Community and ecosystem attributes of the Cedar River watershed above Landsburg

Diversion after arrival of Pacific salmon

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**Executive Summary**

As part of the City of Seattle's Habitat Conservation Plan, a fish ladder was constructed at Landsburg Diversion to allow for passage of salmon. Adult salmon were passed above Landsburg beginning in August 2003; the diversion had blocked migration of salmon into this part of the watershed since about 1905. This report describes fish communities in the Cedar River above the diversion during the first year after passage of adult salmon. In July and August of 2004 we surveyed about 12 km of river habitat from above the diversion pool to about 200 m above the Taylor-main stem confluence. We identified habitat type (e.g., pools, riffles), and measured habitat area, depth, width, slope and substrate composition. Following the habitat survey we conducted snorkel surveys to describe the fish community; 4650 fish were observed during this survey. We also documented the colonization of Rock Creek by juvenile coho salmon. Water samples (311 samples) have been collected from historic sites between September 2004 and October 2005. Samples were also collected in September 2004 to measure concentrations of the isotopes of carbon and nitrogen (368 samples collected and processed). These isotopes can be used as tracers to describe energy flow in the food web and the relative importance of salmon-derived nitrogen to the nitrogen budget in various trophic levels. These data will be used to examine the success of recolonization of coho salmon, whether returning salmon have measurable ecological effects on the food web above Landsburg after isolation for about 100 years, and habitat-fish associations to aid in guiding in river restoration.

The Cedar River and tributaries are relatively cool streams with mean annual temperatures of 8 ℃, (maximum=18 ℃, minimum=2 ℃). Water temperature was coldest

in January (mean=4 ºC) and warmest in August (mean=12 ºC). Nitrogen concentrations ranged from ~150 to 2500 µg/L and total phosphorus ranged from 5 to 70 µg/L. Concentrations of nitrogen and phosphorus were higher in tributary streams during all seasons. Mean annual nitrogen concentrations were almost three-fold higher in tributaries (~500 µg/L) than main stem (~150 µg/L) stations. In general, both main stem and tributary sites were phosphorus limited, with tributary sites relatively more P-limited. The relative degree of P-limitation differed among seasons, as main stem sites appeared to be limited by both N and P in winter versus P in summer. The extremely low inputs of salmon biomass into the large Cedar River main stem should have a little impact on stream phosphorus levels.

To date (2003, 2004, and 2005 spawning records), about 239 kg of salmon biomass has been imported into the Cedar River ecosystem. This number is likely a conservative estimate as more adults were passed above the diversion than the number of fish needed to produce the number of observed nests. The two reaches (CR1 and 2) closest to Landsburg have received the greatest amount of salmon input averaging about 103 and 89 kg of total salmon biomass, respectively. This input translates into about 31 kg N and 4 kg of P into reach 1. Very few salmon have spawned in the next reach, CR3, with the next highest input occurring in CR4 (~19 kg). Correcting salmon input by reach area shows that mean annual inputs (~0.0004 – 0.0006 kg/m$^2$) were relatively similar among CR1, CR2 and CR4. These levels are about 250 – 375 × lower than the amount of carcass biomass (0.15 kg/m$^2$) shown by Bilby et al. (2001) where salmon-derived nitrogen in juvenile fishes reached an asymptote.

Stable isotope data from 2004 suggest that riparian and stream organisms in Rock Creek were enriched in $N^{15}$ relative to organisms in main stem sites, even when compared to a site located below Landsburg that is accessible to spawning salmon. For example, $d^{15}N$ concentrations in mayflies captured from Rock Creek were ~4-5× greater than mayflies from main stem sites including the site below Landsburg. In general, $d^{15}N$ concentrations in tissues collected from the reach (CR1) just above Landsburg were greater than in Taylor Creek above a natural barrier to salmon; however, there was little evidence to suggest that the number of spawning adults has affected the nutrient content of organisms above Landsburg. The higher concentration of $N^{15}$ at CR1 compared to the Taylor Creek site may be due a salmon legacy (i.e., historically salmon had access to 27 km of habitat above Landsburg) or geomorphology. It has been shown in other studies that denitrification rates are higher in low gradient river reaches, such as CR1, thereby enriching aquatic food webs with $N^{15}$, and confounding the effects of salmon-derived N on stream nitrogen budgets.

Juvenile coho densities were largely concordant with adult redd density. Juvenile coho were relatively more abundant in reaches CR1 and 2, which were closest to Landsburg and reaches with high redd densities, and declined upstream. The proportion of coho in reaches CR1 and 2 was ~33% of total fish abundance. Densities of juvenile Chinook were relatively similar among reaches, and peaked in CR 5 and 6 where they composed ~5% of total fish abundance. We observed juvenile coho and chinook at our last sample location about 200 m above the Taylor confluence in large wood jam. Therefore, we are unsure of the upstream distribution of juvenile salmon. Coho were significantly more abundant in side-channel habitat in the main stem reaching densities of

0.05 fish/m$^2$. Although we could not detect significant differences among habitat types, juvenile Chinook were almost 4× more abundant in pool habitat (~0.004 fish/m$^2$) than other habitat types (~0.001 fish/m$^2$). Trout (mainly rainbow) were the most abundant fish taxa across surveyed reaches with densities ranging from 0.03-0.08 (fish/m$^2$). Trout densities in 2004 were similar to those measured in 2000 and 2001 or before the fish ladder was installed: densities averaged across reaches in 2000, 2001 and 2004 (reaches CR1 - 6 only) were 0.07, 0.06 and 0.05 fish/m$^2$, respectively. The slightly lower density in 2004 was likely a result of not surveying the upper reaches of the Cedar River, which had higher trout densities than lower reaches. The recolonization of juvenile salmon above Landsburg increased total fish density in the lower two reaches by 30-50% compared to 2000 and 2001.

Juvenile coho rapidly colonized lower Rock Creek. Juvenile coho were observed in the first pool in Rock Creek above its confluence with the main stem in May 2004. Two months later (July), coho were observed approximately 100 m above the first pool and 2 km above this point in September. No juvenile coho were observed in Williams Creek. In 2005, we observed relatively high densities of juvenile coho in pool 4 of lower Rock Creek; these fish were large (mean fork length = 93 mm) and were likely pre-smolts. In 2005, we observed coho in pools of lower Rock Creek, with fish moving up to the last pool before the Road 40 culvert in August 2005. Overall, densities of coho and trout in Rock and Williams Creek were lower in 2005 than 2004. Sixty-nine young of the year Chinook were also observed in lower Rock Creek in March 2005, with these fish also likely moving from the main stem into Rock Creek. While we have no direct evidence for the movement of individual fish (i.e. mark/recapture) we infer from these

results that juvenile coho migrated into and up Rock Creek in search of productive rearing habitat. Such a finding implies that colonization of tributaries to the main stem Cedar River may be mediated through juvenile dispersal. Expanding our mark/recapture program will provide more data on this fascinating phenomenon.

In August of 2004, we began inserting PIT tags into trout (34 cutthroat, 4 rainbow) and juvenile coho (20) in Rock Creek. In October we caught 3 previously marked coho and 4 trout for a recapture rate of 15% and 12%, respectively. In addition, out of 20 coho tagged in March 2005, 13 were detected at the Ballard Locks

These studies expand upon our previous research where we established baseline conditions in the watershed between Landsburg and Cedar Falls for water chemistry, stable isotopes, and fish populations. In 2004 and 2005, we initiated four additional study components, which will improve our understanding of what abiotic and biotic factors are important in explaining variation in fish abundance. These include: monitoring reach-scale variation in benthic alga standing stocks, measuring invertebrate drift rates, and a fish marking study in Rock Creek. Moreover, we have strengthened collaborations with the University of Washington (T. Quinn, J. Anderson) and further strengthened our collaborations with SPU (K. Burton, H. Barnett, D. Chapin). This has allowed us to develop a comprehensive evaluation of the ecological effects of recolonization of the Cedar River by anadromous salmon (Figure 1).

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## 1.0    Introduction

Pacific salmon have disappeared from approximately 40% of their historical breeding ranges in Washington, Oregon, Idaho, and California over the last century, and many remaining populations are severely depressed in areas where they were formerly abundant (NRC 1996).  As a result, a number of Pacific salmon stocks have been designated as threatened or endangered under the Endangered Species Act.  Recently, the National Marine Fisheries Service listed the Puget Sound chinook (*Oncorhynchus tshawytscha*) as threatened.  In 2006, NMFS recommended that steelhead (*Oncorhynchus mykiss*) be listed as threatened in Puget Sound as well.

Protection and rehabilitation of freshwater habitat and associated watershed processes are critical to conservation and restoration of Pacific salmon (NRC 1996).  There are a number of small diversions and dams that block migration of adult salmon in the Pacific Northwest: barrier removal or installation of passage facilities at these structures will likely be an important measure in restoring access to freshwater habitat.  As part of the city of Seattle's Habitat Conservation Plan (HCP) for the Cedar River Watershed, a fish ladder was installed at the Landsburg Diversion Dam, located on the Cedar River main stem, in August 2003.  This diversion blocked anadromous fish migration to approximately 27 km of main stem and tributary habitat for almost 90 years, and has likely resulted in a significant reduction in the amount of salmon-derived nutrients (SDN) and organic matter delivered to the watershed above Landsburg.  It has been shown in other studies that salmon carcasses provide important nutrient subsidies to their natal streams and the surrounding terrestrial ecosystem (Bilby et al. 1996, Willson et al. 1998, Chaloner et al. 2002).  In addition, resident salmonids in the uppermost Cedar

River watershed have been isolated from anadromous salmonids for a number of generations; there are likely to be ecological effects (e.g., competition, predation) on these resident fishes resulting from the return of anadromous forms above Landsburg. As far as we know, this is one of the first studies to document the natural colonization process of Pacific salmon into naïve habitat. Most other published studies have relied on stocking fish (Bryant 1999) or were in Alaska where salmon colonized streams after glacial recession (Milner et al. 2000). Therefore, this project presents a unique opportunity to understand the colonization process of Pacific salmon under natural conditions when a barrier is removed or altered to allow fish passage.

The goals of this project are to understand how anadromous fish affect aquatic and terrestrial ecosystems above the Landsburg diversion and to gain a better understanding of the demographic processes of salmon populations during recolonization of unoccupied habitat. Results from this study will provide critical insights into the effectiveness of the fish passage facility in restoring populations of anadromous fish in the Cedar River above Landsburg. Our long-term monitoring efforts will also provide insights into environmental factors (e.g., wood abundance, productivity) associated with trout and salmon abundance that will aid in directing restoration actions to increase critical habitat for these fishes. From 2000 to 2003 we collected data on water chemistry (nitrogen, phosphorus, water temperature); stable isotopes of C and N in algae, insects, fish and riparian vegetation; habitat characteristics (wood abundance and distribution, habitat composition, etc.), and fish population from above Landsburg to Cedar Falls (Figure 2). The specific aims of the baseline research were to:

1) To describe habitat characteristics of the Cedar River main stem above Landsburg and two tributaries, Rock and Taylor Creek;

2) To establish baseline conditions for surface water nutrient chemistry and isotopic ratios of carbon and nitrogen in terrestrial and stream biota;

3) To describe population characteristics (e.g., habitat use, size structure) of resident fishes in the Cedar River main stem and Taylor and Rock Creeks; and

4) To develop statistical relationships between reach- and habitat-scale environmental factors (nutrient chemistry, physical habitat) and resident fish abundance and biomass, which will aid in designing effective restoration actions within the watershed.

Adult salmon were passed above Landsburg beginning in August 2003; therefore, we are now in the $2^{nd}$ phase of this research, which aims to document how these fish affect ecological characteristics of the river, to describe their colonization dynamics, and to understand environmental factors associated with trout and salmon distributions. In this report, we present the following results:

(1) water chemistry and stable isotope data collected in fall 2004 from the main stem and tributaries;

(2) fish survey data on the main stem during summer 2004;

(3) the colonization of Rock Creek by juvenile coho in 2004 and 2005; and

(4) size and growth data from trout and coho marked in Rock Creek.

## 2.0    Accomplishments

We have made considerable progress with support from the Anadromous Fish Commission in 2004 (Tables 1 and 2). These include:

1) documenting coho colonization in Rock Creek;

2) analyzing 311 water samples and 368 stable isotope samples;

3) initiating a mark-recapture study in Rock Creek, which has expanded into the main stem and a tributary below Landsburg;

4) supporting M.S. projects of three students;

5) completing a draft of one manuscript describing the coho colonization in Rock Creek and beginning analysis of another manuscript describing baseline fish communities in the Cedar River before salmon; and

6) presented three talks on this study.

## 3.0    Materials and Methods

3.1     Water chemistry

Bi-monthly (August 2004 through February 2005) to monthly (February to July) samples were taken from historic sites (Kiffney et al. 2002); samples were analyzed at the Institute of Watershed Studies, Western Washington University, which is certified by the Washington State of Ecology. This aspect of our study is serving as the master's thesis for Matt Certo, a graduate student at WWU supervised by Dr. Robin Matthews and Dr. Peter Kiffney.  Sites were selected to capture inputs of materials from tributaries; to provide reference sites above a barrier to anadromous fish; and to fall within the different habitat reaches identified on the main stem in 2000 (Kiffney et al. 2002).  Three main stem sites were added in 2004 to improve our overlap with geomorphic reaches and to focus sampling in the lower reaches where the majority of salmon have spawned.

Temperature and conductivity were measured in the field with a YSI model 33. Onset temperature loggers are now installed in all main stem reaches as well as

tributaries. These loggers are recording water temperature every 30 minutes. Subsurface water samples were collected in 500 mL acid-washed Nalgene bottles for total phosphorus/total nitrogen. Stream water was also collected in a syringe (BD, 60 mL, Luer-Lok tip, Graduation, 1 mL) and filtered through Nalgene syringe filters (Acrylic housing; Membrane Material: SFCA; Pore Size: 0.45µm) into 60 mL small mouth Nalgene bottles for analysis of dissolved nutrients. Water samples were transported on ice back to WWU where the filtrate was frozen at -20°C until analysis (within 30 days). Turbidity was measured the day following sample collection.  Nutrient analyses were conducted according to standard protocols (APHA 2002).  100 mL raw water sub-samples were digested with 1g of re-crystalized potassium persulfate ($K_2S_2O_8$) and 0.5mL sodium hydroxide (30% NaOH), autoclaved for 35 minutes, and then stored at 4ºC for no longer than thirty days after the sample date for measurement of TN (as $NO_3^-$ $NO_2^-$) and TP (as $PO_4^{3-}$) concentrations. Dissolved inorganic nitrogen (DIN) and soluble reactive phosphorus (SRP) concentrations were determined from filtrate.  Concentrations of N were measured by Cu-Cd reduction nitrate to nitrite and colorimetry on an O-I Analytical FS3000 autoanalyzer.  TP was determined by acid digestion to orthophosphorus followed by reaction with ammonium molybdate and ascorbic acid.  Detection limits were 10 µg/L for $NO_3$-N and 3 µg/L for SRP.

