Community and ecosystem attributes of the Cedar River watershed above Landsburg Diversion before arrival of Pacific salmon

P. Kiffney[1,2], C. Volk[2], J. Hall[1], and C. Eberhart[2]

[1]Northwest Fisheries Science Center, Environmental Conservation Division, Watershed Program, Mukilteo Biological Field Station, 10 Park Avenue, Building B, Mukilteo, WA 98275, 425-743-6567 (fax), 425-743-3307 ext. 226 (phone), **peter.kiffney@noaa.gov** (internet)

[2]Division of Ecosystem Sciences and Conservation, Box 352100, University of Washington, Seattle, WA, 98195

Executive Summary

Our research has established baseline conditions in the upper Cedar River between Landsburg diversion and Cedar Falls, including the tributaries of Rock, Taylor and Williams Creeks, for the following attributes:

(1) physical habitat;
(2) resident fish populations (salmonids and cottids);
(3) water chemistry; and
(4) the carbon and nitrogen isotopic composition of terrestrial plants and aquatic organisms (Rock, Taylor, and Cedar River).

We conducted two additional studies that increase our understanding of the ecology of fishes in the upper watershed: aging of scales to validate age classes for salmonids used in our snorkel surveys. This study is ongoing, as scales and otoliths from fish collected during the 2001will be analyzed this summer. The second study examined stomach contents of salmonids and cottids collected during 2000 and 2001. These data augment the stable isotope study, as together they can be used to unravel food web relationships and trophic structure in the Cedar River and its tributaries, and how these relationships change with colonization of Pacific salmon.

Overall, our results show that streams in the Cedar River watershed are oligotrophic with low levels of dissolved materials, including nutrients (nitrogen (N) and phosphorus (P)) that limit productivity of primary and secondary consumers. We also observed large differences between mainstem and tributary sites in water chemistry. Tributary sites had N and P concentrations that were two times higher than mainstem

sites. Salmonid abundance was negatively correlated with stream size (Riley et al. 2001); highest salmonid abundances occurred in Williams and Rock Creeks. No relationships were observed between woody debris and other physical variables and trout density. However, we found that dissolved nitrate was positively correlated with trout abundance. Estimates of fish density and biomass in 2000 and 2001 were similar, suggesting that our survey methods were robust despite the high turnover of snorkelers between years.

Carbon and nitrogen isotopes in periphyton, and primary and secondary consumers were highly variable among sites. Some of this variation was likely driven by the variability in periphyton d^{13}C, and differences in the relative importance of autochthonous and allochthonous organic matter as a food resource for consumers. Food webs in small, heavily shaded streams in the watershed were supported by an equal mixture of periphyton and terrestrial detritus, despite the large differences in inputs from the two sources (i.e., higher carbon inputs from leaf litter than in-stream carbon production). In the mainstem, which is wider and receives more sunlight than Rock and Taylor Creeks, food webs were primarily supported by in-stream primary production. The low d^{15}N values for terrestrial vegetation and aquatic biota in the Cedar River watershed compared to similar organic material from a salmon-stream, and the low within site variability of these data suggests that small inputs of salmon-derived nitrogen may have measurable impacts on isotopic signatures of Cedar River and tributary food webs.

This study establishes baseline conditions for water chemistry, fish abundance and distribution, food web structure, isotopes of C and N, and fish diet in the Cedar River above Landsburg and below Cedar Falls plus some of the main tributaries. This summer we are collecting additional information on water chemistry, habitat, fish distribution, aquatic insects and periphyton dynamics. Overall, these data will allow us to assess the ecological effects of returning salmon on the Cedar River watershed. It is important to maintain these studies for a number of years after recolonization, as this project presents a unique ecosystem-scale experiment that will aid in planning the recovery of Pacific salmon across the PNW. Because our study is relatively long-term (three years of data), comprehensive (water chemistry to fish), and spans a large area of the watershed (27 km of mainstem and tributaries), these data will aid Seattle Public Utilities in managing the aquatic resources of the upper Cedar River watershed. We also maintain that this study will assist scientists and managers in other regions deciding whether to provide passage around small dams that block movement of migrating fish.

Table of contents **page #**

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.

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. The city of Seattle's Habitat Conservation Plan (HCP) for the Cedar River Watershed proposes to install a fish ladder at the Landsburg Diversion Dam, located on the Cedar River mainstem. This diversion has blocked anadromous fish migration to approximately 27 km of mainstem 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). In addition, resident salmonids in the uppermost Cedar River watershed have been isolated from anadromous salmonids; there are likely to be ecological effects (e.g., competition, predation) on these resident fishes resulting from the return of anadromous forms above Landsburg.

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. The specific aims of this research are:

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

In this report, we present the following results:

(1) fish survey data collected during 2001;
(2) age validation of trout using scales collected from captured fish in 2000;
(3) analysis of stomach contents of fish collected in 2000 and 2001;
(4) isotopic values for carbon (C) and nitrogen (N) in riparian plants, stream periphyton, aquatic insects, and fish collected in 2000; and
(5) water quality trends from November 2000 to March 2002.

These data establish baseline conditions for ecological, physical, and chemical attributes above Landsburg Diversion before anadromous fish are allowed access to this habitat. This information can be used to determine the ecological effects anadromous fish have on the upper Cedar River watershed; Pacific salmon have been isolated from this area for over 90 years. Moreover, these data will aid Seattle Public Utilities in managing the restoration of habitat within the watershed, such as determining escapement of adult salmon above Landsburg.

2.0 Materials and Methods

2.1 Water quality sampling

Bi-monthly (October through December) to monthly (January to September) collections of river water were taken beginning in June of 2000; however, analysis of samples did not begin until November 2000. In this report, we present data collected between November 2000 and March 2002. 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 mainstem in 2000. Currently, we are collecting water from 15 sites: eight mainstem and seven tributary sites (Appendix 1). Samples were collected according to methods determined by Seattle Public Utility's (SPU's) water quality laboratory. Samples were immediately placed on ice and taken to SPU's water quality laboratory where they were analyzed for total (unfiltered sample) phosphorus and nitrogen; dissolved phosphate; dissolved nitrate + nitrite; total organic carbon; alkalinity; conductivity; and turbidity. Water temperature and pH were measured and recorded in the field.

2.2 Fish

2.2.1 Population surveys

Snorkel counts of resident fish were conducted on the Cedar River and Taylor Creek (211 habitat units were snorkeled). Sites were chosen randomly from habitat units (cascades, pools, riffles, flatwater, step-pools, see Riley et al. 2001 for further description of habitat types) within each reach and habitat type strata mapped during the habitat survey (Appendix 2). 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 salmonids (rainbow or cutthroat trout) were divided into three size classes (fry $\leq$ 80 mm; 1+, 81-120 mm, 2+, 121-200 mm; and adult $\geq$ 201 mm). Sculpins (*Cottus* sp.) were also counted.

Estimates of fish population size were obtained at Rock and Williams Creek by electrofishing (22 units were surveyed). A two to four person crew completed three electrofishing passes at each site using a Smith-Root backpack electrofisher operating at 300-500 volts DC. All sites were sampled between 10:00 – 15:00. Sites were completely enclosed using 10 mm stretched-mesh seines before electrofishing to ensure population closure; nets were installed as quickly as possible to minimize disturbance to fish. All fish captured were anesthetized (MS-222), measured (fork length to the nearest mm), weighed (nearest 0.1 g), and kept in live baskets in the stream until electrofishing was completed, when they were released alive near their point of capture. The pelvic fin of all salmonids > 100 mm was clipped according to the location of their capture (mainstem

- right pelvic; Rock or Taylor creeks - left pelvic). The number of fish captured at all sites was too low to produce meaningful removal estimates of population size, and population estimates were calculated as the sum of all fish caught.

2.2.2 Fish age and diet

Scales of rainbow and cutthroat trout collected for stable isotope analyses in 2000 were analyzed to established age and size classes. In addition, we examined stomach contents of salmonids and sculpins collected in 2000 and 2001 to determine diet composition. Comparing diet composition to age class can be a useful for analyzing the trophic dynamics of fish by age class. In addition, determination of age-to-fork length relationships among fish populations may provide a useful *in situ* method for quick age determination during population surveys. Riley et al. (2001) used adapted fork length ranges from Thurow (1994) to classify surveyed fish into age classes based on fork length. However, it has been found that fish age-to-fork length relationships vary greatly between systems (Beamish and McFarlane 1983, Hining et al. 2000). Therefore, fork length ranges used by Riley et al. (2001) needed to be established for the upper Cedar River ecosystem. We counted fish scale annuli to estimate fish age; this method has been used since the 1930s for ageing fish in North America (Carlander 1987, Hining et al. 2000).

Both electro-shocking and fly-fishing were used to collect fish during 2000 and 2001 sampling trips (Riley et al. 2001). Fish fork length and wet weight were measured in the field. Stomach contents from 177 fish were analyzed by dissection; invertebrates were classified to order level when possible, and preserved in 95% ethanol for further analysis. In all, stomach contents from 37 fry, 16 cutthroat trout, 71 rainbow trout, 2 hybrids, and 51 sculpins were collected and analyzed.

Fish scales were collected from 16 fry, 1 cutthroat, and 36 rainbow trout during 2000 preliminary analysis of fork length ranges used by Riley et al. (2001). All fish scales were removed from between the dorsal and pelvic fins. Fish scales were mounted on 1” x 3” acetate sheets and magnified using a microfiche projector (32x magnification). An annulus was recorded when the distance between circuli increased after a period of decreasing, representing an increase in growth rate at the onset of spring. Samples that contained only regenerated scales were not analyzed. To determine the precision of age classification, a second observer conducted a random sampling of prepared scales. Age classes were grouped, and a mean and standard deviation were calculated for fork lengths for each age class. Fork length distributions for each age class were tested against ranges used in the fish distribution survey by Riley et al. (2001) using a two-tailed t-test (Zar 1984).

Diet composition of salmonids was compared among age class, while all sculpins were group together for diet composition analysis.

2. 3 Carbon and nitrogen isotopes in Cedar River food webs

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 establish baseline levels of C and N stable isotopes in river food webs, we collected tissue from allochthonous and autochthonous organic matter. For allochthonous organic matter we collected foliage from riparian trees (western red cedar, vine maple) and a shrub (salmonberry) common to the mainstem and tributaries. 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. We also collected aquatic insects from six functional feeding groups: a predaceous stonefly (*Hesperoperla pacifica*), 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.). Top predators included four age classes (fry, 1 and 2+, and adults) of rainbow (*Oncorhynchus mykiss*) and cutthroat trout (*Oncorhynchus clarki clarki*); and sculpins (*Cottus* spp.). Samples sites were chosen based on habitat surveys, proximity to water chemistry sampling sites, and barriers to anadromous fish. These included three on the Cedar River mainstem: CR 1 (at the 70 road bridge); CR 3 (at the end of road 40.2); and CR 6 (near road 50.1). One site was located on Rock Creek (upstream of the 40 bridge) and two on Taylor Creek (at the mouth of the Cedar and at the Taylor Creek USGS gauge which is above a barrier to anadromous fish). Tissues were collected in October 2000 and September 2001.

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 micron mesh net. If possible, replicate samples of each functional feeding group were collected from each site. Fish (3-5 of each salmonid age class at each site) were collected 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. Samples collected in 2001 have been processed and will be analyzed at the NWFSC in summer 2002. These data will be presented in an additional report to SPU in 2003.

Samples from 2000 were sent to the Analytical Chemistry Laboratory at the University of Georgia. All data is reported as $d^{15}N$ values using atmospheric nitrogen as a standard, where

$$d^{15}N= \{^{15}N/^{14}N)_{sample}/(^{15}N/^{14}N)_{air}-1\} \text{ x } 1000\ (^{o}/_{oo}).$$

Carbon values are reported as $d^{13}C$ values using PeeDee limestone as a standard, where

$$d^{13}C= \{^{13}C/^{12}C)_{sample}/(^{13}C/^{12}C)_{PDB}-1\} \text{ x } 1000\ (^{o}/_{oo}).$$

3.0 Results and discussion

3.1 Water chemistry

Surface water chemistry was relatively similar among mainstem sites, whereas chemical constituents were generally higher at tributary sites compared to mainstem sites (Fig. 1 and 2). Alkalinity refers to the capability of water to neutralize acid. The presence of calcium carbonate ($CaCO_3$) or other compounds such as magnesium carbonate contribute carbonate ions to the buffering system. Alkalinity is often related to hardness because the main source of alkalinity is usually from carbonate rocks (limestone), which are mostly $CaCO_3$. Alkalinity in the Cedar River and its tributaries ranged from 10 (Fish Creek, FC) to approximately 20 (mg/L $CaCO_3$ (Fig. 1a), and indicates that this water has a low buffering capacity. Conductivity represents the total ionic content of water. Similar to alkalinity, conductivity in the Cedar River was low and ranged from 28 (FC) to 65 (RC 2) µmhos (Fig. 1b). In general, alkalinity and conductivity increased downstream due to the increased time the water is contact with bedrock (Welch et al. 1998). Waters draining the Cascade Mountains generally have a low buffering capacity (i.e., low alkalinity), as they drain erosion resistant granite (Welch et al. 1998).

Turbidity is a unit of measurement quantifying the degree to which light traveling through a water column is scattered by suspended organic (including algae) and inorganic particles. The scattering of light increases with a greater suspended load. The USEPA recommends a maximum turbidity of 25 nephelometric turbidity units (NTU) to protect beneficial uses in fresh waters (USEPA 1986). Turbidity in the Cedar River was low, with values less than 1 NTU at all sites (Fig. 1c). The highest turbidity readings occurred at RC 1, and were likely due to the extensive beaver complex upstream of this site. Beaver dams trap large quantities of organic and inorganic matter, which is then available for downstream transport as suspended materials adding particles to the water column, thereby increasing turbidity.

Phosphorus is an essential element for growth, and is often found to limit algal production in freshwater ecosystems. Background levels of orthophosphate or soluble reactive phosphorus (SRP), which is the form used by plants, are generally less than 30 µg/L (Dunne and Leopold 1978). Although levels of 80 to 100 µg/L SRP may trigger periodic algal blooms, long-term eutrophication will usually be prevented if total phosphorus levels and orthophosphate levels are below 500 and 50 µg/L, respectively (Dunne and Leopold 1978). In the Cedar River watershed, SRP concentrations were considerably below SRP values known to cause algal blooms. Lowest values (2 to 4 µg/L) were measured in the upper mainstem (CR 1, CR 2, and CR 3), and levels generally increased downstream (Fig. 1d). Tributary streams (WC, RC, and TC) had highest SRP concentrations (range from 8-13 µg/L), and concentrations were approximately two to three times greater than mainstem sites. Filamentous green and blue-green algae attain a maximum biomass at about 10 µg/L SRP in experimental channels (Walton et al. 1995), and these levels were only measured in tributary streams. We speculate that the dense canopy of tributary streams limits growth of filamentous algae even though nutrient levels are high enough to support them. We have noted only small patches of filamentous algae growing in the mainstem during our two years of fieldwork. Low filamentous algal cover can be a result of grazing by large (20-30 mm as late instar larvae) *Dicosmoecus* caddisflies, which are abundant throughout the mainstem. In addition, the upper Cedar River is a relatively confined channel with areas of high water velocity; therefore, grazing pressure, low nutrients, and high water velocity may limit attachment and growth of filamentous algal forms in the mainstem. Trends in total phosphorus (dissolved and particulate inorganic and organic P) were similar to SRP, with highest TP concentrations observed in tributary streams.

Organic matter affects biogeochemical processes, nutrient cycling, biological availability of nutrients and metals, chemical transport and interactions. It also has direct implications in the planning of wastewater and drinking water treatment. Organic matter content is typically measured as total organic carbon and dissolved organic carbon, which are essential components of the carbon cycle. The main drivers of total organic carbon in unmanaged ecosystems, such as the Cedar River, are vegetation and climate. Total organic carbon levels in the Cedar River watershed were low, and ranged from less than 1 to 3 mg/L (Fig. 1f). Highest concentrations were observed in Rock Creek (RC1), which is downstream of the beaver complex. Beaver dams are sites of organic matter storage, and thus can serve as significant sources of organic material to downstream reaches.

Naiman et al. (1988) reported a three-fold increase in organic matter standing stock following impoundment of a stream by beaver. Dense stands of red alder in the upper reaches of Rock Creek may also be contributing to the high organic matter at this site, as alder provides a rich and plentiful supply of leaf litter (Volk et al. *in press*). Experimental exclusion of leaf litter from a North Carolina headwater stream resulted in a decrease in stream water dissolved organic carbon compared to before manipulation (Meyer et al. 1998). The combination of dense stands of riparian red alder and changes in geomorphology caused by beaver dams may contribute to the high organic carbon content of Rock Creek surface water.

