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Williston Reservoir River Fisheries Restoration:

The Mesilinka River Fertilization Experiment, 1992-99

G. A. Wilson, K.I. Ashley, P.A. Slaney and R. W. Land
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EXECUTIVE SUMMARY

Williston Reservoir River Fisheries Restoration: *The Mesilinka River Fertilization experiment, 1992-99*

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The Mesilinka River, a large northern oligotrophic river located in the central interior of British Columbia, was fertilized with low-level inorganic nitrogen and phosphorus to evaluate whole-river fertilization as a method of increasing riverine native fish populations. The lower reaches of the river were flooded by the formation of Williston Reservoir in 1968, and fertilization was chosen as a method to offset the loss of riverine habitat and increasing angling demands placed on the remaining adfluvial-lacustrine and adfluvial Arctic grayling, rainbow trout, mountain whitefish, and bull trout populations in the Williston drainage. Following a pre-fertilization assessment in 1992-93, liquid ammonium polyphosphate (10-34-0 % by weight N-P₂O₅-K₂O) and urea-ammonia nitrate (28-0-0 % by weight N-P₂O₅-K₂O) agricultural fertilizers were added in 1994-99 at target concentrations of 20 or 15 µg-N · L⁻¹ and 5 µg-P · L⁻¹. Field assessments completed in two treatment reaches, an upstream control reach, tributaries and an external control river, included nutrient concentrations, chlorophyll *a* accrual, benthic invertebrate biomass and taxonomy, and fish abundance, size, and age distribution.

Fertilizer loading rates were approximately 65% of target concentration due to difficulty in maintaining constant drip rates. Water chemistry analysis suggests the river became nitrogen and phosphorus co-limited during fertilization despite the addition of 9-10 µg · L⁻¹ of nitrogen with the fertilizer at each site, and background concentrations of 5-15 µg · L⁻¹. Regardless, increases in periphyton standing crop and benthic invertebrate abundance were detectable up to 40 km downstream indicating the incorporation of the additional nutrients into the food chain. Significant increases in fish density were detected after the second summer of fertilization, with indications of increasing size trends. The periphyton response moderated over time consistent with increased grazer abundance, as documented elsewhere.

However, the two treatment reaches responded differently to fertilization. The T1 reach showed a larger periphyton and faster benthic invertebrate responses, while the T2 reach showed no sustained periphyton response, with a gradual but consistent increase in benthic invertebrates. Peak chlorophyll *a* concentrations averaged a significant 4.7-fold higher than pre-fertilization values in the T1 reach, where density of benthic invertebrates increased 2.8-fold.

Numerical and growth responses of fish populations also varied between reaches. Mountain whitefish were the dominant species followed by Arctic grayling, rainbow and bull trout. Total density increased significantly in both treatment reaches during fertilization, 163% and 143% in the T1 and T2 reaches, respectively, with whitefish the largest response (73% and 245%, T1 and T2, respectively), followed by rainbow trout (141% and 103%, T1 and T2, respectively). There were small increases in grayling (33%) and bull trout (117%) densities in the T1 reach, but no change in the T2 reach. Density increases were generally not detected until after two summers of fertilization, with peak densities usually recorded in the

latter years of fertilization (1997 or 1999). From tagging of rainbow and grayling, average weight and length-at-age of rainbow decreased in the control reach, but generally increased in the T1 and T2 reaches during fertilization, with weight gains averaging 15% (range 2% to 25%). The average size of grayling also increased in the treatment reaches relative to the control reach, albeit not significantly. As a result of the density and size increases, the biomass of fish (excluding whitefish) increased 134% and 100% in the T1 and T2 reaches, respectively, during fertilization. The largest increase was in the T1 reach where biomass increased from 1.8 to an average 4.2 kg · ha⁻¹ during fertilization, following significant increases in both rainbow and bull trout biomass.

The differential responses in each reach probably stem from different fish habitats, and therefore preferences of the different species, in addition to possible treatment effects such as the distance between fertilizer inputs and assessment reaches. The importance of nutrients in driving the productivity of cool north temperate rivers was demonstrated by this large-scale ecological experiment, and although the results appear promising for whitefish and rainbow trout in this long running river experiment, it is premature to conclude this technique is applicable for restoration of Arctic grayling and bull trout in northern rivers. Natural variation combined with slow fish growth rates have likely resulted in a slow response, and we believe the fish community would require additional time to reach equilibrium.

INTRODUCTION

Indices of nutrients, including conductivity, dissolved solids and alkalinity, are positively correlated with salmonid abundance in streams and lakes (McFadden and Cooper 1962, Egglshaw 1968). Despite this, nutrient addition as a means to increase the invertebrate food supply for salmonids in oligotrophic streams has received limited attention in the past decade for habitat restoration or mitigation (Ashley and Slaney 1997). Additions of inorganic nutrients to oligotrophic streams increases periphytic production (Stockner and Shortreed 1978; Peterson et al. 1985; Perrin et al. 1987) at the base of the food chain, and thereby insect growth and abundance (Milbrink and Holmgren 1981; Peterson et al. 1985; Johnston et al. 1990; Mundie et al. 1991), and thus the growth of steelhead trout (*Oncorhynchus mykiss*), coho salmon (*O. kisutch*; Slaney et al. 1986; Johnston et al. 1990), and Arctic grayling (*Thymallus arcticus*; Deegan and Peterson 1992). Food abundance functions through territory size as a determinant factor affecting the abundance and growth of salmonids, and thus the carrying capacity of streams. Thus, seasonal increases in nutrient concentrations, which can be easily controlled and readily reversed, should be beneficial to fish production in oligotrophic streams.

The use of nutrients to restore or enhance 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). The introduction of non-native invertebrate species intended as a food resource (e.g. mysids) has had unpredictable and disastrous ecosystem effects, and sometimes achieved results exactly opposite of what was intended (Ashley et al. 1997). 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).

Research has been conducted on stream fertilization for over a decade on Vancouver Island, British Columbia, first at the Keogh River during the 1980's (Slaney et al. 1986), and then recently at the Salmon River (Johnson et al. 1990), and Adam River (Slaney et al. 1993; Wilson et al. 1999a), and in the Lower Mainland of Southern B.C. at Big Silver Creek (Toth et al. 1993; Wilson et al. 1999b). Primary objectives were to determine the effect of nutrient additions on the growth and abundance of anadromous salmonids in oligotrophic streams, to determine if controlled seasonal enrichments is a cost-effective enhancement or restoration technique, and more recently, as mitigation for logging impacts on over-winter survival of juvenile steelhead (Salmon River). Fertilization of the Keogh River resulted in a 1.4-2 fold increase in the average weight of juvenile steelhead trout and coho salmon after only 2-3 months of fertilization, with similar results (2-3 fold increase) in the Salmon River (Slaney et al. 1986; Johnston et al. 1990; Slaney and Ward 1993). Periphytic chlorophyll *a* and benthic invertebrate standing crops doubled in the fertilized reaches of the Adam River and Big Silver Creek, followed by an average 4-fold increase in rainbow trout abundance after 4 summers of fertilization (Wilson et al. 2002).