3.2     Stable isotopes

Measuring isotopes of carbon (C) and nitrogen (N) in food webs can be a useful tool to identify differences in food web structure and food resources among and within river systems.  This approach is successful because of the differential absorption of C and N isotopes during assimilation.  In this fractionation process, the lighter isotope is

concentrated in nitrogenous excretion products while the heavier ($^{13}$C or $^{15}$N) isotope is retained in body tissues (Peterson 1999). As a result, we can trace the enrichment of $^{15}$N through trophic levels to identify food web structure (whom eats whom), and $^{13}$C isotopic signatures can serve as naturally occurring labels of distinct food sources (Philips and Koch 2002). For instance, the relative abundance of carbon isotopes ($^{13}$C and $^{12}$C) can help determine the relative importance of in-stream (autochthonous) versus terrestrial derived (allochthonous) sources of C (Jones et al. 1998, Peterson 1999). Aquatic primary producers (algae) are enriched in $^{13}$C relative to terrestrial organic matter (Fry 1991).

Nitrogen isotopes $^{15}$N and $^{14}$N provide structural information about a food web and can be used to determine the trophic position (e.g., primary consumer vs. predator) of specific species (Peterson 1999). The fractionation of N isotopes by individuals leads to the successive enrichment of organisms in $^{15}$N relative to their food sources (Doucett et al. 1996). A survey of 56 trophic enrichment estimations had a range of 0.5 to 5.5 °/∞ (Post 2002), but on average is 3.4 °/∞, as previously estimated by Minagawa et al. (1984). Nitrogen isotopes can also be used to track inputs of salmon-derived nutrients (SDN). The isotopic signature of N derived from marine sources is heavily enriched in $^{15}$N in comparison to terrestrial N sources (Kline et al. 1990, 1994). This difference can be tracked through aquatic and terrestrial food webs. For example, $^{15}$N of periphyton organic matter in a salmon stream was 37% higher than periphyton from a stream without salmon (Bilby et al. 1996).

To compare baseline levels of C and N isotopes in river food webs established in 2000 and 2001 to post-salmon conditions, we collected tissue from different trophic levels including algae, insects, fish and riparian vegetation. We collected foliage from

riparian trees (western red cedar, vine maple) and a shrub (salmonberry) common to the

main stem and tributaries (see Kiffney et al. 2002 for further details).  Stream periphyton

(a complex assemblage of algae, bacteria, and organic matter embedded in a

polysaccharide matrix) was collected from rocks and represented the autochthonous

organic matter.  Depending on presence and abundance, we collected aquatic insects from

different functional feeding groups: predaceous stoneflies, herbivorous mayflies (*Baetis*

and Heptageniidae), a detritivorous stonefly (*Pteronarcys californica*), a collector-filterer

(the caddisfly Hydropsychidae, primarily *Arctopsyche grandis*), a collector-gatherer

(*Juga*, snail) and an omnivorous crayfish (*Pacifastacus* spp.).  Fish included different age

classes of rainbow (*Oncorhynchus mykiss*), cutthroat trout (*Oncorhynchus clarki clarki*),

sculpins (*Cottus* spp.) and juvenile coho (*Oncorhynchus kisutch*).  Sample sites were

chosen based on habitat surveys, proximity to water chemistry sampling sites, and

barriers to anadromous fish. These included four on the Cedar River main stem: one site

in reach CR1 near the railroad trestle; one site on reach CR6 near the main stem – Taylor

Creek confluence; and one site downstream of Landsburg in an area accessible to

sockeye where we collected periphyton and insects (i.e., at the salmon viewing area on

the north bank).  We also sampled a site on Rock Creek (upstream of the 41 bridge) and

one on Taylor Creek (at the Taylor Creek USGS gauge which is above a barrier to

anadromous fish) (Fig. 2).

Periphyton was scraped from five randomly selected rocks collected from riffles

at each location and stored in plastic bottles. Invertebrates were collected from riffles

using a Hess sampler with a 250 µm mesh net.  If possible, replicate samples of each

functional feeding group were collected from each site.  We collected fish (3-5 of each

salmonid age class at each site) by angling and electroshocking.  Riparian foliage was collected from three separate trees of each species at each site.  All samples were placed on ice in the field until returning to the Northwest Fisheries Science Center (NWFSC) where they were immediately frozen at –10 C° until vacuum dried and ground to a fine powder for isotope analyses.  Dorsal muscle tissue was taken from sacrificed fish.

3.3    Invertebrate drift

To assess whether variation in invertebrate drift is correlated with reach-scale fish densities, drift samples were collected from a suite of sites on the main stem and Rock, Williams, Steele and Taylor tributaries in August and September 2004. Four drift nets, with a mesh opening of 250 µm, were placed in parallel at each site for 1-2 hours during two one-week periods. Two to three sites were sampled per day. Water velocity was measured at the net opening to determine discharge through the net during the sample interval. Drift samples are currently being processed. Aquatic invertebrates will be identified to family, and terrestrial insects to order. After identification, drift samples will be dried and ashed to determine drift biomass. This project is the master's thesis of Seth Amhrein in the College of Forest Resources at the University of Washington, co-supervised by Drs. R. Edmonds and P. Kiffney.

3.4    Habitat

We categorized habitat types based methods established and described in detail in 2000 (Riley et al. 2001). The entire length of reaches CR1 and 2 were surveyed, but due to time constraints we surveyed ~ 800 m of reaches CR3-6. Each habitat unit was measured for length and width (bottom, middle and top of each habitat unit), slope (laser range finder), canopy cover (densiometer, Kaufman 2002), average thalweg (deepest part

of channel unit) depth and dominant and subdominant substrate composition (Riley et al.

2001). Maximum depth and tail depth were determined for pool habitats (Lisle 1987).

Bankfull width and a GPS coordinate were taken every fifth unit. The beginning at end of

each habitat was flagged.

3.5     Fish

3.5.1   Population surveys

Snorkel counts of resident fish were conducted on the six lower reaches of the

Cedar River (CR1-6) (Figure 2).  Sites on the main stem were chosen randomly from

habitat units within each reach; the proportion of habitat types snorkeled was based on

the proportion of habitat types mapped during the habitat survey.  Each site consisted of a

single habitat unit; the entire unit was snorkeled unless units were large or dangerous and

were therefore sub-sampled.  One to five observers (depending on stream width) entered

the habitat unit at the downstream end and proceeded upstream through each site,

counting and recording species and size classes of all fish encountered.  Resident fishes

(rainbow, cutthroat trout and whitefish) and juvenile salmon were divided into three size

classes (age $0 \leq 80$ mm; 1+, 81-120 mm, 2+, 121-200 mm; and adult $\geq 201$ mm).

Sculpin (*Cottus* sp.) were also counted.  Data were averaged across habitat units within

each reach.

Snorkel surveys for trout and coho were also conducted as described above in

lower (from Rock Creek –main stem confluence to about 300 m above confluence) and

middle (reach downstream of Welsh Lake diversion screen) Rock Creek and lower

Williams Creek in 2004 and 2005 to determine whether juvenile coho colonized these

tributaries. Rock Creek is a relatively low gradient tributary with abundant wood

compared to the main stem (Kiffney et al. 2002) and is relatively close to salmon redds
from 2003. As a result, we hypothesized that coho salmon would readily colonize this
habitat. In this survey, only pools were snorkeled. The area, and maximum and tail depth
of each pool was determined. In addition, a GPS coordinate was recorded.

3.5.2   Mark-recapture study

We initiated a mark-recapture study in August 2004 in Rock Creek to estimate
fish growth and survival. Fish were initially captured and marked in August 2004, with
follow-up surveys in October 2004 and March 2005. To capture fish we used a Smith-
Root backpack electrofisher operating at 300-500 volts DC.  All coho and trout captured
were anesthetized (MS-222), measured (fork length to the nearest mm), weighed (nearest
0.1 g), and inserted with a PIT tag. After handling fish were kept in live baskets in the
stream until completely recovered when they were released alive near their point of
capture.

## 4.0   Results

4.1     Water chemistry and stable isotopes

Water temperature was highest in July and August and coldest in January (Fig. 3).
Temperatures peaked at upstream stations (WS1 and 2) of the main stem reaching a
maximum of about 18°C at station WS1 during the summer. In general, water
temperatures were relatively similar among stations, with a median of ~(8 °C). Except for
Steele Creek, temperature in tributaries was less variable than in the main stem. Overall,
water temperature patterns show that the Cedar River and its tributaries have low to
moderate stream temperatures.

Tributaries appeared to play a major role in nutrient concentrations of the main stem. Total nitrogen and phosphorus at main stem sites showed relatively similar spatial patterns in that they were higher downstream of tributaries, especially for total phosphorus (Fig. 4). Mean total nitrogen at WS5 was almost 3× higher than station WS4; WS5 is immediately below Taylor Creek, whereas WS4 is located upstream of Taylor. Mean annual concentrations of total N and P at main stem sites ranged from 116-715 µg/L and 9-20 µg/L, respectively. There was considerable variation among tributaries in nutrient concentrations. Mean total nitrogen was highest at Williams Creek (875 µg/L) and lowest at Taylor Creek (375 µg/L), with total phosphorus peaking at Rock Creek (21 µg/L).   Dissolved nitrate+nitrate and soluble reactive phosphorus showed similar patterns to total N and P. Tributary sites exhibited much greater concentrations of nitrogen and phosphorus than main stem sites (Fig. 5). On average, total P and N in tributary sites were about 3 and 1.5× higher than main stem sites.

The ratio of dissolved nitrogen to phosphorus provides a benchmark for whether a stream or lake is N or P-limited. An N:P ratio less than 16 is indicative of N limitation, a ratio between 16 and 20 suggests limitation by both N and P, and a ratio above 20 is indicative of P-limitation.  Overall, the data indicate most sites were P-limited; however, the relative degree of P-limitation differs among seasons and sites (Fig. 6). For example, in summer and fall both main stem and tributary sites indicate P-limitation, whereas main stem sites appeared to become N-limited or co-limited in winter.

Adult salmon input was concentrated in reaches CR1, 2, and 4 where 43, 37 and 8% of total salmon biomass was deposited, respectively (Fig. 7). These patterns are consistent with the hypothesis that redd density was a function of distance from

Landsburg, except for concentrations of adults in CR4 and 6 suggesting reach-scale habitat selection was also occurring. To calculate the mean annual input of salmon biomass and P and N into each reach on an areal basis, we assumed that adult salmon were about 3.03% N and 0.35% P by weight, and an average weight of adult coho and Chinook salmon of ~2.8 and 3.3 kg, respectively (Gresh et al. 2000). Based on these numbers, mean annual input into reach CR1 (closest to Landsburg) was 0.0004 kg wet mass/$m^2$ for total biomass, 0.000015 kg wet mass/$m^2$ for P, and 0.00012 kg wet mass/$m^2$ for N and (Fig. 7).

There was little evidence for salmon-derived N incorporating into food webs above Landsburg. There were no differences among years (2000, 2001, 2004) for $N^{15}$ or $C^{13}$ in riparian vegetation, benthic insects or fishes collected from CR1; however, periphyton collected from this reach was more enriched in $N^{15}$ in 2004 relative to years before salmon (Fig. 8). Juvenile coho collected in CR1 were more enriched in $N^{15}$ compared to juvenile trout and sculpin captured in earlier years, but were similar to adult trout (Fig. 9).

Comparing stable isotope values across sites in 2004 showed that organisms collected from Rock Creek were enriched in $N^{15}$ relative to other sites on the main stem, Taylor Creek above a barrier, and, in some cases, more enriched than a site with a history of salmon spawning (i.e., the salmon viewing park below Landsburg). For example, mayfly herbivores collected from Rock Creek had $d^{15}N$ values of ~4‰ compared to –1 to 0 measured at other sites (Fig. 10). Similar patterns were observed for sculpin and adult trout collected above Landsburg, as $d^{15}N$ values were ~2 - 4‰ higher in fish from Rock compared to other Cedar River sites (Fig. 11).

4.2     Habitat

We surveyed about 12 km of main stem habitat starting above the diversion pool

upstream of Landsburg and ending at the reach break between CR6 and CR7, which is

about 200 m above the Taylor Creek main stem confluence (Figure 2). Reaches CR1 and

2, which are closest to Landsburg, were low gradient, with mostly flatwater, riffle and

pool habitats (Tables 3 and 4). Channel gradient and the abundance of boulders increased

at CR3, as did the proportion of step-pool habitat. Gradient declined at CR4, with a

corresponding decline in the proportion of step-pool habitat.  Habitat composition in CR5

was similar to CR3, except CR3 had no side channel habitat. The relative proportion of

side channel habitat was highest in CR2, 4 and 5 averaging ~9%, whereas CR1 had about

2% side channel habitat.

4.3     Fish

4.3.1   Population surveys

Overall, trout densities were similar among years, with total trout density

averaging about 0.05 to 0.08 fish/m$^2$ (Fig. 12). In general, trout density was highest in the

upper two reaches of the main stem averaging about 0.1-0.2 fish/m$^2$. Juvenile trout

(fish<80 mm in total length) made up the largest proportion of total trout density across

years comprising 33 to 60% of total trout density in the main stem. The relative

proportion of the other size classes (1+, 2+, and 3+) were similar in 2000 and 2004, with

a greater proportion of 3+ fish observed in 2001 (50%) compared to 2000 (1.4%) and

2004 (5%) (Fig. 13).

