Stream Fertilization as a Fisheries Mitigation Technique for Perturbated Oligotrophic Trout Streams in British Columbia

Koning, C. W. Watershed Restoration Program, Ministry of Environment, Lands and Parks, 2204 Main Mall, Fisheries Centre, University of British Columbia, Vancouver, BC V6T 1Z4

Ashley, K. I. Fisheries Research and Development Section, Ministry of Environment, Lands and Parks, 2204 Main Mall, Fisheries Centre, University of British Columbia, Vancouver, BC V6T 1Z4

Slaney P. A. Watershed Restoration Program, Ministry of Environment, Lands and Parks, 2204 Main Mall, Fisheries Centre, University of British Columbia, Vancouver, BC V6T 1Z4

Paul, A. J. Fisheries Research and Development Section, Ministry of Environment, Lands and Parks, 2204 Main Mall, Fisheries Centre, University of British Columbia, Vancouver, BC V6T 1Z4

Abstract

Stream fertilization is a promising habitat restoration technique that is being supported within the Watershed Restoration Program of British Columbia, a program designed to restore watersheds impacted by past timber harvesting practices. In impacted systems, the addition of fertilizer replaces lost nutrients and increases food chain productivity, thereby improving conditions for fish to survive stressed conditions caused to the stream bank by activities such as logging. Three rivers are being experimentally treated: Adam River and Big Silver Creek, located on the south coast, and Mesilinka River, in the northern interior. The Mesilinka River is a large northern river (mean summer flow, 112 $m^3 \cdot s^{-1}$) located 280 km north of Prince George, and flows east into Williston Reservoir which empties into the Peace River. It is one of several oligotrophic streams inhabited by migratory and resident salmonids that were affected by construction of the reservoir, thereby flooding the lowermost and most productive stream reaches. To offset the lost productivity of fish habitat, liquid fertilizers (agriculture-grade nitrogen and phosphorus) were added to the river during the summer months of 1994 and 1995, after 2 years of pre- fertilization monitoring (1992 and 1993) in control and treatment reaches. Target in-river concentrations were very low, namely 5 $\mu g \cdot L^{-1}$ dissolved inorganic phosphorous and 20 $\mu g \cdot L^{-1}$ dissolved inorganic nitrogen.

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Preliminary results (1995) from 5–8 km index reaches suggest rainbow trout and mountain whitefish numbers have increased two-fold and five-fold, respectively. By 1995, weight-at-age of rainbow trout (age 4+ fish only) increased in the treated reach (T2) compared to the control (34%). The response of the food chain, indicated by periphyton accrual, was detectible for >15 km below the fertilizer drip stations. These, and earlier reported results demonstrating strong growth response of fish, indicate that low-level stream fertilization can also be used as one technique (usually within a larger set of habitat measures) in restoring impacted oligotrophic streams. New initiatives in our nutrient addition projects include development and application of a flow-proportional fertilizer injector system for liquid nutrients, and development and application of slow-release solid fertilizer briquettes for annual applications.

Introduction

Research has been conducted on stream fertilization for over a decade on Vancouver Island, British Columbia, first at the Keogh River during the 1980s (Slaney et al. 1986; Johnston et al. 1990), more recently at the Salmon River (Slaney and Ward 1993; Slaney, Ashley, Wightman, Ptolemy, and Zaldokas 1994), and also on a tundra stream in Alaska (Deegan and Peterson 1992). The primary objectives were to determine the effect of nutrient additions on the growth and abundance of anadromous salmonids in oligotrophic streams (Fig. 1), to determine if controlled seasonal enrichments are a cost-effective rehabilitation technique, and to evaluate the technique in order to provide mitigation of logging impacts on, for example, overwinter survival of juvenile and adult salmonids. Fertilization of the Keogh and Salmon rivers resulted in up to 2- to 3-fold increases in the average weight of juvenile steelhead trout after only 2 to 3 months of fertilization (Fig. 2) (Slaney et al. 1986; Johnston et al. 1990; Slaney and Ward 1993). Periphyton responses were detected 50 km downstream from a single fertilizer input site at the upper Nechako River (northern British Columbia), illustrating that nutrient cycling or spiralling can occur over extended distances in large streams (Slaney, Rublee, Perrin, and Goldberg 1994).

