PREDATION OF JUVENILE SALMONIDS BY RESIDENT TROUT AND OTHER FISHES IN THE LOWER CEDAR RIVER, WASHINGTON

DRAFT REPORT TO SEATTLE PUBLIC UTILITIES

by

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EXECUTIVE SUMMARY

From 2006 to 2010, Washington Department of Fish and Wildlife, U.S. Fish and Wildlife Service, and King County undertook a cooperative project to estimate the abundance of resident trout and quantify their predation on juvenile salmonids in the Cedar River below Landsburg Diversion Dam. Summer sampling was conducted in 2006-2008, while winter-spring sampling was conducted in 2008-2010. Efforts to estimate resident trout abundance was conducted during three different summers and two winter-spring periods. Predation and diet sampling was conducted during two summer and two winter-spring periods.

Summer abundance estimates of resident trout from 2006 to 2008 were remarkably similar, ranging from 16,320 to 17,435. In 2006 and 2007, trout were captured and marked for a recapture and/or resight (snorkeling) procedure, while in 2008 snorkel surveys alone were used. The catch of rainbow trout in both 2006 and 2007 was much higher than cutthroat trout, and the proportion of cutthroat trout in the catch decreased from downstream to upstream strata. The most abundant size class of trout (both species) was the 150-250 mm fork length (FL) class.

For both summers combined, 728 trout diet samples were analyzed. Trout predation rates of salmonids were low and those that were consumed were mostly juvenile coho salmon. Only one trout (rainbow/cutthroat trout hybrid) was observed in the summer diet samples. Overall, resident trout did not appear to be an important predator of juvenile trout. Eighty-five percent of the prey fish observed in the diet were sculpin. The trout summer diet consisted primarily of aquatic insects.

Winter-spring trout abundance estimates were approximately 2.5 to 6 times less than the summer abundance. Similar to summer, there was a decreasing trend in the proportion of cutthroat trout in the trout catch from the furthest downstream stratum to the most upstream stratum. The length composition of the winter-spring trout catch was more evenly distributed among the three length classes (< 150, 150-249, and > 250 mm FL) than during the summer.

Predation of sockeye salmon fry by trout was observed from January to April, and was primarily observed in the lower and extreme lower strata. In addition, there were distinct differences in predation of sockeye fry between cutthroat and rainbow trout. Sockeye salmon fry were observed in all size classes of cutthroat trout but made up a minor portion of the diet of cutthroat trout > 250 mm FL. Rainbow trout < 200 mm FL rarely consumed sockeye salmon fry; whereas rainbow trout > 200 occasionally consumed large of fry numbers and made up a substantial part of the overall diet. The maximum number of sockeye salmon fry observed in a rainbow trout was 298, whereas it was 27 for cutthroat trout. For 2010, we estimated that trout consumed 8.8% of the sockeye salmon fry. Of which, 8.5% was attributed to rainbow trout and 0.3% to cutthroat trout.

Results from 2010 indicated that resident trout can be important predators of Chinook salmon. Predation of juvenile Chinook salmon was observed primarily in cutthroat trout. For the three classes of cutthroat trout, juvenile Chinook salmon represented from 5 to 30% of the combined diet from January to April. Chinook salmon never represented more than 2% of the January-April diet of any size class of rainbow trout for either 2008 or 2010. An estimated 66,000 Chinook salmon were consumed by resident trout in 2010, resulting in a rough estimate of 33% predation.

We also examined 141 coho salmon diet samples from 2008 and 2010 winter-spring collections. Eleven percent of the coho salmon collected during the January to April period had consumed sockeye salmon fry. Five juvenile Chinook salmon were also observed in coho salmon samples in 2008 when juvenile Chinook salmon were abundant. Largely because they are smaller, yearling coho salmon usually have a lower predation rate of juvenile salmonids than resident trout. However, coho salmon yearlings may be more abundant than resident trout and may be a more important predator in some situations.

INTRODUCTION

Predation is a source of mortality for anadromous salmonid stocks in the Pacific Northwest. Consequently, considerable research has focused on predation in freshwater by northern pikeminnow *Ptychocheilus oregonesnsis* (e.g., Rieman et al. 1991; Tabor et al. 1993), smallmouth bass *Micropterus dolomieu* (Fayram and Sibley 2000; Fritts and Pearsons 2004; Tabor et al. 1993), walleye *Stizostedion vitreum* (Rieman et al. 1991; Baldwin et al. 2003), and other piscivorous fishes. Sympatric native salmonids also play an important role as predators on salmon and steelhead juveniles. For instance, cutthroat trout *Oncorhynchus clarkii* were found to be significant predators of both sockeye salmon *O. nerka* and Chinook salmon *O. tshawytscha* in Lake Washington (Nowak et al. 2004), and Beauchamp (1995) reported that steelhead smolts *O. mykiss* were the primary riverine predator of sockeye salmon in the Cedar River, Washington, consuming approximately 15% of the emergent fry.

After emerging from their redds in the winter, juvenile salmonids spend a few days to several months in riverine habitats in the Cedar River, Washington. During this period they are vulnerable to a variety of predators, especially piscivorous fishes (Tabor and Chan 1996b; Tabor et al. 2001). For example, survival of hatchery sockeye salmon fry released at Landsburg Dam at river kilometer (Rkm) 35 in the Cedar River can be as low as 1% (Seiler and Kishimoto 1996) and losses are believed to be primarily due to piscivorous fishes including cutthroat trout, rainbow trout, juvenile coho salmon *O. kisutch*, and cottids. The impact that trout have on juvenile salmonid abundance is not well understood, but it is widely believed that trout have higher predation rates on juvenile salmon than other fishes (Tabor et al. 1996a; Tabor et al. 2001). However, preliminary data suggests that there are differences between rainbow and cutthroat trout predation in the Cedar River (Tabor et al. 2001). Tabor et al. (2001) found that during the winter sockeye salmon fry made up a larger proportion of the diet of cutthroat trout (90%) than in the diet of rainbow trout (69%), suggesting that cutthroat trout may be the dominant piscivore. By early May, sockeye salmon fry become less prevalent in the diet of rainbow and cutthroat trout as their diet shifts to aquatic insects and catostomid eggs (Tabor et al. 2001). As the summer progresses, the diet of rainbow trout and cutthroat trout in the Cedar River shifts once again to mostly aquatic and terrestrial insects, larval catostomids, and a small proportion of other prey fish (such as juvenile coho salmon and cottids).

While some preliminary information exists on the diet of rainbow and cutthroat trout below Landsburg Diversion Dam, their abundance during the spring and summer is unknown. In an attempt to protect declining steelhead populations, the Cedar River was closed to angling in 1995. By 2003, concerns were expressed that the fishery closure resulted in a large and thriving resident trout that may be severely limiting the survival of juvenile sockeye salmon and Chinook salmon. Washington Department of Fish and Wildlife (WDFW) responded by establishing a Cedar River catch and release fishery in 2003. In 2006, WDFW, USFWS (U.S. Fish and Wildlife Service), and King County developed a rigorous study plan to estimate resident trout abundance and determine their direct impact on anadromous salmonids via predation in the Cedar River. The objectives of this study were to:

1. Estimate the abundance of rainbow and cutthroat trout during the spring and summer months in the Cedar River below Landsburg Diversion Dam.

2. Quantify predation on juvenile salmonids by resident trout and other piscivorous fishes in the Cedar River below Landsburg Diversion Dam.

3. Determine differences in predation rates and total predation between resident trout species and other piscivorous fishes.

The results of this study will help inform future management of the Cedar River fishery resources and fill gaps in our understanding of the interaction between resident and anadromous salmonid populations in western Washington.

STUDY AREA

The Cedar River is the largest tributary to Lake Washington (Figure 1), accounting for about half of the mean annual surface flow into the lake (King County 1993). The Cedar River drains an area of 477 km^2, originates at approximately 1,090 m elevation, and over its 89-km course falls 1,085 m. Base flows at USGS gage 12119000 near the mouth of the Cedar River are approximately 375 cfs during the winter and 125 cfs during the summer. Daily mean water temperature in the lower reach can range from 5.7°C in the winter to around 20°C during the summer. The gradient of the lower Cedar River ranges from 0.2 to 0.7%. Much of the surrounding drainage area of the lower reach has residential and agricultural development. The lower 3 km of the Cedar River occurs within a large flood plain that is within the City of Renton and is heavily urbanized. The Landsburg Diversion Dam, a water diversion structure at Rkm 35.9, was built in 1901 and prevented upstream fish movements until a fish ladder system was constructed and began operation in fall 2003.

In comparison to other similar-sized basins in the Pacific Northwest, the Lake Washington basin is inhabited by a relatively large number of fish species. Overall, there are 26 native species and at least 20 introduced species within the Lake Washington basin. The Cedar River fish fauna is composed primarily of native salmonids and cottids. Anadromous salmonids in the Cedar River system include sockeye salmon, Chinook salmon, coho salmon, and steelhead. Other salmonids include rainbow trout, cutthroat trout, and mountain whitefish *Prosopium williamsoni*. Cottid species found in the Cedar River include coastrange sculpin *Cottus aleuticus*, prickly sculpin *C. asper*, riffle sculpin *C. gulosus*, shorthead sculpin *C. confusus* and torrent sculpin *C. rhotheus* (Tabor et al. 2007). Besides salmonids and cottids, there are some adfluvial species, primarily longfin smelt *Spirinchus thaleichthys*, largescale sucker *Catostomus macrocheilus*, and peamouth *Mylocheilus caurinus*, that spawn in the lower reach of the Cedar River. Introduced fish species within this basin inhabit primarily Lake Washington and Lake Sammamish, but occasionally occur in the Cedar River. For example smallmouth bass have been found throughout the lower Cedar River but their numbers are low.

Figure 1.—Map of the lower Cedar River displaying four strata (Extreme Lower, Lower, Middle, and Upper) used to sample piscivorous fishes, 2006-2010. Areas of the Cedar River in blue were not sampled.

METHODS

Study Design

Resident trout and other predatory fishes were collected from the Cedar River below Landsburg Dam (Figure 1). The study area included approximately 35 Rkms and was divided into four strata based on gradient, natural confinement, and channel type. We did not include the convergence pool at the downstream end of Cedar River (Rkm 0 – 1.1) with Lake Washington because it has been severely channelized and dredged and functions more as lentic habitat similar to Lake Washington.

The furthest downstream stratum was the extreme lower stratum that extended from the WDFW fry trap at Rkm 1.1 to the Maplewood Park trail bridge at Rkm 4.7. This stratum was characterized by a low gradient (0.2-0.3%) with mostly gravel substrates and was within an unconfined to moderately confined channel. Most of the shoreline in the extreme lower stratum has been armored by revetments and levees. The riparian zone development is predominately commercial and industrial with some sections of deciduous vegetation.

The lower stratum was the longest stratum at 19.6 km in length and extended from the Maplewood Park trail bridge at Rkm 4.7 to the Highway 18 bridge at Rkm 24.3. The lower stratum was characterized by a 0.3 to 0.4% gradient, with gravel and cobble substrates, and a moderately confined channel. Armored shorelines consisting of both levees and revetments are common and the riparian zone development is scattered rural and suburban residential development with a largely deciduous canopy.

The middle stratum extends from the Highway 18 bridge at Rkm 24.3 to the Summit-Landsburg trail bridge at Rkm 32.5. This stratum has a 0.5 to 0.7% gradient and is a moderately confined channel. Some shoreline areas are armored and the riparian zone has scattered rural residential development and includes large segments of mixed coniferous and deciduous forest.

The upper stratum is from the Summit-Landsburg trail bridge at Rkm 32.5 to Landsburg Dam at Rkm 35.9 and has a 0.6 to 0.7% gradient, with mostly cobble and boulder substrates, and a confined channel. Little of the shoreline is armored and the riparian zone is mainly deciduous trees with some mixed conifers.