The purpose of the Mesilinka River Fertilization Experiment was 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 (*Oncorhynchus mykiss*), within the Williston Reservoir watershed. 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 in 1968 (Blackman 1992). Critical over-wintering refuges and foraging zones were lost, especially to highly migratory species such as Arctic grayling and 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 since the mid-1980's (Blackman et al. 1990; Blackman 1992; Northcote 1993), including the disappearance of stocks from many small streams entering the reservoir (Blackman 1992). Therefore, increased grayling production through riverine fertilization may partially offset the loss in grayling stocks resulting from habitat loss and other factors. 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 are potentially subjected to increased angling pressure, and stream fisheries are sensitive to overharvest and decreased quality with increased angling pressure (Slaney et al. 1986). Therefore, river fertilization may potentially develop destination fisheries that can support increased angling pressure while alleviating pressure on other unfertilized systems within the watershed.

The primary objectives of this study were to obtain data to determine the effects of nutrient addition on the Mesilinka River and several key nursery tributaries, compared to external (Nation River) and internal controls. Data collected from 1991-93 (before nutrient additions) and 1994-99 (during nutrient additions) included water levels, flows, temperatures, transparencies, nutrient concentrations, in addition to periphyton accrual (as chlorophyll *a*) and benthic invertebrate biomass. Standardized snorkel and electrofishing surveys, combined with intensive angling was conducted to assess fish population densities, size distributions and size-at-age data. Initial fertilization of two tributaries (Culvert and Gopherhole creeks) was also conducted in 1993, when liquid ammonium polyphosphate (10-34-0; % by weight N-P₂O₅-K₂O) was metered into the creeks between July and September. Fertilization of the Mesilinka mainstem began in 1994 when liquid ammonium polyphosphate and urea-ammonia nitrate (28-0-0; N-P₂O₅-K₂O) fertilizers were added to the Mesilinka River to achieve target phosphorus and nitrogen concentrations, and a similar field sampling regime was conducted to assess the system's biological response to fertilizer additions. In 1995, solid 'slow release' fertilizer briquettes (MgNH₄-PO₄-H₂O; 7-40-0; % by weight N-P₂O₅-K₂O; Sterling et al. 2000) were distributed into Culvert and Gopherhole creeks, replacing the liquid fertilizer, as part of the project assessing the effects of this type of nutrient application on habitat restoration of small streams (Mouldy-Ewing et al. 1998; Paul et al. 1998). Intensive monitoring of the Mesilinka system ended in 1997, but fertilization of the mainstem and fish population assessments continued through the summer of 1999. This report summarises all the results of the project, including data not previously available in annual reports.

STUDY AREA

Mesilinka River

The Mesilinka is a large northern river located 280 km north of Prince George, B.C. The headwaters originate in the Omineca mountain range and the river flows for a distance of approximately 120 km to Williston Reservoir (Fig. 1). Williston Reservoir was formed behind the W.A.C. Bennett Dam in 1968 to provide hydroelectric energy, and is part of the Peace-Slave-MacKenzie rivers system which ultimately flows north and discharges into the Arctic Ocean. Prior to dam construction, the Mesilinka River flowed into the Osilinka River, then to the Finlay River before joining the Peace River, with approximately 32 km of lower Mesilinka and Osilinka rivers inundated by reservoir waters.

Forests within the Mesilinka watershed (area 3,285 km²) include valley-bottom old growth sub-boreal spruce (*Picea sp.*), boreal white spruce (*Picea glauca*) and black spruce (*Picea mariana*), and mid-elevation old growth Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*). Logging has been active in the watershed since the early 1970's, with harvesting primarily of white spruce, lodgepole pine (*Pinus contorta*) and subalpine fir (J. Thomas, Chief Forester, Finlay Forest Industries Inc., Mackenzie, B.C., pers. comm.). Most activity has occurred in the lower watershed where approximately 30-35% of the area has been logged. Mature white and black spruce, aspen (*Populus tremuloides*), balsam poplar (*Populus balsamifera*), willow species (*Salix sp.*), and red alder (*Ainus rubra*) are the dominant trees and shrubs in the riparian zone. The extent of these impacts in the Mesilinka watershed are unknown, but it has been documented that the practice of logging to the streambanks is detrimental to fish habitat due to decreased bank stability, loss of protective cover and increased sediment loads (Babakaiff et al. 1997). Despite the logging, exceptional viewsapes abound within the Mesilinka watershed, and most of the riparian forest is intact, although some clearcut sections are 1 km in length, thus reducing large wood contribution as fish habitat elements.

Wild rainbow trout (*O. 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 in the mainstem, and tributaries of the Mesilinka River including Control, Culvert, Carina, Gopherhole, Tutizzi (also known as Tutizika) and Fatfish creeks. There are no known fish barriers to salmonid fishes on the mainstem. Other species found either in the mainstem or tributaries include burbot (*Lota lota*), sucker species (*Catostomus sp.*), sculpin species (*Cottus sp.*), and various Cyprinids including the northern pike minnow (*Ptychocheilus oregonensis*).

Habitat units in the mid-to-lower Mesilinka River consists of riffles, runs, glides and pools in proportions that vary with flows. Field work carried out in September, 1990 found the Mesilinka River in two sections (1400 m upper and 1700 m lower sections, near river km 20) were 71 and 51% glide, 13 and 23% pool, 8 and 19% riffle and 8 and 7% run, respectively. Mean wetted widths were 36.8 and 40.1 m and mean channel widths were 70.4 and 73.2 m. Mean maximum pool depths were 4.0 and 4.4 m and mean riffle depth, 0.60 and 0.55 m, respectively. Stream slope ranged from 0.2 - 3.0% (Langston and Blackman 1993).

The Mesilinka mainstem flows through one lake, Aiken Lake, located approximately 20 km downstream from the headwaters. Three medium-sized lakes are found in the Mesilinka tributaries, namely, Tutizzi Lake, located on Tutizzi Creek; and Carina and Tomias lakes, located on Carina Creek. All three lakes are considered to contain excellent fish assemblages and/or fish habitat. During the 1970's and early 1980's a fly-in fishing lodge operated on Tutizzi Lake.

The temperature regime of the Mesilinka River is typical of many large Williston Reservoir streams, with monthly averages of 10 - 13°C in summer. Discharge from the Mesilinka River is relatively high in spring and early summer due to melting snow pack and spring rains. Average spring to summer flows for the 10 year period, 1982-91, were 74, 180, 108, 49 and 35 m³ · sec⁻¹ during May to September, respectively (Water Survey of Canada flow data). Minimum flows of 6 to 8 m³ · sec⁻¹ occur in February and March. For the period of record 1968-2001, the maximum and minimum daily flows recorded are 551 and 4.4 m³ · sec⁻¹, respectively, with a mean annual flow of 45 m³ · sec⁻¹.

