PEACE/WILLISTON
FISH & WILDLIFE
COMPENSATION
PROGRAM

BC hydro

BRITISH
COLUMBIA

Development of a Premier Northern River Fishery: Mesilinka River, the Second Year of Fertilization (1995)

A. J. Paul, G. A. Wilson, C. W. Koning, K. I. Ashley, P. A. Slaney, P. W. Davidson and R. W. Land
June 1998

PWFWCP Report No. 187

Peace/Williston Fish and Wildlife Compensation Program, 1011 Fourth Ave.
3rd Floor, Prince George B.C. V2L 3H9

Website: *www.bchydro.bc.ca/environment/initiatives/pwcp/*

This report has been approved by the Peace/Williston Fish and Wildlife Compensation Program Fish Technical Committee.

Citation: A. J. Paul, G. A. Wilson, C. W. Koning, K. I. Ashley, P. A. Slaney, P. W. Davidson and R. W. Land. June 1998. Development of a premier northern river fishery: Mesilinka River, the second year of fertilization (1995). Peace/Williston Fish and Wildlife Compensation Program, Report No. 187. 57pp plus appendices.

Author(s): Andrew J. Paul[1], Gregory A. Wilson[1], Wendell Koning[2], Ken Ashley[1], Pat Slaney[2], Peter Davidson[1] and Robert W. Land[1]
Address(es): [1] Fisheries Research and Development Section,
Fisheries Branch , Ministry of Environment, Lands and Parks
2204 Main Mall, University of British Columbia Vancouver, B.C. V6T 1Z4
[2] Watershed Restoration Program, Ministry of Environment, Lands and Parks
2204 Main Mall, University of British Columbia, Vancouver, B.C. V6T 1Z4

DEVELOPMENT OF A PREMIER NORTHERN RIVER FISHERY: MESILINKA RIVER, THE SECOND YEAR OF FERTILIZATION (1995)

A.J. Paul[1], G. Wilson[1], C.W. Koning[2], K.I. Ashley[1], P.A. Slaney[2],
P.W. Davidson[1] and R.W. Land[1]

Fisheries Research and Development Section, Fisheries Branch
Ministry of Environment, Lands and Parks, B.C.
2204 Main Mall
University of British Columbia
Vancouver, B.C. V6T 1Z4

[2]Watershed Restoration Program
Ministry of Environment, Lands and Parks, B.C.
2204 Main Mall
University of British Columbia
Vancouver, B.C. V6T 1Z4

Fisheries Project Report No. RD62
B.C. Ministry of Environment, Lands and Parks
Fisheries Branch

June 27, 1998

ABSTRACT

Paul, A.J., G. Wilson, C.W. Koning, K.I. Ashley, P.A. Slaney, P.W. Davidson and R.W. Land. 1998. Development of a premier northern river fishery: Mesilinka River, the second year of fertilization (1995). B.C. Ministry of Environment, Lands and Parks, Fisheries Project Report No. RD62.

The addition of inorganic nutrients to increase fish production in the Mesilinka River, a northern interior river of British Columbia, is being investigated. Increased production of native fish stocks is desired to both offset negative impacts following the establishment of the Williston Reservoir and to meet increased angling demands for stream fisheries. We present results from the second year of fertilization (1995) to the mainstem Mesilinka River. Three reaches on the Mesilinka River (an upstream control reach, Blackpine, and two downstream treatment reaches, Tl and T2) and an additional external reference system (the Nation River) were established to test the effects of added nutrients to stream production. Inorganic fertilizer was added above Tl as ammonium polyphosphate, 10-34-0 (indicates percent weight of $N - P_2O_5 - K_2O$), and urea-ammonium nitrate, 28-0-0. Another fertilizer station downstream of T1, but above T2, also added both ammonium polyphosphate and urea-ammonium nitrate. Actual loading rates of nitrogen (N) and phosphorus (P) were lower than target loadings of 15 µg N L^{-1} and 5 µg P L^{-1}; however, loading rates in 1995 were less variable at the upper station than the previous year. Mean summer loadings of N and P at the upper fertilizer station were 9.9 µg N L^{-1} and 3.5 µg P L^{-1}, and at the lower station were 9.2 µg N L^{-1} and 3.2 µg P L^{-1}. Despite lower than targeted fertilizer loading rates, peak accrual of periphyton significantly increased following fertilization in Tl but not T2. In contrast, benthic invertebrate biomass and densities show a strong response to fertilization in T2 but not T1. Densities of mountain whitefish also significantly increased following fertilization in T1; but, inferences in fish densities for T2 could not be tested as no underwater counts were conducted in 1995 due to bad weather. Mean weight-at-age for age 2-4 rainbow trout has increased in T2 relative to the control reach Blackpine in 1995; however, we will require data from 1996 and 1997 to adequately test this difference. Mean weight-at-age for aged 2-4 rainbow trout in Tl and aged 3-5 Arctic grayling in either Tl or T2 does not appear to have increased following fertilization (although this also requires more years data to test). Given the apparent different outcomes to fertilization in either Tl or T2, we postulate two response patterns in northern rivers to fertilization: a) the fish density response and b) the fish growth response. The fish density response is characterized by an increase in fish densities following fertilization which subsequently depress benthic invertebrate biomass and density through increased predation pressure. A low biomass of benthic invertebrates allows standing stocks of periphyton to respond positively with fertilization. We hypothesize that this is the response in Tl reach. Whereas, the fish growth response is characterized by little change in densities of fish following fertilization. Relatively constant predation pressure on benthic invertebrates coupled with increased nutrients allows invertebrate density and biomass to increase resulting in both increased growth of fish (as more food is available) and relatively lower standing stocks of periphyton given the fertilizer input. We hypothesize that this is the response in T2 reach. The

two hypothesizes can be more rigorously addressed with data collected in 1996 and 1997. Mainstem fertilization has pushed the treatment reaches toward N limitation when compared to the control reach; but, it is not clear whether N limitation is more severe in T2 compared to T1. In addition to mainstem fertilization in 1995, two tributaries (Gopherhole and Culvert creeks) were fertilized using slow-release fertilizer briquettes. Mean summer loading concentrations to Gopherhole and Culvert creeks were 7.11 and 7.83 µg P L^{-1}, respectively. Differences between estimated P loading from the briquettes and soluble reactive phosphorus measured downstream near the stream mouths suggest that only a small portion of fertilizer derived P is actually being taken up in the creek. The response in periphyton to tributary fertilization indicate that standing stocks of periphyton have increased following fertilization, especially in Gopherhole Creek. However, several confounding factors (including differing measurement periods and an ineffective fertilizer treatment in 1993) make statistical analysis difficult.

ACKNOWLEDGMENTS

This project was funded by the Peace/Williston Fish and Wildlife Compensation Program. Field activities in 1995 were carried out by a team including Ken Ashley, Brian Blackman, Tom Gratton, Arne Langston, Bob Land, Allister Maclean, Steve Zachary, Paul Davidson and Wendell Koning.

We also acknowledge the following contributions: MELP (Ministry of Environment, Lands and Parks), Fraser Valley Hatchery staff (Dale Larson, Ken Scheer, Morley Rempel, Larry Mitchell, Steve Arnold, Nick Basok, Doug Crawley, Barry Kolodychuk, Charlotte Lawson and Kurt Vinge) who spent many hours organizing, cleaning and sorting benthic invertebrate samples; Karin Mathias weighed benthic invertebrate samples; Theresa Godin developed computer spreadsheets for analysis of underwater fish census data; and Debbie Aird provided office administrative assistance.

Taxonomic identification and enumeration of benthic invertebrates was prepared by Fraser Environmental Services, #16 - 9324 128th Street, Surrey, B.C., V3V 6A4.

We greatly appreciate the contribution of Finlay Forest Industries Ltd. in providing meals and accommodation free-of-charge at their Mesilinka logging camp for project field personnel during the annual August underwater fish census.

Finally, we thank Dr. Art Tautz, Manager, Fisheries Research and Development Section, for his continued support of our endeavours in stream fertilization.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Production of consumers, including benthic invertebrates and fish, in streams is driven by energy inputs from within and outside the system. Energy inputs from outside the stream are derived from the transport of organic matter (e.g. leaf litter) from the watershed (Hynes 1975). Energy pathways developed from within a stream stem from the primary production of periphytic (attached) algae which is dependant on nutrient and light conditions (Minshall 1978; Peterson et al. 1985; Perrin et al. 1987). Increasing the supply rate of inorganic nutrients (nitrogen or phosphorus) within a stream can change a system from relying on energy attained by the transport of organic matter from its watershed to within stream production of periphytic algae (Peterson et al. 1985).

Increased growth of periphytic algae can result in increased production of fish (Johnston et al. 1990; Deegan and Peterson 1992; Slaney and Ward 1993). Increasing algal production can lead to higher biomass of aquatic insects (Johnston et al. 1990; Slaney and Ward 1993), likely due to both higher quality and more abundant food resource for the insects (Cummins and Klug 1979; Gregory 1983). Subsequently, higher insect biomass has been shown to increase salmonid food resources and decrease their territory size, thereby increasing the carrying capacity of a stream for salmonids (Warren et al. 1964; Chapman 1966; Slaney and Northcote 1974; Dill et al. 1981; Wilzbach 1985).

The addition of inorganic nutrients in lakes and streams may be an effective technique to mitigate the negative impacts of either lake impoundment or logging on native fish populations (Milbrink and Holmgren 1981; Slaney et al. 1993). These negative impacts include the loss in productivity of fish in impounded lakes (Milbrink and Holmgren 1981) and a decrease in overwinter survival of steelhead trout *(Oncorhynchus mykiss)* in logged watersheds (Slaney et al. 1993). Nutrient input into an impounded lake in Scandinavia was shown to rapidly increase productivity at all food web levels (Milbrink and Holmgren 1981). Furthermore, nutrient inputs into coastal streams can increase the mean weight of juvenile steelhead trout (Johnston et al. 1990; Slaney and Ward 1993) and thereby increase their overwinter survival (Hume and Parkinson 1988).

The use of nutrients to maintain or restore fish stocks may be a more effective and ecologically sound technique than the introduction of non-native species. The introduction of non-native fishes in freshwaters has likely resulted in a greater loss in biodiversity than any other anthropogenic stress (Schindler 1990); while the introduction of non-native invertebrate species intended as a food resource (e.g. mysids) has had unpredictable and disastrous ecosystem effects (Ashley et al. 1997). Introduced invertebrates have sometimes achieved results exactly opposite of what was intended (Ashley et al. 1997) or have provided an extra food-web link to increase toxin concentrations in top predators (Cabana and Rasmussen 1994). While species introductions proceed largely unregulated after stocking, nutrient additions can be carefully regulated such that species biomass changes but not species richness (Milbrink and Holmgren

1981; Peterson et al. 1993a), thus maintaining biodiversity (Quamme 1994). Furthermore, the effects of controlled nutrient additions on a stream are reversible (Slaney and Ward 1993).

The purpose of the Mesilinka River Fertilization Experiment is to determine whether fertilization is a suitable technique to increase production of native fish species, especially Arctic grayling *(Thymallus arcticus)*, bull trout *(Salvelinus confluentus)* and rainbow trout *(O. mykiss)*, within the Williston Reservoir watershed. The reasons for increasing fish production are twofold. First, a large portion of the riverine habitat of the Rocky Mountain Trench was lost with the creation of the Williston Reservoir behind the W.A.C. Bennet dam (Blackman 1992). Critical over-wintering refuges or foraging zones were probably lost, especially to highly migratory species such as Arctic grayling or bull trout in this large watershed. Lacustrine fish species currently dominate catches within the reservoir while riverine species, such as grayling and mountain whitefish, have declined significantly following impoundment (Blackman 1992). Therefore, increased grayling production through river fertilization may partially offset the loss in grayling stocks from impoundment. Unfortunately, no historical records of grayling stocks prior to impoundment are available for the 3 major rivers that were flooded (Parsnip, Finlay and Peace) and their numerous tributaries. Secondly, user surveys within the Williston watershed indicate that angling preference favours rivers over small lakes and especially over the reservoir (B.C. Hydro 1990). Decreased riverine habitats from impoundment will thus be subject to increased angling pressure. Furthermore, stream fisheries are sensitive to overharvest and decreased quality following increased angling pressure (Slaney 1986). Therefore, river fertilization may develop destination fisheries that can support increased angling pressure while alleviating pressure on other unfertilized systems within the watershed.

The Mesilinka River (Fig. 1) was chosen as the primary site for fertilization for several reasons as outlined in Koning et al. (1995). These include suitable water temperatures, amount and type of nutrient deficiency, suitable rearing and overwintering habitat, adequate juvenile recruitment, and accessibility for anglers (Koning et al. 1995). Data on discharge, temperature, nutrients, periphyton, invertebrates, and fish were collected from the Mesilinka River between 1991-1994 (Langston 1992; Koning et al. 1995; Paul et al. 1996). As well, the Nation River (Fig. 1) was similarly sampled but to a lesser extent between 1992-1994 to serve as an external reference system (Koning et al. 1995; Paul et al. 1996).

The objective of this report is to describe the results from 1995 for both the Mesilinka and Nation rivers. As this marked the second year of fertilization to the mainstem Mesilinka River, we have, where possible, formally assessed the affect of fertilization now that 2 years pre- and post-treatment data exist. However, the conclusions reached are preliminary and subject to change. The overall experimetal design includes fertilization in 1996 and 1997, with formal evaluation based on 4 years of nutrient additions.

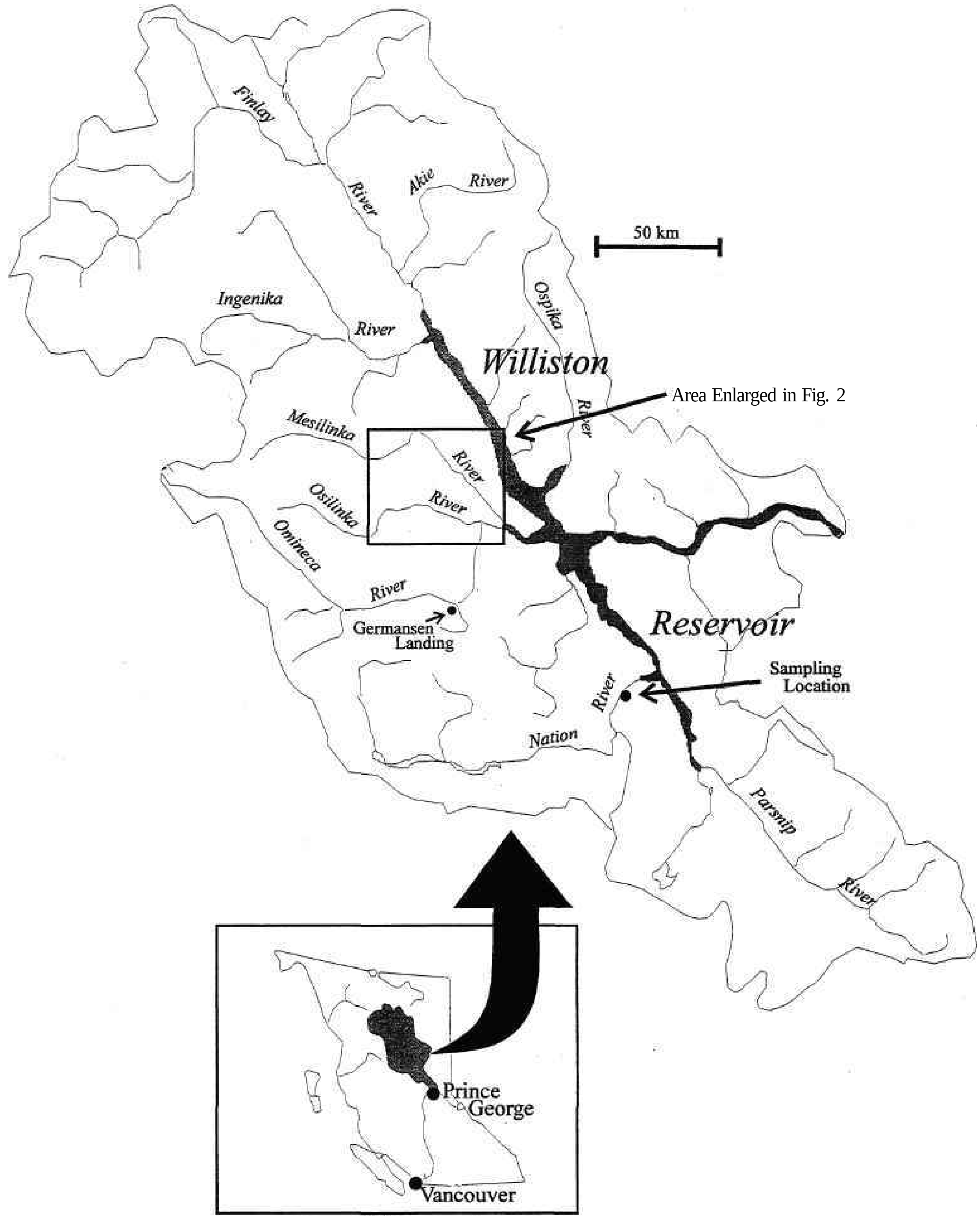

Figure 1 - The Williston Reservoir watershed. Map from Langston (1993).

STUDY AREAS

Mesilinka River

The Mesilinka River is located in north central British Columbia (Fig. 1) originating within the Omineca Mountains and running for approximately 120 km before emptying into the Williston Reservoir. The Mesilinka River flows through one lake, Aiken Lake, approximately 20 km downstream from the headwaters of the Mesilinka. Physical and biological conditions of the Mesilinka River and its watershed are given in Koning et al. (1995). Briefly, flows on the Mesilinka River peak in spring and early summer with the maximum monthly mean occurring in June (175 m^3 s^{-1}). Mean summer temperatures for the river are 10-11 °C and nutrient levels, especially dissolved inorganic phosphorus (SRP), are extremely low and often below detectable levels (ie., 1 µg L^{-1}; Koning et al. 1995). Primary productivity of the system is low, as confirmed by the low accrual of periphyton on artificial substrata and visual inspection of boulders, cobbles and pebbles for periphytic algae (Koning et al. 1995).

The fish community consist of rainbow trout, Arctic grayling, bull trout *(Salvelinus confluentus),* mountain whitefish *(Prosopium williamsoni),* burbot *(Lota lota),* suckers *(Catostomus* spp.), sculpins *(Cottus* spp.), longnose dace *(Rhinichthys cataractae),* northern squawfish *(Ptychocheilus oregonensis)* and likely other cyprinids.

The mid to lower portion of the Mesilinka River was used to examine the effects of fertilization (Fig. 2). This section was chosen because: a) temperatures are warmer than upper reaches, b) nitrogen (N) may not be as limiting in the lower portions due to ground water input of N and c) the lower portion has several road access points making it more suitable for fertilizer delivery (Koning et al. 1995). Three study reaches of the mid to lower river were established in 1992 (Koning et al. 1995) and maintained in subsequent years to facilitate a before and after unreplicated experiment (Stewart-Oaten et al. 1986). A control reach (Blackpine) was located approximately 30 km and 60 km upstream of the upper treatment reach (T1) and lower treatment reach (T2), respectively (Fig. 2).

Several tributaries flow into the mid to lower portion of the Mesilinka River (Fig. 2). A number of these tributaries provide rearing habitat for juvenile rainbow trout, bull trout and mountain whitefish (Koning et al. 1995). Five tributaries (Fatfish, Carina, Gopherhole, Control and Culvert creeks; Fig. 2) in the vicinity of the two treatment reaches were studied in detail (1992-1993) to assess their rearing potential for juvenile fish (Koning et al. 1995). Furthermore, two creeks (Culvert and Gopherhole) were fertilized in 1993 with liquid fertilizer to assess whether fertilization could enhance juvenile growth and recruitment in these tributaries (Koning et al. 1995). The five tributaries were studied in 1994 and 1995; and, Culvert and Gopherhole creeks were again fertilized in 1995 with slow release fertilizer (Mouldey and Ashley 1996).

Nation River

The Nation River, approximately 100 km south of the Mesilinka River, also flows into the Williston Reservoir. The river is headed by a chain of 5 large lakes (the Nation lakes) that are situated at the southern end of the Omineca mountains (Fig. 1). Mean summer water temperatures (14-15°C) and flow rates are higher than the Mesilinka River (Koning et al. 1995). The Nation River tends to be limited in N as well as P unlike the Mesilinka River which has higher concentrations of dissolved inorganic N (Koning et al. 1995). The Nation River was not chosen as a primary fertilization target because the higher flow rates coupled with N-limitation would necessitate larger (more costly) amounts of fertilizer than required for the Mesilinka River. If fertilization of the Mesilinka River produces the desired results in a cost-effective manner the Nation would then be considered as a candidate river for fertilization pending review by the Peace Williston Fish and Wildlife Compensation Program fisheries technical committee.