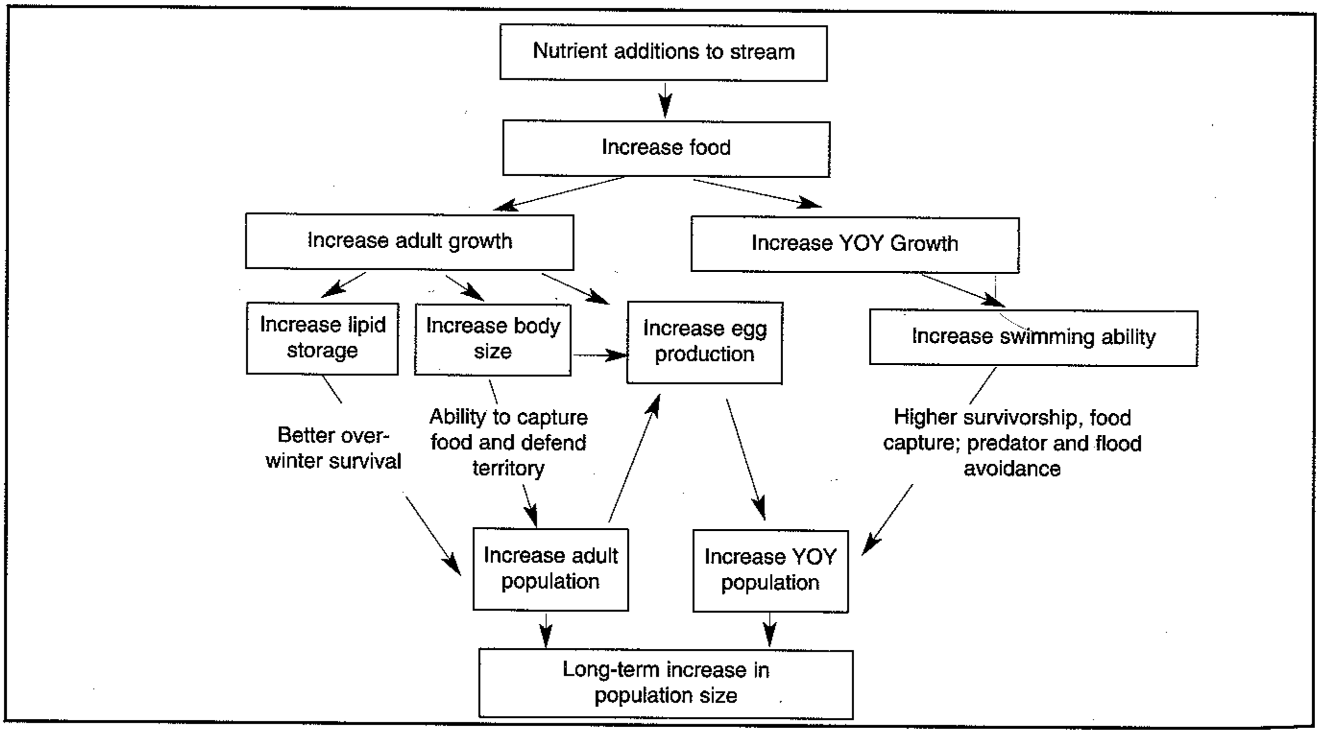

Figure 1. Overview of the response of fish to nutrient additions to the stream, based on Arctic grayling response (Deegan and Peterson 1992).

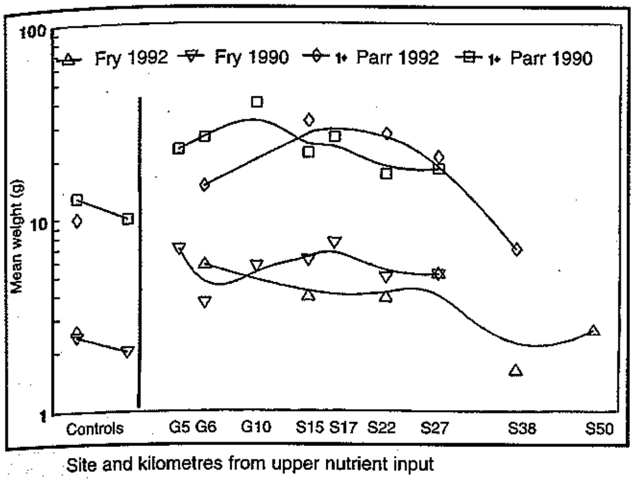

Figure 2. Trends in mean weights of rainbow (juveniles and adults) and steelhead trout (juveniles) within control, fertilized, and downstream sampling sites in Grilse Creek (which flows into the Salmon River) and the Salmon River during 1990 and 1992. Spatial controls were located in the upper Salmon River, Grilse Creek (G), and the mainstem of the Salmon River (S), with distances in km from the upper fertilizer tank at Grilse Creek (Slaney and Ward 1993).

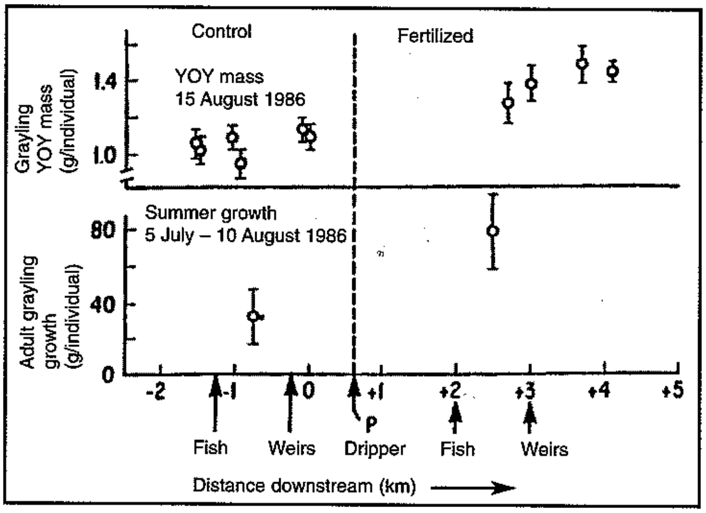

Figure 3. Arctic grayling growth in control and fertilized reaches in 1986. Upper: the mean mass of young-of-the-year (YOY) grayling was significantly larger at sites below the phosphorous addition site compared to sites above (t = 9.7, df - 294, P < 0.001). Lower: the mean mass gain of adult grayling in the fertilized reach during 5 weeks of July and August 1986 was significantly higher than mass gain in the control reach (t = 2.6, df - 39, P = 0.01) (Peterson et al. 1993).

Insect bioassays confirmed there are strong benthic insect responses to nutrient additions (Quamme 1994; Perrin and Richardson, in prep.).

A few trophy-sized resident trout fisheries have been historically associated with cultural enrichment, for example, the Cowichan River (Vancouver Island), and Crowsnest and Bow rivers (Alberta), suggesting that inorganic nutrients from treated sewage effluent can be beneficial if discharged to the river in a controlled manner to avoid contaminants. The response of resident salmonids is likely more evident than with anadromous fish because they remain in the stream for several more years, especially among species with some longevity. With only a six-week growth window in the Kuparuk River in northern Alaska, adult grayling in the fertilized reach gained an average of 78 g (20.6%), while fish in the control reach gained an average of 32 g (8.9%). Young-of-the-year grayling (age 0+ fish) were 40% heavier in the fertilized reach than in the control (Fig. 3) (Petersen et al. 1993).

The establishment of the Williston Reservoir in 1968–1972 flooded substantial portions of the Peace, Parsnip, and Finlay rivers, as well as the lower portion of many large and small tributaries, including the Mesilinka and Nation rivers (Barrett and Halsey 1985). Riverine habitats (such as groundwater channels, off-channel ponds, oxbows, and deep pools) utilized by salmonids, including Arctic grayling, and mountain whitefish were reduced substantially (Bruce and Starr 1985). Thus, the present Mesilinka fertilization project is a mitigation option, to compensate for loss of fish populations in the lower, flooded reaches. The purpose of this paper is to describe the initial results from this investigation, and to describe some of our new developments in stream fertilization work.