The two main components of this study were population estimates and diet/predation analyses. Each component was undertaken during at least two different summer periods (July-August) and two winter-spring periods (January-June) (Table 1). Due to flow conditions as well as time and budget constraints, three different methodologies were used for the population estimation.

Table 1.—Year and seasons when sampling was conducted to determine the population size and diet/predation of resident trout, lower Cedar River. Mark-recapture involved using electrofishing to mark and recapture fish, and mark-resight involved using electrofishing for the mark group and snorkeling for the resight group.

Summer Field Sampling (July-August 2006 and 2007)

Within each stratum, we randomly selected one or two sampling reaches. A total of six reaches were surveyed across all four strata (Figure 1). In the two longer strata (lower and middle), two sites were surveyed and in the other two strata, one site was surveyed. Each site was approximately 1.5 to 2.0 km long and was surveyed during the day in either late-July or early-August. In 2006 each site was sampled twice for a mark-recapture procedure, an initial collection survey to mark fish and a second survey to recapture fish. Diet samples were only collected on the second (recapture) survey that was conducted two to three days after the first survey. We assumed that earlier sampling did not affect the diets of predatory fishes. In 2007, only one electrofishing survey was conducted at each site as the recapture study was modified to only a mark-resight design.

During summer low-flow conditions, fish were collected primarily by barge electrofishing (Smith-Root SR-6 tote barge; settings: 100-1000 V, pulsed DC at 60 Hz). The barge was effective in sampling areas less than 1.2 m deep with low to moderate current velocities. Surveys were conducted when streamflows were less than 200 cfs. The barge crew consisted of one person to guide the barge upstream and operate the generator and cathode, two people to operate the anodes, and another four to six people to dip and then carry fish to a cooler located on the barge. Sampling with the barge unit required discharge low enough for safe operation by foot. Similar sampling techniques are routinely applied in moderate-size streams and flow situations where the river is too wide to effectively sample with a backpack electrofisher unit but too shallow to use a drift boat or raft electrofisher (Mitro and Zale 2002; Thompson and Hayes 2010). When a deep pool was encountered that could not be effectively sampled with the barge electrofisher, we used angling gear. Sampling was conducted throughout the day from early morning to late afternoon.

Winter-Spring Field Sampling (January-June 2008 and 2010)

During the January-June sampling period, the primary sampling technique was a raft electrofishing unit that consisted of a generator and electrofishing unit (with one anode) mounted on a 3-m whitewater raft. The raft allowed us to sample a wide variety of habitat types. The only habitat type we did not sample effectively was secondary channels. The crew consisted of one person to row the raft and other person to dip fish from a platform on the bow. The raft was guided slowly downstream and generally sampled areas near the thalweg. A second whitewater raft was used as a support boat and crew of this boat also collected a few stunned fish that were missed by the crew of the electrofishing raft. Each stratum was sampled once per month from January to June with the raft electrofishing unit. The extreme lower and upper strata were relatively short reaches and we sampled the entire length. Sample reaches in the lower and middle strata were based on access points for launching the raft and catch rates. Our goal was to collect 40 resident trout from each stratum for each month. Fifty to ninety percent of the middle stratum length was sampled depending on launch site. In the lower stratum, we typically sampled approximately 25 to 50% of the stratum length

Our general sampling strategy was to collect fish after a nightly feeding period. During the winter and spring when water temperatures are low, trout are primarily nocturnal and most feeding occurs at night. Our sampling started shortly before or after dawn. The extreme lower and part of the lower stratum were sampled at night shortly before dawn to increase catch rates. Other sections were not sampled at night due to safety concerns. Most sampling was conducted during the morning hours but occasionally it extended into the early afternoon.

To supplement raft electrofishing catch, we occasionally used backpack electrofishing equipment. Within each stratum, we identified potential sites that were easily accessible. Most backpack electrofishing was done along riprap banks because trout were easier to catch at this shoreline type than at other shoreline types. The number of sites sampled varied depending on whether we caught enough fish with the electrofishing raft within each stratum and the amount of time available. Backpack electrofishing was only conducted during early morning hours.

Fish Sampling

Abundance Sampling

We used electrofishing in conjunction with snorkeling to collect mark-recapture and mark-resight data during summer (July and August), 2006 and 2007. A single marking pass was conducted in each of the six study sites followed by both a recapture pass (electrofishing) and a resight (snorkel) pass in 2006 and just a resight (snorkel) pass in 2007. All trout captured were anaesthetized with tricaine methanesulfonate (MS-222), identified to species, and measured for fork length to the nearest millimeter. Trout were marked with an individually-numbered Floy tag inserted into the base of the dorsal fin. A different color tag was used for each of the three size categories (< 150 mm, 150-249 mm, and ≥ 250 mm FL) of trout. Fish were allowed to fully recover in a net pen prior to release. We avoided releasing fish into deep pools in order to maximize the opportunity for marked fish to mix randomly with the unmarked population within each study site between the marking pass and the recapture/resight passes.

Both recapture and resight data were collected in each of the six study sites about 48 hours after the initial marking pass. An additional 200-m upstream and downstream of each study site was sampled to test the closed population assumption. Prior to the electrofishing recapture pass, a snorkel resight pass was conducted following techniques described by Thurow (1994). Four snorkelers would float in a downstream direction through the extended study site. Snorkelers were spaced laterally across the river channel such that it allowed some overlap in the field of view of adjacent snorkelers to maximize fish observations. Snorkelers paused at natural habitat breaks (e.g., pool tailouts) to communicate with each other and minimize double counting. Rainbow and cutthroat trout counts were combined because it was difficult to distinguish between the two species while snorkeling and to improve precision of the trout abundance estimates. All observed trout were recorded as either marked or unmarked. Recapture passes were conducted using the same electrofishing techniques employed during the marking pass. Collected trout were anesthetized and measured in the same manner as the marking trout group. Additionally, all trout were examined for previous marks, a PIT tag was injected, and a subsample was gastrically lavaged for diet analysis.

After reviewing the results from the summer 2006 and 2007 sampling, we decided to use snorkeling as a method to calculate abundance of trout during winter-spring and summer 2008 and winter-spring 2009. Starting at the upstream limit of the upper stratum (Landsburg Bridge), snorkelers floated downstream through the entire lower Cedar River during both sampling occasions in 2008; except the Extreme Lower stratum was not sampled during the summer 2008 because flows were too low to snorkel and our sampling permit precluded sampling with electrofishing gear. Snorkelers conducted two replicate floats in each of the six study sites in winter-spring 2009. All observed trout were divided into the three size classes for each snorkel survey.

Diet Sampling

For the summer sampling, we limited our diet sampling of resident trout to fish ≥ 100 mm FL because of time constraints. All resident trout (except fry) were sampled for diet during the January-June sampling. Juvenile coho salmon were primarily sampled from January through April because few yearling coho salmon were present after mid-May and sub-yearling coho salmon were generally too small to be piscivorous. Large numbers of mountain whitefish were encountered during our sampling and a few were sampled to obtain some basic information on their diet. Of the five sculpin species that inhabit the lower Cedar River, our diet sampling focused on torrent sculpin because they are abundant, are widespread through the lower Cedar River, inhabit a wide range of habitat types, have a relatively large mouth, and are often piscivorous (Tabor et al. 1998; Tabor et al. 2007). We concentrated our diet sampling efforts of torrent sculpin in the extreme lower and lower strata from Rkm 2.4 to 7.1 because they appeared to be abundant in that area and several large torrent sculpin (> 125 mm TL) were collected. Other species of sculpin were sampled as time permitted. Every smallmouth bass encountered was also sampled for diet.

For salmonids and smallmouth bass, we measured fork length (FL, nearest mm) and for sculpin, we measured total length (TL, nearest mm). During the January-June sampling, all fish were also weighed to the nearest gram. To determine fishes' diet, their stomach contents were removed using gastric lavage as described in Foster (1977). Stomach contents of each fish was put in a plastic bag, put on ice (dry ice used for January-June sampling), and placed in a freezer upon returning from the field (approximately two to six hours after sampling). Samples were preserved in a freezer for later laboratory analysis.

Other Fish Sampling

Besides abundance and diet sampling, some fish were also processed for additional analyses that included: 1) genetic analysis, 2) age analysis, 3) PIT tagging, 4) microchemistry otolith analysis and 5) isotope analysis. Genetic analysis was undertaken in 2006 and 2007 for species identification and degree of hybridization. A small fin clip was removed and stored in 70% ethanol. Samples were sent to WDFW's Molecular Genetics Laboratory in Olympia, Washington for analysis. Age analysis consisted of removing several scales from between the dorsal fin and lateral line. Scales were analyzed at WDFW's aging laboratory in Olympia, Washington. In 2006 and 2007, we also PIT tagged most resident trout to provide some information on their movement patterns. Stationary PIT tag readers were present at Landsburg Dam and Ballard Locks. Additionally, mobile PIT tag readers were used during all of our trout collection efforts. In 2007, 29 rainbow trout were sacrificed (some were unintentional mortality from electrofishing) for microchemistry otolith analysis. Elevated strontium levels in the otoliths suggest they were progeny of anadromous females. Samples were processed at the WDFW otolith lab in Olympia, Washington. Stable isotope analysis provided information of resident trout trophic position and the relative yearly importance of piscine and invertebrate prey. Isotope samples were collected in 2008 and 2010, by removing a small fin clip from each fish and preserving the sample on dry ice and then stored in a freezer upon returning from the field following the procedures of Sanderson et al. (2009). Samples were sent to National Marine Fisheries Service's lab in Seattle, Washington for analysis.

Diet Analysis

In the laboratory, each stomach sample was thawed and placed under a dissecting microscope. Stomach contents were separated into major prey taxa. Aquatic insects and crustaceans were identified to order while other invertebrate prey items were identified to a convenient, major taxonomic group. Each prey group was enumerated and then blotted for ten seconds on a paper towel and weighed to the nearest thousandth of a gram. Caddisflies were removed from their cases and weighed separately. Some prey groups such as fish eggs and plant material were not enumerated because it is unclear if the prey was consumed individually or as a group. Rocks, caddisfly cases, and pieces of woody debris (sticks and bark) were weighed but were not included in the diet calculations. We assumed these items provided little, if any caloric value to the diet.

Prey fish that were slightly digested were identified to species based on external characteristics. Fishes in more advanced stages of digestion were identified to family, genus, or species from diagnostic bones, gill raker counts, pyloric caeca counts, or vertebral columns. The fork length of prey fish was measured to the nearest millimeter. If a fork length could not be taken, the original fork lengths of prey fish were estimated from measurements of standard length, nape-to-tail length, or diagnostic bones (Hansel et al. 1988; Vigg et al. 1991). Prey fish were individually weighed to the nearest thousandth of a gram. For trout that consumed more 20 sockeye salmon fry, we individually measured the length and weight of the first 20 fry. The remaining fry were enumerated and grouped together based on their digestive state (He and Wurtsbaugh 1993) and weighed as a group. To account for the effect of freezing, we adjusted prey lengths. For salmonid prey we used the equation: ingested length = (observed length + 1.237)/0.933 (Armstrong and Stewart 1997). Sculpin prey lengths were increased by 1.4% (Paradis et al. 2007).

We also measured the diameter of fish eggs with an ocular micrometer. Typically, three to four eggs of each type ingested were measured to obtain an average size consumed. Fish eggs were identified as salmonid, sculpin, sucker, or peamouth based on their size and appearance. Sculpin eggs are typically in a cluster and 1.0-1.6 mm. Peamouth and sucker eggs are typically not in a cluster and are 2.0-2.8 mm and 3.0-3.7 mm, respectively. Eggs greater than 5 mm were considered salmonid eggs.

