick Pond and was wider and shallower than the upstream portion. Substrate composition was similar to the Cabin site with marl and exposed gravel at the upper end and primarily silt at the downstream end. Riparian vegetation at this site was dominated by grasses, sedges, and extensive growths of bulrush (*Scirpus spp.*).

Wetted stream width at the Martin Bridge site ranged from 10 to 25 m. Deep pools were common at this site with some as deep as 2 to 3 m. Substrate was primarily gravel with intermixed silt deposits. Riparian vegetation was similar to the Stalker Creek sites, comprised mainly of dense growths of willows and birches. *Potamogeton spp.* was the dominant aquatic macrophyte at the site.

METHODS

Five sites in upper Silver Creek that had been sampled in 1986 were electrofished in fall 1992 and summer 1993 to estimate game fish species composition and abundance (Figure 1). A 4.3 m-long raft equipped with a 3500 watt generator and a spherical bow-mounted anode was used to sample the sites. Typical output from the variable voltage pulsator was 240-260 volts, 2.5 to 3.0 amps, 40 Hz, and 80% pulse width. Two bow-mounted flood lights were used for night electrofishing. Fish were captured and held in an aerated live-well in a dilute anesthetic (MS-222) solution. Trout ≥ 150 mm total length (unless specified, total length was used) were given a temporary mark and a sub-sample of all trout captured were weighed and measured for length. Mountain whitefish and nongame fish were enumerated during each electrofishing run but were not marked.

Due to high angler densities during the day, summer 1993 sampling was performed at night at all sites except Lower Stalker. Fall 1992 sampling was conducted exclusively during the day. In matched day and night electrofishing runs at the same Silver Creek sites, Riehle et al. (1989) did not find any bias toward larger rainbow or brown trout at night. However, their sample sizes of brown trout were small for all sites.

Electrofishing was conducted during the periods 3 October through 15 November 1992 and 3 June through 21 July 1993. Population data from 1992-1993 were collected during the same periods sampling was performed in 1986-1987. A 7-10 day period was allotted between electrofishing runs to minimize electrofishing bias in population estimates (Yundt 1983). Three to five runs were typically made through each site. Using multiple mark-recapture data collected from each site, abundance estimates of game fish larger than 150 mm were calculated using the Chapman modification of the Schnabel estimate (Ricker 1975). Abundance estimates were obtained for brown trout, rainbow trout, and brook trout. A 150 mm length limit for population estimates was established to prevent underestimating smaller fish that were not fully recruited to the electrofishing gear.

Abundance estimates (number of fish per site) and surface area for the five sites were used to calculate densities (number of fish per hectare of stream surface) for fall 1992 and summer 1993. Biomass estimates (kilograms per hectare) were made by utilizing density estimates and the mean weight for each species for the sample period. Length-frequency data were analyzed to evaluate the size structure of the brown and rainbow trout populations. Where possible, 1992-1993 length-frequency histograms were compared to data from 1986 to aid in interpreting changes in density and biomass.

I attempted to evaluate the Silver Creek population data to determine the extent to which electrofishing was size-selective. Schill (1992) outlined a method for assessing and correcting size-selective electrofishing bias using data collected from Idaho rivers and streams. It was not possible, however, to utilize this method on 1992-1993 data due to an insufficient number of recaptured fish in individual length classes.

RESULTS

Species Composition

Game vs Nongame

Game fish as a percent of the electrofishing sample appeared to have increased at the Lower Stalker and Martin Bridge sites since 1976-1977 (Table 2). Game species increased slightly from 73% to 88% of the sample at the Lower Stalker site and nearly doubled at the Martin Bridge site from 25% to 47% of the sample. Of the nongame species present in Lower Stalker Creek, bridgelip suckers and speckled and longnose dace experienced the greatest decline in relative abundance. At the Martin Bridge site, bridgelip suckers decreased in relative abundance from 49% of the sample in 1976-1977 to 25% in 1992-1993. No change in game and nongame species composition was observed at the Cabin and Kilpatrick sites.

Rainbow and Brown Trout

Rainbow trout accounted for a lower percentage of the electrofishing sample at all sites in 1992-1993 compared to 1986 (Table 3). However, the percent of the sample comprised of rainbow trout was still greater than the percentage for brown trout at all sites except Martin Bridge. Rainbow trout comprised between 30% and 78% of game fish (by number) collected in 1992-1993. Their percentage of the sample at the Lower Stalker site decreased from 87% in summer 1986 to 52% in summer 1993. Similarly, rainbow trout declined from 69% to 30% of the sample at the Martin Bridge site.

Brown trout accounted for between 12% and 69% of the game fish sampled during 1992-1993 (Table 3). Their percentage of the sample increased at all sites from values reported by Reihle et al. (1989). At the Lower Stalker site brown trout increased from 5% to 36% of the sample. Similar increases occurred at the other sites.

Brook Trout and Mountain Whitefish

Brook trout and mountain whitefish individually usually comprised less than 10% of the sample at all sites in 1986-

1993 was three times higher than estimates from 1986. Similar increases were recorded at the other four sites. Because of the low abundance of brown trout at some sites in 1986, Riehle et al. (1989) were not able to obtain estimates for all sites. Therefore, it was not possible to evaluate increases in abundance, density, and biomass since 1986 at all sites.

Mean weights for brown trout were greater than rainbow trout at all sites in summer and fall (Table 4). As a result, brown trout biomass in the Lower Stalker and Martin Bridge sites exceeded rainbow trout biomass even though rainbow trout density was higher than brown trout density at these two sites. Brook trout sample sizes were usually too small to obtain representative estimates of mean weight.

Rainbow Trout Density and Biomass

Rainbow trout densities were higher than brown trout densities in 1986 and 1993 at all sites except Martin Bridge and during the summer at the Lower Stalker site (Table 5). The density of rainbow trout at the Lower Stalker site decreased by 73% from 1228 fish/ha in summer 1986 to 327 fish/ha in summer 1993 (Figure 7). No significant change in summer rainbow trout density was recorded at the Cabin, Kilpatrick, and Martin Bridge sites from 1986 to 1993. Fall rainbow trout density at the Upper Stalker site did not change, but fall 1992 rainbow trout density at the Cabin and

1987 and 1992-1993 (Table 3). However, at the Cabin site, mountain whitefish comprised 40% of the electrofishing sample in 1976-1977 and 25% in summer 1986. Mountain whitefish accounted for only 3% of the sample in fall 1992 and summer 1993 samples.

Thurow (1978) estimated the abundance of mountain whitefish at 18 fish per 1000 m of stream. Using the same measure of abundance, the 1986 and 1992-1993 data yielded estimates of approximately 4 fish per 1000 m of stream in summer and fall.

Rainbow and Brown Trout Abundance and Mean Weight

Three of the five electrofishing sites that were sampled in 1992-1993 experienced a significant change in the abundance of rainbow trout (Figures 3-4). The estimated number of rainbow trout at the Lower Stalker site decreased from 1085 in summer 1986 to 289 in summer 1993. Conversely, at the Cabin and Martin Bridge sites fall rainbow trout abundance increased. At the Cabin site the number of rainbow trout increased from 590 to 1707 fish. In 1986 there were too few rainbow trout at the Martin Bridge site to obtain an abundance estimate, while 429 rainbow trout were estimated at the site in 1992.

Significant increases in brown trout abundance occurred at all five sites (Figures 5-6). The number of brown trout estimated at the Martin Bridge site in fall 1992 and summer

Martin Bridge sites was significantly greater than densities in 1986 (Figure 8). The density of rainbow trout tripled from approximately 200 fish/ha in 1986 to nearly 600 fish/ha in 1992 at the Cabin site.

Rainbow trout summer biomass was unchanged at the Cabin, Kilpatrick, and Martin Bridge sites but decreased at the Lower Stalker site by 71% from 216 kg/ha to 63 kg/ha (Figure 9). Fall rainbow trout biomass at the Cabin and Martin Bridge sites was higher in 1992 than in 1986 but did not change at the Upper Stalker site (Figure 10). At the Cabin site, rainbow trout fall biomass increased from 97 kg/ha in 1986 to 242 kg/ha in 1992, a 150% increase and the highest rainbow trout biomass recorded for any site during the sampling period (Table 6).

Brown Trout Density and Biomass

Summer 1993 brown trout densities were greater than summer 1986 estimates at all sites (Figure 11). At the Lower Stalker site, brown trout density increased 366% from 18 fish/ha in 1986 to 84 fish/ha in 1993.

Brown trout density ranged from 116 to 525 fish/ha in fall 1992 (Table 5). In fall 1986, brown trout were present in such low numbers that at two of the three sites density could not be estimated. At the only site where an estimate was made in 1986, Martin Bridge, brown trout density more than doubled from 158 fish/ha to 525 fish/ha (Figure 12).

Summer 1993 brown trout biomass was greater than estimates from 1986 at all four sites (Figure 13). The largest increase (494%) occurred at the Lower Stalker site where summer brown trout biomass was estimated at 17 kg/ha in 1986 and 101 kg/ha in 1993. Summer brown trout biomass increased by 1266% at the Kilpatrick site and at the Martin Bridge site it increased from 31 kg/ha to 82 kg/ha, a 164% increase.

Fall brown trout biomass at the Upper Stalker and Cabin sites increased from levels that were too low to estimate in 1986 to 62 kg/ha and 105 kg/ha, respectively in 1992 (Figure 14). Fall brown trout biomass at the Martin Bridge site nearly doubled from 184 kg/ha to 331 kg/ha. The largest biomass of brown trout (602 kg/ha) measured in Silver Creek during this study was at the Lower Stalker site in fall 1992 (Table 6).

Brown and Rainbow Trout Biomass

General Observations

In summer and fall 1986, brown trout biomass exceeded rainbow trout biomass only at the Martin Bridge site, but in 1992-1993 brown trout biomass exceeded rainbow trout biomass at the Lower Stalker and Martin Bridge sites (Table 6). Brown trout biomass was less than that of rainbow trout at the Upper Stalker, Cabin, and Kilpatrick sites. The Lower

Stalker and Martin Bridge sites had the highest brown trout biomass of all sites. Fall biomass of each species was generally greater than summer biomass at all sites.

Brown and Rainbow Trout Combined Biomass

The summer combined biomass of rainbow and brown trout at the Lower Stalker site decreased from 233 kg/ha in 1986 to 164 kg/ha in 1993 (Figure 15). Summer combined biomass increased at the Kilpatrick and Martin Bridge sites but did not change at the Cabin site.

The fall 1992 combined biomass estimates at the Cabin and Martin Bridge sites were higher than estimates from 1986 (Figure 16). Combined biomass at the Cabin site increased by 257% from 97 kg/ha to 347 kg/ha. At the Martin Bridge site the combined biomass rose from 184 kg/ha to 417 kg/ha, a 126% increase. No change in fall combined biomass was observed at the Upper Stalker site.

Rainbow Trout Size Composition

Summer

The percentage of rainbow trout ≥ 300 mm increased at all sites from 1986 values (Table 7). Rainbow trout ≥ 300 mm comprised 21% of the sample at the Lower Stalker site in 1986 while accounting for 39% of the sample in 1993. At the Martin Bridge site, rainbow trout ≥ 300 mm increased from 27% to 64% of the sample. In 1986, 64% of the rainbow trout sampled at the Martin Bridge site were ≤ 200 mm. In 1993, 16% of the rainbow trout sampled were in this size range. Smaller increases in the percentage of rainbow trout ≥ 300 mm were observed at the Cabin and Kilpatrick sites.

Fall

An unusually strong age-2+ year-class of rainbow trout was present at the Upper Stalker site during fall 1992 sampling. In 1986, 57% of the rainbow trout collected at this site were 200-299 mm compared to 86% in this range in 1992 (Table 7). The strong year-class was also apparent at the Cabin site where rainbow trout 200-299 mm comprised a much larger fraction of the sample in 1992 than in 1986. In 1986, rainbow trout ≤ 300 mm accounted for 38% of the sample at the Cabin site. In 1992, 84% of the sample was comprised of rainbow trout ≤ 300 mm. No significant change in the fall length distribution of rainbow trout was observed at the Martin Bridge site. Rainbow trout ≥ 300 mm comprised 35% and 39% of the sample in this site in 1986 and 1992, respectively.

Brown Trout Size Composition

Summer

An increase in the percentage of brown trout > 500 mm was observed at the Lower Stalker and Kilpatrick sites (Table 8). In 1986, 14 brown trout were captured at the Lower Stalker site. Of those 14, 21% were > 500 mm. In 1993, out of 65 brown trout that were captured at this site 43% were > 500 mm. At the Kilpatrick site, brown trout > 500 mm increased from 28% to 39% of the sample. At both of these sites, brown trout ≤ 200 mm increased from 0 in 1986 to 6% in 1993. Out of the 37 brown trout that were captured at the Martin Bridge site in summer 1986, 82% were ≥ 400 mm. In 1993, 52% of the brown trout from this site were ≥ 400 mm.

Fall

The proportion of brown trout > 500 mm increased from 0 to 14% and from 15% to 21% at the Upper Stalker and Cabin sites, respectively (Table 8). Conversely, at the Martin Bridge site brown trout > 500 mm decreased from 33% of the sample in 1986 to 11% in 1992. However, a 39% increase in brown trout ≤ 300 mm also occurred.

DISCUSSION

Riehle et al. (1989) reported that brown trout had become well established in upper Silver Creek by 1986-1987. Considering that a small number of brown trout had been introduced into the system only eight years prior to their study, Riehle et al. (1989) concluded that the brown trout population had expanded rapidly and predicted that the population would continue to grow. Population data from 1992-1993 indicated that the brown trout population in upper Silver Creek had expanded and that other changes in the fish community had occurred since the 1976-1977 fishery evaluation.

In 1986, Riehle et al. (1989) were not able to make estimates of brown trout density and biomass at the Cabin and Upper Stalker sites because of the low number of fish that were present. The brown trout population present in 1986 might have been best described as a "colonizing" population with a relatively small number of large, reproducing individuals with a few juveniles and virtually no intermediate size-classes. In 1992-1993, a healthy, abundant brown trout population was present. Population data from 1992-1993 showed that large brown trout were present in all of upper Silver Creek and that many areas of the creek contained an abundance of juvenile and intermediate-sized brown trout.

Species Composition

Game species composition in Silver Creek shifted from 1986 to 1992. The change could have been linked to a natural fluctuation in game fish abundance, but it was more likely a result of an increase in brown trout abundance.

Riehle et al. (1989) documented a decline in mountain whitefish abundance in Silver Creek over the ten-year period, 1976 to 1986. Mountain whitefish had not rebounded from this decline in 1992-1993. Multiple mark-recapture abundance estimates were not made for mountain whitefish in 1976-1977, 1986, or 1992-1993; however, Thurow (1978) reported a catch per unit effort estimate for mountain whitefish. Based on the 1976-1977 estimate, and 1986 and 1992-1993 relative abundance data, I estimated that a 79% decrease in the abundance of mountain whitefish had occurred in upper Silver Creek from 1976 to 1986. Therefore, the decreased relative abundance of mountain whitefish in electrofishing samples from 1986 and 1992-1993 was primarily a result of lower mountain whitefish abundance and, to a much lesser extent, increases in rainbow and brown trout abundance.

Lower nongame fish relative abundance since 1976-1977 could not be solely attributed to an increase in game fish abundance because of the lack of absolute abundance estimates for nongame species in 1976-1977 and 1992-1993. Thus, it was not entirely clear whether the lower relative abundance was due to an actual decrease in the abundance of nongame fish or an increase in the abundance of game species or both. Thurow (1978) reported that the bridgelip sucker was the most abundant nongame species in 1976-1977 and that it was more abundant than trout in two of three sites in upper Silver Creek. During sampling in 1992-1993, no single nongame species was more abundant than trout at any of the sites and other nongame species appeared to be as abundant as bridgelip suckers.

Rainbow and Brown Trout Density and Biomass

Except for the Lower Stalker site, 1993 summer rainbow trout density and biomass estimates were similar to 1986 estimates. This was not surprising, though, since spring-fed streams with their relatively uniform annual flow, resistance to drought and flooding, and moderated water temperatures have been shown to support highly stable trout populations. Hunt (1974) found that annual production of a brook trout population in Wisconsin varied by only 20% over an 11-year period. His Wisconsin study stream, Lawrence Creek, was physically and biologically very similar to Silver Creek. Nehring (1987) also reported that brown trout density and biomass were highly stable over a three-year period in the Rio Grande River, Colorado. Density varied by less than 3% and biomass by less than 6.5% of each year's estimate. The Rio Grande River is not an entirely spring-fed system, but the section Nehring (1987) sampled was regulated by an upstream reservoir and, similar to a spring creek, was probably insulated from flow and temperature extremes.

Higher rainbow trout density and biomass estimates at the Cabin and Martin Bridge sites in fall 1992 compared to fall 1986 were difficult to interpret. The large increase at the Cabin site might have been related to 1) the presence of a very strong age-II year-class, 2) movement of fall-spawning rainbow trout, and/or 3) movement of rainbow trout in response to an abundant, spawning brown trout population. At the Martin Bridge site, the increase was probably due to the regulation change that was implemented in that section following the 1986 study.

From creel census data collected in 1986-1987, Riehle et al. (1989) predicted that by decreasing the allowable harvest to two fish and excluding fish > 300 mm from harvest, total harvest would be reduced by 75% in the Martin Bridge section. In 1990, the Idaho Fish & Game Department implemented a new regulation that restricted harvest to two fish with none between 300 and 400 mm (Thurow and Schill 1994). Reduced harvest apparently resulted in an increase in the percentage of rainbow trout > 300 mm, increasing summer rainbow trout biomass at the Martin Bridge site. The regulation change would have also aided the expanding brown trout population at the site.

Density and biomass estimates of brown and rainbow trout in Silver Creek were among the highest measured for mixed-species salmonid fisheries in the United States. Silver Creek rainbow trout density ranged from 46 to 1573 fish/ha in 1992-1993. The Railroad Ranch section of the Henry's Fork of the Snake River supported 390 rainbow trout/ha (Angradi and Contor 1988). Nehring (1987) reported a range of 138 to 1509 fish/ha for rainbow trout in Colorado's Fryingpan River. Vincent (1987) found that the Madison River in Montana held from 281 to 727 fish/mile, compared to 356 to 5141 fish/mile for Silver Creek in 1992-1993. The Colorado River was found to contain between 16 and 889 rainbow trout/ha (Nehring 1987). Brown trout density varied from 40 to 930 fish/ha in Silver Creek during 1992-1993. This range was similar to the very productive brown trout fishery in the Fryingpan River (161-999 fish/ha) and much higher than the density range of 22 to 294 brown trout/ha in the Colorado River (Nehring 1987). Reporting a linear rather than an aerial estimate of density, Vincent (1987) found the density of brown trout in the Madison River to be between 764 and 851 fish/mile. The linear density estimate of brown trout in Silver Creek varied from 106 to 1685 fish/mile.

Brown trout biomass in Silver Creek ranged from 37 to 602 kg/ha. This biomass ranges was similar to or exceeded that reported for productive waters in Colorado (Nehring

1987), Montana (Vincent 1987), Utah (Modde et al. 1991), and California (Platts and McHenry 1988). For instance, Nehring (1987) found that brown trout biomass in the Fryingpan River varied from 40 to 254 kg/ha between 1972 and 1986. The fall 1992 biomass estimate of 602 kg/ha at the Lower Stalker site was one of the highest values reported for brown trout. One of the few rivers with a higher brown trout biomass was the Owens River, California, where biomass ranged from 150 to 829 kg/ha (Platts and McHenry 1988). Biomass values reported for brown trout in Michigan (Gowing and Alexander 1980), Wisconsin (Avery and Hunt 1981), and Minnesota (Waters 1983) were lower than Silver Creek estimates. Waters (1983) reported that brown trout biomass in a Minnesota stream ranged from 0 to 109 kg/ha over a fifteen-year period.

Silver Creek rainbow trout biomass was between 41 and 242 kg/ha in 1992-1993. Similar to brown trout biomass, rainbow trout biomass was high relative to most western streams but, unlike brown trout biomass, it was somewhat average when compared to the most productive waters. Nehring (1987) estimated that the biomass of rainbow trout ranged from 15 to 707 kg/ha in the Fryingpan River and from 234 to 566 kg/ha in the South Platte River. Rainbow trout biomass in the Green River, Utah, varied from 131 to 725 kg/ha between 1985 and 1989 (Modde et al. 1991).