Study Area

The Mesilinka River is a large northern river (watershed area, 3285 km^2) located about 280 km north of the city of Prince George, B.C. The headwaters originate in the Omineca mountain range and the river flows for about 120 km before emptying into B.C.'s largest freshwater body, Williston Reservoir (Fig. 4). Williston Reservoir (watershed area, 70 860 km^2; reservoir surface area, 1775 km^2) was formed behind the W.A.C. Bennett Dam during the late 1960s to provide hydroelectric energy, and is part of the Peace–

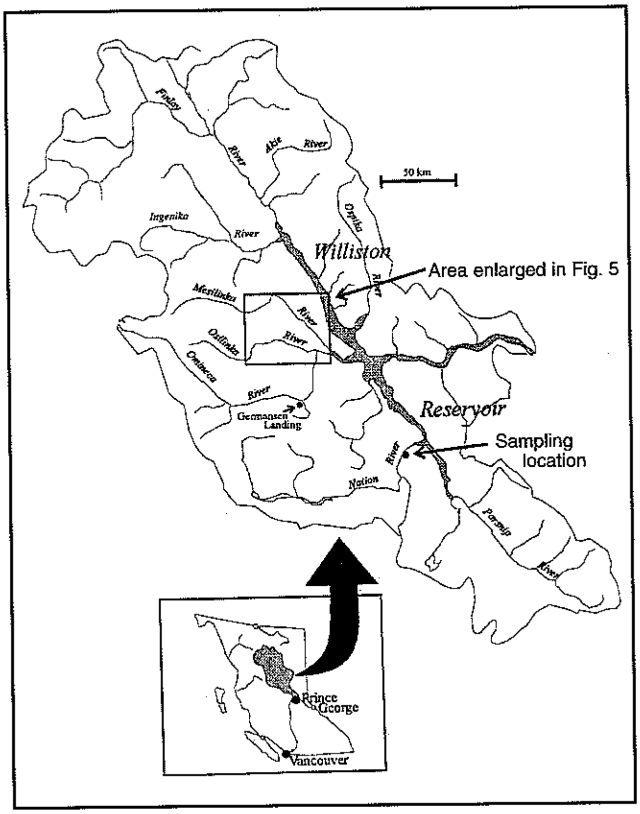

Figure 4. Project area, Mesilinka River located in northern British Columbia.

Slave–Mackenzie River system, which ultimately flows north and discharges into the Arctic Ocean.

Flows of the Mesilinka River are relatively high in spring to early summer due to melting snowpack and spring rains. Mean spring to summer flows for the 10-year period of 1982–91 were 74, 180, 108, 49, and 35 $m^3{\cdot}s^{-1}$ during May, June, July, August, and September, respectively (Water Survey of Canada data). Minimum flows of 6 to 8 $m^3{\cdot}s^{-1}$ occur in February and March. The temperature regime of the Mesilinka River is typical of many large Williston Reservoir streams, averaging 10–13°C (mean monthly) in summer.

Concentrations of soluble reactive phosphorous (SRP) and total dissolved phosphorous (TDP) are extremely low, typically below detectable limits of <1 $\mu g{\cdot}L^{-1}$ and <3 $\mu g{\cdot}L^{-1}$, respectively, indicating that the river and its main tributaries are highly oligotrophic. Nitrate–nitrogen ranges from 5 to as high as 40 $g{\cdot}L^{-1}$ during the summer season. Nitrate–nitrogen values below 20 $g{\cdot}L^{-1}$ are considered to be algal growth limiting (Slaney, Rublee, Perrin, and Goldberg 1994). Periphyton accrual is very low (peaking at 10–16 $mg{\cdot}m^{-2}$), which corresponds with low insect abundance in stream substrates. Underwater inspection of the substrate of several riffles in the main stem confirm that the periphyton and insect communities are poorly developed and of low biomass. The low nutrient concentrations are typical of a northern interior watershed of shallow soils overlying bedrock, and without returning salmon or kokanee to provide an external source of marine- or reservoir-derived nutrients.

Wild rainbow trout (*Oncorhynchus mykiss*), Arctic grayling (*Thymallus arcticus*), and mountain whitefish (*Prosopium williamsoni*) populations inhabit the river, as well as smaller populations of bull trout (*Salvelinus confluentus*). Aside from bull trout, adult salmonid fish are small in size (≤ 30 cm on average). Salmonid spawning and rearing habitat is found primarily in tributaries of the Mesilinka River. There are no known fish barriers to salmonid fishes on the main stem. Other species found either in the main stem or tributaries include burbot (*Lota lota*), sucker species (*Catostomus* spp.), sculpin species (*Cottus* spp.), and various Cyprinids including northern squawfish (*Ptychocheilus oregonensis*). Mature white and black spruce, aspen (*Populus tremuloides*), balsam poplar (*Populus balsamifera*), willow species (*Salix* spp.), and red alder (*Alnus rubra*) are the dominant trees and shrubs in the riparian zone. Logging has occurred to the stream bank of some of the tributaries and within sections of the main stem, and these activities have likely impacted fish habitat; however, the extent of these impacts in the Mesilinka watershed is undocumented.

The external control in this project, the Nation River, is located about 100 km south of the Mesilinka River, and also flows into the Williston Reservoir (Fig. 4). The river has a lake at its head and has a drainage area of 5880 km^2. Mean monthly flows in May, June, July, August, and September are 244, 293, 108, 40, and 27 $m^3{\cdot}s^{-1}$, respectively. The Nation River tends to be more nitrogen (N) limited than the Mesilinka River because of the large lake, while both rivers are equally phosphorous (P) limited.