A total of 40 units were snorkeled in August 2004, with a mix of pools, riffles,

flatwaters, side channels and step-pools. Trout densities were relatively similar among reaches ranging from 0.03 to 0.08 fish/m$^2$ (Fig. 14). Coho densities (~0.04 fish/m$^2$) were highest in the two reaches (CR1 and 2) closest to Landsburg, with only a few fish observed in reach 6; coho were not observed in reaches 3-5. In contrast, juvenile Chinook density was relatively similar among reaches, ranging from 0.0026 to 0.004 fish/m$^2$. The relative proportion of each taxon (trout, coho, Chinook, whitefish) reflected this variation in density, with the proportion of trout (trout fry + large trout) ranging from ~0.90 in reaches CR3-6 to about 0.6 in reaches CR1 and 2. The relative proportion of coho was highest in reach 1 and 2 at about 33%. The proportion of Chinook peaked in reaches 3, 5 and 6 at about 5%. Whitefish were only observed in reaches 1 and 2.

There were relatively large differences in fish density among habitat types (Fig. 16. Trout fry were most abundant in pools, side channels and step-pool habitat averaging about 0.04 fish/m$^2$ in these habitats, which was two-fold higher than flatwater or glide habitat and riffles. Large rainbow trout (>1+) peaked in pool habitat: 1 and 2+ rainbow trout averaged ~ 0.02 fish/m$^2$ in pools compared to 0.005 fish/m$^2$ in flatwater habitat. Juvenile coho were most abundant in side channel habitat averaging about 0.05 fish/m$^2$ compared to 0.01 fish/m$^2$ in other habitat types. Juvenile Chinook densities were highest in pool habitat (0.006 fish/m$^2$), with low densities in other habitat types.

In May 2004, juvenile coho were observed in the first pool of Rock Creek immediately upstream of the Rock Creek-main stem confluence. Two months later coho had moved approximately 100 m above this point, and 2 km from the confluence in September (Fig. 17). No coho were observed above the culvert at the 40-road culvert in either year. Densities were relatively high ranging from about 0.1 to 0.9 fish/m$^2$ in

September, which were about 1-2 orders of magnitude higher than coho densities in the

main stem. Similar patterns were noted in 2005, except coho observed in Rock Creek

during March were pre-smolts with no fry present.  In addition, we observed 69 juvenile

Chinook in Rock Creek in the first pool above the Cedar River confluence in March

2005. Trout densities in Rock Creek were generally equal to or higher than coho

densities, with trout densities in Williams Creek about 2-fold higher than in Rock. We

also found that trout densities in 2005 were 2× lower in Rock and Williams Creek than in

2004 (Fig. 18), while coho densities were relatively similar between years (Fig. 19).

4.3.2    Mark-recapture in Rock Creek

In August 2004, 20 coho and 38 trout were inserted with PIT tags. We recaptured

3 coho and 4 trout in October 2004. Mean length and weight of coho were greater than

trout; coho were about 30% longer in October than trout of the same age class (Fig.20).

Recapture rates were relatively high, ranging from 12-14%, with juvenile trout growing

at a faster rate than coho (Fig. 21). This recapture rate was remarkable given the high,

murky water occurring during our October field visit.  Of 20 coho PIT tagged in Rock

Creek in March 2005, 65% were recaptured at the Ballard Locks.

## 5.0    Discussion

5.1    Water chemistry and stable isotopes

The long-term record of water chemistry shows substantial spatial and temporal

variation in nitrogen and phosphorus, key elements that limit primary productivity. Some

of this variation was driven by inputs of nutrient-rich tributary water. These results show

that main stem sites immediately below tributaries were receiving high concentrations of

nutrients from Steele, Williams, Rock and Taylor Creeks. These data also suggest that

streams in the watershed are mostly limited by phosphorus; however, the relative

importance of P-limitation differed among seasons and location. Our data suggest P-

limitation in summer and fall, but N-limitation in winter, especially in the main stem.

Although the Cedar River main stem sites were largely P-limited, the current

number of adult salmon entering the watershed likely has no to little impact on stream

productivity. Mean annual (averaged across 2003, 2004, and 2005) salmon carcass input

was low (~0.0004 kg wet mass/$m^2$) in CR1, CR2 and CR4, and, as result, P input was

extremely low (~0.00001 kg P wet mass/$m^2$).  We suggest that at these adult densities

there is little chance for P enrichment of algal biomass in the Cedar River. For example, P

concentrations would increase by only 0.02 µg/L in CR1 at this biomass input, assuming

a loss rate of 50% in 15 d for a salmon carcass (Schuldt and Hershey 1995), a cumulative

flow of 2.5 x $10^{10}$ liters at CR1 during October over a 15 d period, and a total P input of

1.2 kg for CR1 (averaged across years). Using these estimates, surface water total P

would increase by 6 µg/L in CR1 at a salmon input of 26 434 kg wet mass or a total of

4333 adult salmon. These estimates are highly liberal because they assume no hyporheic

exchange (O'Keefe and Edwards 2003), no movement of carcasses into the terrestrial

environment (Helfield and Naiman 2001), and a mean monthly flow for October (much

higher flows during winter). Moreover, a fraction of this total P would be bioavailable for

algal uptake.

There was also little evidence that stable isotope values of organisms in the Cedar

River were affected by salmon inputs. This result, however, is not surprising given the

low densities of adult spawners. Bilby et al. (2001) showed that $N^{15}$ values in juvenile

coho saturated at about 0.15 kg salmon wet mass/$m^2$, which was 250 – 375× the average

annual input in CR1 and 2. Chaloner et al. (2002) observed significant increases in $N^{15}$

values in juvenile coho salmon at a carcass biomass of 1.86 kg salmon wet mass/$m^2$ in

experimental channels, which was the lowest loading level. This level was 4650× the

annual loading level observed in CR1. Most studies examining loading of salmon and

ecological effects have used levels much higher than observed in the Cedar. Experiments

planned in mesocosms in 2006 to test the effects of carcasses on water chemistry and

stream food webs will use as one treatment loading levels observed in the Cedar River.

This experiment will, therefore, provide insight into whether these low salmon input

levels has any measurable ecological affects on stream food webs.

5.2     Population surveys

Juvenile coho and chinook were observed in the last habitat sampled in summer

2004; therefore, we cannot document the extent of upstream distribution. No coho were

observed between reaches 3 - 5, while coho and Chinook observed in reach 6 were

associated with a large tree spanning the channel. The distribution of juvenile coho

salmon in the main stem partially reflects where their parents spawned the previous year,

with highest densities of juvenile coho observed in the lower reaches. In contrast, there

was little apparent pattern in redd abundance and juvenile Chinook density suggesting

significant movement from their spawning location. This movement could have been

associated with downstream migration. Assuming these were primarily ocean-type

Chinook, the relative high density of juvenile Chinook in the main stem at this late date

(August 2004) was surprising.  Healey (1991) reported that most ocean-type Chinook

migrate seaward between February and May, with southern populations moving earlier.

Coho densities in the lower two reaches of the main stem and Rock Creek (~0.05 – 0.4 fish/$m^2$) were at the high end of values estimated in other west coast streams (Burns 1971, Murphy et al. 1986, Rosenfeld et al. 2000, Burnett 2001, Roni 2002). For example, Burnett (2001) estimated juvenile coho densities of 0.003 fish/$m^2$ in the Elk River, Oregon, Burns (1971) estimated coho densities of ~0.06 fish/$m^2$ in streams of northern California, while Rosenfeld et al. (2000) observed densities of ~ 0.4 fish/$m^2$ in streams of Vancouver Island. Juvenile Chinook densities were towards the low end of values reported by Burnett (2001) (range 0.007 – 0.15 fish/$m^2$) in the Elk River, Oregon. Similarly, total trout densities in the main stem (~95% rainbow trout) were towards the low end reported in other studies. Platts and McHenry (1988) estimated that the mean trout density in small streams in the Pacific Ecoregion was 0.29 fish/$m^2$; mean densities of cutthroat trout ranged from 0-2.5 fish/$m^2$. Rosenfeld et al (2000) reported densities of cutthroat trout of 0.05 to 0.8 fish per $m^2$ in coastal streams of Vancouver Island, and Burns (1971) reported combined rainbow/cutthroat densities ranging from 0.09 to 1.63 fish/$m^2$ in northern California streams. We are unsure of why trout densities in the main stem were low compared to other systems. There are a number of possibilities that likely interact including: (1) low wood abundance in the main stem, (2) high density of large trout that potentially consume trout fry, (3) high density of bird predators also consuming trout fry, and (4) low productivity due to loss of salmon inputs. We reported earlier that wood abundance in the main stem was lower than in other rivers of similar size in Western Washington (Riley et al. 2001).

Juvenile coho appeared to select side-channel and pool habitat in the main stem. Other studies have show that coho are more abundant in pool habitat and were relatively

more abundant in small streams (e.g., Rosenfeld et al. 2000). A number of studies have

also documented that coho salmon prefer side-channel habitat during winter because of

the more favorable rearing environment relative to main channel habitat (Gianicco and

Hinch 2003). Our data suggest a similar pattern for summer rearing conditions for coho,

possibly due to the relative large size and high water flows of the main stem. Burnett

(2001) observed that selection of side-channel habitat by coho was variable across years,

with coho selecting this habitat during one year and using it according to availability in

two other years. We also found that juvenile Chinook and coho were more abundant in

main stem pools, especially pools with abundant brush (P. M. Kiffney, personal

observation). Burnett (2001) also observed that juvenile Chinook preferred pools relative

to fast water habitat. To improve summer rearing conditions in the main stem Cedar

River, these results suggest the following restoration actions: (1) increase abundance of

main stem side-channel habitat (coho) and (2) increase the abundance and complexity of

pool habitat (coho and Chinook). These actions might be most successful in the lower

gradient reaches of the main stem (e.g., CR1, 2 and 4), where wood additions are more

likely to withstand high flow events.

The rapid dispersal and colonization of Rock Creek by juvenile coho was

expected given that this tributary is relatively low gradient and has a relatively complex

channel (at least the lower two-thirds). The distance between the nearest coho redd in

CR1 and Rock Creek, however, was relatively long (~1 km) suggesting considerable

movement of juvenile coho. In addition, juvenile coho have dispersed ~2 km from the

Rock Creek- main stem confluence to the last pool below the culvert near the 40 road.

We have observed no coho above this point, which suggests this structure was a barrier to

further dispersal. Installation of a culvert that does not impede fish movement might allow coho access to the large wetland complex upstream of the 40 road. It is well known that juvenile coho prefer low-gradient, complex habitat for rearing.

Another surprising aspect of coho colonization of Rock Creek was the relatively high density of coho moving into this stream, which in September was 0.38 fish/$m^2$. This density was orders of magnitude higher than coho and trout densities in the main stem and about equal to trout densities in Rock. There are few data to compare our results with; however, Milner et al. (2000) observed coho salmon in streams around 43 years of age in Glacier Bay, Alaska. Fish density in these streams was a function of habitat complexity, stream age, water quality, flow stability and food abundance (Milner et al. 2000). We speculate that Rock Creek, which has high nutrient levels, a wetland complex potentially stabilizing downstream flows, and high habitat complexity may be the focal point for coho colonization in the future.

The snorkel surveys of Rock and Williams Creek also revealed substantial inter-annual variation in fish densities, especially for trout. Trout densities in 2005 were about 2-fold lower than in 2004. Variation in climate between years may explain some of these differences. Mean annual stream flow during the 2003 water year was about $2\times$ higher than in 2004. Less water in 2004 may have increased the intensity of inter- and intra-specific competition in trout and coho populations thereby reducing survival or increasing movement of trout into the main stem. Installation of the PIT tag detector at the mouth of Rock Creek will provide insight into whether the movement of coho and trout in Rock is related to flow dynamics. This result points out the benefit of long-term monitoring using consistent protocols.

5.3      Mark-recapture in Rock Creek

Based on our limited mark-recapture data, juvenile coho in Rock Creek were about 30% larger but grew at a slower rate than juvenile trout. This result was not surprising, as coho emerge earlier than rainbow or cutthroat trout, but their larger size suggests that coho may have a competitive advantage over similar sized trout. Moreover, we observed coho at densities comparable to trout; therefore, these two factors may lead to a shift in community structure in Rock Creek. Baseline surveys showed that this stream was previously (i.e., before arrival of coho) dominated by cutthroat trout. If coho continue to colonize Rock Creek at similar numbers, we predict a shift to a coho dominated system, which may have implications for other parts of the food web.

## 6.0   Summary

The main findings of this research are:

1)   tributary streams supply high concentrations of limiting elements to the Cedar River main stem, which likely supports the overall productivity of main stem habitat;

2)   salmon biomass input was highest in CR1, CR2 and CR4; however, loading levels were 250 - 4650× lower than levels reported in other studies where carcasses had a significant effect on nitrogen dynamics;

3)   there was little evidence that current inputs of salmon can affect surface water chemistry. Crude estimates suggest that 26 434 total kg of salmon biomass in one year would increase surface water phosphorus by ~6 µg/L in CR1 during October.

4)   there was also little evidence of a salmon signal in food webs of the Cedar River, except in Rock Creek, which we speculate was either due to hyporheic exchange with the Welsh Lake diversion and/or high rates of dentrification in Rock Creek compared to other sites;

5)   coho densities during summer 2004 were highest in CR1 and 2, which were closest to Landsburg, while Chinook densities were highest in CR1, CR5 and CR6. CR6 was about 10 km from Landsburg. Coho density was highest in side-channel habitat, while Chinook density was highest in pools;

6)   coho rapidly colonized Rock Creek at high densities in 2004 and 2005 and their distribution extended to the last pool below the culvert at the

40 road bridge. We also observed some juvenile Chinook in lower

Rock Creek in March 2005.

## 7.0    Current and future activities

We are currently conducting the following studies:

1) snorkel surveys of pools in Rock, Taylor, Williams and the Cedar River about every three months (weather permitting) to determine seasonal and spatial patterns of abundance and distribution of trout and salmon. In addition, we are measuring habitat characteristics of each pool unit surveyed;

2) intensive mark-recapture study on Rock Creek. This includes weighing, measuring and PIT tagging all coho and trout above 50 mm in size, as well as recording other vertebrates collected. In addition, we are measuring habitat characteristics of each unit surveyed. This work and item 3 below will serve as part of George Pess's Ph.D. project;

3) recording movement of tagged trout and coho in Rock Creek using PIT technology developed by Earl Prentice;

4) processing drift samples collected during summer of 2005;

5) drafting a manuscript describing spatial patterns of fish abundance in the Cedar River and tributaries based on data collected between 2000 and 2003;

6) supervising three M.S. theses of students working on various projects related to the Cedar River recolonization project.