In addition to our standard laboratory analysis, 50 unidentified salmonid samples were sent to the WDFW Molecular Genetics Laboratory for species identification (Appendix 1). Samples sent in for genetic analysis were large salmonid fry that were likely Chinook salmon, coho salmon, or trout. Small unidentified salmonid fry were also commonly observed in the stomach samples from February through April. These fry were most likely sockeye salmon and we were unable to analyze most of these fry due to budget constraints. The 50 samples sent in to the genetics laboratory were identified to species using mitochondrial markers. Thirteen allele specific primers produce DNA fragments of different lengths that are diagnostic for identifying salmonid species (Appendix 1).

Data Analysis

Abundance Estimation

Deriving total in-river trout abundance was an iterative process of estimating study site abundance, estimating average stratum abundance, expanding average stratum abundance to total stratum length, and summing the stratum abundances. Study site abundance estimates for summer 2006 and 2007 were calculated using a Chapman modification to the Petersen estimator (Seber 1982);

(1)

Where = the number of resident trout captured and marked during the marking pass within study site *k* of stratum *i*,

= the number of resident trout observed during the recapture or resight pass within study site *k* of stratum *i*, and

= the number of marked resident trout observed during the resight pass within study site *k* of stratum *i*.

The within-study site variance was approximated as (Seber 1982)

(2)

Average trout abundance within each stratum was estimated as

(3)

where = the estimated abundance for study site k within stratum i and

= the number of study sites sampled within stratum i.

The representative among-study site variance within each stratum was approximated as

(4)

Total trout abundance within stratum *i* was estimated by expanding the average abundance as

; (5)

where = the total number of possible study reaches within stratum *i*.

The variance associated with the expanded trout abundance within stratum *i* was approximated as

. (6)

Total trout abundance within the study reach was estimated as

. (7)

The total variance associated with the study reach trout abundance was approximated as

. (8)

Standard errors of the study reach trout abundance were approximated as

. (9)

The winter-spring 2008, summer 2009, and winter-spring 2009 trout abundances were estimated using a calibration ratio described by Hankin and Reeves (1988) that relates snorkel counts to an independent abundance estimate. However, unlike summer counts we did not have an independent abundance estimate of trout in the Cedar River during the winter to calibrate the winter counts. Further, snorkel counts are directly related to river temperature, below 14°C day time counts account for about 50% of the fish present and below 9°C they account for less than 20% (Hillman et al. 1992; Griffith and Smith 1993; Roni and Fayram 2000) and could not use our summer mark-resight estimates to calibrate our winter snorkel counts. Consulting the literature for validated snorkel counts at river temperatures similar to those we observed we found that Hillman et al. (1992) and Roni and Fayram (2000) had sampled Washington streams similar ($t = 2.02$, $df = 15$, p-value = 0.062) to winter-spring 2008 and ($t = 2.17$, $df = 8$, p-value = 0.062) winter-spring 2009, respectively. We used their trout (combined steelhead and cutthroat) snorkel counts and associated abundance estimates to calculate specific winter temperature calibration ratios. The winter-spring 2008 calibration ratio was calculated as

(10)

where c_{st} = the snorkel count of trout pulled from the literature in study site *s* of temperature range stratum *t* and

= the independent estimated abundance of trout pulled from the literature in study site *s* of temperature range stratum *t*.

The average of temperature range stratum *t* calibration ratio was calculated as

(11)

and the associated variance was calculated as

. (12)

Total trout abundance within stratum *i* was estimated by expanding the average abundance as

(13)

where = the total snorkel count within stratum *i*.

The variance associated with the expanded trout abundance within stratum *i* was approximated using the delta method as

. (14)

Note that counts are totals within the stratum and not estimates (i.e., is zero, thus eliminating the right portion of the equation within the parentheses).

Total trout abundance, associated variance, and standard errors were calculated according to equations 5-9.

The summer 2008 trout abundance estimate was also calculated using the calibration ratio method. We used the study site snorkel counts collected in summer 2006 and 2007 and their associated abundance estimates to calculate study site specific calibration ratios;

. (15)

Average strata calibration ratios were calculated as

(16)

and the associated variance as

. (17)

The estimated count for the extreme lower stratum was calculated as

(18)

where $p(C_{XL})$ was the proportion of trout counted in the extreme lower stratum to the trout counted in the lower, middle, and upper strata was calculated as

(19)

where C_{XL} = the snorkel count within the extreme lower stratum in year *y* and

C_O = the snorkel count within the other strata (i.e., lower, middle, and upper) in year *y*.

The variance associated with estimated count for the extreme lower stratum was approximated as

. (20)

Total trout abundance within stratum *i* was estimated by expanding the average abundance as

(21)

where = the total snorkel count within stratum *i*.

The variance associated with the expanded trout abundance within stratum *i* was approximated using the delta method as

. (22)

Total trout abundance, associated variance, and standard errors were calculated according to equations 5-9.

The winter-spring 2009 calibration ratio and associated variance was calculated using the same methods as winter-spring 2008. Study site *k* within stratum *i* abundance was estimated as

(23)

where = the maximum snorkel count for study site *k* within stratum *i*.

The variance associated with the expanded trout abundance within stratum *i* was approximated using the delta method as

. (24)

Average trout abundance within each stratum was estimated as

(25)

The representative among-study site variance within each stratum was approximated as

(26)

Total trout abundance within stratum *i* was estimated by expanding the average abundance as

. (27)

The variance associated with the expanded trout abundance within stratum *i* was approximated as

. (28)

Total trout abundance, associated variance, and standard errors were calculated as before.

Species composition and length frequency were parsed out using ratios encountered during appropriate electrofishing sampling events to assess differences in predation rates by species and size class within each stratum. The variance for species length class specific estimates was adjusted as

(29)

where, = the ratio of rainbow or cutthroat trout encountered in each stratum during the electrofishing sampling event and

= the ratio of rainbow or cutthroat trout within a predefined length bins i.e., >150 mm, 150-250 mm, and <250 mm encountered in each stratum during the electrofishing sampling event.

Diet Analysis

To quantify diet composition, we calculated percent composition by weight ($\%W_i$), percent composition by number ($\%N_i$) or percent frequency of occurrence ($\%O_i$) as follows:

$\%W_i =$, (30)

$$\%O_i = \quad ,\qquad (31)$$

$$\%N_i = \quad ,\qquad (32)$$

where n is the total number of prey categories found in a given sample, and W_i, O_i, and N_i are the total wet weight, occurrence, or number of prey type *i* in a category (Liao et al. 2001). For trout samples, we used three size classes of trout (< 150 mm, 150-249 mm, and ≥ 250 mm FL), four strata, and four time periods (January-February, March-April, May-June, and July-August) to describe the diet. Each prey type was placed into one of ten categories (sockeye, Chinook, coho, sculpin, other fish, fish eggs, crayfish, aquatic insects [aquatic life stages only], other invertebrates, and other (mostly plant and unidentified matter). In addition to the basic diet composition calculations, we used a scatterplot to determine the size range when trout become piscivorous (Beauchamp et al. 2007). Regression analysis was used to determine if there was a relation between predator size and prey fish size.

Consumption Estimation (Direct Consumption Model)

For winter and spring samples, we used a meal-turnover method (Adams et al. 1982; Naughton et al. 2004). During the winter and spring, salmonids are generally nocturnal and prey fish are more available at night. Therefore, we collected predatory fishes shortly before or after dawn and expected the remains of all ingested fish from the previous night to be present. We used digestion models to predict which fish were consumed the previous night and which were consumed earlier. The basic formula for the simple meal-turnover method was;

$$C = n / N; \qquad (33)$$

C = consumption rate of prey fish (number consumed/day), n = number of prey fish consumed within the night prior to sampling, and N = number of predators sampled, including those with empty stomachs. Based on the observed water temperatures, and sizes of the predators and prey, more than 5% of the each fish consumed from the previous night would still be present in the stomach after it was captured. An advantage of this model is that the predation rates are based on digestion of fish and are not influenced significantly by differential digestion rates between prey types. Hard-bodied prey such as crayfish can have a significantly different digestion rate than prey fish (Bromley 1994). Other models which incorporate all prey types in the calculations can have large errors if crayfish or other hard-bodied prey make up a large portion of the diet and a digestion equation is used that was developed for digestion of fish (Elliot 1991; He and

Wurtsbaugh 1993). Additionally, because predatory fish were not able to digest the prey fish over one night, we did not have to consider diel feeding patterns. We compared the observed weight of each partially digested prey fish versus the predicted weight if it had been consumed at dusk of previous night. If the observed weight was larger than the predicted dusk digestion weight than the prey fish was considered to have been consumed within the previous night. Prey fish in more advanced states of digestion were not used to calculate the nightly consumption rate. The grams evacuated from dusk to time of capture were estimated from various digestion rate equations:

1) Salmonid fry consumed by trout; $R_e = 0.0354\ e^{0.114\,T}$; (34)

The equation was developed for brown trout *Salmo trutta* (range, 100-320 mm) digesting salmonid fry (range, 25-35 mm) (Elliot 1991).

2) Sculpin and other large fish consumed by trout; $R_e = 0.053\ e^{0.073\,T}$; (35)

The equation was developed for brown trout (range, 352-457 mm) digesting fingerling rainbow trout (mean, 66 mm, 5.3 g) (He and Wurtsbaugh 1993).

3) Salmonid fry consumed by juvenile coho salmon; $R_e = 0.133+0.021(T)-0.402(PS)$; (36)

The equation was developed for juvenile coho salmon (range, 83-143 mm) digesting sockeye salmon fry (means of test groups, 0.166-0.367 g) (Ruggerone 1989).

4) All fish consumed by sculpin; $R_e = 0.049\ e^{0.072\,T - 0.060 \log_e(PS)}$; (37)

The sculpin equation used is a generalized equation developed from digestion rates of 22 fish species (He and Wurtsbaugh 1993).

where R = evacuation rate (h^{-1}); T = temperature (^oC); and PS = food particle size (g). Meal weight was the estimated weight of the prey fish plus the digested weight of all other food items in the stomach (Vigg et al.1991). This assumes that the observed weight of all other food items is the average amount of prey in the stomach while the prey fish was being digested.

Because trout are generally diurnal during the summer and our summer sampling was conducted throughout the day, we used a different consumption model than for the winter and spring samples. We used a simplified direct consumption method of Ward et al. (1995) and Fritts and Pearsons (2004);

$$C = n\ (24\ /\ ET_{90}), \qquad (38)$$

where n is the number of prey fish observed in the predator's stomach during time of sampling and ET_{90} is the amount of time it takes a fish to digest 90% of its stomach contents. Meal weight was the estimated original weight of the prey fish plus the digested weight of all other food items in the stomach (Vigg et al. 1991). This assumes that the observed weight of all other food items is the average amount of prey in the stomach while the prey fish was being digested. The gastric evacuation rates of He and Wurtsbaugh (1993) were used to determine ET_{90}. This model assumes that the observed prey weights at time of capture represents the average prey weight for the entire 24 hour period. Because feeding activity may be more intense during crepuscular hours, we felt that samples collected throughout the daytime might be a reasonable approximation of the average prey weight.

Lastly, total predation for each prey fish type for each trout species was calculated as:

$$TP_k = \sum (C_{ij} * N_{ij}) \qquad (39)$$

Where TP_k = total predation of prey fish k; C_{ij} = predation rate (number consumed/day) of prey fish k in stratum i for time period j; N_{ij} = population size in stratum i for time period j. Total predation standard errors are based solely on population estimates.

RESULTS

Abundance Estimates and Length Composition

We sampled 2,030 trout including 1,834 maiden captures and 196 recaptures between 85 and 455 mm FL for mark-recapture abundance estimates during summer 2006. In summer 2007, 1,878 trout were sampled including 1,724 maiden captures and 154 recaptures between 84 and 595 mm FL. We sighted 276 and 3,398 trout during winter-spring and summer 2008 respectively. During winter-spring 2009 we sighted 40 trout.