Nitrogen can limit growth of plants and animals in aquatic and terrestrial ecosystems. In water, the form most available for uptake by plants is dissolved inorganic nitrogen, but plants can also use organic nitrogen, such as urea, amino acids or nitrogen released from plants and animals. Dissolved nitrate-nitrogen concentrations in the Cedar River watershed ranged from 100 µg/L (CR 1) to 800 µg/L (RC 2) (Figure 2a). Similar to phosphorus, highest concentrations were observed in tributary streams. High concentrations in Rock Creek may be partially due to the beaver complex and presence of riparian red alder in the upper reaches of Rock Creek. Total N and dissolved nitrate-N were 72 and 208% higher, respectively, after recovery of beaver populations in Minnesota (Naiman et al. 1994). Red alder is a nitrogen-fixer, and thus can be a major source of nitrogen to terrestrial and aquatic ecosystems. Surface water dissolved nitrate concentrations were three times higher in streams dominated by riparian red alder compared to streams dominated by coniferous trees in watersheds of the Olympic Peninsula, Washington (Volk et al. *in press*). Trends in total nitrogen (dissolved and particulate organic and inorganic N) concentrations were similar to dissolved nitrate-nitrogen (Fig. 2b).

As was mentioned previously, water chemistry data showed that tributary streams had higher concentrations of materials known to limit ecosystem productivity, specifically N and P. To further examine this pattern, we pooled monthly water chemistry measurements across mainstem sites, at Fish Creek, and tributary sites. Except for alkalinity and conductivity, mean values for water chemistry parameters were higher at tributary streams compared to mainstem or Fish Creek. Specifically, concentrations of SRP, TP, TOC, dissolved nitrate-N and total nitrogen were about two to three times greater in tributaries compared to other sites (Fig. 3 and 4).

Our data, therefore, show that tributaries of the Cedar River are important sources of limiting nutrients to the mainstem, and suggest these tributaries should be managed to subsidize mainstem productivity. Rock and Williams Creek have extensive wetlands in their basins that may contribute to the high nutrient and carbon concentrations of their surface water. Red alder may also be contributing to the nutrient capital of tributary sites, as other studies have shown that riparian red alder is a significant source of phosphorus and nitrogen to terrestrial and aquatic ecosystems (e.g., Volk et al. *in press*). We have noted dense stands of riparian red alder along Taylor and Rock Creeks; the proportion of a watershed comprised of red alders is positively related to dissolved nitrate-N of streams on the Olympic peninsula (P. M. Kiffney, unpublished data). A popular restoration technique for riparian zones is the removal of broadleaf species and replanting with conifers. This is because of the important contributions conifers make to instream habitat complexity after they fall into the stream channel forming pools (Beechie et al. 1997).

However, red alder forests may be especially critical to ecosystem productivity of the Cedar, as the mainstem has low concentrations of limiting elements (N and P). We recommend that red alder remain an integral component of the riparian community in the Cedar River watershed, because it is an important source of limiting elements that can promote the productivity of terrestrial and aquatic ecosystems. Riparian management and restoration within the Cedar River watershed should promote processes that lead to the formation of a heterogeneous riparian landscape, with large conifers to provide important habitat forming structures and large stands of alder and other broadleaf species to provide important inputs of nutrients. This approach may improve the likelihood of recovery of endangered salmonids and other wildlife in the watershed.

3.2 Fish

3.2.1 Population surveys

Results from population surveys during 2001 were similar to trends observed in 2000 (Riley et al. 2001). Density estimates of trout (primarily rainbow trout) on the mainstem decreased from upstream to downstream (above Landsburg diversion) (Fig. 5), and were highest in reaches immediately downstream of Cedar Falls. Specifically, trout density increased as stream width narrowed (Riley et al. 2001). Similar patterns have been observed for cutthroat trout in Alaska (Murphy et al. 1986) and British Columbia (Rosenfeld et al. 2000). Rosenfeld et al. (2000) suggest that this pattern may be due to smaller streams having relatively more edge habitat, providing a more benign environment for spawning and rearing.

High total trout density in reaches nine and 10 was due to the large number of fry, and 1+ and 2+ individuals. In 2001, we split reach nine from the 2000 habitat survey into two reaches (reaches 9 and 10). The canyon reach (reach nine in 2001, begins at the small dam at the power station and continues until end of canyon) is geomorphically distinct from reach 10. Reach 10 extends from the end of the canyon reach to the bottom of Cedar Falls. The high trout densities, especially juvenile trout, in reaches 9 and 10 was surprising given the lack of wood or slow water habitat in the canyon reach. The canyon reach, however, does have abundant deep pools due to large boulders and bedrock outcrops; these sites may provide adequate rearing habitat for juvenile trout.

Fry, 1+, and total trout densities were highest in cascades (high gradient habitat with large boulders and deep pools formed downstream of these boulders), reflecting high densities in the canyon reach, which is approximately a 1 km long cascade (Fig. 6). Pools (mainstem and side pools) and step-pools also contained relatively high densities of trout. Adult fish (>200 mm) were most abundant in step-pools and pools. The high density of adult trout in the step-pools and pools was likely a complex function of water depth and velocity, and food concentrations. These large fish were typically concentrated at the intersection of pools and fast water; riffles are sites of high food abundance, whereas pools are sites of low energy demand (Rosenfeld et al. 2000). Furthermore, deep pools provide some measure of protection of fish-eating birds. Lowest trout densities were observed in flatwater and riffle habitat. In general, these habitats had shallow water depth and low habitat complexity, such as lack of large boulders or woody debris.

Trout densities were about two to five times greater in Rock and Williams Creek compared to mainstem sites (note scale differences for y-axes, Fig. 6-8). Although only one cascade unit was surveyed in Rock Creek, highest densities of trout (primarily cutthroat trout were observed in cascades, which was similar to the high trout densities associated with cascades in the mainstem. The majority of fish in cascades were 1 and 2+ trout (Fig. 7). No fry were observed in cascades, which was in contrast to what we observed in the mainstem. Fry were twice as abundant in pools than in riffles. We also conducted electroshocking surveys in three habitat units (two pools and one riffle) in Williams Creek in 2001 (Fig. 8). Williams Creek had trout densities two to five times higher than Rock and Taylor or mainstem sites, with highest fish densities observed in pools. We captured no sculpins from Williams Creek.

Eleven habitat units were snorkeled at Taylor Creek in 2001. Slightly more trout were observed in pool habitat compared to riffle and cascade habitat (Fig. 9). Age distributions were different among habitat types, with fry most abundant in riffles and adult fish most abundant in pools. However, only a small proportion of Taylor Creek was surveyed, and these estimates may not be representative of the entire system. We are conducting additional snorkel surveys this year in Taylor Creek, which should improve on these estimates. High concentrations of nutrients in Taylor Creek suggest that this system is relatively productive and may support trout densities higher than those observed in our surveys.

As was mentioned previously, trout densities were highest in Williams Creek compared to other sites, with lowest densities in Taylor Creek (Fig. 10). For example, fry density in Williams Creek was 65 times greater than in Taylor Creek. Next highest total trout densities were observed in Rock Creek. Trout densities were relatively similar between years; total trout density in the Cedar River was approximately 0.06 fish/m^2 in 2000 and 0.05 fish/m^2 in 2001.

We used electroshocking data collected in 2000 and 2001 to determine fish biomass (g/m^2) (Fig. 11). Trout biomass in 2000 ranged from about 0.1 (Cedar River) to 2.0 g/m^2 (Rock Creek). The low trout biomass at the Cedar obtained by electroshocking is likely an underestimate, as snorkel surveys provided much higher density estimates than shocking in the mainstem (Riley et al. 2001). Although Taylor Creek had the lowest biomass of trout, it had relatively high sculpin (*Cottus* spp.) biomass (1.7 g/m^2); no sculpins were captured at Williams Creek. Estimates of fish biomass were relatively similar among sites between years for Rock Creek; trout biomass at Rock Creek was approximately 2.0 g/m^2 in 2000 and 1.7 g/m^2 in 2001. Estimates of sculpin biomass at Rock Creek were also similar between years.

Average total trout density in the Cedar (0.05 and 0.06 fish/m^2) falls at the extreme low end of the range of trout densities reported in other studies in the Pacific Northwest. Platts and McHenry (1988) estimated that 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. Estimates of cutthroat density in the Chehalis River basin (WA) ranged from 0.22 to 0.23 fish/m^2 (Johnson et al. 1999). 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. Highest trout densities in the Cedar were observed in reaches 5, 6, 9, and 10 (0.07 to 0.12 fish/m^2). The relatively high total densities in reach 5 and 6 may be related to high densities of wood (Rosenfeld et al. 2000, Riley et al. 2001), whereas high densities in reaches 9 and 10 were possibly due to the deep pools created by boulders and bedrock or abundant food.

Densities observed at Rock and Williams Creeks were within the range observed by Platts and McHenry (1988) and Johnson et al. (1999).

There are a number of potential hypotheses explaining low trout abundances in the mainstem and these include (1) lack of woody debris (Riley et al. 2001), which creates structurally complex habitat such as scour pools; (2) predation; (3) low primary and secondary productivity, and (4) some combination of these factors. Over the last two years, we have observed a number of piscivorous birds (mergansers, kingfishers, American dippers, and osprey) along the mainstem Cedar, and these birds are likely consuming fish. The impacts of piscivorous birds on fish populations in the Cedar River are unknown, and deserve further research. The low amount of wood in the mainstem may contribute to high predation rates, as wood provides important cover for stream fishes. The mainstem Cedar River also has low levels of nutrients that can limit algal productivity. Highest concentrations of these nutrients occur in Rock, Williams, and Taylor Creek, while trout densities were highest at Rock and Williams Creek. We used simple linear regression to examine the relationship between trout density and nutrient levels. When we included both mainstem and tributaries sites in this analysis, total trout abundance was positively related to dissolve nitrate levels (r^2=0.76).

3.2.2 Fish age

Examination of scales collected from fish in 2000 showed that observed fork length ranges were age 0+ < 88 mm, 105 = age 1+ < 179 mm, 202 = age 2+ < 260 mm, 249 = age 3+ < 365 mm, and 301 mm = age 4+. The determined age of the fish agreed with fork length ranges used in the snorkel surveys 75% of the time, with each age class agreeing as follows; 92.9% in age 0+, 55.6% in age 1+, 85.7% in age 2+, 33.3% in age 3+, and 66.7% in age 4+.

Although size categories used in the 2000 snorkel survey were not significantly different from size categories developed from scale readings (Table 1), observed fork lengths were based upon a relatively small sample size (*n*=49), and therefore, may not accurately represent the resident salmonid population. Riley et al. (2001) found that there is 405,360 m^2 of habitat accessible to salmonids between the Landsburg diversion dam and Cedar Falls, with average resident salmonid densities of 0.06 fish/m^2. Therefore, 0.2% of the population was sampled to determine the fork length ranges of each salmonid age class. Analysis of scales and otoliths collected from fish in 2001 will provide additional data to identify salmonid age classes and size categories used in snorkel surveys.

3.2.3 Fish diet

Several trends were observed in stomach contents of salmonids. The proportion of Diptera larva in trout stomachs was relatively constant between age 0+ and 2+ (14.4 to 21%), but decreased in 3+ and 4+ fish (6.9 to 7.0%). Presence of Ephemeroptera nymphs in the diet decreased from 23.8 in 0+ to 1.4% in 4+ (Table 2). Relative abundance of Ephemeroptera adults increased from 1.1% for age 0+ fish to 31.8% for 3+ fish, but decreased to 0% in age 4+ salmonids. Trichoptera in trout stomachs increased as fish became larger: larvae (11.6 to 30.6%), pupae (3.3 to 12.5%), and adults (0 to 6.9%) increased from age 0+ to 4+ salmonids. This suggests ontogenetic changes in foraging tactics from drift feeding to epibenthic foraging, as caddisfly larvae are not common in drift (Radar 1999). The energy expenditures and handling time necessary to consume large cased caddisfly larvae may restrict them as prey to larger salmonids. It may also partly depend on the relative abundance of caddisflies. We have observed high densities of the large cased caddisfly *Dicosmoecus* along the mainstem; the high density and large size of these insects potentially make them energetically profitable to large trout. Consumption of terrestrial prey species also increased with age from 4.4 (0+) to 9.7% (4+). Ephemeroptera nymphs (26.4%) and Diptera larvae (22.5%) were the dominant prey items in sculpin stomachs.

The dietary intake of fish usually changes over the course of the fish's lifespan due to morphological changes and age-specific habitat usage or foraging tactics (Grey 2001). Maximum and mean prey size increases with increased salmonid size (Mittelbach and Persson 1998), because larger prey are more energetically favorable than smaller prey (Keeley and Grant 2001) and salmonids grow larger when mean prey size increases (Keeley and Grant 2001).

3.3 Stable isotopes

3.3.1 Carbon

The $\delta^{13}C$ signatures of cedar, maple and salmonberry vegetation were similar across sites (see Table 3 for list of biota collected for stable isotope analysis). Isotope data for alder and western hemlock, two other prevalent species in the watershed, collected from the Olympic peninsula were also used in isotopic comparisons (P. M. Kiffney, unpublished data). Salmonberry, alder, and western hemlock had similar carbon signatures (-32.52, -31.12, and -32.56‰, respectively). The $\delta^{13}C$ for epilithic biofilm or periphyton (complex mixture of algae, bacteria, organic matter that accumulates on rock surfaces) was significantly different among sites ($p<0.001$) (Fig. 12). Mean C concentrations in vegetation ranged from 42.82-48.18% (Table 4). Carbon concentrations for periphyton were only half that of terrestrial vegetation (21% and 45%, respectively; independent sample t-test, $p<0.001$).

Invertebrate carbon signatures differed by species and sites within species. In general, $\delta^{13}C$ values for invertebrates were more similar to periphyton at CR 1 and CR 3, whereas invertebrates from RC, TC, and CR 6 were more similar to terrestrial carbon. Herbivorous mayflies (*Baetis* and Heptageniidae) (Fig. 13) and hydropsychid caddisflies (Fig. 14) had isotope signatures that were site specific ($\delta^{13}C$, $p<0.001$). For example, at CR 1 and CR 3 these groups were consistently enriched in $\delta^{13}C$ (-20 to –25), while herbivorous mayflies and hydropsychids at TC sites and CR 6 grouped between –25 and –30 ‰. The $\delta^{13}C$ signature for the detritivorous stonefly, *Pteronarcys californica*, was also variable among sites (-27.69 to –23.94 ‰, $p=0.019$) (Fig. 15). The relatively wide range in $\delta^{13}C$ for *Pteronarcys* among sites also suggests that this species feeds on detritus with distinct $\delta^{13}C$ signatures. The predaceous stonefly *Hesperoperla pacifica* (Fig. 16) and the filter-feeding caddisfly Hydropsychidae showed similar enrichment patterns across sites for $\delta^{13}C$ (ANOVA and Tukey's HSD, $p<0.001$).

Crayfish (*Pacifastacus* spp.) and snails (*Juga*) were collected from a subset of sites. Crayfish were collected at Rock Creek and CR 1; C isotope values were different between sites ($p=0.005$, Fig. 17). Aquatic snails were only collected at CR 1, and C signatures were distinctly different from other primary consumers. Furthermore, snail $d^{13}C$ signatures did not match well with terrestrial vegetation or periphyton, suggesting snails may have a food source not measured in this study. Snails also had low C content compared to other invertebrates, resulting in high C:N ratios than other invertebrates (Table 4).

Lamprey, sculpins, cutthroat trout, rainbow trout, and trout fry were collected from CR 1, CR 3, and CR 6 on the Cedar River, and TC 2 on Taylor Creek. We collected only a few adult cutthroat trout (1 at CR 1 and 5 at TC 2), with a mean δ^{13}C of -24.60 (SE 0.38) (Table 4). The δ^{13}C signatures for rainbow trout were significantly different between CR 6 and the other two sites, CR 1 and CR 3 ($p<0.001$, ANOVA and Tukey's HSD); rainbow trout from CR 6 were close to –25º/∞, while CR 1 and CR 3 had greater enrichment and were closer to –20º/∞ (Figure 18). As with invertebrates, these data suggest that fish from CR 1 and 3 were more dependent on periphyton carbon, whereas fish from TC and CR 6 relied more on terrestrial carbon.

3.3.2 Nitrogen

The d^{15}N signature for riparian vegetation was similar across sites, but there were differences among plant types, with salmonberry significantly more enriched in d^{15}N than cedar or vine maple. The d^{15}N for periphyton, the other major energy source for streams, differed among sites (Fig. 12). Specifically, periphyton at Rock Creek was more enriched in d^{15}N than other sites.

Salmonberry was also significantly more enriched in total N than other riparian plant species, with periphyton about 1.5 times richer in N than alder or salmonberry, and 2.3 times richer than cedar, vine maple, and western hemlock vegetation. As a result, C:N ratios of periphyton were about three times lower than alder and salmonberry, and six times lower than cedar, vine maple, and western hemlock. If higher N content is an indicator of food quality, than periphyton, followed by alder and salmonberry are more nutritious food resources than conifer needles and vine maple.