Several factors explain higher rainbow and brown trout fall density and biomass estimates compared to summer, including: upstream movement of spawning brown trout and fall-spawning rainbow trout, recruitment of age-0 brown trout and age-1+ rainbow trout to the sampling gear, and downstream movement of age-0 and age-1+ rainbow trout from tributary rearing areas.

Rainbow and Brown Trout Combined Biomass

Riehle et al. (1989) reported that the mean combined biomass of rainbow and brown trout at their Silver Creek catch-and-release section was 193 kg/ha. Mean combined biomass for this same section in 1992-1993 was 277 kg/ha, a 43% increase from 1986 due almost entirely to added brown trout biomass. The range of the combined biomass of rainbow and brown trout (113 to 810 kg/ha) in Silver Creek in 1992-1993 was impressive when compared to other streams also containing the two species. Nehring (1987) found that the combined biomass of rainbow and brown trout in the Colorado River was between 241 and 362 kg/ha. The Fryingpan River supported a combined biomass of 85 to 961 kg/ha and the South Platte River in Colorado had a combined biomass of 320 to 736 kg/ha from 1979 to 1985 (Nehring 1987). Combined biomass in the Green River varied between 136 and 689 kg/ha (Modde et al. 1991). Gowing and Alexander (1980) reported a combined biomass range of 75 to 172 kg/ha for several streams in Michigan. In an evaluation of 93 New Zealand streams and rivers, Teirney and Jowett (1990) found that most reaches had a combined biomass range between 0 and 10 kg/ha but ranged up to 83.2 kg/ha.

Rainbow and Brown Trout Population Changes

The most dramatic changes in rainbow and brown trout density and biomass since 1986 occurred at the Lower Stalker site. Lower Stalker was the only site that experienced a large decrease in the density and biomass of rainbow trout for summer or fall. Given that this site also experienced the largest increase in brown trout biomass and second largest increase in brown trout density of all sites sampled in summer 1993, interaction (competition and/or predation) between brown and rainbow trout appeared to be responsible for the changes. Also, during the same period in which dramatic rainbow trout population changes occurred at the Lower Stalker site, stream discharge in Silver Creek and its tributaries reached historical lows (USGS 1986-1994).

Record low flows in Stalker Creek could have decreased available habitat for juvenile trout, especially along stream margins, compounding the impact brown trout would have had on rainbow trout. Waters (1983) reported that brown trout had replaced brook trout in Minnesota within fifteen years in a stream that had experienced major habitat perturbations during the study period. Waters (1983) attributed the shift in species composition to a combination of differences in species behavior (life history attributes) and habitat alteration. Rainbow trout may have been excluded to a great extent from the Lower Stalker site by either habitat limitations related to drought or interactions with brown trout, or a combination of the two. Considering the magnitude of the increase in brown trout abundance at this site, however, it was not unreasonable to conclude that interaction between the species was primarily responsible for the change in rainbow trout abundance. For instance, the presence of many large, brown trout at the Lower Stalker site appeared to be related to reduced numbers of rainbow trout. In summer 1993, 72% of the brown trout captured at the site were ≥ 400 mm while in fall 1992, 19% were ≥ 400 mm. The Cabin (downstream) and Upper Stalker (upstream) sites had fewer large brown trout.

Rainbow and Brown Trout Size Structure

I interpreted changes in the size structure of brown and rainbow trout in Silver Creek to be based on several factors. Shifts in summer rainbow trout size structure at the Martin Bridge and Lower Stalker sites to a higher percentage of rainbow trout ≥ 300 mm were attributed to different variables. At the Martin Bridge site, where summer rainbow trout density was unchanged but biomass increased, the shift was due to an increase in the number of large rainbow trout and a slight decrease in the number of rainbow trout ≤ 300 mm. Changes in size structure here were probably related to the regulation change which reduced harvest in the Martin Bridge area. Size composition at the Lower Stalker site was influenced primarily by the presence of many large brown trout.

Large brown trout (> 500 mm) have been accumulating in Silver Creek at least since 1986. Two brown trout that had been jaw-tagged in 1986 (then between 490-540 mm) were recaptured during the 1992-1993 field season. One fish was estimated by Riehle et al. (1989) to be age-4 and one was age-5. In a sample of 20 brown trout > 450 mm from which scales were collected in 1993 in upper Silver Creek, 18 (90%) fish were age-5 or older, 9 (45%) were age-6 or older, and 3 (15%) were age-7 or older. I estimated the oldest fish to be age-9. Reihle et al. (1989) found that brown trout in Silver Creek reached at least age-7 while the oldest rainbow trout was age-5. Riehle et al. (1989) reported capturing numerous brown trout > 500 mm at upper Silver Creek sites, and their data also indicated a lack of fish in intermediate size-classes. In 1992-1993, these larger brown trout were abundant at all sites and intermediate size-classes were also strongly established. The decline in relative abundance of brown trout > 500 mm at the Martin Bridge site was primarily due to an increase in the number of age-0 brown trout at the site.

Brown trout are known to live longer than most North American salmonids (Svalastog 1991; Sigler 1951; Carlander 1969). Because of this characteristic, many populations have the potential to accumulate a high proportion of large individuals. This accumulation of large brown trout has been observed in Montana in the Beaverhead and Bighole Rivers and in several popular spring creeks (Dick Oswold, Montana Fish Wildlife and Parks, personal communication). The accumulation of large brown trout (> 500 mm) in upper Silver Creek is even more impressive when one considers the simultaneous increase in the smaller size-classes of brown trout. The increased abundance of smaller size-classes was an indication that larger brown trout were spawning successfully and that recruitment was occurring.

Brown Trout Abundance and Habitat

Although no quantitative assessment of habitat at electrofishing sites was undertaken in 1992-1993, differences in brown trout biomass between sites appeared to be related to habitat differences between the sites. Electrofishing sites possessed obvious differences in habitat, particularly in the amount of overhead cover that was present. The Martin Bridge and Lower Stalker sites contained dense stands of willows and birches and both had undercut banks and deep pools. Overhead cover and shade were much more abundant in these sites than the Cabin and

Kilpatrick sites which had a more open riparian zone with fewer undercut banks and sparse overhead vegetation. The Upper Stalker site was similar to the Lower Stalker and Martin Bridge sites in that it had a dense, brushy riparian zone but it lacked undercut banks and deep pools. Riehle et al. (1989) mentioned that the Lower Stalker site with undercut banks, brushy overhead cover, and deep pools was well suited for brown trout and that the population there could expand and become similar to the Martin Bridge site downstream. Indeed, the brown trout population at the Lower Stalker site did expand and it did so to the extent that it surpassed brown trout biomass at the Martin Bridge site.

Competition between brown trout and other salmonids has been evaluated by evaluating habitat utilization of the species in sympatry and allopatry in laboratory and field environments (Dewald and Wilzbach 1992; Fausch and White 1981, 1986; Kocik 1992; Gatz et al. 1987; Morse and MacCrimmon 1986). In most of these studies and in field radio-telemetry studies, the tendency of brown trout to use overhead cover to a great extent has been demonstrated (Meyers et al. 1992; Clapp et al. 1990). Since the Martin Bridge and Lower Stalker sites contained more overhead cover and deep pools than the other sites, it was not surprising to find that these two sites contained the highest density and biomass of brown trout in Silver Creek. It was also not surprising to find that these sites experienced the largest increases in brown trout density and biomass. While electrofishing in 1992-1993, the largest brown trout were consistently captured at the Lower Stalker and Martin Bridge sites. Large brown trout captured at these sites during daylight hours were nearly always under or near banks, overhead cover, or shade and usually occupied deep pools.

Fish Community Effects

Several pieces of evidence in the 1992-1993 population evaluation suggested that the brown trout population has impacted the fish community in Silver Creek. For example, decreases in the relative abundance of bridgelip suckers and speckled and longnose dace at the Lower Stalker site and in bridgelip suckers at the Martin Bridge site were probably related to predation by the abundant population of large brown trout at these sites. Garman and Nielsen (1982) found that brown trout significantly reduced the abundance of several nongame fish species in Bottom Creek, Virginia. Similarly, mountain whitefish abundance in Silver Creek decreased to very low levels following the introduction of brown trout. Sowards (1958) reported that an inverse relationship existed between brown trout abundance and mountain whitefish abundance in the Tongue River, Wyoming. The large decrease in rainbow trout abundance at the Lower Stalker site with the concurrent increase in brown trout abundance suggested that some interaction between the species occurred at this site.

Many factors are likely responsible for the brown trout's successful expansion in upper Silver Creek. Behavioral studies have documented the brown trout's ability to successfully compete with other salmonids (Glova and Field-Dodgson 1995; Wang and White 1994; Dewald and Wilzbach 1992; Gatz et al. 1987; Hayes 1989). Habitat use and behavioral characteristics of brown trout are thought to reduce their vulnerability to predation and angling (McMichael and Kaya 1991; Robinson and Tash 1979; Cooper 1951). Rainbow trout, on the other hand, are apparently more susceptible to aerial predation than many other salmonids (Matkowski 1989) and they are more easily caught by anglers than brown trout (Bachman 1991). Given these factors and the piscivorous feeding habits of brown trout (Alexander 1977; Hannuksela 1969; Klammer 1984) and their potential to live long and grow to a large size, community-level effects in Silver Creek should not have been entirely unexpected. Nehring (1994) made observations from 1986 to 1992 on the Fryingpan River where, during a precipitous decline in the rainbow trout population, brown trout were found foraging heavily on stocked rainbow trout fingerlings. Intense predation by brown trout on stocked rainbow trout was also observed on the Rio Grande River (Nehring 1994). Overall, the effects of species interactions, drought, year-class strength, and regulation changes in some combination were responsible for changes in the rainbow trout population in upper Silver Creek.

An expanding brown trout population in Silver Creek negatively impacted a productive rainbow trout fishery at at least one site over the period 1986-1993. Overall fish community composition changed in Silver Creek from 1976 to 1992 as brown trout abundance increased. Total trout density and biomass in upper Silver Creek increased with the addition of a burgeoning brown trout population. However, because the brown population was relatively immature, impacts on the Silver Creek fish community were likely not fully realized at the time of this study.

Potential Sampling Biases

Because sampling in 1992-1993 was conducted at night at some sites and during the day at others, comparisons with 1986 data and between seasons relied on the assumption that no bias toward larger fish existed in night electrofishing samples. Riehle et al. (1989) found that in matched day and night electrofishing runs at upper Silver Creek sites, there was no significant bias toward larger rainbow and brown trout in night samples.

Night electrofishing samples probably presented a more accurate representation of the brown trout population structure in Silver Creek. Brown trout have been shown to be more nocturnal than other salmonids (Hudson 1993; Clapp et al. 1990; Regal 1992; Bachman et al. 1979; Robinson and Tash 1979; Chaston 1969). Because their nocturnal activity, larger brown trout may have been more easily captured at night compared to daytime because of their tendency to use mid-channel areas during the night (Shuler et al. 1994; Clapp et al. 1990). In daylight, many large brown trout utilize cover next to or under stream banks (Clapp et al. 1990; Jenkins 1969a; DeVore and White 1978) where they may not be captured as easily by an electrical field. Therefore, larger brown trout could have been underrepresented if electrofishing was performed only during daylight hours. This would have positively biased brown trout abundance estimates.

After examining electrofishing data from Idaho streams and rivers, Schill (1992) showed that positive selection for larger size-groups of salmonids was a common occurrence. Data from boat-shocking efforts revealed that sampling efficiency increased an average of 4.5-fold from 150 to 400 mm fish while efficiencies in wade-shocking efforts increased 3-fold from 100 to 300 mm fish. Schill (1992) also reported that correcting for size-selection produced major changes in population, size structure, and biomass estimates. Uncorrected estimates consistently underestimated population size by grossly underrepresenting smaller fish. However, the effects of correction on biomass estimates were not consistent and selection for brown trout was apparently different than rainbow and cutthroat trout.

Because it was not possible to construct recapture efficiency curves for Silver Creek rainbow and brown trout, and given that size-selection is common, 1992-1993 density and biomass estimates were undoubtedly negatively biased. However, I assumed that size-selection was similar between studies and that analysis of population trends in Silver Creek was still possible because no correction for size-selection was made in 1976-1977 or 1986.

Whirling Disease

With the discovery of whirling disease in wild rainbow trout in Loving Creek in 1995, additional concern has developed for Silver Creek rainbow trout. Whirling disease was first detected at the Hayspur State Fish Hatchery in 1988 (Bob Esselman, Idaho Fish & Game Department, personal communication). Since the hatchery discharged water to Loving Creek, it would be unreasonable to assume that rainbow trout in Silver Creek were not infected with the water-born pathogen in 1988. The rainbow trout population, therefore, should be infected with the diseases but appears to be asymptomatic. During my electrofishing surveys and snorkeling observations in Silver Creek from 1992 to 1994, there were no obvious signs of infected fish of any size or species. If rainbow trout begin to show symptoms of the disease and young-of-the-year rainbow trout densities begin to decline, then an alternative management strategy will have to be adopted to maintain a healthy rainbow trout population in Silver Creek. Since brown trout have been shown to be more resistant to the disease than most other salmonids (Markiw 1992), brown trout impacts on rainbow trout could be magnified, especially if the infection decreases juvenile rainbow trout survival.

CHAPTER II:

THE DIET OF BROWN TROUT AND AN ASSESSMENT OF PREDATION ON SYMPATRIC FISHES IN UPPER SILVER CREEK, IDAHO

INTRODUCTION

Anglers and fisheries biologists have long considered the brown trout (*Salmo trutta*) to be an inherently piscivorous salmonid with the ability to negatively impact sympatric salmonid species. While this line of thought has been responsible for liberal bag limits and even bounties for brown trout in at least one state (Dick Oswold, Montana Department of Fish, Wildlife and Parks, personal communication), very few studies have been conducted to assess whether brown trout are able to reduce the abundance of sympatric salmonids through predation. Fewer yet are evaluations of the possible negative impacts of brown trout on sympatric nongame species in North America.

Most diet investigations involving brown trout have concentrated sampling efforts during spring and summer. Data are lacking on the brown trout diet during fall and winter months. Additionally, most diet investigations have not adequately evaluated the diet of larger (i.e. > 400 mm) brown trout. It has been demonstrated that brown trout increase their utilization of fish as prey as they grow larger and that this shift toward a more piscivorous diet occurs when brown trout reach 250-300 mm (Alexander 1977; Hannuksela 1969; Garmen and Nielsen 1982; Klammer 1984; Allen 1951). Many studies indicating that brown trout consumed only invertebrate organisms may have been a result of the absence of these larger fish in the sample.

In a study that evaluated the diet of large, piscivorous brown trout in Michigan's North Branch Au Sable River, predation by brown trout > 300 mm was estimated to account for 6.6% of the estimated total annual mortality of brook trout and 0.2% of the total annual mortality of brown trout (Alexander 1977). In another Michigan study, brown trout collected from the Anna River preyed on salmonids even though sculpins were nine times more abundant than salmonids (Hannuksela 1969). Brook trout were replaced by brown trout within a fifteen-year period in a small Minnesota stream, but no evaluation of the brown trout diet was undertaken to assess whether predation was partly responsible for the shift in species composition (Waters 1983). Garman and Nielsen (1982) reported that brown trout stocked in Bottom Creek, Virginia significantly reduced the abundance of native nongame fish species. Torrent suckers (*Moxostoma rhothoecum*) and central stonerollers (*Campostoma anomalum*) were heavily preyed upon, and predation was greatest among large (> 280 mm) brown trout.

In the western United States, where brown trout have been introduced into many streams containing native and nonnative salmonids, the need for an understanding of the diet of the species in various types of streams and fish communities is imperative for successful management of these mixed-species salmonid fisheries. The introduction of brown trout to Silver Creek, Idaho provided a unique opportunity to examine predation by an expanding brown trout population on sympatric game and nongame species. An evaluation of the diet of the recently established brown trout population in Silver Creek was begun in summer 1993. Specific objectives of the research were to:

a. seasonally characterize the diet of large ($\geq$ 300 mm) brown trout and to a lesser extent smaller brown trout,

b. estimate the annual brown trout consumption of rainbow and brown trout from seasonal consumption estimates,

c. estimate the relative abundance of potential prey fish species and evaluate the spatial and temporal selection of prey fish species by brown trout.

Description of Study Sites

Three sites were chosen for collecting brown trout stomach samples in 1993-1994 based on differences in the prey fish species available and brown trout density at the sites. Two sites (Lower Stalker and Kennedy) were within The Nature Conservancy's Silver Creek Preserve and a third site (Martin Bridge) was approximately 5 km downstream within Idaho Department of Fish and Game property (Figure 17). Sites ranged in length from 998 to 1250 m and contained different aquatic and riparian habitats (Table 9).

Substrate in the Lower Stalker site was predominantly silt with small patches of gravel and marl. *Chara* and *Potamogeton* species were the most abundant macrophytes and dense stands of willow (*Salix spp.*) and water birch (*Betula spp.*) dominated the riparian zone. The Lower Stalker site had a mean wetted width of 9.3 m and contained several deep (> 2.5 m) pools. A dense riparian zone throughout this site provided an abundance of overhead cover and shade for fish and stable banks were undercut in many places, creating additional cover.

The stream substrate at the Kennedy site was comprised mostly of gravel and marl and *Chara* spp. was the predominant macrophyte. Riparian vegetation consisted mainly of willow and water birch intermixed with sections of bulrushes and grasses. Mean wetted width was 28.1 m and there were very few pools in the site deeper than 1.5 m. Undercut banks at this site were few and overhead cover from riparian vegetation was much less abundant than in either of the other sites. Much of the Kennedy site was very shallow (< 1.5 m depth) and had a slightly higher gradient than the other two sites. Observations made during 1992-1994 indicated that much of the brown and rainbow trout spawning in upper Silver Creek occurred within the Kennedy site. Preliminary electrofishing at this site also indicated a high abundance of age-0 rainbow and brown trout.

Gravel with small patches of silt characterized the substrate at the Martin Bridge site. *Potamogeton* spp. was the most abundant macrophyte and dense willow and water birch were present in the riparian zone. Mean wetted width was 19.8 m. This site contained several deep (> 2.0 to 3.0 m) pools and was similar to the Lower Stalker site in that riparian vegetation and undercut banks provided overhead cover through most of the site. Preliminary electrofishing at this site revealed that it contained a very high density of nongame fish species and few age-0 salmonids.

Continuously recording thermographs monitored water temperature in Silver Creek at the Lower Stalker and Martin Bridge sites during the 1993-1994 field season. Winter water temperatures ranged from -0.5 to 10.5 °C, while summer water temperatures varied between 7.5 and 21.5 °C. The highest summer water temperatures recorded during the study were at the Martin Bridge site. Mean discharge during the 1993-1994 field season ranged from a low of 2.6 m^3/sec in June 1994 to a high of 5.1 m^3/sec in March 1994 (Water Resources Data for Idaho, 1994). Unlike most freestone streams and rivers, discharge in Silver Creek reaches its lowest level during summer then increases in the fall due to groundwater recharge from irrigation.

Diet Sampling

Brown trout were sampled in August and October in 1993 and in February and May in 1994. An electrofishing raft (vvp settings: 80% duty cycle, 250 V, 3.3 A, 40 Hz) was used to capture brown trout for collection of stomach contents. Total length, weight, and sex were recorded for all brown trout sampled. A pulsed gastric lavage technique (Foster 1977), traditionally used with smaller fish, was modified and used on brown trout ranging in size from 174-715 mm. Gastric lavage has been shown to be a very efficient method for removing stomach contents from live fish (Light et al. 1983; Strange and Kennedy 1981; Meehan and Miller 1978) without affecting survival or feeding.

In the field, brown trout were anesthetized with MS-222 and stomach contents were flushed, collected, and preserved in 70% ethanol for examination in the laboratory. A gardenhose water nozzle (gun style) attached to a submersible water pump (11.35 liters/minute) was used with various sizes of polythene tubing (2-10 mm outside diameter, based on fish size) to pulse water into the fish's stomach. Water pressure forced stomach contents out and they were collected with a funnel fixed with a 50 mm pvc tube screened at the bottom with 1 mm mesh. The contents of the tube were washed into plastic sample bags and 70% ethanol was added to preserve the material. Immediately following gastric lavage, a glass tube (diameter based on fish size) and a small flashlight were used as a gastroscope to verify that stomach contents had been completely flushed.