Total trout abundance estimates for 2006-2009 indicate that the summer abundances were similar (consistent) among years and were greater than the winter-spring abundances (Figure 2). The summer and winter-spring abundance estimates were significantly different (t = 2.35, df = 3, P = 0.0042). Summer abundances ranged from 16,320 to 17,435 and averaged 16,955 and whereas winter abundance estimates were 2,878 and 6,373 in 2008 and 2009, respectively and averaged 4,626 (Table 2).

Figure 2.—Cedar River trout summer and winter-spring abundance estimates with approximate 95% confidence intervals.

Table 2.—Total abundance estimates with approximate lower (LCI) and upper (UCI) 95% confidence intervals for trout (combined rainbow and cutthroat) during the summer (June-August) and the winter-spring in the Cedar River below Landsburg Dam.

Year	Season	Abundance (N)	SE	LCI - UCI
2006	Summer	17,111	5,153.6	7,010 - 27,212
2007	Summer	17,435	1,837.2	13,834 - 21,036
2008	Summer	16,320	2,899.6	10,792 - 15,268
2008	Winter-Spring	2,878	827.4	1,078 - 3,361
2009	Winter-Spring	6,373	1,018.9	4,344 - 8,361

Composition of the trout catch consisted of 32% (636 of 1,976) cutthroat trout and 67.8% (1,340 of 1,976) rainbow trout, on average, during the summer. There was a decreasing trend in the proportion of cutthroat in the trout composition moving upstream through the study reach and conversely there was an increasing trend in the proportion of rainbow trout (Figures 3 and 4) in both years.

XLower Lower Middle Upper

Figure 3.—Percent rainbow trout and cutthroat trout species composition for summer 2006 in the Extreme Lower (XLower), Lower, Middle, and Upper strata of the lower Cedar River.

XLower **Lower** **Middle** **Upper**

Figure 4.—Percent rainbow and cutthroat trout species composition for summer 2007 in the Extreme Lower (XLower), Lower, Middle, and Upper strata.

Summer length composition of the trout catch was predominately in the 150-250 mm length class (Figure 5 and 6). Mean fork lengths in 2006 were 186.7 mm (range, 122-410 mm) for cutthroat trout and 183.0 mm (range, 85-445 mm) for rainbow trout and 187.0 mm (range, 84-515 mm) for cutthroat trout and 212.8 mm (range, 118-595 mm) for rainbow trout in 2007. Length composition of the cutthroat trout was similar (t = 0.14, df = 573, P = 0.89) and rainbow trout lengths were statistically different (t = -10.03, df = 1,235, P < 0.001) between years. Numerically, rainbow trout were consistently more abundant than cutthroat trout for all size categories in all strata except the extreme lower (Table 3).

During the winter-spring, the trout catch composition consisted of 42.1% (373 of 887) cutthroat trout and 58.0% (514 of 887) rainbow trout. Again, there was a decreasing trend in the proportion of cutthroat trout in the trout composition moving upstream through the study reach and conversely there was an increasing trend in the proportion of rainbow trout (Figures 7 and 8).

Figure 5.—Total rainbow and cutthroat trout size composition for summer 2006 in the three length classes.

Figure 6.—Total rainbow trout and cutthroat trout size composition for summer 2007 in the three length classes.

Table 3.— Abundance estimates with standard errors (SE) for three size categories of rainbow and cutthroat trout during the summer (June - August) in the four stratified reaches of the Cedar River below Landsburg Dam.

	< 150		150 - 250		> 250	
Year/Strata	Abundance (N)	SE	Abundance (N)	SE	Abundance (N)	SE
			Rainbow Trout			
2006						
Extreme Lower	18	2.1	67	8.1	7	0.9
Lower	1,083	531.6	4,134	2,030.0	447	219.6
Middle	762	128.8	2,911	491.8	315	53.2
Upper	286	26.5	1,092	101.1	118	10.9
2007						
Extreme Lower	6	0.6	98	10.4	20	2.1
Lower	334	42.3	5,678	718.8	1,136	143.8
Middle	110	29.2	1,871	495.6	374	99.1
Upper	39	4.8	671	82.4	134	16.5
2008						
Extreme Lower	35	5.6	193	30.6	28	4.4
Lower	735	646.8	4,036	3,549.1	582	511.7
Middle	300	40.0	1,644	219.4	237	31.6
Upper	178	74.3	976	407.8	141	58.8
			Cutthroat Trout			
2006						
Extreme Lower	34	4.1	189	22.8	15	1.8
Lower	677	332.4	3,723	1,828.2	301	147.7
Middle	102	17.2	562	94.9	45	7.7
Upper	32	3.0	176	16.3	14	1.3
2007						
Extreme Lower	45	4.8	262	27.9	12	1.3
Lower	862	109.2	4,988	631.6	233	29.5
Middle	64	17.0	371	98.2	17	4.6
Upper	16	1.9	90	11.0	4	0.5
2008						
Extreme Lower	43	6.8	240	38.0	16	2.5
Lower	523	460.0	2,937	2,583.0	195	171.9
Middle	123	16.4	688	91.8	46	6.1
Upper	37	15.5	208	86.9	14	5.8

XLower Lower Middle Upper

Figure 7.— Percent rainbow and cutthroat trout composition for winter-spring 2008 in the Extreme Lower (XLower), Lower, Middle, and Upper strata, based on encounters during diet sampling.

XLower Lower Middle Upper

Figure 8.— Percent rainbow and cutthroat trout composition for winter-spring 2010 in the Extreme Lower (XLower), Lower, Middle, and Upper strata, based on encounters during diet sampling.

Winter-spring length composition of the trout catch was more evenly distributed among the length classes (Figures 9 and 10) than during the summer. Mean fork lengths of 235.2 mm (range; 77-530 mm) for cutthroat trout and 224.7 mm (range; 64-555 mm) for rainbow trout during 2008 and 227.3 mm (range; 77-513 mm) for cutthroat trout and 247.1 mm (range; 64-643 mm) for rainbow trout in 2010. Length composition of cutthroat trout were similar ($t = 0.58$, df $= 371$, $P = 0.56$) and rainbow trout lengths were statistically different ($t = -2.18$, df $= 511$, $P = 0.03$) between years. Rainbow trout were consistently more abundant than cutthroat trout for all size categories in all but the extreme lower strata during the winter-spring as well (Table 4).

Figure 9.— Total rainbow trout and cutthroat trout size composition for winter-spring 2008 in the three length classes, based on encounters during diet sampling.

Figure 10.— Total rainbow trout and cutthroat trout size composition for winter-spring 2010 in the three length classes, based on encounters during diet sampling.

Table 4.— Abundance estimates with standard errors (SE) for three size categories of rainbow and cutthroat trout during the late winter to early spring (March - May) in the four stratified reaches of the Cedar River below Landsburg Dam.

Year/Strata	< 150		150 - 250		> 250	
	Abundance (N)	SE	Abundance (N)	SE	Abundance (N)	SE
	Rainbow Trout					
2008						
Extreme Lower	42	19.9	33	15.9	34	16.3
Lower	345	164.3	276	131.5	284	135.1
Middle	178	84.7	142	67.7	146	69.6
Upper	149	71.2	119	56.9	123	58.5
2009						
Extreme Lower	13	0.7	23	15.3	34	22.1
Lower	427	2.6	787	119.8	1,141	173.6
Middle	163	3.0	301	129.5	436	187.7
Upper	89	3.0	164	130.0	238	188.4
	Cutthroat Trout					
2008						
Extreme Lower	47	2.1	41	19.5	39	18.7
Lower	230	4.1	198	94.3	190	90.6
Middle	68	1.8	59	28.0	56	26.8
Upper	29	0.9	25	12.0	24	11.5
2009						
Extreme Lower	30	1.8	57	37.4	38	25.1
Lower	439	2.6	826	125.7	555	84.5
Middle	98	1.8	184	79.1	123	53.1
Upper	49	1.7	93	73.2	62	49.2

Age analysis

There was significant overlap in the length ranges between species and among ages (Figures 11 and 12).

Figure 11.—Mean length at age with minimum and maximums for cutthroat and rainbow trout in summer 2006.

Figure 12.—Mean length at age with minimum and maximums for cutthroat and rainbow trout in summer 2007.

Diet

Trout

Of the 1,614 trout examined (all seasons and years combined) for diet analysis, 87 (5.4%) were empty. Overall the percent of empty stomach for trout during the winter and spring combined was only 5.6% for 2008 and 4.8% for 2010. The percentage of empty stomachs was highest for fish > 350 mm FL (15.4% in 2008 and 18.1% in 2010), which was most evident during the January-February period (43.8% in 2008 and 21.2% in 2010). The percent of trout with an empty stomach in the July-August period was similar to the winter and spring. During July-August 2006, 6.6% of the trout sampled were empty and 4.7% were empty in July-August 2007.

July-August Diet.-- Prey fish were present in 9.1% of the trout stomachs and numerically only represented 0.53% of the prey items. For the 728 trout sampled, the total number of prey fish included 88 sculpin, 7 coho salmon, 1 trout, 1 unidentified salmonid, and 6 unidentified fish. The one trout was identified as a cutthroat/rainbow hybrid though genetic analysis. Predation of sculpin was primarily observed in cutthroat trout in either the extreme lower or lower strata. For the two years combined, sculpin made up at least 25% of the diet of each cutthroat trout size class. In contrast, sculpin were not present in the diet of rainbow trout < 150 mm FL and comprised only 5.9% and 13.5% of the diet of rainbow trout 150-249 and ≥ 250 mm FL, respectively.

During the July-August period, trout diets were comprised primarily of aquatic insects, sculpin, crayfish, and various terrestrial invertebrates (Figures 13 and 14). In general, the July-August diet was similar between 2006 and 2007. Numerically, aquatic insects comprised 89.1% of all prey items (2006 and 2007 combined) and at least 75% of the prey items for each size class and species. Aquatic insects comprised 38.0% of the overall trout diet (%W) in 2006 and 48.6% in 2007. By weight, the most important aquatic insects in the diet were trichoptera (51.7% of aquatic insect biomass), ephemeroptera (17.7%), plecoptera (14.0%) and diptera (15.5%). For both species and both years, the percentage of the diet by weight of trichoptera larvae increased in the larger size classes. This was largely due to the inclusion of large limnephilids in the diet of larger trout. Conversely, the percentage of the diet comprised of ephemeroptera nymphs decreased in larger size classes. Crayfish were present in 6.7% of the trout stomachs and numerically represented 0.25% of the prey items. However, they represented 24.9% of the overall diet (by weight) in 2006 and 15.5% in 2007. Ingested crayfish appeared to be mostly adult crayfish and were observed primarily in larger trout. Only 2.9% of trout < 150 mm FL had consumed crayfish; whereas, 5.2% of trout 150-249 mm FL and 20% of trout ≥ 250 mm FL had consumed them. In some cases, only crayfish claws were present and we are not sure if the entire crayfish was consumed. The rest of the crayfish may have been digested or perhaps the gastric lavage may have been incomplete. Other invertebrates were comprised of a wide variety of prey types including adult aquatic insects, hymenoptera, coleoptera, and arachnids.

Figure 13.**—**Diet composition by weight (%) of three classes of trout within four strata of the lower Cedar River, July-August 2006. Number above each column is the number of stomach samples analyzed (not including empty stomachs). Colored areas indicate fish in the diet while black and white areas indicate invertebrates and other diet items.

Figure 14.—Diet composition by weight (%) of three classes of trout within four strata of the lower Cedar River, July-August 2007. Number above each column is the number of stomach samples analyzed (not including empty stomachs). Colored areas indicate fish in the diet while black and white areas indicate invertebrates and other diet items.