Nutrient concentrations in the Mesilinka are extremely low indicating that the river and its main tributaries are highly oligotrophic (data on file from samples from 1991). Concentrations of soluble reactive and total dissolved phosphorous are typically at-or-below detection limits of $1 \mu\text{g} \cdot \text{L}^{-1}$ and $3 \mu\text{g} \cdot \text{L}^{-1}$, respectively, and nitrate-nitrogen ranges from 5 to $40 \mu\text{g} \cdot \text{L}^{-1}$. Periphyton accrual is very low, peaking at $10 - 16 \text{ mg} \cdot \text{m}^{-2}$, which corresponds with low insect abundance in stream substrates. Underwater inspection of the substrate of several riffles in the mainstem confirm that the periphyton and insect communities are scarce and of low biomass.

Several of the tributaries which flow into the mid to lower portion of the Mesilinka River 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 included in the study to assess their rearing potential for juvenile fish.

Nation River (External Control)

The Nation River is located approximately 100 km south of the Mesilinka River and also flows south-east into Williston Reservoir, while draining a watershed of $5,880 \text{ km}^2$. 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). Water chemistry, periphyton accrual, benthic invertebrate populations and fish size and age were measured concurrently with investigations on the Mesilinka in 1992-97, to serve as an external control to the Mesilinka River Experiment. Mean summer water temperatures ($14-15^\circ\text{C}$) and flow rates in the Nation River are higher than the Mesilinka River (Koning et al. 1995), and the Nation tends to be limited in nitrogen as well as phosphorus. The Nation River was not chosen as a primary fertilization target because the higher flows coupled with nitrogen-limitation would necessitate larger and more costly amounts of fertilizer than required for the Mesilinka River. Also, the Mesilinka River was more typical of the cool streams within the Williston Basin. If fertilization of the Mesilinka River produces cost-effective results as a case study, the Nation River could be a candidate river for fertilization in the Peace/Williston Fish and Wildlife Compensation Program.

MATERIALS AND METHODS

Methods utilized in the Mesilinka River project were consistent between years (Koning et al. 1995; Paul et al. 1996, 1998, Wilson et al. 1999c; Larkin et al. 1999), and with methods followed on two other fertilization projects run concurrently by the B.C. Fisheries, Research and Development Section, in the Adam River (Slaney et al. 1993; Wilson et al. 1999a), and Big Silver Creek (Toth et al. 1993; Wilson et al. 1999b).

Sample Sites

Three study reaches in the lower half of the river were chosen in 1992 to facilitate a before and after, control and impacted experiment as described by Stewart-Oaten et al. (1986). The control reach (Blackpine) was located between river km 93 and 100, the upper treatment reach (T1) between river km 55 and 62, and lower treatment reach (T2) between river km 23 and 31 (Fig. 2).

Water Temperatures and Discharge

The addition of nutrients to maintain a target concentration is a direct function of stream discharge, therefore, stream flow measurements are required to calculate and adjust nutrient input rates. Mesilinka River 1992-99 daily discharge rates were obtained from the Water Survey of Canada (WSC) station no. 07EC003 located upstream of Gopherhole Creek (Fig. 1), and Nation River flows were obtained from WSC station no. 07ED003 located near its mouth. Nation River flows were also obtained from the station near Fort St. James (no. 07ED001) from 1992 until it was discontinued in 1994. To determine the discharge in the Mesilinka River, while calibrating fertilizer drip rates, a stage-discharge relationship was established using 1993-94 WSC flow data and a staff gauge located at the Blackpine station (Paul et al. 1996). This relationship was used until the end of the 1998 field season when it was replaced with a similar relationship (Appendix A).

Stream discharge was also measured in Gopherhole, Control, Culvert, Carina, and Fatfish creeks (Fig. 1) from 1992 (1993 for Fatfish) to 1997. Discharge was determined from water level gauges installed near the mouth of each tributary and associated stage-discharge relationships. The stage-discharge relationships were updated from previous annual reports in 1997 to include additional instream measurements, and past flows were recalculated. Instream flow measurements were taken by dividing the stream into appropriate cross sectional areas, the flow within each area was determined (using a Marsh-McBirney current meter to determine water velocity), and these flows were summed to produce the total flow in the stream.

To aid the assessment of salmonid growth potential in the Mesilinka system, growing season water temperatures were measured in the mainstem and tributaries during the 1992-97 growing seasons. TempMentors (Ryan Instruments) in 1992-93, and Stowaway (Onset Instruments) miniature data loggers in 1994-97, were placed in the control reach (Blackpine) and below the T2 reach at Gratton's camp, plus one of the latter was placed in the T1 reach during 1992. Temperatures in the Nation River were measured with TempMentors in 1993 and 1996-97, otherwise Stowaway loggers were used. Water temperatures were also measured in Gopherhole, Control, Culvert, and Carnia creeks with Bennan max-min thermometers in 1992, TempMentors in 1993, and Stowaway loggers in 1994-97. A max-min thermometer was used in Fatfish Creek during 1993, and was replaced with a Stowaway logger during 1994-97. The temperature loggers were located at the water chemistry sites near the mouth of each creek. Readings from the min-max thermometers were taken on every sampling trip and averaged to get a value representative of the temperatures since the last trip. The loggers recorded temperature every 2 hours, and the daily maximum, minimum and average temperatures calculated from the data. Langston (1993-96) and Zemplack and Langston (1997) provide annual data reports on Mesilinka system water temperatures.

Inorganic Fertilizer Additions

Fertilization of the Mesilinka River mainstem started in 1994, when solutions of phosphorus (ammonium polyphosphate; 10-34-0 % by weight N-P₂O₅-K₂O) and nitrogen (urea-ammonium nitrate; 28-0-0 % by weight N-P₂O₅-K₂O) based agricultural fertilizers were added to the river at the Roadend site upstream of the T1 reach. At the lower fertilizer site, at the top of the T2 reach, approx 20 km below the Roadend site, only the phosphorus solution was added (Fig. 2) but starting in 1995, urea-ammonium nitrate was also added to prevent nitrogen limitation. The fertilizers were stored in individual tanks, and dripped into the river through separate valve systems. Drip rates were adjusted manually on each site visit (3-8 days apart) to flow conditions in the

stream at that time, to increase downstream phosphorus concentrations by $5 \mu\text{g} \cdot \text{L}^{-1}$ and nitrogen by $15 \mu\text{g} \cdot \text{L}^{-1}$. Daily river discharge was estimated from a stage-discharge relationship. Drip rates were measured and adjusted on each site visit based on calculated fertilizer loadings, according to river flows. Drip rates were calculated from the mean of three repeated volumetric measurements of fertilizer taken over two minutes. Dates of fertilizer addition varied between years, but typically occurred from early-June through August. Additions continued past August in most years, but drip rate adjustments were not recorded. The total amount of fertilizer added each year varied, and values given in Table 1 are approximations. Fertilizer remaining after one summer occasionally remained in the tanks over winter and was combined with fertilizer delivered the following summer.