Routine measurements and stomach flushing were usually performed in less than 2 minutes. Fish that had been flushed were allowed to recover in a livewell attached to the side of the raft for at least 30 minutes before being released. After sampling fish at the Kennedy site in October, I held 24 brown trout (316-705 mm) in an enclosure for 48 hours with no mortality.

In the laboratory, stomach contents of individual fish were sorted into nine categories: fish, insects, leeches, molluscs, worms, crustaceans, fish eggs, vegetation, and an "other" category. "Insects" included aquatic and terrestrial forms as nymphs and adults. "Other" mainly included small mammals, birds, amphibians, and unidentifiable animal material. Annelids were separated because of the seasonal abundance of worms (Oligochaetae) in the diet of some fish. Fish remains were also separated for identification, drying, and weighing. When possible, digested fish were identified to species. Fish that could not be identified to species were always identified as salmonid or nonsalmonid. Stomach contents were oven-dried at 65 °C for 48 hours and then weighed to the nearest 0.001 g. Bowen (1983) suggested that dry weight is more precise than wet weight and probably better represents the organic material present in a prey item.

Diagnostic Bone Key

A diagnostic bone key for all fish species in Silver Creek was developed to aid in identification of partially digested fish in the stomachs of brown trout. Diagnostic bones for most species of fish have been found to persist during digestion. The cleithra, dentary, and operculum, in particular, are diagnostic for many species (Hansel et al. 1988). Bone keys have been used successfully for identification to the species level in other predation studies where the number of prey species was three to four times the number present in Silver Creek (Hansel et al. 1988; Poe et al. 1991; Tabor et al. 1993). Even so, I was unable to distinguish between speckled and longnose dace diagnostic bones and, therefore, I grouped the two species for all diet analyses.

Prey fish species ≤ 200 mm were collected from Silver Creek by backpack electrofishing and frozen within two hours of capture. In the lab, the fish were boiled to remove muscle and tissue from the diagnostic bones. Large sketches of cleaned diagnostic bones were made to aid in the identification process. Measurements were made on the diagnostic bones using dial-calipers and a dissecting scope. These measurements were later used to back-calculate the original lengths of fish that had been consumed. Simple linear regression equations were calculated to estimate the original total lengths of prey species from measurements of the cleithra, dentary, operculum, and pharyngeal teeth (Table 10). Significance of the slopes of the regression formulae was tested by the F-test ($P < 0.05$) to determine if they were significantly different from zero.

Diet Composition

Frequency of occurrence and percent by weight of prey groups in the diet was calculated for each site. These data were used to evaluate the composition of the diet among sites and months. ANOVA procedures could not be used to evaluate the diet among sites and months because of unequal replication.

The brown trout diet was examined by size-groups to assess the extent to which the diet changed with fish length. In addition, differences in the mean length of prey fish ingested were evaluated by a nonparametric one-way ANOVA procedure (Zar 1984). Growth in length of age-0 rainbow trout from June to October of 1993 was analyzed to compare with the size distribution of rainbow trout consumed by brown trout.

Potential Prey Fish Species

Preliminary data gathered in 1992-1993 while performing population estimates in Silver Creek indicated that the composition of prey fish species (≤ 200 mm) available to brown trout was different among the three sites. The relative abundance of game and nongame fish ≤ 200 mm at each site was estimated each month within two weeks of collecting brown trout stomach contents. Estimates were obtained by snorkeling and electrofishing representative 80 m reaches within each site.

I obtained prey relative abundance estimates in August by snorkeling one randomly selected bank and mid-channel lane at each site and enumerating all fish ≤ 200 mm. Electrofishing equipment (vvp settings: 250-300 V, 4-5 A, 30 Hz) had to be used to obtain estimates in October and February because juvenile salmonids and most nongame species were concealed within the substrate and aquatic macrophytes during the day, rendering snorkeling estimates unreliable. The accuracy of underwater counts of salmonids decreases with decreasing water temperature due to the tendency for juvenile salmonids and at least some nongame species to conceal themselves at low water temperatures (i.e. below 8 °C) (Hillman et al. 1992; Rodgers et al. 1992). At low water temperatures, juvenile salmonids and some nongame fish species hide in the stream substrate and/or macrophytes and emerge at night to feed (Griffith and Smith 1993; Riehle and Griffith 1993; Cunjak and Power 1986a, 1986b). Because fish were concealed in October and February and due to the inaccuracy of underwater counts at lower temperatures, absolute density estimates of potential prey species from snorkeling were not reliable. Relative abundance in May was also assessed using electrofishing equipment, though fish were no longer concealing during the day.

To evaluate selection of prey species by brown trout, I used the electivity index (D) formula of Jacobs (1974),

$$D = \frac{r - p}{(r + p) - 2rp}$$

where r is the proportion of the prey item in the diet and p is the proportion of the prey item in the environment. I interpreted selection and avoidance strength based on the following: strong selection $D \geq 0.5$, moderate selection $D > 0.25$ but < 0.5, no selection $D = 0 \pm 0.25$, moderate avoidance $D > -0.5$ but < -0.25, and strong avoidance $D \leq -0.5$.

Daily Ration and Annual Consumption Estimates

Original total length was used to estimate the original wet weight of prey items in the diet by using length-weight equations from Carlander (1969) and those I developed from measurements of fish collected at Silver Creek. Since dry weight was used as the measure of weight of stomach contents, wet weights of back-calculated fish had to be converted to dry weight. Following Elliott (1975), dry weight of ingested fish was assumed to be 24% of wet weight. Gastric evacuation rates for piscivorous brown trout were obtained from He and Wurtsbaugh (1993) and used to estimate the time since ingestion of individual prey fish.

I estimated the consumption of prey fish by brown trout with a method similar to that used by Alexander (1977) on piscivorous brown trout in Michigan. All prey fish consumed within 24 hours of the time a particular brown trout was sampled were considered part of the daily ration of prey fish for that brown trout. Brown trout average daily ration (dry weight) estimates were calculated for: 1) all fish consumed, 2) salmonids only, 3) nonsalmonids only, 4) rainbow trout, and 5) brown trout.

Daily ration estimates for individual sites and an average for all sites combined were calculated for each month. In calculating the annual consumption of rainbow and brown trout, I assumed that the monthly average daily ration estimates were representative of the three-month period during which they were collected.

To estimate the annual consumption of rainbow and brown trout at each site, the number of brown trout ≥ 300 mm was estimated from population data gathered at the sites in 1992-1993. Because population estimates of brown trout were performed in the fall and summer only, it was necessary to estimate winter and spring densities from the fall and summer values and from observations made while electrofishing for brown trout in winter and spring for stomach samples. Based on densities that were measured in late fall and early summer, I assumed that 100 fish/hectare and 50 fish/hectare, in winter and spring respectively, were conservative estimates of the density of brown trout ≥ 300 mm.

Annual brown trout consumption of rainbow and brown trout at each site was estimated by multiplying the number of days in the period by the number of brown trout ≥ 300 mm per hectare by the daily consumption rate for each species for the period. This resulted in a total dry weight (g) of rainbow and brown trout consumed per hectare for each period. The total number of each species consumed per hectare was estimated by dividing these values by the mean original dry weight of rainbow trout in the brown trout diet for each period. The sum of the estimates for each period was the total number of rainbow and brown trout consumed per hectare annually at the site.

To estimate the number of rainbow trout prey available to brown trout at each site annually, I used rainbow trout density data from 1992-1993 and literature values for rainbow trout fecundity and mortality (Carlander 1969). I assumed an even sex ratio in estimating the number of females per hectare. Female rainbow trout ≥ 250 mm (approximately age-III) were considered capable of spawning and were assumed to produce 4000 eggs annually. Based on length-frequency data for rainbow trout from Silver Creek and their size in the brown trout diet, [redacted] assumed that brown trout did not prey on rainbow trout larger than 200 mm or age-II. Assuming mortality rates of 0.98 and 0.90 from egg to age-I and 0.50 from age-I to age-II, I estimated the number of age-0+ and age-I+ rainbow trout prey available in a year. These values were compared to consumption estimates to assess the potential impact of brown trout predation on the rainbow trout population.

RESULTS

Diet Composition

A total of 410 brown trout ranging in length from 174 to 715 mm were captured for diet analysis in 1993-1994. Brown trout < 300 mm comprised 8.5% (35) of the sample, while brown trout > 500 mm accounted for 36% (146) of the sample (Figure 18). Of the 410 fish that were sampled, 300 (73.4%) had food in their stomachs; taxa from nine prey groups were consumed (Table 11). Fish comprised 57.4% of the brown trout diet by weight and approximately 25% of the brown trout had ingested fish.

Bridgelip suckers accounted for 24.7% of the weight of food consumed, followed distantly by rainbow (7.9%) and brown trout (7.3%). Although bridgelip suckers were the dominant fish species by weight, only 4% of the brown trout had consumed them while 6.7% had consumed rainbow trout. Excluding bridgelip suckers, salmonids comprised a larger percentage of the diet by weight than all nongame species combined.

Eighty percent of the brown trout sampled had consumed insects but, insects comprised less than 6% of the weight of food in the diet. Molluscs and crustaceans were present in about half of the stomachs and leeches were present in 29.3% of the fish. Worms were present in only 13.7% of the stomachs, but accounted for the highest invertebrate proportion (10% by weight) of the diet. Molluscs and crustaceans were the second and third most important invertebrate food items by weight, respectively.

Spatial and Temporal Variation in Diet Composition

The diet of Silver Creek brown trout varied between sites, but a general pattern was an increase in the presence of nongame fish and invertebrates from the Lower Stalker site downstream to the Martin Bridge site (Figure 19). Invertebrates and rainbow trout were the two most important prey groups in the diet at the Lower Stalker site, while invertebrates and nongame fishes predominated in the diet at the Kennedy and Martin Bridge sites. Invertebrates were nearly equal in importance at 28.7% and 27.9% of the weight in the diet at the Lower Stalker and Kennedy sites, respectively. Invertebrates at the Martin Bridge site accounted for 54.1% of the diet.

Nongame fish were important in the diet at the Kennedy (52.3%) and Martin Bridge (44.2%) sites but were less important at the Lower Stalker site (9.8%). Rainbow trout at the Lower Stalker site comprised the largest percent (28.7%) by weight in the diet of any salmonid species consumed at any site. Rainbow trout were not found in the diet at the Martin Bridge site and they comprised only 3% of the diet at the Kennedy site. Brook trout were second in abundance in the diet at the Lower Stalker site at

were any present?

20.9% but were a minor component at the Kennedy site and were not found in brown trout from the Martin Bridge site. Brown trout were more important in the diet at the Kennedy site (14.6%) than the Lower Stalker site (8.8%) or the Martin Bridge site (1.7%). Mountain whitefish accounted for 3.1 and 2% of the weight of food consumed at the Lower Stalker and Kennedy sites, respectively. Brown trout stomachs from the Martin Bridge site did not contain mountain whitefish. none present ?!

Seasonal differences in brown trout diet composition were apparent from percent weight values for each site (Tables 12-14). In August, the diet at the Lower Stalker site was dominated by salmonids (72.1%) (Figure 20). Rainbow trout became a more important dietary component in October at this site, increasing from 7.2% in August to 34.2%. In February, 41.2% of the weight of the diet was rainbow trout while other salmonids accounted for 39.3%. By May, however, brown trout at the Lower Stalker site consumed more invertebrates (71.9% by weight) than fish.

The diet of brown trout at the Kennedy site was similar to Lower Stalker from August to October (Figure 21). In August, invertebrates and salmonids were the major items in the diet, but by October rainbow trout and salmonids had increased in importance and invertebrates had declined. Rainbow trout rose from 0.8% of the diet by weight in August to 24.5% in October. The general diet pattern at the

Kennedy site from October to May was an increase in the presence of nongame fish while rainbow trout disappeared completely from the diet in February and May. After a large decrease from August to October, invertebrates increased as a percentage of the diet between October and May at this site.

Brown trout consumed invertebrates almost exclusively (96.4%) at the Martin Bridge site in August (Figure 22). In October, however, nongame fish became the dominant (72.1%) food item. Rainbow trout were never observed in the diet at the Martin Bridge site and brown trout preyed on other salmonids only in February when they comprised 34.6% of the diet (brown trout alone accounted for 25.0%). As in August, invertebrates were an important food item (47.8%) in February, while nongame fish again became the major diet item in May at 68.7% of the diet.

Diet Composition and Brown Trout Size

Fish were almost nonexistent in the diet of brown trout < 300 mm (Figure 23). Of the 409 brown trout that were sampled in 1993-1994, 35 (8.5%) were < 300 mm. The diet of fish between 100 and 200 mm was 100% invertebrates while those between 200 and 300 mm consumed 99.5% invertebrates by weight. Fish, as a whole, became more important in the diet with increasing predator size. Brown trout between 300 and 400 mm consumed 32.3% fish by weight. This percentage increased to a maximum of 97.7% for brown trout between 600 and 700 mm. Brown trout between 300 and 400 mm included a larger proportion of rainbow trout (18.1%) than nongame fish and other salmonids in their diet. All other size-groups included nongame fish or other salmonids in the diet to a greater extent than rainbow trout. Rainbow trout accounted for 11.8% of the weight of the diet of brown trout between 500 and 600 mm, while nongame fish and salmonids comprised 54.2%. Brown trout between 600 and 700 mm contained 2.5% rainbow trout and 95.1% nongame fish and salmonids by weight.

Rainbow trout consumed by brown trout were significantly smaller than other fish in the diet (Figure 24). The mean total length of ingested rainbow trout was 86 mm followed by nongame fish (103 mm), other salmonids (112 mm), and brown trout (126 mm). Brown trout were significantly larger on average than any other fish in the diet but were followed closely by nongame fish (Figure 25). Of 40 salmonids that were consumed by brown trout, only 3 were larger than 140 mm compared to 9 of 44 nongame fish greater than 140 mm. All nine nongame fish were bridgelip suckers.

Regression procedures found no significant linear relationship between predator brown trout size and the size of rainbow trout that were consumed. Brown trout between 300 and 715 mm indiscriminantly preyed on rainbow trout between 60 and 120 mm (Figure 26). Twenty out of 23 ingested rainbow trout were between 60 and 120 mm. Age-0 rainbow trout appeared to become vulnerable to brown trout predation in late-July to early-August, 1993 when they reached approximately 60 mm (Figure 27).

Potential Prey Fish Species Abundance

The relative abundance of game and nongame prey fish species varied among sites and months (Figures 28-30). Game species were the main prey fish available at the Lower Stalker and Kennedy sites, and nongame species dominated the Martin Bridge site. When all months were combined, game species comprised between 50% and 86% of the sample at the Lower Stalker site and between 51% and 95% of the sample at the Kennedy site. At the Martin Bridge site, game species comprised from 0% to 39% of the sample.

Game prey fish species reached their highest abundance at the Lower Stalker site in November and May at 83% and 86%, respectively (Figure 28). At the Kennedy site, game species were most abundant in March (80%) and May (95%) and accounted for 50 to 60% of the sample in August and November, respectively (Figure 29). Similar to the Lower Stalker site, game species reached a peak abundance in November and May at the Martin Bridge site (Figure 30). Nongame species dominated the sample in all months at the

Martin Bridge site, reaching their largest proportions in August (84%) and March (100%).

The relative abundance of individual salmonid prey species varied seasonally among sites (Figures 31-33). At the Lower Stalker site, brown trout were the most abundant salmonid in August (38%) and May (80%) and rainbow trout were most abundant in November (51%) and March (33%) (Figure 31). The Kennedy site contained nearly equal proportions of rainbow (23%) and brown (24%) trout in August. In November and May, however, rainbow trout were the most abundant salmonid accounting for 37% and 56% of the sample, respectively. Brown trout accounted for the largest percentage of the sample in March (76%) at the Kennedy site (Figure 32). Brown trout also comprised the largest part of the salmonid prey at the Martin Bridge site in every month that salmonid prey species were present in the sample (Figure 33). Rainbow trout were present at the Martin Bridge site in August and May at 1% and in November at 10% of the sample. Rainbow trout were not found at the Martin Bridge site in March.

Individual nongame species' relative abundance also varied seasonally among sites (Figures 34-36. Paiute sculpins were most abundant at the Lower Stalker site in August at 15% of the sample but were not present in any other month sampled (Figure 34). Speckled dace at this site were the dominant species in the sample in March (50%), but the species made up less than 10% of the prey fish base in the other three months. At the Kennedy site, Paiute and Wood River sculpins were the most abundant nongame prey fish species in all months (Figure 35). The two sculpin species were equally abundant in May. In March, Wood River sculpin (13.5%) were more abundant than Paiute sculpin (5.6%) while in November Paiute sculpin were the more abundant of the two sculpin species. Speckled dace and longnose dace were the most abundant nongame prey species present at the Martin Bridge site in August and November (Figure 36). In March, redside shiner and speckled dace each comprised 46.7% of the prey species at this site, and speckled dace accounted for 52.7% of the prey species present in May.

Prey Fish Species Selected by Brown Trout

Mountain whitefish were strongly selected as prey in August and October but were consumed in proportion to their abundance in February and May (Table 15). In all months sampled, brown trout and Wood River sculpins were moderately to strongly avoided as prey. Rainbow trout were preyed on in proportion to their abundance in October and May. In February, rainbow trout were strongly selected, and in August they were moderately selected. Brown trout selected brook trout as prey in all months except August when they were avoided.

In general, nongame species were selected as prey in February and May. Bridgelip suckers and speckled and longnose dace were strongly selected nongame fishes in February. In May, brown trout strongly selected bridgelip suckers and Paiute sculpins and showed moderate selection of redside shiners.

Daily Ration and Annual Consumption Estimates

The daily ration of fish for brown trout was 12.14 g in May compared to 2.65 g in August, 3.26 g in October, and 3.83 g in February (Table 17). Nonsalmonid daily ration was highest in May (11.44 g) and was responsible for the high daily ration estimate. The lowest daily salmonid ration of 1.17 g was also recorded in May. The high nonsalmonid component in May was attributed to a few large brown trout that had consumed several large (190-220 mm) bridgelip suckers.

Brown trout daily ration of salmonids in August, October, and February ranged from 2.22 to 2.63 g while nonsalmonid daily ration was 0.43 g, 0.63 g, and 1.28 g in each month, respectively. Excluding May, salmonid daily ration estimates were two to four times higher than nonsalmonid daily ration estimates. Rainbow trout accounted for approximately 40 to 50% of the total salmonid daily ration in all months except August when it accounted for approximately 15%. Brown trout daily ration of rainbow trout was higher than brown trout in all months except August. In August, the daily ration of brown trout was nearly three times that of rainbow trout.

Silver Creek brown trout consumed approximately 28,498 rainbow trout and 1,518 brown trout per hectare at the Lower Stalker site in 1993-1994 (Tables 18-19). At the Kennedy site, 10,362 rainbow trout and 3,370 brown trout were eaten. No rainbow trout were consumed at the Martin Bridge site, but 8,875 brown trout were preyed on. Most rainbow and brown trout were consumed during the September-November period, followed by the December-February period.

Assuming an egg to age-I mortality rate of 0.98, I estimated that 16,800 rainbow trout per hectare would have been available to brown trout at the Lower Stalker site in 1993-1994 (Table 20). When the egg to age-I mortality rate was decreased to 0.90, this estimate increased to 84,000 rainbow trout per hectare. At the Kennedy site, the estimate was 14,160 and 70,800 rainbow trout per hectare under a 0.98 and 0.90 mortality rate, respectively. Density at the Martin Bridge site was the lowest of the three sites at 8,280 rainbow trout per hectare at a 0.98 mortality rate and 41,400 rainbow trout per hectare with a 0.90 mortality rate.