The d^{15}N values for invertebrates were relatively similar among mainstem sites, whereas Rock Creek invertebrates were more enriched in d^{15}N than other sites (Fig. 13-17). Mayflies, hydropsychid caddisflies, *H. pacifica*, and *Pacifastacus* were 1-5‰ higher in d^{15}N than similar taxa from mainstem sites. This enrichment could be due to a number of factors, including: (1) invertebrates from Rock feeding at a higher trophic position than other sites; (2) differential utilization of nitrogen in Rock compared to mainstem sites; (3) higher rates of dentritification in Rock, which can contribute to ^{15}N enrichment; (4) higher total N inputs into Rock Creek; or (5) inputs of marine-derived nitrogen via salmon escaping from the Walsh Lake diversion.

Adult rainbow trout from CR 1 and CR 3 had higher d ^{15}N than fry, and higher than adult trout from CR 6 (Fig. 18). In addition, fry from TC were less enriched in d ^{15}N than fry from other sites suggesting a greater dependence upon terrestrially derived organic matter (has a lower d ^{15}N than periphyton).

3.3.3 Trophic structure

The δ^{13}C isotope signature of organisms from CR 1 (Figure 19) and CR 3 (Figure 20) were more similar to periphyton than leaf litter, suggesting periphyton is the main energy source for food webs at these sites. The δ^{13}C signal of invertebrates and fish at CR 6 was shifted more to the left than CR 1 and 3 supporting the notion that this food web also relied upon terrestrial carbon in addition to periphyton. Although riparian trees along mainstem are large (~30-40 m tall), the channel is wide (20-30 m wetted width) and open; therefore, it receives more sunlight relative than the small (~4 to 10 m), heavily shaded tributary streams such as Rock and Taylor Creeks. The δ^{13}C signatures of invertebrates and fish from TC (Fig. 22) and RC (Fig. 23) supports the idea that these heavily shaded streams rely more on terrestrial carbon than mainstem sites.

The d ^{15}N value can suggest trophic position within the food web: higher d ^{15}N values indicate a higher trophic position. Our data suggests that adult trout were the primary predators in the mainstem followed by trout fry, sculpins, and crayfish (Fig. 19-21, Table 5). Intermediate invertebrate predators included the stonefly *H. pacifica* and the filter-feeding caddisfly *A. grandis*. As this species grows, it likely increases the consumption of insects captured in their nets. At the base of the food web were herbivorous mayflies, which supported both the invertebrate and vertebrate predators. Our analysis of stomach contents suggests that chironomid larva and mayfly nymphs were the dominant food items of trout, especially young trout, and sculpins.

The N isotope content of fish increases with biomass, which suggests that fish become piscivorous at larger sizes. Therefore, fish biomass and N isotope content were compared as previous research has suggested a relationship between δ^{15}N enrichment and biomass (Cabana and Rasmussen 1996). Across all sites, trout biomass ranged from 2.3 to 774 g. Using simple linear regression, we observed a positive relationship between δ^{15}N and trout biomass (r^2= 0.67); this trend supports the hypothesis that trout assume a higher trophic position (i.e., become more piscivorous), as they grow. No relationship was found between biomass and δ^{15}N in sculpins (r^2=0.14).

3.3.5 Mixing models

Stable isotope analysis is used frequently to determine the relative contributions of different food sources to an animal's diet (Hobson 1999). Isotopic ratios for animal tissues and each of its potential food sources provide an idea of their relative importance in the diet. To do this with the Cedar River food web, we used a concentration corrected, two-end member, mixing model to determine the relative contribution of terrestrial versus in-stream primary production to secondary consumers (Phillips and Koch 2002). The mean C concentration from all terrestrial vegetation (45.07%) and periphyton (21.08%) were used to correct a standard two-end member mixing model using $\delta^{13}C$ isotope signatures across all sites. Trophic fractionations from C_{source} (primary producer) to secondary consumers were used as listed in Table 6. Trophic fractionations for periphyton were calculated for each site based on periphyton $\delta^{13}C$ signatures and herbivorous mayflies C enrichment plus one trophic fractionation (mean across sites: 3.5‰). Mass balance equations incorporating concentration were used as follows:

$$0=[C]_x*f_{x,c}\,(\delta^{13}C_x-\delta^{13}C_m)+[C]_y*f_{y,c}\,(\delta^{13}C_y-\delta^{13}C_m)$$

$$1=f_{x,c}+f_{y,c}$$

$[C]_x$ and $[C]_y$ refer to the concentration of C in each C source (terrestrial vegetation or periphyton) while $f_{x,c}$ and $f_{y,c}$ represent the fractions of assimilated biomass from respective sources (X and Y). $\delta^{13}C_m$ is the observed C signature of the secondary consumer of interest. $\delta^{13}C_x$ and $\delta^{13}C_y$ are the C signatures of each respective C base and were corrected for trophic position according to Table 6. The mixing model was only used with secondary consumers due to high variability in algal primary production among sites for primary producer and primary consumer trophic levels.

The importance of terrestrial vegetation (% C source) ranged from 15 to 57% for trout fry and sculpins. Periphyton comprised about 76% of the C source for fry at CR 1 and 43% at TC 2 (Table 7). The C source for sculpins was predominantly periphyton across all sites (67-84%). However, terrestrial vegetation was relatively more important as a food base for sculpins at TC 2 than at CR 1 and CR 3. These results suggest that trout and sculpins at the more open mainstem sites received more of their energy from autochthonous organic matter, as did sculpins from Taylor Creek. In contrast, energy demands of trout from Taylor Creek were met by approximately equal contributions from riparian vegetation and algal organic matter.

Previous studies have also concluded that energy sources of smaller, headwater streams and lakes are often derived from riparian vegetation (Finlay 1999, Post 2002). Low levels of sunlight and high canopy cover likely inhibit primary production in Rock and Taylor Creeks, increasing the relative importance of terrestrial vegetation as a C source for these streams compared to mainstem sites. In contrast, food webs of large rivers with lower levels of canopy cover and higher levels of sunlight are driven by in-stream primary production from macrophytes and algae (autochthonous energy sources) (Allan 1995).

The stable isotope data provide a powerful tool to assess the relative importance of salmon-derived nutrients to the Cedar River food web after the Landsburg fish ladder is installed and anadromous salmonids colonize the upper Cedar River. The utility of these data as a means to determine the influence of salmon on Cedar River food webs is shown in the comparison of $d^{15}N$ values between Cedar River sites and streams accessible to anadromous salmonids (data from Bilby et al. 1996, Table 5). The $d^{15}N$

signatures for terrestrial and aquatic organisms are much higher in salmon-streams compared to Cedar River sites. For example, the d^{15}N for periphyton is approximately seven times higher in salmon-streams compared to d^{15}N for periphyton averaged across all Cedar River sites. The high within site precision of stable isotopic data will allow us to detect relatively small increases in stable isotope values at these sites; however, to maximize the statistical power of these data, we recommend that samples be collected in September/October and from the same locations as were used in 2000 and 2001.

Not only will introduced salmon influence the stable isotope values of the Cedar River food web, they may impact food web structure via competition with or predation on resident fishes. For example, salmon fry might compete with trout fry for positions within a habitat or for drifting insects causing trout fry to shift their habitat and diet preferences. These shifts in food web structure due to behavioral interactions may also affect stable isotope values of stream food webs. We speculate, however, that these shifts will have less an affect on isotope values compared to inputs of salmon-derived nitrogen.

4.0 Predicting impacts of salmon carcasses on the Cedar River

The river is large (20-30 m) and anadromous fish will have access to approximately 27 km of river habitat. The mainstem Cedar River has an open canopy and the food web is fueled by primary production. Based on these characteristics, we can make the following qualitative predictions regarding the impacts of anadromous fish on the Cedar River ecosystem:

(1) The influx of salmon-derived nutrients (SDN) will boost productivity of the mainstem food web via an increase in the amount of phosphorus; the low levels of dissolved P compared to relatively high dissolved nitrate suggests

that the Cedar River is primarily P limited. This increase in P inputs will likely lead to an increase in primary and secondary productivity via leaching of P from carcasses and direct consumption of carcasses and eggs by primary and secondary consumers;

(2) Increased input of SDN will also boost ecosystem productivity of Taylor, Williams, and Rock Creeks, but because these systems are primarily fueled by energy from terrestrial vegetation, this increase will likely be due to direct consumption of carcasses and increased bacterial production;

(3) Because within site variability in $d^{15}N$ was low, we suggest that measuring the isotopes of C and N provide a sensitive tool for detecting inputs of SDN to the Cedar River food web. Isotopes may also be used to track the saturation of the food web by SDN (Bilby et al. 2001).

(4) The mainstem is wide and open to sunlight. Moreover, its' surface water contains low dissolved nutrient levels; therefore, we speculate that N, P, and C leached from carcasses will be immediately utilized by heterotrophic organisms and primary producers or adsorbed onto stream sediments predominantly within the immediate area of the carcass (Bilby et al. 1996). Furthermore, because fish are a highly nutritious food resource for scavengers, such as bears (e.g., Hilderbrand et al. 1999), we predict that carcasses will be removed from the stream to the surrounding riparian zone. Removal of salmon from the mainstem by scavengers will limit direct input of nutrients from carcasses into water. Experiments planned for this summer or next, will

directly test the effects of different carcass loadings on surface water chemistry.

5.0 Current activities

This summer we measured physical habitat, water chemistry, periphyton biomass, and fish abundance along four 800-m reaches on the mainstem around Rock, Taylor, Williams, and Steele Creeks. In addition, we surveyed 200-m reaches of each tributary. In the habitat surveys, we measured the following about every 40-m: substrate composition using pebble counts; thalweg depth; velocity profile; wetted and bankfull width; canopy cover; fish cover; gradient; and azimuth. Every 8 meters we measured thalweg depth and wetted and bankfull width. Woody debris was counted along the entire reach. After the habitat surveys, the study reaches were snorkeled and fish were identified and counted. Trout were placed into one of four size categories: juveniles (<60 mm); 1+ (≥61 mm and ≤ 120); 2+ (≥121 mm and ≤ 200 mm); and adult (≥ 200 mm). We also collected rocks every 40-m within each 800-m reach to measure periphyton biomass. These data will add to our baseline information on the ecological condition of the Cedar River watershed before arrival of anadromous salmon.

This summer we also surveyed potential locations for an experimental stream facility where the effects of nutrient enrichment will be tested on Cedar River food webs, as per Task B of our contract with SPU. We have tentatively located a site on the upper Taylor Creek watershed. Currently, we are investigating permits needed before installation can proceed.

6.0 Future research

We suggest that monitoring of water chemistry and fish communities continue on a reduced basis. The long-term monitoring of water chemistry will provide data that managers, regulators, and the public can use to gauge the impacts of adult salmon on water quality. Continued monitoring of fish populations will provide insights into how resident fish are affected by colonization of a novel species, as Pacific salmon have been isolated from resident populations for over 90 years. Such re-introduction of Pacific salmon will occur in other areas where access to habitat is made available due to restoration efforts (e.g., Elwha Dam). To monitor fish populations, we recommend that electroshocking be used on Rock and Williams Creek and snorkel surveys on the mainstem and Taylor Creek (Riley et al. 2001, and unpublished data). The exact nature of the survey design should be discussed this fall/winter between SPU and NMFS.

Although time consuming, we recommend that spawning surveys begin after installation of the ladder. We suggest that a two-stage (reach, habitat type) random sampling design can be used to select survey sites. Specifically, each year we could randomly select from a subset of habitat reaches (e.g., reach one of the mainstem) and units (e.g., pool) determined in 2000 for the mainstem, Rock, and Williams Creek. This approach could limit the amount of time spent on spawning surveys. This study provides a unique opportunity to determine habitat selection by adults, and will provide critical data on where adults of a variety of species spawn and how long it takes for anadromous fish to colonize the Cedar and how this differs by species.

We recommend the continued collection of biological tissues from the Cedar River, Rock, and Taylor Creeks plus initiate collection of samples from Williams Creek for analysis of ^{13}C and ^{15}N stable isotopes. This component of the study provides data that have low within site variability; therefore, we predict that this technique will require less sampling effort to detect the ecological effects of Pacific salmon on the watershed compared to other measures. To complement our stable isotope study, we suggest sampling three additional aspects of the Cedar River food web to improve our understanding of trophic linkages within the watershed and how these linkages will be affected by influx of Pacific salmon: 1) isolating algal communities from periphyton to better understand the isotopic signature of baseline food sources; 2) collection of *Dicosmoecus* caddisflies (they had already emerged by the time we were sampling in September and October), which are the dominant component of stomach contents of adult trout collected in 2000 and 2001; and (3) collection of tissues from locations downstream of Landsburg that are used by Pacific salmon. Measuring C and N isotopes in food webs accessible to Pacific salmon will allow us to predict how C and N isotope values might change above Landsburg after colonization by salmon.

7.0 Future environmental issues

The Cedar River watershed is a relatively pristine location within a rapidly growing urban area. One of the most pressing environmental issues facing the PNW and the west coast of the United States within the next 5-10 years is the deposition of contaminants into watersheds due to automobile emissions and long distance transport of atmospheric pollutants from Asia. Of critical concern are inputs of nitrogen compounds that can lead to acidification of surface waters. The Cedar River has low alkalinity and levels of dissolved ions, both of which are essential for buffering against compounds that can lower the pH of water (i.e., acidification). In addition, some sites (Rock Creek) have relatively high levels of dissolved nitrate. Based on these chemical characteristics, we suggest that the upper Cedar River watershed may be particularly susceptible to acidification; therefore, we recommend long-term monitoring of precipitation and surface water chemistry. This program will allow for the early detection of changes in surface water chemistry due to atmospheric deposition.

8.0 Acknowledgements

Seattle Public Utilities, the National Marine Fisheries Service, and the Center for Streamside Studies at the University of Washington provided funding for this research. The staff of the Cedar River provided logistical support, especially Jim Erckmann, Dwayne Paige, Bill Belknap, and David Chapin. David Chapin provided comments on an earlier draft of this report. A number of people helped in the field over the past two years and we thank them. If anyone was omitted from this acknowledgement, we apologize. Thanks to Carrie Inman, Stephen Riley, Amy Robinson, Heidy Peterson, Eric Buhle, Lisa Holsinger, Bill Belknap, David Chapin, Cara Campbell, Ashley Steel, Bill Richards, Tamara Harms, Martin Liermann, Rod O'Conner, George Pess, Tim Beechie, Sarah Morley, Blake Feist, Beth Sanderson, William Reichart, Juliet Fabri, Amy Gilbert, Chris Konrad, Mary Ruckelshaus, Janis Hill, Cory Ruedebusch, and Paul McElhany.

9.0 References cited

Allan, J. D. 1995. Stream Ecology: structure and function of running waters. Chapman and Hall: New York.

Beamish, R.J., and G.A. McFarlane (1983). The forgotten requirement of age validation in fisheries biology. Transactions of the American Fisheries Society. 112(6): 735-743.

Beechie, T. and T. Sibley. 1997. Relationships between channel characteristics, woody debris, and fish habitat in northwestern Washington streams. Transactions of the American Fisheries Society 126: 217-229.

Bilby, R. E. B. R. Fransen, and P. A. Bisson. 1996. Incorporation of nitrogen and carbon from spawning coho salmon into the trophic system of small streams: evidence from stable isotopes. Canadian Journal of Fisheries and Aquatic Sciences 53: 164-173.

Burns, J.W. 1971. The carrying capacity for juvenile salmonids in some northern California streams. California Fish and Game 57: 44-57.

Cabana, G. and J.B. Rasmussen. 1996. Comparison of aquatic food chains using nitrogen isotopes. Proceedings of the National Academy of Science 93:10844-10847.

Carlander, K.D. (1985). Sampling problems in deriving a body-scale regression for growth calculation from fish scales. International Association of Theoretical and Applied Limnology 22(4): 2534-2536.

Doucett, R.R., G. Power, D.R. Barton, R.J. Drimmie, and R.A. Cunjak. 1996. Stable isotope analysis of nutrient pathways leading to Atlantic salmon. Canadian Journal of Fisheries and Aquatic Sciences 53:2058-2066.

Dunne, T. and Leopold, L. B., 1978, Water in Environmental Planning, Freeman, San Francisco, 818 p.

France, R.L. 1995. Differentiation between littoral and pelagic food webs in lakes using carbon isotopes. Limnology and Oceanography 40:1310-1313.

Fry, B. 1991. Stable isotope diagrams of freshwater food webs. Ecology 72:2293-2297.

Grey, J. (2001). Ontogeny and dietary specialization in brown trout (*Salmo trutta* L.) from Loch Ness, Scotland, examined using stable isotopes of carbon and nitrogen. Ecology of Freshwater Fish. 10(3): 168-176.