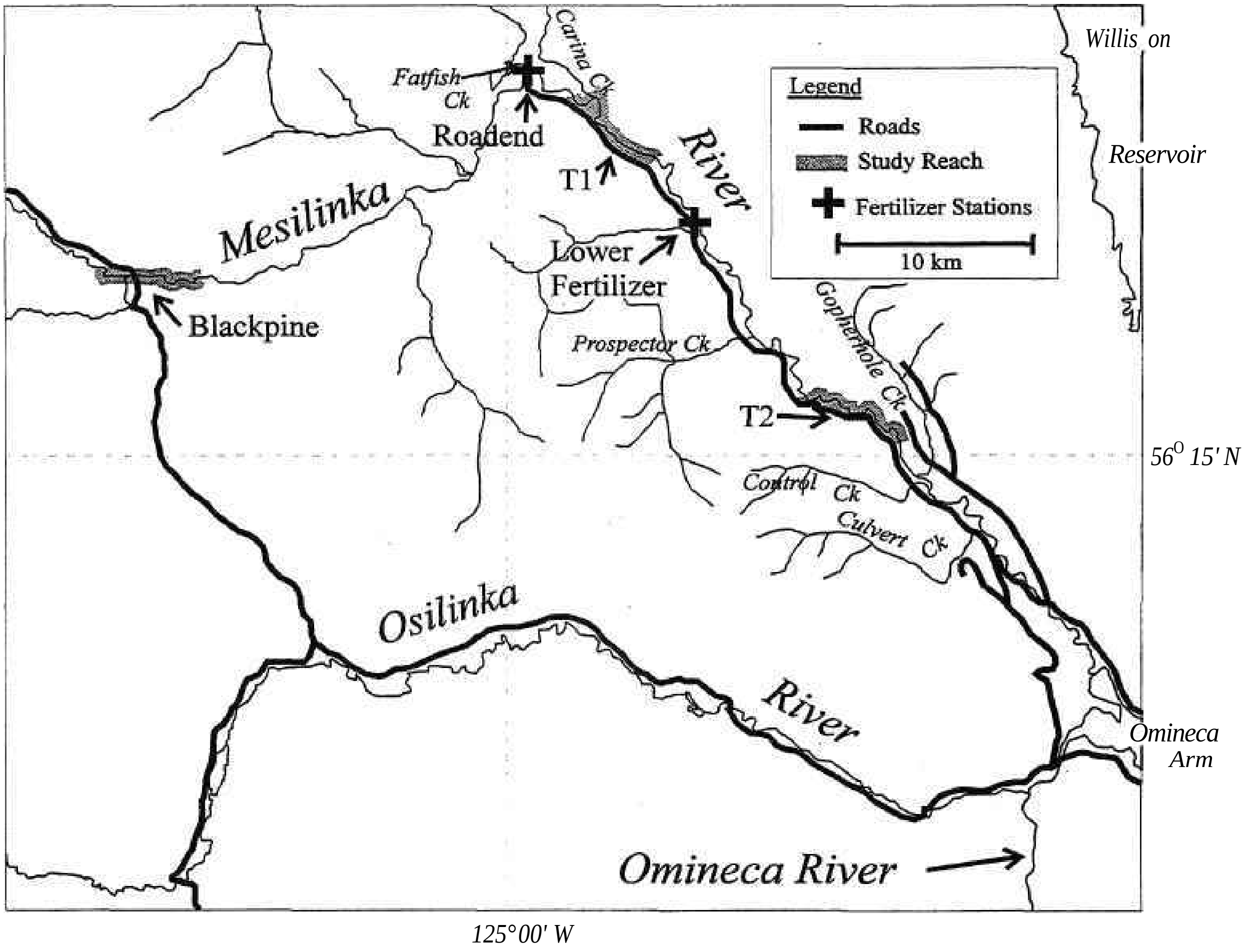

Figure 2 - Mid to lower portion of the Mesilinka River.

METHODS

Methods utilized in 1995 were consistent with those followed in previous years for the Mesilinka River (Koning et al. 1995). Furthermore, the methods followed for the Mesilinka Fertilization Project are similar to a number of fertilization projects headed by the Fisheries Research and Development section within the Ministry of Environment, Lands and Parks. These methods have been described elsewhere (Slaney et al. 1993; Toth et al. 1993; Koning et al. 1995; Paul et al. 1996). Methods for the Mesilinka River in 1995 are outlined below.

Hydrology

Daily discharge from the Mesilinka and Nation rivers was obtained from the Water Survey of Canada (WSC). WSC monitor discharge from 1 site on the Mesilinka (approx. 20 km from its mouth) and 2 sites on the Nation. Daily discharge rates for the Mesilinka River were required to set fertilizer drip rates that would achieve target nutrient loading. Therefore, discharge was estimated from the stage-discharge relation of Paul et al. (1996)

$$Y = 10^{(0.81X \ +1.557)} \qquad (1)$$

where Y is the estimated discharge ($m^3 \ s^{-1}$) at the WSC station *and* X *is* the staff gauge reading (m) from the Blackpine reach.

Discharge readings for the 5 tributaries were determined directly from instream discharge measurements. Instream measurements of discharge were taken for each of the tributaries between 2 June and 29 August 1995. Discharge was calculated by summing flows from cells at 0.5 m intervals across the creek. Flows from the individual cells were calculated by multiplying velocity by cell area (0.5 m X water depth). Velocities were measured at 60% total depth from the surface using a Marsh-McBirney current meter. Water level readings (ie., stage) were taken from staff gauges located in each of the tributaries weekly to biweekly between the same intervals. However, these readings were not used in 1995 to estimate discharge based on the stage-discharge relations of Paul et al. (1996). This was a result of the staff gauges in Culvert, Gopherhole and Carina creeks needing to be replaced in the spring of 1995 and the staff gauge in Control Creek showed a poor relation between estimated and measured discharge. Stage-discharge relations were not recalculated in 1995 as too few instream measurements existed for Control, Carina and Fatfish creeks; and, the instream measurements for Gopherhole and Culvert creeks were nearly equal to staff gauge readings making a stage-discharge relation pointless.

Water Temperatures

The growth rates of periphyton, invertebrates and fish are dependant on ambient thermal regimes. Water temperatures were recorded at 2 sites in the Mesilinka River (Blackpine and Gratton's; Fig. 3) and 1 site in the Nation River (Fig. 1) using remote thermographs (Onset

Instruments, Pocasset, MA.) that digitally record temperature every 2 hours. Water temperatures of the five tributaries at sites near their mouths (Fig. 3) were also recorded using these thermographs. Thermographs were installed by mid June and removed at the end of August. Temperatures from the thermographs for 1995 are summarized in Langston (1995).

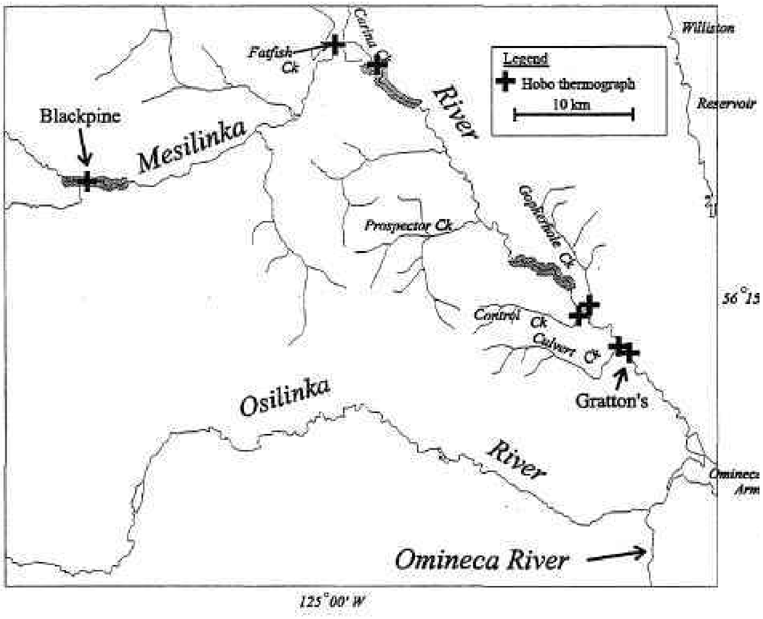

Figure 3 - Location of thermographs in the Mesilinka River and tributaries.

Mesilinka Mainstem Fertilization

Fertilization of the two treatment reaches, T1 and T2 (Fig. 2), in 1995 was initiated on the 27th of June. The two fertilizer stations on the Mesilinka River, an upper one at Roadend and a lower station approximately 20 km downstream (Fig. 2), were established to administer both inorganic N and P to the river at two locations. Nitrogen was added in solution as urea-ammonium nitrate, 28-0-0 (values indicate percent weight of solution containing N - P_2O_5 - K_2O, respectively) and P was added in solution as ammonium polyphosphate, 10-34-0 (14.9 % P by weight), also an additional source of N (10 % by weight). Instream target concentrations of N and P were 15 $\mu g\ L^{-1}$ and 5 $\mu g\ L^{-1}$, respectively. In contrast to 1994 when only ammonium polyphosphate was used at the lower fertilizer station, both ammonium polyphosphate and urea-ammonium nitrate were utilized in 1995 at the Roadend and lower fertilizer station. Total weight of 28-0-0 and 10-34-0 fertilizer used at Roadend was approximately 14 and 15 tonnes, respectively; and for the lower fertilizer station 13 and 14 tonnes, respectively.

Fertilizer additions were set by metering drip rates to preset amounts that would achieve target concentrations at a given river discharge. Drip rates were calculated from the mean of 2-3 repeated volumetric measurements of fertilizer taken over 2 minutes. River discharge was estimated from the stage-discharge relationship for Blackpine staff gauge readings and WSC discharge readings described previously in the hydrology section. Arrival drip rates, measured before adjusting rates, and departure rates, measured after resetting rates, were calculated every 3-4 days.

Estimated fertilizer loadings of N and P to the Mesilinka River were calculated using measured arrival and departure drip rates and actual WSC daily discharge readings for 1995. The assumption was made that discharge at each fertilizer stations was equal to the discharge at WSC station approximately 45 km downstream from Roadend. Drip rates were interpolated based on the assumption that rates changed linearly at departure on day D and arrival on day D + x (where x is the number of days between readings). Estimated daily loading rates and mean summer loadings were calculated up until the end of August. Drip rates continued through September until most of the tanks were empty.

Mesilinka Tributaries Fertilization

In 1993, a pilot fertilization study of Culvert and Gopherhole creeks was undertaken to increase production of juvenile fish (Koning et al. 1995). Ammonium-polyphosphate liquid fertilizer, identical to that used in the mainstem Mesilinka River, was utilized in 1993 for tributary fertilization. However, the gravity-fed drip system was difficult to calibrate for these low-discharge creeks; and, Koning et al. (1995) recommended the use of slow-release solid fertilizers. During 1995, the Nutri-Stone briquettes developed by IMC Vigoro Inc. in cooperation with B.C. Environment (Mouldey and Ashley 1996) were used to fertilize Culvert and Gopherhole creeks. The Nutri-Stone briquettes consist of 17.7% P and 6.7% N by weight, dissolve at a rate of approximately 0.5%•day^{-1} and retain a relatively constant chemical composition over time (Mouldey and Ashley 1996). The weight of solid fertilizer placed in Culvert and Gopherhole creeks was 149 kg and 111 kg, respectively.

Daily loading of P and N to Culvert and Gopherhole Creeks was estimated from the above dissolution rate of the Nutri-Stone briquettes and estimated daily discharge for each of the creeks. The loss rate of phosphorus from the briquettes can be described as

$$\frac{dW_p}{dt} = -R \cdot W_p \qquad (2)$$

where R is the dissolution rate (day^{-1}) and W_p is the weight of P in the briquette. Therefore, the loading rate of P to a stream from the solid fertilizer is equal to the flux from the briquettes minus the loss of P downstream. This loading (weight•day^{-1}) can be converted to a P concentration (C_p, weight•L^{-1}) by dividing by discharge (Q). The rate of change in C_p is described by

$$\frac{dC_p}{dt} = \frac{1}{Q}(R \cdot W_p - Q \cdot C_p) \quad .$$

The term $R \bullet W_p$ describes the influx of P from the briquettes and $Q \bullet C_p$ is the loss of fertilizer derived P downstream. Because Q is time (t) dependent but not easily described as a function of t, we used a discrete time version of the model described by equations 2 and 3. Simply, we made the rather bold assumption that W_p and Q are relatively constant over a given day, then solving equation 3 under equilibrium conditions for that day leaves

$$C_p = \frac{R \cdot W_p}{Q} \quad . \qquad (4)$$

We interpolated daily discharge (Q) by assuming discharge changed linearly between successive dates that staff gauge readings were taken. Finally, daily estimates of W_p can be determined by integrating equation 2 leaving

$$W_p = W_i e^{-Rt} \qquad (5)$$

with W_i being the initial weight of P in the fertilizer briquettes.

Water Chemistry

Dissolved nutrients were monitored to assess: a) mainstem and tributary nutrient limitation on stream production, b) nutrient loading from the tributaries to the mainstem, and c) the downstream fate of added nutrients from fertilization. Water chemistry samples were collected and processed as described by Perrin et al. (1987). All analyses were carried out by Zenon Environmental Laboratories of Burnaby following standard methods outlined in APHA (1985). Samples were collected from each of the reaches of the Mesilinka (mid-reach), the Nation and the five tributaries biweekly from 20 June to 29 August (Fig. 4). An upper and lower site on Gopherhole and Culvert creeks were sampled, the upper sites were located above the fertilizer briquettes (Fig. 4). The nutrient parameters monitored were NO_3+NO_2-N, NH_4-N, total dissolved N, soluble reactive phosphorus (as dissolved ortho-P) and total dissolved phosphorus.

Total organic nitrogen, total nitrogen and total phosphorus were also measured. Water samples were kept cool with ice and shipped within two days to Zenon labs.

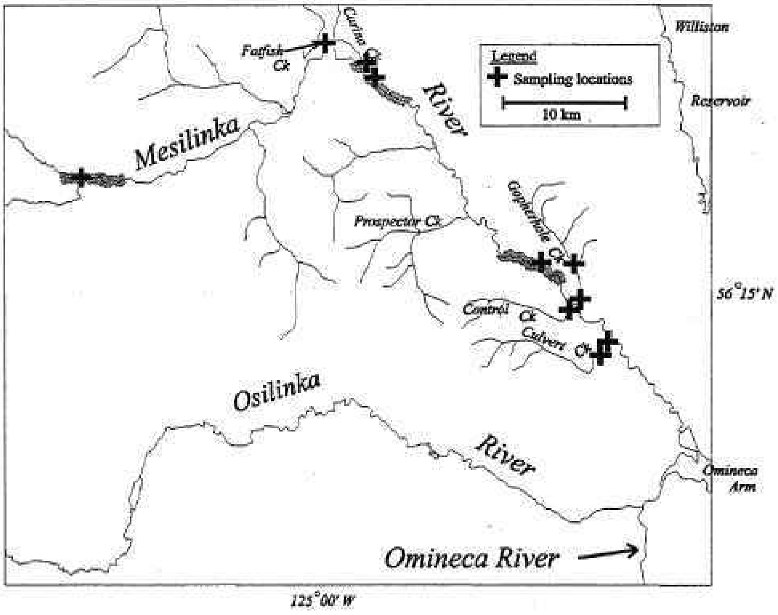

Figure 4 - Sampling locations for water chemistry from the Mesilinka River and tributaries.

Periphyton Accrual

Areal chlorophyll a, as measured from artificial substrates, provides a good index of the effects of nutrient addition on periphyton growth and biomass (Perrin et al. 1987). We measured chlorophyll a accrual and peak biomass on artificial substrate using methods described by Perrin et al. (1987) and Bothwell (1988). The artificial substrate consisted of styrofoam (0.40 m X 0.20 m X 0.006 m) attached to a plexiglass plate with stainless steel wire and bolted to a concrete block. Periphyton blocks were placed in moderate riffles at a depths of about 0.4 m. Blocks were moved as water levels varied to ensure that blocks were not washed away at high flows or left dry at low flows.

Periphyton blocks were installed at 6 locations on the mainstem Mesilinka (Blackpine, Tl, Mid-Launch, T2, Gratton's and the lower bridge; Fig. 5) and one site on the Nation by mid-July and removed at the end of August. The six sites on the Mesilinka River were approximately

100, 62, 34, 23, 12 and 7 km downstream, respectively, from the mouth of the Mesilinka River (Koning et al. 1995). Periphyton blocks were installed in the 5 tributaries (2 sites in Gopherhole and Culvert creeks) by mid-July and removed at the end of August (Fig. 5).

Duplicate chlorophyll a samples were collected biweekly from each block. A 7 dram vial was used to extract a circular sample of styrofoam with attached algae. Samples (2 vials per block) were carefully labeled, wrapped in aluminum foil and frozen until analysis. Chlorophyll a concentrations (mg m^{-2}) from the styrofoam samples were measured at Zenon Laboratories using acetone extraction and spectrophotometry (Strickland and Parson 1972). The minimum detectable limit for chlorophyll a was 0.3 mg m^{-2}.

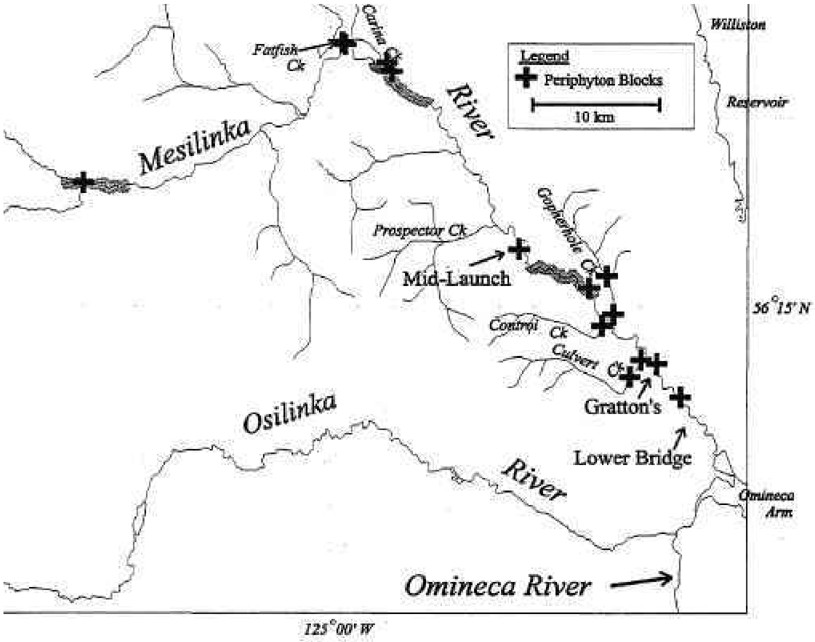

Figure 5 - Location of periphyton blocks on the Mesilinka River and its tributaries.

Benthic Insect Biomass

The response of aquatic invertebrates to fertilization was assessed by measuring colonization of invertebrates on artificial substrates (Slaney and Ward 1993). The artificial substrate consisted of a cylindrical plastic basket (0.22 m in diameter and 0.13 m) filled with clean gravel (0.03 m - 0.06 m) as substrate. Ten baskets were placed in riffle areas within each of the study reaches on the Mesilinka River in mid-July (Fig. 6). Five baskets were installed in a riffle on the Nation River, also in mid-July. Baskets were surrounded with cobbles to prevent dislodgement and some baskets were moved deeper as water levels receded. Two baskets from T1 and one from the Nation River were lost over the course of the summer. All baskets were removed after 6 weeks and colonized invertebrates collected. At removal a Surber sampler (200 µm mesh) was placed directly downstream of the basket and the contents of the basket washed into the Surber sampler. Depths and water velocities (Marsh McBimey current meter) were recorded for each basket on its removal. Contents of the baskets were labeled and preserved in jars with either formalin or ethanol.

Invertebrate samples were sorted at the Ministry of Environment, Fisheries Research Section lab at the Fraser Valley Trout Hatchery, Abbotsford. Samples were sorted by hand at 10 X magnification and total invertebrate wet weight measured. Total invertebrate wet weight was measured using an electronic balance (accurate to 0.001 g) after blotting the organisms to remove excess preservative (Johnston et al. 1990). Benthic invertebrates collected from the artificial substrate samples were identified to genus (or the lowest taxonomic group feasible) and enumerated by Fraser Environmental Services (Surrey, B.C.).

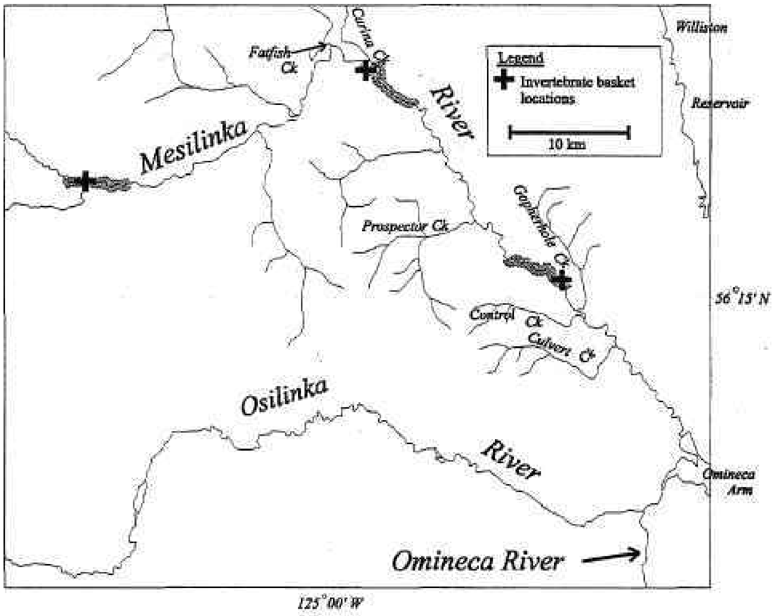

Figure 6 - Location of invertebrate baskets on the Mesilinka River.