## 8.0    Acknowledgements

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Table 1. Monitoring task and associated accomplishments for 2004-2005.

| Task | Accomplishment | Time period |
|---|---|---|
| Habitat survey | ~12,000 m surveyed | August 2004 |
| Main stem snorkel survey | 1) ~ 2,000 m snorkeled 2) 4650 fish observed | August 2004 |
| Rock and Williams snorkel survey | 2819 fish observed | May, July and September 2004; March, June and August 2005 |
| Mark-recapture fish study | 1) ~ 300 fish processed 2) Marked: 50 coho, 57 cutthroat, 23 rainbow, and 17 trout fry | August, October 2004 and March 2005 |
| Water chemistry analysis | 311 samples analyzed | ~ bimonthly August-February 2004, 2005 |
| Stable isotope analysis | 368 samples collected, processed and analyzed | September 2004 |

Table 2. Products generated by funding from the Cedar River Anadromous Fish

Commission.

| Product | Title | Author's | Venue |
| --- | --- | --- | --- |
| Manuscript[1] | Distribution and growth of juvenile coho salmon (Oncorhynchus kisutch) during colonization of newly accessible habitat | J. H. Anderson, P. M. Kiffney, and T. Quinn | Environmental Biology of Fishes |
| Manuscript[2] | Fish community structure at network, reach and habitat scales | P. M. Kiffney | Transactions of the American Fisheries Society |
| M. S. Thesis[3] | The spatial variation in invertebrate drift in the Cedar River between Landsburg and Cedar Falls | S. Amrhein | College of Forestry, University of Washington |
| M. S. Thesis[4] | The regulation of nutrient chemistry in a reference Washington Cascade watershed | M. Certo | Department of Biology, Western Washington |

| | | | University |
|---|---|---|---|
| Talk | Colonization of the lower Cedar River by anadromous fish: population, community and ecosystem-level effects | P. M. Kiffney, J. Anderson, G. Pess and T. Quinn | School of Fisheries, University of Washington |

[1] Chapter 2 of J. H. Anderson's M. S. thesis, School of Fisheries, University of Washington.

[2] Anticipated submission to journal, Fall 2006.

[3] Anticipated defense, Fall 2006.

[4] Anticipated defense, Summer 2006.

Table 3. Relative proportion of habitat types in reaches CR1-6 during August 2004. The

entire reach of CR1 and 2 were surveyed, while ~800 m long sections of the

remaining reaches were surveyed. CR1 began ~ 300 m above the Landsburg

Diversion, while CR6 ended ~200 m above the Taylor Creek- Cedar River

confluence.

| Reach | Flatwater | Pool | Riffle | Side channel | Step pool |
|-------|-----------|------|--------|--------------|-----------|
| CR1 | 0.27 | 0.38 | 0.31 | 0.02 | 0.02 |
| CR2 | 0.10 | 0.40 | 0.38 | 0.10 | 0.03 |
| CR3 | 0.23 | 0.35 | 0.17 | 0 | 0.24 |
| CR4 | 0.24 | 0.38 | 0.29 | 0.10 | 0 |
| CR5 | 0.27 | 0.27 | 0.18 | 0.09 | 0.18 |
| CR6 | 0.06 | 0.67 | 0.17 | 0.06 | 0.06 |

Table 4. Mean ($\pm$ upper and lower 95% CI) wetted width, thalweg depth, residual pool

depth, slope and percent boulders in reaches CR1-6 of the main stem during

August 2004. CR1 began ~ 300 m above the Landsburg Diversion, while CR6

ended ~200 m above the Taylor Creek- Cedar River confluence.

| Reach | Mean wetted width (m) | Mean thalweg depth (m) | Residual pool depth (m) | Average slope (%) | Boulders (%) |
|---|---|---|---|---|---|
| CR1 | 24 (21, 26) | 0.7 (0.6, 0.8) | 0.8 (0.6, 1.1) | 0.6 (0.4, 0.7) | 2.6 (1.0, 4.2) |
| CR2 | 26 (23, 29) | 0.7 (0.6, 0.8) | 2.9 (-1.7, 8.0) | 0.5 (0.4, 0.6) | 14.0 (5.0, 23.0) |
| CR3 | 24 (21, 27) | 1.2 (1.0, 1.3) | 1.4 (0.7, 2.0) | 0.9 (0.5, 1.4) | 8.0 (6.0, 9.2) |
| CR4 | 21 (17, 25) | 0.6 (0.5, 0.7) | 1.4 (1.0, 1.9) | 0.6 (0.3, 0.8) | 1.0 (0.3, 1.4) |
| CR5 | 25 (19, 31) | 0.7 (0.5, 0.9) | 0.80 (0.14, 1.4) | 0.54 (0.2, 0.9) | 8.0 (3.0, 12.4) |
| CR6 | 19 (14, 23) | 0.5 (0.3, 0.7) | 1.0 (0.7, 1.0) | 0.46 (0.2, 0.7) | 2.4 (1.0, 4.0) |
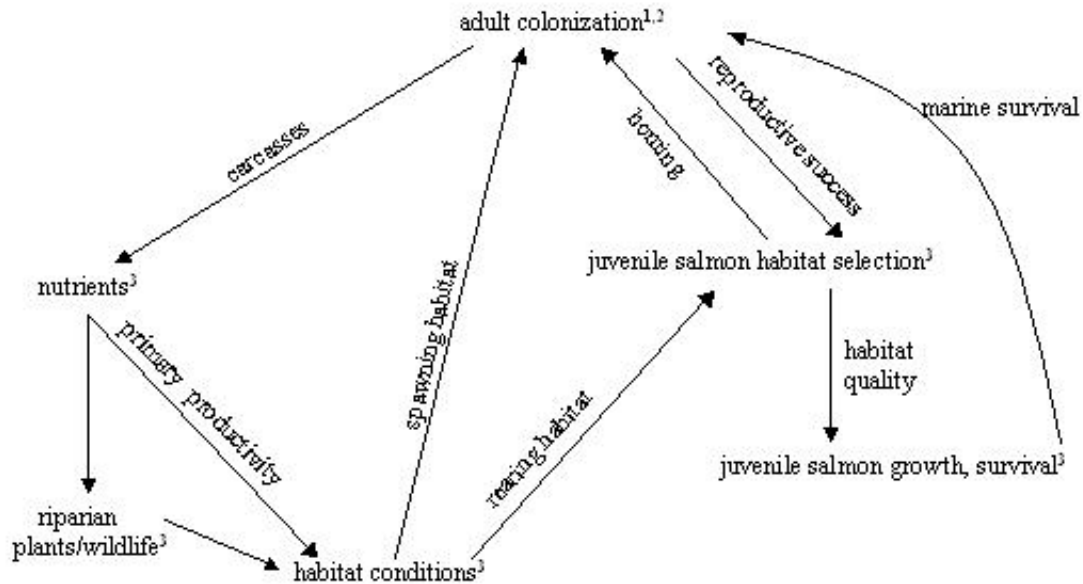
Figure 1. Schematic depicting relationships among proposals. Habitat surveys (proposal 3) provide data on the physical environment driving adult colonization (proposal 1 and 2), and juvenile habitat use (proposal 3), growth and survival (proposal 4). Genetic studies (proposal 1) are linked to juvenile studies as both examine survival (proposal 4), but at two different life history stages. All proposals are linked, whereby one proposal supplements the other providing a more holistic understanding of the relative success of fish passage and factors that may aid in conservation and restoration.