Harmon, M. E. et al. 1986. Ecology of coarse woody debris in temperate ecosystems. Advances in ecological research 15:133-302.

Hartman, G.F., and C.A. Gill. 1968. Distributions of juvenile steelhead and cutthroat trout (*Salmo gairdneri and S. clarki clarki*) within streams in southwestern British Columbia. Journal of the Fisheries Research Board of Canada 25: 33-48.

Hilderbrand, G. V., C. C. Schwartz, C. T. Robbins, M. E. Jacoby, T. A. Hanley, S. M. Arthur, and C. Servheen. 1999. The importance of meat, particularly salmon, to body size, population productivity, and conservation of North American brown bears. Canadian Journal of Zoology 77:132-138.

Hining, K.J., J.L. West, M.A. Kulp, and A.D. Neubauer. (2000). Validation of scales and otiliths for estimating age of rainbow trout from southern Appalachian streams. North American Journal of Fisheries Management. 20: 978-985.

Johnson, O. W., M. H. Ruckelshaus, W. S. Grant, F. W. Wakintz, A, M. Garrett, G. J. Bryant, K. Neely, and J. J. Hard. 1999. Status review of coastal cutthroat trout from Washington, Oregon, and California. NOAA Technical Memorandum NMFS-NWFSC-37.

Keeley, E.R., and J.W.A. Grant. (2001). Prey size of salmonid fishes in streams, lakes, and oceans. Canadian Journal of Fisheries and Aquatic Sciences 58(6): 1122-1132.

Kline, T.C., Jr. J.J. Goering, O.A. Mathisen, P.H. Poe, and P.L. Parker. 1990. Recycling of elements transported upstream by runs of Pacific salmon: I. δ^{15}N and δ^{13}C evidence in Sashin Creek, southeastern Alaska. Canadian Journal of Fisheries and Aquatic Sciences 47:136-144.

Kline, T.C., Jr. J.J. Goering, O.A. Mathisen, P.H. Poe, P.L. Parker, and R.S. Scanlan. 1994. Recycling of elements transported upstream by runs of Pacific salmon: II. δ^{15}N and δ^{13}C evidence in the Kvichak River watershed, Bristol Bay, southwestern Alaska. Canadian Journal of Fisheries and Aquatic Sciences 50: 2350-2365.

LaZerte, B.D. and J.E. Szaldos. 1982. Stable isotope ratio of submerged freshwater macrophytes. Limnology and Oceanography 27:413-418.

MacLeod, N.A., and D.R. Barton. 1998. Effects of light intensity, water velocity, and species composition on carbon and nitrogen stable isotope ratios in periphyton. Canadian Journal of Fisheries and Aquatic Sciences 55:1919-1925.

Merritt, R. W. and K. W. Cummins. 1996. An introduction to the aquatic insects of North America. Kendall/Hunt, Dubuque, Iowa.

Minagawa, and M.E. Wada. 1984. Stepwise enrichment of 15N along food chains: Further evidence and the relation between δ15N and animal age. Geochimica Cosmochimica Acta 48:1135-1140.

Mittelbach, G.C., and L. Persson. (1998). The ontogeny of piscivory and its ecological consequences. Canadian Journal of Fisheries and Aquatic Sciences 55(6): 1454-1465.

Meyer, J. L., J. B. Wallace, and S. L. Eggert. 1998. Leaf litter as a source of dissolved organic carbon in streams. Ecosystems 1: 240-249.

Murphy, M. L., J. Heifetz, S. W. Johnson, K. V. Koski, and J. F. Thedinga. 1986. Effects of clear-cut logging with and without buffer strips on juvenile salmonids in an Alaskan stream. Canadian Journal of Fisheries and Aquatic Sciences 43:1521-1533.

Naiman, R. J., C. A. Johnston, and J. C. Kelley. 1988. Alteration of North American streams by beaver. Bioscience 38: 753-672.

Naiman, R. J., G. Pinay, C. A. Johnston, and J. Pastor. 1994. Beaver influences on the long-term characteristics of boreal forest drainage networks. Ecology 75:905-921.

Natural Research Council. 1996. Upstream: Salmon and the society of the Pacific Northwest. 441 pp.

Osmond, C.B. N. Valaane, S.M. Halam, P. Uotila, and Z. Roksandic. 1981. Comparisons of δ13C values in leaves of aquatic macrophytes from different habitats in Britain and Finland: some implications for photosynthetic processes in aquatic plants. Oecologia (Berlin) 50:117-124.

Peterson, B.J. 1999. Stable isotopes as tracers of organic matter input and transfer in benthic food webs: A review. Acta Oecologia 20:479-487.

Philips, D.L. and P.L. Koch. 2002. Incorporating concentration dependence instable isotope mixing models. Oecologia 130:114-125.

Platts, W.S., and M.L. McHenry. 1988. Density and biomass of trout and char in western streams. Gen. Tech. Rep. INT-241. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 17 p.

Post, D.M. 2002. Using stable isotopes to estimate trophic position: models, methods, and assumptions. Ecology 83:703-718.

Radar, R. B.1999. A functional classification of the drift: traits that influence invertebrate availability to salmonids. Canadian Journal of Fisheries and Aquatic Sciences 54:1211-1234.

Riley, S.R., P.M. Kiffney, and C. Inman. (2001). Cedar river habitat inventory and salmonid stock assessment. Report, National Marine Fisheries Service, Environmental Conservation and Conservation Biology Divisions. Seattle, WA, 78 pages.

Rosenfeld, J. M. Porter, and E. Parkinson. 2000. Habitat factors affecting the abundance and distribution of juvenile cutthroat trout (*Oncorhynchus clarki*) and coho salmon (*Oncorhynchus kisutch*). Canadian Journal of Fisheries and Aquatic Sciences 57: 766-774.

Smith, P.J. (1987). Maximum likelihood estimation of the distribution of length at age. Biometrics. 43(3): 601-615.

Thurow, R.F. (1994). Underwater methods for study of salmonids in the intermountain west. Report, United States Forest Service, Intermountain Research Unit. Ogden, UT, 28 pages.

Volk, C. J., P. M. Kiffney, and R. L. Edmonds. (*in press*). Role of riparian red alder (*Alnus rubra*) on the nutrient dynamics of coastal stream of the Olympic Peninsula, WA, USA. Transactions of the American Fisheries Society.

Wachniew, P. and K Rozanski. 1997. Carbon budget of a mid-latitude, groundwater-controlled lake: isotopic evidence for the importance of dissolved inorganic carbon recycling. Geochimica Cosomchimica Acta 61:2453-2465.

Walton, S. P., E. B. Welch, and R. R. Horner. 1995. Stream periphyton response to grazing and changes in phosphorus concentration. Hydrobiologia 302:31-46.

Welch, E., J. Jacoby, and C. May. Stream quality. pages 69-85 *in* R. Naiman and R. Bilby (editors). River ecology and management: lessons from the Pacific coastal ecoregion. Springer, New York.

Wigington, P. J., M. R. Church, T. C. Strickland, K. N. Eshleman, and J. Van Sickle. 1998. Autumn chemistry of Oregon Coast Range streams. Journal of the American Water Resources Association 34: 1035-1049.

Willson, M. F., S. M. Gende, and B. Marston. 1998. Fishes and the forest: expanding perspectives on fish-wildlife interactions. Bioscience 48: 455-462.

Zar, J.H. (1984). Biostatistical Analysis. Englewood Cliffs, New Jersey. Prentice Hall.

Table 1. Two-tailed *t*-test of the hypothesized fork length (FL) ranges (mm) for the different salmonid size classes.

Age Class	H_o FL Range (mm)	H_o Mean FL (mm)	Sample Set Mean FL (mm)	Sample Set FL SE (mm)	n – 1	t	$t_{a(2)}$
0+	FL < 80	–	75.0	13	20	–	–
1+	80 = FL < 120	100	142	37	7	1.05	0.50 = $t_{a(2)}$ < 0.20
2+	120 = FL < 200	160	231	29	10	1.26	0.50 = $t_{a(2)}$ < 0.20
3+	200 = FL	–	307	58	5	–	–
4+	NA	–	335	34	2	–	–

Table 2. Average percent of each prey taxon present in gut samples of rainbow and cutthroat trout, and sculpins. Each fish was placed into an age class according to adjusted fork lengths from Table 1.

Prey	0+ trout (n=43)	1+ trout (n=41)	2+ trout (n=22)	3+ trout (n=14)	4 + trout (n=6)	Sculpin (n=51)
Chironomidae	0.6		0.2		6.9	1.6
Other Diptera						
Larvae	14.4	21.0	14.8	7.0	6.9	22.5
Pupae	0.6			0.8		
Adult	2.2	2.2	4.8	8.9	1.4	
Coleoptera	2.2	1.0	0.7	1.4	1.4	1.6
Ephemeroptera						
Nymph	24.4	8.6	4.3	2.3	1.4	26.4
Adult	1.1	12.7	13.0	31.8		0.8
Plecoptera						
Nymph	7.7	7.7	3.5	46	5.6	17.8
Adult		0.3	0.9	0.6	1.4	
Trichoptera						
Larvae	11.6	20.4	20.0	16.8	30.6	14.0

Pupae	3.3	2.9	7.4	7.0	12.5	
Adult		1.0	0.4	1.1	6.9	
Miscellaneous						
Bivalves				0.3		
Gastropoda	12.2	1.0	9.3	0.6	1.4	3.1
Decapoda			0.4	0.8		
Oligoechaete	0.6	6.7	10.9	2.2	1.4	2.3
Fish		0.6	0.2	0.3	2.8	0.8
Hymenoptera	0.6	1.3	2.0	0.8	1.4	
Unidentified terrestrial	5.0	4.5	4.8	8.7	9.7	
Unknown	13.3	8.3	2.2	3.6	8.3	10.1

Table 3. Samples collected for $^{15}N/^{14}N$ and $^{13}C/^{12}C$ analysis. FFG=functional-feeding groups and includes FF=filter feeder, G=grazer, PR=predator, SH=shredder, and CG=collector-gatherer (based on Merritt and Cummins 1996).

	FFG	Food source	Collection location
Western red cedar (*Thuja plicata*)			CR 1, CR 3, CR 6, ROCK, TC 1, TC 2
Vine maple (*Acer circinatum*)			CR 1, CR 3, CR 6, ROCK, TC 1, TC 2
Salmonberry (*Rubus spectabilis*)			CR 1, CR 3, CR 6, ROCK, TC 1, TC 2
Periphyton			CR 1, CR 3, CR 6, ROCK, TC 1, TC 2
Hydropsychidae (Trichoptera)	FF	Suspended organic matter (algae, detritus, and insects)	CR 1, CR 3, CR 6, ROCK, TC 1, TC 2
Baetis sp. and Heptageniidae (Ephemeroptera)	G, CG	periphyton	CR 1, CR 3, CR 6, ROCK, TC 1, TC 2
Pteronarcys californica (Plecoptera)	SH	detritus	CR 1, CR 3, CR 6, TC 1, TC 2

Juga (Gastropoda)	CG,G	periphyton	CR 1
Hesperoperla pacifica (Plecoptera)	PR	insect larvae	CR 1, CR 3, CR 6, ROCK, TC 1, TC 2
Pacifastacus spp. (Decapoda)	CG,PR	snails, algae, insect larvae, worms, and tadpoles	CR 1, ROCK
Cutthroat trout (*Oncorhynchus clarki clarki*)	PR	insect larvae and adults, crayfish, snails, fish	CR1, TC2
Rainbow trout (RBT) (*Oncorhynchus mykiss*)	PR	Insect larvae and adults, crayfish, snails, fish	CR1, CR3, CR6
Salmonid fry	PR	Insect larvae and adults	CR1, CR6, TC2
Lamprey ammocoetes		detritivores	CR3, CR6
Sculpin sp. Riffle (*Cottus gulosus*) Torrent (*Cottus rhotheus*)	PR	small crustaceans, aquatic insect larvae, and snails	CR1, CR3, CR6, TC2

Table 4. Mean (1se) C and N content of vegetation, invertebrates, and vertebrates.

	%C	%N	C:N
Alder*	48.28 (0.20)	2.37 (0.09)	20.37
Cedar	48.18 (0.67)	1.24 (0.06)	38.85
Maple	44.21 (0.27)	1.79 (0.10)	24.69
Salmonberry	42.82 (0.63)	2.20 (0.09)	19.46
W. hemlock*	50.56 (0.12)	0.77 (0.03)	65.66
Periphyton	21.08 (1.07)	3.48 (0.17)	6.06
Herbivorous mayflies	44.06 (0.68)	10.30 (0.20)	4.28
Hydropsychidae	45.24 (0.42)	10.68 (0.15)	4.24
H. pacifica	46.14 (0.23)	11.23 (0.11)	4.11
P. californica	46.47 (0.56)	9.65 (0.42)	4.82
Pacifastacus	31.61 (0.86)	7.02 (0.34)	4.50
Juga	20.51 (1.82)	3.04 (0.40)	6.75
Cutthroat trout	45.84 (0.80)	13.14 (0.42)	3.49
Salmon fry	45.36 (0.23)	12.83 (0.08)	3.54
Rainbow trout	44.89 (0.22)	13.53 (0.08)	3.32
Sculpin	45.09 (0.16)	13.19 (0.06)	3.42
Lamprey	48.49 (2.83)	8.56 (1.33)	5.66

*Data from unpublished study on the Olympic peninsula (Volk et al. *In press*).

Table 5. Mean (1se) $d^{13}C$ and $d^{15}N$ averaged across Cedar River mainstem and tributary sites. We also present $d^{15}N$ from a salmon-stream (Bilby et al. 1996) for comparison.

	$d^{13}C$	$d^{15}N$	$d^{15}N$ for salmon-stream[1]
Alder*	-30.9 (0.17)	-1.96 (0.21)	
Cedar	-28.15 (0.23)	-3.51 (0.19)	
Maple	-29.77 (0.27)	-3.90 (0.23)	
Salmonberry	-32.52 (0.21)	-1.60 (0.36)	
W. hemlock*	-31.12 (0.27)	-4.55 (0.21)	
Terrestrial vegetation			0.7 (1.4)
Stream detritus	-26.2	0.2	
Periphyton	-25.55 (0.49)	-0.69 (0.25)	7.1 (1.6)
Herbivorous mayflies	-26.62 (1.20)	-0.42 (0.49)	8 (1.4)
Hydropsychidae	-25.23 (0.62)	1.49 (0.39)	
H. pacifica	-25.09 (0.51)	1.56 (0.33)	7.9 (1.0)[1]
P. californica	-25.68 (0.45)	0.26 (0.15)	4.3 (1.9)[2]
Pacifastacus	-22.60 (1.07)	3.52 (0.44)	
Juga	-16.17 (0.97)	0.66 (0.14)	
Trout fry (< 80 mm)	-21.98 (0.61)	4.2 (0.12)	10.0 (1.6)
Cutthroat trout (> 80 mm)	-24.60 (0.32)	4.4 (0.38)	10.8 (2.2)

Rainbow trout (> 80 mm)	23.1 (0.31)	4.89 (0.16)		
Sculpin	-23.32 (0.26)	3.02 (0.20)		10.4 (0.2)
Lamprey ammocoetes	-24.14 (0.1)	0.28 (0.15)		6.4 (1.4)

*From Olympic peninsula study (Kiffney et al. unpublished data).

[1] Data from Bilby et al. (1996); values equal means (1 standard deviation).

[2] Data from “Predator” category in Bilby et al. (1996).

[3] Data from “Shredder” category in Bilby et al. (1996).

Table 6. Trophic fractionations for mixing model calculations.

Trophic fractionations	1° fraction	2° fraction	Total
Terrestrial (δ13Cx)	---	---	3.3*
Periphyton (δ13Cy)	0.47	3.5	3.97

*from Hildebrand et al. (1996)

Table 7. Relative contribution of terrestrial and in-stream organic matter to secondary consumers, as calculated from a two-end member-mixing model.

	% Terrestrial	% Periphyton
Salmonid fry		
TC 2	57	43
CR 1	24	76
Rainbow trout		
CR 1	15	85
CR 3	36	66
Cutthroat trout		
TC 2	45	55
Sculpins		
TC 2	33	67
CR 1	16	84
CR 3	21	79

10.0 Figure legend

Figure 1. Mean (1SD) annual values averaged across months at mainstem and tributary stations for a) alkalinity, b) conductivity, c) turbidity, d) soluble reactive phosphorus, e) total phosphorus (particulate and dissolved inorganic+organic), and f) total organic carbon.

Figure 2. Mean (1SD) annual values averaged across months at mainstem and tributary stations for a) dissolved nitrate-N and b) total nitrogen (particulate and dissolved inorganic+organic). See Figure 1 for further details.