Table 1. History of fertilizer additions to the Mesilinka River mainstem and tributaries. Dates followed by a “+” indicate fertilizer additions continued past date given, but no drip rates are available.

system	year	reach	fertilizer type	application dates	approx. amount added ^b
Mesilinka River	1994	T1, T2	liquid 10-34-0	June 28 – August 28+	29 tonnes
		T1	liquid 28-0-0	June 28 – August 28+	10 tonnes
	1995	T1, T2	liquid 10-34-0	June 27 – August 27 +	15 tonnes
		T1, T2	liquid 28-0-0	June 27 – August 27 +	14 tonnes
	1996	T1, T2	liquid 10-34-0	July 5 – August 18	unknown
		T1, T2	liquid 28-0-0	July 5 – August 18	unknown
	1997	T1, T2	liquid 10-34-0	June 29 – Oct 19 ^a	unknown?
		T1, T2	liquid 28-0-0	June 29 – Oct 13	unknown?
	1998	T1, T2	liquid 10-34-0	June 10 – July 15+	18.6 tonnes
		T1, T2	liquid 28-0-0	June 10 – July 15+	20.8 tonnes
1999	T1, T2	liquid 10-34-0	June 11 – July 30+	26 tonnes	
	T1, T2	liquid 28-0-0	June 11 – July 30+	30.2 tonnes	
Culvert Creek	1993		liquid 10-34-0	July 8 – Sept 8	unknown
	1995		solid 7-40-0	June 10	149 kg
Gopherhole Creek	1993		liquid 10-34-0	July 8 – Sept 8	unknown
	1995		solid 7-40-0	June 11	111 kg

^a 10-34-0 added to the T2 reach only until Oct 13.

^b total amount of liquid fertilizer added.

Culvert and Gopherhole creeks were initially fertilized in 1993 with liquid phosphorus (ammonium polyphosphate; 10-34-0 % by weight N-P₂O₅-K₂O) based agricultural fertilizer. The fertilizer was added from tanks located 4-5 km upstream from the mouth of each creek, and dripped into the creeks through hose and valve systems. Metering of the fertilizer to maintain nitrogen and phosphorus at target concentrations proved difficult because of low flows associated with these streams (Koning et al. 1995), and therefore did not continue in 1994. In 1995, these tributaries were fertilized using solid ‘slow release’ fertilizer briquettes (7-40-0; % by weight MgNH₄-PO₄-H₂O) designed to dissolve gradually throughout the summer (Sterling et al. 2000). Based on the nutrient content of the briquettes, the amount of potential growing season, the previously determined flow regimes and nutrient limitations of each stream, Culvert Creek received 149 kg of fertilizer

and Gopherhole received 111 kg of fertilizer. In each stream, the fertilizer was distributed approximately 4-5 km upstream from its confluences with the Mesilinka River, in riffle areas of approximately 20-30 cm depth. A full report of this experimental product can be found in Ewing and Ashley (1996) and Mouldey- Ewing et al. (1998).

Water Chemistry

Dissolved nutrients were monitored in the Mesilinka River and tributaries during the 1992-97 growing seasons to determine pre-fertilization nutrient levels, nutrient loading from the tributaries, and nutrient changes in response to fertilizer applications. Samples were collected biweekly to monthly from each of the mainstem reaches, from Gopherhole, Control, Culvert, Carina, and Fatfish creeks, and the Nation River. Additional samples were collected above the fertilizer sites in Gopherhole and Culvert creeks in 1993-95, and from the Gratton's Camp site in 1992-97. Water samples were regularly analyzed for soluble reactive (SRP) and total dissolved (TDP) phosphorous, nitrate+nitrite, (NO₂₊₃-N), ammonium (NH₄-N) and total organic nitrogen (TON). Additional parameters occasionally collected include total phosphorus, pH, alkalinity, conductivity, total dissolved solids and turbidity (Appendix B). Diurnal samples were also collected at the Gratton's Camp site in 1995-97, when samples were collected at four hour intervals over a 24 hour period (Appendix C).

Samples collected were immediately placed on ice in a cooler and transported within 2 days to Zenon Environmental Laboratories in Burnaby (1993-95) or the Pacific Environmental Science Center (PESC) in North Vancouver (1996-97). Standard methods of analysis as described in APHA (1992) or PESC's Organic and Inorganic Analytical Procedures Manual (Andrew Soo, PESC, pers. comm.) were utilized.

Periphyton Accrual: Chlorophyll *a*

Periphyton accrual on artificial substrate (indicated by chlorophyll *a*) provides an index of the effects of nutrient addition on periphyton growth and biomass (Perrin et al. 1987). Chlorophyll *a* concentrations were measured in the three Mesilinka reaches, and four tributaries (Gopherhole, Culvert, Control, and Carnia creeks) from the pre-fertilization assessment in 1992, until 1997; with additional sites added at Roadend, the Nation River and Fatfish Creek in 1993-97, and Gratton's Camp and Lower Bridge in 1995-97. Assessments were also conducted above the regions of fertilizer additions in Gopherhole and Culvert creeks in 1993-95.

The assessments were conducted by attaching a white styrofoam block (19 cm x 39 cm x 1.25 or 0.075 cm) to a concrete anchor block and placing in 25-40 cm of water at moderate velocities (15-30 cm · sec⁻¹), as described in Perrin et al. (1987). Blocks were moved as water levels varied to ensure they remained submerged. Replicate cores (5.7 cm² each) of styrofoam substrata were extracted from each block, on approximately biweekly intervals, and placed in plastic vials. The vials were wrapped in aluminum foil to exclude light and stored on ice in a cooler until they were transported to the lab. Extraction was completed in 90% acetone with spectrophotometric determination of chlorophyll *a*, as described in Strickland and Parsons (1972). Replicates were averaged to get the chlorophyll *a* value for each site. Periphyton accrual rates in each reach were calculated by dividing the peak chlorophyll *a* concentrations recorded during each incubation period, by the days since the periphyton block was installed in the stream.

Benthic Invertebrate Abundance and Diversity

Colonization of artificial substrata by aquatic insects was used to assess benthic invertebrate biomass. Analysis of benthic invertebrate populations can provide a useful indicator of the response of the salmonid food chain response to enrichment, thus accounting for some of the variability in trout growth (Slaney and Ward 1993). During the 1993-97 growing seasons, groups of ten baskets of gravel were placed in each reach of the Mesilinka mainstem and in the Nation River during July. Each of the cylindrical baskets (22 cm in diameter by 13 cm in depth; 0.04 m² in area and 0.005 m³ in volume) were filled with 1-3 cm diameter clean gravel, and were placed in approximately 40 cm of water, surrounded by cobbles, and left to colonize with invertebrates for 6 weeks (baskets were occasionally moved to deeper water as the rivers receded). The baskets were removed using a Surber sampler (0.15 mm mesh net), and then invertebrates and detritus were collected and fixed in 10% formalin, and preserved in 80% ethanol (1993-94), or placed directly in ethanol. In 1995, ten invertebrate samples were also collected from within each reach with a Surber sampler, at the same time and location as the baskets were removed, to compare the two collection methods. No significant difference was found between the collection methods (Paul et al. 1996). All samples were taken to the Ministry of Environment research facility at the Fraser Valley Trout Hatchery where they were stained with Rose Bengall, and all invertebrates were separated from detritus with the aid of a 10X dissection microscope. The total wet-weight of invertebrates in each basket was determined using an electronic balance, after the samples were blotted and allowed to air dry for 2-3 minutes to remove excess preservative.