Estimated Fish Growth, Abundance and Size Distribution

Adults

Fish were angled from all reaches of the mainstem Mesilinka (Blackpine, T1 and T2) through July and intensively in August. Weight, fork length, scale sample, tag colour, tag number, location and condition of fish at release were recorded for all angled fish. All fish > 200 mm in length were tagged using Floy anchor tags. Fish tagged in July were given green tags and fish tagged in August were given tags colour coded to the reach from which they were captured (Blackpine - blue/white, T1 - green/yellow, T2 - orange/white). Tags were used to facilitate growth estimation upon recapture and allow for a mark-recapture estimate to be conducted from the underwater fish counts.

Fish abundance from the mainstem Mesilinka River was carried out using standardized underwater counts as described in Slaney and Martin (1987). Six experienced divers, equipped with dry suits and snorkels, swam each reach (Blackpine, T1, T2) counting and recording fish species, length (100 mm increments), presence of tags and colour of tag if present. Each reach was replicated once (2 swims per reach) and all underwater counts took place the week of 14 August. Fish densities were calculated from expanded underwater counts and reach areas (see Koning et al. 1995). Briefly, underwater counts were expanded to account for mid-channel regions not covered as described in Slaney and Martin (1987). Reach areas were calculated from lengths (Koning et al. 1995) and mean measured wetted widths.

Size distributions of fish were estimated from both angling data (weight, length and age) and underwater counts (length and abundance) for the mainstem Mesilinka and from angling data only for the Nation River. Size distribution of adult fish from the tributaries was limited to captures while electrofishing for juveniles (see below). Age of angled fish was estimated from scale samples for rainbow trout and Arctic grayling using the technique outlined in Ward and Slaney (1988).

Juveniles (mainstem Mesilinka and Tributaries only)

Size distribution of juvenile fish from the tributaries or the mainstem was obtained from electroshocking suitable rearing habitat in each site. Culvert, Gopherhole and Control creeks were shocked twice during the summer (mid-July and early September). Fatfish and Carina creeks along with several side channels and river margins of the mainstem were shocked once during the summer (late August or early September). Species, fork length, weight, and condition at release were recorded for all rainbow trout, bull trout, Arctic grayling, mountain whitefish, sucker, or cyprinid caught. Lengths and weights were recorded for only a sub-sample of sculpins because of the large number being caught; however, all sculpins were enumerated. Length of channel shocked and shocker time was recorded from all shocking runs. Wetted widths at 10 m intervals were recorded for all shocking runs from the tributaries. Catch-per-unit-shocker-effort was calculated for each shocking run.

Abundance estimates of juvenile rainbow trout, bull trout and mountain whitefish were carried out on Culvert, Control and Gopherhole creeks. Abundance was estimated using Peterson mark-recapture techniques. A 100-200 m section of good rearing habitat was isolated with upstream and downstream stop nets. Fish were captured by electroshocking and marked with a caudal fin clip (see below) and their length taken (marking phase). Marked fish were released back into the stream over the length of the channel shocked, excepting 25 m directly above the downstream stop net. The recapture phase occurred approximately 2.5 hours after releasing the marked fish. During the recapture phase the channel was shocked with the same effort as the marking phase; total shocker time was kept roughly equal for both shocking runs. Recaptured fish were weighed, measured and presence of fin clip noted. Total salmonid abundance (rainbow trout, bull trout and mountain whitefish) was calculated using Chapman's modification of the Lincoln-Peterson mark-recapture estimate

$$N = \frac{(M+1)\cdot(C+1)}{(R+1)} - 1$$

where N is the estimated abundance, M is the number of individuals marked in the first sample, C is the number of individuals captured in the second sample and R is the number of recaptures (White et al. 1982). These estimates are unbiased if $(M+C) \geq N$ and nearly unbiased if $R > 7$ (Krebs 1989). Binomial confidence intervals were calculated for the abundance estimates according to Krebs (1989). Density was calculated by dividing total abundance by the area shocked; area shocked was calculated by multiplying length between stop nets with mean wetted width.

Statistical Analysis

The Mesilinka River Fertilization Project was designed following the methodology of Stewart-Oaten et al. (1986). They proposed a sampling scheme designed to detect the effect of a given perturbation on a single system sampled through time. Simply the methodology relies on temporal series of samples taken Before and After a perturbation simultaneously at both a Control and Impact site (and is called a BACI design). Stewart-Oaten et al. (1986) make clear that the intent of the statistical analysis for the BACI design is to detect the impact of a perturbation *on a given system.* The use of inferential statistics for the much broader question "what is the effect of a perturbation on a population of systems" requires replicated systems.

The essential principal behind the BACI design is that the response variables of interest are not individual measurements at control or impact locations; but rather, the difference between these measurements taken over time. Inferential statistics are then applied to the differences in mean values from either the before or after period (Stewart-Oaten et al. 1986). The BACI design is replicated through time provided there are > 2 before and after sampling times for a single system and the following assumptions are met. The two key assumptions to the BACI design are a) constancy of differences and b) the independence of observed differences calculated at different times (Stewart-Oaten et al. 1986). We will leave the reader to consult Stewart-Oaten et al. (1986) for a detailed discussion of these assumptions; and rather, present here methods used to test for these assumptions. Constancy of differences implies that the difference between the impact and control site are additive; which can be tested using the Tukey test for nonadditivity (Tukey 1949). In our case, a slope not different from zero for the regression of differences against averages indicates additivity (Stewart-Oaten et al. 1986). The failure in additivity may be a result of a problem in scale where transformation of the data (e.g., log transformation) will result in additivity (Stewart-Oaten et al. 1986). The assumption of independence in differences was tested using the von Neumann ratio test (Stewart-Oaten et al. 1986). If D_{ij} represents the difference in values between the impact and control site during period *i* (either before or after) at time j, then we calculate

$$Q = \frac{\sum (D_{i,j+1} - D_{ij})^2}{\sum (D_{ij} - D_{i.})} \qquad (7)$$

where $D_{i.}$ is the average of D_i over all *j*'s. Small values of Q indicate a correlation in successive values of Q which suggests non-independence for the differences. Significance of the Q statistic can be determined from Hart (1942) using *nQ/(n-1)* where *n* is the number of differences and significance indicates the ratio *(nQ/(n-l)}* is not different from zero. For all test, statistical significance was set with the probability of committing a Type I error at less than 5%.

Underwood (1992, 1994) criticized the approach of Stewart-Oaten et al. (1986) due to its lack of spatial replication. The BACI design depends on the assumption that the difference in control and impact locations is not changing relative to each other through time even in the absence of the perturbation under question (i.e., assumption of constancy in differences). Although acknowledged by Stewart-Oaten et al. (1986), Underwood (1992, 1994) presents a solution by using additional control locations (assuming that additional treatment locations are not feasible). Data are then analyzed using an involved analysis-of-variance which we again leave readers to consult its original presentation (Underwood 1992, 1994). We recommend that the methodology of Underwood (1992, 1994) be further explored in the final analysis of the Mesilinka River Fertilization Project as the experimental design utilizes more than one control location (e.g., Nation River) for measures of periphyton accrual, benthic invertebrate biomass and size-at-age for rainbow trout.

RESULTS AND DISCUSSION

Hydrology

Discharge from the Mesilinka River in 1995 was similar to 1994 in that it consisted of several spring freshets between May-early July (Fig. 7). This contrasts the previous two years where spring run-off was dominated by a single large flow event (Fig. 7). Maximum flows in 1992 and 1993 were 349 and 254 $m^3 \cdot s^{-1}$, respectively, compared to only 185 and 193 $m^3 \cdot s^{-1}$ in 1994 and 1995, respectively. Discharge in all years decreased below 75 $m^3 \cdot s^{-1}$ by late July and remained below this value for the remainder of the year except for brief flow events that were likely rain driven (Fig. 7). Therefore, despite a marked difference in spring discharge between pretreatment (1992-1993) and treatment years (1994-1995) their does not appear to be a lasting trend through the summer months when field work and fertilization were carried out (Fig. 7).

Discharge from each of the tributaries was similar in 1995 to previous years (Fig. 8; Paul et al. 1996; Koning et al. 1995). However, discharge for Control, Carina and Fatfish creeks in 1995 are based on few observations and poorly describe discharge for these creeks over the summer (Fig. 8). Peak flows for Gopherhole, Control, Culvert, Carina and Fatfish creeks were similar to previous years, excepting 1992 (Table 1). Measurements in 1992 did not begin until mid-July and likely missed any run-off events (Koning et al. 1995).

Table 1 - Peak discharge for tributaries to the Mesilinka River as determined from instream measurements. Measurements were taken between late June and the end of August, except in 1992 when measurements began in mid-July.

	Year			
Creek	**1992**	**1993**	**1994**	**1995**
Gopherhole Ck.	0.24	2.09	2.51	2.87
Control Ck.	0.35	1.88	2.33	1.47
Culvert Ck.	0.37	4.10	4.56	3.67
Carina Ck.	3.00	5.83	4.05*	3.24
Fatfish Ck.	n.a.	0.39	0.27	0.26

* - estimated from stage-discharge relationship
n.a. - not available

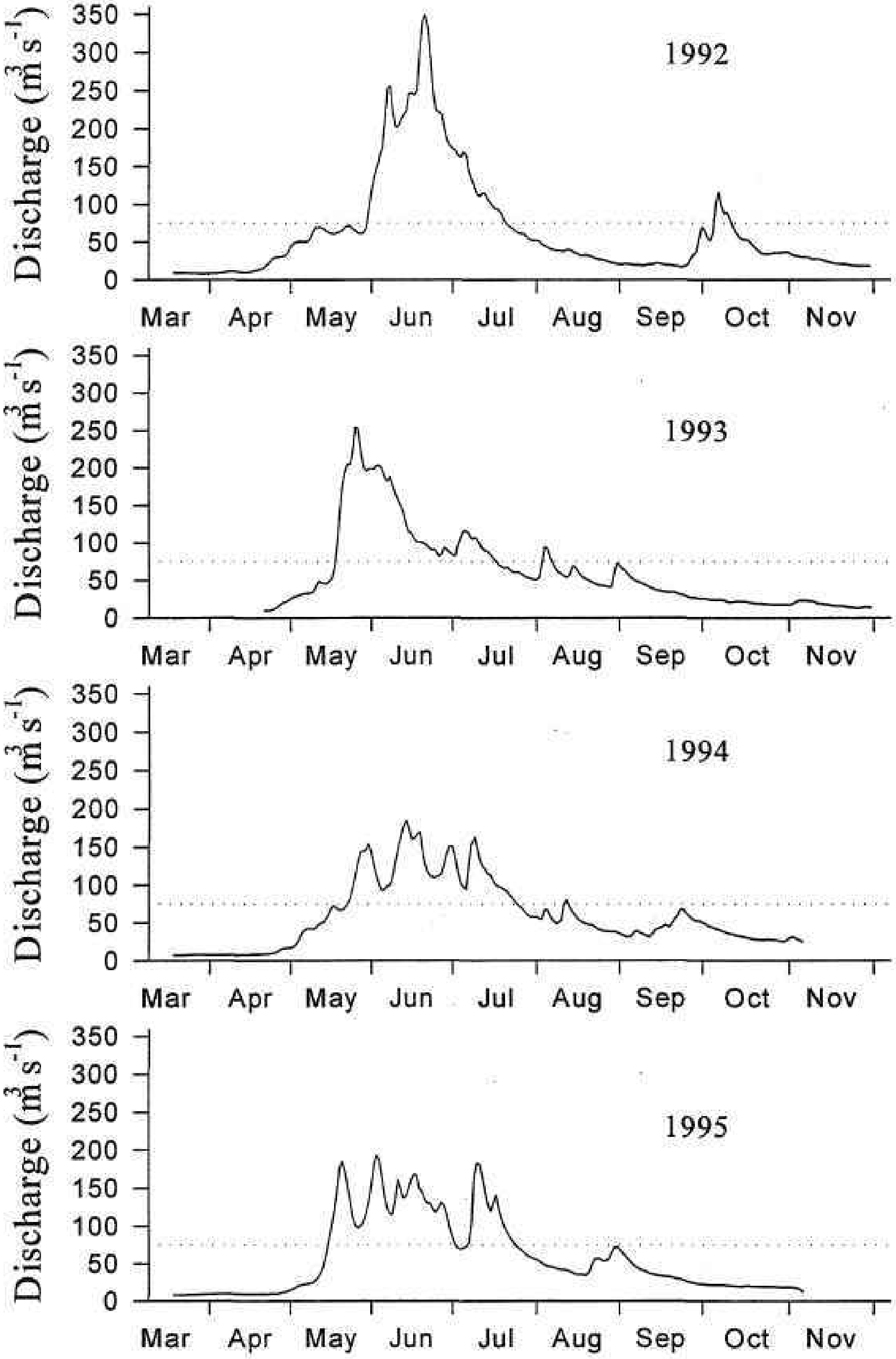

Figure 7- Daily discharge from the Mesilinka River measured by WSC for 1992 - 1995. Dotted line indicates 75 $m^3 \cdot s^{-1}$ flows for reference.

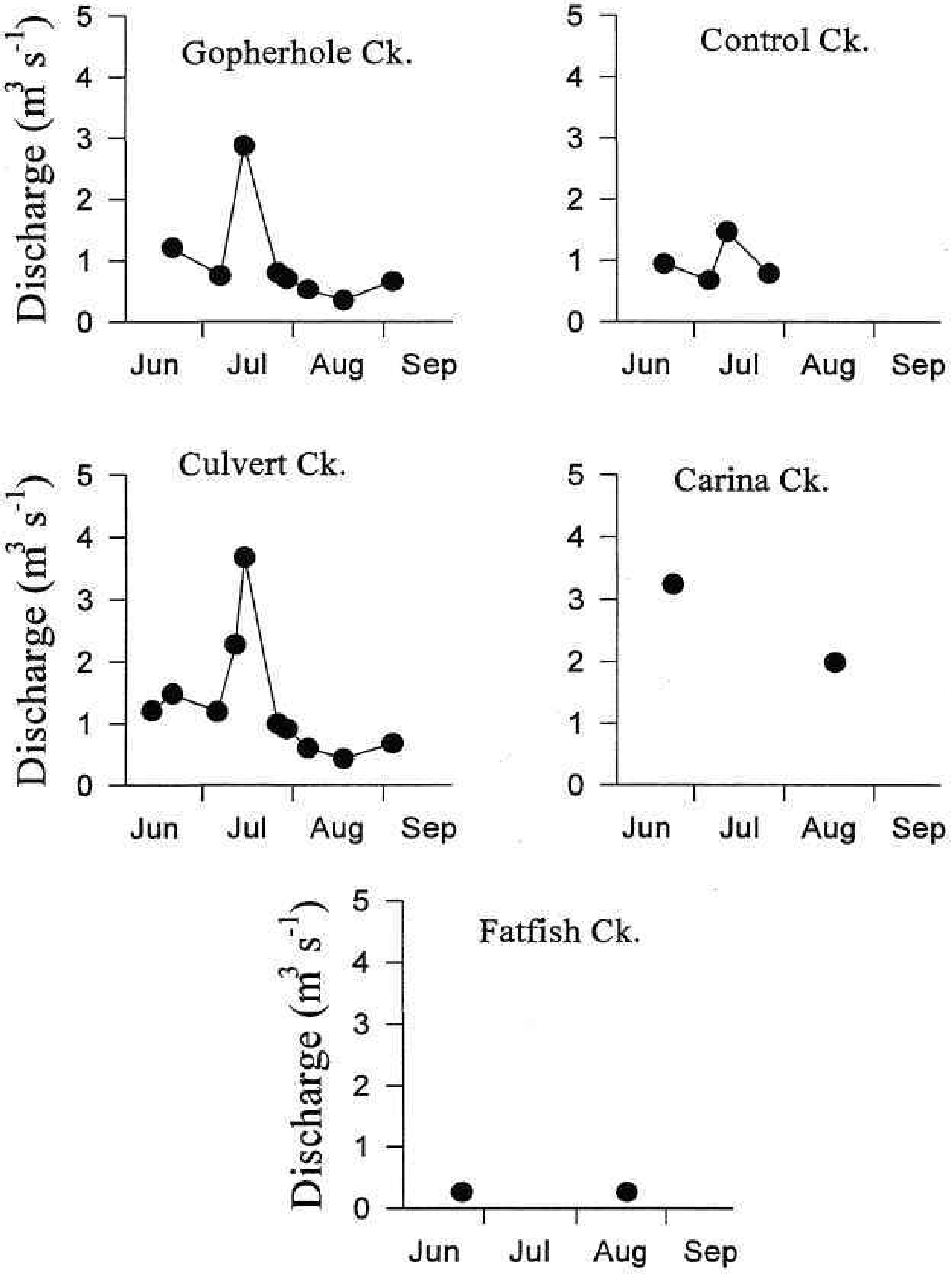

Figure 8 - Discharge from five tributaries of the Mesilinka River for 1995. Discharge values are from instream measurements.

Water Temperature

Water temperatures for the Mesilinka River at Gratton's (Fig. 9) ranged between a minimum of 8.8°C and a maximum of 13.8°C from the 18th of June to the 28th of August, 1995 (Fig. 9). During the same period, water temperatures were similar 85 km upstream at Blackpine with a minimum of 9.8°C and a maximum of 13.3°C (Fig. 9). Maximum temperatures were greater in 1992 and 1994 at 14.4 and 14.7°C, respectively, for Blackpine and 15.4 and 15.5°C, respectively, for Gratton's (Fig. 9). Maximum water termperatures in 1993 were 14.6 and 13.3°C for Gratton's and Blackpine, respectively, which are similar to 1995. The difference between water temperatures at Blackpine and Gratton's were the lowest in 1995 compared to previous years (Fig. 10). The mean difference was 0.78°C for 1992, 0.24°C for 1993, 0.51 °C for 1994 and 0.13°C for 1995 (Fig. 10).

Mean August temperatures were the coldest in 1995 when compared to 1992-1994 for both the Mesilinka and Nation rivers (Fig. 11; Table 2). For all years, the monthly mean temperatures, during July and August, for the Nation River were 2-4 °C warmer than the Mesilinka River. Mean August temperatures of Control, Culvert and Gopherhole creeks were also lower in 1995 compared to previous years (Fig. 11; Table 2). Whereas, Carina and Fatfish creeks were similar to, or warmer than, previous years (Fig. 11; Table 2).

Table 2 - Mean monthly temperatures for two sites on the Mesilinka River (Blackpine and Gratton's), the Nation River and 5 tributaries to the Mesilinka River. July and August are presented as complete daily thermograph records exist only for these months.

	1992		**1993**		**1994**		**1995**	
Location	**July**	**August**	**July**	**August**	**July**	**August**	**July**	**August**
Blackpine	11.6	12.1	11.2	11.9	11.8	12.9	11.5	11.2
Gratton's	12.6	12.8	11.5	12.1	12.2	13.4	11.6	11.3
Nation	16.9	16.8	14.4	15.4	16.1	17	16.1	15.1
Carina	n.a.	n.a.	13.6	14.4	12.2	13.4	14.4	13.8
Control	n.a.	n.a.	7.4	8.2	n.a.	n.a.	7.8	7.4
Culvert	n.a.	n.a.	8.2	9	9.1	10	8.6	8.2
Fatfish	n.a.	n.a.	n.a.	n.a.	9.8	7.4	10.8	9
Gopherhole	n.a.	n.a.	8.3	9.1	8.9	10.6	8.5	8.2

n.a. - not available

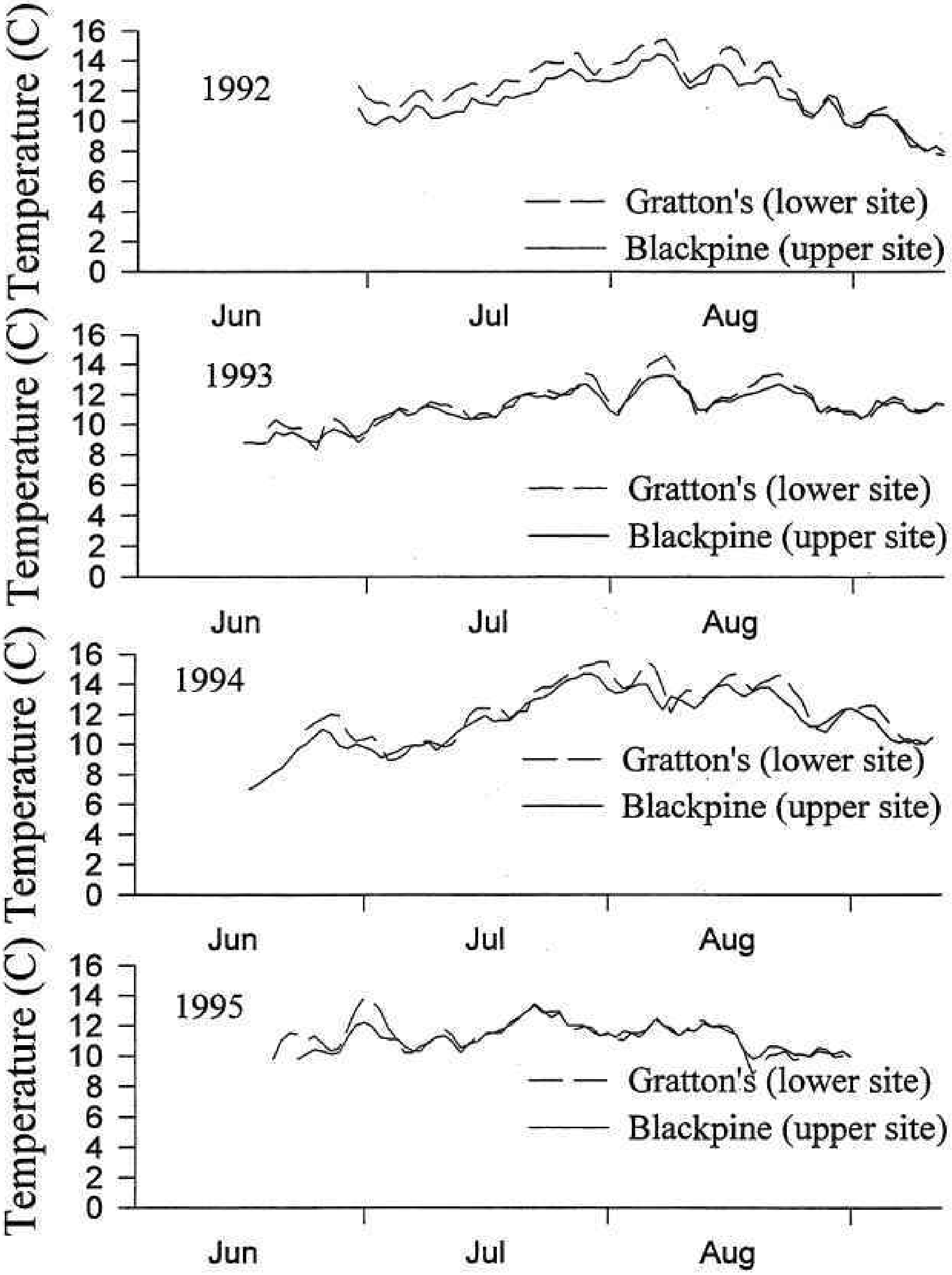

Figure 9 - Mean daily temperatures from two locations of the Mesilinka River separated by a distance of approximately 85 km.