Figure 3. Mean (1sd) annual values for water quality constituents (see Figure 1 for description) at Fish Creek, mainstem (Main), and tributary sites. Mainstem and tributary values were based on averaging monthly values across all mainstem (CR) and tributary (WC, TC, RC, SC) sites. Fish Creek values were also averaged across months.

Figure 4. Mean (1sd) annual values for water quality constituents for a) dissolved nitrate-N and b) total nitrogen. See Figure 3 for further details.

Figure 5. Mean (1sd) density of different size classes of salmonids (primarily rainbow) and total density in each reach of the mainstem Cedar. All density estimates were based on snorkel surveys.

Figure 6. Mean (1sd) density of different size classes of salmonids (primarily rainbow) and total density in each habitat type averaged across reaches in the mainstem Cedar. C=cascade, F=flatwater, R=riffle, P=pool, and SP=step-pool. All density estimates were based on snorkel surveys.

Figure 7. Mean (1sd) density of different size classes of trout (primarily cutthroat trout) in different habitat types averaged across reaches 1 and 2 at Rock Creek.

Figure 8. Mean (1sd) density of different size classes of trout (primarily cutthroat trout) in different habitat types at Williams Creek.

Figure 9. Mean (1sd) density of different size classes of trout (primarily cutthroat trout) in different habitat types at Taylor Creek.

Figure 10. Mean (1sd) density of different size classes of trout (cutthroat and rainbow) averaged across habitat types and reaches at the Cedar River (CR), Rock Creek (RC), Taylor Creek (TC) and Williams Creek (WC). Density estimates at CR and TC were based on snorkel surveys, whereas estimates from RC and WC are based on electroshocking surveys.

Figure 11. Biomass (g/m^2) of trout and sculpin averaged across reaches and habitat types at TC, RC, CR, and WC in 2000 and 2001. Estimates of fish biomass at TC and CR are likely underestimates, as they are based on electroshocking and not snorkel surveys (Riley et al. 2001).

Figure 12. Mean (1se) d^{13}C and d^{15}N for periphyton collected from Cedar River (CR 1, CR 3, CR 6), Taylor and Rock Creek during September and October 2000.

Figure 13. Mean (1se) d^{13}C and d^{15}N for herbivorous mayflies (baetid and heptageniid mayflies were combined) collected from Cedar River (CR 1, CR 3, CR 6), Taylor and Rock Creek during September and October 2000.

Figure 14. Mean (1se) d^{13}C and d^{15}N for the filter-feeding caddisfly Hydropsychidae collected from Cedar River (CR 1, CR 3, CR 6), Taylor and Rock Creek during September and October 2000.

Figure 15. Mean (1se) d^{13}C and d^{15}N for the shredding stonefly *Pteronarcys californica* collected from Cedar River (CR 1, CR 3, CR 6), and Taylor Creek during September and October 2000.

Figure 16. Mean (1se) d^{13}C and d^{15}N for the predaceous stonefly *Hesperoperla pacifica* collected from Cedar River (CR 1, CR 3, CR 6), Taylor and Rock Creek during September and October 2000.

Figure 17. Mean (1se) d^{13}C and d^{15}N for the omnivorous crayfish *Pacifastacus* spp. collected from Cedar River (CR 1) and Rock Creek during September and October 2000.

Figure 18. Mean (1se) d^{13}C and d^{15}N for rainbow and cutthroat trout collected from Cedar River (CR 1, CR 3, CR 6) and Taylor Creek during September and October 2000.

Figure 19. Mean (1se) d^{13}C and d^{15}N for the food web collected from CR 1 during September and October 2000.

Figure 20. Mean (1se) d^{13}C and d^{15}N for the food web collected from CR 3 during September and October 2000.

Figure 21. Mean (1se) d^{13}C and d^{15}N for the food web collected from CR 6 during September and October 2000.

Figure 22. Mean (1se) d^{13}C and d^{15}N for the food web collected from Taylor Creek during September and October 2000.

Figure 23. Mean (1se) d^{13}C and d^{15}N for the food web collected from Rock Creek during September and October 2000.

11.0 Appendices

Appendix 1. List of reaches for Rock and Williams Creek, and their approximate locations and habitat features.

Rock Creek	1	junction with Cedar to ~ 600 m upstream	pool/riffle
	2	~ extends 400 m upstream of reach 1	high gradient pool/riffle
	3	extends from reach 2 to road 40 and 41 intersection	pool/riffle
	4	upstream of 40/41 to 200 m upstream of road 16 crossing	beaver complex
	5	200 m upstream of road 16 crossing to 800 m upstream of road 10 crossing	high gradient; pool/riffle
	6	800 m upstream of road 10 to 600 m upstream of Kerriston Road	high gradient; riffle/cascade
Williams Creek	1	junction with mainstem Cedar to 500 m upstream	high gradient; cascade/riffle
	2	extends 600 m upstream of reach 2	low gradient; pool/riffle
	3	extends 1200 m upstream of reach 2 to headwater tributaries	high gradient; cascades/riffles

Appendix 2. List of reaches for the Cedar River, and their approximate locations and habitat features.

Reach	Location	Features
1	100 m upstream of boardwalk to RM 24.5	pool-riffle
2	RM 24.5 to RM 26	high gradient pool/riffle
3	RM 26 to 27.6	boulders; riffle/step-pool
4	RM 27.6 to RM 28.3	pool riffle
5	RM 28.3 to RM 29	boulders; step-pool/flatwater
6	RM 29 to RM 30	boulders; high gradient riffles/step-pools
7	RM 30 to RM 31.3	boulders; flatwater/pools/riffles
8	RM 31.3 to 33.5	flatwater/riffles
9	RM 33.5 to sub-station	confined channel; cascade
10	End of canyon reach to falls	Mix of riffles and flatwater; large pool below falls

Appendix 3. List of water quality sites on the Cedar River mainstem and tributaries.

FC: Fish Creek: control site above Cedar Falls

CR 1: upstream of two major bridges the cross mainstem (i.e. near 50 road); and upstream of Steele Creek

SC: at mouth of Steele

CR 2: downstream of Steele

CR 3: upstream of Williams Creek

WC: at mouth of Williams

CR 4: upstream of Taylor Creek

TC 1: at the mouth of Taylor

TC 2: upstream of fish barrier at USGS gauge

CR 5: downstream of Taylor

CR 6: end of 40.1 road, approx. 1 mile downstream of Taylor

CR 7: upstream of Rock Creek

RC 1: mouth of Rock

CR 8: upstream of 41 bridge; downstream of Rock Creek

RC 2: at 10 bridge upstream of beaver complex

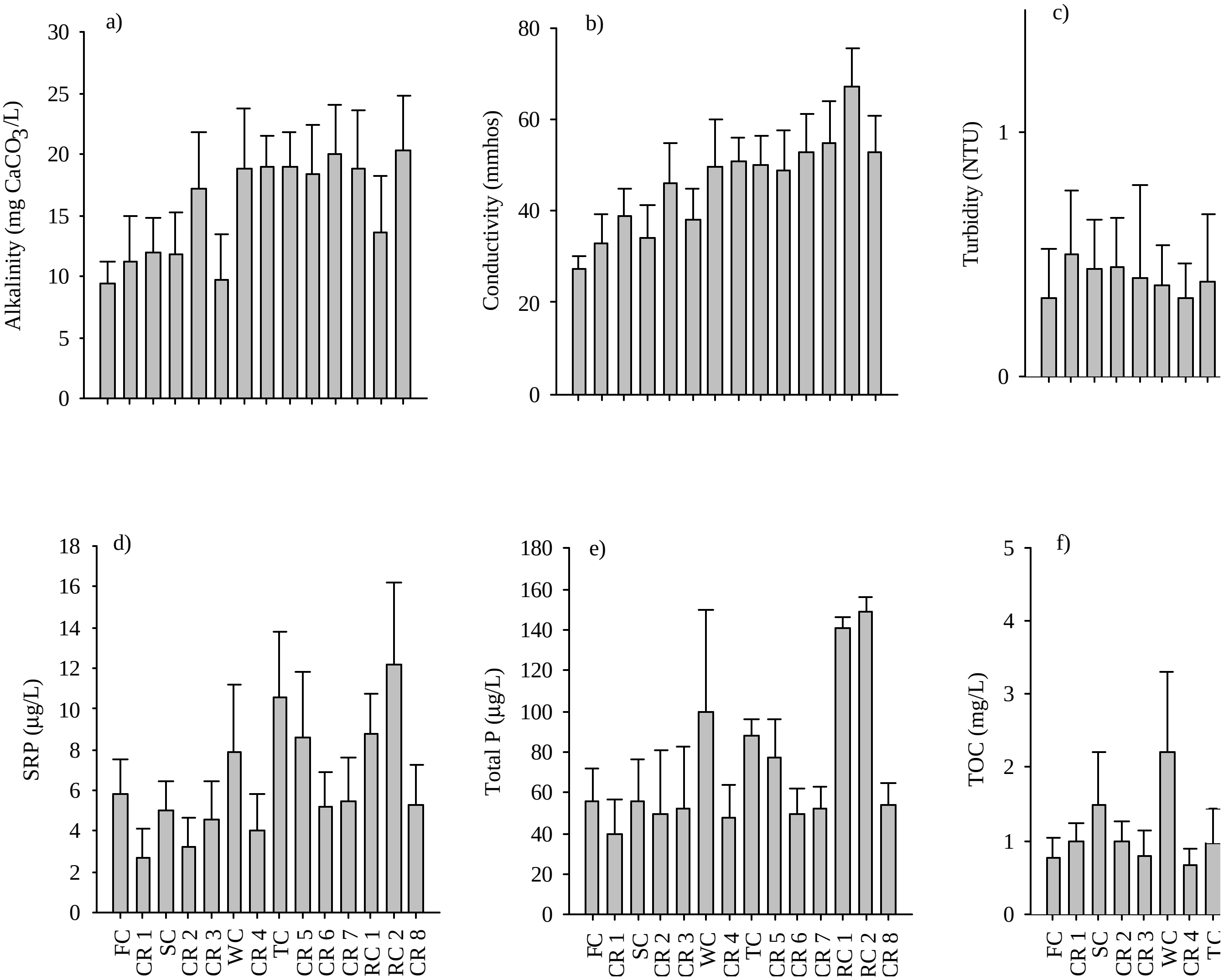
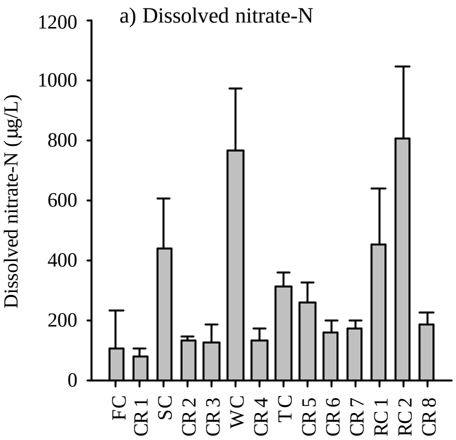
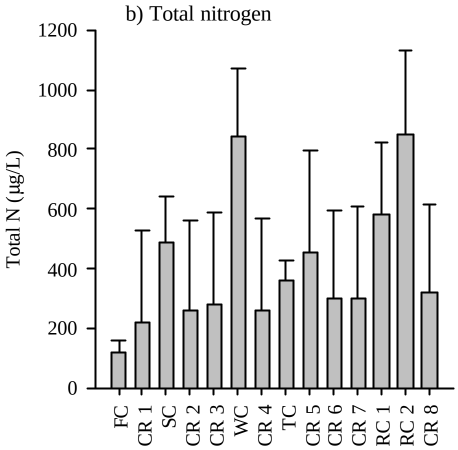

a)
30
25
20
15
10
5
0
Alkalinity (mg $CaCO_3$/L)
b)
80
60
40
20
0
Conductivity (mmhos)
c)
1
0
Turbidity (NTU)
d)
18
16
14
12
10
8
6
4
2
0
SRP (µg/L)
FC
CR 1
SC
CR 2
CR 3
WC
CR 4
TC
CR 5
CR 6
CR 7
RC 1
RC 2
CR 8
e)
180
160
140
120
100
80
60
40
20
0
Total P (µg/L)
FC
CR 1
SC
CR 2
CR 3
WC
CR 4
TC
CR 5
CR 6
CR 7
RC 1
RC 2
CR 8
f)
5
4
3
2
1
0
TOC (mg/L)
FC
CR 1
SC
CR 2
CR 3
WC
CR 4
TC

Figure 2



a) Dissolved nitrate-N



b) Total nitrogen

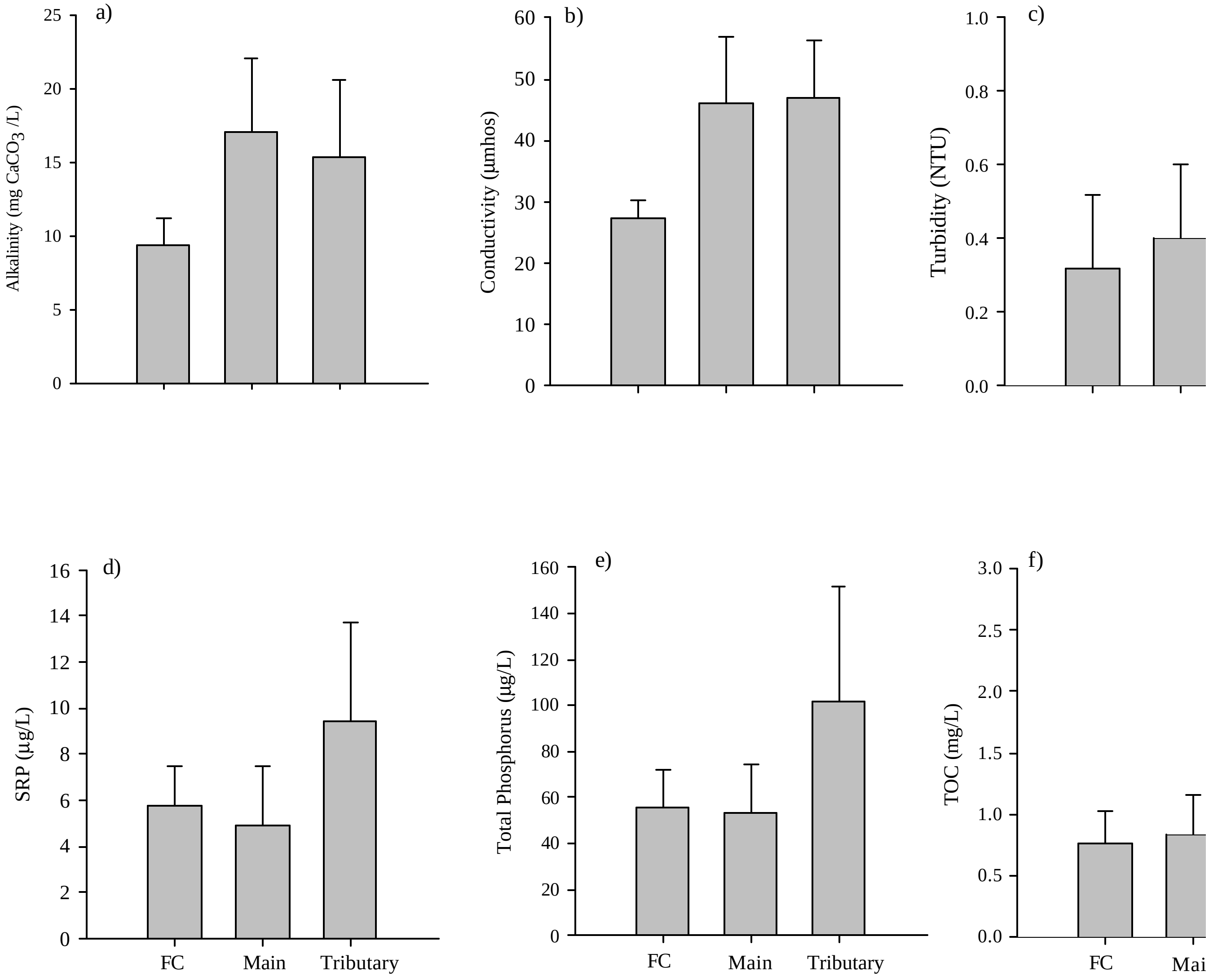
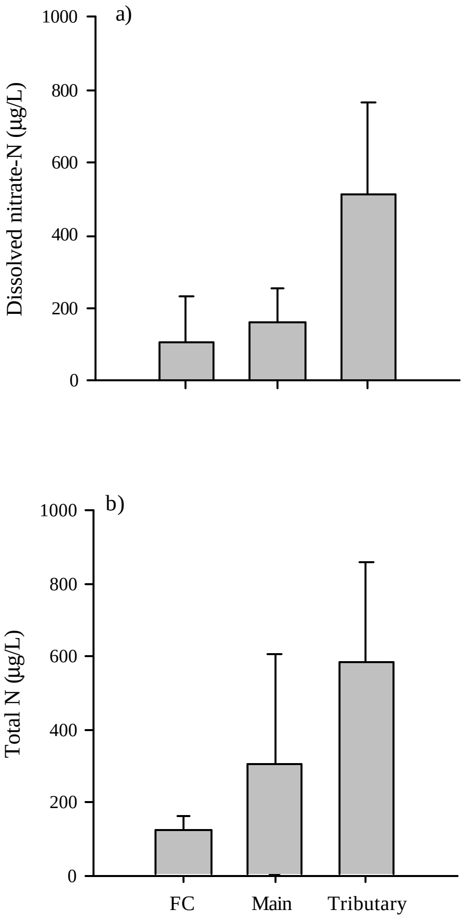

a)
Alkalinity (mg CaCO3 /L)
0
5
10
15
20
25
b)
Conductivity (µmhos)
0
10
20
30
40
50
60
c)
Turbidity (NTU)
0.0
0.2
0.4
0.6
0.8
1.0
d)
SRP (µg/L)
0
2
4
6
8
10
12
14
16
FC
Main
Tributary
e)
Total Phosphorus (µg/L)
0
20
40
60
80
100
120
140
160
FC
Main
Tributary
f)
TOC (mg/L)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
FC
Mai