[1] Anderson and Quinn- Success of Cedar River salmon colonization: A genetic assessment
[2] Anderson and Burton- Colonization dynamics of the Cedar River by adult salmon
[3] Kiffney et al.-An ecosystem-level assessment of recolonization of the Lower Cedar River, WA by Pacific salmon
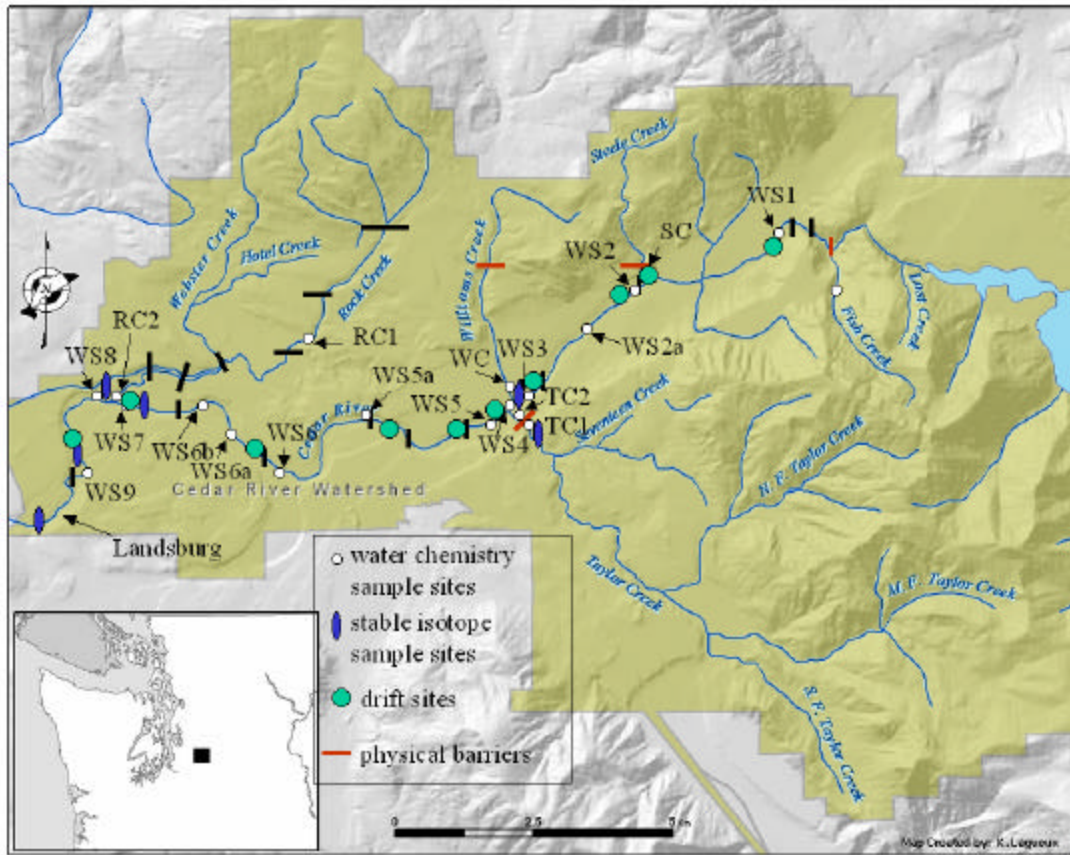
Figure 2. Map of geomorphic reaches used in habitat and snorkel survey and sample locations for water chemistry and stable isotopes.
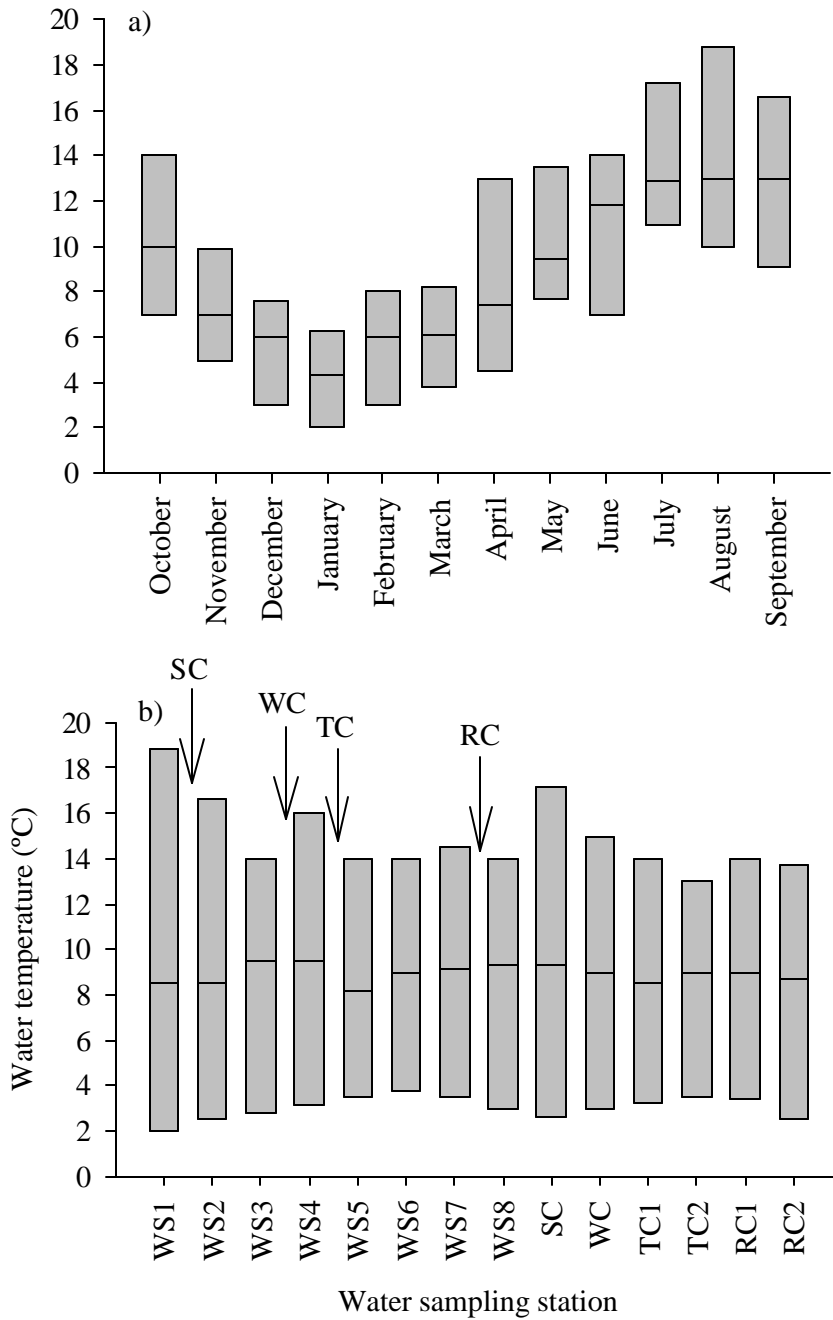
Figure 3. a) Monthly maximum, median and minimum water temperature averaged
across dates and stations; and b) maximum, median and minimum water temperature
at each station averaged across dates.  WS= main stem Cedar River stations; SC=Steele Creek
at the confluence; WC=Williams Creek at the confluence; TC1=Taylor Creek at the
confluence, TC2=Taylor Creek at the USGS gauge; RC1=at 10 road bridge; RC2=at the
confluence. RC1=Rock Creek at the confluence, RC2=Rock Creek at the 10 road bridge.
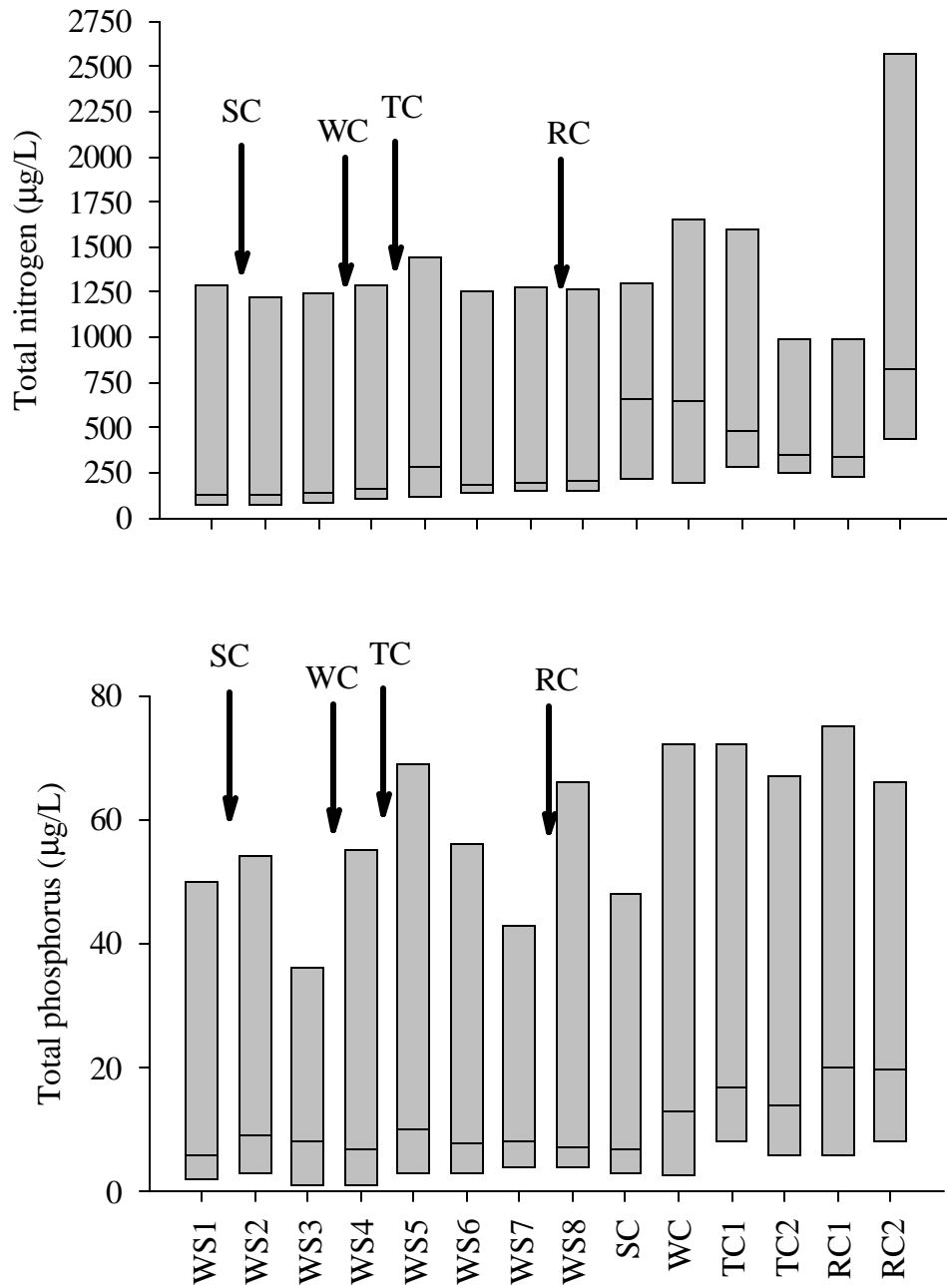
Figure 4. Maximum, median and minimum total nitrogen (µg/L) and
total phosphorus (µg/L)  averaged across dates. See Figure 5
for site descriptions.Arrows denote approximate location of tributary inputs.
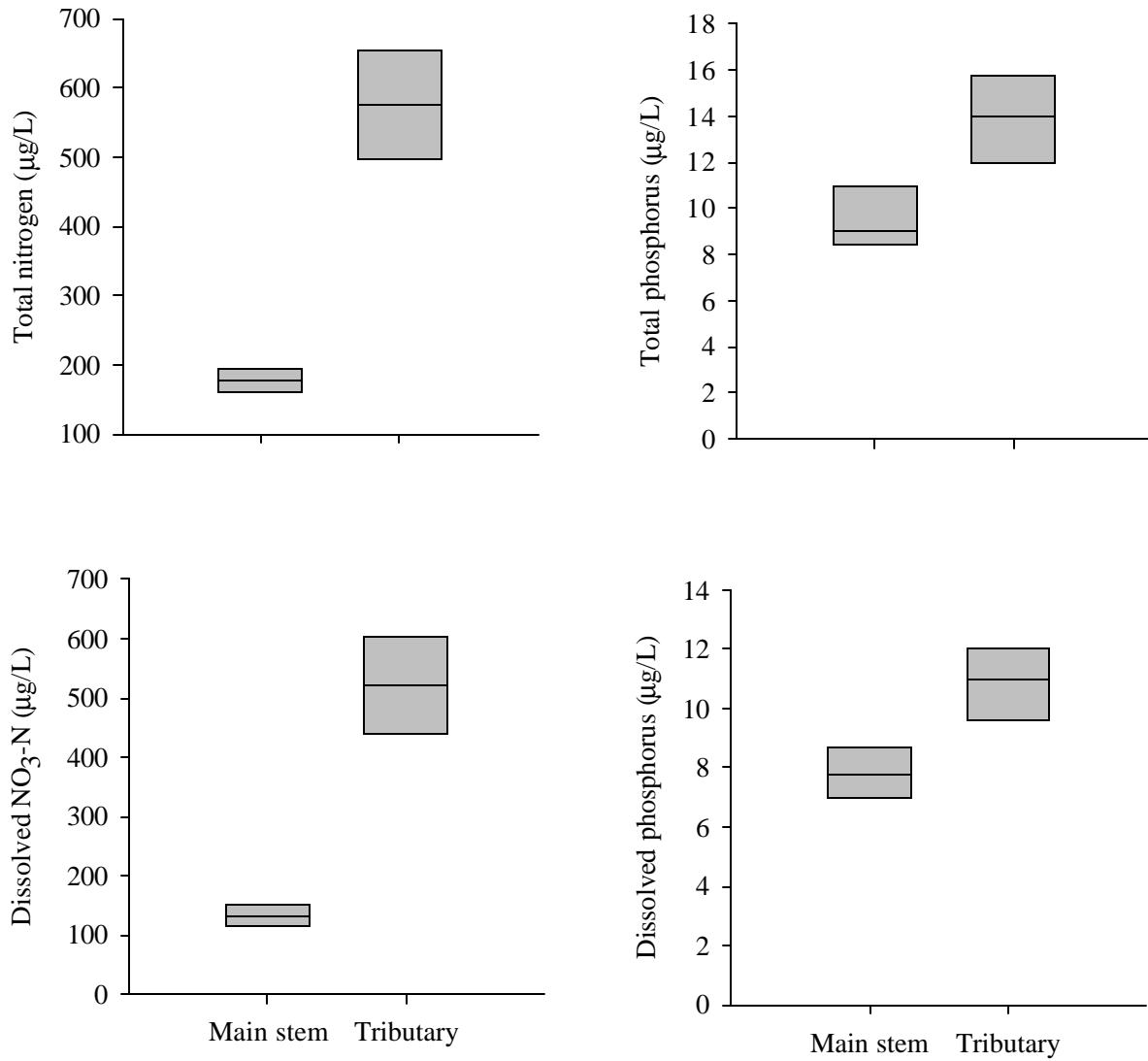
Figure 5. Means ($\pm$ lower and upper 95% CI) of total nitrogen and phosphorus and dissolved nitrogen and phosphorus during summer in the mainstem Cedar River and tributary streams averaged across dates and sites.
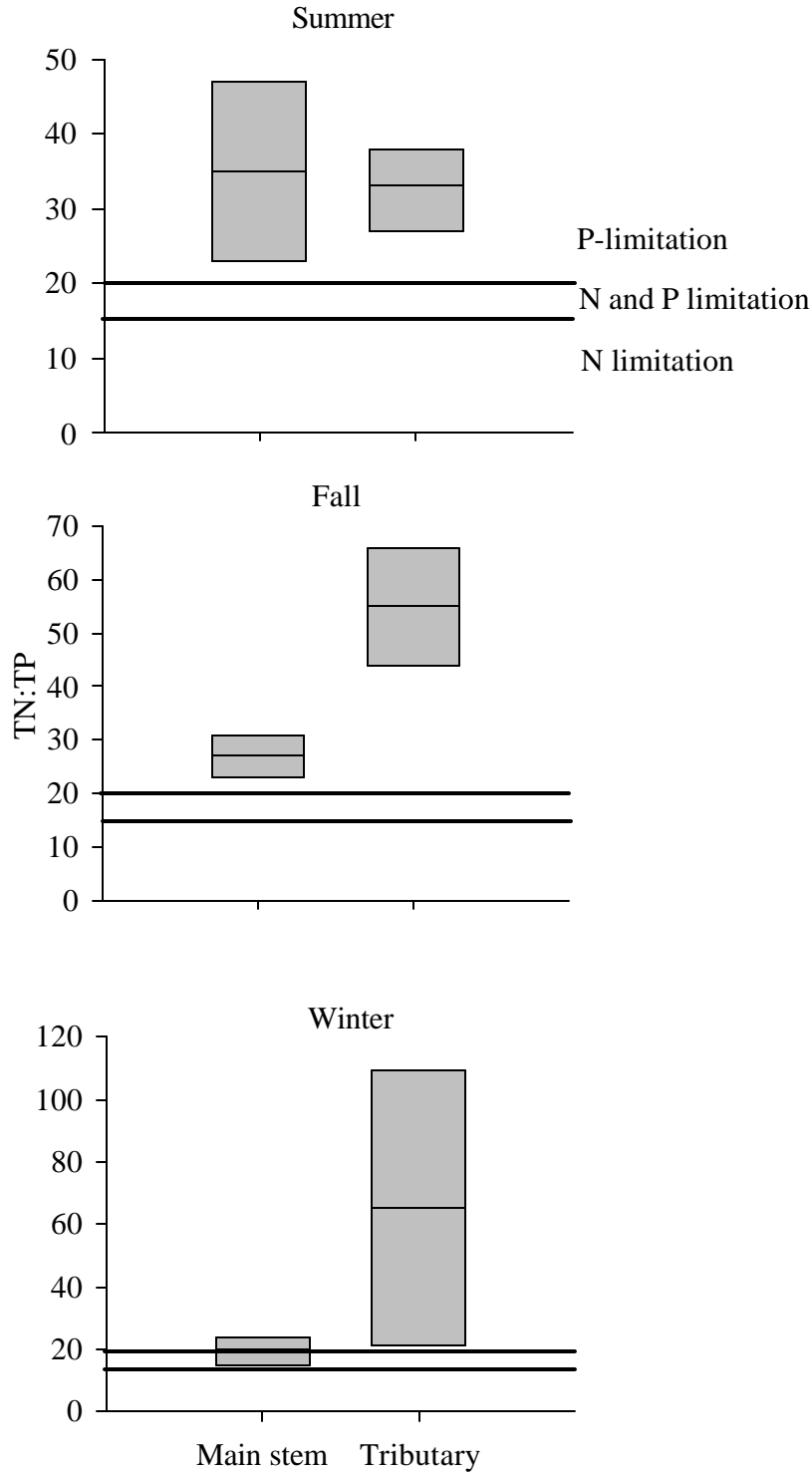
Figure 6. Mean (± lower and upper 95% CI) total nitrogen:total phosphorus averaged across dates and sites during Summer (June-September), Fall (October-November) and winter (January-February). Values below 16 are indicative of N-limtation, between 16-20 co-limitation and above 20 P-limitation.