Taxonomic identification was conducted on all sample baskets collected in 1992-95, but only on four randomly chosen baskets from each reach in 1996-97. It was conducted by Frazer Environmental Services (Surrey, B.C.) following the procedure outlined in their Methods Manual (Looy, 1994) for benthic invertebrate identification and enumeration. Samples were rinsed to remove the dye, then placed in petri dishes and separated into insect orders. Insects were then identified to at least the family level using Curtis (1967), Edmunds et al. (1967), Johannsen (1969), Wiggins (1977), Pennak (1989), and Merritt and Cummins (1996). Subsampling was conducted when a sample contained a very large number of individuals of a given taxon (e.g. Chironomids). Size fraction and subsample volumes were based on the apparent density of invertebrates in the sample, with 1-3 subsamples randomly removed for identification.

Fish Populations

Adult Density, Size-at-Age and Biomass

Standardized underwater fish counts were conducted in the Mesilinka River to systematically estimate the abundance and size distribution of fish during August of 1992-95, in 1997 and 1999. The methodologies for swims remained constant, but with dates and distances varying slightly (Table 2). Counts in T2 in 1995, and in all reaches in 1996 were cancelled due to high flows and reduced visibility. Duplicate underwater counts were conducted within each reach by groups of six divers equipped with dry suits and snorkel gear, using standardized methods described in Gardiner (1984) and Slaney and Martin (1987). Accuracy of underwater counts have been well tested elsewhere, and provided temperatures are >10°C the technique provides a reliable assessment of fish abundance in rivers with water clarity >2 m (Northcote and Wilkie 1963; Goldstein 1978; Slaney and Martin 1987; Hankin and Reeves 1988; Heggenes et al. 1990; Rogers et al. 1992). Griffith (1981) confirmed that with practice, trout size can be accurately estimated within 1 cm, and Slaney and Martin (1987)

demonstrated that the visually estimated size distribution of sub-adult to adult trout is near-identical to that captured by anglers. However, Slaney and Godin (1989) established that sub-adult rainbow trout moved deep into cover when temperatures were $<10^{\circ}\text{C}$, which was confirmed by repetitive counts and electrofishing at the Kettle River, British Columbia, and juveniles became more visible as temperatures increased to 13°C (data on file, P. Slaney).

Table 2. An overview of underwater fish counts conducted in the Mesilinka River during 1992-99.

year	date	river reach	distance swam (km)	mean reactive distance (m)	mean wetted width (m)	river flow ($\text{m}^3 \cdot \text{sec}^{-1}$)
1992	Aug 22, 23	control	7.5	4.2	37.6	23
	Aug 20, 21	T1	7.2	4.0	40.8	26
	Aug 18, 19	T2	8.1	4.0	38.7	27
1993	Aug 16, 17	control	7.5	3.8	37.6	46
	Aug 18, 20	T1	7.2	4.0	40.8	43
	Aug 19	T2	8.1	4.0	38.7	43
1994	Aug 17, 19 ^a	control	6.5	2.3	45.7	43
	Aug 15, 16	T1	6.5	2.5	52.0	47
	Aug 18	T2	8.0	2.0	37.2	42
1995	Aug 16	control ^b	7.5	2.5	38.5	50
	Aug 14, 15	T1	7.2	3.2	43.0	37
		T2	not swum due to rising water and low visibility			
1997	Aug 20	control	7.5	2.8	37.8	43
	Aug 18, 19	T1	7.2	3.1	43.5	47
	Aug 21, 22	T2	8.1	2.7, 4.0	40.1	40
1999	Aug 18	control	6.7	3.8	41.1	40
	Aug 16, 17	T1	7.2	3.0, 4.0	46.2	43
	Aug 19, 20	T2	8.1	3.3	41.4	39

^a only 4 swimmers used on second swim

^b not replicated

All counts at the Mesilinka River were restricted to later in the day (typically 1100-1600 hrs.) when temperatures were $12-14^{\circ}\text{C}$, and when visibility was 3-6 m. A minimum of ten measurements of wetted width were taken within each reach, and swimmers' reactive distance (water clarity) was measured during each swim. Swimmers were assigned a lane (right shore, right near shore, right middle, left middle, left near shore, left shore), and attempted to maintain an equal distance from other swimmers while counting fish to the front and to one side of themselves. The salmonids seen were identified to species and lengths estimated within 10 cm size classes (0-10 cm, 11-20 cm, 21-30 cm, etc.). The 4 mid-lane counts were expanded over the mid-channel width, then the shore lane counts were added to provide expanded population estimates.

Mark-recapture estimates of fish population were also conducted to compare with the underwater counts, and provided they produce unbiased estimates (Robson and Regier 1964) and a minimum percentage of fish were marked (Vincent 1971), correction factors can be calculated for use in adjusting future snorkel survey results (Slaney and Martin 1987). Fish were angled with barbless hooks from within each reach for two weeks prior to the underwater swims counts. The weight, fork length, species, and general observations of each fish were

recorded, and scale samples taken (fin rays from bull trout) to determine age. Scale samples were taken, processed, and read as described in Ward and Slaney (1988). Fish >20 cm were tagged at the base of the dorsal fin with colour coded and numbered anchor tags (Floy tag Co.), colours specific for each reach and year (Table 3), to accomplish the marking phase of the population assessment. Recaptures were counted by observation of the correct tag colour during the underwater snorkel surveys (unexpanded numbers). Abundance estimates for each swim were calculated for rainbow trout, bull trout, and Arctic grayling using Chapman's modification of the Lincoln-Peterson mark-recapture estimation:

$$\text{Estimated Abundance} = \frac{(M + 1) \cdot (C + 1)}{(R + 1)} - 1$$

where M = number of individuals marked in the first sample
 C = number of individuals captured in the second sample
 R = number of recaptures

Fish angled outside the two week mark/recapture tagging period were tagged with a different colour, and were only used to estimate growth rate upon recapture in successive years. Angling was also conducted in the Nation River, with species, weight, fork length, and capture location recorded, and scale samples taken for each fish caught.