Figure 4


a)
Dissolved nitrate-N (µg/L)
1000
800
600
400
200
0
b)
Total N (µg/L)
1000
800
600
400
200
0
FC
Main
Tributary

Cedar River

Figure 5

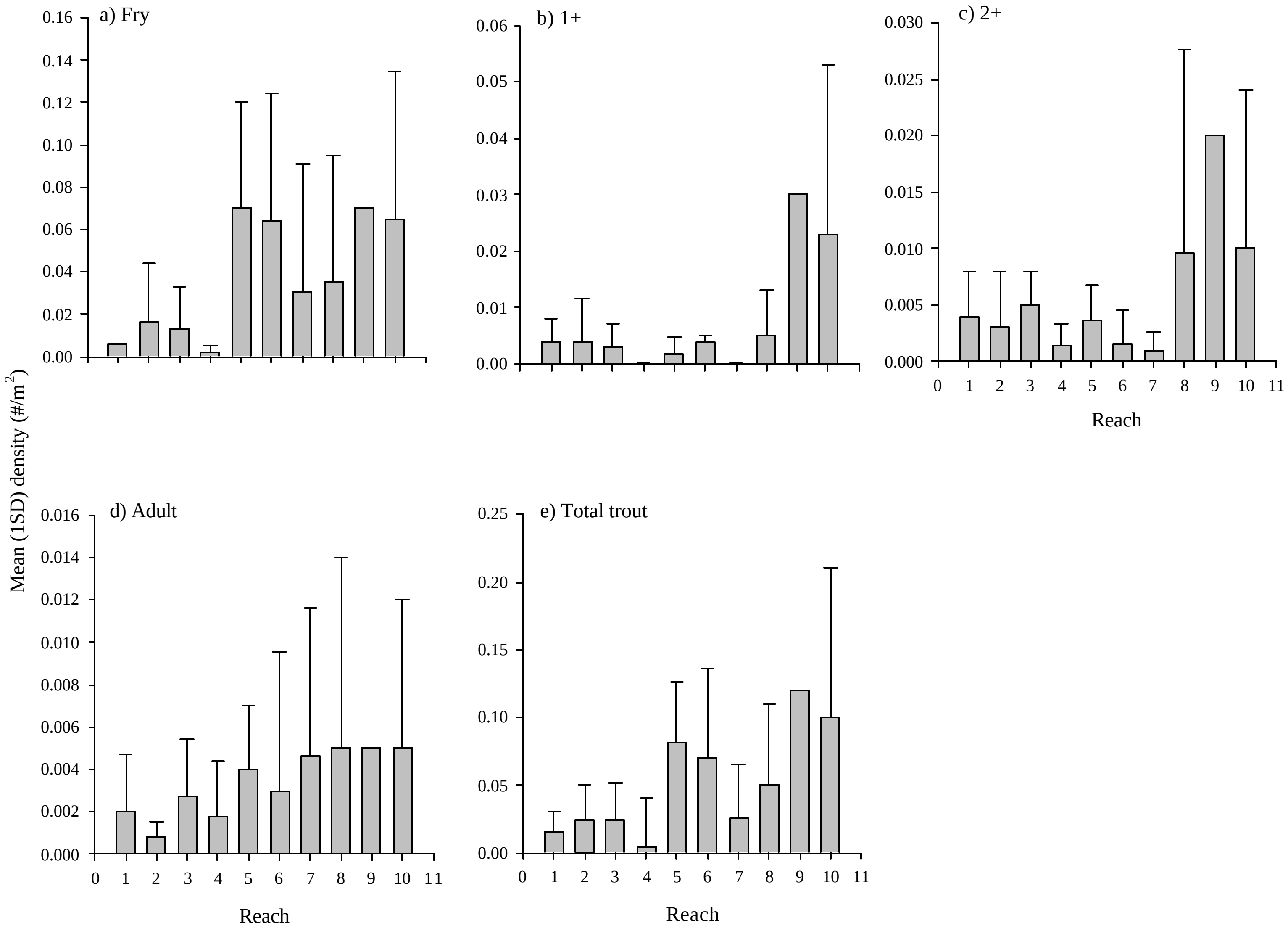


Figure 6

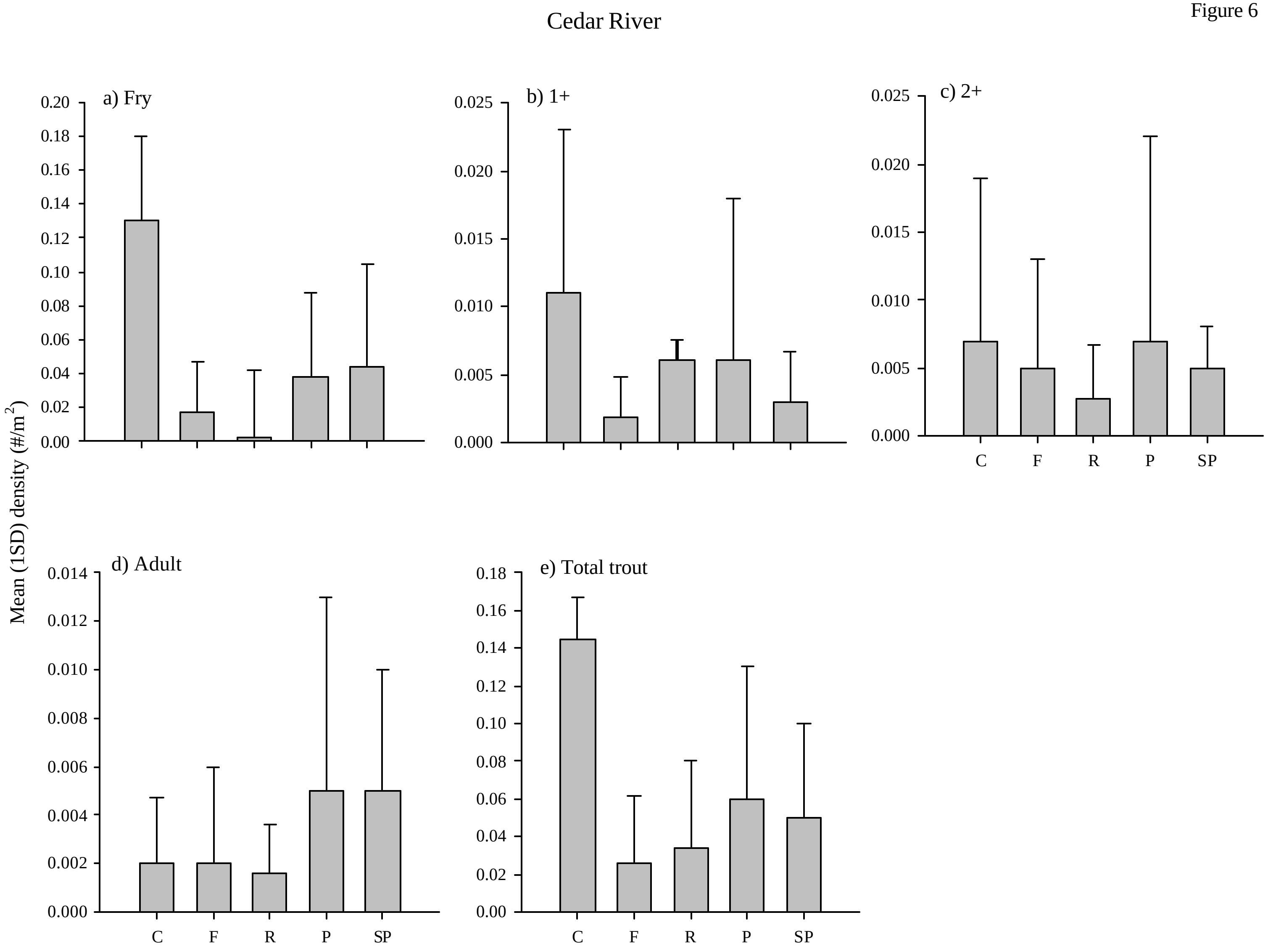

Cedar River
Mean (1SD) density (#/m²)
a) Fry
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
b) 1+
0.025
0.020
0.015
0.010
0.005
0.000
c) 2+
0.025
0.020
0.015
0.010
0.005
0.000
C
F
R
P
SP
d) Adult
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
C
F
R
P
SP
e) Total trout
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
C
F
R
P
SP

Figure 7

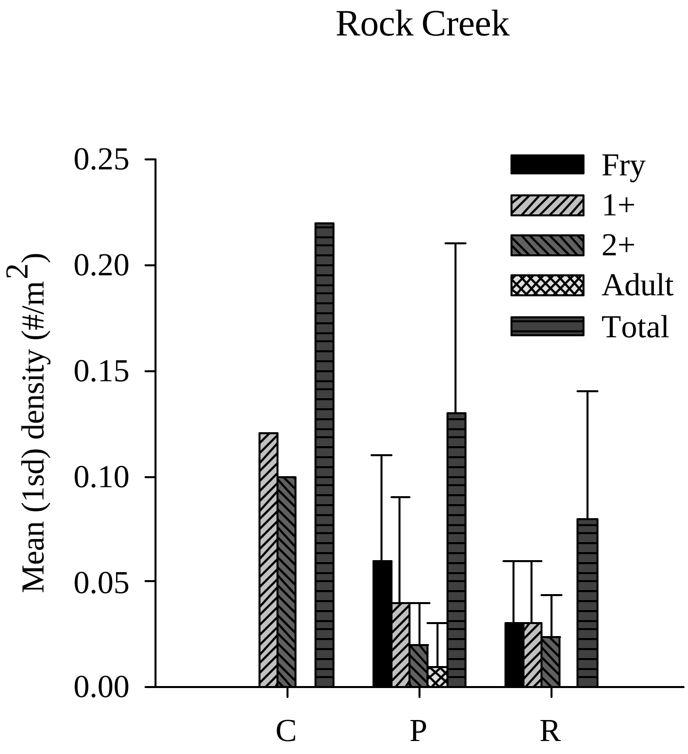

Rock Creek
Mean (1sd) density (#/m^2)
0.25
0.20
0.15
0.10
0.05
0.00
C
P
R
Fry
1+
2+
Adult
Total

Figure 8

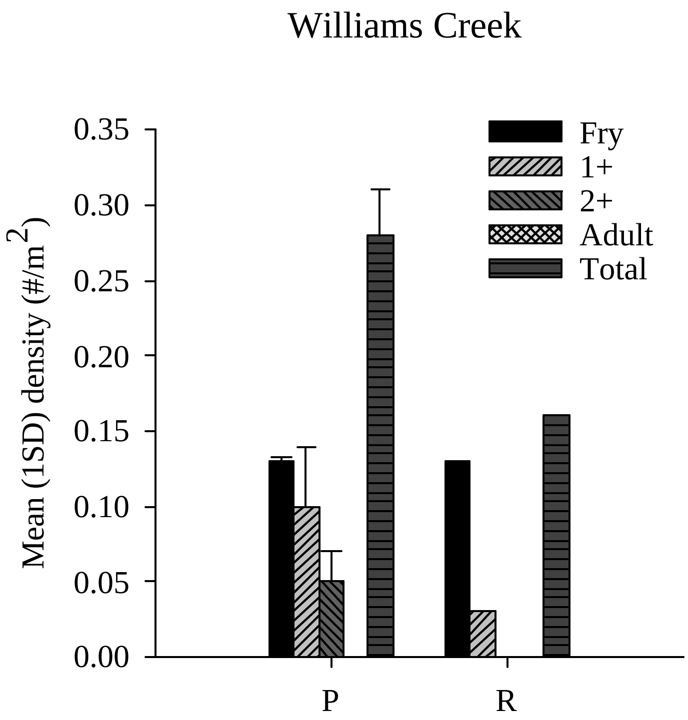

Williams Creek
Mean (1SD) density (#/m^2)
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
P
R
Fry
1+
2+
Adult
Total

Figure 9

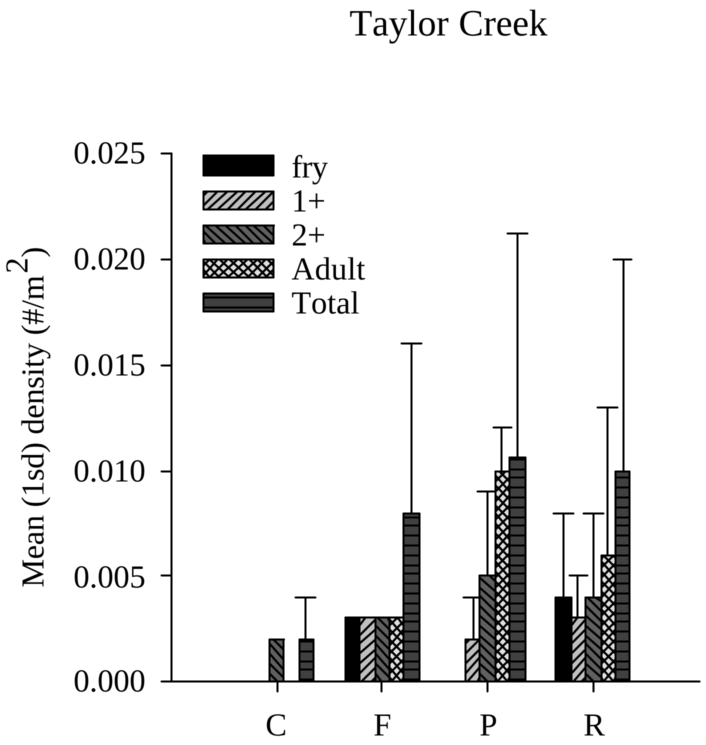

Taylor Creek
Mean (1sd) density (#/m²)
0.025
0.020
0.015
0.010
0.005
0.000
fry
1+
2+
Adult
Total
C
F
P
R

Figure 10

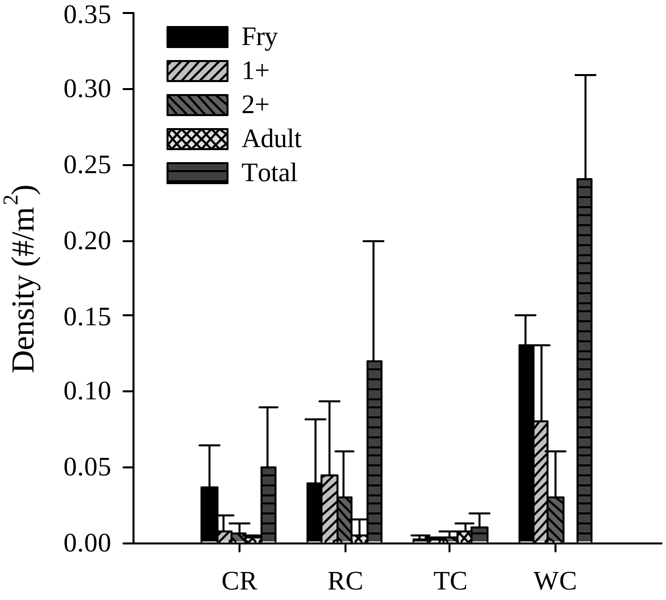

0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Density (#/m^2)
Fry
1+
2+
Adult
Total
CR
RC
TC
WC