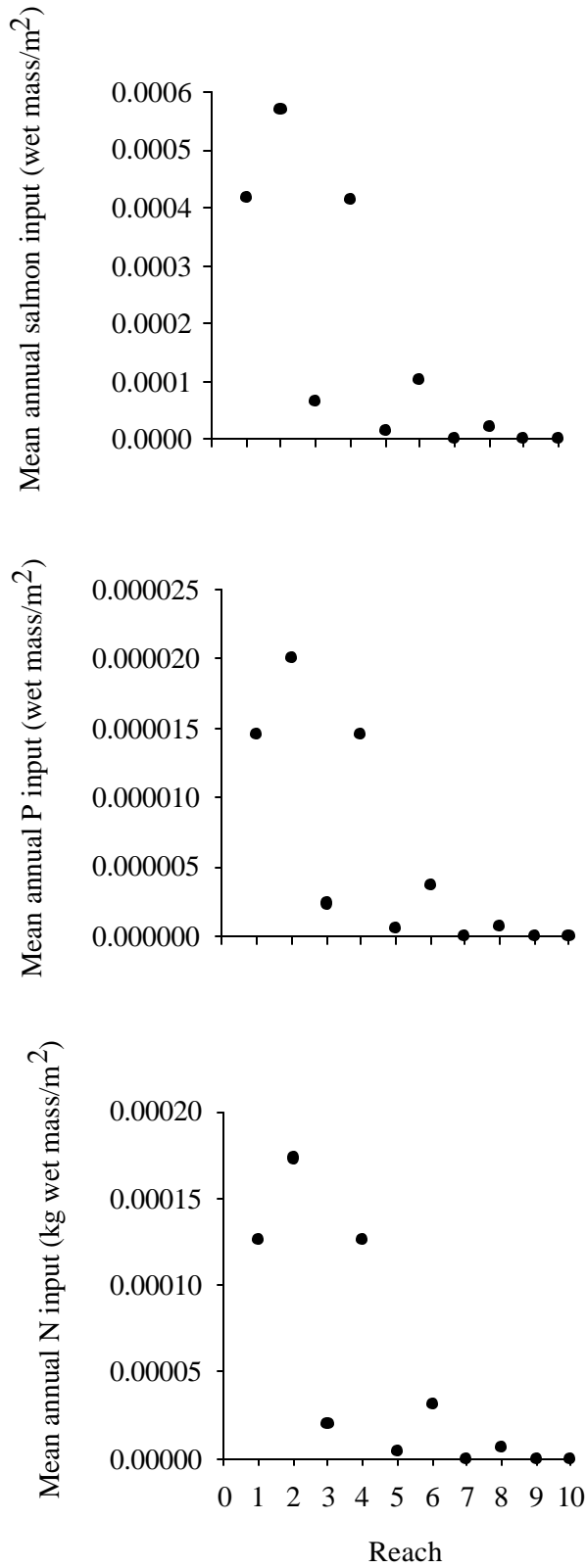
Figure 7. Mean annual total salmon biomass input, total salmon
P input, and total salmon N input into the Cedar River averaged
across 2003, 2004 and 2005. Inputs were based on redd surveys.
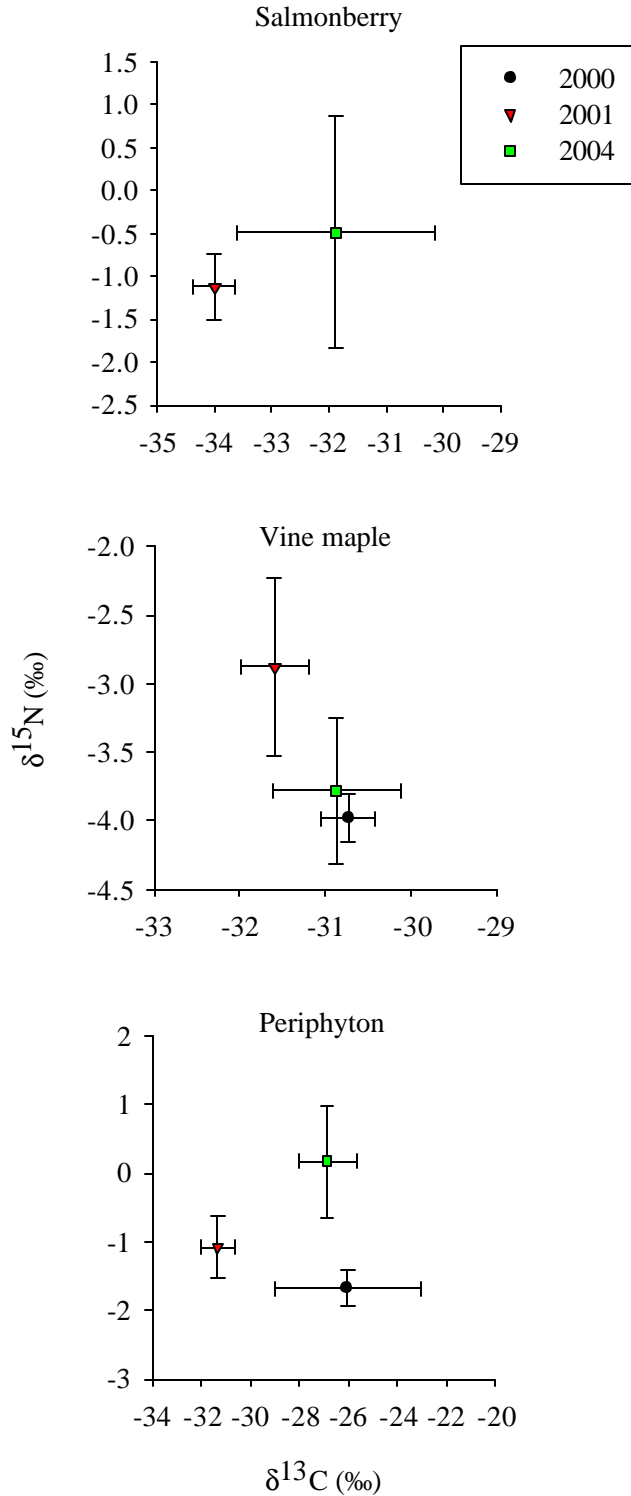
Figure 8. Dual isotope plots showing d $^{13}$C and d $^{15}$N in salmonberry and vine maple collected from the riparian zone and periphyton collected from the stream at reach CR1 in 2000 (black dot), 2001 (inverted triangle) and square (2004). 2000 and 2001 data were collected before salmon, while 2004 was the first summer after adult salmon were passed above Landsburg.
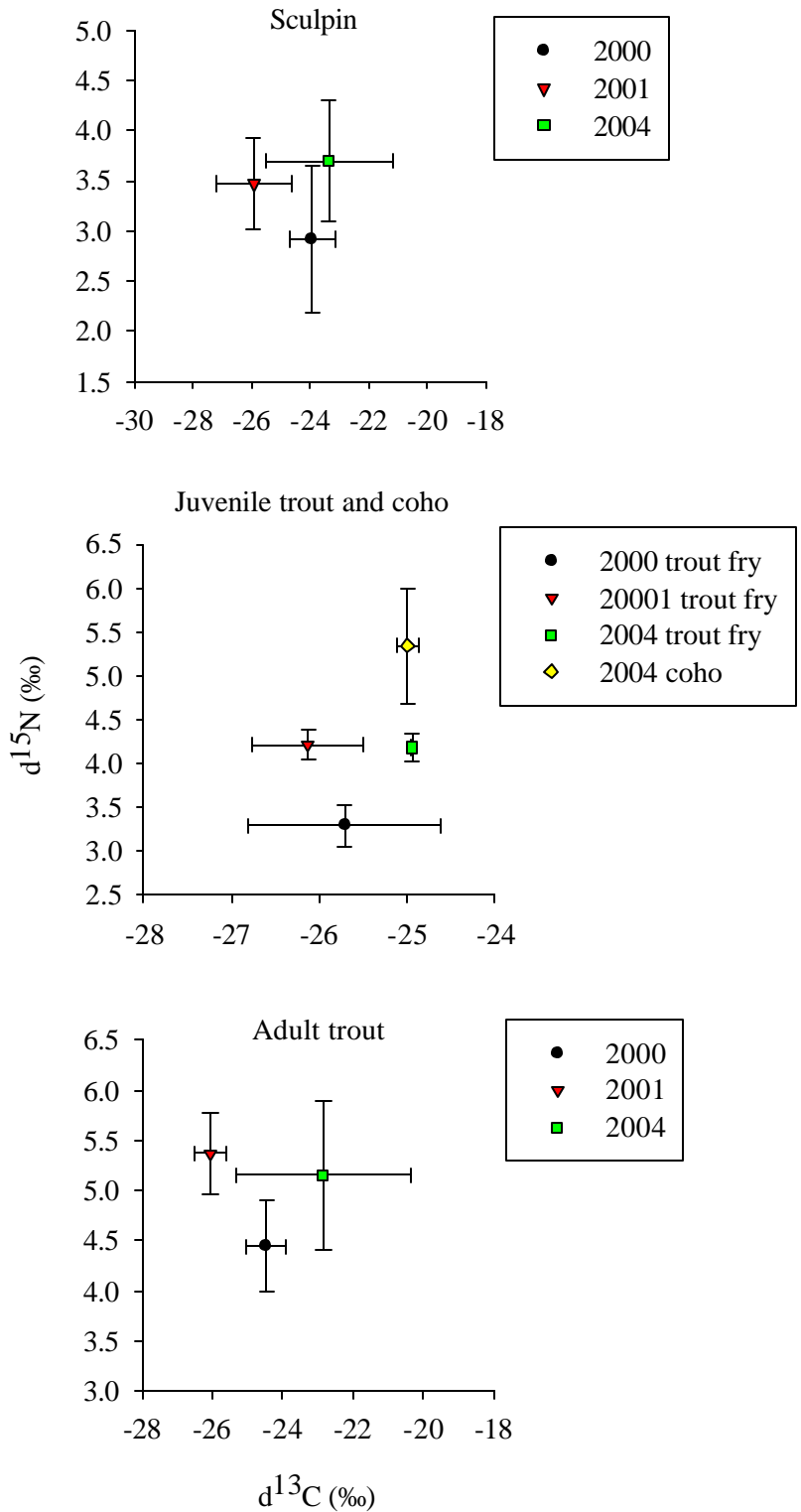
Figure 9. Dual isotope plots showing d$^{13}$C and d$^{15}$N in sculpin,
juvenile trout and coho (2004 only), and adult trout collected from reach
CR1 in 2000 (black dot), 2001 (inverted triangle) and square (2004). 2000
and 2001 data were collected before salmon, while 2004 was the
first summer after adult salmon were passed above Landsburg.
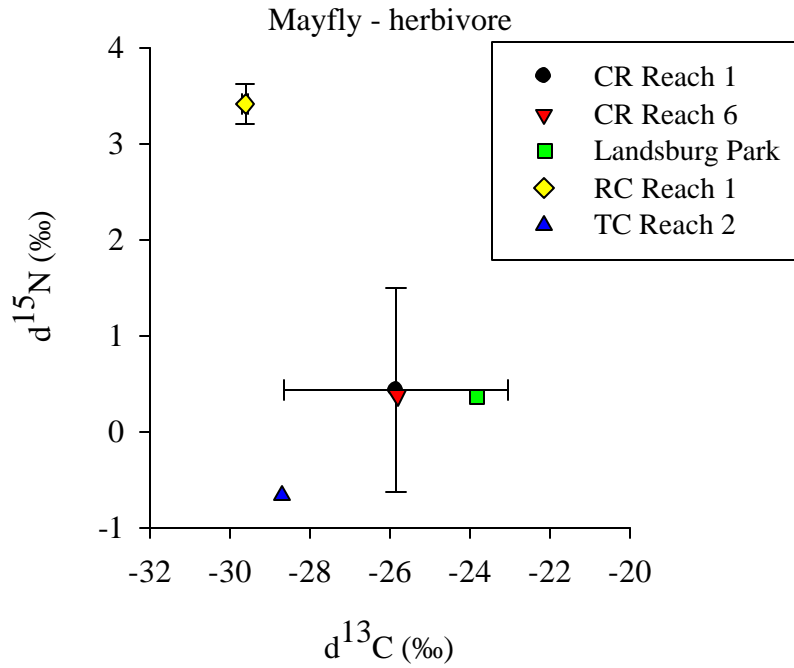
Figure 10. Dual isotope plots showing $\delta^{13}$C and $\delta^{15}$N in mayflies collected from reach CR1 (dot) and CR6 (inverted triangle) above Landsburg Landsburg Park (square) below Landsburg, Rock Creek (RC, diamond) and Taylor Creek (TC2, triangle). The Taylor Creek site is above a natural barrier to adult salmon.
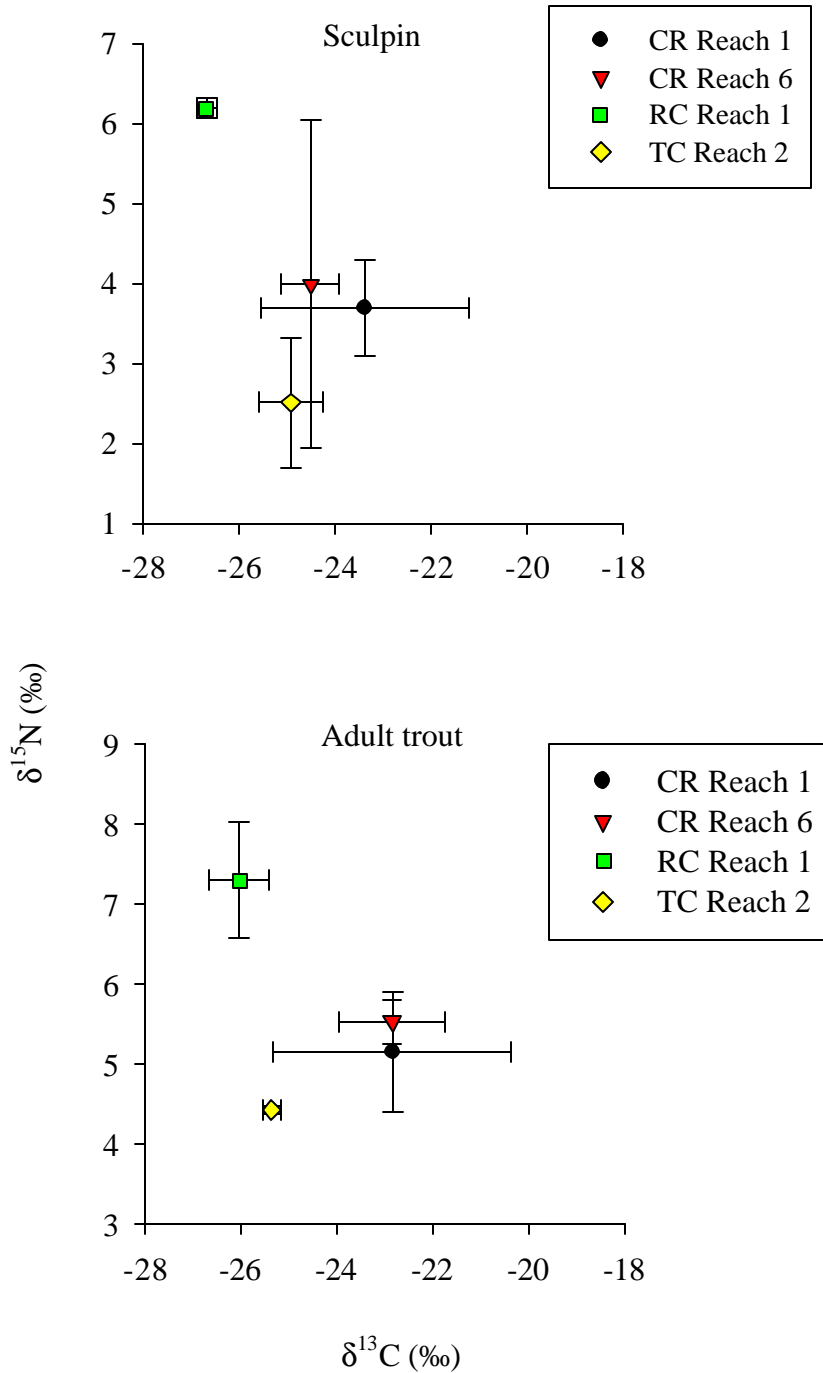
Figure 11. Dual isotope plots showing $\delta^{13}C$ and $\delta^{15}N$ in sculpin and adult trout collected from reach CR1 (dot) and CR6 (inverted triangle) above Landsburg, Rock Creek (RC, diamond) and Taylor Creek (TC2, triangle). The Taylor Creek site is above a natural barrier to adult salmon.