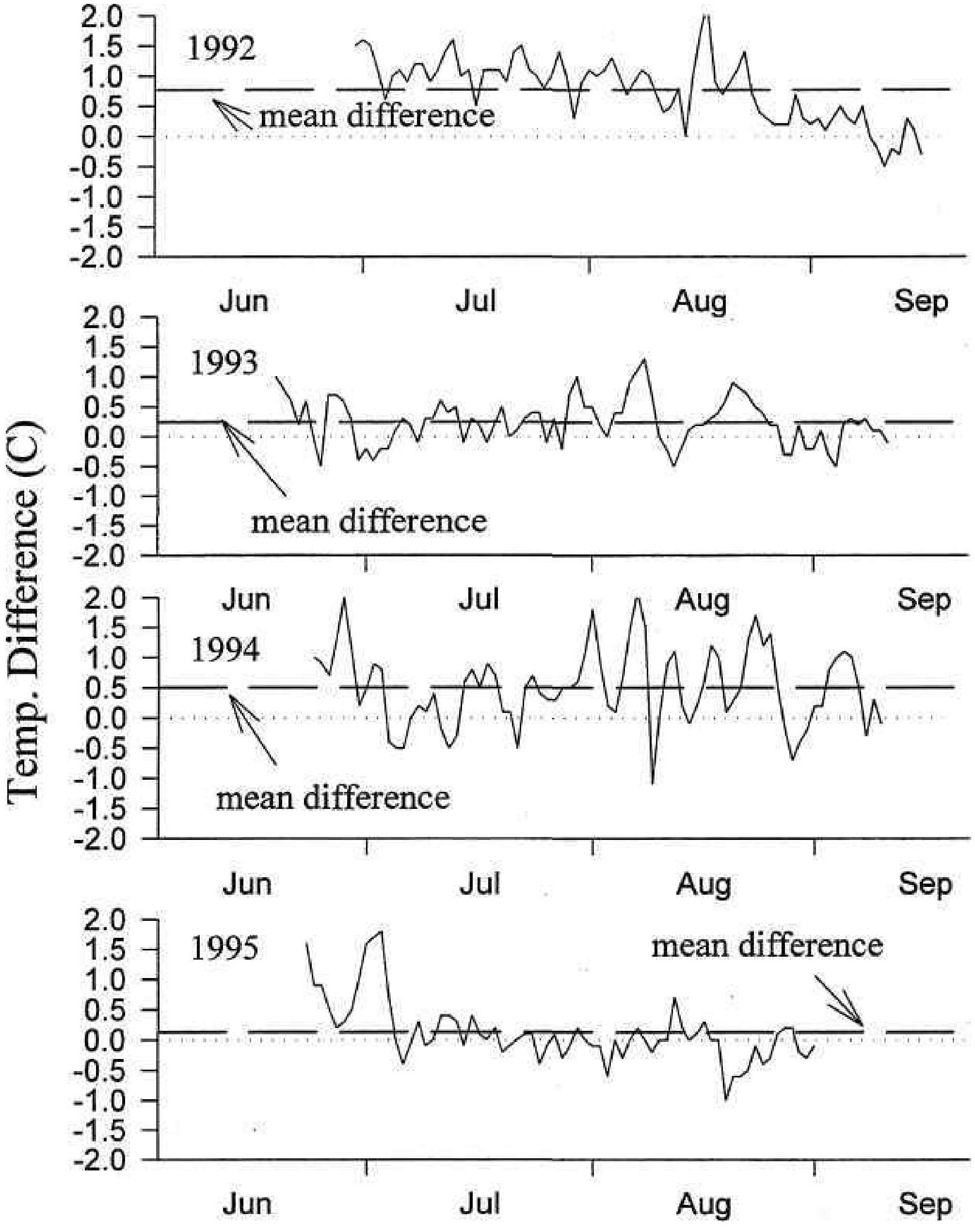

Figure 10 - Difference between mean daily temperatures taken from Gratton's and Blackpine on the Mesilinka River. Mean differences (see text) are indicated.

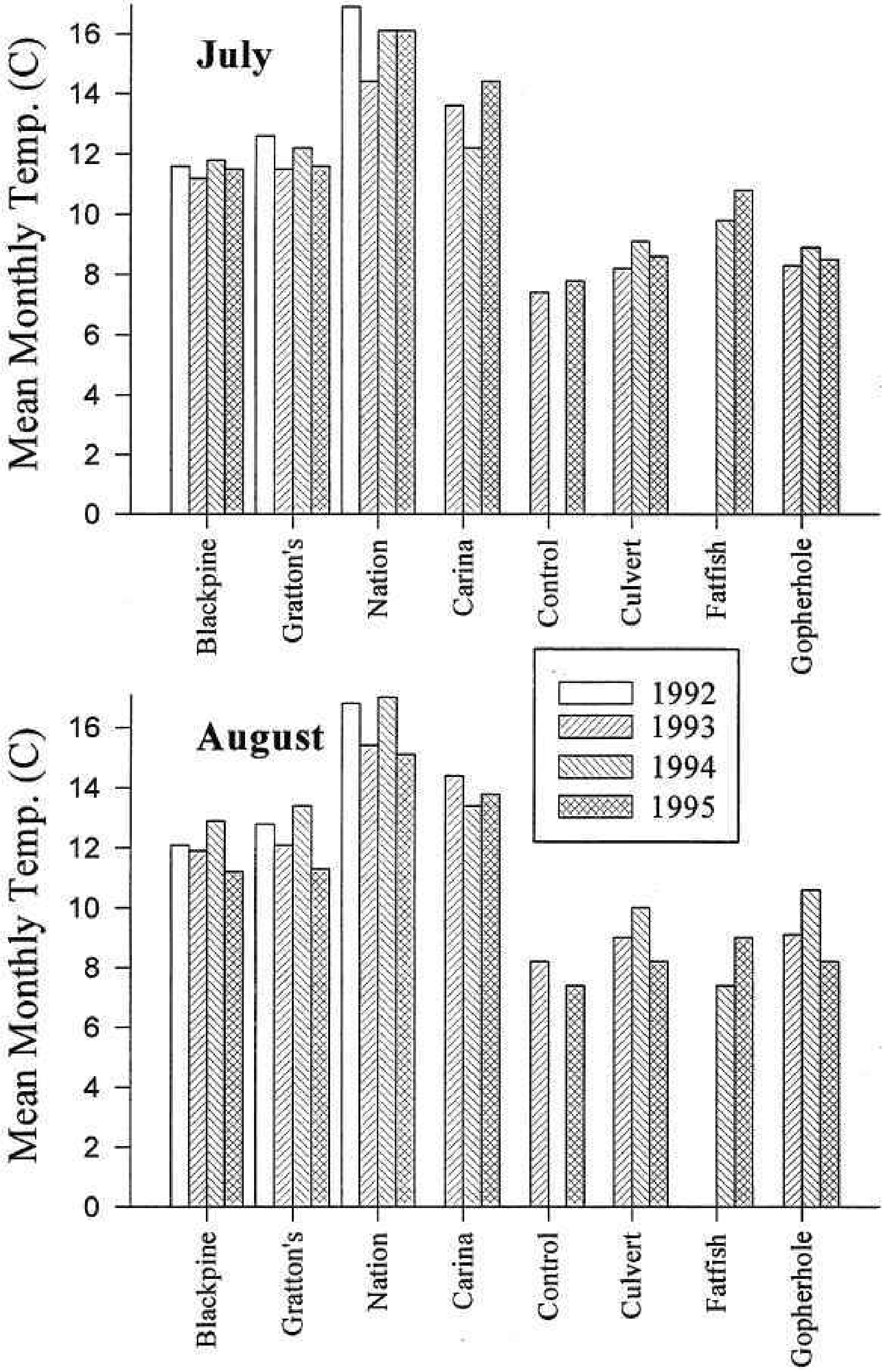

Figure 11 - Mean monthly temperatures for two sites on the Mesilinka River (Blackpine and Gratton's), the Nation River and 5 tributaries to the Mesilinka River. Raw data values are given in Table 2.

Mainstem Mesilinka Fertilization

The mean estimated daily summer loading of P and N at the upper fertilizer station (Roadend) in 1995 was 3.5 and 9.9 µg•L^{-1}, respectively (Fig. 12; Table 3). This is significantly less than the estimated 1994 mean daily P loading but similar to the N loading (Table 3). However nutrient uptake by algae is not only dependent on mean nutrient concentrations, but also on the variability in nutrient concentrations. The daily variability in estimated N loading, from its summer mean, was significantly greater in 1994 (Table 3).

Table 3 - Mean loading rates (µg•L^{-1}) of P and N to the Mesilinka River for 1994 and 1995 as estimated from discharge and fertilizer drip rates (see text). The number of days (N), standard deviation (SD) and mean of the absolute value for residuals are also shown. The residuals are deviations of the daily loadings from the mean loading and provide an indication in the fluctuation (either + or -) for fertilizer loading. Statistically significant differences between years for mean loading and mean residuals were tested using a t-test, excepting N in the lower station since ammonium nitrate was not used in 1994.

Location	Fertilizer	Year	N	SD	Mean	Mean |Residuals|
Roadend	P	1994	61	0.92	4.55*	0.74 $^{n.s.}$
		1995	62	0.71	3.54	0.61
Roadend	N	1994	61	3.82	8.99 $^{n.s.}$	3.05 *
		1995	62	2.07	9.92	1.62
Lower Station	P	1994	58	1.34	3.58 $^{n.s.}$	1.08 $^{n.s.}$
		1995	60	1.56	3.16	1.13
Lower Station	N	1994	58	0.90	2.41 $^{n.t.}$	0.73 $^{n.s.}$
		1995	60	4.26	9.23	2.88

* - significant difference between years, $P < 0.05$
n.s. - no significant difference between years, $P > 0.05$
n.t. - not tested

Estimated loading of P at the lower fertilizer site was similar among years and with similar variance (Fig. 13; Table 3). Nitrogen loading in 1995 increased by nearly a factor of 4 from 1994 with the addition of ammonium nitrate fertilizer at this station (Table 3). Variability in ammonium nitrate at the lower station was large (Fig. 13) as indicated by the standard deviation in the estimated daily mean N loading and the mean of these residuals.

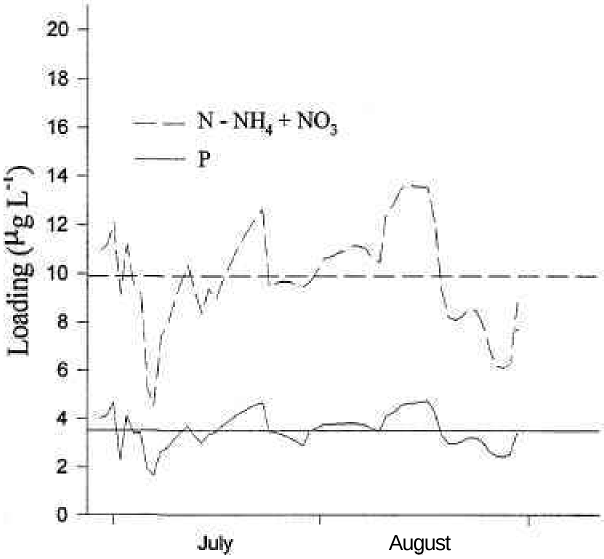

Figure 12 - Estimated 1995 daily loading of P and N at the upper fertilizer station (Roadend). Mean loading rates are shown by the horizontal lines.

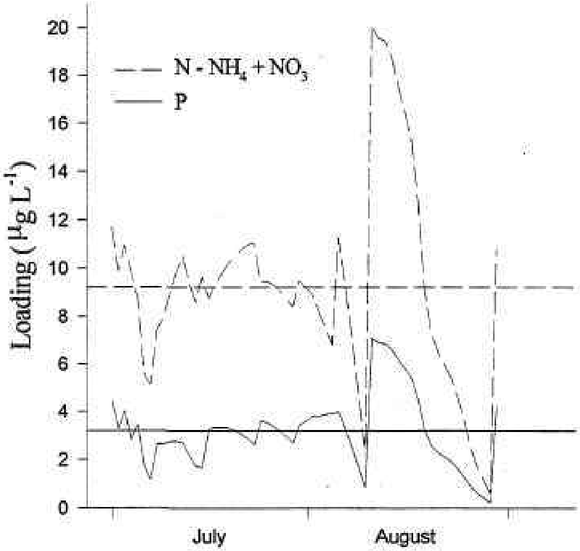

Figure 13 - Estimated 1995 daily loading of P and N at the lower fertilizer station. Mean loading rates are shown by the horizontal lines.

Mesilinka Tributaries Fertilization

The estimated mean daily concentrations of P to Culvert and Gopherhole creeks from the solid fertilizer briquettes were 7.83 and 7.11 µg•L^{-1}, respectively, during the summer (Fig. 14). The temporal dynamics of N from the briquettes would be identical to P but reduced by a factor of 38%. Therefore, mean daily concentrations of N from the briquettes were 2.96 and 2.69 µg•L^{-1} for Culvert and Gopherhole creeks, respectively. Fluctuations in the loading concentrations are driven by both the dissolution of P and N from the briquettes and discharge from the creek (equation 4). Dissolution of P and N shows a constant exponential decline with time (equation 5). Given the dissolution rate of 0.5%•day^{-1}, the time required for P, or N, to reach one-half its original weight is approximately 139 days. Therefore, and not surprisingly, much of the variability in P loading is driven by discharge. Maximum loading of P to both Culvert and Gopherhole creeks occurs in mid-August at 14.73 and 13.61 µg•L^{-1}, respectively (Fig. 14), when discharge for both creeks was at its lowest (Fig. 8). Similarly, minimum loading of P occurred mid-July when discharge was at its greatest (Fig. 8) with P loading at 2.01 and 1.92 µg•L^{-1} for Culvert and Gopherhole creeks, respectively (Fig. 14).

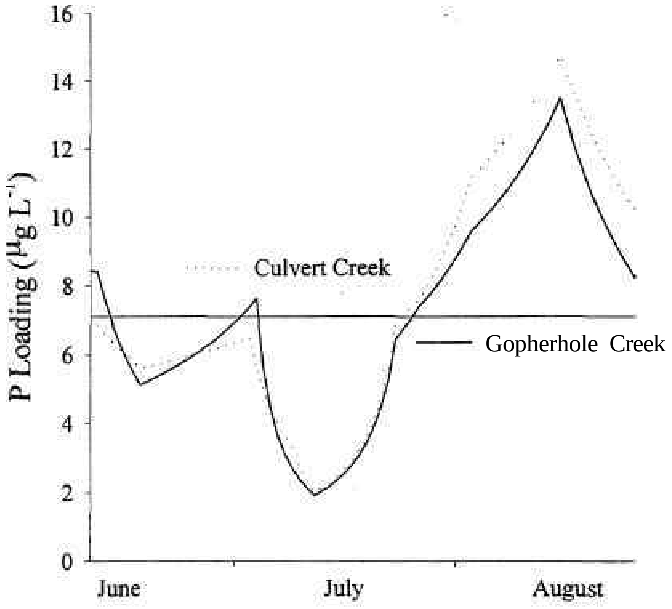

Figure 14 - Estimated 1995 daily loading of P to the Mesilinka River tributaries Culvert and Gopherhole creeks. Mean loading rates are shown by the horizontal lines.

Water Chemistry

In contrast to previous years, soluble reactive phosphorus (SRP) was greater than detection limits for most of the summer in the Nation River and all reaches of the Mesilinka River (Fig. 15; Koning et al. 1995; Paul et al. 1996). During 1994, the Mesilinka and Nation rivers showed a strong "pulse" in SRP during mid-July (Paul et al. 1996); to some extent this pattern was shown in previous years (1992 & 1993), although the less frequent sampling intervals during these years make comparisons difficult (Koning et al. 1995). The observed "pulse" in 1994 was matched by a similar pulse in SRP from the tributary streams during measured peak flow conditions; this lead Paul et al. (1996) to hypothesize that P input to the tributaries, and hence the Mesilinka River, would be positively correlated with discharge due to the proportionally greater source of P from "near-surface" sources (see Prairie and Kalff 1988). Therefore, the high levels of SRP in 1995 may be a result of the higher than average July rainfall in 1995.

Total organic nitrogen (TON) in the Mesilinka River followed a similar trend to inorganic nitrogen with peak values occurring in mid-July (Fig. 15). The similarity in trends between TON and inorganic nitrogen observed in 1995 is consistent with previous years (Koning et al. 1995; Paul et al. 1996). In the Nation River, TON decreased steadily from a peak in June to lows by late August (Fig. 15), which is also consistent with previous years.

Nitrate and nitrite ($NO_3 + NO_2$) levels in the Mesilinka and Nation rivers peaked in mid-July (Fig. 15) with a range in peak values between 15 - 30 $\mu g \bullet L^{-1}$, excepting the Blackpine reach of the Mesilinka River. These peak values, excluding Blackpine, are similar to highs from previous years (Koning et al. 1995; Paul et al. 1996). Peak nitrate and nitrite values in Blackpine also occurred in mid-July but were about a factor of 3 greater at 66 $\mu g \bullet L^{-1}$ (Fig. 15). This is greater than has been previously recorded in any reaches of the Mesilinka River or Nation River combined (Koning et al. 1995; Paul et al. 1996). Nitrate and nitrite accounted for the majority of inorganic nitrogen as ammonium was below detectable levels throughout the summer for the Mesilinka River in 1995. Ammonium increased above detectable levels in the Nation River once during sampling; this occurred on the 1st of August and reached a value of 14 $\mu g \bullet L^{-1}$.

Data from 1995 (Fig. 15) and 1994 (see Fig. 14 in Paul et al. 1996) suggest that fertilization may be leading to a period of N limitation during late July and August (see Conclusions). Pre-fertilization years did not show a low in $NO_3 + NO_2$ during late July or August (Koning et al. 1995) nor does Blackpine reach in any year (Koning et al. 1995; Paul et al. 1996; Fig. 15). In contrast, the two treatment reaches show $NO_3 + NO_2$ at or below detectable levels during late July or August in both 1994 (Paul et al. 1996) and 1995 (Fig. 15).