Winter-Spring Diet.— From January through June, trout diets contained a variety of fish, fish eggs, aquatic insects, and other vertebrates. Sockeye salmon fry were only observed in the diet during the January-February and March-April time periods (Figures 15 and 16). Consumption of sockeye salmon was observed in all four strata; however, it comprised less than 5% of the trout diet in the middle and upper strata (Figures 17 and 18). The maximum number of sockeye salmon fry observed in a rainbow trout diet was 298 and 27 in a cutthroat trout diet (Figures 19 and 20). Trout that had consumed several sockeye salmon were usually rainbow trout. For example, of the 15 trout observed with over 20 sockeye salmon fry, all but one was a rainbow trout. The maximum number of sockeye salmon fry per rainbow trout diet tended to increase in larger size classes; whereas, there was no pronounced relationship in cutthroat trout (Figure 21). Total rainbow trout diet (January-April 2010 combined) comprised of sockeye salmon fry increased with length size class from 3.8% (%W) for fish < 150 mm to 21.8% for fish 150-249 mm and to 28.5% for fish ≥ 250 mm. Conversely for cutthroat trout, the percentage decreased with length size class from 34.2% for fish < 150 mm to 11.2% for fish 150-249 mm and to 4.1% for fish ≥ 250 mm.

The number of sockeye salmon fry in a trout diet varied widely temporally and spatially. Also, there appeared to be large differences between individual fish that were caught in the same stratum on the same date. For example on March 16, 2010, we collected six trout > 300 mm in the extreme lower, one trout had 298 sockeye salmon fry, another had six, and the other four had not consumed any fry. The observed sockeye salmon predation by trout was from a few individuals. For 2008 and 2010 combined, 12.9% (109 of 842) trout contained at least one sockeye salmon fry. However, 73.3% of the total number of sockeye salmon fry (n = 1,603) consumed was from 15 trout.

For 2008 and 2010 combined, a total of 61 juvenile Chinook salmon were observed in trout diets; 41 in cutthroat trout and 20 in rainbow trout. Chinook salmon were primarily observed in trout during the January-February and March-April periods (Figures 15 and 16). For the combined period of January to April 2008, Chinook salmon represented at least 18% of the diet of each size class of cutthroat trout. The percent of the 2010 diet (January-April combined) of cutthroat trout comprised of Chinook salmon was 9.3% for fish < 150 mm, 28.9% for fish 150-249 mm, and 4.8% for fish ≥ 250 mm. In contrast, Chinook salmon never represented more than 2% of the January-April diet of any size class of rainbow trout for either 2008 or 2010.

Other salmonids observed in trout diets were coho salmon, pink salmon, and trout. For 2008 and 2010 combined, a total of 20 coho salmon were observed, which consisted of 15 fry and 5 parr. In 2010 samples, six pink salmon fry were observed in the stomach samples. Of which, four were present in the individual that had also consumed 298 sockeye salmon fry. All pink salmon fry were from trout collected downstream of Rkm 6.9. Only two juvenile trout were observed in the trout samples (extreme lower stratum). Both were identified as cutthroat trout through genetic analysis.

Figure 15.—Diet composition by weight (%) of three classes of trout within three time periods, lower Cedar River, January-June 2008. Number above each column is the number of stomach samples analyzed (not including empty stomachs). Colored areas indicate fish or fish eggs in the diet while black and white areas indicate invertebrates and other diet items.

Figure 16.**—**Diet composition by weight (%) of three classes of trout within three time periods, lower Cedar River, January-June 2010. Number above each column is the number of stomach samples analyzed (not including empty stomachs). Colored areas indicate fish or fish eggs in the diet while black and white areas indicate invertebrates and other diet items.

Figure 17 —Diet composition by weight (%) of three classes of trout within four strata of the lower Cedar River, January-June 2008. Number above each column is the number of stomach samples analyzed (not including empty stomachs). Colored areas indicate fish or fish eggs in the diet while black and white areas indicate invertebrates and other diet items.

Figure 18.**—**Diet composition by weight (%) of three classes of trout within four strata of the lower Cedar River, January-June 2010. Number above each column is the number of stomach samples analyzed (not including empty stomachs). Colored areas indicate fish or fish eggs in the diet while black and white areas indicate invertebrates and other diet items.

Figure 19.**—**Number of sockeye salmon fry and juvenile Chinook salmon observed in stomach samples of various sizes of cutthroat trout and rainbow trout in lower Cedar River, January-June 2008. The top graphs only display the number of sockeye salmon and includes trout that did not consume sockeye salmon. The bottom graphs are displayed on a log scale and include both sockeye salmon (solid diamonds) and Chinook salmon (open circles) (trout that did not consume sockeye salmon or Chinook salmon are not shown).

Figure 20.—Number of sockeye salmon fry and juvenile Chinook salmon observed in stomach samples of various sizes of cutthroat trout and rainbow trout in lower Cedar River, January-June 2010. The top graphs only display the number of sockeye salmon and includes trout that did not consume sockeye salmon. The bottom graphs are displayed on a log scale and include both sockeye salmon (solid diamonds) and Chinook salmon (open circles) (trout that did not consume sockeye salmon or Chinook salmon are not shown).

Figure 21.**—**Maximum number of sockeye salmon fry observed in one stomach sample of three size classes of cutthroat trout and rainbow trout in lower Cedar River, January-April 2008 and 2010. Number above each column is the number of stomach samples analyzed for January to April (May and June samples were not included because no sockeye salmon was consumed during that period).

Nonsalmonid fish consumed by trout included 138 sculpin, 1 dace, and 10 unidentified fish. Overall, frequency of occurrence of sculpin in the diet was similar for cutthroat trout (9.6%) and for rainbow trout (9.4%). Sculpin were an important component of the diet of trout ≥ 250 mm FL. Frequency of occurrence of sculpin was higher for trout ≥ 250 mm FL (17.2% for cutthroat trout and 18.3% for rainbow trout) than the other size classes (3.7% for all other trout; cutthroat trout: < 150 - 1.1%, 150-249 – 9.9%; rainbow trout: < 150 - 0%, 150-249 – 2.5%). In 2010, sculpin comprised at least 15% of the diet (by weight) of trout ≥ 250 mm FL for each time period and each species. Sculpin comprised at least 15% of the 2010 diet (%W) of trout ≥ 250 mm FL for each strata and each species except for rainbow trout in the extreme lower stratum (sockeye salmon fry and fish eggs were primarily consumed).

Fish eggs were an important component of trout diets in both 2008 and 2010, particularly in the lowest sampling reach (extreme lower). In the lower stratum, fish eggs were also important but to a lesser degree than in the extreme lower. In the middle and upper strata, fish eggs were always a minor component of the diet. Overall, 41.3% (by weight) were peamouth eggs, 31.7% were sucker eggs, 25.0% were sculpin eggs, and 2.0% were salmonid eggs. Salmonid and sculpin eggs were the primary eggs consumed in Janaury-February. In March-April, sculpin and sucker eggs were the main types of eggs consumed. Peamouth and sucker eggs were the primary fish eggs consumed in May and fish eggs of all types were rare in June.

Aquatic insects were a common prey item of trout in all strata and size classes for both 2008 and 2010. Numerically, aquatic insects comprised 74.5% of all prey items in 2008 and 70.4% in 2010. Composition of aquatic insects was similar between trout species and between years. For both years combined, aquatic insects by weight consisted of 30.5% ephemeroptera, 28.8% trichoptera, 27.9% plecoptera, 8.3% diptera, and 4.5% other aquatic insects; and numerically consisted of 35.5% ephemeroptera, 32.3% trichoptera, 11.2% plecoptera, 17.6% diptera, and 3.4% other aquatic insects

From January through April, crayfish were only observed in 3.4% of the trout and usually comprised less than 1% (%W) of the diet. In contrast, 15.8% of the trout sampled during the May-June period contained crayfish. Within the May-June period, 92.3% of the occurrences of crayfish in the trout diet were from June samples. Ingested crayfish appeared to be mostly adult crayfish and were observed primarily in larger trout.

Other invertebrates were also a common prey type of both species of trout for each strata, time period, and size class. In 2010, other invertebrates comprised an average of 12.1% by weight (range, 2.8-27.8%) for all size classes and time periods. They were made up of a wide variety of prey groups including adult aquatic insects, slugs, isopods, millipedes, oligochaetes, hymenoptera, coleoptera, and arachnids.

We did not see any obvious patterns that demonstrate when trout become piscivorous (Figure 22). Cutthroat trout were often piscivorous at the smallest size that we sampled. The frequency of rainbow trout that were piscivorous was much higher for rainbow trout > 200 mm FL than those < 200 mm FL. The frequency of piscivory for trout < 200 mm FL was substantially higher for cutthroat trout than rainbow trout (Figure 23). For example, 25.4% of all cutthroat trout < 200 mm FL were piscivorous, whereas only 5.8% of rainbow trout < 200 mm FL were piscivorous.

Figure 22.—Scatterplots of trout size (fork length, mm) and the percent of their diet (by weight) comprised of fish, lower Cedar River. Total sample size is also indicated (not including empty stomachs).

Figure 23.**—**Percent of two size classes (mm FL) of cutthroat trout and rainbow trout that had consumed fish (% piscivorous) from the lower Cedar River. Number above each column is the number of stomach samples analyzed (not including empty stomachs). Win-Spr = winter-spring.

Trout consumed a wide range of prey fish sizes from 18 to 121 mm. The maximum prey fish size increased with increasingly larger trout (Figure 24). Sockeye salmon fry ranged in size from 21 to 34 mm FL and there was little relation between predator length and fry size (cutthroat trout, n = 117, y=-0.003x+27.4, r^2 = 0.01; rainbow trout, n = 574, y=0.004x+26.2, r^2 = 0.02). Similarly, there was little relation between predator length and Chinook salmon length (cutthroat trout, n = 39, y=-0.023x+26.2, r^2 = 0.07; rainbow trout, n = 17, y=0.008x+37.02, r^2 = 0.02). Cutthroat trout size was related to prey size for both coho salmon (n = 15, y=0.304x-9.37, r^2 = 0.79) and sculpin size (n = 130, y=0.144x+16.23, r^2 = 0.36). In contrast, there was little relation between rainbow trout size and both coho salmon (n = 8, y=0.167x+22.7, r^2 = 0.07) and sculpin size (n = 85, y=0.065x+41.7, r^2 = 0.03).

Figure 24.**—**Relation between predator length and ingested fish length in samples from the lower Cedar River, summer 2006-2007and winter-spring 2008 and 2010. Prey length is fork length for salmonids and total length for sculpin. Other prey fish includes pink salmon, cutthroat trout, and unidentified trout. For each trout that consumed sockeye salmon fry, we usually only measured the first 20 fry.

Coho Salmon

Juvenile coho salmon were primarily sampled from January through April (n = 137). Of these fish, only one had an empty stomach. During each time period, aquatic insects comprised at least 40% of the diet by weight (Figure 25). Numerically, aquatic insects represented 90.8% of the overall diet (at least 83% for each time period). Ephemeroptera, plecoptera, and trichoptera were the most important types of aquatic insects consumed by both weight and number.

In 2008, salmonid fry made up a substantial portion of the diet by weight in both the January-February and March-April periods. Twenty-four percent of coho salmon sampled had consumed salmonid fry. Frequency of occurrence of sockeye salmon fry predation ranged from 46.2% (6 of 13) in the extreme lower stratum, 33.3% (1 of 3) in the upper startum, 19.4% (7 of 36) in the lower stratum, and 0% (0 of 7) in the middle strata. A total of 24 sockeye salmon fry and 5 Chinook salmon fry were observed from 59 samples. Predation of Chinook salmon was observed in four coho salmon (range, 81-105 mm FL) and all were from the lower stratum. In contrast to 2008, few salmonids were observed in the diet in 2010. Of the 77 coho salmon sampled in 2010 (lower strata – 29 fish, middle strata – 26 fish, upper strata – 22 fish), only one from the lower stratum had consumed salmonid fry (4 sockeye salmon).

During the May-June period, only six coho salmon were sampled. Similar to other time periods, their diet was composed primarily of aquatic insects. The only occurrence of piscivory was a 120 mm FL individual that had consumed a coho salmon fry. Additionally, four coho salmon were sampled during the summer period. The only prey items in their stomachs were aquatic insects.