The biomass of Arctic grayling, rainbow trout and bull char in each reach was estimated annually using length–weight regressions developed from the angled fish, and density values from the snorkel surveys, in each reach. The weight of a fish equal in length to the midpoint of each size class was calculated from the length-weight regressions. The estimated weight was then multiplied by the density of the size class and the values for each size class summed to produce a biomass estimate for each species in each reach. When angling/electroshocking for samples was not conducted (as in 1999), fish weights were estimated from length–weight regressions based on all fish of the species captured in that reach.

Table 3. Anchor-tag colours used to mark fish > 20 cm fork length in the mark-recapture population and growth rate determinations in the Mesilinka River, 1992-99.

year	mark-recapture tags			growth tags
	control reach	T1 reach	T2 reach	
1992	red	red	red	green
1993	pink	yellow	white	? ^a
1994	green	orange	red	blue
1995	blue/white	green/yellow	orange/white	green
1996	green/yellow	orange/white	blue/white	blue
1997	orange/white	blue/white	fluorescent orange	blue
1999	blue	yellow	orange	none

^a 1993 tag colour unknown

Juvenile Density and Size-at-Age

Collection of juvenile fish for size-at-age and density data was done by electroshocking suitable habitat in the Mesilinka River mainstem, and by using net-traps and electroshocking in tributaries (Table 4). Trapping was discontinued in 1993 as changing flows following storm events reduced their effectiveness (Koning et al. 1995). All fish captured (except for sculpins) were anaesthetised, measured to the nearest millimetre, weighed to the nearest 0.1 g on an electronic balance, and inspected for clips before release. Scale samples were taken, processed, and read as described in Ward and Slaney (1988).

Abundance estimates in the tributaries were determined by electroshocking enclosed sites and using Chapman's modification of the Lincoln-Peterson mark-recapture estimation, as outlined above. A 100-200 m section of good rearing habitat was isolated with up and downstream stop nets, fish were captured by electroshocking, marked with a clip, and their lengths and weights taken. Marked fish were released back into the stream over the length of the channel shocked, except for the 25 m directly above the downstream net. The recapture phase occurred approximately 2.5 hours after releasing the fish, and was equal in shocking time to the marking phase. Fish captured were weighed, measured, and inspected for clips. Dimensions of each enclosure were measured to compute the area assessed and calculate density.

Caudal clips from previous years' mark-recapture estimates have been observed on fish caught in the mainstem; therefore, differential fin clips were used in each creek in 1994 to identify juvenile rearing habitat of fish caught in the mainstem. The clips used were: upper caudal clip for Control, lower caudal clip for Gopherhole, and both upper and lower caudal clips for Culvert Creek. Differential clips were also used in the following years.

Stable Isotope Analysis

Stable isotopes of nitrogen and carbon can be used to determine information on source-sink and process relations (Peterson and Fry 1987). The movement (source-sink relation) of nitrogen, from artificial fertilizers, through a food web can be observed by examining the ratio of $^{15}\text{N}:^{14}\text{N}$ at different food web levels (Peterson et al. 1993b). ^{15}N and ^{14}N are stable isotopes of nitrogen that occur naturally in the environment. The ratio of $^{15}\text{N}:^{14}\text{N}$ can be significantly different between natural nitrogen sources and artificial fertilizers, and the fractionation of the artificial fertilizers can produce further shifts in the natural $^{15}\text{N}:^{14}\text{N}$ ratio (Peterson et al. 1993a). Therefore, nitrogen isotopic ratios can be used to trace nitrogen, and hence food web, sources in an organism provided baseline ratios are known under natural and fertilized conditions (Peterson et al. 1993b).

The primary source (source-sink relation) of carbon in an aquatic food web can be examined by determining ratios of $^{13}\text{C}:^{12}\text{C}$ (Fry 1991). Aquatic algae and terrestrial plant detritus can have distinctly different ratios of $^{13}\text{C}:^{12}\text{C}$ and little isotopic fractionation of carbon isotopes occurs across trophic levels (Fry 1991). Therefore, the $^{13}\text{C}:^{12}\text{C}$ ratio can reflect whether the carbon source for an organism is primarily from the transport of terrestrial organic matter or from within stream production of algae.

Table 4. An overview of juvenile fish collection conducted in the Mesilinka River mainstem and tributaries during 1992-97.

date	stream	assessment method	area (m ²)	date	stream	assessment method	area (m ²)
1992-July-Sept	Carina	traps	----	1994-July 21	Culvert	open site	----
July-Sept	Control	traps	----	July 22	Control	open site	----
July-Sept	Culvert	traps	----	July 23	Gopherhole	open site	----
July-Sept	Gopherhole	traps	----	Sept 7	Carina	open site	----
Aug 20	Culvert	open site	----	Sept 7	Fatfish	open site	----
Aug 20	Control	open site	----	Sept 1	Control	mark/recap	723
Aug 21	Carina	open site	----	Sept 1	Gopherhole	mark/recap	1,225
Aug 22	Gopherhole	open site	----	Sept 3	Culvert	mark/recap	372
Sept 6	Control	mark/recap	360	1995-Aug 11	Control	mark/recap	----
Sept 6	Culvert	mark/recap	500	Aug 12	Culvert	mark/recap	----
Sept 6	Gopherhole	mark/recap	340	Aug 17	Fatfish	open site	----
Sept 7	Tutizzi	open site	----	Aug 18	Gopherhole	mark/recap	----
1993-July-Aug	Control	traps	----	1996-Aug 13	Control	open site	----
July-Aug	Culvert	traps	----	Aug 21	Control	mark/recap	540
July-Aug	Gopherhole	traps	----	Aug 21	Culvert	mark/recap	1,005
Aug 28	Control	open site	----	Aug 20	Gopherhole	mark/recap	855
Aug 28	Culvert	open site	----	1997-July 28	T2 reach	open site	----
Aug 31	Gopherhole	open site	----	July 29	T2 reach	open site	----
Aug 31	Gratton's Ck	open site	----	Aug 10	Lay Ck	open site	----
Sept 1	Fatfish	open site	----	Aug 22	Control	mark/recap	578
Sept 10	Control	mark/recap	580	Aug 23	Gopherhole	mark/recap	----
Sept 12	Gopherhole	mark/recap	660				
Sept 14	Culvert	mark/recap	800				
Sept 15	Carina	mark/recap	900				

Stable nitrogen and carbon ratios in food webs from the Mesilinka River were analysed in 1994 to trace the fate of introduced fertilizers, determine primary carbon sources and examine the trophic relations of organisms. Sampling was conducted under the supervision of B. Peterson and L. Deegan, research scientists from The Ecosystem Centre at Woods Hole, Massachusetts. Organisms (algae, invertebrates and fish) at each food web level were sampled from the Mesilinka River. Samples were collected from 2 sites (2 km and 1 km) upstream of the upper fertilizer station (Roadend; Fig. 2), 2 sites (1.5 km and 4.5 km) downstream of the upper station and 1 site downstream of the lower fertilizer station (mid-launch, 35 km downstream from the upper fertilizer station). Algae were collected by scraping periphyton from rocks and concentrating them on glass fibre filters. Mosses, willows and alders were sampled as terrestrial vegetation. Invertebrates were sampled from riffle regions using a drift net and hand picking from the substrate. Juvenile fish were sampled by electroshocking and adults by angling. Baseline ¹⁵N:¹⁴N ratios for the fertilizer were obtained by sampling fertilizer at the upper station (both 28-0-0 and 10-34-0). A full review of the stable isotope methodology and results can be found in the 1994 Mesilinka report by Paul et al. (1996).