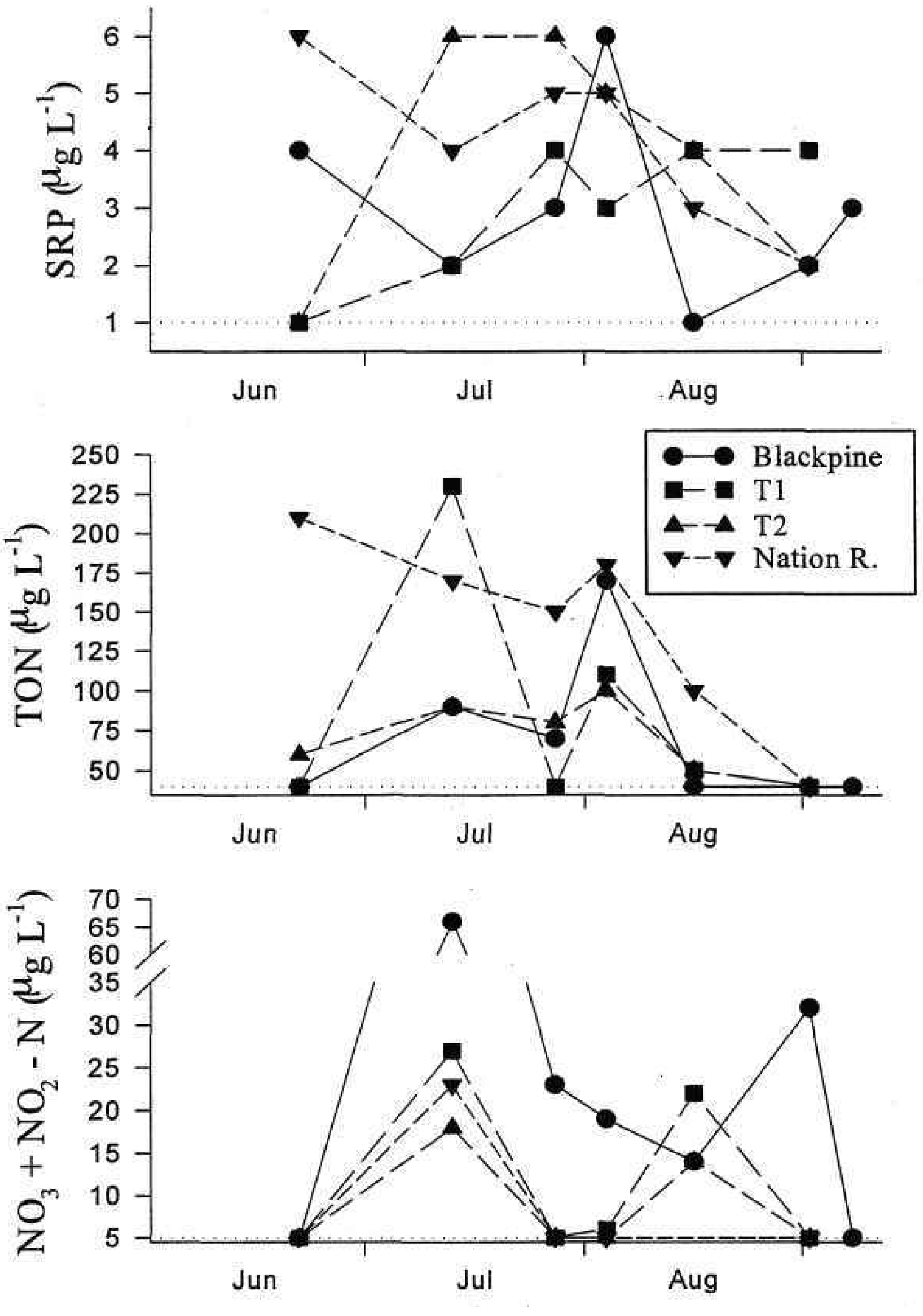

Figure 15 - Soluble reactive phosphorus (SRP), nitrate and nitrite nitrogen ($NO_3 + N0_2$) and total organic nitrogen (TON) from the Mesilinka and Nation rivers (1995). Minimum detectable limits shown by dashed line.

The tributaries showed similar patterns in SRP to the Mesilinka River, with levels relatively higher than previous years and constant through the summer (Fig. 17). A peak in SRP did occur during mid-August in the two fertilized creeks Gopherhole and Culvert at 11 and 10 µg•L^{-1}, respectively, and is approximately 2-3 fold greater than peak values reported in previous years from any of the tributaries (Fig. 17). This peak corresponds to estimated peak loading levels from the fertilizer briquettes in each of these streams (Fig. 16); however, the peak SRP level in 1995 occurs in the upper Culvert Creek site above any fertilizer inputs (Fig. 17). It seems hard to explain the SRP level in upper Culvert Creek given a) the SRP reading at the downstream site was only 4 µg•L^{-1} at the same time, b) the SRP reading is higher than has ever been recorded in any tributary since the study began in 1992 and c) there is a plausible explanation for the high SRP measurements at the lower site from loading of P to the system by the fertilizer briquettes (Fig. 16). If we replace the SRP measurement in lower Culvert Creek during mid-August with the corresponding reading in upper Culvert Creek and compare SRP measurements with estimated fertilizer loading, we can see that there is reasonable agreement between the two for either Culvert or Gopherhole creeks (Fig. 16). This also implies that only a small portion of P derived from the fertilizer briquettes is taken up in the tributary.

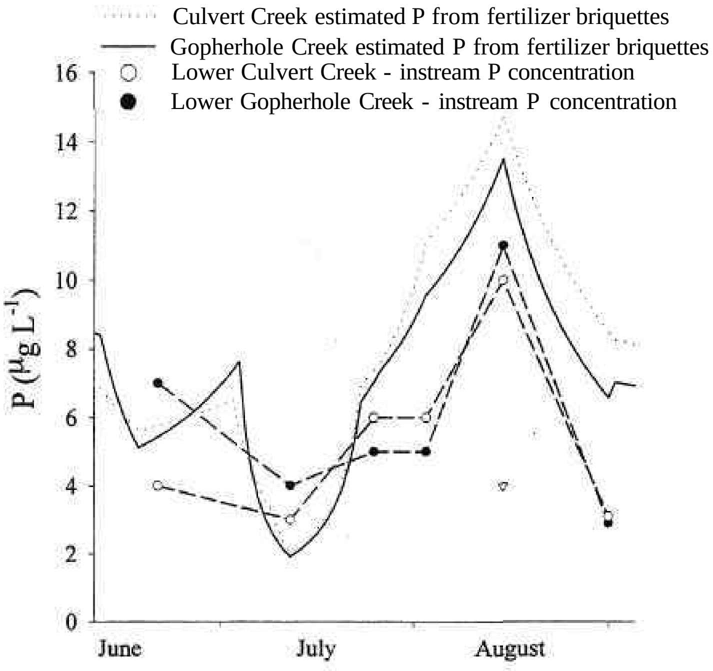

Figure 16 - Comparison of P loading from fertilizer briquettes (Fig. 14) to measured SRP (symbols and lines) in the sites downstream of the briquettes for both Culvert and Gopherhole creeks. The mid-August value for Culvert Creek has been replaced with the upstream SRP reading for reasons outlined in the text. The actual SRP reading for lower Culvert Creek is shown as a single point (inverted triangle).

Total organic nitrogen showed a similar trend among all tributaries during the months of June and July in 1995, with a low in late June and peak in mid-July (Fig. 17). The peak in TON corresponds to the measured peak run-off from the tributaries (Fig. 8). Nitrate and nitrite nitrogen showed a similar peak during mid-July; although less pronounced among all tributaries (Fig. 17). Ammonium nitrogen contributed a small portion of the inorganic nitrogen throughout the summer except in mid-August. Ammonium N reached peak values of 98 and 48 $\mu g \bullet L^{-1}$ in lower and upper Gopherhole Creek sites, respectively (Fig. 18). Culvert Creek also showed higher ammonium nitrogen levels below the fertilizer inputs in mid-August; although, the values were much lower at 15 and 10 $\mu g \bullet L^{-1}$ at the lower and upper sites, respectively (Fig. 18).

During the peak of inorganic nitrogen during mid-July in the tributaries, and assumed to consist solely of nitrate and nitrite nitrogen, there was a significant negative correlation with SRP (Fig. 19). This significant correlation did not exist throughout the summer (Fig. 17), nor does it exist in previous years (see Figs. 14 and 15 in Koning et al. 1995 and Fig. 15 in Paul et al. 1996). The relatively large range in concentrations of inorganic nitrogen and high concentrations of SRP likely allowed this relation to be detected in 1995. While only speculative at this stage, the relationship does suggest that P fertilization within the tributaries may lead to nitrogen limitation.

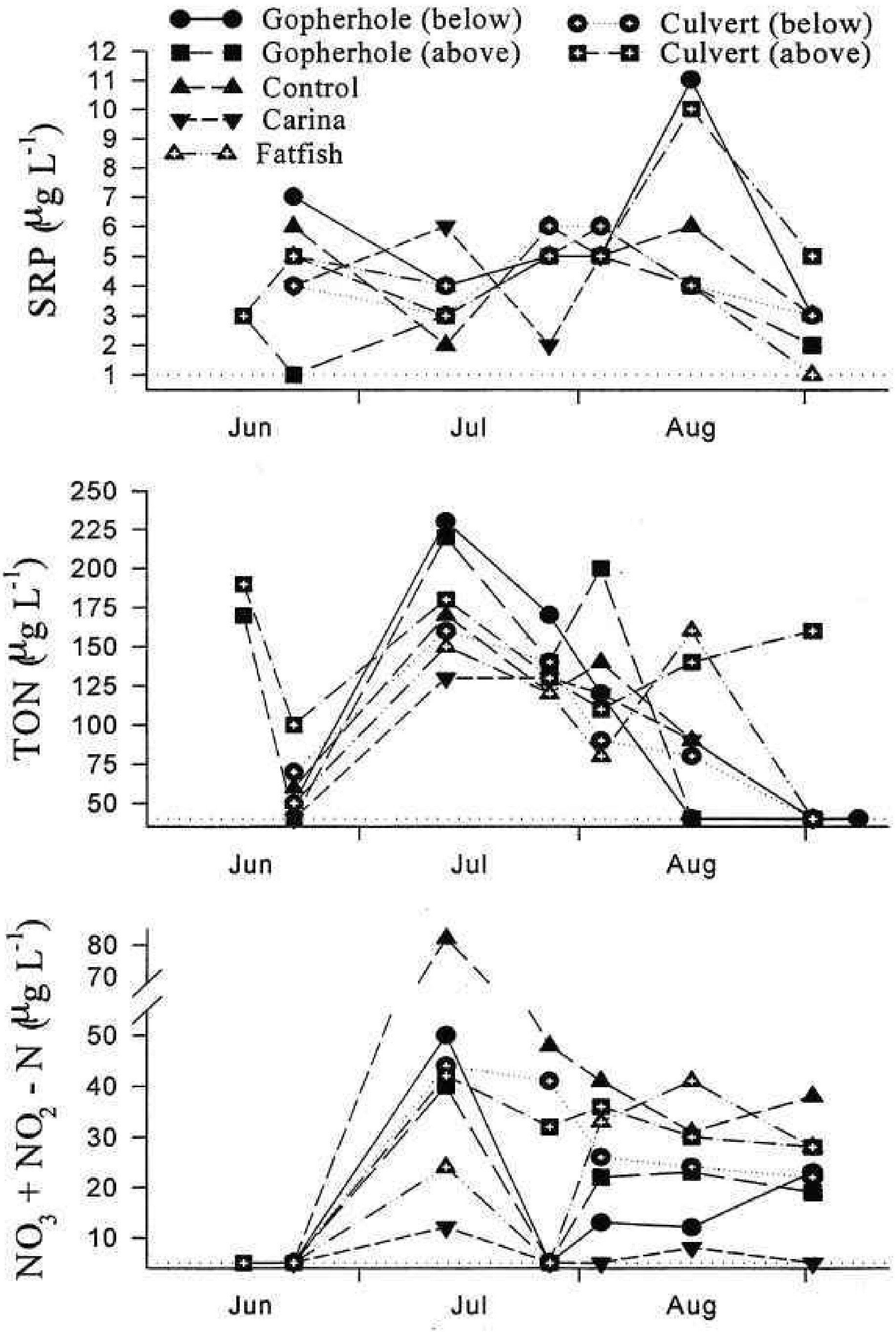

Figure 17 - Soluble reactive phosphorus (SRP), nitrate and nitrite nitrogen ($NO_3 + NO_2$-N) and total organic nitrogen (TON) from 5 tributaries of the Mesilinka River. Above and below sites are upstream and downstream, respectively, of slow release fertilizer briquettes. Minimum detectable limits are shown by the horizontal dashed line.

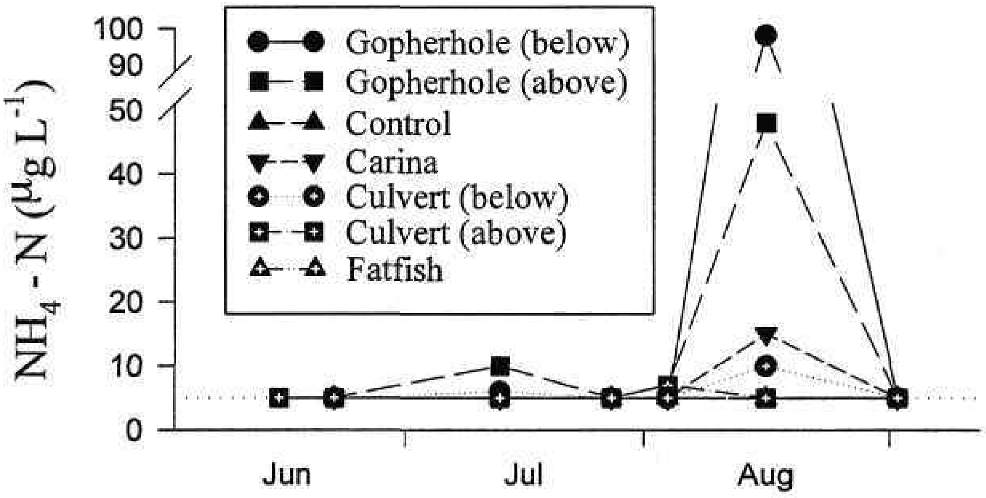

Figure 18 - Ammonium nitrogen (NH_4 from 5 tributaries of the Mesilinka River. Minimum detectable limits are shown by the dashed line.

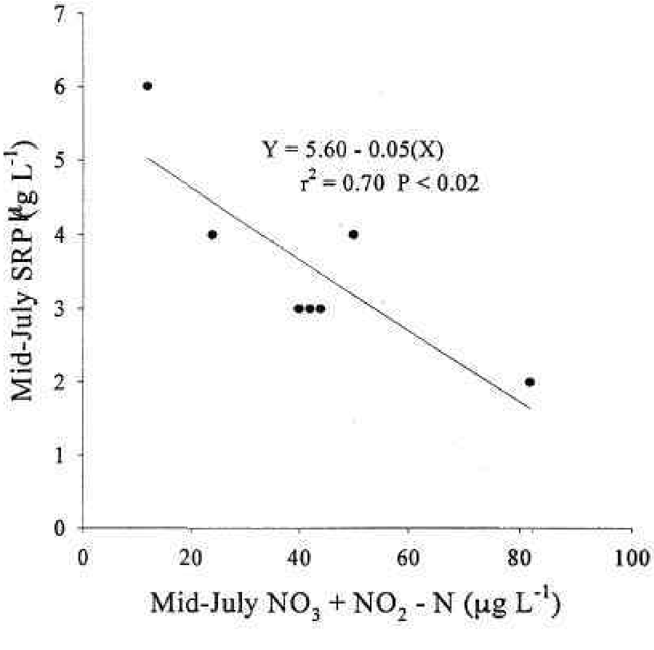

Figure 19 - Relation between SRP and inorganic nitrogen (NO_3 + NO_2 only) during mid-July in 5 tributaries of the Mesilinka River. Dashed lines show 95% confidence interval around the regression line.

Periphyton Accrual

The greatest peak periphyton accrual occurred in the treatment reach T1 (Fig. 20) which is consistent with 1994 results when fertilizers were initially applied (Paul et al. 1996). Peak periphyton accrual for T1 in 1995 was approximately one half the value for 1994 (Table 4). Peak periphyton accrual in the second treatment reach T2 was similar to the control reach for 1995 (Fig. 21; Table 4). The difference between log transformed peak periphyton accrual in T1 and Blackpine was significantly greater following fertilization (Fig. 21; $t = -5.44$, $df = 2$, $P = 0.03$). Data were log transformed as untransformed data did not meet the assumption of additivity as indicated by the significant relation between mean peak accrual for the two locations and the difference (Fig. 22; see Stewart-Oaten et al. 1986). Log transformation appropriately scaled the data and met the assumption of additivity (Fig. 22). The temporal replicates, before and after fertilization, met the assumption of independence as indicated by the von Neumann ratio test ($k = 16.3$, $n = 4$, P » 0.07). The difference in log-transformed peak periphyton accrual between T2 and Blackpine was not tested as the assumption of independence in differences through time was not met ($k = 0.38$, $n = 4$, $P < 0.01$). However, given the value of peak periphyton accrual in 1995 (Table 4) it seems probable that fertilization did not increase periphyton biomass accrual in T2.

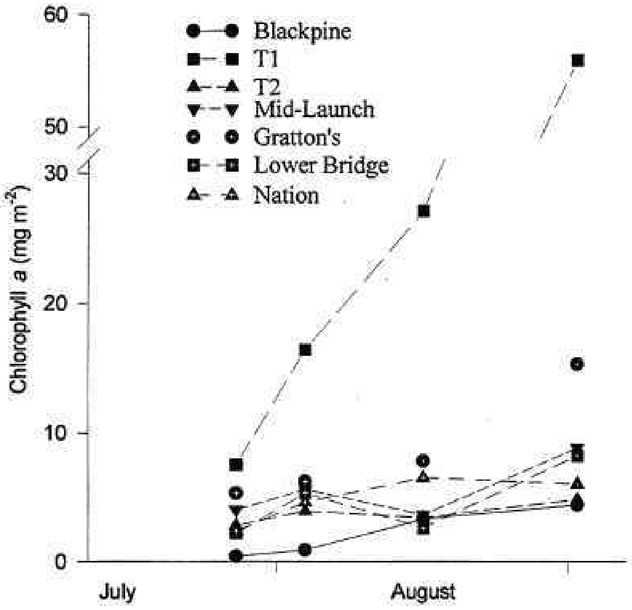

Figure 20 - Accrual of chlorophyll *a* on artificial substrate from 6 locations on the Mesilinka River and the Nation River.

Table 4 - Peak periphyton accrual in reaches of the Mesilinka River from 1992 - 1995. Fertilization began in 1994 upstream of T1 and T2 reaches.

	Peak Periphyton Accrual (mg•m^{-2})		
Year	**Blackpine**	**T1**	**T2**
1992	15.7	12.5	13.3
1993	7.3	13.0	8.5
1994	10.8	127.5	29.7
1995	4.40	55.9	4.80

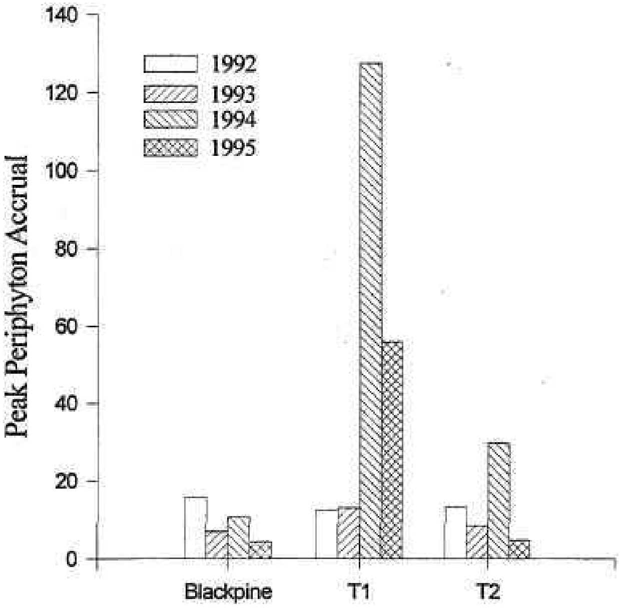

Figure 21 - Peak periphyton accrual (mg•m^{-2}) for 3 reaches of the Mesilinka River from 1992 to 1995. Fertilization began in 1994.

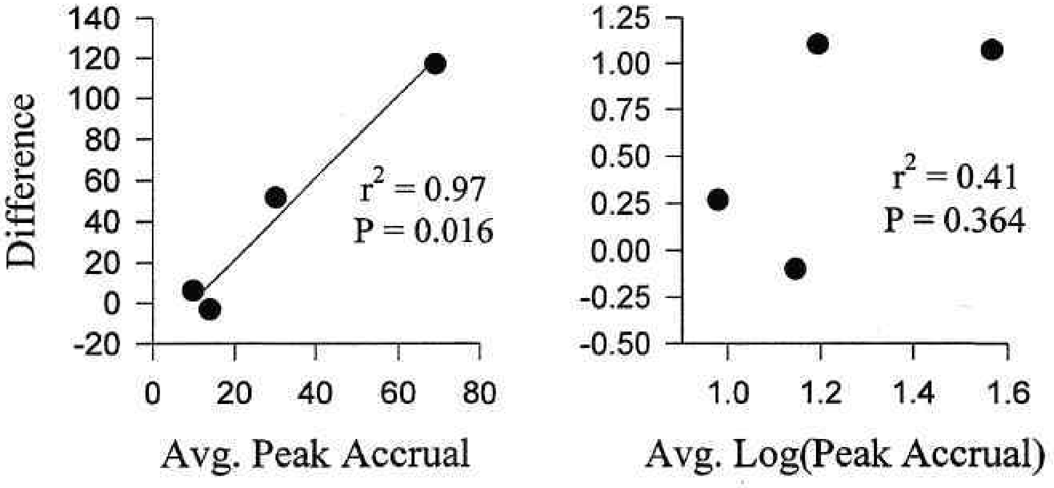

Figure 22 - Test for non-additivity in differences between peak periphyton accrual for T1 and Blackpine. A significant regression indicates non-additivity.