The potential for riverine fertilization to substantially enhance salmonid and grayling production is limited to those streams with: a) adequate juvenile recruitment; b) nutrient deficiencies; c) warmer streams with mean summer temperatures more than 10°C, preferably 12–15°C; d) abundant adult fish habitat; and e) high overwinter survival, the latter positively related to winter flow level and availability of pool habitat. The Mesilinka River is near ideal in physical habitat within its upper, middle, and lower reaches because it has sufficient flows, pools,

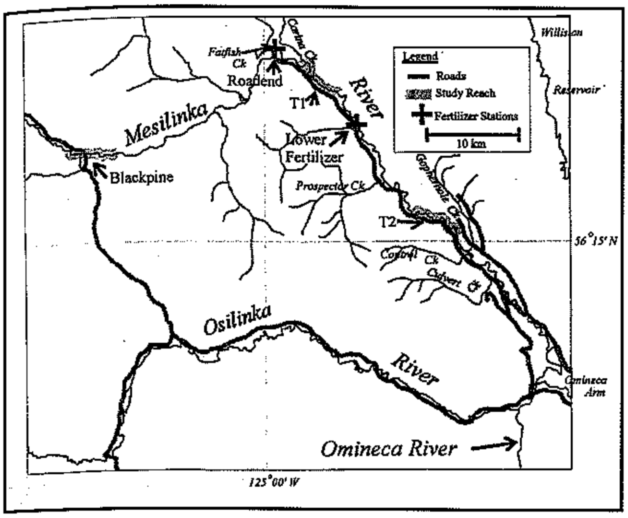

Figure 5. **Location of control and fertilized reaches (N and P added), Mesilinka River.**

and cover. Side-channel and tributary fish rearing areas are also sufficient. Mean monthly water temperatures in the Mesilinka middle and lower reaches during July and August (12–13°C) are within the lower acceptable range to augment salmonid growth.

Materials and Methods

The 1992–1995 (June–September only) sampling programs on the Mesilinka River (main stem and selected tributaries) consisted of sampling stream flows, water temperature, water chemistry, periphyton, benthic insects, and fish species. The Nation River was also sampled in a similar manner, but to a lesser extent. Three reaches were designated and individually sampled in the Mesilinka River: Blackpine (the experiment control reach), and T1 and T2 (fertilizer treatment reaches, in July and August 1994–95) (Fig. 5). These reaches are 7.5, 7.2, and 8.1 km in length, respectively, with wetted widths of about 35–40 m (August). They were chosen on the basis of accessibility and general similarities.

Mesilinka flows were obtained from the Water Survey of Canada. Tributary flows were derived from instream velocity measurements and stream area. Water temperatures were recorded with automated temperature data loggers (Tempmentor, by Ryan Instruments; and Hobo by Onset Computer Corp.) in each of the three reaches and in selected tributaries. Dissolved nutrient concentrations were sampled and measured as described in Johnston et al. (1990). Nutrient water chemistry variables measured were: low-level nitrate–nitrogen, ammonium–nitrogen, total dissolved nitrogen, low-level ortho-phosphorus (also called soluble reactive phosphorus, or SRP), and total dissolved phosphorus (TDP) on a biweekly to monthly basis. All of the above nutrients were measured in dissolved rather than particulate form. Nutrients, and in addition, total alkalinity, pH, and total dissolved solids (1992 only) were sampled on a monthly basis. Nonfilterable residue (NFR) and turbidity samples (indicators of water transparency) were collected weekly because of glacial turbidity in spring to early July. Handling and analysis of samples followed standard methods as in American Public Health Association (1985). Transparency was also measured *in situ* in the main stem using Secchi disk visibility.

Periphyton accrual, as measured by peak chlorophyll-a content, provides a useful indicator of the potential effects of nutrient stimulation (Perrin et al. 1987). Periphyton accrual was measured as described in Bothwell (1988) and Johnston et al. (1990). In this method, plexiglass plates, black in color, were bolted to concrete blocks using four stainless bolts per block. Styrofoam (30 cm x 30 cm x 0.6 cm) was fastened to the plexiglass plates with stainless steel wire. At each site the blocks were placed in a pool tailout at a depth of about 0.5 m below the water surface. Two 2-cm cores of periphyton (duplicate samples) were sampled at approximately 2- to 4-week intervals from the styrofoam substrata at each station, and each was analyzed as in Bothwell (1988). In each summer sampling season, 10 periphyton sampling blocks were installed from mid-July to mid-September in each of the three main stem reaches and in select tributaries. Styrofoam substrata were replaced after periphyton accrual peaked, or after 4–6 weeks (as in Johnston 1990). Thus, each set of chlorophyll-a determinations provided replicated accrual rates and peak levels in each of the three reaches.

Insect colonization baskets (cylindrical in shape, 22 cm in diameter by 13 cm in depth; 0.04 m^2 in area and 0.005 m^3 in volume, made of plastic) containing 3–6 cm diameter gravel were installed in riffle areas within the control and test reaches. For statistical purposes at least five baskets were installed at each reach. Baskets were surrounded by cobbles to minimize dislodgement, then left to colonize with insects for 6–8 weeks. At removal a Surber sampler (0.2-mm mesh net) was placed directly downstream from the basket, the gravel was scrubbed, and the contents of the basket (insects and detritus) were washed into the sampler. Based on earlier studies in other rivers, 80% of the peak abundance of insects is usually attained in 6 weeks and peak abundance attained at 8 weeks (Mason et al. 1973).

Fish Sizes and Abundance

During July and the first 2 weeks of August, fish were sampled in the three test reaches of the Mesilinka River, using standard angling techniques with barbless hooks. Fish lengths (fork-length) and weights were measured and recorded for catchable (mainly ≥ 20 cm) rainbow trout, Arctic grayling, bull trout, and mountain whitefish. Scales of rainbow trout and grayling were sampled for size-at-age determination. Scales were processed and aged as described in Ward and Slaney (1988).