DISCUSSION

Brown Trout Diet Composition

Brown trout in Silver Creek became piscivorous after reaching approximately 300 mm, and the extent of piscivory increased with brown trout size. The level of piscivory in Silver Creek brown trout was within the range of that observed in fish from other systems. Alexander (1977) demonstrated extensive brown trout piscivory in fish > 300 mm in Michigan where the diet was 75-82% fish by weight over the course of a year. Similarly, Klammer (1984) reported that the brown trout diet in a Nebraska stream was 76.9 to 94.1% fish by volume in June and April for fish > 200 mm. Levels of brown trout piscivory similar to that in Silver Creek were reported by Evans (1952) and Hannuksela (1969) who found that brown trout consumed 50 to 65% fish by weight in populations from New York and Michigan.

A host of diet evaluations have reported little or no fish consumption by brown trout (Allen 1951; Kelly-Quinn and Bracken 1990; Kimball 1972; Montanes and Lobon-Cervia 1986). However, brown trout sampled in most of these studies were smaller than 350 mm. Thus, any change in diet (e.g. toward piscivory) that may have occurred in larger fish would not have been fully evaluated.

Bridgelip suckers dominated the weight of fish in the brown trout diet in Silver Creek when all sites and months were combined. However, brown and rainbow trout comprised the second highest proportions by weight and, excluding bridgelip suckers, salmonids collectively made-up a larger percentage of the diet than all other nongame species combined. Metzelaar (1929) reported that 44.4% of all fish eaten by large brown trout were young salmonids. Similarly, Idyll (1942) found that salmonids were the principal fish consumed by brown trout in a British Columbia stream. In the Anna River, Michigan, Hannuksela (1969) showed that large, piscivorous brown trout selected salmonids over slimy sculpins (*Cottus cognatus*) even though sculpins were nine times more abundant than salmonids. Alexander (1977) also reported that the largest proportion (30-61%) of fish consumed by brown trout were brook trout.

Spatial and Temporal Variation in the Diet

Variation in the brown trout diet among sites provided valuable insight into the forage preferences of brown trout in various types of prey communities. Brown trout at the Lower Stalker and Kennedy sites included fish in their diet to a greater extent than at the downstream Martin Bridge site. The Lower Stalker and Kennedy sites were found to contain a higher proportion of game fish prey species than the Martin Bridge site which was comprised mainly of nongame prey fishes. The tendency for more invertebrates to be included in the diet at the Martin Bridge site than at the

Lower Stalker and Kennedy sites was probably related to differences in prey fish species composition among the sites. [redacted] and, when the former is absent, will consume a greater percentage of invertebrates. In addition, the absolute abundance of prey fish may have been lower overall at the Martin Bridge site which could have further accounted for brown trout consuming a greater proportion of invertebrates.

Seasonal patterns in brown trout food consumption varied by location in Silver Creek. General patterns emerged within each site and were best explained by changes in the abundance or availability of prey species. Brown trout consumed a higher percentage of fish than invertebrates at all sites and during all months, with two exceptions: 1) invertebrates dominated the diet in May at the Lower Stalker site, and 2) invertebrates dominated in August at the Martin Bridge site. During these two periods, brown trout apparently shifted their diet in response to either an increase in invertebrate abundance or a decrease in prey fish species abundance. Indeed, juvenile salmonid densities at the Lower Stalker site were likely very low in May due to downstream movement of age-0 fish, and invertebrate abundance was probably at its peak in August at the Martin Bridge site. Also, use of dense macrophyte beds as cover by nongame fish may have effectively made many of the species unavailable to brown trout in August.

One explanation for an increase in the rainbow trout proportion of the diet that occurred at the Lower Stalker and Kennedy sites from August to October might be the increase in size of young-of-the-year rainbow trout that occurred between August and October. By October, age-0 rainbow trout were probably large enough to serve as important prey items for brown trout and, therefore, may have been consumed more frequently. The lowest consumption of rainbow trout occurred in August when young-of-the-year were between 55 and 65 mm. Rainbow trout consumed by brown trout were usually between 60 and 120 mm. Young-of-the-year rainbow trout would have been well into this range by October.

Another explanation for the increase in rainbow trout in the diet in October could be that adult brown trout spawning in October at these sites came into contact with juvenile rainbow trout more frequently due to changes in brown trout behavior and habitat use during spawning. Brown trout typically spend more time away from cover and in open-channel areas while constructing redds and spawning. As such, they would have come into contact with juvenile rainbow trout during the day more often than during nonspawning periods. Daylight observations made in 1993-1994 suggested that many more large brown trout were out in mid-channel areas during the spawning period than at any other time of the year (Wilkison, personal observation). Juvenile rainbow trout were found to be very abundant at these two sites and snorkel observations indicated they were more abundant in mid-channel areas during the day than at night (Wilkison, unpublished data). At night, juvenile rainbow trout appeared to be concealed in mid-channel areas and their density appeared to be highest along the stream banks.

Predation on juvenile salmonids, and particularly on rainbow trout, was greatest during October and February. The limestone, spring-fed character of Silver Creek supports several species of aquatic macrophytes that become very abundant during late-summer and fall. During this time, macrophytes are the dominant form of cover used by juvenile salmonids (Riehle and Griffith 1993). In winter, however, macrophytes senesce, leaving very little cover for juvenile salmonids until new growth begins in early spring. Juvenile salmonids in Silver Creek are likely very vulnerable to predation by brown trout during periods when aquatic macrophytes are absent. In pond experiments, Tabor and Wurtsbaugh (1991) found that brown trout predation on rainbow trout was significantly higher when near-shore cover for the juvenile rainbow trout was absent than when cover was present.

Brown Trout Size and Piscivory

Silver Creek brown trout became more piscivorous with increasing size. Invertebrates, however, still comprised a significant portion of the diet in fish as large as 450 mm. Fish between 450 and 600 mm usually included less than 30% invertebrates in their diet while fish larger than 600 mm fed almost exclusively on fish all year. Other researchers have reported similar findings for changes in diet with increasing size. Fish were included in the diet to a greater extent in brown trout larger than 300 mm in Michigan (Hannuksela 1969; Alexander 1977) and England (Hunt and Jones 1972). Klammer (1984) found that the switch toward a higher percentage of fish in the diet occurred at about 200 mm in Nebraska sandhill streams. Hunt and Jones (1972) further reported that brown trout above 430 mm included a significantly larger proportion of fish in their diet than those between 300 and 430 mm.

Prey Fish Species Selected by Brown Trout

[redacted]. Alexander (1977) also reported that large brown trout avoided eating juvenile brown trout in favor of juvenile brook trout in tank feeding experiments. Similarly, brown trout in the Anna River, Michigan preyed on coho salmon and rainbow trout instead of juvenile brown trout (Hannuksela 1969).

Strong selection by brown trout of nongame fish species in the spring was probably related to movement and habitat use patterns of spring spawning minnows and suckers. Dense groups of spawning redside shiners, speckled and longnose dace, and bridgelip suckers were frequently observed in spring during the day and at night in mid-channel habitat away from cover. This type of behavior would have made these fish more vulnerable to predation in the spring than at other times of the year when they were less concentrated and more closely associated with cover.

The brown trout diet from the Lower Stalker and Kennedy sites indicated very strong negative selection of Wood River sculpin in all months except February at the Lower Stalker site. Paiute sculpin, however, which were more abundant than Wood River sculpin, were moderately to strongly selected in February and May. Vulnerability of the Wood River and Paiute sculpins to predation may have increased in February at the Lower Stalker site because of the loss of aquatic macrophyte cover during the winter period. Because this site was dominated by a silt substrate and lacked cobble, interstices would not have been available to serve as winter cover for sculpins. Paiute sculpins may have utilized different habitats or behaved differently than Wood River sculpins which would have at least partly accounted for greater selection of Paiute sculpins.

Prey Fish Size and Species Composition in the Diet

Size differences between rainbow trout and other fish species consumed by brown trout could have been related to different microhabitat use patterns. Also, predator recognition and avoidance abilities probably varied among the species. Different habitat use patterns among the species would likely have influenced their vulnerability to predation. Many researchers have demonstrated that juvenile salmonids change their behavior and habitat use in the presence of a predator to avoid being preyed upon (Bugert and Bjornn 1991; Brown and Moyle 1991; Bardonnet and Heland 1994; Tabor and Wurtsbaugh 1991). If a shift in behavior and/or habitat use was not possible for juvenile rainbow trout in Silver Creek because of the presence of age-0 brown and brook trout, brown trout may have been able to more effectively prey on rainbow trout. Since age-0 brown and brook trout initially have a size advantage over rainbow trout, they may have displaced rainbow trout which would have made the smaller rainbow trout easier prey. Once rainbow trout reach about 120 mm, however, they appear to be more efficient at avoiding being eaten by brown trout. The tendency of brown and brook trout to use cover to a greater extent than rainbow trout (Jenkins 1969a; Dewald and Wilzbach 1992; Hayes 1989) may also have lowered these two species' vulnerability to predation until reaching a larger size and/or changing habitat use.

In a broader sense, rainbow trout may simply be more susceptible to brown trout predation because they probably have not evolved adequate defenses against predation from a large piscine predator like the brown trout. Johnson et al. (1993) suggested that attempts at reintroducing the endangered razorback sucker (*Xyrauchen texanus*) in the Colorado River basin have been unsuccessful because the species evolved in a predator-poor environment. Today the suckers face numerous nonnative piscine predators against whom they lack antipredator mechanisms necessary to persist in the system. In New Zealand, brown trout have been charged with having detrimental effects on the distribution and abundance of native Galaxiids (Ault and White 1994). Researchers have suggested that the native Galaxiids have been seriously impacted by the introduction of brown trout because the former evolved without a piscine predator and lacks the predator defense mechanisms necessary to coexist with brown trout (Townsend and Crowl 1991; Jackson and Williams 1980). Indeed, brown trout have been shown to be very effective at foraging at night (Jenkins 1969; Oswald 1978) when many sympatric species may be less effective at avoiding predators.

The largest fish consumed by brown trout were brown trout and bridgelip suckers. Suckers larger than 200 mm were particularly abundant in the diet relative to other fish. It is not entirely clear, however, why these two species were the largest individuals consumed. Perhaps, these species' tendency to more closely associate with the stream substrate than many of the others is somehow related to these results.

Daily Ration and Annual Consumption Estimates

Salmonid daily ration estimates for Silver Creek brown trout were in the range reported for brown trout from Michigan (Alexander 1977; Stauffer 1977). Silver Creek brown trout on average consumed more salmonids than nonsalmonids in a day and rainbow trout usually comprised the largest portion of the salmonid ration.

Alexander (1977) estimated that large, predatory brown trout consumed 3,579 to 7,626 brook trout and approximately 218 brown trout per mile of river per year. [redacted]. Alexander (1977) also indicated that consumption of juvenile brook and brown trout in fall and winter was significant. Similarly, consumption in Silver Creek was greatest during the fall and winter periods.

in 1992/93 with many more large browns — how many today? significantly more!!

Brown trout predation probably removes between 5 and 34% of the age-0+ and age-I+ rainbow trout from Silver Creek annually. At a mortality rate of 0.90, 15% of the rainbow trout ≤ 200 mm at the Kennedy site and 34% of those at the

Lower Stalker site were preyed on by brown trout. However, given the spring-fed nature of Silver Creek, it would not be unreasonable to assume an egg to age-I mortality rate lower than 0.90. McFadden (1961) reported mortality rates ranging from 0.42 to 0.64 for age-0 to age-I brook trout in Lawrence Creek, Wisconsin, a spring creek similar in character to Silver Creek. Assuming a mortality rate of 0.70, brown trout would have consumed 11% of the rainbow trout available at the Lower Stalker site and only 5% of those available at the Kennedy site.

Brown trout in the North Branch Au Sable River were responsible for 58% of the annual mortality of age-0 brook trout and 16% of the annual mortality of age-0 brown trout (Alexander 1977). Large brown trout were the most significant vertebrate predator on small brook and brown trout in the North Branch Au Sable River. Alexander (1977) reported that brown trout in the North Branch Au Sable also consumed significant numbers of nongame fish.

Fish Community Effects

Introduced brown trout have negatively impacted sympatric rainbow trout in upper Silver Creek. Diet information, combined with documentation of an accumulation of large, piscivorous brown trout at the Lower Stalker site and a simultaneous large decline in rainbow trout biomass at this site (Chapter I of this document), suggested that brown trout predation was at least partly responsible for the decline. Further downstream at the Martin Bridge site, very high densities of large brown trout appeared to be responsible for the virtual absence of age-0 rainbow trout. Similarly, bridgelip suckers and mountain whitefish were strongly selected as prey items by brown trout in this study and both species have seriously declined in abundance since the appearance of brown trout in Silver Creek. Mountain whitefish, in particular, declined to very low levels and were present in only a small section of upper Silver Creek.

Brown trout selection of the more abundant Paiute sculpin appeared to be insulating the endemic Wood River sculpin from predation. However, a decrease in other prey species densities as a result of predation from an expanding brown trout population could increase predation on Wood River sculpin.

Population and diet information from Silver Creek further underscore the potential for introduced species to negatively impact important native salmonids. For example, populations of most subspecies of cutthroat trout in the western U.S. have been severely impacted by hybridization, interspecific competition, habitat degradation, and overfishing. Predation from introduced brown trout in streams containing remnant metapopulations of these subspecies could further reduce their distribution and abundance. Certainly, the brown trout's potential to impact

[illegible] of the [illegible] Heights
[illegible] in only a short section of upper [illegible] Creek.

native nongame species has gone virtually unexplored while fisheries biologists continue to stock the species into waters which contain diverse native nongame fish communities.

To fully evaluate the potential impact of brown trout on other fish species through predation, the diet and population dynamics of recently established brown trout populations need to be monitored early in the development of the populations. Monitoring the abundance of the sympatric fish species originally present and a periodic reexamination of the brown trout diet would allow researchers to assess the effects, if any, of brown trout on sympatric fish species in various aquatic environments.

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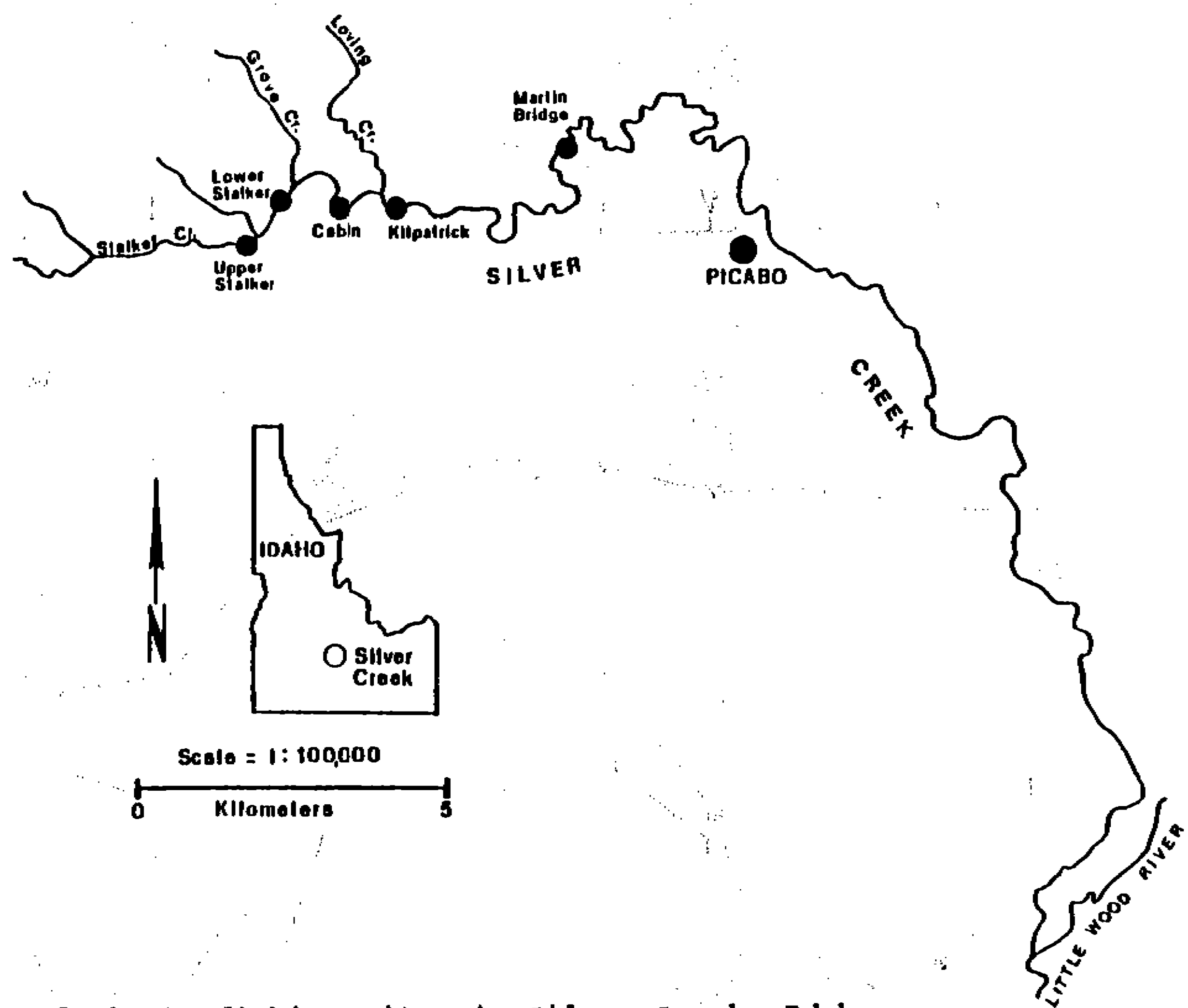


Figure 1. Location of electrofishing sites in Silver Creek, Idaho for the 1992-1993 field season. The same five sites were sampled by Riehle et al. (1989) in 1986.

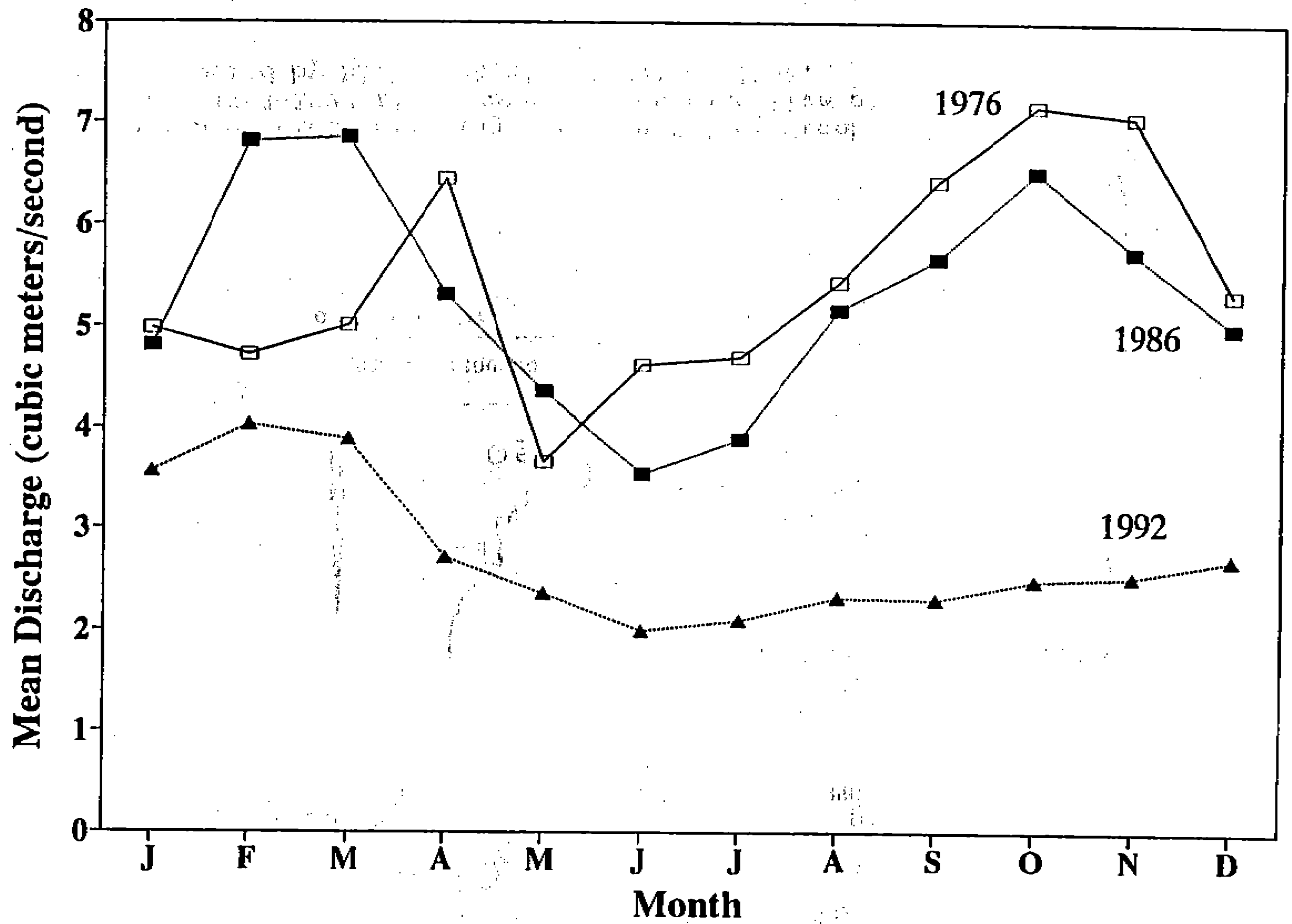


Figure 2. Monthly mean discharge (ft³/s) for Silver Creek during the 1976, 1986, and 1992 calendar years (Water Resources Data for Idaho, USGS).