Peterson et al. (1993) found that fertilization of a tundra stream resulted in increased algal biomass for the first two years but not in the subsequent two years as an increase in grazing insects prevented any algal buildup. The lower accrual of periphyton in T1 and *12* reaches during 1995 over 1994, despite similar P loading between years, may reflect a greater increase in grazing insects from fertilization in the second year. We will explore this hypothesis further in the following sections and in future years.

Next to T1 reach, measured periphyton accrual in 1995 was greatest at Gratton's reaching a peak of 15.3 mg•m^{-2} in late August (Fig. 20). Since this is the first year periphyton accrual was measured at this location it is difficult to speculate as to why the difference occurred; however, Gratton's is approximately 8 and 2 km downstream of Gopherhole and Culvert creeks, respectively. Therefore, the increased periphyton accrual at Gratton's may reflect an influx of fertilizer from Culvert and Gopherhole creeks through the slow-release fertilizer briquettes. Using a line of reasoning similar to that used for the derivation of equation 3, we can model the rate of change in P concentration in the Mesilinka River (P_M, where P_M represents P derived solely from the fertilizer briquettes in either Gopherhole or Culvert creeks) as

$$\frac{dP_M}{dt} = \frac{1}{Q_M}(Q_G P_G + Q_C P_C + Q_M P_M) \quad . \qquad (8)$$

The terms Q_M, Q_G, and Q_C are discharge from the Mesilinka River, Gopherhole Creek and Culvert Creek, respectively; and, $P_{subscript}$ is the fertilizer briquette derived P concentration in each of the respective systems. Again assuming that equilibrium conditions exist (note that this implies we are below any mixing zone and no P uptake occurs within this mixing zone) then we can write equation 8 as

$$P_M = \frac{Q_G P_G}{Q_M} + \frac{Q_C P_C}{Q_M} \quad . \qquad (9)$$

Equation 9 intuitively implies that the fertilizer derived P concentration in the Mesilinka River is equal to the P concentration from a tributary multiplied by the proportional contribution of the tributary to the mainstem. We can estimate the maximum possible P loading from the tributaries to the mainstem by assuming that there is no uptake of fertilizer derived P within the tributaries (i.e., P_{GorC} comes from Fig. 14). Given these conditions, the concentration of P in the mainstem would show an average increase of only 0.20 µg•L^{-1} and a maximum of 0.32 µg•L^{-1} (Fig. 23).

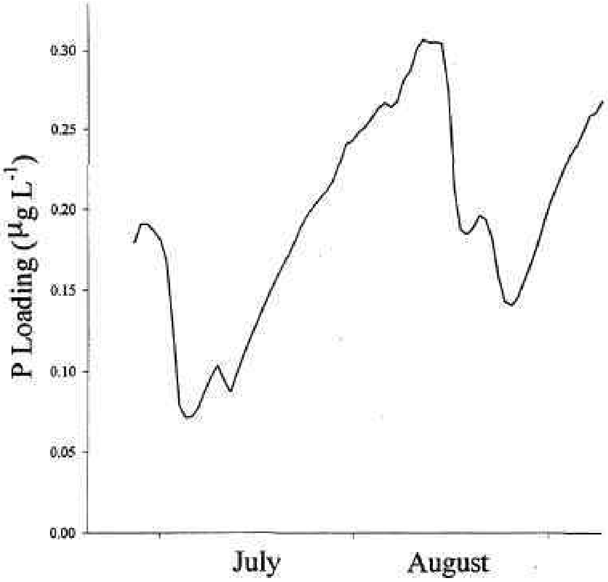

Figure 23 - Maximum P loading to the Mesilinka River from fertilizer briquettes in Gopherhole and Culvert creeks. Dotted line shows the estimated maximum summer mean of 0.20 µg•L^{-1}.

Although the estimated increase in Mesilinka P concentration from tributary fertilizer is low, two things should be considered. First, small additions of P (0.1 - 0.2 µg•L^{-1}) in P limited systems can substantially increase peak periphyton biomass (Bothwell 1989). Secondly, our estimation of P loading from the tributaries assumes complete mixing in the mainstem occurs.

Accrual of chlorophyll *a* among all tributaries reached its peak value in Gopherhole Creek downstream of the fertilizer inputs (Fig. 24). The peak in lower Gopherhole Creek for 1995 was greater than had been recorded in previous years; however, this was also true of the upper Gopherhole Creek site (Table 5). Periphyton blocks installed at both locations in Culvert Creek during early June washed out during early July and high water levels prevented the periphyton block for Control Creek to be installed until mid-July (Fig. 24). This makes comparisons among sites difficult as periphyton blocks were not within a site for equal amounts of time. Furthermore, the absence of upstream measurements in Gopherhole Creek during 1992 and Culvert Creek during 1994 coupled with an error prone fertilizer application in 1993 (see Koning et al. 1995) requires that any statistical analysis be carefully considered.

Table 5 - Peak periphyton accrual (mg•m^{-2}) in 5 tributaries of the Mesilinka River from 1992 - 1995. Liquid fertilizer was applied to Gopherhole and Culvert creeks in 1993 downstream of upper sites, and again, in 1995 as solid fertilizer briquettes. Entries with -- indicate no measurement was available in that year.

	Peak Periphyton Accrual (mg•m^{-2})			
Location	**1992**	**1993**	**1994**	**1995**
Gopherhole (below)	36.0	37.8	33.3	59.9
Gopherhole (above)	--	17.2	26.9	36.3
Control	23.4	39.6	36.8	12.7
Carina	113.0	45.1	39.2	32.3
Culvert (below)	10.8	32.9	7.3	14.0
Culvert (above)	–	56.6	–	17.2
Fatfish	–	87.5	2.6[a]	56.7

a - peak value likely underestimated as styrofoam block broke away before last sampling date

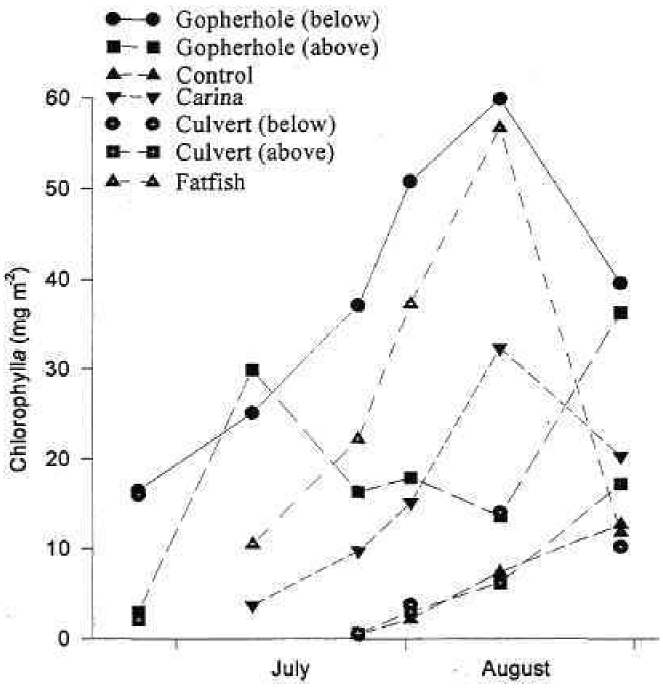

Figure 24 - Accrual of chlorophyll *a* on artificial substrate in 5 tributaries of the Mesilinka River. Fertilizer was applied downstream of the upper Gopherhole and Culvert creek sites. Unconnected data points indicate that the periphyton block was washed away and needed to be reinstalled with a new styrofoam substrate.

Benthic Invertebrates

Preliminary results indicate that fertilization has increased the biomass of benthic invertebrates in both the T1 and T2 reaches. Benthic invertebrate biomass measured from the basket samplers was greater in both fertilized reaches (T1 and T2) than in the control (Blackpine) for 1995 (Table *6;* Fig. 25). This contrasts the single pre-fertilization year (1993) when Blackpine had a greater biomass of benthic invertebrates than either T1 or T2 (Table *6;* Fig. 25). As shown from the percent difference from Blackpine reach, T1 may have shown the greatest response to fertilization in the first year (1994). Whereas, T2 showed little response in 1994 but a strong response in 1995.

Wet weight of benthic invertebrates were approximately an order of magnitude lower in 1995 than in previous years, excepting T2 reach which was similar to 1994 (Fig. 25; Table 6). To determine whether the lower biomass measured in 1995 was due to an unaccounted bias in weighing methods, the samples were again re-weighed in April of 1998. Upon re-weighing, the mean wet weight for samples actually decreased by -2.76% but this was not significantly

Table 6 - Mean wet weights of benthic invertebrates from artificial substrate baskets. The percent difference (% diff.) indicates the difference between the given location and Blackpine for that year.

	1993		1994		1995	
Location	**mean**	**% diff.**	**mean**	**% diff.**	**mean**	**% diff.**
Blackpine	0.28	0%	0.26	0%	0.03	0%
Tl	0.21	-25%	0.57	119%	0.05	67%
T2	0.02	-93%	0.07	-73%	0.10	233%
Nation R.	0.50	79%	1.03	296%	0.06	100%

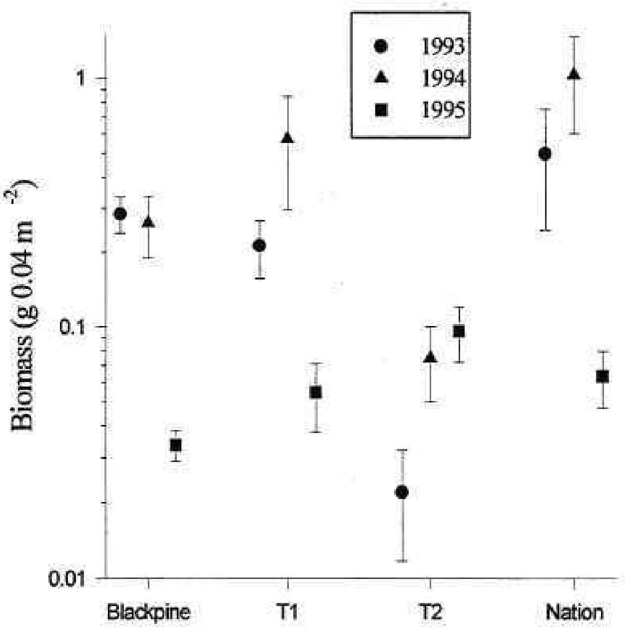

Figure 25 - Mean wet weights of benthic invertebrates from artificial substrate baskets. Error bars are 1 SE of the mean.

different from the initial weights (paired t-test, P>0.07). Therefore, we concluded that there was not a bias in the weighing method used initially.

Numerical abundance of some taxonomic groups of invertebrates showed an increase following fertilization, (Fig. 26; Appendix A). Taxonomic groups other than the dipterans, ephemeropterans, plecopterans and trichopterans were not analysed here because their numerical abundance accounted for less than <1% of aquatic invertebrates collected by the basket sampler (Paul et al. 1996). The control locations (Blackpine reach and Nation River) showed similar numbers of invertebrates among years and locations, excepting trichopterans (Fig. 26; Appendix A). However, their does appear to be a negative trend in numbers of invertebrates for both of the control locations (Fig. 26). In contrast, dipteran larvae in T1 and T2 increased by about an order of magnitude in both years following fertilization. The increase in dipterans can primarily be attributed to an increase in chironomids. Mundie et al. (1991), using stream mesocosms, reported a significant response in small chironomids following 7 weeks of fertilization. Chironomid larvae also increased in the Keogh River following whole-river fertilization and were also an important component of the diet for steelhead *(O. mykiss)* and coho *(O. kisutch)* fry (Johnston et al. 1990).

The response in other taxonomic groups following fertilization of the Mesilinka River was more variable. Ephemeropterans, plecopterans and trichopterans increased in T2 following fertilization, while T1 showed either no-difference in numbers from the control locations or a decrease in numbers (Fig. 26). Considering both wet weights and numerical abundance, it appears the greatest response in aquatic invertebrates to fertilization occurred in T2 reach.

The variable we can statistically test using the BACI design of Stewart-Oaten et al (1986) is the difference in wet weights between the treatment reaches and the control during prefertilization and fertilization years (Table 6). However, because we have only one pretreatment year (1993), our experiment is unreplicated in pretreatment years using the BACI design. Therefore, we must use the study design of Underwood (1992,1994) to statistically analyze the invertebrate data. We recommend this be done at the completion of the study.

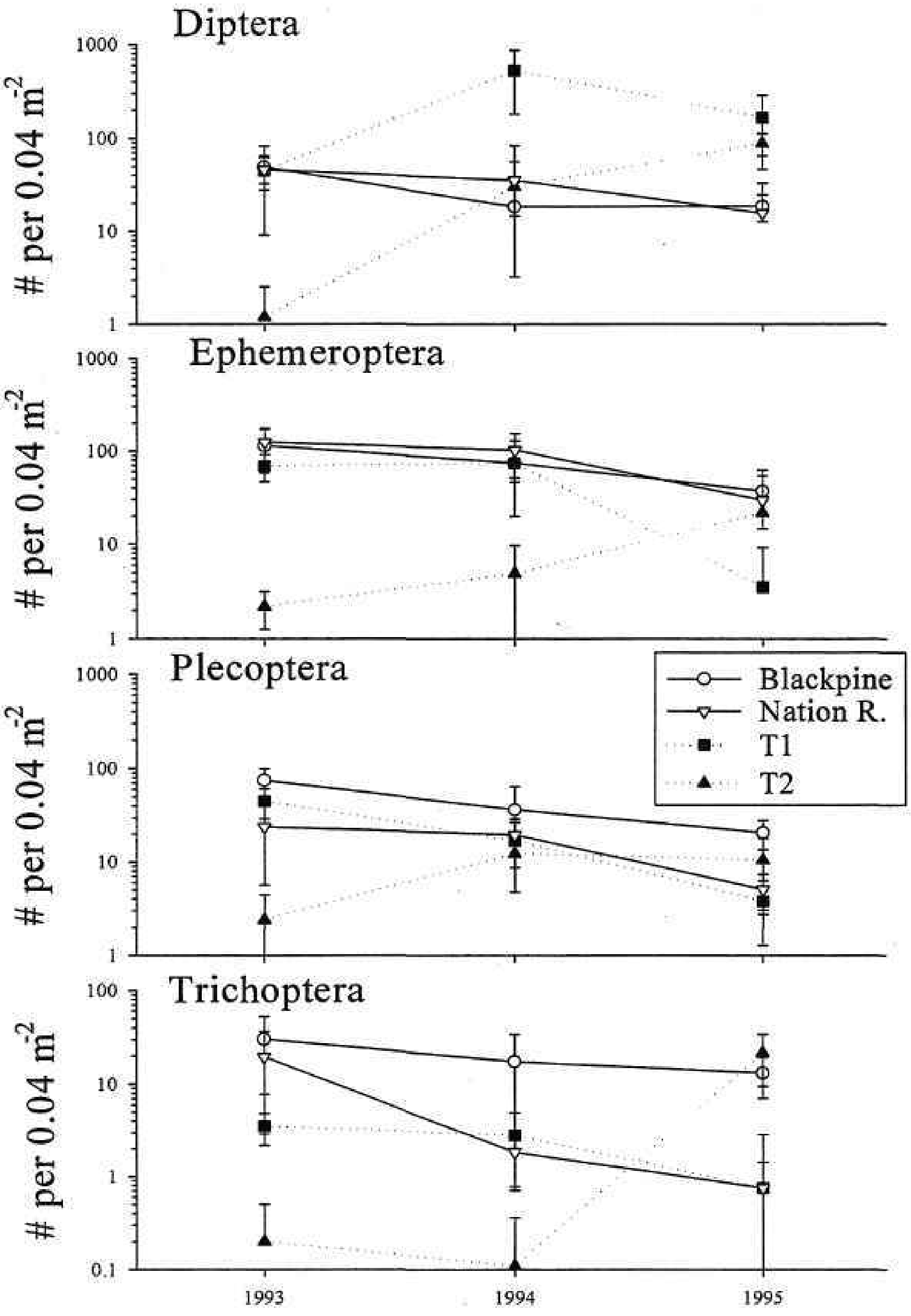

Figure 26 - Density of major benthic invertebrates collected from basket samplers located in the Nations River and 3 reaches of the Mesilinka River from 1993 to 1995. Error bars are 95% confidence intervals for the estimated mean. Sample sizes are given in Appendix A.

Estimated Fish Abundance, Growth and Size Distribution

Mesilinka Mainstem

Fish composition as determined from underwater counts were similar to previous years in that mountain whitefish were the dominant species in all reaches (Table 7); unfortunately, no underwater counts were completed in 1995 for the T2 reach due to bad weather. Densities of fishes in T1 reach were greater in 1995 than in any of the previous years, excepting suckers which were slightly lower than 1994 numbers (Fig. 27; Table 7). Although this may suggest a positive response in fish numbers to fertilization, we must take into account the population dynamics of a species (especially prior to fertilization). For instance, greater densities of rainbow trout in both T1 and T2 following fertilization may have resulted from the increasing pre-fertilization trend in their numbers (Fig. 27). Since, the control reach (Blackpine) also showed a positive pre-fertilization trend in numbers (Fig. 27), then as before, we must look at differences between treatment reaches and Blackpine. Prior to calculating differences, fish densities were log-10 transformed to meet the assumption of additivity.

Differences suggest that fertilization has had an impact on rainbow trout, mountain whitefish and suckers in T1 reach (Fig. 28; note little can be inferred for T2 reach with missing data for 1995). However, since suckers show a declining trend in Blackpine which is not evident in the pretreatment years for T1 (Fig. 27) and rainbow trout differences increased only in 1995 (Fig. 28), we can at this time only infer that mountain whitefish densities significantly increased in T1 from fertilization (Fig. 28; t-test, $t = 6.431$, $P < 0.02$). The data meet the assumption of independence (von Neumann ratio test, $k = 5.33$, $P >> 0.07$). Koning et al. (in press) tentatively reached the same conclusion. Trends in abundance of rainbow trout and suckers in T1, in addition to assessing the response of T2 reach, will be possible in later years (i.e., 1996 and 1997).

Table 7 - Density of fishes (#•ha^{-1}) in three reaches of the Mesilinka River as determined from underwater counts. No counts were conducted in T2 reach for 1995 due to high discharge and low visibility.

	1992			1993			1994			1995		
	Black	**T1**	**T2**	**Black**	**T1**	**T2**	**Black**	**T1**	**T2**	**Black**	**T1**	**T2**
Rainbow Trout	0.5	1.5	2.8	1.1	1.9	3.8	1.2	3.4	5.6	0.6	4.9	
Bull Trout	0.2	0.8	1	0.3	0.5	1.3	0.4	0.8	0.8	0.5	1.3	
Arctic Grayling	2.6	3.6	2.1	1.4	3	1.7	1.3	2.1	2	2.9	5.2	
Mountain Whitefish	40.4	38	9.5	21.3	13.7	11.8	10	26.7	13.9	32	98.2	
Suckers	1.9	0.9	5.3	0.4	0.6	2.2	0.1	0.9	4	0.12	0.7	
Squawfish	0	0	0	0	0	0.2	0	0	0	0	0	

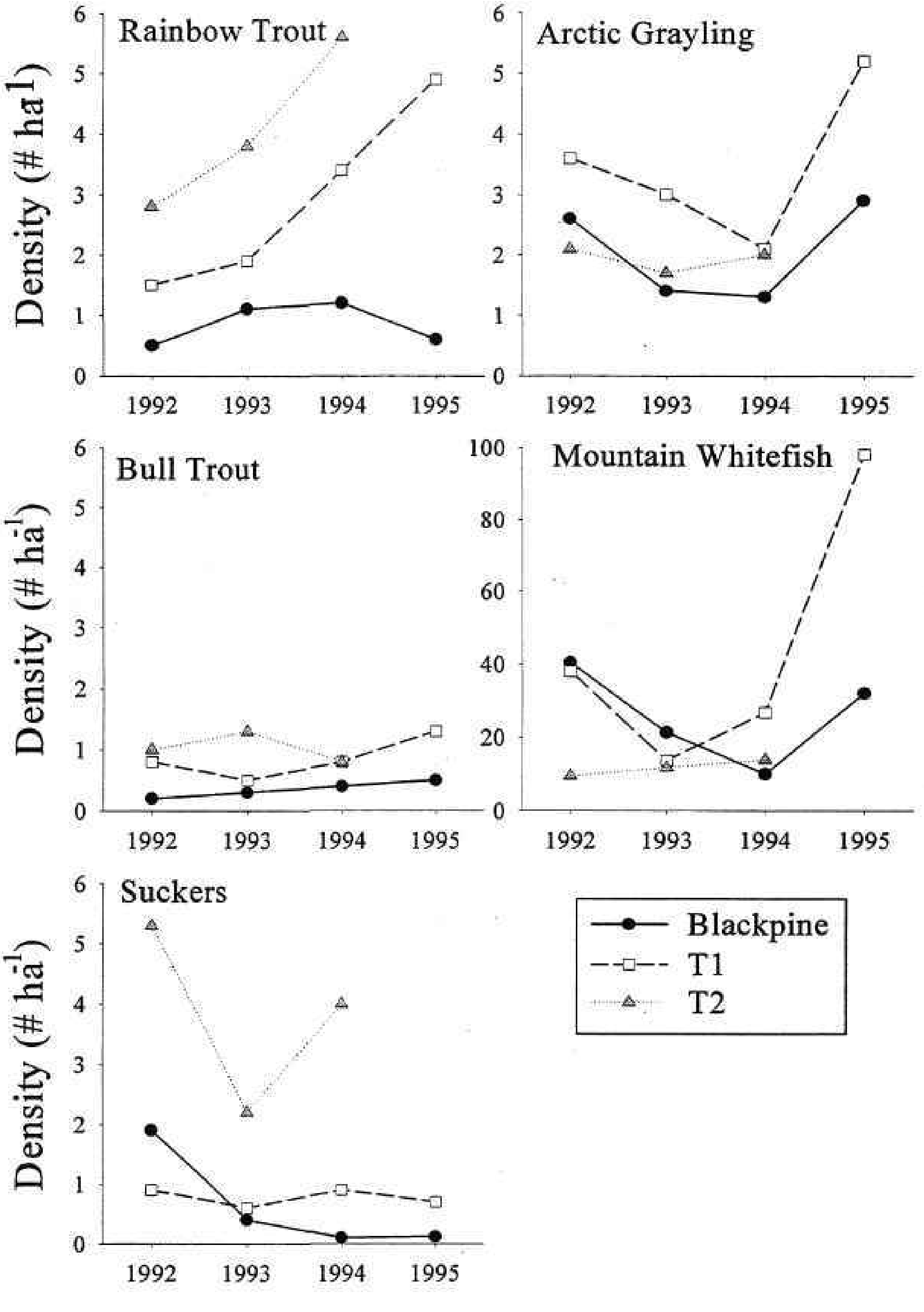

Figure 27 - Density of fishes in three reaches of the Mesilinka River from 1992 to 1995 as determined from underwater counts. No estimates are available for T2 reach in 1995.