Low conductivity confirmed that boat-shocking would be ineffective in the Mesilinka River, and therefore an alternative method for estimating fish populations was utilized, namely, underwater census (also referred to as snorkel surveys, or swim counts). Fish caught in the first 2 weeks of August (1992–95) were tagged with Floy tags (different colors per reach and per year) for subsequent population estimate studies using mark–recapture (visual) techniques. In the third week of August, highly standardized underwater counts were completed by a crew of six experienced divers using the method described in Slaney and Martin (1987). Water temperatures at the time of each swim were 11°C or higher because otherwise fish are found to be inactive and easily missed (Slaney and Martin 1987). Underwater census had been conducted previously by Fisheries Program staff in several trout streams in British Columbia including the St. Mary River (Slaney and Martin 1987), Adam River (Slaney et al. 1993; Toth et al. 1996a), and Big Silver Creek (Toth et al. 1996b). Systematic evaluations of underwater census techniques are found in Northcote and Wilkie (1963), Goldstein (1978), Griffith (1981), Gardiner (1984), Hankin and Reeves (1988), and Heggenes et al. (1990), which confirm the usefulness of the method, provided low temperatures (<11°C) were avoided for resident salmonids. In mark–recapture activities, fish are typically marked up to 2 weeks in advance of recapture to facilitate redistribution, as recommended by Vincent (1971).

Fish in the three Mesilinka reaches were counted by underwater census over a 5- to 6-day period. Within each of the three reaches, each float was replicated twice at random, within shore and mid-channel lanes. Tagged (i.e., recaptured fish) and untagged fish were recorded by species and by 10-cm-length category within each of the three reaches. Underwater census combined with mark–recapture techniques were then used to calculate correction factors for the underwater swim counts (as in Slaney and Martin 1987), because not all fish are detected in every swim. These correction factors provide a more accurate estimate of fish numbers, and can be used in subsequent years when mark–recapture estimates are not conducted. Complete details regarding methods (including calculation of correction factors, and methods used in the tributaries) are provided in Koning et al. (1995).

Nutrient Addition

Nutrients were added to the Mesilinka River (upstream from T1 and T2) in 1994 and 1995 (end of June to the beginning of September), by the addition of liquid ammonium polyphosphate fertilizer (10-34-0; % by weight $N:P_2O_5:K_2O$) and urea-ammonium nitrate (28-0-0; % by weight $N:P_2O_5:K_2O$). These fertilizers were added (via streambank-located tank and valve-controlled gravity-fed plastic hose) in sufficient quantity to provide an instream concentration of 5 μg·L dissolved inorganic P and 20 μg·L dissolved inorganic N. In 1994 both P and were added above T1, while only N was added above T2. In 1995, we added N and P fertilizers at both sites.

Results and Discussion

Complete data on 1992–95 area air temperatures, precipitation, main stem hydrology and water quality are found in Koning et al. (1995) and Paul et al. (1996, 1998). Pre-fertilization N (nitrate–nitrite N) and P (soluble reactive P) ranged from 5–26 μg·L N and from < 1–3 μg·L P. Target concentrations of N and P (in T1 and T2) were not always recorded or achieved in (July–August) 1994 and 1995. This was likely due to the poor injector system, based on gravity feed that frequently became plugged, and secondly due to rapid uptake by periphyton. A portion of the phosphorus will likely pool at depth in river sediments which will subsequently be available for release gradually throughout the year, but there is limited information on nutrient spiral-pathways in smaller (Newbold et al. 1981) and larger streams (Slaney, Rublee, Perrin, and Goldberg 1994). Total dissolved solids (TDS), pH, and total alkalinity were measured in 1992 but not in 1993. Mesilinka River values of TDS were 48–90 $mg{\cdot}L^{-1}$, pH 7.5–7.8, and total alkalinity 29–60 $mg{\cdot}L^{-1}$ (based on 1992 results). Over the summer, nonfilterable residue (NFR) (detection limit 4 $mg{\cdot}L^{-1}$) at main stem sites ranged from 4–30 $mg{\cdot}L^{-1}$, and turbidity from 0.1–5 NTU. Secchi disk depths (visibility from the water surface) ranged from 0.7–2 m. These values (1992–93) are typical and suggest sufficient water clarity exists for periphyton growth in areas with available nutrients.

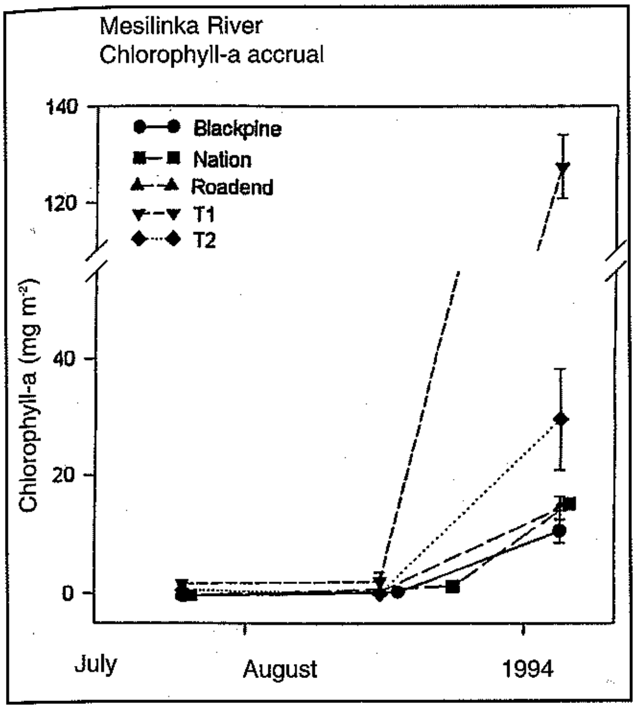

Figure 6. Chlorophyll-a accrual, Mesilinka River 1994 (year one of nutrient addition). Blackpine and Roadend are two upstream control reaches in the Mesilinka River; the Nation River serves as an external control. T1 and T2 are the two treated reaches.

Periphyton accrual, based on measurement of chlorophyll-a content (mid-July to mid-September), peaked at approximately the same rate and low magnitude (7–16 $mg \cdot m^{-2}$ over 8 weeks) at Blackpine, T1, and T2 in pre-fertilization years 1992–93. This suggests that the three sites are similar for comparison of impacts from input of nutrients in future years. Nation River results were similar. Addition of N and P in 1994 resulted in significant increases in periphyton accrual in the treated reaches T1 and T2 (Fig. 6). Results in 1995 were similar, except in T2, where accrual remained low, possibly due to increased periphyton grazing by benthic insects.