Experimental Design and 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 the before and during fertilization periods (Stewart-Oaten et al. 1986). The BACI design is replicated through time provided there are more than 2 before and after sampling times for a single system and several 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, see Stewart-Oaten et al. (1986) for a detailed discussion of these assumptions. Constancy of differences implies that the difference between the impact and control site are additive; which can be tested using the Tukey (1949) test for nonadditivity. In our case, a slope not different from zero for the regression of differences against averages indicates 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).

Data was log transformed prior to testing, to improve normality and homogeneity of variances (Stewart-Oaten et al. 1986). Assumptions were met for significant results reported and variation given as \pm standard error unless otherwise noted. Statistical significance was set with the probability of committing a Type I error at less than 0.05.

RESULTS AND DISCUSSION

Water Temperatures and Discharge

Typically in the Mesilinka River, high flows resulting from the spring snowmelt ($100\text{-}200\text{ m}^3 \cdot \text{sec}^{-1}$) occur between mid-May and mid-July, with flows otherwise below $50\text{ m}^3 \cdot \text{sec}^{-1}$ (Fig. 4). The average daily discharge recorded since 1992 was 161, 106, 53, and $38\text{ m}^3 \cdot \text{sec}^{-1}$ from June to September, respectively. Discharge was anomalous in 1996 when runoff from the spring snowmelt started a month later, and continued until the end of August, resulting in the highest summer flows recorded during the project. The daily discharge averaged 204, 180, 77, and $47\text{ m}^3 \cdot \text{sec}^{-1}$, in June through September of 1996, respectively.

The spring runoff also occurred later on the Nation River in 1996, resulting in the highest early summer flows recorded during the project. The May to August daily average flows were 267, 500, 197, and $70\text{ m}^3 \cdot \text{sec}^{-1}$, respectively, compared to the 1992-96 averages of 304, 273, 100, and $48\text{ m}^3 \cdot \text{sec}^{-1}$ also recorded in May through August (Fig. 4).

Carina Creek was the largest Mesilinka tributary monitored, with flows usually declining from $5 \text{ m}^3 \cdot \text{sec}^{-1}$ in June to $1\text{-}2 \text{ m}^3 \cdot \text{sec}^{-1}$ in September (Fig. 5). Control, Culvert and Gopherhole creeks usually decreased from $3\text{-}5 \text{ m}^3 \cdot \text{sec}^{-1}$ in June to $< 1 \text{ m}^3 \cdot \text{sec}^{-1}$ in August, while Fatfish was the smallest creek, with flows below $0.5 \text{ m}^3 \cdot \text{sec}^{-1}$ between June and September. The discharge measured in these tributaries during June/July of 1996 was also the highest recorded during the project; Carina Creek averaged $8 \text{ m}^3 \cdot \text{sec}^{-1}$ in June/July, while Control, Culvert, and Gopherhole creeks averaged $2\text{-}3 \text{ m}^3 \cdot \text{sec}^{-1}$. Fatfish Creek remained low, below $0.5 \text{ m}^3 \cdot \text{sec}^{-1}$, but was only monitored from mid-July through August.

Mesilinka River water temperatures recorded (at Blackpine) in 1992-97 usually increased from $8\text{-}9^\circ\text{C}$ in mid-June, to highs of about 13°C in August, before dropping below 8°C by the end of September (Fig. 6). Maximum instantaneous temperatures of $14\text{-}16^\circ\text{C}$ were recorded in late-July or early-August. Diurnal variations averaged 2°C , and the temperature were usually 0.5°C higher at Gratton's Camp compared to Blackpine. In 1996, water temperatures were the coldest recorded during the project, as they increased from 6°C in mid-June to a high of only 11°C in late-August, and temperatures at Blackpine were usually 3°C cooler than the Gratton's Camp station.

Water temperatures in the Nation River have averaged 4.5°C higher than in the Mesilinka River during July and August of 1992-97. Temperatures in the Nation usually increased from 14°C at the end of May, to highs around 20°C in August (Fig. 6). Similar to the Mesilinka, 1996 was also a cool year on the Nation River as temperatures averaged only 13°C and 14°C in July and August, respectively.

Lake-headed Carina Creek was the warmest Mesilinka tributary monitored, and averaged 14°C during July/August of 1992-97, whereas Gopherhole and Culvert averaged 9°C , while Fatfish and Control creeks averaged 8°C (Fig. 7). Temperatures in most creeks peaks in early August, corresponding to the lowest flows and highest ambient air temperatures. Fatfish creek was the exception with seasonally high temperatures usually occurring in early July. Diurnal variations in the creeks usually ranged between $1\text{-}3^\circ\text{C}$. Tributary temperatures measured in 1996 were also cooler than normal, averaging $1\text{-}1.5^\circ\text{C}$ less than normal.

Inorganic Fertilizer Additions

Fertilizer was added to the Mesilinka T1 and T2 reaches through hoses from on-shore storage tanks and dripped through valves with rates manually adjusted to flow conditions in the river at the time of each site visit. Daily nutrient loading rates varied considerably each year, as input rates declined between site visits (Figs. 8 & 9). Input rates between visits varied due to sedimentation of the fertilizer tended to obstruct flow through the valves, viscosity of the liquid changed with ambient air temperature, and head pressure from the tanks declined through the summer. Changes in river flow between visits also added to variability. As a result, daily loading rates ranged from near $1 \mu\text{g-P} \cdot \text{L}^{-1}$ to the target concentrations of $5 \mu\text{g-P} \cdot \text{L}^{-1}$ and $15 \mu\text{g-N} \cdot \text{L}^{-1}$. For example, in the T1 reach in 1995 daily phosphorus loading rates ranged from $1\text{-}5 \mu\text{g-P} \cdot \text{L}^{-1}$ and nitrogen from $5\text{-}14 \mu\text{g-N} \cdot \text{L}^{-1}$.