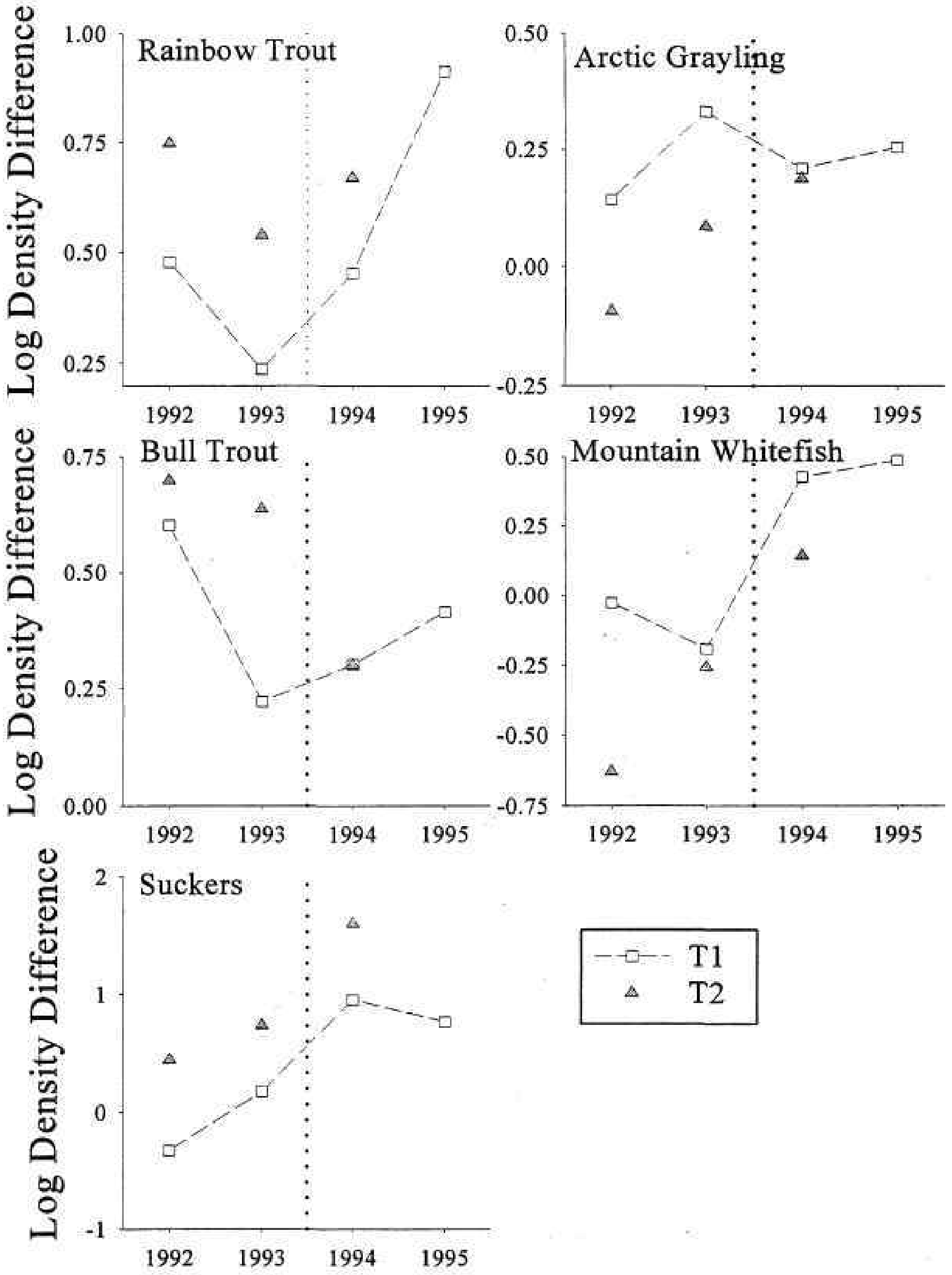

Figure 28 - Difference in log-10 transformed densities of fishes between either T1 or T2 and Blackpine from 1992 to 1995. Densities were determined from underwater counts and no counts are available for T2 in 1995. The dotted line indicates the start of fertilization.

Size-at-age was determined for rainbow trout and Arctic grayling only (Appendix B). Mean fork length of rainbow trout from 1992 to 1995 show the growth rate of these fish in the Mesilinka River (Fig. 29). On average, 3 year-old rainbow trout are > 200 mm fork length in all reaches (Fig. 29). Mean fork length of Arctic grayling for a given age was more variable among years than rainbow trout (Fig. 30), but grayling tended to be slightly larger for a given age than rainbow trout (Figs. 29 & 30). Weight for a given age for rainbow trout and Arctic grayling among years are given in Appendix B but are not shown here.

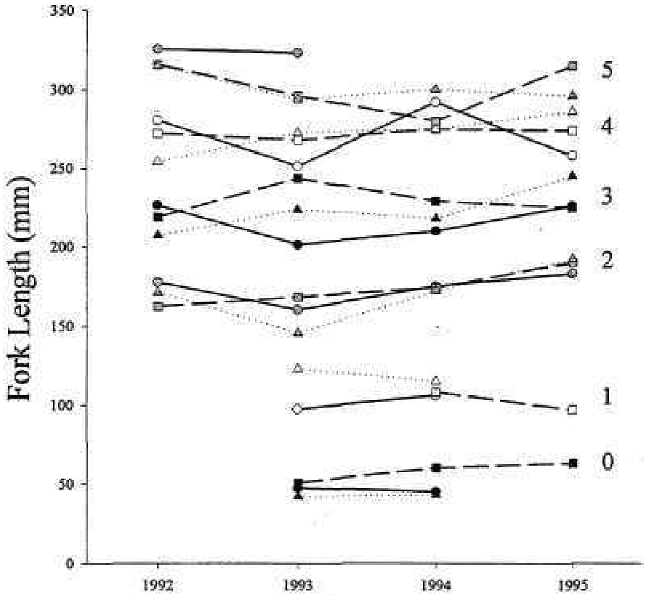

Figure 29 - Mean fork length at a given age for rainbow trout from 1992 to 1995 in three reaches of the Mesilinka. Circles (●) are for Blackpine reach, squares (■) for Tl reach and triangles (▲) for T2 reach. Age groups are indicated by numbering and colouring of symbols (black for age O and 3, white for age 1 and 4 and grey for age 2 and 5).

Assessing the impact of fertilization on mean size of fishes at a given age will be difficult due to variability in the size-at-age data. As Koning et al. (1995) notes, variability in size-at-age information among years will depend on the timing of capture of individuals for a given year. To minimize this variance, field crews have limited sampling of fish for size-at-age data to the last two weeks of July and first two weeks of August. However, recalling the BACI experimental design, the more important standardization would be that collections among reaches of the Mesilinka (but within the same year) occur at a similar time. For example, if in one year all sampling in Blackpine occurred after Tl and T2 and then the following year all sampling in Blackpine occurred before Tl and T2, we would expect that the difference between treatment reaches and control would change (i.e., increase) between years independent of any real treatment affect. Although this represents a rather extreme example, the timing of sampling should be examined among years to determine if any bias may exist.

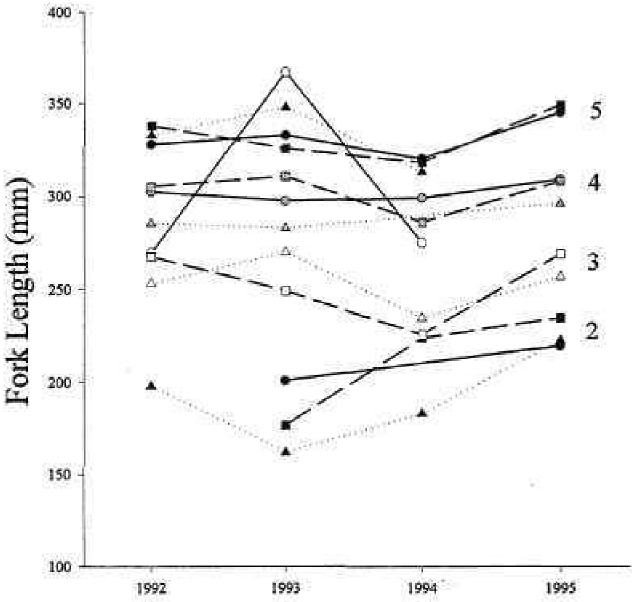

Figure 30 - Mean fork length at a given age for Arctic grayling from 1992 to 1995 in three reaches of the Mesilinka River. Circles (●) are for Blackpine reach, squares (■) for Tl reach and triangles (▲) for T2 reach. Age groups are indicated by numbering and colouring of symbols (black for age O and 3, white for age 1 and 4 and grey for age 2 and 5).

We assessed the impact of fertilization on size-at-age of rainbow trout and Arctic grayling using data lumped from the summer. A cursory examination suggests that sampling occurred randomly among the three study reaches within a year; however, this assumption should be more rigorously examined in future reports. Furthermore, we looked at the difference in weight-at-age between either treatment reach and Blackpine rather than length-at-age as we felt weight would be more sensitive to a change from fertilization. For instance, a 25% increase in the length of fish could be translated into approximately a 95% increase in weight and thus a much larger difference between treatment and control reaches. Although, this interpretation assumes variance due to either process or observation uncertainty is similar between length and weight.

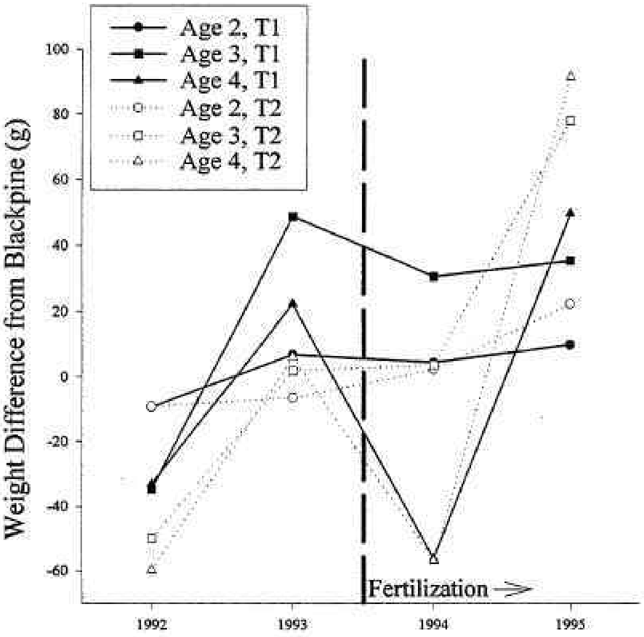

Figure 31 - Difference in weight for rainbow trout between T1 or T2 and Blackpine. Only age 2-4 fish shown as insufficient data exists for other age classes.

The difference in weight between T2 and Blackpine suggests that fertilization may have had a positive effect on the weight of age 2-4 rainbow trout in 1995 (Fig. 31). The greatest response seems to have occurred in age 3 and 4 fish; but, this needs to be statistically tested using data collected in 1996 and 1997. Because size-at-age data among years are not necessarily independent, we could expect differences in age 4 and 5 fish from T2 to be even greater in 1996[1]. In contrast to T2, age 2-4 rainbow trout in T1 seem to have not responded to fertilization (Fig. 31). Age 3-5 Arctic grayling, also, appear to have shown no response in growth to fertilization during 1994 and 1995 in either reach (Fig. 32). An interesting aspect, with respect to grayling, is that age 3 fish in either T1 or T2 weigh less than similarly aged fish in Blackpine for all years (Fig. 32).

---

[1] The lack of independence in size-at-age data will need to be carefully considered when statistically analysing this data. One possible alternative is to utilize the design of Underwood (1992, 1994).

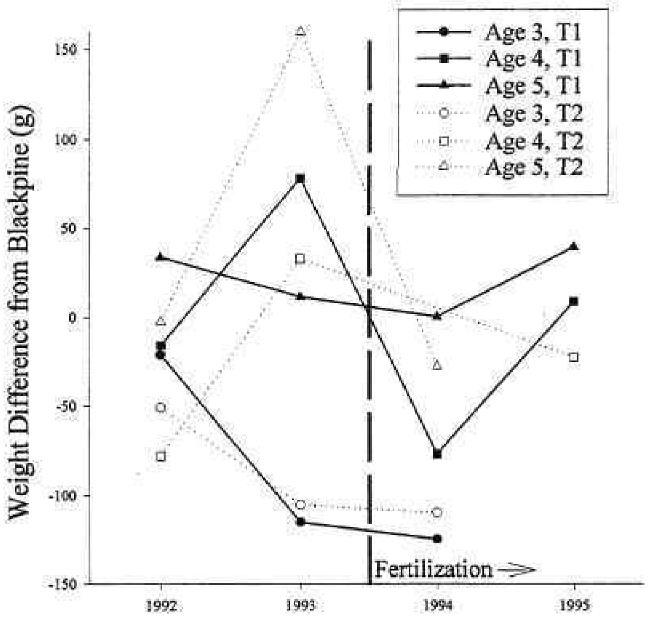

Figure 32 - Difference in weight between T1 or T2 and Blackpine for Arctic grayling. Only age 3-5 fish shown as insufficient data exists for other age classes.

Mesilinka Tributaries

Population estimates conducted on Control, Culvert and Gopherhole creeks show a high degree of variability among years for bull trout but not rainbow trout (Table 8). Other Salmonidae fishes occur relatively infrequently with mountain whitefish making up a small portion of the catch numerically (Table 8) and three arctic grayling were caught in Culvert and Control creeks only in 1993 (Koning et al. 1995). Other fishes consist primarily of sculpins (Koning et al. 1995; Paul et al. 1996) and there numbers are not reported here.

Although many of the population estimates are biassed due to insufficient fish either being tagged or recaptured, a strong positive trend in bull trout numbers is evident among all three streams with minimum and maximum densities recorded in 1992 and 1995, respectively (Table 8). Since tributary fertilization did not occur in Control Creek, the increase in bull trout numbers can not be attributed to tributary fertilization. Furthermore, we believe that it is unlikely that the increase can alternately be attributed to mainstem fertilization. Fluctuations in juvenile bull trout populations of several orders of magnitude over only a few years have been observed elsewhere (Paul and Post 1996). The maximum bull trout densities for all three streams that were observed in 1995 (Table 8) were dominated by a strong young-of-year cohort (Fig.

33). This contrasts previous years when multiple cohorts were present and the young-of-year cohort did not dominate the catch (Fig. 33).

Table 8 - Linear and areal density estimates for rainbow trout (RNTR), bull trout (BLTR) and mountain whitefish (MNWH) in three tributaries to the Mesilinka River. Unbiased population estimates are shown in bold (see table footnote and methods). Population estimates were determined by mark/recapture methods. Number of fish marked (M), captured (C) and recaptured (R) are shown. In addition, the study section population estimate (N) and its associated lower (LCI) and upper confidence interval (UCI) are also given.

Trib.	Date (dd/mm/yy)	Spec	M	C	R	N	LCI	UCI	Len. (m)	Wid. (m)	Linear Density (#•100 m^{-1})	Areal Density (#•100 m^{-2})
Gopher.	06/09/92	RNTR	16	6	4	22*	17	58	100	3.4	22	6
		BLTR	2	3	2	3	2	4	100	3.4	3	1
		MNWH	3	5	3	5	4	6	100	3.4	5	1
	12/09/93	RNTR	6	5	1	20*	9	338	100	6.6	20	3
		BLTR	10	7	3	21*	13	68	100	6.6	21	3
	01/09/94	RNTR	0	1	0				56	6.6		
		BLTR	6	7	1	27*	12	459	56	6.6	48	7
	18/08/95	RNTR	7	10	2	28*	14	141	100*	5.5$^{\#}$	28	5
		BLTR	35	36	11	110	78	188	100$^{\#}$	5.5$^{\#}$	110	20
		MNWH	1	0	0				100*	5.5$^{\#}$		
Culvert	06/09/92	RNTR	7	9	2	25*	13	127	100	5	25	5
		BLTR	9	4	1	24*	12	541	100	5	24	5
		MNWH	3	3	1	7*	4	64	100	5	7	1
	14/09/93	RNTR	3	16	2	21*	11	56	100	8	21	3
		BLTR	7	5	2	15*	9	71	100	8	15	2
		MNWH	5	11	3	17*	10	39	100	8	17	2
	03/09/94	RNTR	16	8	4	29*	20	81	173	7.1	17	2
		BLTR	16	7	1	67*	29	2207	173	7.1	39	5
		MNWH	8	3	0				173	7.1		
	12/08/95	RNTR	2	3	1	5	3	30	100$^{\#}$	6.7*	5	1
		BLTR	35	39	15	89	68	130	100$^{\#}$	6.7$^{\#}$	89	13
Control	06/09/92	RNTR	9	10	8	11	10	14	100	3.6	11	3
		BLTR	13	4	4	13	0	0	100	3.6	13	4
		MNWH	5	5	4	6	5	10	100	3.6	6	2
	10/09/93	RNTR	6	1	0				100	5.8		
		BLTR	11	15	2	63*	30	405	100	5.8	63	11
		MNWH	1	2	0				100	5.8		
	01/09/94	RNTR	1	1	1	1	0	0	139	5.2	1	<1
		BLTR	17	9	2	59*	30	434	139	5.2	42	8
		MNWH	1	0	0				139	5.2		
	11/08/95	RNTR	2	2	1	3	2	21	100*	4.9*	3	1
		BLTR	33	27	8	104	69	210	100*	4.9*	104	21
		MNWH	1	0	0				100*	4.9*		

* - Biased population estimate (N) as both conditions $(M+C)\geq N$ and $R>7$ were not met.

- Reach lengths and widths were not recorded in 1995 so a length of 100 m was assumed and the wetted width is the mean from the previous 3 years.

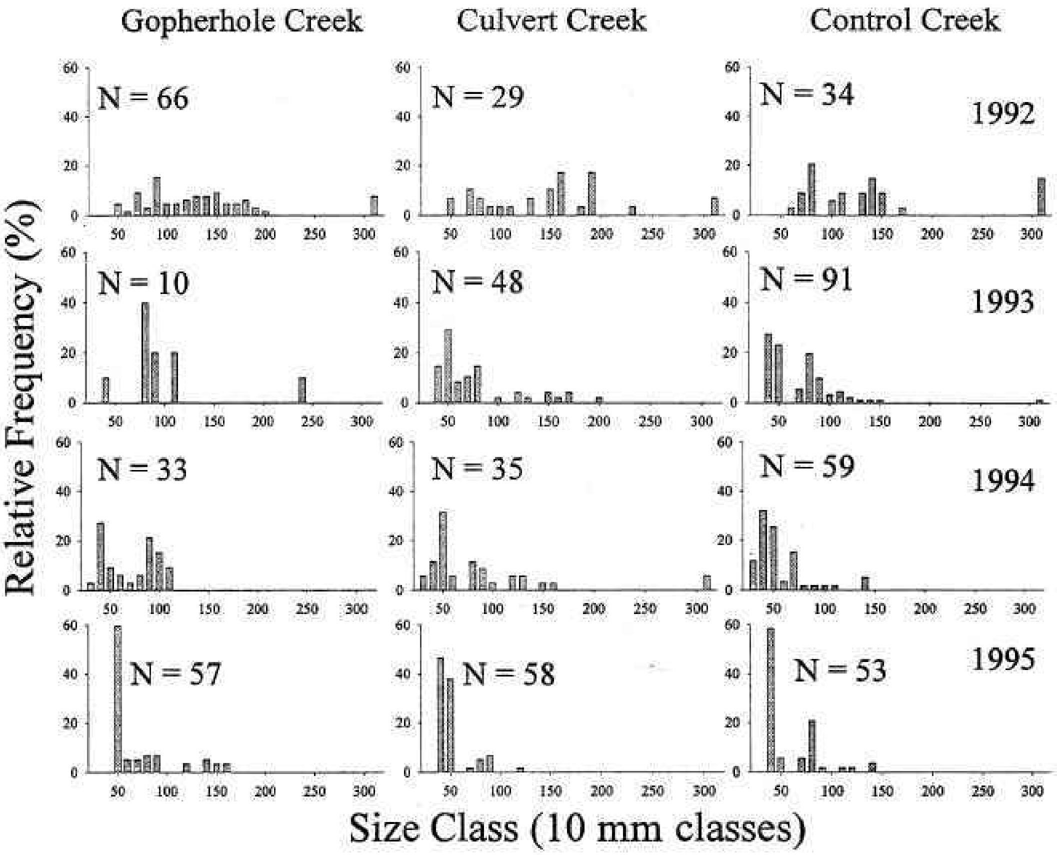

Figure 33 - Length-frequency plots for all bull trout captured in three tributaries of the Mesilinka River from 1992 to 1995. The last length category represents all fish >300 mm in fork length.