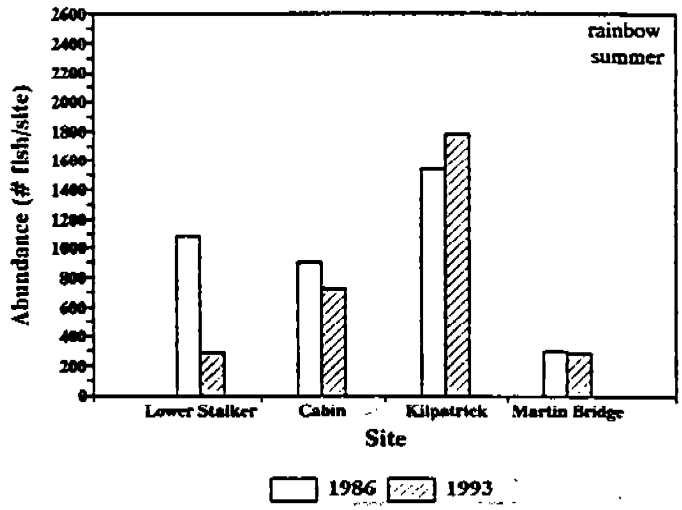


Figure 3. Abundance estimates for rainbow trout (≥ 150 mm) at four electrofishing sites in Silver Creek for summer 1986 and summer 1993.

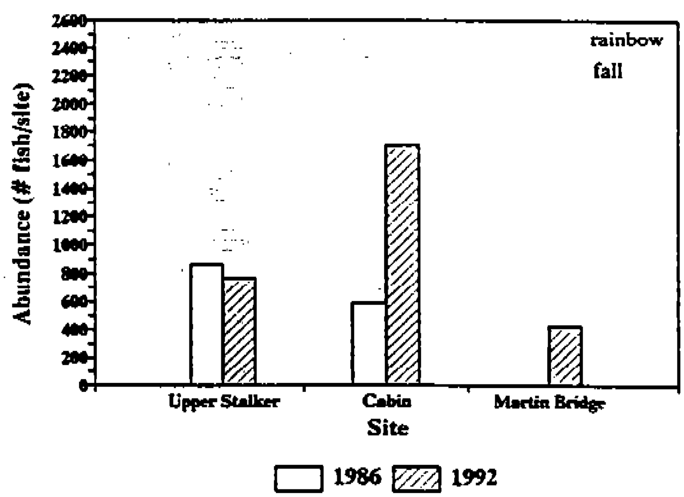


Figure 4. Abundance estimates for rainbow trout (≥ 150 mm) at four electrofishing sites in Silver Creek for fall 1986 and fall 1992.

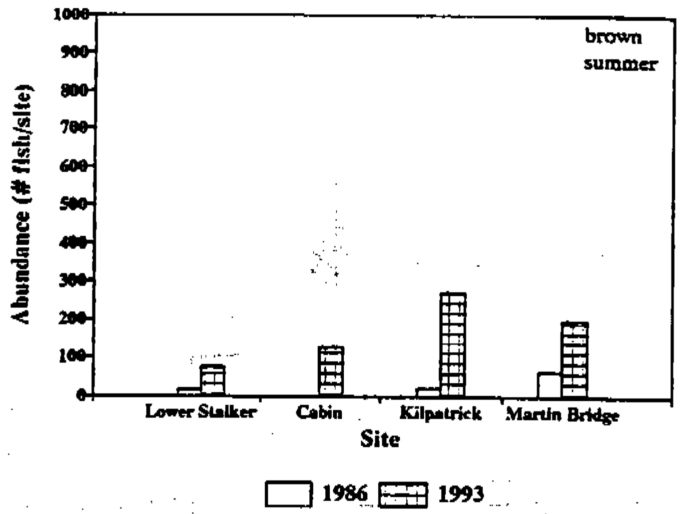


Figure 5. Abundance estimates for brown trout (≥ 150 mm) at four electrofishing sites in Silver Creek for summer 1986 and summer 1993.

note huge incr
in browns!

how much more
in 1997?!

note huge in

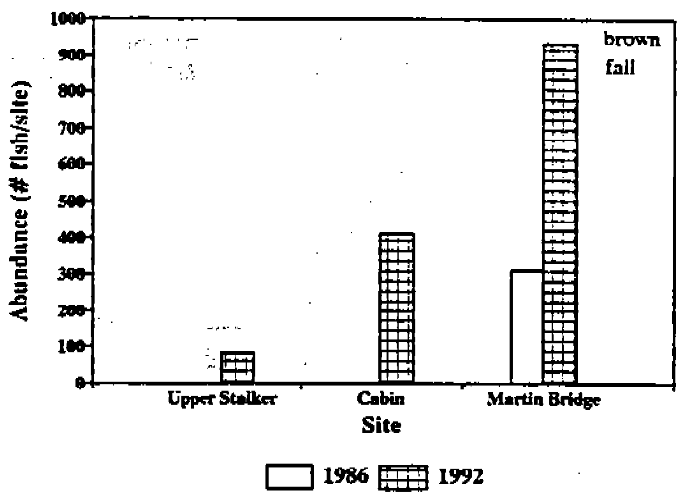
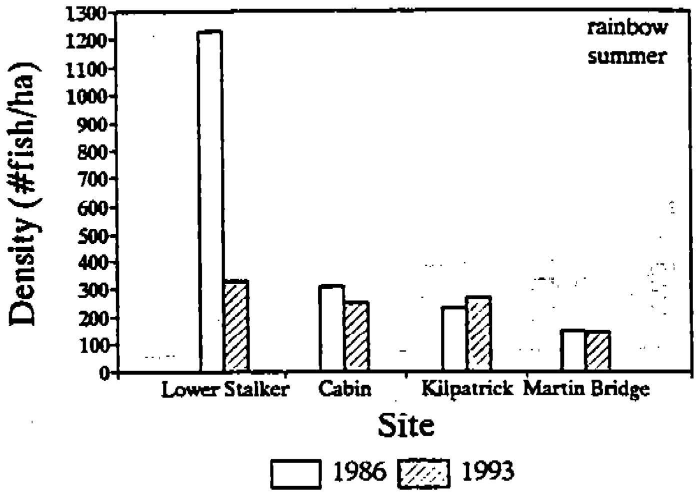


Figure 6. Abundance estimates for brown trout (≥ 150 mm) at four electrofishing sites in Silver Creek for fall 1986 and fall 1992.



general decline

Figure 7. Density estimates for rainbow trout (≥ 150 mm) at four electrofishing sites in Silver Creek for summer 1986 and summer 1993.

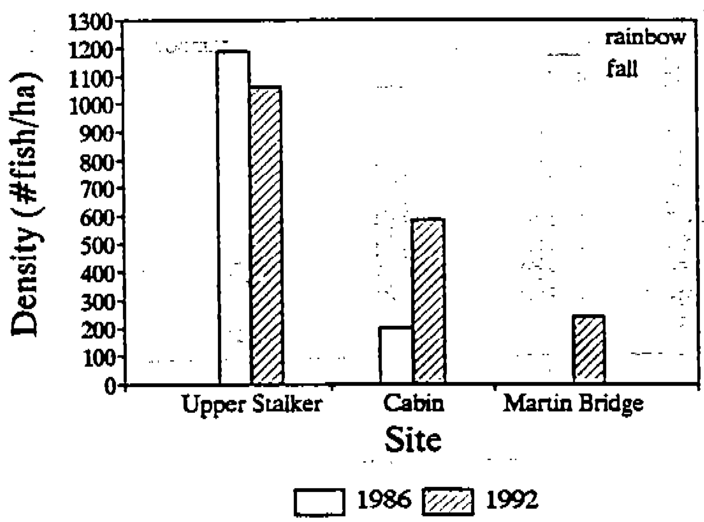


Figure 8. Density estimates for rainbow trout (≥ 150 mm) at four electrofishing sites in Silver Creek for fall 1986 and fall 1992.

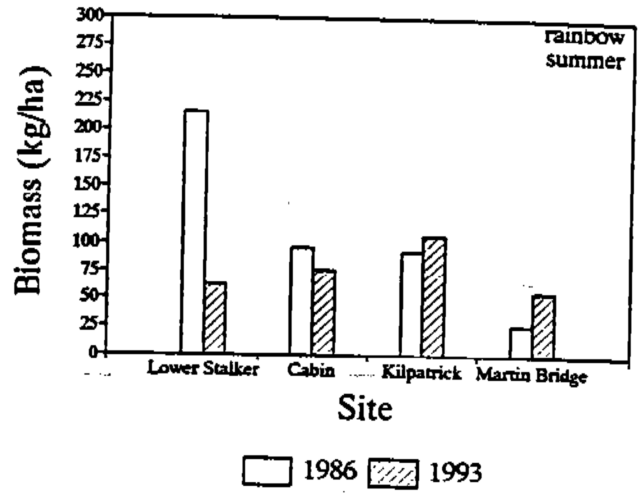


Figure 9. Biomass estimates for rainbow trout (≥ 150 mm) at four electrofishing sites in Silver Creek for summer 1986 and summer 1993.

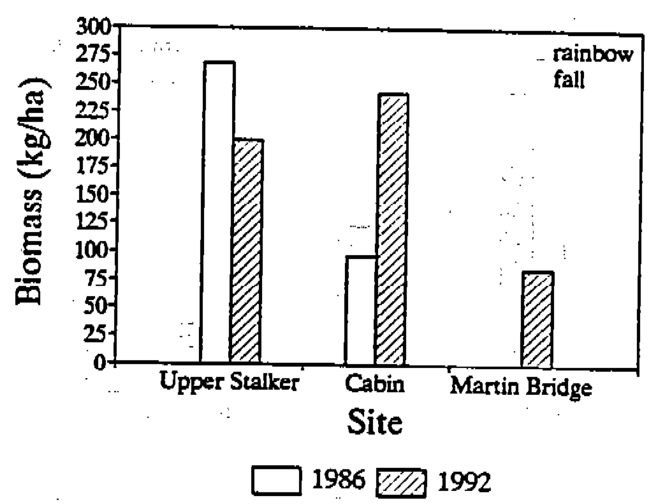


Figure 10. Biomass estimates for rainbow trout (≥ 150 mm) at four electrofishing sites in Silver Creek for fall 1986 and fall 1992.

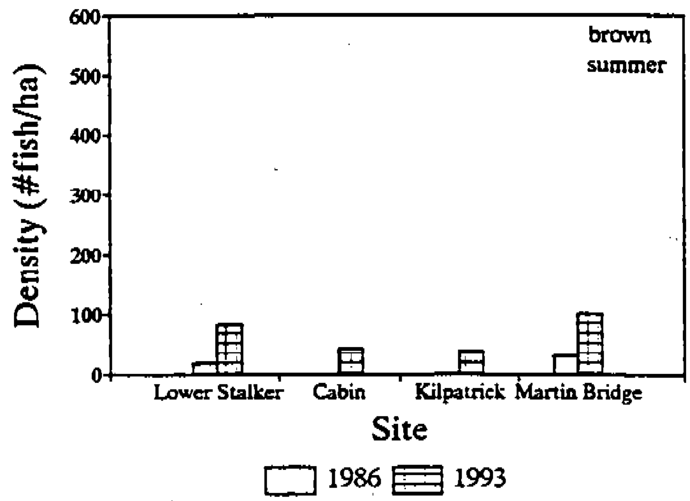


Figure 11. Density estimates for brown trout (≥ 150 mm) at four electrofishing sites in Silver Creek for summer 1986 and summer 1993.

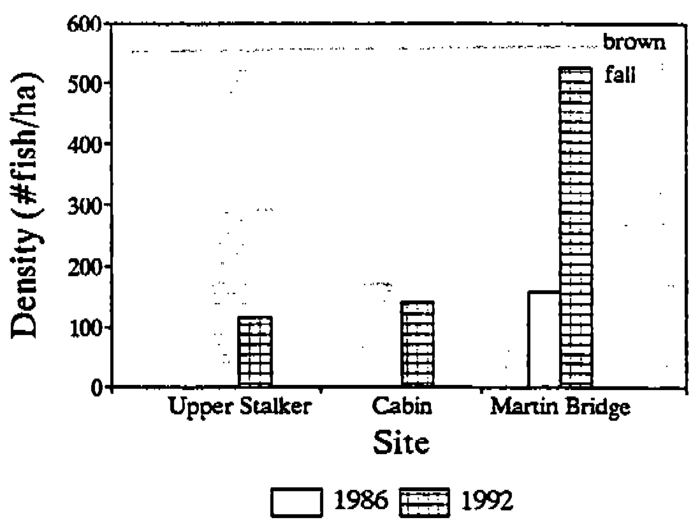


Figure 12. Density estimates for brown trout (≥ 150 mm) at four electrofishing sites in Silver Creek for fall 1986 and fall 1992.

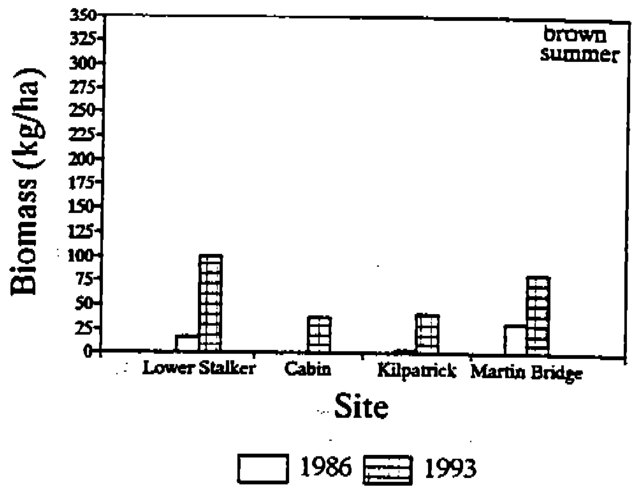


Figure 13. Biomass estimates for brown trout (≥ 150 mm) at four electrofishing sites in Silver Creek for summer 1986 and summer 1993.

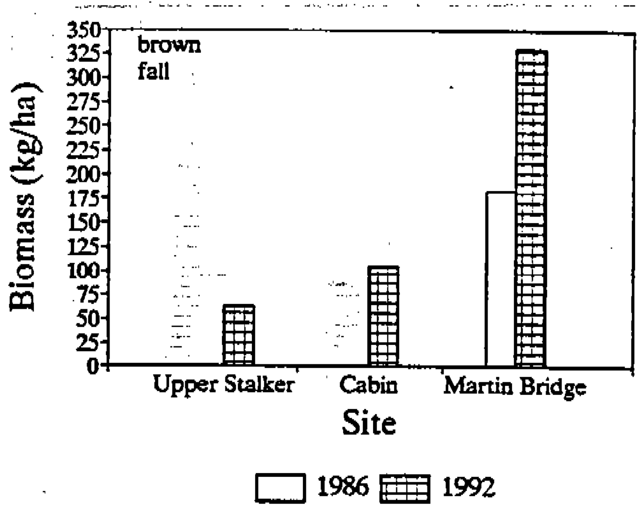


Figure 14. Biomass estimates for brown trout (≥ 150 mm) at four electrofishing sites in Silver Creek for fall 1986 and fall 1992.

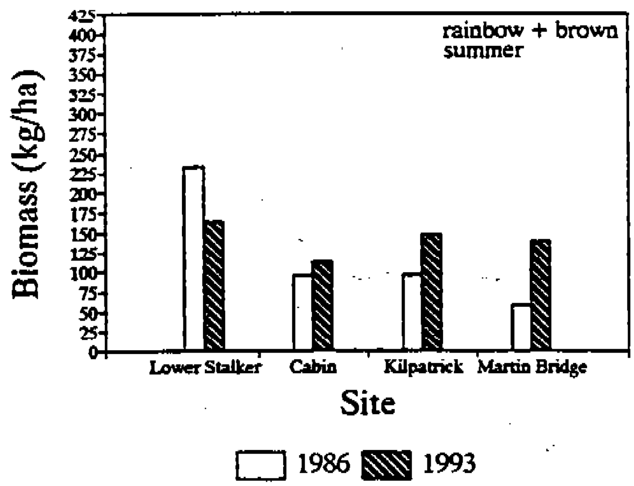


Figure 15. Combined biomass of brown and rainbow trout (≥ 150 mm) at electrofishing sites in Silver Creek for summer 1986 and summer 1993.

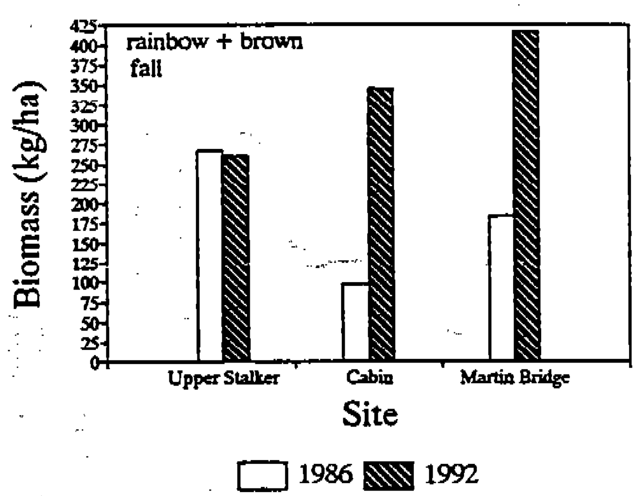


Figure 16. Combined biomass of brown and rainbow trout (≥ 150 mm) at electrofishing sites in Silver Creek for fall 1986 and fall 1992.