Assessment of the colonization of artificial substrate by aquatic insects provides a useful indicator of the response of salmonid food chains to enrichment, and is thus a good indicator of the potential for trout growth as documented elsewhere (Slaney and Ward 1993). In 1993 (pre-fertilization), mean benthic invertebrate biomass at Blackpine, T1, and T2 varied from 0.5 to 17 $g \cdot m^2$. Invertebrate biomass in T2 increased from 0.5 to 6 $g \cdot m^2$ between 1993 and 1995. Biomass in T1 remained between 4 and 7 $g \cdot m^2$; and biomass in the control reach (Blackpine) decreased from 1993 to 1995 (by about 60%). By comparison, samples from the Salmon River on Vancouver Island weighed between 5 and 12 $g \cdot m^2$ at un-enriched sites, and up to 38 $g \cdot m^2$ at enriched sites (Slaney, Ashley, Wightman, Ptolemy, and Zaldokas 1994). Numbers of individual invertebrates in the Mesilinka samples followed the same trends as in the biomass. Based on preliminary observations of the Mesilinka samples, most common were various genera from the orders Plecoptera (Chloroperlidae family), Ephemeroptera (Baetidae family), and Diptera (Tipulidae and Chironomidae families).

Fish Sizes and Abundance

Fish species for which we recorded size and age data include rainbow trout, bull trout, Arctic grayling, and mountain whitefish. In total, in each of the 4 years about 500–700 fish were caught by methods that included angling, electrofishing, trapping, and gill netting. Rainbow trout were the most numerous fish species sampled, based on the type of sampling methods used (mainly by angling). In actual numbers, mountain whitefish (a species much less catchable by angling gear) were by far the most abundant fish species, based on underwater census.

Length (fork-length) and weight records for Mesilinka and Nation river salmonids indicate bull trout range in size up to 800 mm and 4.6 kg (average length less than 400 mm). Mountain whitefish were the smallest salmonid species with fork-lengths mostly in the 225 to 300 mm range. Most rainbow trout were in the 200–350 mm range, and most Arctic grayling ranged from 250 to 390 mm. Age composition of rainbow trout and Arctic grayling were similar between the two rivers. In both rivers age 3+ rainbow trout and age 4+ Arctic grayling predominated. Overall, there was a tendency towards slightly greater sizes and growth rates per year for rainbow trout and Arctic grayling in the Nation River, and this is probably a result of warmer summer water temperatures there. Length and weight data in 1994–95 (Arctic grayling and rainbow trout, age 3+ and 4+) did not show significant increases over the pre-fertilization data (from 1992–93), with the exception of 1995 (year two of fertilization), when for the first time, size at age of rainbow trout (4+ fish only) increased significantly in the treated reach, T2, compared to the control [34% increase in weight, analysis of variance (ANOVA), $p<0.05$]. The response of the fish populations to fertilization may initially lag in the Mesilinka, because the cooler temperature regime of the Mesilinka (<12°C mean monthly summer temperatures) can be expected to moderate both the response and potential benefits to a fishery.

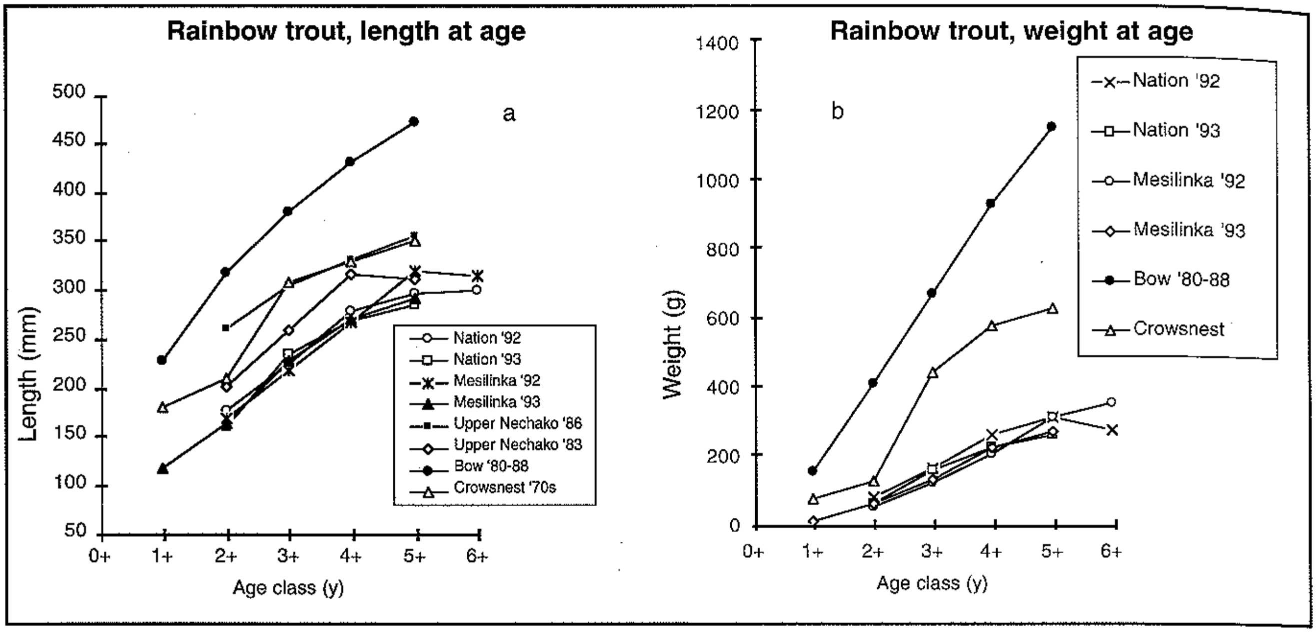

Figure 7. A comparison of rainbow trout, (a) length at age, and (b) weight at age in various rivers. The Mesilinka values (1992, 1993) are prior to fertilization. The Bow (below Calgary) and Crowsnest (in the 1970s) rivers are located in Alberta and are subject to treated municipal wastewater discharge. The Nechako River is in north-central B.C. and is quite similar to the Mesilinka River; the difference between the two years (1983, 1986) reflects a sport fishing closure in the river after 1983.