Figure 25.**—**Diet composition by weight (%) of two size classes of juvenile coho salmon in the lower Cedar River, 2008 and 2010. Number above each column is the number of stomach samples analyzed (not including empty stomachs). Colored areas indicate fish in the diet while black and white areas indicate invertebrates and other diet items.

Mountain Whitefish

The stomach contents of 24 mountain whitefish (11 in 2006 and 13 in 2010) were examined. For each time period examined (January-February, March-April, and July), over 99% of the diet by weight and by number was composed of aquatic insects. Large numbers of ephemeroptera nymphs and trichoptera and diptera larvae were often in each stomach sample (Figure 26). For example, the stomach of a 213 mm FL mountain whitefish collected in July 2006 had 1,059 aquatic insects. No evidence of piscivory was found in any mountain whitefish diets.

Figure 26.—Diet composition by weight (%W) and by number (%N) of mountain whitefish in the lower Cedar River. Number above each pair of bars is the number of stomach samples analyzed.

Sculpin

A total of 344 sculpin stomach samples were examined (not including 54 sculpin that were empty). Sixty-eight percent of the samples were torrent sculpin. In the extreme lower and lower strata, fish comprised a large portion of the diet (by weight) of torrent sculpin during each time period (Figure 27). Twenty-six percent of the torrent sculpin sampled had been piscivorous. Sockeye salmon fry were only present in the diet in January-February and were only observed in fish 56-105 mm TL. During the other time periods, the only type of fish consumed was sculpin. The presence of sculpin was usually found in torrent sculpin ≥ 100 mm TL diets. During the summer, sculpin were only present in 11.5% of the torrent sculpin 50-99 mm TL diets yet comprised 88.7% of the overall diet by weight. For torrent sculpin ≥ 100 mm TL during the summer, sculpin were present in 34.7% of the samples and comprised 87.3% of the diet by weight. In addition to piscivory, torrent sculpin in the extreme lower and lower strata also preyed on aquatic insects during each time period. By weight, plecoptera nymphs made up 57.8% of aquatic insects and by number, ephemeroptera nymphs made up 48.4% of the aquatic insects.

In the middle and upper strata, aquatic insects were the dominant prey type during each time period and for both the 50-99 and ≥ 100 mm TL size classes except for the large size class during the summer (Figure 27). Overall, the occurrence of fish in the diet was considerably less than in the lower strata. However of the 13 torrent sculpin > 100 mm TL sampled in the summer, five were piscivorous; one torrent sculpin (118 mm TL) had consumed a juvenile coho salmon, another had consumed a dace (*Rhinichthys* sp.), and three others had consumed sculpin.

Figure 27.—Diet composition by weight (%) of two size classes of torrent sculpin in two sections of the lower Cedar River. January-June results represent combined samples from 2008 and 2010. July-August results represent combined samples from 2006 and 2007. Number above each bar is the number of stomach samples analyzed (not including empty stomachs). Colored areas indicate fish in the diet while black and white areas indicate invertebrates and other diet items.

Most samples of coastrange sculpin were collected downstream of Rkm 7.1. Within the extreme lower and lower strata, the abundance of coastrange sculpin appears to gradually decline in further upstream sites (Tabor et al. 2007). They comprise less than 0.5% of the scuplin in the middle strata and are not known to occur in the upper reach. Of the 51 coastrange sculpin sampled from January through April with contents in the stomach sample, 13.7% had consumed sockeye salmon fry (n = 18). All instances of sockeye salmon fry predation were from 2008 samples; however, 76.5% of the samples were from 2008. Aquatic insects (primarily ephemeroptera, plecoptera, and trichoptera) and fish eggs (primarily sculpin) were also important prey items in both years (Figure 28). From May through August, the diet of coastrange sculpin consisted of only aquatic insects (primarily chironomid and trichoptera larvae) and other invertebrates.

Figure 28.**—**Diet composition by weight (%) of two size classes of coastrange sculpin in extreme lower and lower strata of the lower Cedar River. January-June results represent combined samples from 2008 and 2010. July-August results represent combined samples from 2006 and 2007. Number above each bar is the number of stomach samples analyzed (not including empty stomachs). Colored areas indicate fish or fish eggs in the diet while black and white areas indicate invertebrates and other diet items.

Three other sculpin species were collected, which included 16 riffle sculpin, 10 prickly sculpin, and 9 shorthead sculpin. Riffle sculpin (range 68-99 mm TL) were occasionally sampled from the extreme lower to the middle stratum. The diet of riffle sculpin consisted of 78% aquatic invertebrates and 2.3% fish (1 sockeye salmon fry). Upstream of Rkm 1.0, prickly sculpin are generally uncommon (Tabor et al. 2007). All ten prickly sculpin we collected were in the extreme lower stratum. Eight prickly sculpin (80-139 mm TL) were sampled from February through March and their diet (%W) was comprised of relatively large prey items including sockeye salmon fry (n = 6), oligochaetes, and leeches. Two prickly sculpin (158 and 190 mm TL) were sampled in the July-August period. Both had consumed smaller sculpins, which made up 98% of their diet (%W). The only identifiable prey items in shorthead sculpin (n = 9; range, 86-120 mm TL) were aquatic insects (dipteran larvae: %N 67%; %O 89%, %W 12%).

Smallmouth Bass

During the July-August period, six adult smallmouth bass were collected (5 in 2006 and 1 in 2007) (range, 300-350 mm FL). No smallmouth bass were ever collected during the 2008 and 2010 winter-spring sampling. Smallmouth bass were collected as far upstream as Rkm 31.4 in the middle strata. Of the six smallmouth bass collected, three were empty, one had consumed two dace, one had consumed three unidentified salmonids, and the other had consumed a rainbow trout (177 mm FL) that had been captured and tagged two days earlier.

Consumption Estimates

Trout

July-August Predation Estimates.— Overall, July-August predation estimates were similar between 2006 and 2007. An estimated 10,984 juvenile salmonids (4,922 coho salmon and 6,092 trout) and 149,624 sculpin were consumed in 2006 and 11,373 juvenile salmonids (all coho salmon) and 165,049 sculpin were consumed in 2007. Predation of coho salmon by resident trout was only documented in the upper stratum in 2006, whereas it was documented in the lower and middle strata in 2007. Predation of sculpin by trout occurred primarily in the lower and extreme lower strata (Figure 29).

Figure 29.**—**Estimated cutthroat trout and rainbow trout consumption of sculpin in four strata of the lower Cedar River, July-August 2006 and 2007. Predation estimates are based on a direct consumption model.

Winter-Spring Predation Estimates.— Trout predation rates of sockeye salmon fry varied widely between time periods, strata, and species; however in general, predation rates tended to progressively decrease in more upstream strata (Table 5). Total predation was highest in the lower stratum but on a per km basis, the highest predation levels were in the extreme lower stratum for both years. For rainbow trout, predation rates tended to increase in larger size classes; whereas for cutthroat trout, there was no trend between size classes. Total estimated trout predation of sockeye salmon fry was 291,701 in 2008 and 1,245,676 in 2010 (Table 6). In 2008, 15.8% of the trout predation on sockeye salmon fry was by cutthroat trout and in 2010 it was only 3.2%.

Trout predation rates and total predation of Chinook salmon were generally higher for cutthroat trout than rainbow trout (Tables 7 and 8). Although the abundance of Chinook salmon was considerably higher in 2008 than 2010, our estimate of predation was 2.6 times higher in 2010 than in 2008. All predation of Chinook salmon in 2008 by rainbow trout was by the largest size class and in 2010, 82.2% of the predation was by the large size class. For cutthroat trout, 65.3% of the predation of Chinook salmon was by the smallest size class in 2008 and in 2010, 56.8% of the predation was by the middle size class.

Predation of other salmonids in 2010 included 22,059 coho salmon fry, 4,323 yearling coho salmon, 2,580 cutthroat trout fry, and 2,405 pink salmon fry (Figure 30). None of these salmonids were found in the 2008 diet samples. Predation of coho salmon fry was observed in all three size classes and in the lower and middle strata, while predation of yearling coho salmon was only by the largest size class and in all strata. Predation of cutthroat trout fry and pink salmon fry was only documented in the extreme lower strata.

Similar to trout predation of sockeye and Chinook salmon, estimated predation of sculpin was considerably higher in 2010 than 2008 (Tables 9 and 10). Predation of sculpin was predominantly in the large size class. For both years combined, 81% of the estimated predation of sculpin by cutthroat trout was by the large size class and 97% for the predation by rainbow trout was by the large size class. The amount of predation per river kilometer was substantially higher in the lower stratum than the other strata (2010: lower stratum - 5,029 sculpin per km; middle – 1,902; extreme lower – 897; upper – 244). Predation of sculpin by cutthroat trout occurred primarily in May and June, while predation of sculpin by rainbow trout was spread out over each period.

Table 5.—Cutthroat trout and rainbow trout predation rates (fry/day) of sockeye salmon fry in four strata of the lower Cedar River, winter-spring 2008 and 2010. Predation rates are based on a direct consumption model. Dashes indicate no predators were collected.

Table 6.—Estimated number (SE) of sockeye salmon fry consumed by cutthroat trout and rainbow trout in four strata of the lower Cedar River, winter-spring 2008 and 2010. Predation estimates are based on a direct consumption model. Standard errors are based on population estimates. Dashes indicate no predators were collected.

Table 7.—Trout predation rates (fry/day) of Chinook salmon fry in four strata of the lower Cedar River, winter-spring 2008 and 2010. Predation rates are based on a direct consumption model. Dashes indicate no predators were collected.

Table 8.—Estimated number (SE) of Chinook salmon fry consumed by cutthroat trout and rainbow trout consumption in four strata of the lower Cedar River, winter-spring 2008 and 2010. Predation estimates are based on a direct consumption model. Standard errors are based on population estimates. Dashes indicate no predators were collected.

Figure 30.**—**Estimated cutthroat trout (CUT) and rainbow trout (RBT) predation (number consumed) of other salmonids (coho salmon [yearlings and fry], cutthroat trout fry, and pink salmon fry) in four strata of the lower Cedar River, winter-spring 2010. Predation estimates are based on a direct consumption model.

Table 9.—Trout predation rates (fish/day) of sculpin in four strata of the lower Cedar River, winter-spring 2008 and 2010. Predation rates are based on a direct consumption model. Dashes indicate no predators were collected.

Table 10.—Estimated number (SE) of sculpin consumed by cutthroat trout and rainbow trout in four strata of the lower Cedar River, winter-spring 2008 and 2010. Predation estimates are based on a direct consumption model. Standard errors are based on population estimates. Dashes indicate no predators were collected.

Coho Salmon (Winter-Spring Only)

To estimate the abundance of juvenile coho salmon, we used the production estimates from the Cedar River screw trap (Kiyohara and Zimmerman 2009; Kiyohara and Zimmerman 2011). Production estimates were 13,322 (SE, 6,526) in 2008 and 83,060 (SE, 6,746) in 2010. These estimates represent the production for the watershed above the trap and thus include some areas outside our sample area (i.e., tributaries to lower Cedar River and area above Landsburg Dam). To account for area outside our study area, we used two estimates; either 90% or 50% of the juvenile coho salmon inhabited our study area, the lower Cedar River mainstem. We also assumed that distribution of juvenile coho salmon was uniform between strata and the abundance for each strata was based on river length. Because our sample sizes of juvenile coho salmon in the extreme lower and upper strata were small, we combined the extreme lower with the lower stratum and the upper with the middle stratum.

Using the two abundance estimates, we estimated that juvenile coho salmon consumed 228,213 to 410,824 sockeye salmon fry in 2008 and 371,056 to 667,909 fry in 2010 (Table 11). Total predation of Chinook salmon ranged from 42,776 to 99,674 in 2008. Predation of Chinook salmon was not observed in 2010. In addition to sockeye salmon and Chinook salmon, juvenile coho salmon also consumed coho salmon fry, which was only observed in May 2010 samples. An estimated 47,903 to 86,226 coho salmon fry were consumed; however, these estimates are based on a sample of four fish and is likely inaccurate.