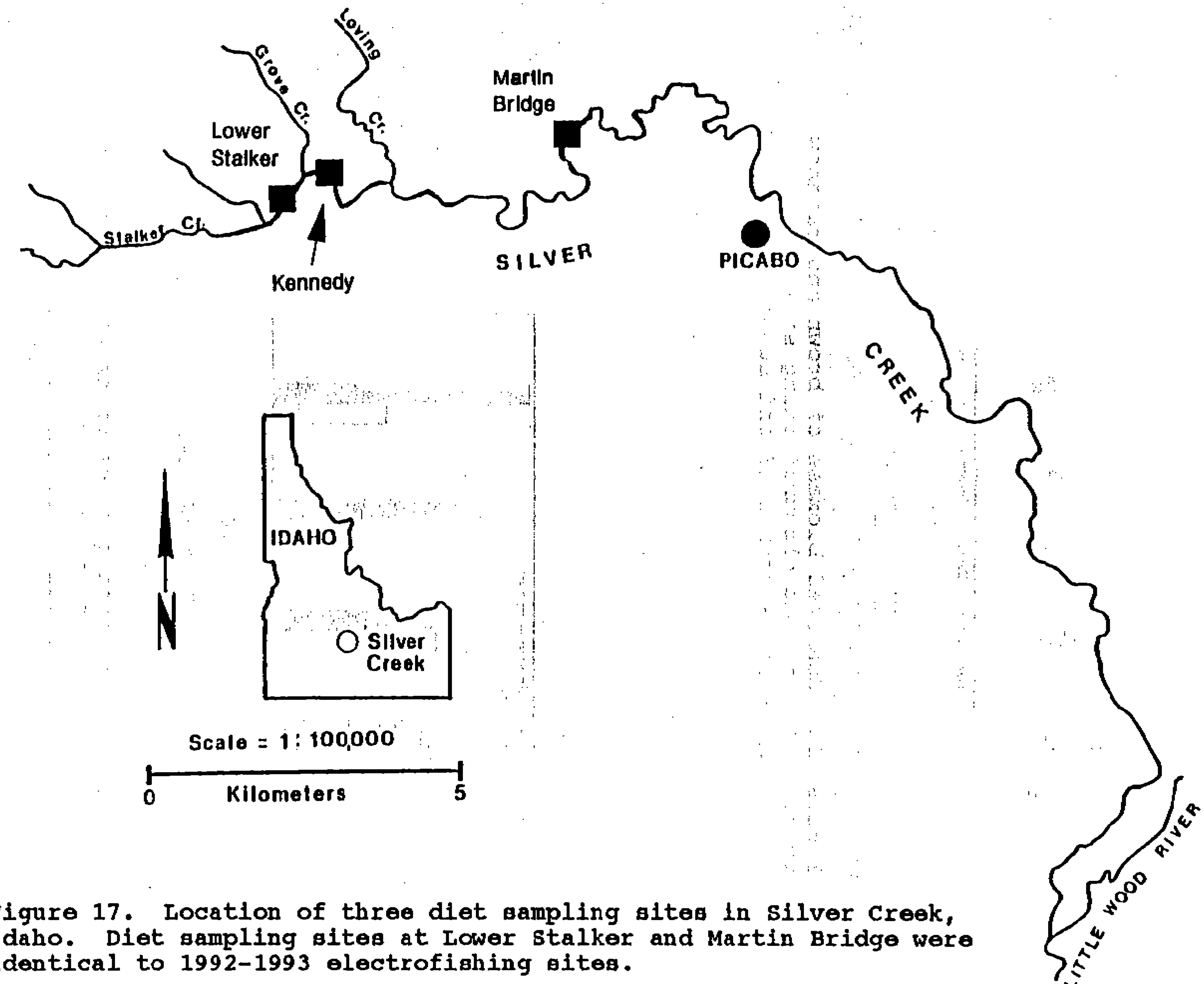


Figure 17. Location of three diet sampling sites in Silver Creek, Idaho. Diet sampling sites at Lower Stalker and Martin Bridge were identical to 1992-1993 electrofishing sites.

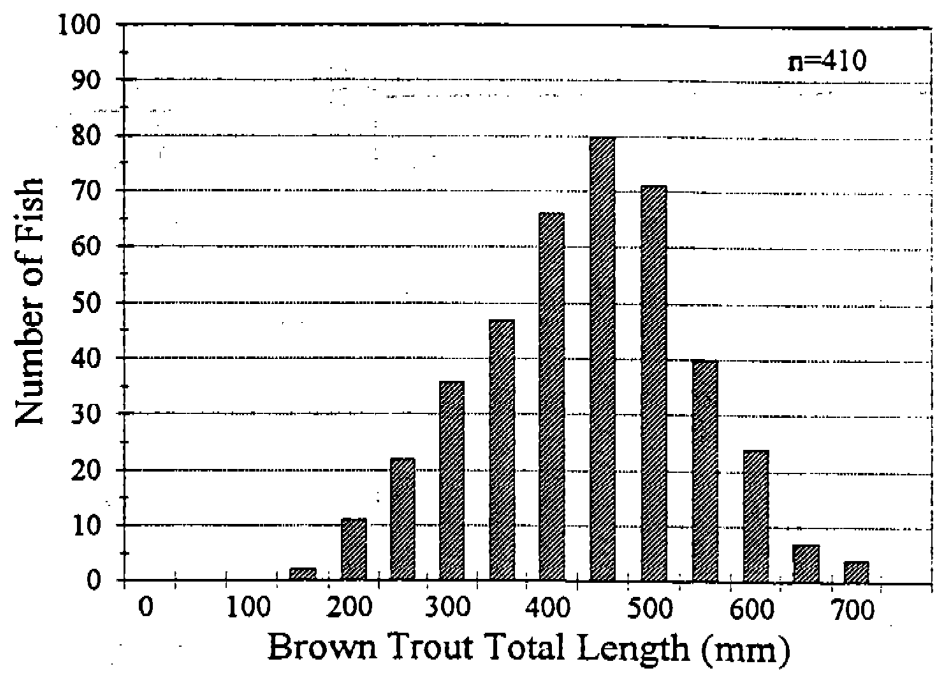


Figure 18. Length distribution of brown trout captured for diet analysis in 1993-1994 from Silver Creek, Idaho.

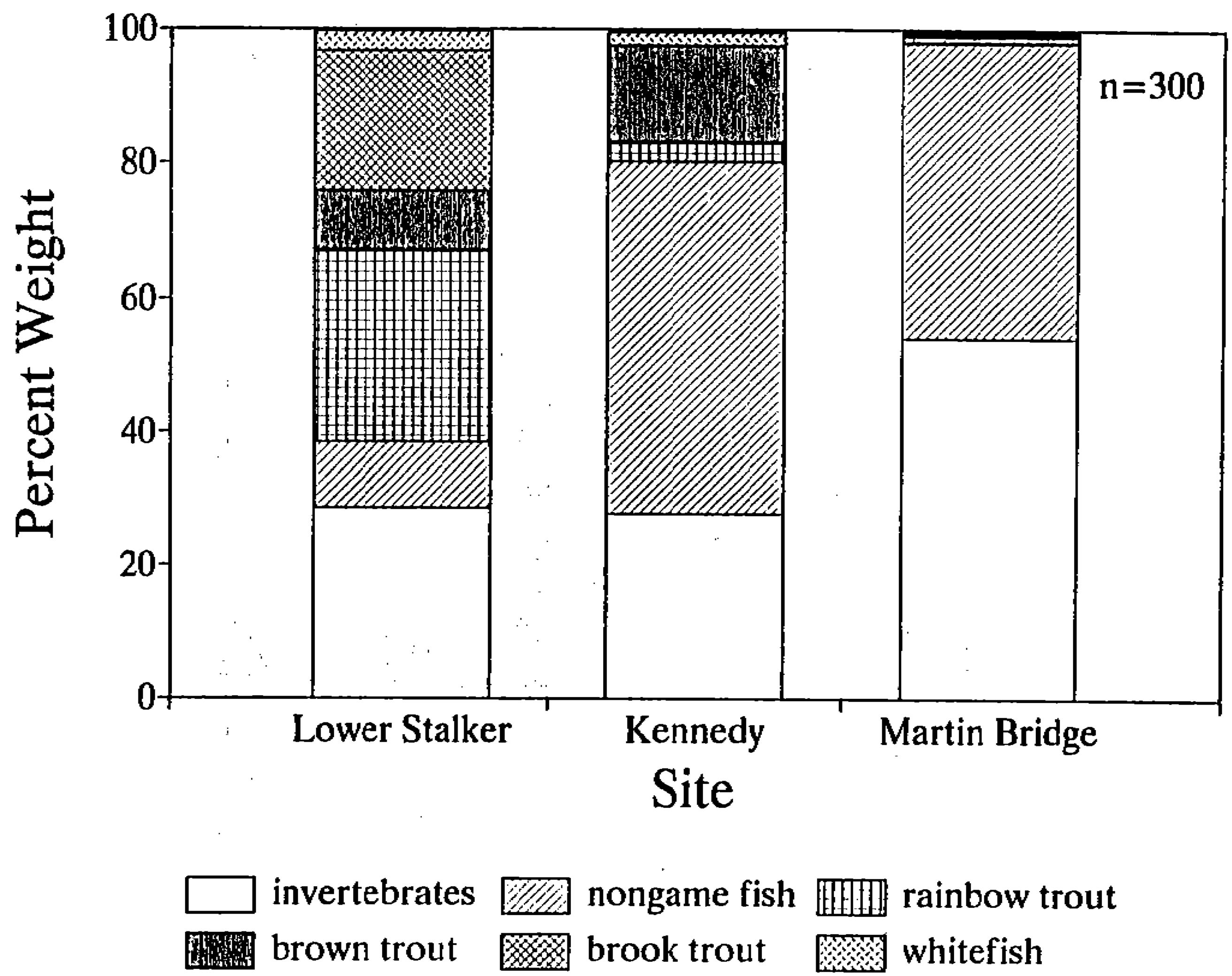


Figure 19. Variation in the composition (percent weight) of the brown trout diet at three sites in Silver Creek during 1993-1994 (all months combined).

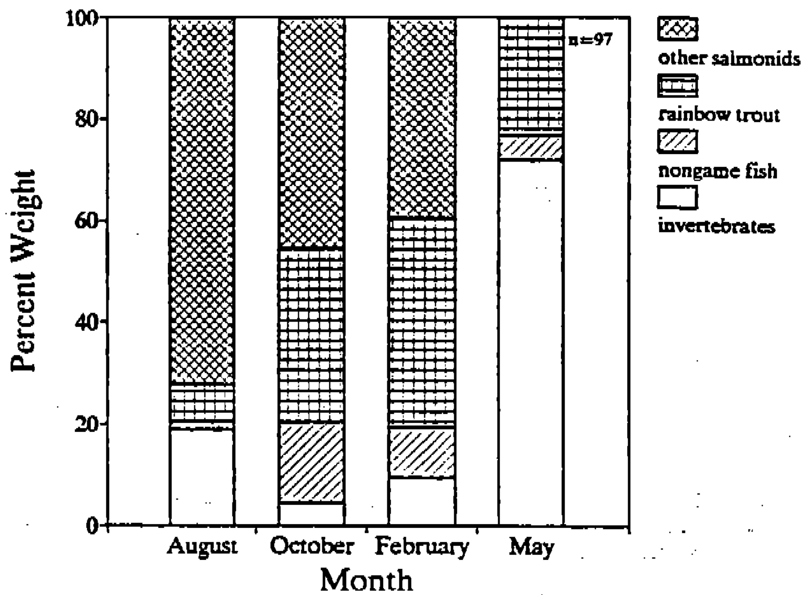


Figure 20. Seasonal variation in composition (percent weight) of the brown trout diet at the Lower Stalker site.

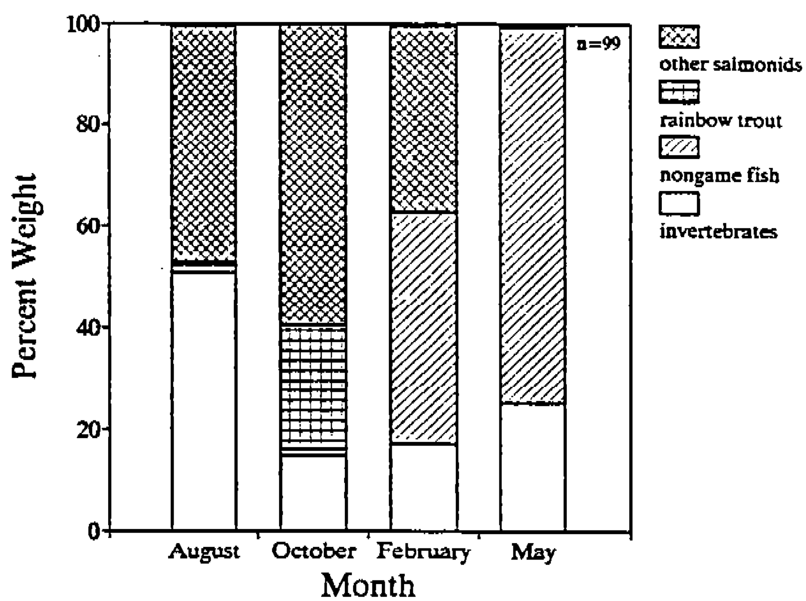


Figure 21. Seasonal variation in composition (percent weight) of the brown trout diet at the Kennedy site.

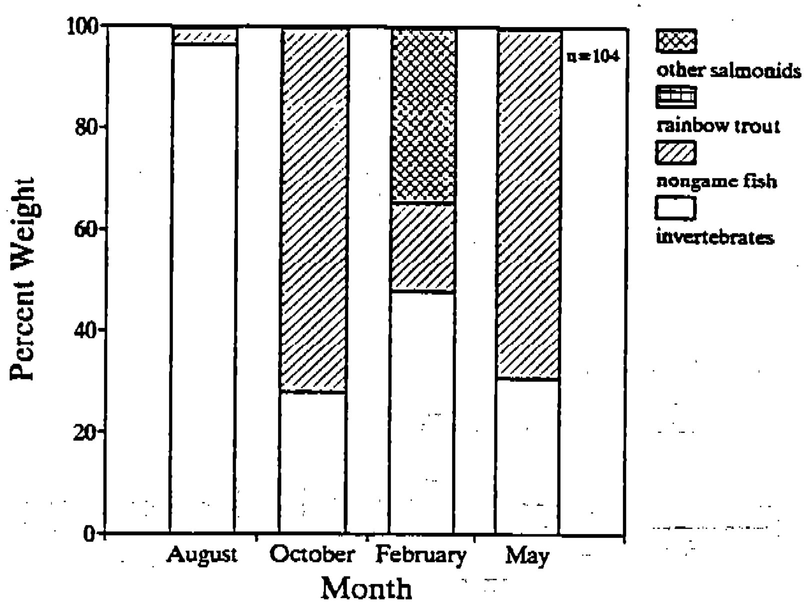


Figure 22. Seasonal variation in composition (percent weight) of the brown trout diet at the Martin Bridge site.

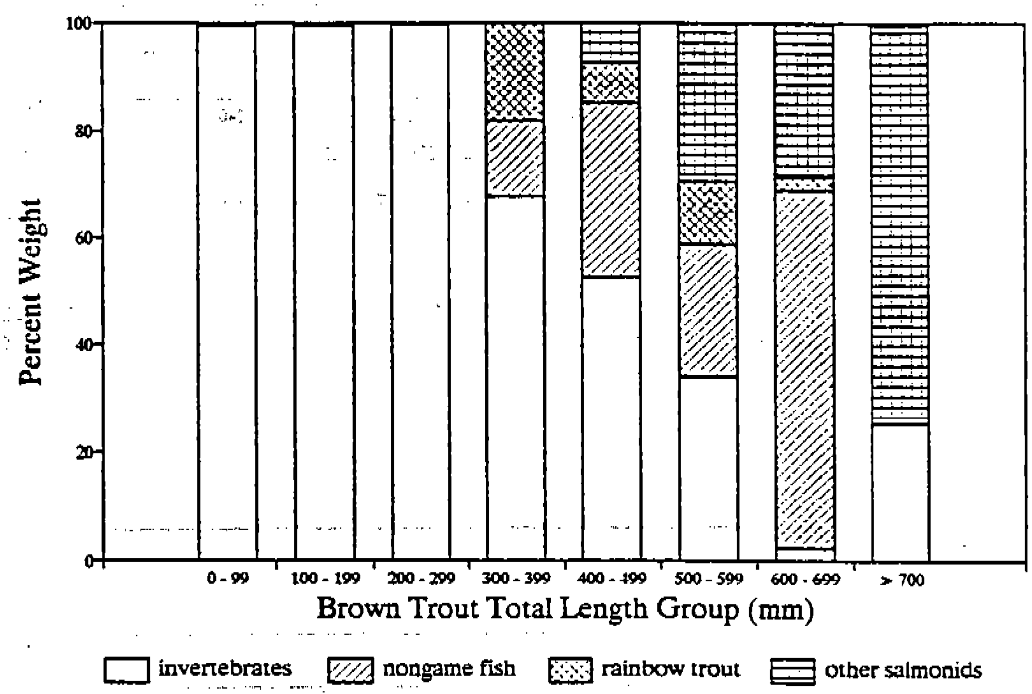


Figure 23. Diet composition of brown trout by 100 mm length-groups in Silver Creek (all sites and months combined).

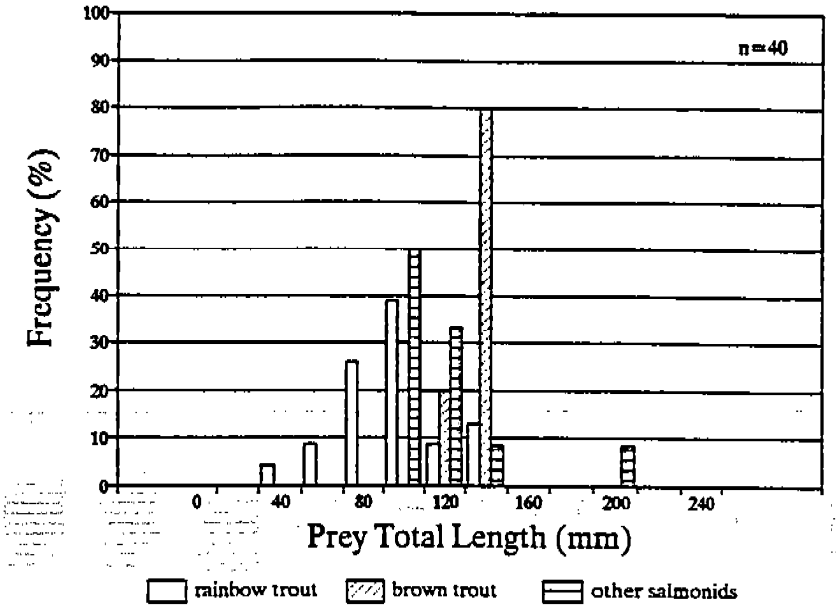


Figure 24. Length-frequency of rainbow trout, brown trout, and other salmonids consumed by brown trout in Silver Creek during 1993-1994.

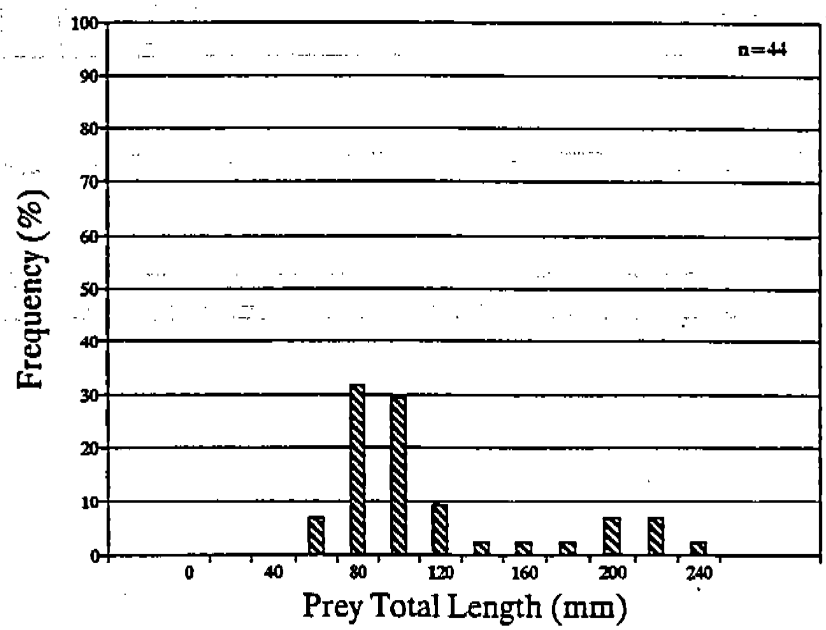


Figure 25. Length-frequency of nongame fish consumed by brown trout in Silver Creek during 1993-1994.