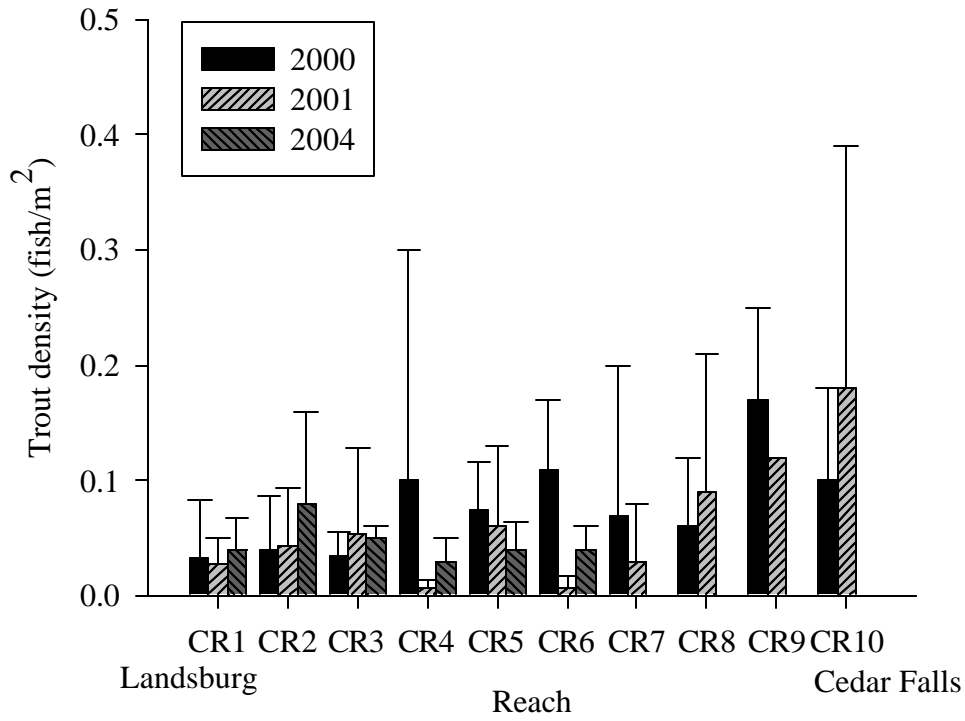
Figure 12. Mean ($\pm$ 1sd) density of trout averaged across habitat types in reaches of the Cedar River in 2000, 2001 and 2004.
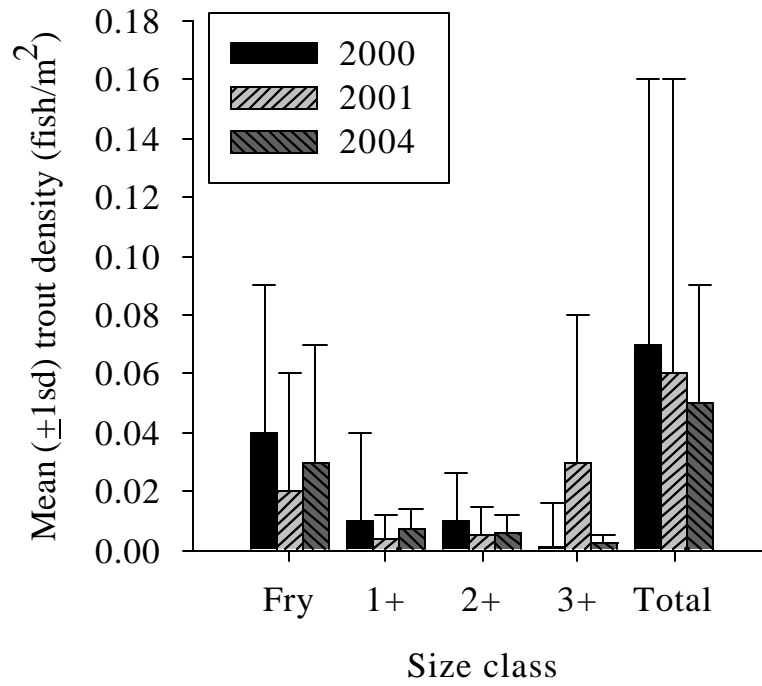
Figure 13. Mean ($\pm$ 1sd) density of fry, 1+, 2+ and 3+ trout averaged across habitat types and reaches in 2000, 2001 and 2004.
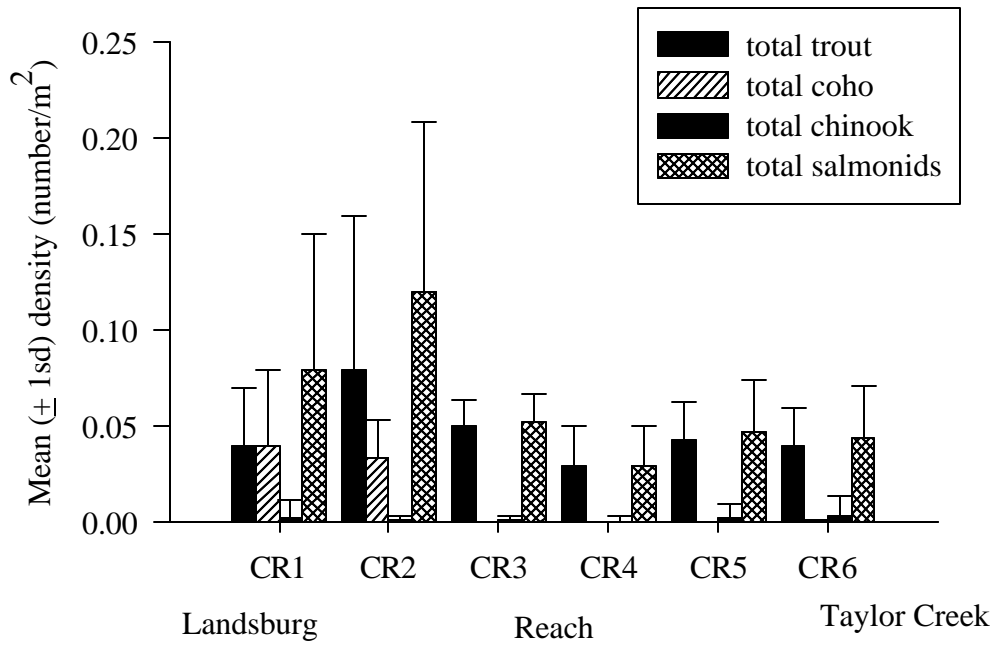
Figure 14. Mean (± 1sd) density of trout, coho, chinook and total salmonids (trout+salmon) in the lower five reaches of the mainstem Cedar River during summer 2004.
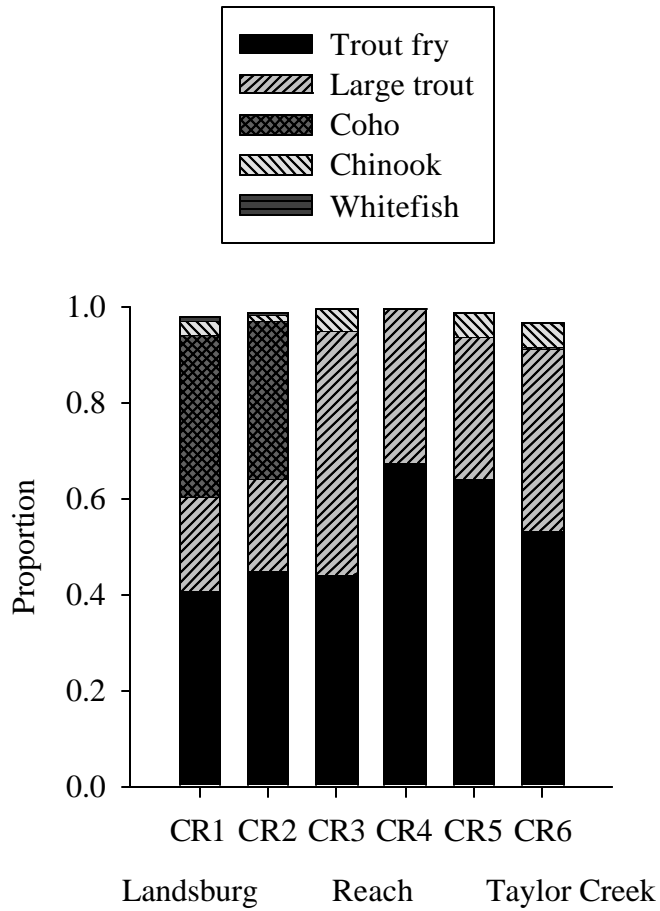
Figure 15. Relative proportion of trout fry (< 80 mm total length) and  large trout (>80  mm), and coho, chinook and whitefish in the lower 5 reaches of the mainstem Cedar during summer 2004.
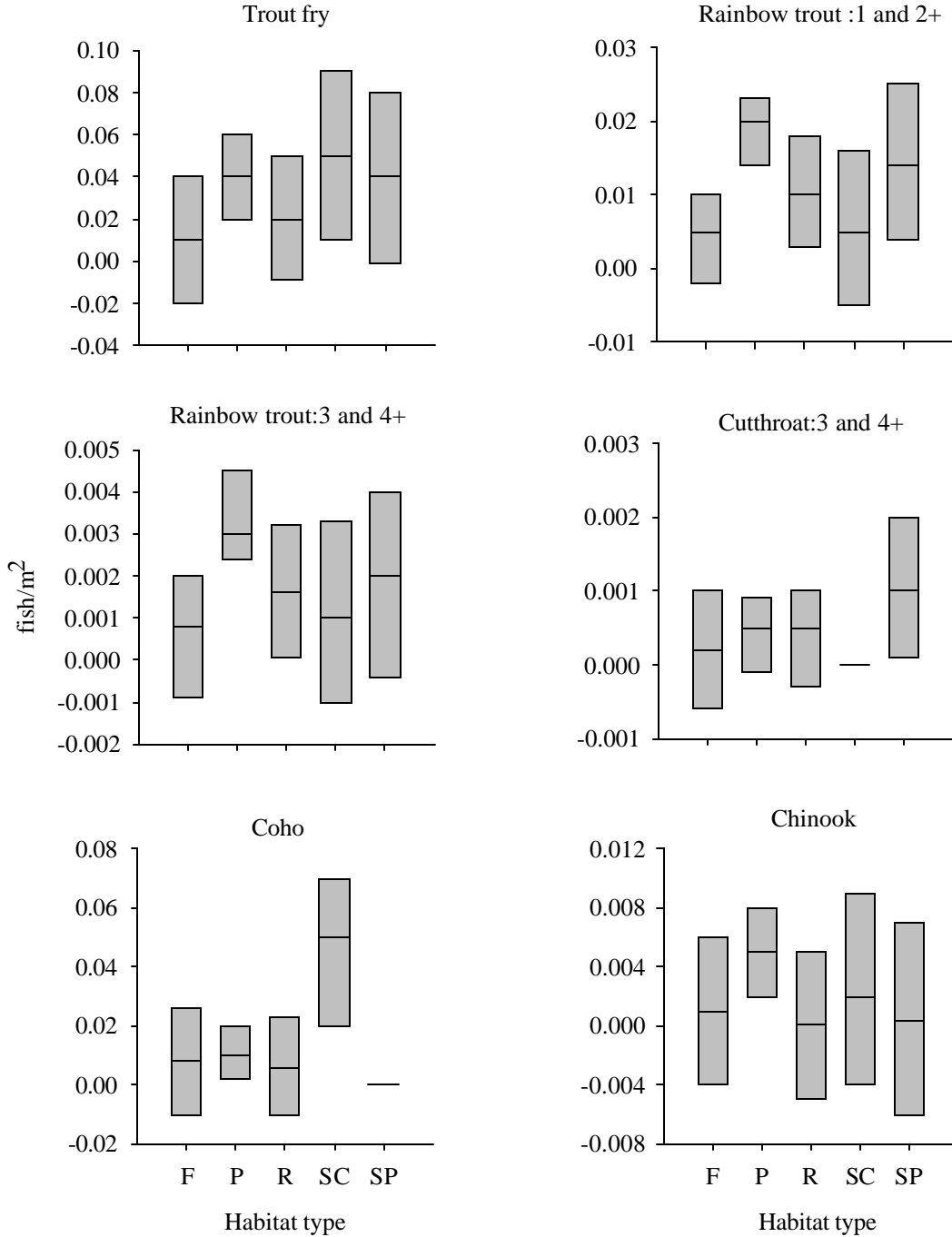
Figure 16. Mean (± lower and upper 95% CI) for trout, rainbow, cutthroat, coho and chinook densities in different habitat types (F=flatwater, P= pool, R=riffle, SC=side channel, SP=step pool) averaged across reaches in the Cedar River mainstem during August 2004.
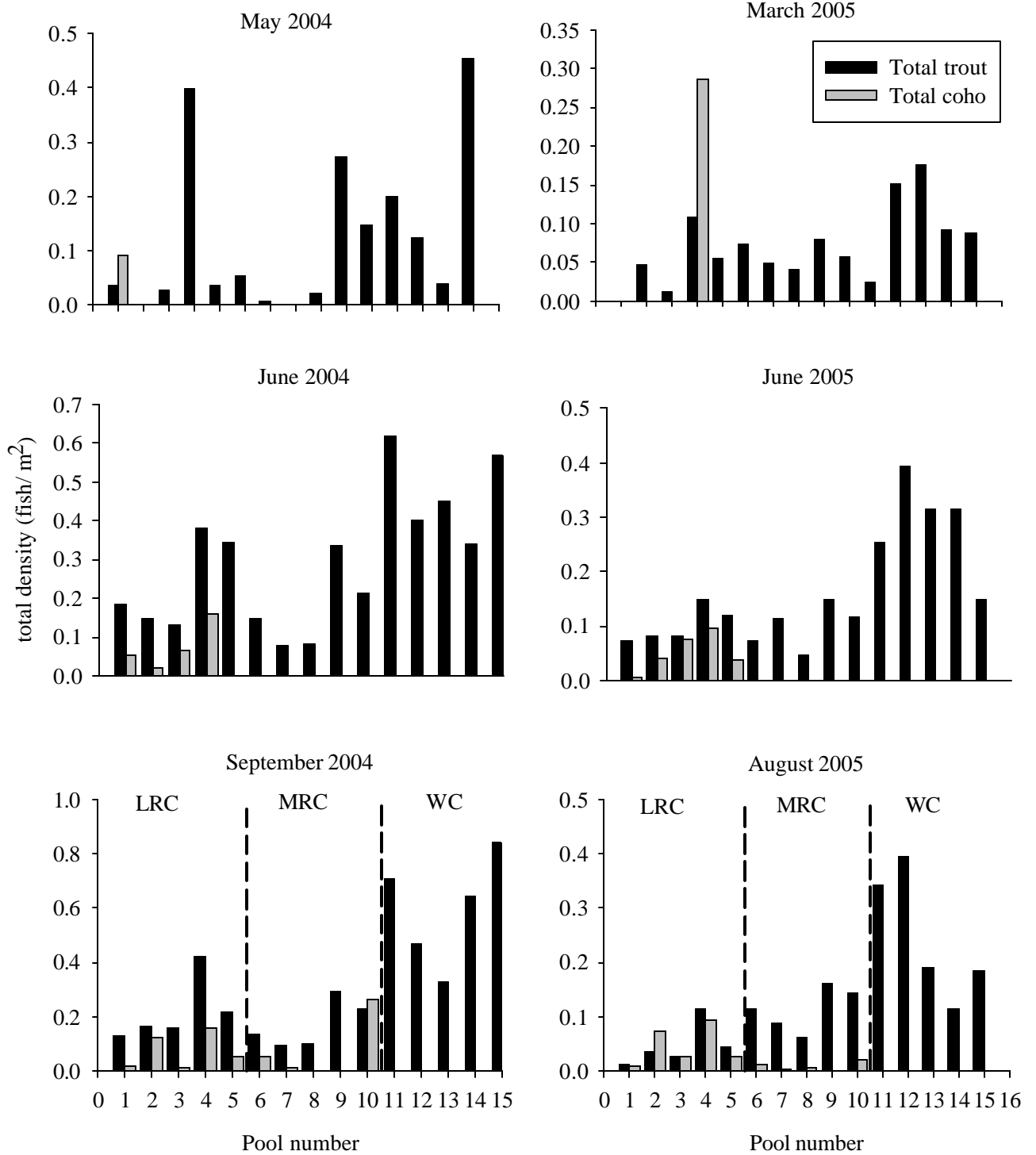
Figure 17. Total trout and coho density (fish/m$^2$) in pools of lower Rock Creek (LRC) and middle Rock Creek (MRC), and Williams Creek during 2004-2005.
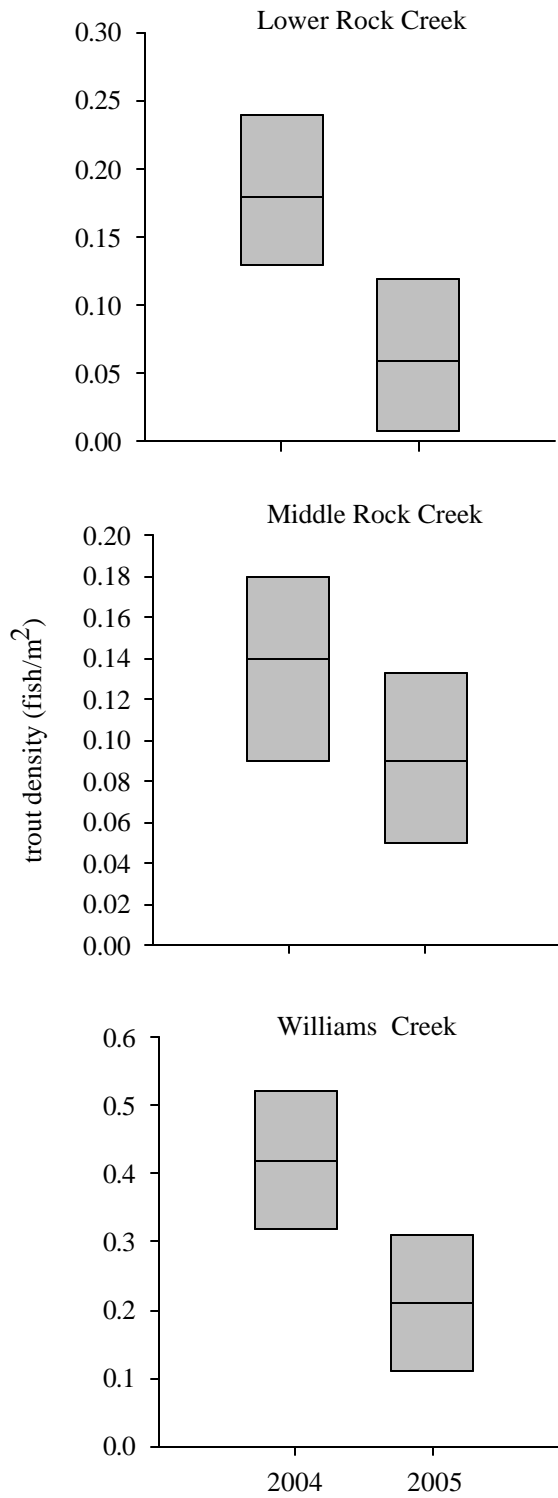
Figure 18. Mean ($\pm$ lower and upper 95% CI) trout density in lower and middle Rock Creek and Williams Creek in 2004 and 2005.
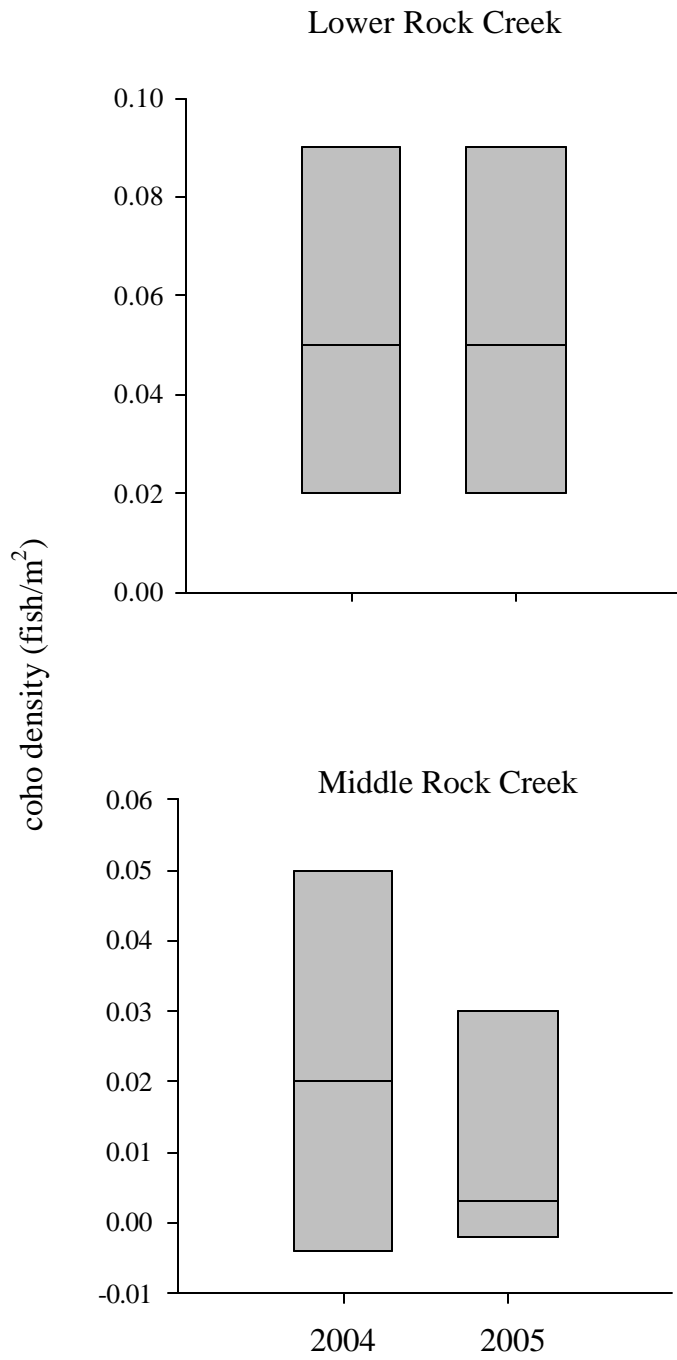
Figure 19. Mean ($\pm$ lower and upper 95% CI) coho density in lower and middle Rock Creek and Williams Creek in 2004 and 2005.
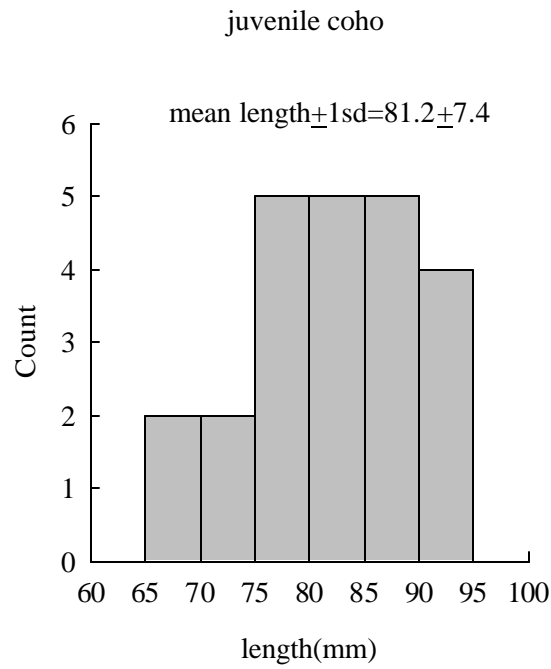
juvenile cutthroat