CONCLUSIONS

Fertilization has significantly affected periphyton, invertebrates and fish in the Mesilinka River but this effect has been variable between the two treatment reaches. Different responses between T1 and T2 to fertilization may be explained through differences in community structure. The increased density of mountain whitefish in T1 following fertilization may have resulted in a significant increase in predation on benthic invertebrates. Subsequently, a lower biomass of grazing invertebrates could allow standing stocks of periphyton to increase. We will call this the fish density response. In contrast, little change in densities of fish following fertilization may have allowed invertebrate densities to increase in T2. Higher abundance of invertebrates in T2 could result in: a) better growth of fish present in the reach and b) decreased standing stocks of periphyton. This we will term the fish growth response. One mechanism behind the two responses is that predation on invertebrates increases relatively more following a density response than it would given a growth response. This could be explored further by modelling fish (predator) and invertebrate (prey) populations.

Table 9 summarizes the response to fertilization in reaches T1 and T2 to fertilization for the first two years. We can see that T1 reach tends to support the fish biomass response; whereas, T2 reach tends to support the fish growth response (Table 9). Supposing that these responses are substantiated from data collected in 1996 and 1997, the question then becomes what is the mechanism that leads to the different responses.

Table 9 - Summary of significant responses in periphyton, invertebrates and fish to fertilization for T1 and T2 reaches. The arrow indicates a positive response.

Response	Tl	T2
Periphyton Biomass	⇑	no change
Invertebrate Biomass	no change	⇑
Invertebrate Density	It (dipterans only)	⇑
Fish Density	⇑	no change*
Fish Size	no change*	⇑*

* -requires data from 1996 and 1997 to confirm

One possible reason that T2 shows little response in periphyton production may be that this reach becomes severely N limited following fertilization. Recalling the standard Redfield ratios of N:P (by atomic number), a ratio of less than 10:1 suggests severe N limitation; whereas, a ratio of greater than 20:1 suggests strong P limitation (Ashley and Slaney 1997). Adjusting these ratios to atomic weight we have < 4.5:1 and > 9.0:1 for N and P limitation, respectively. If we assume that all N available to primary producers in the Mesilinka river is in the form of NO_3 or NH_4, then the data suggests that fertilization has pushed both T1 and T2 reaches into N limitation (Fig. 34). However, this trend is not entirely clear as their is a large difference between the prefertilization years (Fig. 34). For instance, data from 1992 indicate that the three reaches from the Mesilinka River are essentially P limited; in contrast, data from 1993 indicate that the reaches are colimited for both N and P and the two lower reaches (T1 and T2*)* become N limited during mid-summer. Regardless of the prefertilization years though, T1 and T2 show a higher degree of N limitation than Blackpine during mid-summer when fertilizer is being applied. While there may be some evidence that N limitation is greater in T2 than T1 (Fig. 34), N limitation in T2 alone can not solely explain the different responses in invertebrates and fish noted above. Therefore, N limitation appears to be an important factor in the response of the Mesilinka River to fertilization; but, there also appears to be differing food-web responses between the two treatment reaches that produce different outcomes to fertilization.

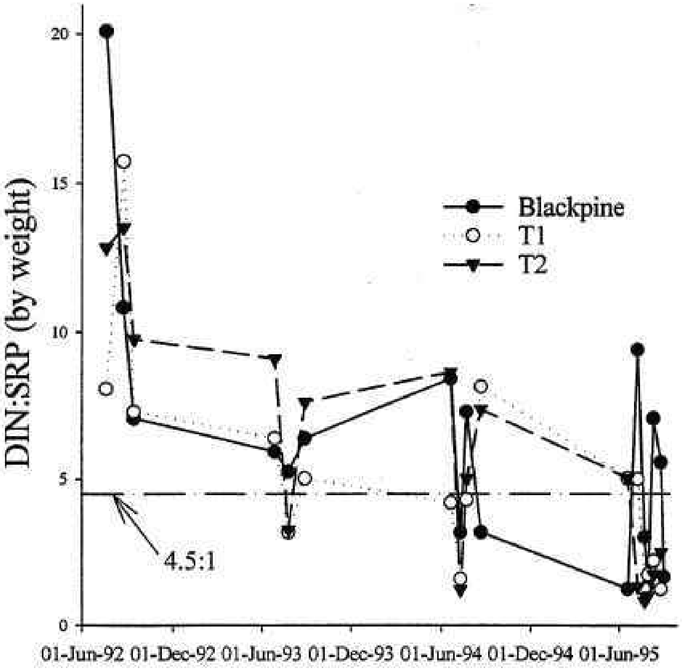

Figure 34 - Dissolved inorganic nitrogen (DIN) to soluble reactive phosphorus (SRP) ratios by atomic weights for the Mesilinka River for the two prefertilization years (1992 and 1993) and the first two years of fertilization (1994 and 1995). DIN was assumed to consist solely of $N0_3$ and NH_4. Values of $N0_3$, NH_4 and SRP that were below detection levels of 5, 5 and 1 µg•L^{-1}, respectively, (see *Water Chemistry* section) were arbitrarily set at theses detection levels.

LITERATURE CITED

APHA. 1985. Standard methods for the examination of water and waste water. 16th edition. Arner. Public Health Assoc. 1268 p.

Ashley, K.I., L.C. Thompson, D.C. Lasenby, L. McEachern, K.E. Smokorowski and D. Sebastian. 1997. Restoration of an interior lake ecosystem: the Kootenay Lake fertilization experiment. Water Qual. Res. J. Can. 32: 295-323.

Ashley, K.I. and P.A. Slaney. 1997. Accelerating recovery of stream, river and pond productivity by low-level nutrient replacement. In: Slany, P.A. and Zaldokas, D. [eds.] Fish Habitat Rehabilitation Procedures. Province of B.C. Ministry of Environment, Lands and Parks and Ministry of Forests. Watershed Restoration Technical Circular No. 9. 341 p.

B.C. Hydro. 1990. Williston Lake Compensation Program: Fisheries, Summary of Management Plan. 5 p.

Blackman, B.G. 1992. Fisheries Resouces of Williston Reservoir Twenty Years After Impoundment. M.S. Prov. B.C. Fish. Branch and B.C. Hydro Env. Res. 65 p.

Bothwell, M.L. 1988. Growth rate responses of lotic periphyton diatoms to experimental phosphorus enrichment: the influence of temperature and light. Can J. Fish. Aquat. Sci. 45: 261-270.

Bothwell, M.L. 1989. Phosphorus-limited growth dynamics of lotic periphyton diatom communities: areal biomass and cellular growth rate responses. Can. J. Fish. Aquat. Sci. 46:1293-1301.

Cabana, G. and J.B. Rasmussen. 1994. Modelling food chain structure and contaminant bioaccumulation using stable nitrogen isotopes. Nature. 372: 255-257.

Chapman, D.W. 1966. Food and space as regulators of salmonid populations in streams. Am. Natur. 100: 345-357.

Cummins, K.W. and M.J. Klug. 1979. Feeding ecology of stream invertebrates. Ann. Rev. Ecol. Syst. 10:147-172.

Deegan, L.A., and BJ. Peterson. 1992. Whole-river fertilization stimulates fish production in an Arctic tundra river. Can. J. Fish. Aquat. Sci. 49: 1890-1901.

Dill, L.M., R.C. Ydenberg and A.H.G. Fraser. 1981. Food abundance and territory size in juvenile coho salmon (Oncorhynchus kisutch). Can. J. Zool. 59: 1801-1809.

Gregory, S.V. 1983. Plant-herbivore interactions in stream systems, p. 157-189. In J.R. Barnes and B.W. Minshall [ed.] Stream ecology: application and testing of general ecological theory. Plenum Press, New York, NY.

Hart, B.I. 1942. Tabulation of the probabilities for the ratio of the mean square successive difference to the variance. Ann. Math. Stats. 13:207-214.

Hume, J.M.B. and E.A. Parkinson. 1988. Effects of size at and time of release on the survival and growth of steelhead fry stocked in streams. North Am. J. Fish. Manage. 8: 50-57.

Hynes, H.B.N. 1975. The stream and its valley. Verh. Int. Ver. Limnol. 19: 1-15.

Johnston, N.T., C. J. Perrin, P. A. Slaney, and B.R. Ward. 1990. Increased juvenile growth by whole-river fertilization. Can. J. Fish. Aquat. Sci. 47: 862-872.

Krebs, CJ. 1989. Ecological Methodology. Harper Collins Publishers, New York, NY. 654 p.

Koning, C.W., K.I. Ashley, P.A. Slaney and P.W. Davidson. 1995. Development of a premier northern river fishery: Mesilinka River pre-fertilization progress 1992-93. B.C. Ministry of Environment, Lands and Parks, Fisheries Project Report No. RD46.

Koning, C.W., K.I. Ashley, P.A. Slaney and A.J. Paul, *in press.* Stream fertilization as a fisheries mitigation technique for purturbated oligotrophic trout streams in British Columbia. In: Proceedings of the Forest-Fish Conference (May 1996), Trout Unlimited, Calgary, Alberta.

Langston, A.R. 1992. Williston Fisheries Compensation Program stream fertilization feasibility study, 1991 data report. Peace/Williston Compensation Program (fisheries), B.C. Hydro, Prince George.

Langston, A.R. 1995. Water temperatures of the Nation and Mesilinka rivers systems 1995. Peace/Williston Compensation Program (fisheries) report, Prince George. 22 p.

Milbrink, G. and S. Holmgren. 1981. Addition of artificial fertilizers as a means of reducing the negative effects of "oligotrophication" in lakes after impoundment. Drottningholm Rept. 59:121-127.

Minshall, G. W. 1979. Autotrophy in stream ecosystems. Bioscience 28: 767-771.

Mouldey, S. and K.I. Ashley. 1996. Development and testing of slow release fertilizer for restoring salmon habitat. Province of British Columbia, Ministry of Environment, Lands and Parks, Fisheries Project Report. No. RD54.

Mundie, J.H., K.S. Simpson and CJ. Perrin. 1991. Responses of stream periphyton and benthic insects to increased in dissolved inorganic phosphorus in a mesocosm. Can. J. Fish. Aquat. Sci. 48: 2061-2072.

Paul, A.J., C.W. Koning, K.I. Ashley, P.A. Slaney, P.W. Davidson and R.W. Land. 1996. Development of a premier northern river fishery: Mesilinka River, the first year of fertilization (1994). Ministry of Environment, Lands and Parks. Fisheries Project Report No. RD 50.

Paul, A.J. and J.R. Post. 1996. A quantitative assessment of the recovery of bull trout populations in Alberta and development of models of sustainable yield: the first year of investigation (1995). University of Calgary, Calgary, AB. 57 p.

Perrin, C.J., M.L. Bothwell and P.A.Slaney. 1987. Experimental enrichment of a coastal stream in British Columbia: effects of organic and inorganic additions on autotrophic periphyton production. Can J. Fish. Aquat. Sci. 44: 1247-1256.

Peterson, B.J., L. Deegan,, J. Helfrich, J.E. Hobbie, M. Jullar, B. Moller, T.E. Ford, A. Hershey, A. Hiltner, G. Kipphut, M.A. Lock, D.M. Fiebig, V. Mckinley, M.C. Miller, J.R. Vestal, R. Ventullo and G. Volk. 1993. Biological responses of a tundra river to fertilization. Ecology 74: 653-672.

Peterson, B.J., J.E. Hobbie, A.E. Hershey, M.A. Lock, T.E. Ford, J.R.Vestal, V.L. McKinley, M.C. Miller, R.M. Ventullo and G.S.Volk. 1985. Transformation of a tundra stream from heterotrophy to autotrophy by addition of phosphorus. Science. 229:1383-1386.

Praire, Y.T., and J. Kalff. 1988. Dissolved phosphorus dynamics in headwater streams. Can. J. Fish. Aquat. Sci. 45: 200-209.

Quamme, D.L. 1994. Phosphorus limited community dynamics of stream benthic algae and insects. University of British Columbia Masters thesis. 78p.

Schindler, D.W. 1990. Natural and anthropogenically imposed limitations to biotic richness in fresh waters, p. 425-462. In G.M. Woodwell [ed.] The Earth in Transition: Patterns and Processes of Biotic Impoverishment. Cambridge University Press, New York, NY.

Slaney, P.A. 1986. An assessment of the rainbow trout (Salmo, gairdneri) population of the Upper Nechako River and the effects of a sport fishery closure. B.C. Ministry of Environment Fish. Man. Rept. 89: 37 p.

Slaney, P.A. and A.D. Martin. 1987. Accuracy of underwater census of trout populations in a large stream in British Columbia. North Arner. J. Fish. Man. 7: 117-122.

Slaney, P.A. and T.G. Northcote. 1974. Effects of prey abundance on density and territorial behavior of young rainbow trout (Salmo gairdneri) in laboratory stream channels. J. Fish. Res. Board Can. 31:1201-1209.

Slaney, P.A. and B.R. Ward. 1993. Experimental fertilization of nutrient deficient streams in British Columbia, p. 128-141. In G. Shooner et S. Asselin (Ed.). Le developpement du Saumon atlantique au Quebec: connaitre les regies du jeu pour reussir. Colloque international de la Federation quebecoise por le saumon atlantique. Quebec, decembre 1992. Collection Salmo salar n° 1: 201 p.

Slaney, P.A., D. Zaldokas, K.I. Ashley and D. Rimmer. 1993. Development of a Trophy Fishery on the Adam River by Enhancing Habitat Productivity: Pre-Fertilization Progress 1992-93. Prov. B.C. Fish. Proj. Rep. No. RD36: 25 p.

Stewart-Oaten, A. W.W. Murdoch and K.R. Parker. 1986. Environmental impact assessment: "pseudoreplication" in time? Ecology 67: 929-940.

Strickland, J.D.H. and T.R. Parsons. 1972. A practical handbook of seawater analysis. Bull. Fish. Res. Board Can. 67: 311 p.

Toth, B.M., P.A. Slaney, T.I. Bodin and K.I. Ashley. 1993. Development of a Premier River fishery: Big Silver Pre-Fertilization Progress 1993. Prov. B.C. Fish. Proj. Report No. RD37: 38 p.

Tukey, J.W. 1949. One degree of freedom for non-additivity. Biometrics. 5:232-242.

Underwood, A.J. 1992. Beyond BACI: the detection of environmental impacts on populations in the real, but variable, world. J. Exp. Mar. Biol. Ecol. 161:145-178.

Underwood, A.J. 1994. On beyond BACI: sampling designs that might reliably detect environmental distrubances. Ecologcial Applications. 4:3-15.

Ward, B.R. and P.A. Slaney. 1988. Life history and smolt-to adult survival of Keogh River steelhead trout (Salmo gairdneri) and the relationship to smolt size. Can. J. Fish. Aquat. Sci. 45:1110-1122.

Warren, C.E., J.H. Wales, G.E. Davis and P. Doudoroff. 1964. Trout production in an experimental stream enriched with sucrose. J. Wild. Manage. 28: 617-660.

White, G.C., D.R. Anderson, K.P. Burnham and D.L. Otis. 1982. Capture-recapture and removal methods for sampling closed populations. Los Alamos National Laboratory, LA-8787-NERP, Los Alamos, New Mexico. 235 p.

Wilzbach, M.A. 1985. Relative roles of food abundance and cover in determining habitat distribution of stream-dwelling cutthroat trout (Salmo clarki). Can. J. Fish. Aquat. Sci. 42: 1668-1672.

APPENDICES

Appendix A - Densities of dipterans, ephemeropterans, plecopterans and trichopterans collected on insect baskets from three reaches of the Mesilinka River (Blackpine, Tl and T2) and the Nation River. Number of insect baskets (n), mean densities (#•0.04m^{-2}) and standard deviation (SD) are shown.

		1993				1994				1995			
Location		Dipt.	Ephem.	Plec.	Tric.	Dipt.	Ephem.	Plec.	Tric.	Dipt.	Ephem.	Plec.	Tric.
Blackpine	n	10	10	10	10	10	10	10	10	10	10	10	10
	mean	48.8	114.0	74.9	30.1	18.3	74.5	36.4	17.3	18.5	36.8	20.6	13.1
	SD	22.96	78.02	33.08	31.30	21.09	39.81	38.70	23.10	8.26	23.72	10.01	8.49
Tl	n	10	10	10	10	10	10	10	10	8	8	8	8
	mean	44.9	69.2	45.0	3.5	523.3	74.2	17.0	2.8	166.5	3.5	3.8	0.8
	SD	24.20	31.45	22.01	1.84	477.32	76.07	17.17	2.94	159.94	7.52	3.28	0.89
T2	n	10	10	10	10	9	9	9	9	10	10	10	10
	mean	1.2	2.2	2.4	0.2	30.1	4.9	12.3	0.1	88.1	21.7	10.4	21.6
	SD	1.87	1.32	2.80	0.42	71.02	6.29	21.56	0.33	33.05	10.06	10.30	17.01
Nation R.	n	4	4	4	4	6	6	6	6	4	4	4	4
	mean	45.8	124.0	23.8	19.5	35.2	102.8	19.5	1.8	15.5	29.3	5.0	0.8
	SD	26.41	37.26	13.05	11.96	18.23	45.53	6.38	0.98	12.29	24.07	1.63	1.50

Appendix B - Size-at-age data for rainbow trout and Arctic grayling from 1992 to 1995 collected from three reaches of the Mesilinka River by angling and electrofishing.

Rainbow Trout

		Number of Fish				Fork Length (mm)				Weight (g)			
Age	Location	1992	1993	1994	1995	1992	1993	1994	1995	1992	1993	1994	1995
0	Blackpine		7	2			47	45			1	1	
	T1		6	8	6		51	60	63		1	3	3
	T2		7	44			42	43			1	1	
1	Blackpine		2	10			98	106			11	13	
	T1			9	4			108	97			13	10
	T2		2	6			123	115			25	24	
2	Blackpine	3	12	5	3	177	160	175	183	66	66	79	63
	T1	10	9	2	2	162	168	174	190	57	73	84	73
	T2	10	14	9	21	171	146	172	192	57	59	81	86
3	Blackpine	21	4	5	11	227	201	210	226	166	128	130	97
	T1	19	4	17	21	219	244	229	225	131	177	161	132
	T2	28	25	25	25	207	224	218	245	116	130	134	175
4	Blackpine	10	6	2	11	281	251	292	258	255	208	309	187
	T1	6	8	4	17	272	268	275	274	222	230	252	237
	T2	19	29	15	29	254	273	275	286	195	214	252	279
5	Blackpine	2	3			326	323			383	378		
	T1	7	5	3	5	316	296	280	315	320	284	258	334
	T2	7	6	3	1	315	294	300	296	304	236	308	306
6	Blackpine												
	T1	2		2	1	315		331	343	369		386	338
	T2	4	1			311	310			355	482	0	
7	Blackpine												
	T1												
	T2	1				342				397			

Arctic Grayling

Age	Location	Number of Fish				Fork Length (mm)				Weight (g)			
		1992	1993	1994	1995	1992	1993	1994	1995	1992	1993	1994	1995
0	Blackpine			1				55				1	
	T1				1				57				2
	T2			5				73				7	
1	Blackpine			1				129				129	
	T1												
	T2												
2	Blackpine		3		1		201		220		114		124
	T1		5	1	2		177	224	235		91	156	152
	T2	2	4	1	6	198	162	183	223	128	57	90	119
3	Blackpine	5	1	1	0	269	367	275		227	304	276	
	T1	4	3	2	9	268	249	226	269	206	189	151	222
	T2	14	2	3	8	253	270	235	257	176	199	166	211
4	Blackpine	19	14	6	18	302	298	299	309	333	279	346	334
	T1	6	5	3	19	305	311	286	308	317	357	269	342
	T2	5	2		4	285	283		296	255	312		311
5	Blackpine	12	5	4	12	328	333	320	345	409	352	397	466
	T1	5	5	7	9	338	326	318	349	442	363	397	505
	T2	3	1	2	0	333	348	313		406	511	369	
6	Blackpine	6	4		5	366	354		336	489	483		445
	T1	2	3	1	3	378	368	369	360	554	492	546	557
	T2												
7	Blackpine	3	2	1		375	366	365		489	482	506	
	T1	1	1	1		360	382	379		454	425	606	
	T2												