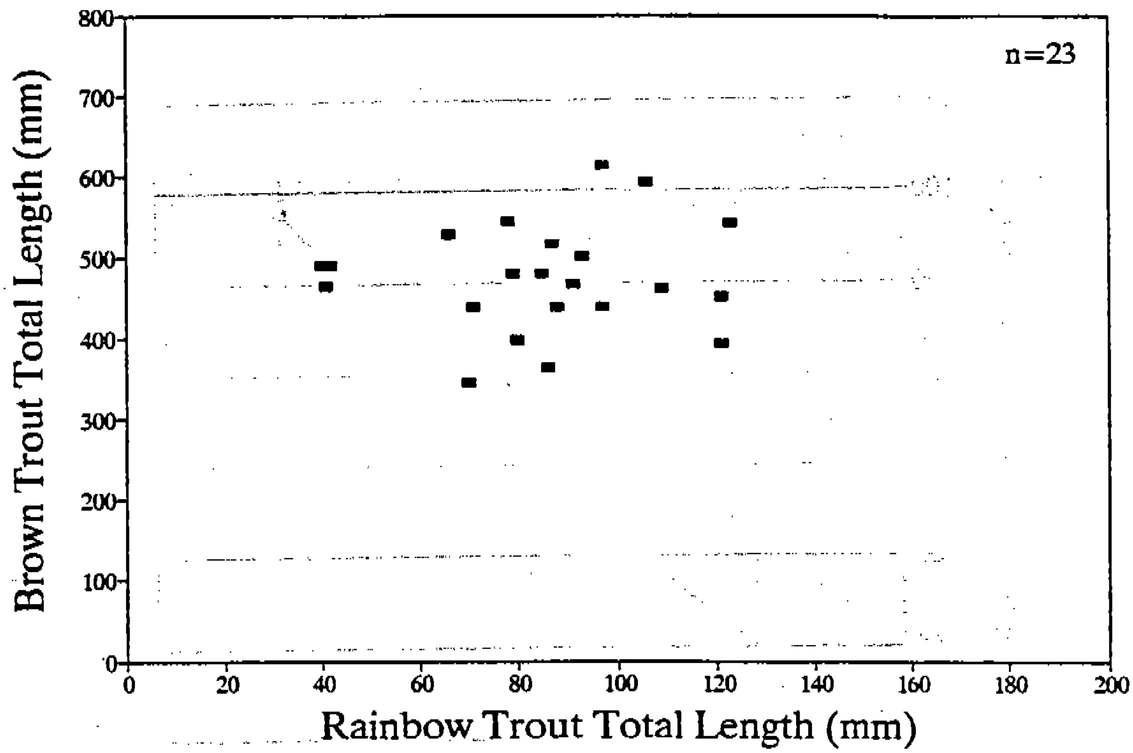


Figure 26. Length of predator brown trout compared with length of rainbow trout consumed. Data are from brown trout collected in 1993-1994 from Silver Creek, Idaho.

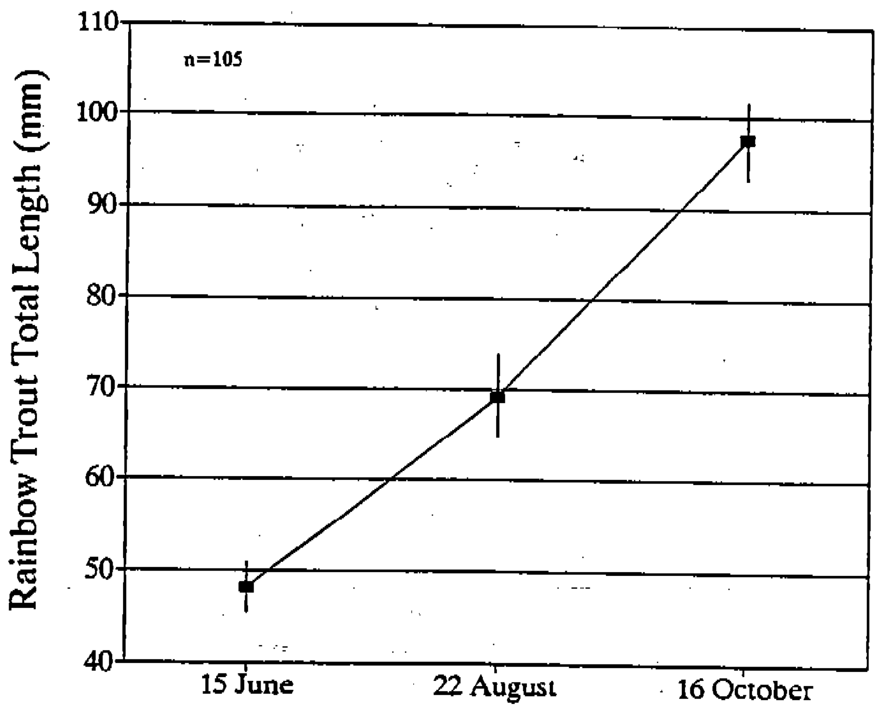


Figure 27. Mean length of juvenile rainbow trout captured at the Lower Stalker and Kennedy sites on three dates in 1993 (vertical lines indicate 95% confidence limits).

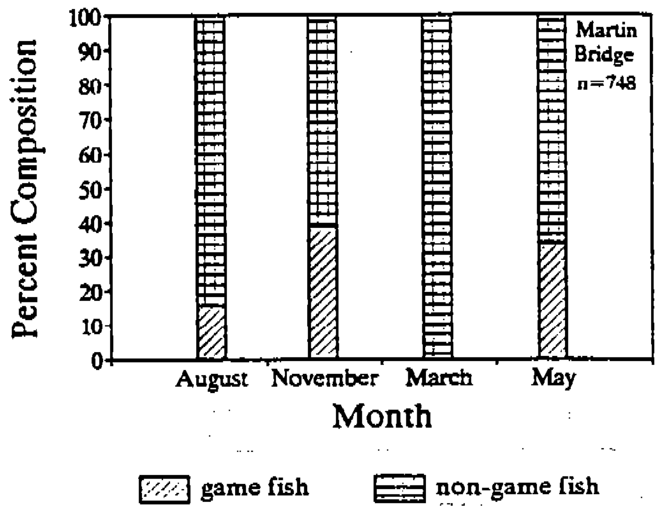


Figure 30. Seasonal composition (percent by number in the sample) of potential game and nongame prey fish species of brown trout at the Martin Bridge site in 1993-1994.

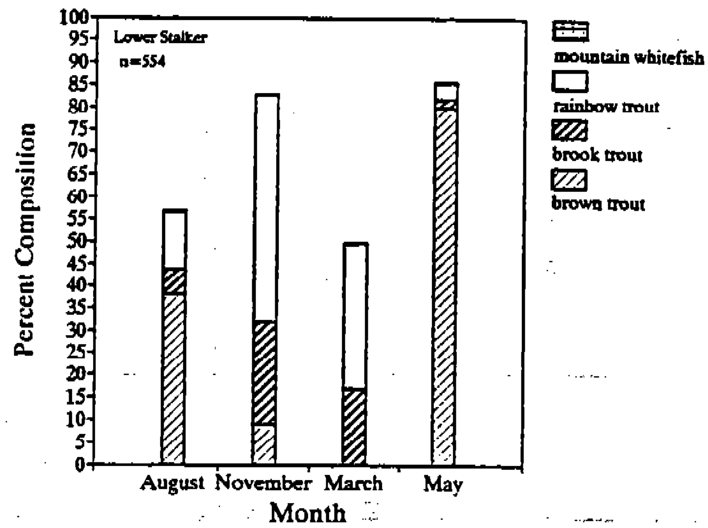


Figure 31. Seasonal composition (percent by number in the sample) of potential salmonid prey fish species of brown trout at the Lower Stalker site in 1993-1994.

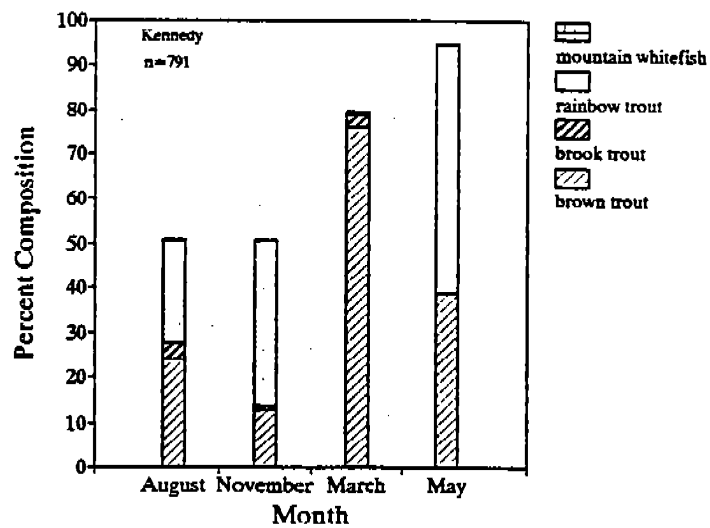


Figure 32. Seasonal composition (percent by number in the sample) of potential salmonid prey fish species of brown trout at the Kennedy site in 1993-1994.

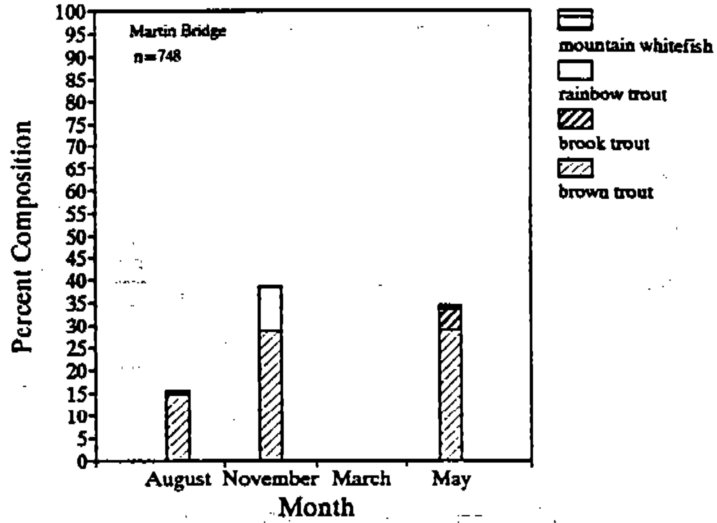


Figure 33. Seasonal composition (percent by number in the sample) of potential salmonid prey fish species of brown trout at the Martin Bridge site in 1993-1994.

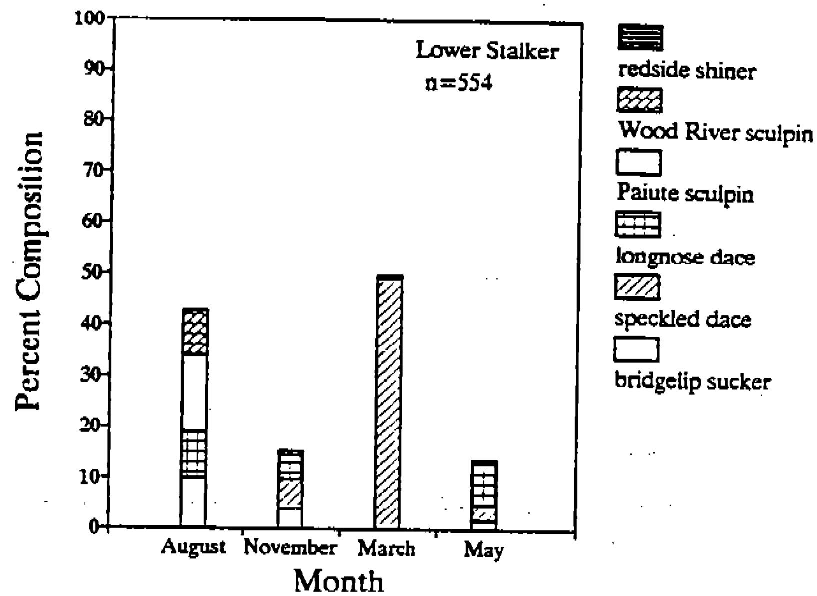


Figure 34. Seasonal composition (percent by number in the sample) of potential nongame prey fish species of brown trout at the Lower Stalker site in 1993-1994.

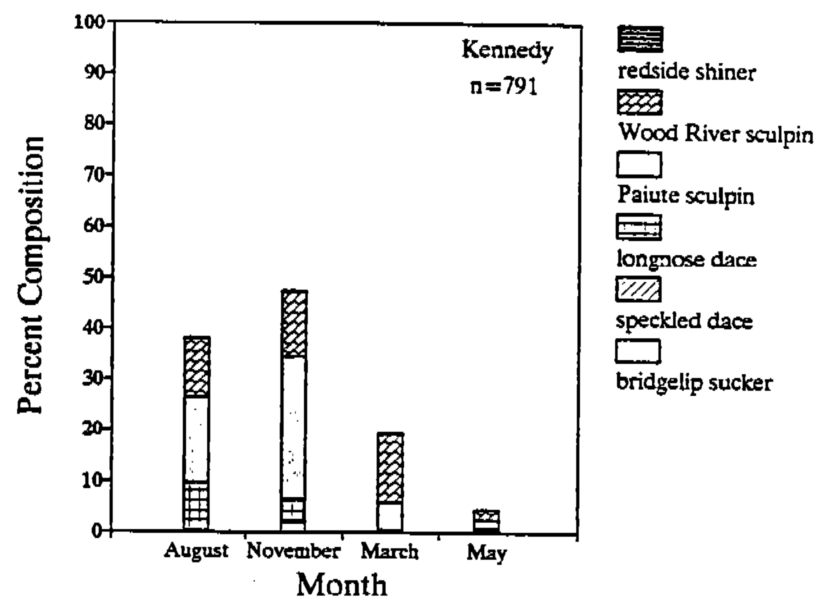


Figure 35. Seasonal composition (percent by number in the sample) of potential nongame prey fish species of brown trout at the Kennedy site in 1993-1994.

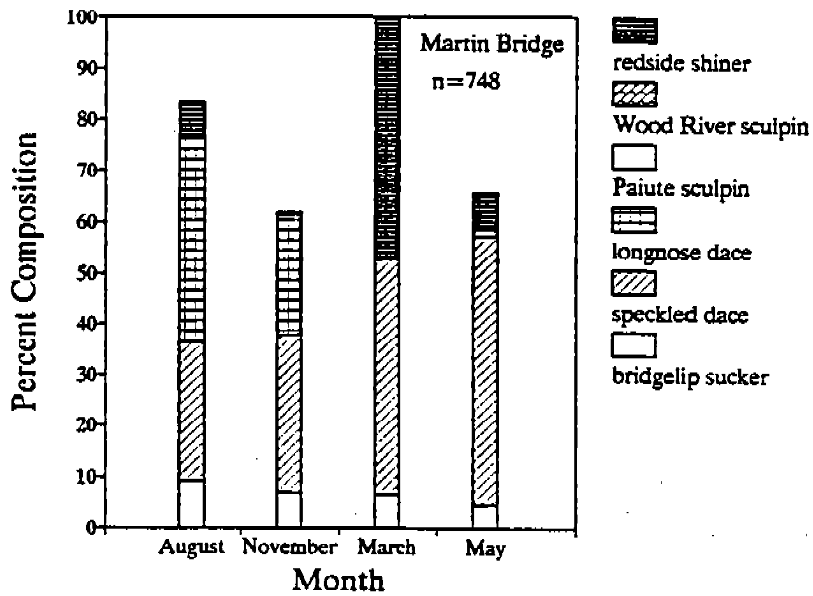


Figure 36. Seasonal composition (percent by number in the sample) of potential nongame prey fish species of brown trout at the Martin Bridge site in 1993-1994.

Table 1. Physical and biological characteristics of electrofishing sites in Stalker and Silver Creeks sampled in 1992-1993.

Site	Dominant Substrate	Dominant Macrophytes	Riparian Zone	Mean Wetted Width (m)	Length (m)	Surface Area (m^2)
Upper Stalker	silt	*Chara* & *Potamogeton* spp.	dense stands of *Salix* and *Betula* spp.	9.0	805	7,245
Lower Stalker	silt	*Chara* & *Potamogeton* spp.	dense stands of *Salix* and *Betula* spp.	9.3	950	8,835
Cabin	gravel and marl (upstream end) silt (downstream end)	*Chara* spp.	few *Salix* and and *Betula* spp., more *Carex* and *Poa* spp.	30.3	958	29,085
Kilpatrick Bridge	gravel (upstream) silt (downstream)	*Chara* & *Potamogeton* spp.	*Poa* and *Carex* spp. & extensive growths of *Scirpus* spp.	67.3	986	66,452
Martin Bridge	gravel	*Potamogeton* spp.	dense *Salix* and *Betula* spp.	19.8	998	19,760

Table 2. Species composition (percent by number) of electrofishing samples from Silver Creek for 1976-1977[a] and 1992-1993.

Site	Game	Nongame	Nongame Species				n
			sucker	dace	sculpin	shiner	
Lower Stalker							
1976-1977	73	26	11	14	1	0	
1992-1993	88	12	5	6	1	0	2535
Cabin & Kilpatrick							
1976-1977	82	18	15	3	0.2	0	
1992-1993	79	21	12	6	3	0	3336
Martin Bridge							
1976-1977	25	75	49	19	0	7	
1992-1993	47	53	25	22	0	6	1260

[a] Thurow (1978)

Table 3. Species composition (percent by number of game fish ≥ 150 mm TL collected at each site) in Stalker and Silver Creeks from electrofishing samples collected in 1976-1977[a], 1986[b], and 1992-1993.

Site	Rainbow	Brown	Brook	Mountain whitefish	n
Upper Stalker					
Fall 1986	85	7	6	1	303
Fall 1992	74	12	14	0	489
Summer 1993	76	14	9	1	358
Lower Stalker					
1976-1977	73	0	11	17	-
Fall 1992	55	37	8	0	956
Summer 1986	87	5	3	5	270
Summer 1993	52	36	10	2	371
Cabin					
1976-1977	57	0	2	40	504
Fall 1986	76	12	6	6	230
Fall 1992	75	14	7	3	689
Summer 1986	69	2	3	25	295
Summer 1993	58	36	3	3	469
Kilpatrick					
Fall 1992	78	17	0	4	700
Summer 1986	85	9	1	6	325
Summer 1993	69	24	0	7	656
Martin Bridge					
1976-1977	93	0	2	4	199
Fall 1986	39	61	0	0	183
Fall 1992	32	68	0	0	381
Summer 1986	69	30	2	0	125
Summer 1993	30	69	1	0	192
All Sites Combined					
1976-1977	68	0	2	30	703
Fall 1986	70	22	4	2	716
Fall 1992	64	28	6	2	3215
Summer 1986	79	8	2	11	1015
Summer 1993	61	31	4	3	2046

[a] Thurow (1978) [b] Riehle et al. (1989)

Table 4. Mean weights (g) of rainbow, brown, and brook trout (≥ 150 mm TL) captured by electrofishing at Stalker and Silver Creek sites in 1986[a] and 1992-1993.

Site	Rainbow Mean Weight	Rainbow n	Brown Mean Weight	Brown n	Brook Mean Weight	Brook n
Upper Stalker						
Fall 1986	226	132	497	12		
Fall 1992	187	360	533	57	150	67
Summer 1993	168	61	1013	31	70	22
Lower Stalker						
Fall 1992	132	202	647	178	133	39
Summer 1986	176	257	943	20		
Summer 1993	192	69	1203	72	170	15
Cabin						
Fall 1986	479	140	501	27		
Fall 1992	413	173	746	84	263	48
Summer 1986	311	223	1486	6		
Summer 1993	307	128	856	34	383	5
Kilpatrick						
Fall 1992	427	167	964	26	422	3
Summer 1986	403	246	1057	27		
Summer 1993	399	204	1024	73	610	1
Martin Bridge						
Fall 1986	349	67	1163	122		
Fall 1992	356	74	630	188	–	–
Summer 1986	183	97	992	54		
Summer 1993	392	42	813	120	305	1

[a] Riehle et al (1989)

Table 5. Density estimates (number of fish/hectare) of rainbow, brown, and brook trout (≥ 150 mm TL) in Stalker and Silver Creeks for 1986[a] and 1992-1993. Values in parentheses are 95% confidence limits.

Site	Rainbow	Brown	Brook
Upper Stalker			
Fall 1986	1188(785-1891)	no est	no est
Fall 1992	1066(820-1384)	116(69-206)	202(112-403)
Summer 1993	46(185-334)	73(51-109)	87(41-202)
Lower Stalker			
Fall 1992	1573(1182-2140)	930(695-1275)	269(144-550)
Summer 1986	1228(810-1953)	18(9-40)	no est
Summer 1993	327(189-612)	84(61-117)	36(18-76)
Cabin			
Fall 1986	202(130-329)	no est	no est
Fall 1992	587(425-835)	141(78-282)	36(21-69)
Summer 1986	308(201-493)	no est	no est
Summer 1993	248(170-374)	43(24-84)	3(1-6)
Kilpatrick			
Fall 1992	474(280-856)	60(35-114)	0.45
Summer 1986	231(147-382)	3(1-6)	no est
Summer 1993	268(201-365)	40(30-52)	0
Martin Bridge			
Fall 1986	no est	158(97-273)	no est
Fall 1992	241(143-436)	525(366-782)	0
Summer 1986	149(86-279)	31(19-51)	no est
Summer 1993	145(59-362)	101(77-131)	0

[a] Riehle et al (1989)

Table 6. Biomass (kilograms/hectare) estimates of rainbow, brown, and brook trout (≥ 150 mm TL) in Stalker and Silver Creeks for 1986[a] and 1992-1993. Values in parentheses are 95% confidence limits.