mean length$\pm$1sd=62.5$\pm$9.3

juvenile coho
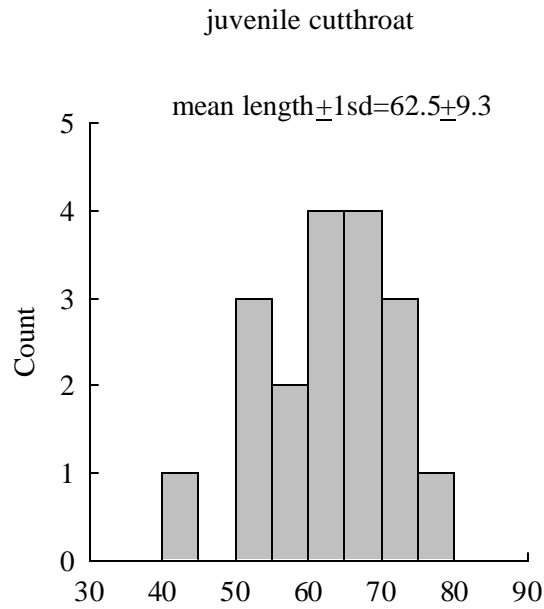
mean length$\pm$1sd=81.2$\pm$7.4

length(mm)

Figure 20. Histograms of individual fork lengths (mm) of juvenile cutthroat and coho captured in lower Rock Creek during August 2004.
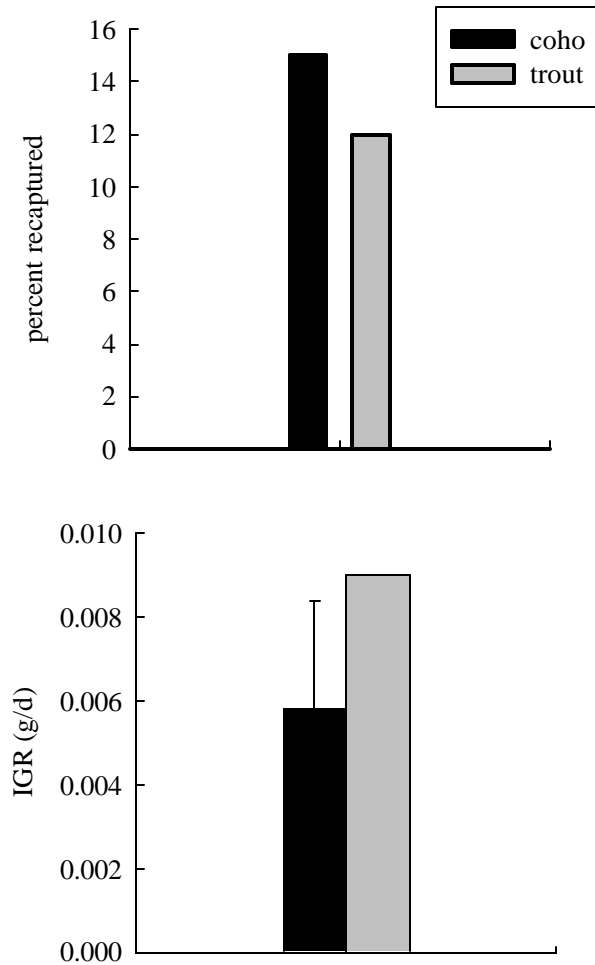
Figure 21. Percent coho and trout recaptured in October 2004 that
were marked in August 2004 and instantaneous growth
rate for fish recaptured in October.