Table 11.—Juvenile coho salmon predation rates (fish/day) and estimated total predation of sockeye salmon fry and Chinook salmon in the lower Cedar River, winter-spring 2008 and 2010. Predation estimates are based on a direct consumption model. Total predation was estimated with two abundance estimates: assuming 50% and 90% of the coho salmon smolt production (from WDFW smolt enumeration trap) inhabited the lower Cedar River mainstem and the rest were in tributaries or above Landsburg Dam. The lower and uppermost strata were combined to increase the sample size. Sample size is the number of stomach samples analyzed (including empty stomachs). ExL = Extreme Lower

Other Analyses

PIT Tag Analysis

We PIT tagged 577 rainbow trout during summer 2006 and 3.6% (21 of 577) were detected at the Ballard Locks PIT tag detection flume during the spring 2007, suggesting an anadromous life history. Mean fork lengths of 184.3 mm (range, 115-445 mm FL) for all tagged trout and 159.4 mm (range, 138-183 mm FL) for the trout detected at the Ballard Locks flume were statistically different (t = 1.96, P = 0.0186). We PIT tagged an additional 139 rainbow trout during the summer of 2007 and none were detected at the Ballard Locks flume.

Otolith Analysis

Seventeen percent (5 of 29) of the rainbow trout collected for microchemistry otolith analysis in 2007 had elevated strontium levels suggesting that they were progeny of anadromous females.

DISCUSSION

Abundance Estimates and Length Composition

Our estimates of the summer abundance of trout in the Cedar River below Landsburg Dam were consistently around 17,000 from 2006 to 2008; however, our estimates may have been biased because our electrofishing sampling methods may have been size selective and underrepresented small (<150 mm) trout. Summer catch curves for both 2006 and 2007 showed that age-0 trout were underrepresented (i.e., below the diagonal line or not represented in the sample), and snorkel length distribution of trout was predominately in the 150-250 mm size category. A similar pattern was observed in winter-spring day snorkeling. We conducted two night-snorkel surveys during winter-spring 2008 and the observed trout length composition was 71% <150 mm, 19% 150-250 mm, and 10% >250 mm, which is what we expected with an assumption of constant recruitment and survival. Small trout, especially around abundant cover and near the shore in shallow water (i.e., < 10 cm depth), can be difficult to observe during snorkel surveys (Hillman et al. 1992; Thurow and Schill 1996). Additionally, some portion of the small trout may be small tributaries and side channels that were not surveyed.

Winter-spring trout abundance in the Cedar River appears to be considerably lower than the summer abundance. Lower winter-spring abundances may be attributed in part to trout moving upstream in February through April into the upper Cedar River through the Landsburg Dam fish ladder (SPU, unpublished data) or non-gravid trout emigrating to Lake Washington during the winter and early spring months seeking thermal refuge. Additionally, some may move into off-channel ponds, small tributaries, and other habitats to avoid high flows during the winter. Nowak et al. (2004) found that cutthroat trout in Lake Washington immigrate into the rivers to spawn in February through April and emigrate and reside back in the lake throughout the rest of the year. This observation is supported by our findings that trout observed during the winter-spring were larger on average than in the summer. Fish tagging and tracking studies are needed to better understand the seasonal movement patterns of fluvial and adfluvial trout in Cedar River and Lake Washington.

Low winter population estimates may also have been an artifact of visual estimation techniques. Unlike the summer snorkel survey estimates, we did not have Cedar River specific winter-spring sightability (transparency) values to correct our survey counts and were forced to use available literature as an approximate. Experienced snorkelers can observe greater than 70% of the fish present during the day in summer conditions when water temperatures are above 10°C (Northcote and Wilkie 1963; Hillman et al. 1992; Thurow and Schill 1996; Jakober et al. 2000). However, at water temperatures below 10°C, salmonids shift to a nocturnal behavior and seek cover expressing concealment behavior during the day (Bonneau and Scarnecchia 1998) reducing observation rates to less than 35% (Jakober et al. 2000; Hillman et al. 1992; Roni and Fayram 2000). Night snorkel surveys can account for greater than 75% of the trout present at water temperatures below 10°C (Griffith and Smith 1993; Thurow 1994; Thurow and Schill

1996; Jakober et al. 2000; Roni and Fayram 2000), but can be difficult to do safely in large rivers. Based on these observations, we conducted three night snorkel surveys during 2008; Maplewood in summer and Lions Club and Landsburg in winter-spring. Swift currents coupled with boulder substrate and the inability to see large woody debris made night snorkel surveys hazardous. In the lower and extreme lower strata, large amounts of suspended debris in the water column in the slower potions of the river resulted in visibility similar to a "driving in a snow storm effect", severely limiting visibility. Ultimately we used Hillman et al. (1992) and Roni and Fayram (2000) to approximate our 2008 and 2009, respectively, sightabilities. Both of these studies used four Washington streams each to compare the efficiency of snorkel survey counts to total trout abundance estimates at water temperatures similar to those we observed during our winter-spring surveys. We expect that our winter-spring abundance estimates are biased; however, which way or to what magnitude is unclear.

Within the lower Cedar River, cutthroat trout were consistently the dominant trout species in the extreme lower stratum, whereas rainbow trout were the dominant trout species in the middle and upper strata. Upstream of our study area, between Landsburg Dam and Cedar Falls, rainbow trout are the dominant species. Outside of the mainstem of the Cedar River, cutthroat trout are the dominant trout species in Lake Washington (Nowak et al. 2004) as well as in small tributaries of Lake Washington and lower Cedar River (H. Berge, unpublished data). This overall pattern is somewhat different than has been observed in other systems, where cutthroat trout are generally located in small headwaters streams while rainbow trout are located in lower reaches (Hartman and Gill 1968; Reeves et al. 2011). However, Hartman and Gill (1968) also found cutthroat trout were common in streams near lakes and in systems that have a low-gradient slough at the mouth. This finding would suggest that the reason cutthroat trout are more common in the lower reaches of the Cedar River is because these reaches are adjacent to Lake Washington and they have a lower gradient than other reaches of the Cedar River (Perkins Geosciences and Harper Houf Righellis 2002). In the Cedar River, the middle and upper strata have a higher gradient which tends to favor rainbow trout (Bisson et al. 1988).

The proportion of cutthroat trout to rainbow trout in the Cedar River appears to have increased in recent years. In this study, cutthroat trout represented 42% of the trout collected during the winter and spring and 32% during the summer sampling. Sampling from 1995 to 2000 by the USFWS also indicated that cutthroat trout were common in the lower Cedar River (Tabor et al. 1996b; Tabor et al. 1998; R. Tabor, unpublished data). In contrast, sampling by Casne (1975) and Beauchamp (1995) found cutthroat trout were generally rare in comparison to rainbow trout. The combined electrofishing collections in August 1973 at Rkm 2.6, 18.5, and 27.7 found cutthroat trout only represented 2.6% of the trout collected (Casne 1975). Similarly, Beauchamp (1995) found cutthroat trout made up less than 10% of the trout collected in February-May of 1983-1985 from the lower 9.6 km. Exact mechanisms for this change are not well known, but possible mechanisms include: 1) population reduction of steelhead/rainbow trout due to ocean conditions, sea lion predation, harvest, etc.; 2) change in lake conditions (e.g.

temperature or food supply); 3) hybridization; 4) reduced interspecific competition with the end of hatchery releases of rainbow trout in the 1990s; and 5) increased urbanization throughout the Lake Washington basin resulting in a large cutthroat trout population (Scott et al. 1986; Serl 1999).

The catch and release fishery implemented in 2004 appears to have had minimal effects on annual trout survival, although the abundance of trout redds in the Cedar River has been reduced (K. Burton, personal communication). In this study, we observed a 27.0% annual survival rate for rainbow trout ages 1-5 in 2003 and 36.7% in 2006 and 37.9% in 2007. This conclusion is based on a single year (2003) of age-length data collected prior to opening the fishery and should be used with caution.

Predation and Diet

Trout

Overall, resident trout did not appear to be an important predator of juvenile trout. Out of 1,614 trout analyzed for diet, we only documented three trout fry. Two were cutthroat trout fry and the other was a probable rainbow/cutthroat trout hybrid. One of the major aspects of this study was to determine if resident trout were having an impact on the Cedar River's steelhead population. We found no evidence that predation by resident trout was having an impact on the steelhead population. Our sampling occurred from late January to early August and predation of juvenile steelhead may be more prevalent during other times of the year. However, juvenile steelhead may be large enough by late August to avoid most piscivorous trout and an increase in alternative prey (primarily salmon eggs) for large trout might minimize predation of juvenile trout.

Results from 2010 indicated that resident trout can be important predators of Chinook salmon. An estimated 66,000 Chinook salmon were consumed by resident trout, while an estimated 115,500 emigrated as fry and another 36,900 emigrated at parr (Kiyohara and Zimmerman 2011), resulting in a rough estimate of 33% predation (Table 12). An earlier predation study in the Cedar River in 2000 estimated a trout predation rate of Chinook salmon of 27% (Tabor et al. 2004). Predation of young-of-the-year Chinook salmon by trout can be an important source of mortality in other systems. For example, Hawkins and Tipping (1999) documented high predations rates of wild juvenile Chinook salmon by steelhead and cutthroat trout in Lewis River, Washington.

Table 12.**—**Summary table of abundance and predation of cutthroat trout, rainbow, and juvenile coho salmon in the lower Cedar River, 2006-2010. The population estimate and predation of juvenile coho salmon is based on a projection that 50% of the total number of coho salmon smolts (WDFW trap data) inhabited the lower Cedar River study area and the other 50% inhabited tributaries or upper Cedar River areas. Percent predation of sockeye salmon fry and juvenile Chinook salmon is based on the number of migrants at WDFW traps.

In 2010, trout predation rates of Chinook salmon were substantially higher than other piscivores. Because trout obtain a large size and can forage throughout the water column and in a wide range of current velocities, they are more likely to prey on Chinook salmon than other predatory fishes in the Cedar River such as cottids and coho salmon. In Elokomin River, Washington, a system with similar predator species as the Cedar River, Patten (1971) also found that cutthroat trout and rainbow trout had a higher predation rate of newly-released hatchery Chinook salmon than other piscivorous fishes.

Sizes of Chinook salmon consumed by rainbow trout were generally smaller than those consumed by cutthroat trout. Earlier sampling in the Cedar River from 1995 to 2000 found this same trend (Tabor et al. 2004). Additionally, this earlier sampling effort found predation of Chinook salmon by rainbow trout occurred primarily in large deep pools; whereas, predation by cutthroat trout occurred primarily in secondary pools. Rearing juvenile Chinook salmon typically inhabit shallow, low-velocity areas such as secondary pools along the river’s edge and few are in large, deep pools. Therefore, rainbow trout may prey mostly on emigrating newly-emerged Chinook salmon fry while cutthroat trout may prey on rearing Chinook salmon that have remained in the river for some time and thus are larger than newly-emerged fry.

Although resident trout appear to be an important predator of Chinnok salmon fry, predation of emigrating juvenile Chinook salmon in May and June appears to be extremely rare. During this study, we sampled 292 resident trout in May and June and no predation was detected. Predation may have been low due to high streamflow conditions in late-May to mid-June in both 2008 and 2010. However, in collections of resident trout in the lower two km of the Cedar River in May-June 1995 to 2000 during low streamflow conditions, only one Chinook salmon was found out of 326 trout samples (Tabor et al. 2001). During this period, juvenile Chinook salmon are probably large enough to effectively avoid resident trout. Additionally, the availability of some types of alternative trout prey (e.g., aquatic insects, sculpin, crayfish, and sucker and peamouth eggs) is much higher during this period than earlier in the year.