Site	Rainbow	Brown	Brook
Upper Stalker			
Fall 1986	268(177-427)	no est	no est
Fall 1992	199(153-259)	62(38-110)	30(17-60)
Summer 1993	41(31-56)	74(52-110)	6(3-14)
Lower Stalker			
Fall 1992	208(156-282)	602(450-825)	36(19-73)
Summer 1986	216(142-344)	17(8-38)	no est
Summer 1993	63(36-117)	101(73-141)	6(3-13)
Cabin			
Fall 1986	97(62-158)	no est	no est
Fall 1992	242(176-345)	105(58-210)	9(5-18)
Summer 1986	96(62-153)	no est	no est
Summer 1993	76(52-115)	37(21-72)	1(<1-2)
Kilpatrick			
Fall 1992	202(120-366)	58(34-110)	< 1
Summer 1986	93(59-154)	3(1-6)	no est
Summer 1993	107(80-146)	41(31-53)	0
Martin Bridge			
Fall 1986	no est	184(113-317)	no est
Fall 1992	86(51-155)	331(230-493)	0
Summer 1986	27(16-51)	31(19-50)	no est
Summer 1993	57(23-142)	82(63-106)	0

[a] Riehle et al (1989)

Table 7. Length frequencies of rainbow trout (≥150 mm TL) from electrofishing sites in Silver Creek for 1986[a] and 1992-1993. Values shown are percentages of the total electrofishing sample.

Study site	Date	Length class in mm					
		150-199	200-299	300-399	400-499	>500	n
Upper Stalker	Fall 1986	22	57	15	6	0	217
Upper Stalker	Fall 1992	5	86	6	2	1	363
Upper Stalker	Summer 1993	84	7	6	3	0	271
Lower Stalker	Fall 1992	14	80	5	1	0	561
Lower Stalker	Summer 1986	46	33	15	6	0	234
Lower Stalker	Summer 1993	49	13	27	12	0	86
Cabin	Summer 1986	28	31	22	19	0	205
Cabin	Summer 1993	34	17	35	13	1	218
Cabin	Fall 1986	9	29	27	35	0	114
Cabin	Fall 1992	2	82	10	5	0	516
Kilpatrick	Fall 1992	7	32	40	21	1	597
Kilpatrick	Summer 1986	15	14	47	24	0	275
Kilpatrick	Summer 1993	11	8	55	24	1	453
Martin Bridge	Summer 1986	64	9	22	5	0	86
Martin Bridge	Summer 1993	16	20	46	16	2	56
Martin Bridge	Fall 1986	6	58	24	10	1	67
Martin Bridge	Fall 1992	0	62	23	14	2	125

[a] Riehle et al. (1989)

Table 8. Length frequencies of brown trout (≥150 mm TL) from electrofishing sites in Silver Creek for 1986[a] and 1992-1993. Values shown are percentages of the total electrofishing sample.

Study site	Date	Length class in mm					
		150-199	200-299	300-399	400-499	>500	n
Upper Stalker	Fall 1986	45	9	18	27	0	22
Upper Stalker	Fall 1992	20	39	16	11	14	56
Upper Stalker	Summer 1993	29	31	6	10	24	51
Lower Stalker	Fall 1992	28	42	10	8	10	356
Lower Stalker	Summer 1986	0	14	21	43	21	14
Lower Stalker	Summer 1993	6	11	11	29	43	65
Cabin	Fall 1986	62	8	0	15	15	26
Cabin	Fall 1992	23	16	28	12	21	106
Cabin	Summer 1993	0	30	27	8	34	59
Kilpatrick	Fall 1992	6	3	29	29	33	125
Kilpatrick	Summer 1986	0	0	0	72	28	29
Kilpatrick	Summer 1993	2	4	19	37	39	158
Martin Bridge	Fall 1986	5	5	7	51	33	111
Martin Bridge	Fall 1992	44	5	21	20	11	258
Martin Bridge	Summer 1986	0	16	3	58	24	37
Martin Bridge	Summer 1993	6	33	9	28	24	132

[a]Riehle et al (1989)

Table 9. Physical and biological characteristics of sites at Stalker and Silver Creeks where brown trout were captured for diet analysis in 1993-1994.

Site	Dominant Substrate	Dominant Macrophytes	Riparian Zone	Mean Wetted Width (m)	Length (m)	Surface Area (m^2)
Lower Stalker	silt	*Chara* & *Potamogeton* *spp.*	dense stands of *Salix* and *Betula spp.*	9.3	1,250	11,625
Kennedy	gravel and marl	*Chara spp.*	*Salix* and and *Betula spp.*, some *Carex* and *Poa spp.*	28.1	950	26,695
Martin Bridge	gravel	*Potamogeton* *spp.*	dense *Salix* and *Betula spp.*	19.8	998	19,760

Table 10. Regression statistics ($Y = a + bX$) relating measurements (in mm) of the cleithrum, pharyngeal teeth, dentary, and operculum (X) to total length (Y) for 8 prey fish species from Silver Creek, Idaho.

			Cleithrum 1			Cleithrum 2			Pharyngeal Teeth			Dentary			Operculum		
Species	TL Range (mm)	n	a	b	R^2	a	b	R^2	a	b	R^2	a	b	R^2	a	b	R^2
RBT	66-147	30	-10.92	9.55	.96	-6.66	13.21	.91				-10.29	20.75	.89	-7.82	18.59	.86
BNT	92-148	13	-12.72	9.34	.96	-9.12	14.10	.95				10.70	15.02	.86	15.54	13.20	.69
BKT	95-142	12	23.85	7.26	.83	46.58	8.14	.68				60.88	6.92	.66	45.59	10.52	.70
PSC	75-114	13	9.97	5.01	.97							34.47	12.28	.96		*	
WRSC	54-114	13	9.42	5.10	.97							34.02	12.78	.88		*	
SKR	102-214	8	-1.27	8.86	.97	3.73	11.23	.99	-3.40	15.37	.96	29.62	20.44	.86		*	
RS	56-115	22	14.34	6.64	.96	9.13	9.60	.92	13.36	12.59	.94	19.62	13.87	.90	23.06	13.46	.76
SD	57-85	14	-4.38	9.36	.80	12.18	11.45	.77	.67	17.49	.71	21.42	17.44	.60	26.37	14.60	.62

RBT=rainbow trout BNT=brown trout BKT=brook trout PSC=Paiute sculpin WRSC=Wood River sculpin SKR=Bridgelip sucker RS=redside shiner SD=speckled dace

* not significant ($P < .05$)

Table 11. Percent frequency of occurrence (FO) and percent by weight (WT) of prey consumed by brown trout (n = 300) in Silver Creek, Idaho, during 1993-1994 (all sites and months combined).

	FO (%)	WT (%)
Insects	80.3	5.8
Leeches	29.3	4.1
Worms	13.7	10.0
Molluscs	48.0	9.3
Crustaceans	50.0	7.1
Vegetation	57.7	1.5
Fish eggs	8.0	3.2
Other (included small mammals, birds, and unidentifiable organic materials)	1.0	1.6
Fish	25.3	57.4
unidentified salmonid	1.3	2.6
rainbow trout	6.7	7.9
brown trout	1.7	7.3
brook trout	2.3	5.2
mountain whitefish	1.0	1.4
unidentified nonsalmonid	3.0	0.3
bridgelip sucker	4.0	24.7
redside shiner	1.7	0.8
speckled & longnose dace	5.0	2.4
Paiute sculpin	1.7	4.3
Wood River sculpin	0.3	0.5

Table 12. Percent frequency of occurrence (FO) and percent by weight (WT) of prey consumed by brown trout (n=97) at the Lower Stalker site in Silver Creek, Idaho during 1993-1994.

	August		October		February		May	
	FO (%)	WT (%)	FO (%)	WT (%)	FO (%)	WT (%)	FO (%)	WT (%)
Insects	90.0	9.0	63.0	2.0	89.5	4.1	85.7	8.7
Leeches	16.7	1.0	7.4	.4	10.5	0.1	57.1	19.5
Worms	10.0	2.0	7.4	.6	0.0	0.0	23.8	2.0
Molluscs	26.6	5.0	33.3	1.4	15.8	1.9	76.2	10.2
Crustaceans	23.3	0.3	7.4	0.0	89.5	3.4	71.4	29.8
Vegetation	70.0	3.0	37.0	0.2	36.8	0.5	47.6	2.0
Fish eggs	0.0	0.0	3.7	0.4	0.0	0.0	4.8	0.4
Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fish	23.3	78.6	40.7	94.9	42.1	90.0	33.3	27.5
unidentified salmonid	0.0	0.0	0.0	0.0	5.3	1.8	0.0	0.0
rainbow trout	10.0	6.9	18.5	34.0	15.8	41.0	23.8	22.5
brown trout	3.3	67.9	0.0	0.0	0.0	0.0	0.0	0.0
brook trout	0.0	0.0	7.4	37.1	15.8	37.4	4.8	0.2
mountain whitefish	3.3	1.9	3.7	8.0	0.0	0.0	0.0	0.0
unidentified nonsalmonid	3.3	0.9	7.4	0.2	0.0	0.0	4.8	0.7
bridgelip sucker	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
redside shiner	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
speckled & longnose dace	0.0	0.0	0.0	0.0	0.0	0.0	4.8	4.0
Paiute sculpin	6.6	0.9	3.7	15.6	0.0	0.0	0.0	0.0
Wood River sculpin	0.0	0.0	0.0	0.0	5.3	9.9	0.0	0.0

Table 13. Percent frequency of occurrence (FO) and percent by weight (WT) of prey consumed by brown trout (n=99) at the Kennedy site in Silver Creek, Idaho during 1993-1994.

	August		October		February		May	
	FO (%)	WT (%)	FO (%)	WT (%)	FO (%)	WT (%)	FO (%)	WT (%)
Insects	86.0	8.2	52.9	3.5	80.0	2.9	88.9	4.8
Leeches	42.8	8.4	11.8	0.6	15.0	0.1	40.7	3.1
Worms	34.3	14.0	11.8	2.3	0.0	0.0	0.0	0.0
Molluscs	54.3	12.6	47.0	5.0	50.0	5.6	55.6	7.1
Crustaceans	31.4	1.6	29.4	2.2	75.0	8.1	63.0	8.1
Vegetation	82.8	7.7	82.3	2.4	55.0	1.1	44.4	0.9
Fish eggs	0.0	0.0	17.6	5.2	25.0	2.0	0.0	0.0
Other	2.8	3.8	0.0	0.0	0.0	0.0	3.7	7.7
Fish	20.0	43.5	23.5	78.6	15.0	80.2	22.2	68.3
unidentified salmonid	2.8	0.7	0.0	0.0	5.0	35.6	0.0	0.0
rainbow trout	5.7	0.7	11.8	22.6	0.0	0.0	0.0	0.0
brown trout	5.7	32.5	5.9	54.8	0.0	0.0	0.0	0.0
brook trout	0.0	0.0	0.0	0.0	0.0	0.0	3.7	0.5
mountain whitefish	2.8	8.1	0.0	0.0	0.0	0.0	0.0	0.0
unidentified nonsalmonid	2.8	0.0	5.9	0.7	0.0	0.0	0.0	0.0
bridgelip sucker	0.0	0.0	0.0	0.0	5.0	0.0	14.8	67.2
redside shiner	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
speckled & longnose dace	5.7	1.4	5.9	0.5	0.0	0.0	0.0	0.0
Paiute sculpin	0.0	0.0	0.0	0.0	5.0	44.6	3.7	0.7
Wood River sculpin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 14. Percent frequency of occurrence (FO) and percent by weight (WT) of prey consumed by brown trout (n=104) at the Martin Bridge site in Silver Creek, Idaho during 1993-1994.

	August		October		February		May	
	FO (%)	WT (%)	FO (%)	WT (%)	FO (%)	WT (%)	FO (%)	WT (%)
Insects	84.0	1.9	63.6	6.6	86.4	38.3	91.7	5.5
Leeches	52.0	1.1	6.1	0.3	4.5	0.3	83.3	5.6
Worms	64.0	65.6	0.0	0.0	0.0	0.0	4.2	0.0
Molluscs	80.0	24.5	33.3	2.6	22.7	1.9	83.3	10.0
Crustaceans	56.0	2.5	33.3	1.0	68.2	6.8	87.5	9.4
Vegetation	64.0	0.7	60.6	1.4	50.0	1.0	50.0	0.7
Fish eggs	0.0	0.0	42.4	60.9	0.0	0.0	0.0	0.0
Other	4.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Fish	20.0	3.6	15.2	27.1	22.7	51.7	33.3	68.7
unidentified salmonid	4.0	0.0	0.0	0.0	4.5	9.2	0.0	0.0
rainbow trout	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
brown trout	0.0	0.0	0.0	0.0	4.5	25.0	0.0	0.0
brook trout	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
mountain whitefish	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
unidentified nonsalmonid	0.0	0.5	0.0	0.0	9.1	2.1	0.0	0.0
bridgelip sucker	0.0	0.0	3.0	2.6	4.5	0.2	20.8	64.8
redside shiner	4.0	0.7	3.0	0.1	4.5	5.0	8.3	2.6
speckled & longnose dace	16.0	2.3	9.0	24.4	13.6	10.2	4.2	1.3
Paiute sculpin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wood River sculpin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 15. Electivity Index (D) values calculated for brown trout (n = 300) captured in Silver Creek, Idaho, in 1993-1994 (all sites combined). D ranges from -1 to +1 and indicates negative or positive selection for individual prey species.

Prey Species	August	October	February	May
rainbow trout	0.3	0.1	0.7	0.1
brown trout	-0.4	-0.7	-1.0	-1.0
brook trout	-1.0	0.1	0.8	0.4
mountain whitefish	1.0	1.0	0.0	0.0
bridgelip sucker	-1.0	0.0	0.8	0.9
speckled and longnose dace	-0.1	-0.2	0.6	0.0
Paiute sculpin	-0.1	-0.4	0.2	0.6
Wood River sculpin	-1.0	-1.0	-0.5	-1.0
redside shiner	0.2	1.0	0.0	0.4

Table 16. Daily ration (g dry weight of fish only) estimates for brown trout collected at three sites in Silver Creek, Idaho, during 1993-1994. Values for all sites combined were used to estimate annual brown trout consumption of rainbow and brown trout.

Month/Site	Average Daily Fish Meal	Average Daily Salmonid Meal	Average Daily Nonsalmonid Meal	Average Daily Rainbow Trout Meal	Average Daily Brown Trout Meal	n
August						
Lower Stalker	2.34	2.10	0.24	0.18	1.37	7
Kennedy	4.86	4.55	0.31	0.90	0.00	6
Martin Bridge	0.74	0.00	0.74	0.00	1.46	5
All Sites	**2.65**	**2.22**	**0.43**	**0.36**	**0.94**	**18**
October						
Lower Stalker	3.87	3.07	0.80	1.50	0.00	9
Kennedy	4.96	4.96	0.00	2.52	0.00	3
Martin Bridge	0.77	0.00	0.77	0.00	2.45	5
All Sites	**3.26**	**2.63**	**0.63**	**1.30**	**0.49**	**17**
February						
Lower Stalker	3.24	2.76	0.48	1.77	0.00	7
Kennedy	8.30	0.00	8.30	0.00	3.20	2
Martin Bridge	3.38	3.20	0.17	0.00	0.00	4
All Sites	**3.83**	**2.55**	**1.28**	**1.18**	**0.71**	**13**
May						
Lower Stalker	1.79	1.53	0.26	1.53	0.00	7
Kennedy	13.48	2.46	12.98	0.00	0.00	5
Martin Bridge	18.33	0.00	18.33	0.00	0.00	8
All Sites	**12.14**	**1.17**	**11.44**	**0.45**	**0.00**	**20**

Table 17. Brown trout consumption of rainbow trout at three sites in upper Silver Creek, Idaho, during 1993-1994. Aerial and linear (number per mile in parentheses) estimates were calculated for comparison with literature values.

Site/Period	Days in Period	Density of Brown Trout ≥ 300 mm TL (number/hectare)	Average Daily Rainbow Trout Consumption (g dry weight)	Dry Weight of Rainbow Trout Consumed Per Hectare (g)		Total Number of Rainbow Trout Consumed Per Hectare
Lower Stalker						
Jun-Aug	92	69 (103)	0.180	1,143 (1,706)		589 (879)
Sep-Nov	91	315 (471)	1.497	42,911 (64,163)		19,784 (29,582)
Dec-Feb	90	100 (339) *	1.768	15,912 (53,942)		4,501 (15,259)
Mar-May	92	50 (220) *	1.533	7,052 (31,028)		3,624 (1,862)
					Total	**28,498 (47,582)**
Kennedy						
Jun-Aug	92	30 (247)	0.900	2,484 (20,452)		1,280 (10,542)
Sep-Nov	91	86 (719)	2.517	19,698 (164,685)		9,082 (75,926)
Dec-Feb	90	75 (339) *	0	0		0
Mar-May	92	25 (220) *	0	0		0
					Total	**10,362 (86,468)**
Martin Bridge						
Jun-Aug	92	61 (315)	0	0		0
Sep-Nov	91	245 (1,261)	0	0		0
Dec-Feb	90	100 (323) *	0	0		0
Mar-May	92	50 (210) *	0	0		0
					Total	**0**

* estimated density

Table 18. Brown trout consumption of brown trout at three sites in upper Silver Creek, Idaho, during 1993-1994. Aerial and and linear (number per mile in parentheses) estimates were calculated for comparison with literature values.

Site/Period	Days in Period	Density of Brown Trout ≥ 300 mm TL (number/hectare)	Average Daily Brown Trout Consumption (g dry weight)	Dry Weight of Brown Trout Consumed Per Hectare (g)		Total Number of Brown Trout Consumed Per Hectare
Lower Stalker						
Jun-Aug	92	69 (103)	1.370	8,697 (12,982)		1,518 (2,266)
Sep-Nov	91	315 (471)	0	0		0
Dec-Feb	90	100 (339) *	0	0		0
Mar-May	92	50 (220) *	0	0		0
					Total	**1,518 (2,266)**
Kennedy						
Jun-Aug	92	30 (247)	0	0		0
Sep-Nov	91	86 (719)	0	0		0
Dec-Feb	90	75 (339) *	3.200	21,600 (97,632)		3,370 (15,234)
Mar-May	92	25 (220) *	0	0		0
					Total	**3,370 (15,234)**
Martin Bridge						
Jun-Aug	92	61 (315)	1.460	8,194 (42,311)		1,430 (7,384)
Sep-Nov	91	245 (1,261)	2.450	54,623 (281,140)		7,445 (38,319)
Dec-Feb	90	100 (323) *	0	0		0
Mar-May	92	50 (210) *	0	0		0
					Total	**8,875 (45,703)**

* estimated density

Table 19. Values used to estimate the number of rainbow trout prey available to brown trout annually in Silver Creek, based on population data collected in 1992-1993. Calculations were made assuming mortality rates from egg to Age-I of 0.98 and 0.90. A mortality rate of 0.50 to Age-II was used in both calculations.

Site	# of Females Per Hectare ≥ 250 mm	# of Eggs Per Female	# of Eggs Per Hectare	Mortality Rate to Age-I	# of Fish Age-I	Mortality Rate to Age-II	# of Fish Age-II	# of Fish Age-I + Age-II Per Hectare Per Year
Lower Stalker	140	4000	560,000	0.98	11,200	0.50	5600	16,800
Kennedy	118	4000	472,000	0.98	9,440	0.50	4720	14,160
Martin Bridge	69	4000	276,000	0.98	5,520	0.50	2760	8,280
Lower Stalker	140	4000	560,000	0.90	56,000	0.50	28,000	84,000
Kennedy	118	4000	472,000	0.90	47,200	0.50	23,600	70,800
Martin Bridge	69	4000	276,000	0.90	27,600	0.50	13,800	41,400