Comparisons to Other River Systems

Length- and weight-at-age (Fig. 7a, 7b) of rainbow trout size from the Mesilinka and Nation rivers were compared to those in the upper Nechako River (1983 and 1986, *in* Slaney 1986), the Bow River below Calgary (Courtney and Fernet 1991), and the Crowsnest River, flowing east out of the Rocky Mountains in southern Alberta (Alberta Fish and Wildlife Branch files, Lethbridge, Alberta). The Nechako is a northern river quite similar in geographic character to the Mesilinka and Nation rivers but with an oligo-mesotrophic nutrient regime (Slaney 1986). Water temperatures in the upper Nechako River (data on file) during the summer are higher than those in the Mesilinka, and similar to or slightly higher than those in the Nation River (Slaney 1986). The Bow River below Calgary contains ideal rainbow trout habitat combined with a very high nutrient regime due to treated wastewater effluent being discharged by the city. Similarly, the Crowsnest River (in the 1970s) also received treated municipal wastewater but to a lesser extent. Mean monthly water temperature in the Bow River in August ranges from 15–16°C (1975 data, *in* Culp et al. 1992), which is similar to the Nation River. Climate and geography in the Bow and Crowsnest systems are similar to those of the Mesilinka and Nation rivers. Clearly, rainbow trout in the Mesilinka and Nation rivers are substantially smaller than those in the upper Nechako, Bow, and Crowsnest rivers. Thus, data from the Nechako, Bow, and Crowsnest are supportive of the potential of low-level nutrient addition to enhance fish growth in cold-water, oligotrophic, interior systems such as the Mesilinka and Nation rivers.

Fish Abundance Estimated by Underwater Census and Mark–Recapture

Based on underwater counts (Fig. 8), the density (number of fish per hectare) of all four fish species in T1 increased in year two (1995) of fertilization. (Note that correction factors based on mark–recapture results have not been applied in Fig. 8.) Recognizing that substantial variability in fish density occurs from year to year, the results nevertheless are supportive of beneficial responses in the fish populations. In particular, these initial results for rainbow trout and mountain whitefish suggest increases over pre-fertilization years of at least two-fold and five-fold, respectively. Due to precipitation-induced turbidity problems, underwater census results are not available for T2 in 1995, and we completed only a single unreplicated swim result in the control reach (the replicated T1 and single control swims were carried

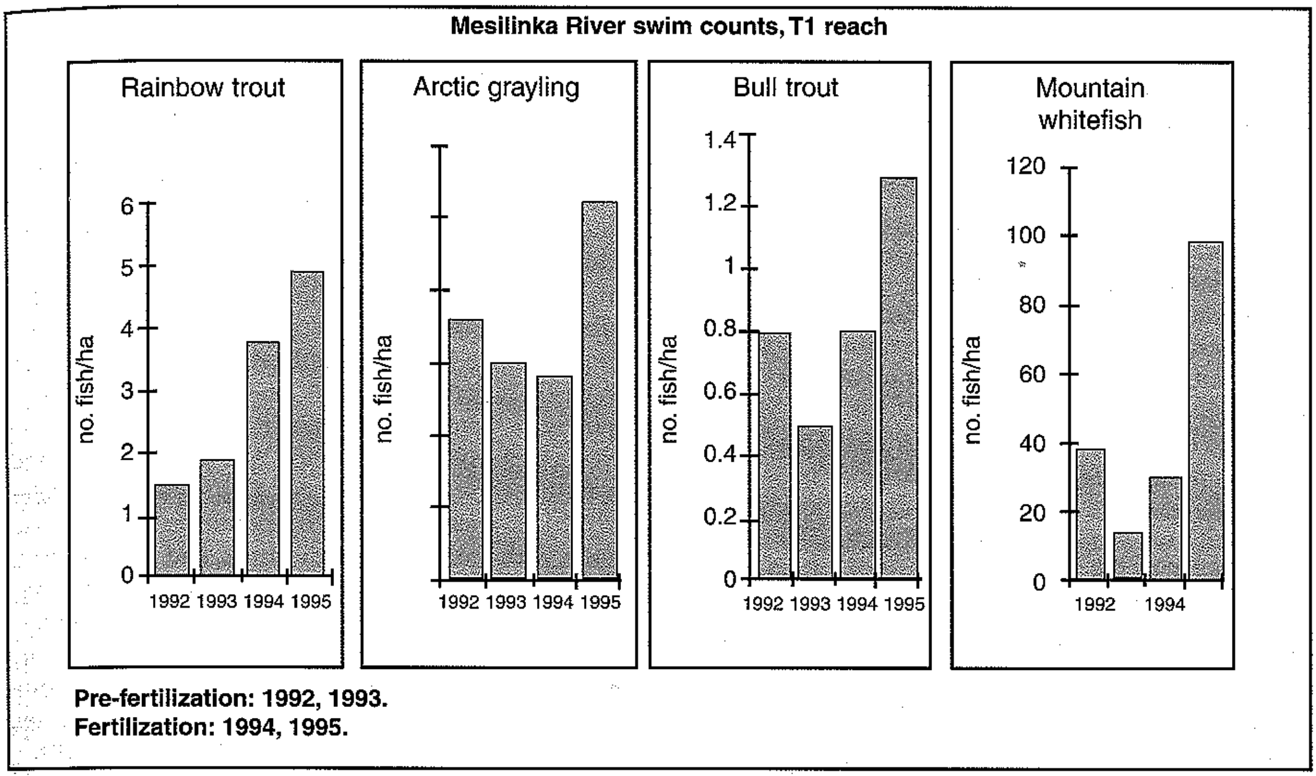

Figure 8. Mesilinka River swim counts in treated reach, T1. Numbers are based on census by six swimmers with mask and snorkel floating in line (in six lanes) in a downstream direction and expanded to account for fish not counted between lanes. No correction factor has been added to account for fish not observed by the swimmers, e.g., fish hidden within woody debris, and/or missed due to high velocity sections.

out prior to elevated turbidity levels). The unreplicated control reach swim result in 1995 combined with the previous 3 years of data do not show the same rainbow trout and mountain whitefish results as evident in T1 in 1995. Further comparisons, confirmations, and conclusions await several additional years of data collection.