Figure 11

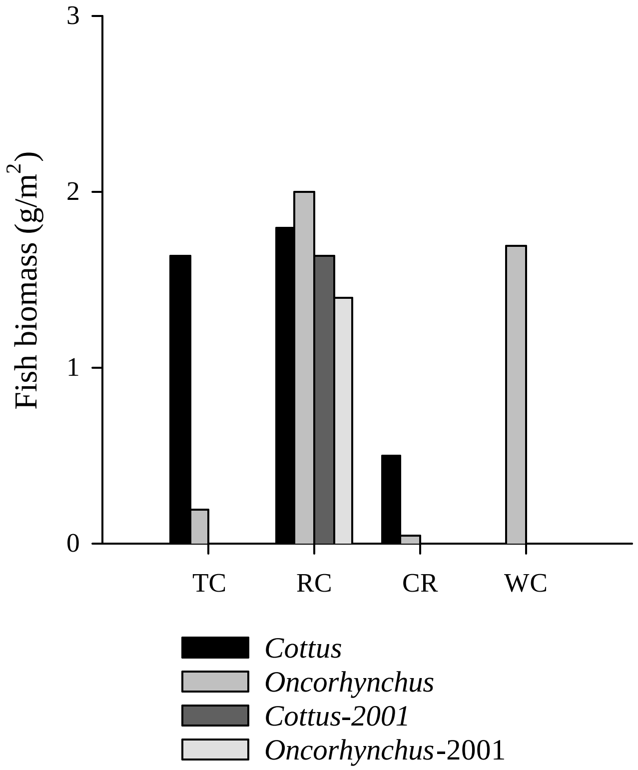

Fish biomass (g/m^2)
3
2
1
0
TC
RC
CR
WC
Cottus
Oncorhynchus
Cottus-2001
Oncorhynchus-2001

Figure 12

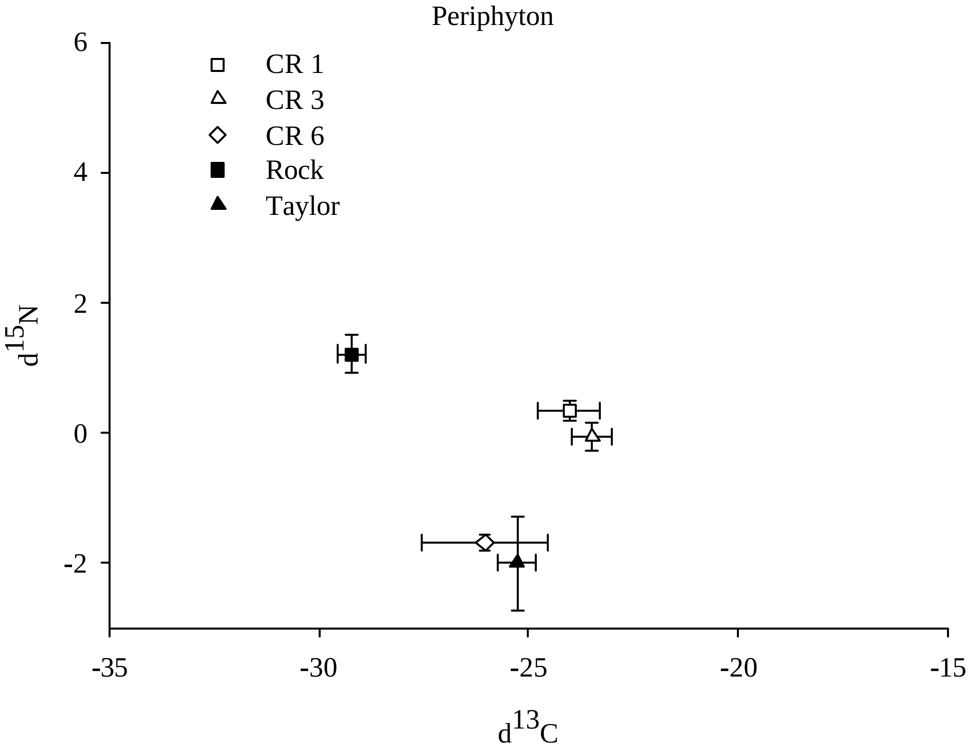

Periphyton
6
4
2
0
-2
d15N
□ CR 1
△ CR 3
◇ CR 6
■ Rock
▲ Taylor
-35
-30
-25
-20
-15
d13C

Figure 13

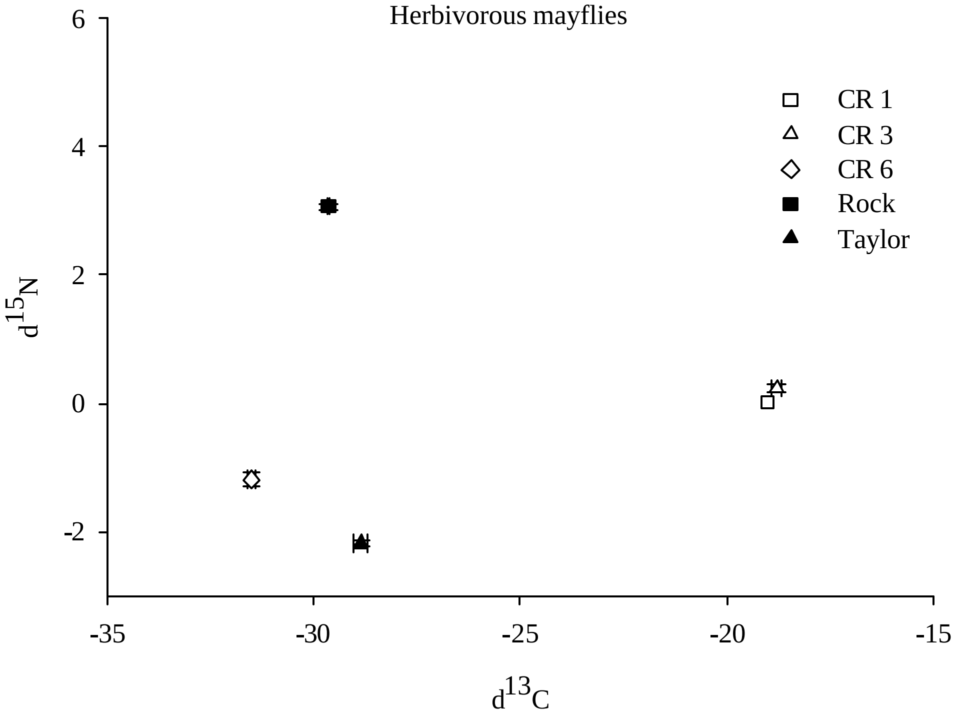

Herbivorous mayflies
□ CR 1
△ CR 3
◇ CR 6
■ Rock
▲ Taylor
$d^{15}N$
6
4
2
0
-2
-35
-30
-25
-20
-15
$d^{13}C$

Figure 14

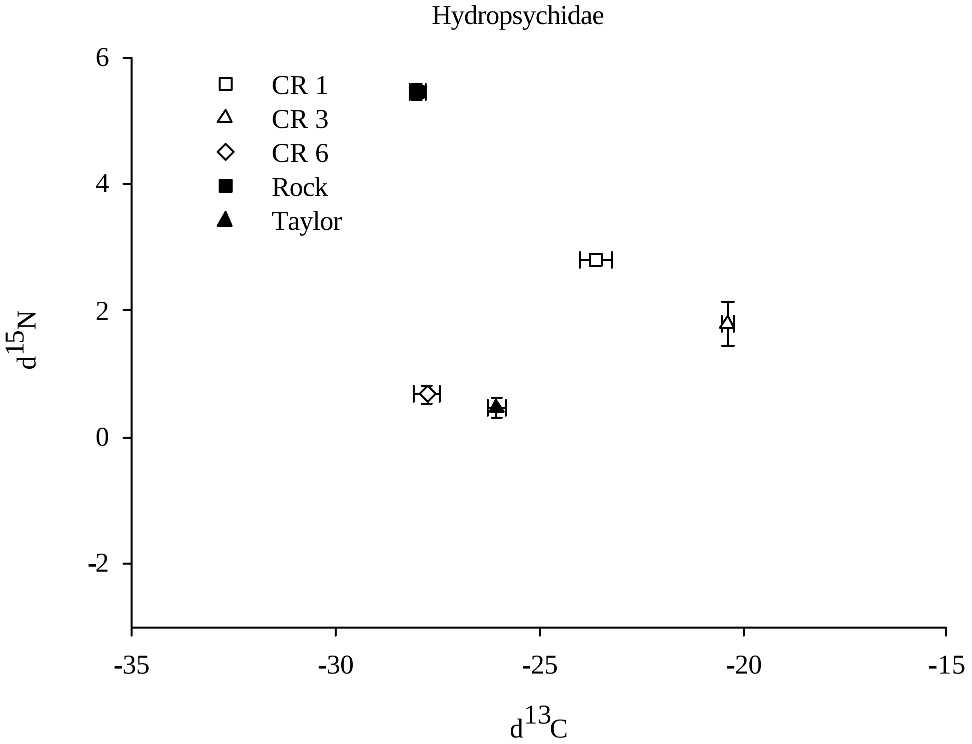

Hydropsychidae
CR 1
CR 3
CR 6
Rock
Taylor
6
4
2
0
-2
-35
-30
-25
-20
-15
$d^{15}N$
$d^{13}C$

Figure 15

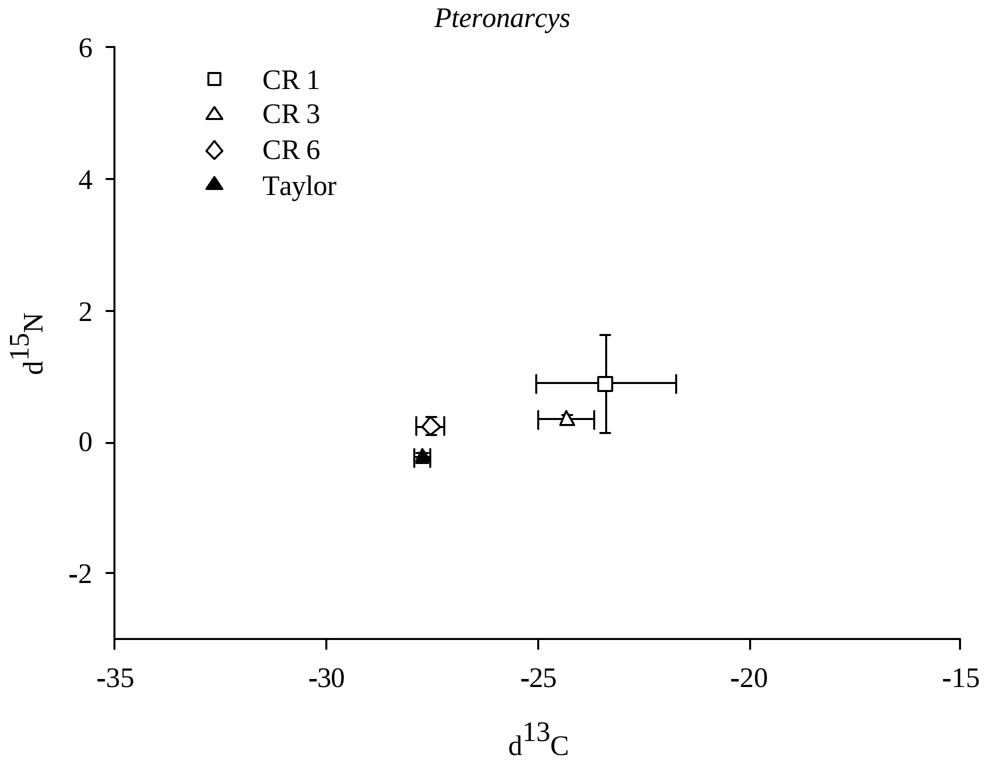


Figure 16

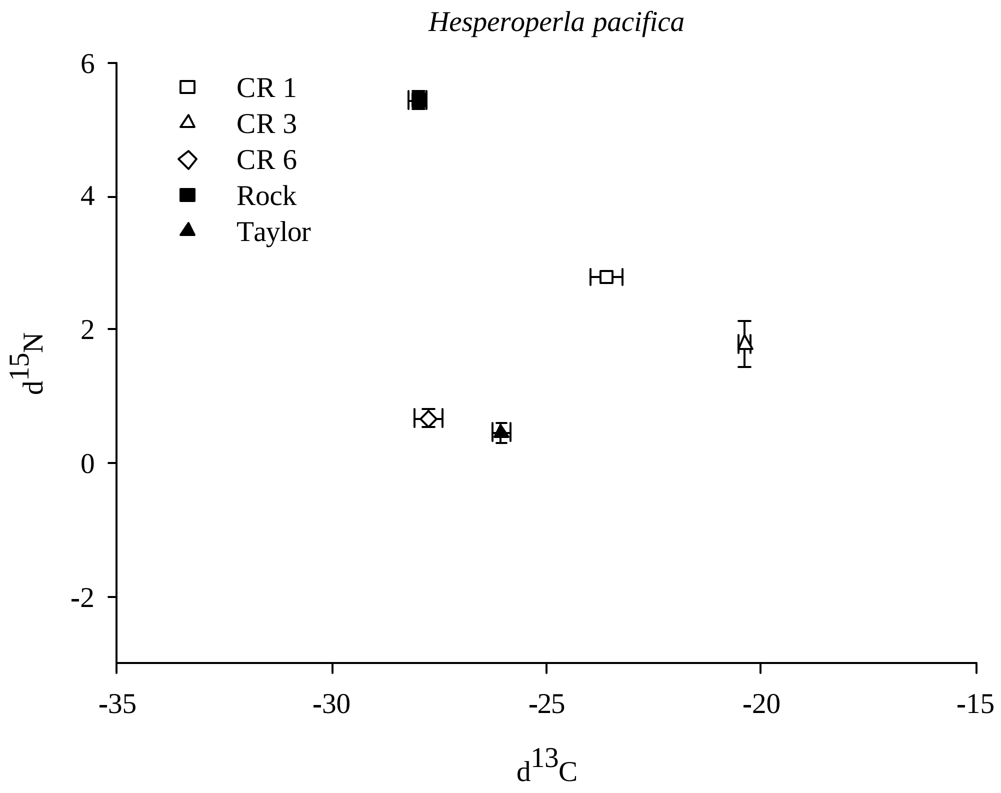

Hesperoperla pacifica
□ CR 1
△ CR 3
◇ CR 6
■ Rock
▲ Taylor
6
4
2
0
-2
$d^{15}N$
-35
-30
-25
-20
-15
$d^{13}C$

Figure 17

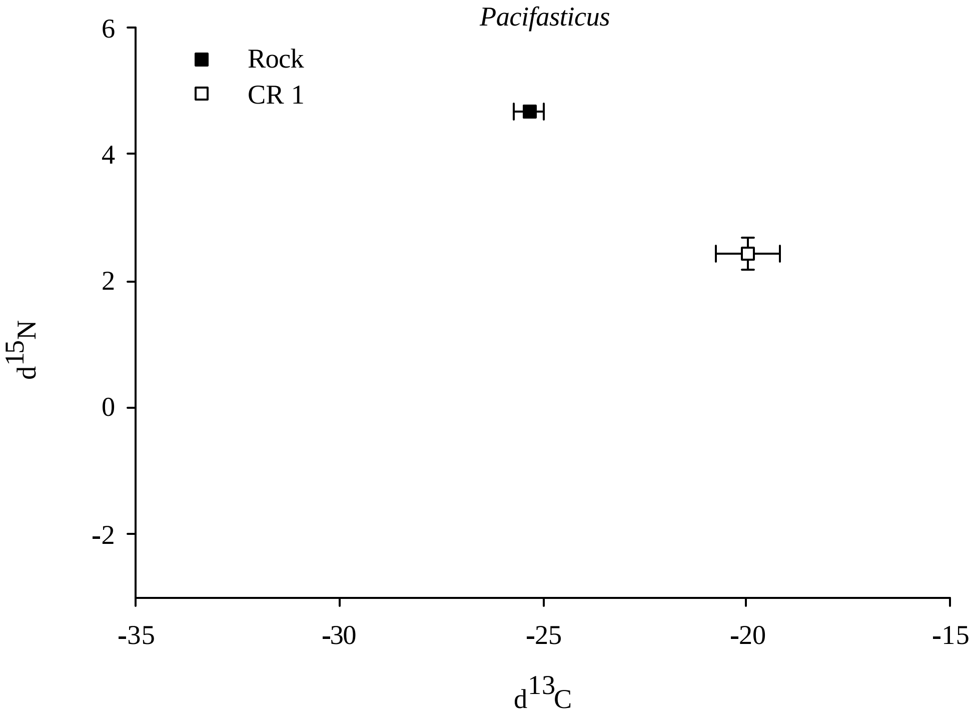


Figure 18

Trout (rainbow and fry)