Predation of sockeye salmon fry by resident trout was highest in the extreme lower and lower stratum. Even within the lower strata, predation of sockeye salmon fry appeared to be more pronounced in downstream areas. The higher predation rates may be related in large part to higher abundance of fry. If the spawning distribution of sockeye salmon was evenly spread out over the lower Cedar River, the abundance of fry will be much higher in the lower section because all fry must pass through the extreme lowest stratum whereas few fry have to pass through the upper stratum. Also in 2007 and 2009 (brood years for this study), sockeye salmon spawning was more concentrated in the lower reaches (H. Berge, unpublished data) which would have resulted in a substantially higher abundance of fry in the extreme lower and lower stratum.

Resident trout consumed about 9% of the available sockeye salmon fry in 2010. In comparison to observed survival rates of hatchery sockeye salmon fry, our estimate of 9% seems like a reasonable estimate of predation. At 500 cfs (approximate discharge level during 2010 sampling), the predicted loss of hatchery sockeye salmon fry from Landsburg Hatchery (Rkm 34.9) to the mouth is approximately 53% (Seiler et al. 2005). Hatchery fry do not appear to be more vulnerable to predation than naturally-produced fry (R. Tabor, unpublished data). In 2009-2010, the density of spawning sockeye salmon was much higher in the lower 7 km of the Cedar River than in other areas. Therefore, the loss of fry in 2010 would be expected to be substantially less than 53%. A rough calculation based on spawner distribution and predicted loss of hatchery fry indicated the loss of fry should be 20%. Additionally, the abundance of large rainbow trout, the primary predator of sockeye salmon fry, was higher in more upstream reaches and thus hatchery fry released at Landsburg would be exposed to a higher density of predators than most wild fry. Earlier sampling of predatory fishes in the Cedar River found predation rates were much higher in large pools than other habitats (R. Tabor, unpublished data). These large pools tend to be more frequent in upstream reaches (Gendaszek et al. 2012) and thus predation rates would be expected to be higher in more upstream reaches. Lastly, our estimated loss of 9% does not include loss due to other predators such as juvenile coho salmon and sculpin. By adding in the 2.6% loss by juvenile coho salmon and assuming another 2 to 3% loss by sculpin, then our total predation estimate would be around 14%, which seems reasonable compared to the predicted level of 20% and taking into account longitudinal differences in habitat and predator abundance.

Of the predatory fishes we examined, predation of sockeye salmon fry (both total predation and predation rate) was most pronounced in rainbow trout > 200 mm FL. Habitat use patterns of sockeye salmon fry and their predators likely influence the predation rates. Sockeye salmon fry reduce their vulnerability to predators by selecting areas of the river channel with the highest current velocities (McDonald 1960). Of the predatory fishes present in the Cedar River, large rainbow trout are probably the best adapted to inhabit high current velocities and effectively forage (Bisson et al. 1988) and thus would be expected to have the highest overlap with sockeye salmon fry. Other predatory species and smaller rainbow trout are probably more associated with the substrate (e.g., sculpin) or shoreline (e.g., coho salmon, cutthroat trout, and small rainbow trout) and would have less overlap with sockeye salmon fry.

Our predation estimates for 2008 and 2010 were markedly different. For each prey species (salmonids and sculpin), 2010 estimates were considerably higher. Predation of sockeye salmon and Chinook salmon fry was expected to be higher in 2008 than 2010 because the abundance of fry migrating to Lake Washington was much higher in 2008 than 2010. Likely explanations for this discrepancy were that sampling effort and streamflow conditions were different between the two years. In 2008, we did not have access to an electrofishing raft until late March and instead, relied primarily on backpack electrofishing, which tends to collect substantially smaller and fewer fish than with raft electrofishing equipment. Most of the emigration of sockeye and Chinook salmon fry occurs in February and March and we likely did not adequately sample the resident trout population, especially the large rainbow trout that can consume large number of sockeye salmon fry. Because we did not adequately sample large trout, we may have also underestimated predation on large prey types such as sculpin and yearling coho salmon.

The other major difference between 2008 and 2010 was streamflow conditions. In 2010, the streamflow at the Renton gauge was rarely above 600 cfs from February 1 to May 1; whereas in 2008, streamflow was usually between 600 and 1,200 cfs from March 7 to April 1. Therefore, emigration of sockeye and Chinook salmon fry generally occurred during the higher streamflow conditions in 2008 than 2010. Streamflow appears to have a strong influence on predation of sockeye salmon fry. Seiler and Kishimoto (1996, 1997) found that the survival of hatchery sockeye salmon fry from Landsburg to Renton was positively related to streamflow. In a review of several Columbia River studies, Cada et al. (1997) concluded there was a positive relationship between streamflow and juvenile salmonid survival. Overall, there appears to be a negative relationship between streamflow and predation rates of emigrating salmonids. However, the relationship between streamflow and predation of other prey fish (sculpin and non-emigrating salmonids) is not known.

Ontogenetic diet shifts of cutthroat trout and rainbow trout appeared to be quite different. Cutthroat trout appear to be piscivorous at a smaller size and as they grow they progressively shift to large prey fishes. In the Cedar River, they shifted from preying on sockeye and Chinook salmon fry to preying on large sculpin and other large prey fishes. In contract, rainbow trout are rarely piscivorous until they were > 250 mm FL and piscivory often consists of relatively small prey fishes such as sockeye salmon fry. In general, our results appear to be consistent with earlier research of these predators in riverine and lacustrine environments. In the Cowichan River on Vancouver Island, piscivory was rare in all sizes of rainbow trout, whereas cutthroat trout > 100 mm FL were piscivorous and the percent that were piscivorous increased with size (Idyll 1942). In Lake Washington, cutthroat trout predation of sockeye salmon fry has been primarily observed in fish < 250 mm FL, while larger cutthroat trout prey on larger prey fishes (Nowak et al. 2004). Rainbow trout in Lake Washington are generally not piscivorous until they are 250 mm (Beauchamp 1990). Also, Johannes and Larkin (1961) found rainbow trout did not become piscivorous in British Columbia lakes until they were 250 mm.

As a whole, each species appeared to forage opportunistically; however, within each species there did appear to be some specialization between individuals. Most of the predation of sockeye salmon fry was often confined to a few individuals. On a given sample, we may have had a few trout with over 20 fry each in their stomachs and then have several other similar-sized trout that had not consumed a single fry. Some of these other trout may have consumed primarily caddisflies or cottids, suggesting they were foraging on the bottom. Other trout may have preyed on terrestrial insects and aquatic insect exuvia, suggesting they were foraging on drift. Differences between individuals may reflect differences in foraging locations within the water column and/or differences in search patterns. Food specialization has been demonstrated in brook trout (*Salvelinus fontinalis*), rainbow trout, cutthroat trout (Bryan and Larkin 1972), and brown trout (*Salmo trutta*) (Birdcut and Giler 1995).

The common occurrence of sculpin, crayfish, and large aquatic insects (primarily trichoptera and plecoptera that have low drift rates) in the diet of cutthroat trout and rainbow trout suggest they often have a substrate-oriented feeding strategy. In many systems, cutthroat trout and rainbow trout appear to feed primarily on drift and substrate-oriented feeding is minimal (Antonelli et al. 1972; Elliot 1973; Griffith 1974; Cada et al. 1987). However in some locations, substrate-oriented feeding may be common (Angradi and Griffith 1990; Tippets and Moyle 1978). In the Cedar River, substrate-oriented feeding was most notable in the large size class of both trout species. Tippets and Moyle (1978) found the same effect for rainbow trout in McCloud River, California. As salmonids increase in size there is a general tendency for prey size to increase (Keeley and Grant 2001) and thus they may switch to large benthic prey.

In this study, terrestrial invertebrates were common in the diet but did not make up a major component of the overall diet. Some diet studies of cutthroat trout and rainbow trout have stressed the importance of terrestrial invertebrates (Antonelli et al. 1972; Elliot 1973; Hunt 1975; Cada et al. 1987). Diet studies that have shown a prevalence of terrestrial invertebrates were usually conducted in small streams where riparian areas may have a greater influence on prey availability. In larger streams, trout may have to rely more on autochthonous prey (Angradi and Griffith 1990). Changes to the Cedar River riparian zone (e.g., armoring and residential development) may also have reduced the input of terrestrial invertebrates. Additionally, Cedar River trout are able to utilize other prey resources of marine and lacustrine origin. Nutrients from these sources may also result in high levels of autochthonous prey.

Coho Salmon

Similar to resident trout, yearling coho salmon commonly consumed sockeye salmon fry under some conditions; such as in extreme lower strata in February and March. Largely because they are smaller, yearling coho salmon usually have a lower predation rate than resident trout. However, coho salmon yearling may be more numerous than resident trout and may be a more important predator in some situations. For example, in 2010 coho salmon smolt production was estimated at 83,060 (Kiyohara and Zimmerman 2011) and assuming at least half inhabited the lower mainstem and resident trout population during the winter-spring period was less than 10,000, then the yearling coho population would be at least four times greater than the trout population. Other studies have also found that yearling coho salmon is a major predator of sockeye salmon fry in riverine and lacustrine habitats, largely because they are far more numerous than other piscivores (McCart 1967; Ruggerone and Rogers 1992).

Yearling coho salmon also appeared to be an important predator of Chinook salmon fry. Total predation of Chinook salmon ranged from 42,776 to 99,674 in 2008. Assuming coho salmon and trout were the main predators of Chinook salmon, and then coho salmon would have consumed roughly 5.1 to 11.1% of the Chinook salmon fry. No predation of Chinook salmon was observed in 2010. The large difference between the two years was likely due to the small sample sizes and the large number of Chinook salmon fry in 2008 (fry migration to Lake Washington; 2008, 691,200 fry; 2010, 115,500 fry). Coho salmon predation rates of Chinook salmon fry are generally low and a large sample is likely needed to obtain an accurate estimate. Additionally, our 2008 predation estimate by coho salmon was higher than for cutthroat and rainbow trout combined. This may have been largely because an electrofishing raft was not available in February and most of March when Chinook salmon are migrating downstream and therefore we may have missed much of the predation by trout.

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APPENDIX A

Use of Genetic Methods for Species Identification of Stomach Contents from Cedar River Salmon and Trout

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In this study we used genetic methods to determine the species identification of suspected salmonids collected from the stomach contents of salmon and trout in the Cedar River.

Methods

Laboratory Analyses

Genomic DNA was extracted for all samples by digesting a small piece of fin tissue using silica membrane based kits obtained from Macherey-Nagel (Bethlehem, PA, USA) following the manufacturers recommendations. PCR reactions were conducted with a thermal profile as follows: an initial denaturation step of 2 min at 94oC, 40 cycles of denaturation at 94^{o}C for 15 s, 30 s at the appropriate temperature for each multiplex, and 1 min at 72^{o}C, plus a final extension at 72^{o}C for 10 min and final holding step at 10 ^{o}C. Genotypes were visualized using an ABI-3730 DNA Analyzer (Applied Biosystems, Foster City, CA, USA) with internal size standards (GS500LIZ 3730) and GENEMAPPER 3.7 software.

Species Identification

A total of 50 juvenile were identified to species using markers located in the mitochondrial region COIII/ND3. Thirteen allele specific primers (see below) produce DNA fragments of different lengths that are diagnostic for identifying salmonid species. This process used the polymerase chain reaction (PCR) based fragment analysis to visualize genetic markers. The

COIII/ND3 region spans a 368-nucleotide segment across the cytochrome oxidase subunit III gene, tRNA-Gly gene, and NADH subunit 3 gene, and contains 10 single nucleotide polymorphisms.

Mitochondrial cytochrome-b gene primers used for identifying samples to salmonid species.

Results

The species identification analysis revealed 12 samples were Chinook salmon, 19 were coho salmon, nine were sockeye salmon, two were pink salmon, two were cutthroat trout, one was a probable rainbow/cutthroat hybrid, four could not be identified, and the amplification failed for one individual and no species identification could be determined.