The observed increase in rainbow trout and mountain whitefish numbers in T1 (and not in the control reach) after only 2 years of fertilization is likely attributable to fish attracted into the river from downstream areas, such as the reservoir, rather than to within-reach increases (recruitment). Recent observations in Sweden suggest that fish from downstream areas are likely being attracted by food odors, possibly responding to chemicals released by the periphyton, or periphyton-based community. Attracting fish from other reaches allows for greater overall productivity in the river.

Migratory adfluvial (lacustrine) stocks in the embayment area may benefit from the proposed river fertilization project because of stimulation of the riverine food chain and resultant spiralling of nutrients downstream to the embayment. Results of this kind were found with small-scale nutrient treatment at a stream and embayment at a northern Swedish reservoir, where increased zooplankton and benthic fauna benefited Arctic char and European grayling, respectively (Milbrink and Holmgren 1981). In addition, attraction of rainbow and bull trout into the Mesilinka River from the embayment could be substantial, based on the Milbrink and Holmgren (1981) study. The substantial size of some of the larger bull trout (3–5 kg) caught in the Mesilinka River (1992–95) suggests that this may already be occurring (i.e., the bull trout spend winter to spring months in the reservoir, similar to adult bull trout and rainbow trout in the Skagit River–Ross Reservoir, a system in southern B.C.).

Preliminary Conclusions

Results of field work in 1992–93 confirmed the suitability of the Mesilinka River for whole-river fertilization to mitigate some of the earlier impacts of reservoir flooding of the lower riverine reaches. The Mesilinka River contains sufficient flow and abundant adult-rearing habitat. Water temperatures are low but within the acceptable range for salmonid growth (especially for char and grayling growth), and water quality is adequate. Turbidity and suspended sediment levels can persist into mid-July, but transparency (more than 1 m) appears to be sufficient to initiate river fertilization in late June to early July. Suitable juvenile fish habitat is available in the tributaries and in the side-channels of the main stem. Underwater counts indicate the Mesilinka River has demonstrated there are sufficient numbers of rainbow trout, Arctic grayling, bull trout, and mountain whitefish (up to 31, 31, 9, and 310 fish/km, respectively) to continue and support fertilization as a mitigation option. Based on capture methods used, most catchable-sized rainbow trout and Arctic grayling are small and less than 30 cm. Results of nutrient addition (1994–95) show impacts on the food chain (increased periphyton growth and benthic invertebrate biomass and density) within the treated reaches, with an apparent trend towards increased fish biomass and numbers. These results await further confirmation, with expansion of fish populations as a likely outcome (Milbrink and Holmgren 1981).

Application of the Mesilinka results and of those obtained previously from the Keogh and Salmon rivers in B.C. are directly applicable to restoration of stream impacts due to past timber harvesting activities, in particular where harvesting to the stream bank has reduced the quantities of organic debris and food materials (allochthonous materials) entering the stream, or where degraded habitat results in higher than average metabolic energy required to maintain basic fish survival. Recent studies using stable isotope analyses have identified the important role of salmon carcasses in returning nutrients and food materials to anadromous streams (Schuldt and Hershey 1995; Bilby et al. 1996) and thus the negative consequences on stream trophic levels where due to overharvest or degraded habitat, numbers of returning salmon are far below natural levels. Adding nutrients in such situations aids in returning streams to pre-impact fish productivity levels.

Stream fertilization therefore is one more tool in the restoration toolbox. It does not take the place of hillslope stabilization, riparian rehabilitation, fish access improvements, input of large woody debris and boulder placements in streams, as well as other restoration techniques that are available, but in many streams it is an appropriate technique, to be used with others, to accelerate the restoration process.

New Developments

Recent developments (1995) in stream fertilization projects conducted by the B.C. Ministry of Environment are: a) the use of a flow-proportional liquid fertilizer injector system; and b) in smaller streams the use of slow-release solid fertilizer briquettes. The currently used manually operated liquid metering systems require daily adjustment to maintain constant application rates; hence, their cost effectiveness is reduced and the high maintenance requirements limit the application of this technique to easily accessible sites. A lab-scale automated system was developed to meter liquid fertilizer into rivers and streams (Ward and Associates 1995a), and was subsequently field tested (Ward and Associates 1995b). It was designed to operate in remote locations with minimal maintenance, and to automatically adjust metering rates to variations in river stage to maintain a constant low-level nutrient addition. This automated system significantly reduces the labor requirements of stream fertilization and provides a more accurate injection of liquid fertilizer, which should reduce the variability of our results.

Slow-release solid briquettes containing fertilizer (N and P) have been developed by Vigoro Chemicals (Winterhaven, Florida) at our request as an alternative to the use of liquid fertilizer. Although initially more expensive to purchase, their advantage lies in ease of use. The briquettes, which are the size of small spheres (diameter 3 cm) or cylinders (length 4–5 cm), are measured out (by weight) and added to a stream (in low stream velocity locations) at the beginning of the summer growing season, during the summer low stream flows. They slowly release nutrients (N and P) on a continuous basis over several months. During the current testing period, water quality, periphyton accrual, invertebrate biomass, and fish numbers are being monitored (Mouldey and Ashley 1996). The intention is to use slow-release briquettes in smaller systems where regulating very small amounts of liquid fertilizer injection is too labor intensive and inaccurate.

The flow proportional injectors were used for the first time in the summer of 1995 in Big Silver Creek (summer flows 8–42 m^3/s), which flows into Harrison Lake, and the Adam River (summer flows 8–17 m^3/s) located on Vancouver Island. Results suggest a highly uniform and highly productive growth of periphyton downstream of the fertilizer additions (Toth et al. 1996a, 1996b). The slow-release briquettes were also field tested for the first time in the summer of 1995, at about 10 locations, including tributaries of Big Silver Creek and the Adam River. Water quality analyses and positive periphyton accrual at downstream monitoring stations confirm the ability of the slow-release briquettes to produce the expected results over the growing season (Mouldey and Ashley 1996).

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