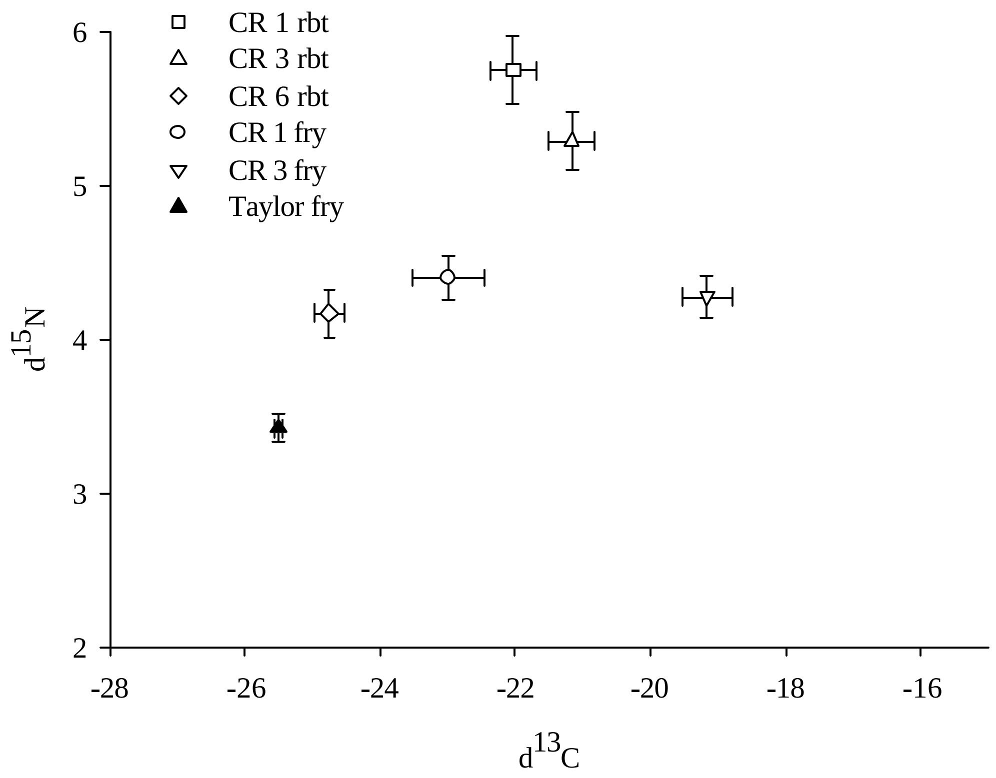
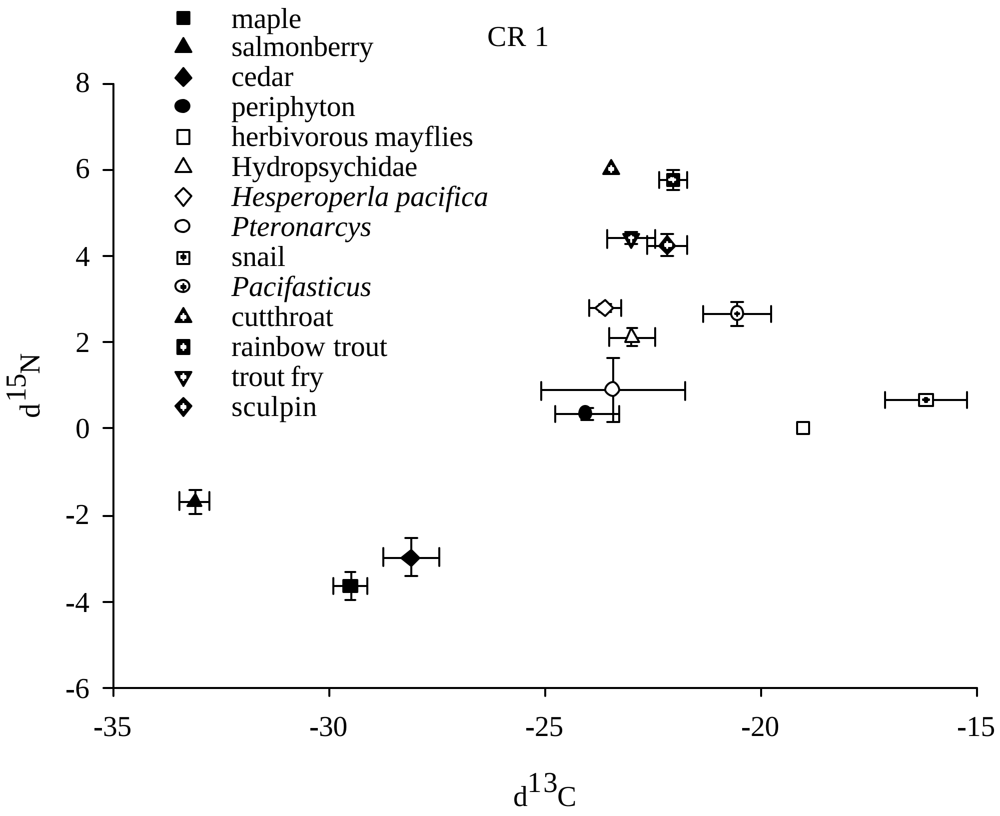


Figure 19



■ maple
▲ salmonberry
◆ cedar
● periphyton
□ herbivorous mayflies
△ Hydropsychidae
◇ *Hesperoperla pacifica*
○ *Pteronarcys*
snail
Pacifasticus
cutthroat
rainbow trout
trout fry
sculpin
CR 1
8
6
4
2
0
-2
-4
-6
-35
-30
-25
-20
-15
$d^{15}N$
$d^{13}C$

Figure 20

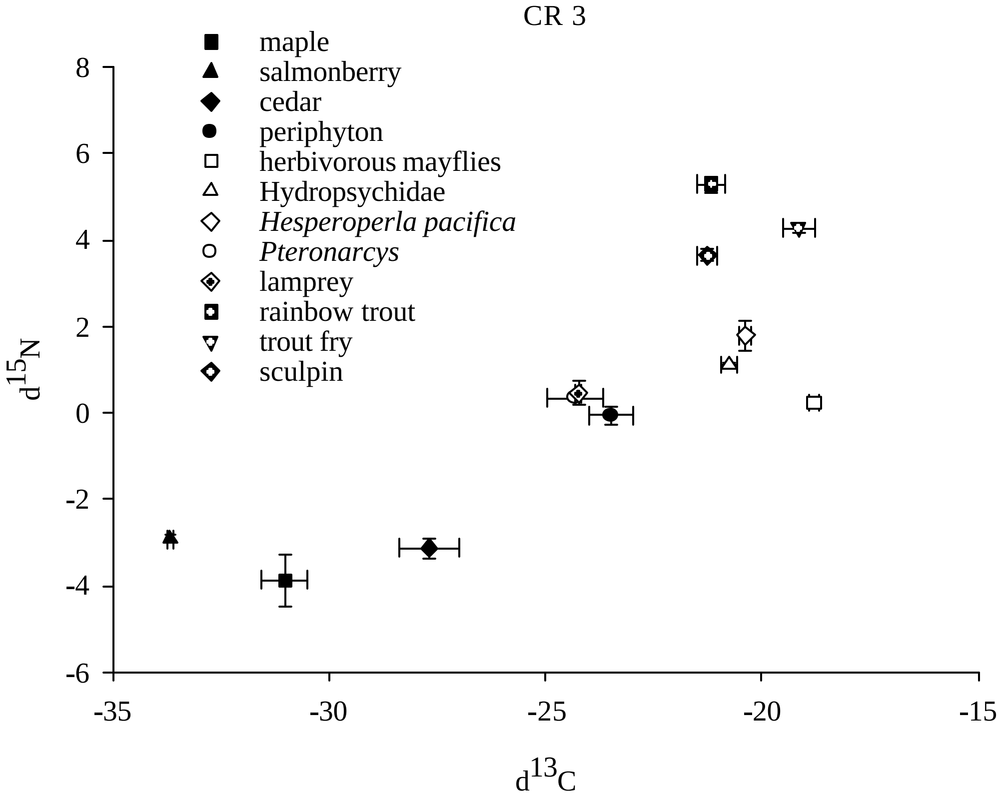

CR 3
maple
salmonberry
cedar
periphyton
herbivorous mayflies
Hydropsychidae
Hesperoperla pacifica
Pteronarcys
lamprey
rainbow trout
trout fry
sculpin
8
6
4
2
0
-2
-4
-6
-35
-30
-25
-20
-15
$d^{15}N$
$d^{13}C$

Figure 21

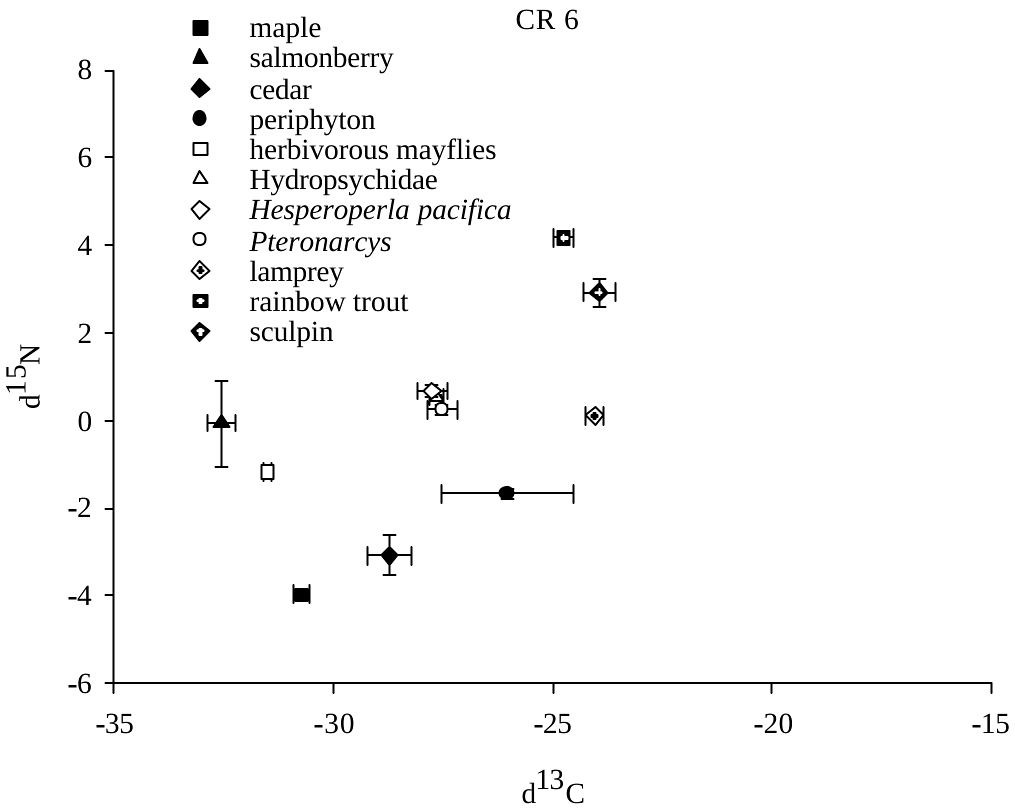

CR 6
■ maple
▲ salmonberry
◆ cedar
● periphyton
□ herbivorous mayflies
△ Hydropsychidae
◇ *Hesperoperla pacifica*
○ *Pteronarcys*
lamprey
rainbow trout
sculpin
$d^{15}N$
8
6
4
2
0
-2
-4
-6
-35
-30
-25
-20
-15
$d^{13}C$

Figure 22

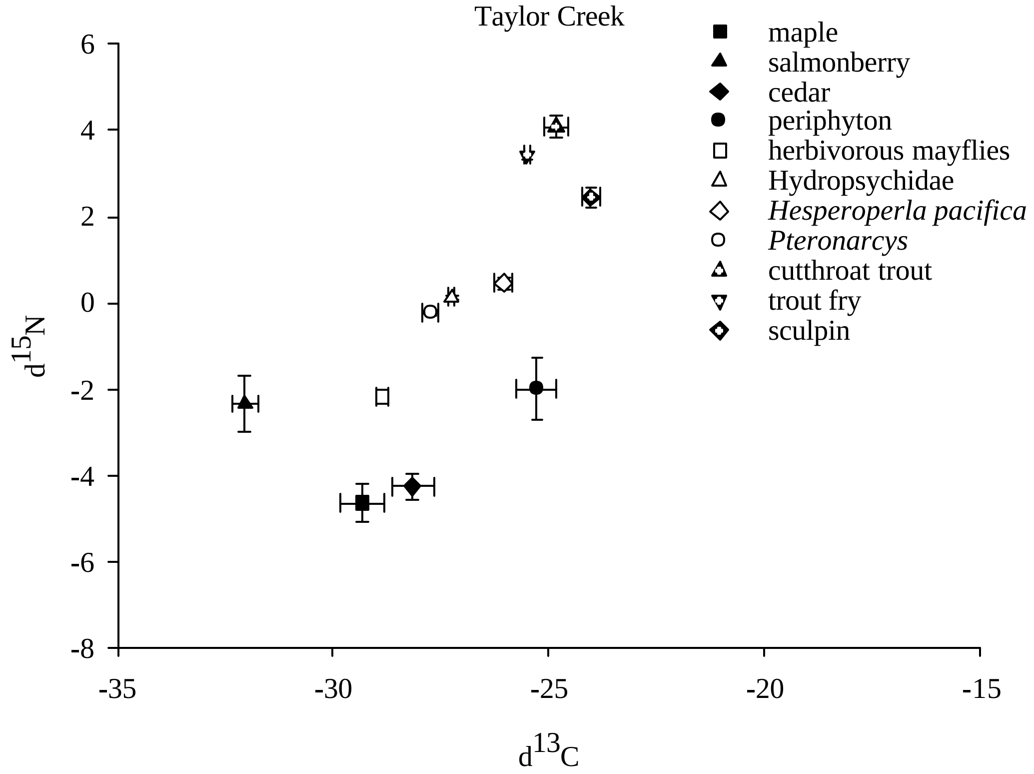
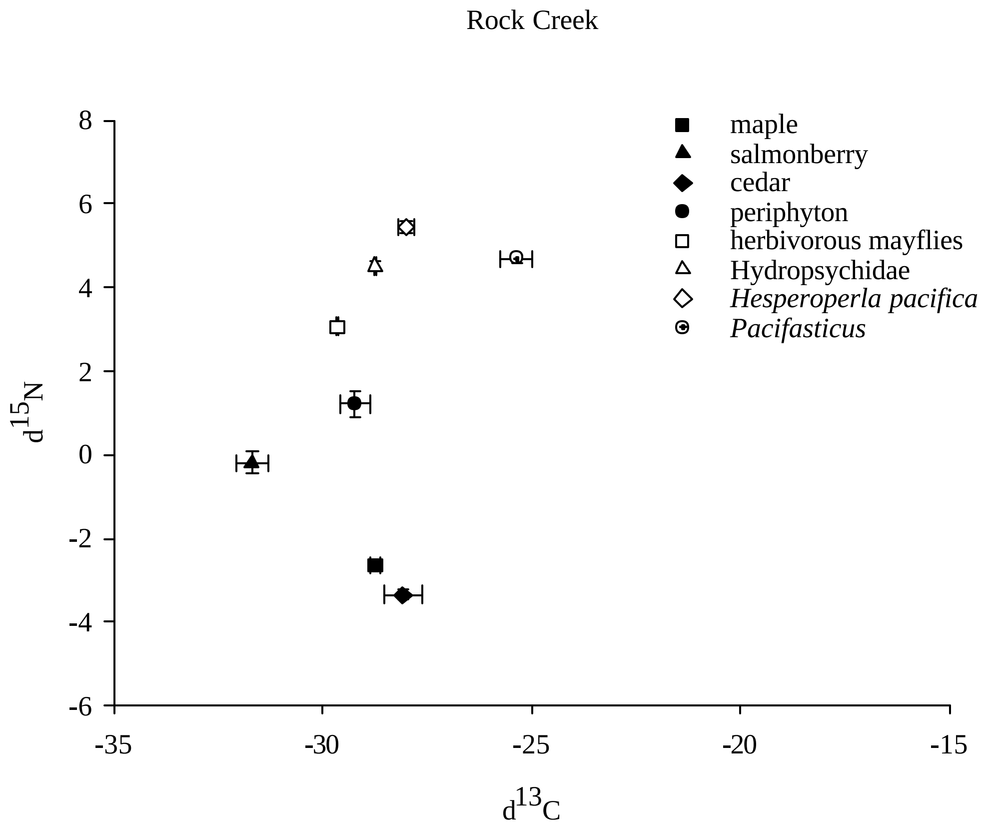

Taylor Creek
■ maple
▲ salmonberry
◆ cedar
● periphyton
□ herbivorous mayflies
△ Hydropsychidae
◇ *Hesperoperla pacifica*
○ *Pteronarcys*
△ cutthroat trout
▽ trout fry
◇ sculpin
6
4
2
0
-2
-4
-6
-8
d15N
-35
-30
-25
-20
-15
d13C

Figure 23


Rock Creek
maple
salmonberry
cedar
periphyton
herbivorous mayflies
Hydropsychidae
Hesperoperla pacifica
Pacifasticus
8
6
4
2
0
-2
-4
-6
-35
-30
-25
-20
-15
$d^{15}N$
$d^{13}C$