Nutrient loading rates were consistently below target concentrations at each fertilizer site (Table 5). In the T1 reach, which had the highest average loading rates, phosphorus loading averaged $3.5 \mu\text{g-P} \cdot \text{L}^{-1}$ (or 70% of target) and nitrogen averaged $9.4 \mu\text{g-N} \cdot \text{L}^{-1}$ (or 63% of target). The annual average phosphorus loading rates declined from $4.6 \mu\text{g} \cdot \text{L}^{-1}$ in 1994 to a low of $2.0 \mu\text{g} \cdot \text{L}^{-1}$ in 1999, and was directly related to the number of site

visits. Drip rates were adjusted every 2-3 days in 1994 and the phosphorus loading rate was 92% of target, whereas in 1999 the loading rate decreased to 40% of target when adjusted on average every 6 days. Annual loading rates were slightly less in the T2 reach which averaged $3.2 \mu\text{g} \cdot \text{L}^{-1}$ of phosphorus (or 63% of target) and $7.6 \mu\text{g} \cdot \text{L}^{-1}$ of nitrogen (or 51% of target). Annual averages also declined from 1994-99, as they did in the T1 reach.

Table 5. Average daily loading rates of fertilizer (phosphorus and nitrogen) to the Mesilinka River in 1994-99.

fertilizer site	year	phosphorus		nitrogen	
		average loading rate $\mu\text{g} \cdot \text{L}^{-1}$ \pm SD	% of target	average loading rate $\mu\text{g} \cdot \text{L}^{-1}$ \pm SD	% of target
Road-end (T1 reach)	1994	4.6 \pm 0.9	92 %	9.0 \pm 3.8	60 %
	1995	3.5 \pm 0.7	70 %	9.9 \pm 2.1	66 %
	1996	3.8 \pm 0.8	76 %	11.2 \pm 2.4	75 %
	1997	3.6 \pm 0.7	72 %	10.5 \pm 1.7	70 %
	1998	3.6 \pm 1.0	72 %	9.5 \pm 3.0	63 %
	1999	2.0 \pm 0.8	40 %	6.2 \pm 2.2	42 %
	ave	3.5	70 %	9.4	63 %
Lower Site (T2 reach)	1994	3.6 \pm 1.3	72 %	2.4 ^a \pm 0.9	--- ^a
	1995	3.2 \pm 1.6	64 %	9.2 \pm 4.2	61 %
	1996	3.8 ^b ---	76 %	9.6 ^b ---	64 %
	1997	3.5 \pm 0.7	70 %	8.9 \pm 2.7	59 %
	1998	3.4 \pm 1.1	68 %	10.0 \pm 3.1	67 %
	1999	1.5 \pm 1.1	30 %	5.7 \pm 2.6	38 %
	ave	3.2	63 %	7.6	51 %

^a 28-0-0 nitrogen fertilizer not added at lower site in 1994

^b only an estimate as daily loading values not known

The seasonal phosphorus loading rates during the 1992-97 study phase of the project ranged between 3.2 - $4.6 \mu\text{g} \cdot \text{L}^{-1}$ (Table 5), with daily values above $1 \mu\text{g} \cdot \text{L}^{-1}$. The phosphorus levels, while below target concentrations, were above the levels found to saturate periphytic diatoms at the cellular level, and produce exponential growth at the community levels (Bothwell 1988, 1989). They were also within the range of 3 - $5 \mu\text{g} \cdot \text{L}^{-1}$ soluble reactive phosphorus recommended for stream fertilization to be effective over several kilometres, while remaining well below potential “nuisance” concentrations (Ashley and Slaney, 1997).

Response Mechanisms – Mesilinka Mainstem

Water Chemistry

There was no change in most water chemistry parameters collected from the Mesilinka River during fertilization, with the exception of some macronutrients. Alkalinity values ranged from 28 - $60 \text{mg} \cdot \text{L}^{-1}$ during 1993-97, with values increasing both downstream from the control to T2 reaches, as well as through the summer (Appendix B). pH values ranged from 7 - 8 units with just a slight increase in all reaches as summers progressed. Conductivity and total dissolved solids values ranged from 80 - $120 \mu\text{S} \cdot \text{cm}^{-1}$ and 45 - $85 \text{mg} \cdot \text{L}^{-1}$, respectively, with values declining during summers. The lowest annual values were during wet summers such as 1996.

The fertilized reaches did not appear to have a higher concentration of any measured macronutrient in any of the years sampled to date, despite the addition of the two blends of inorganic fertilizer. Nitrate was depleted to detection limit levels in both treatment levels during 1994-96, probably incorporated by the algae, as chlorophyll *a* concentrations (discussed in next section) indicate an enriched algal community in the treated reaches. In combination with soluble reactive phosphorus concentrations $> 2 \mu\text{g} \cdot \text{L}^{-1}$, this suggests the river was often nitrogen limited during fertilization.

Phosphorus

SRP determinations during prefertilization monitoring (1992-93), were at-or-below the detection limit of $1 \mu\text{g} \cdot \text{L}^{-1}$, except on one sample date, in July of 1993, when concentrations of $2\text{-}3 \mu\text{g} \cdot \text{L}^{-1}$ were measured in the T1 and T2 reaches (Fig. 10). In the first year of fertilization (1994), concentrations were below $2 \mu\text{g} \cdot \text{L}^{-1}$, except for the samples collected in the T1 and T2 reaches after the start of fertilization in July, which were as high as $5 \mu\text{g} \cdot \text{L}^{-1}$. The high concentrations are probably unrelated to the fertilizer additions as phosphorus loading rates (discussed earlier) from both fertilizer sites was $< 5 \mu\text{g P} \cdot \text{L}^{-1}$. The increase is likely the result of sediment and nutrient transport in the large July freshet seen in the mainstem and tributaries (Paul et al. 1996). In 1995 however, concentrations in all reaches fluctuated as high as $6 \mu\text{g} \cdot \text{L}^{-1}$ during the entire field season. Blackpine and the T1 reach averaged $3 \mu\text{g} \cdot \text{L}^{-1}$, while in the T2 reach concentrations were $4\text{-}6 \mu\text{g} \cdot \text{L}^{-1}$ in July and August. These samples were an anomaly, probably resulting from contamination at some point in the field-filtering procedure. Mesilinka tributary and Nation River concentrations were also abnormal at this time, with Nation River concentrations otherwise at the detection limit of $1 \mu\text{g} \cdot \text{L}^{-1}$. The anomalous SRP concentrations were also above total dissolved phosphorus levels (Fig. 11), which were collected unfiltered in a different bottle, and above nutrient loading rates (Fig. 8). The 1996 and 1997 Mesilinka SRP concentrations were back at detection limit levels, with the occasional determination in the T2 reach at $2 \mu\text{g} \cdot \text{L}^{-1}$ (Fig. 10).

TDP concentrations were similar in most years, declining from highs between 6 and $8 \mu\text{g} \cdot \text{L}^{-1}$ in July, to below the detection limit of $3 \mu\text{g} \cdot \text{L}^{-1}$ in August (Fig. 11). In 1995, most of the determinations were at-or-below the $3 \mu\text{g} \cdot \text{L}^{-1}$ detection limit. This is in contrast to the 1995 orthophosphate concentrations, most of which were $2\text{-}6 \mu\text{g} \cdot \text{L}^{-1}$. Nation River concentrations were similar to those from the Mesilinka mainstem in all years.

Nitrogen

$\text{NO}_3 + \text{NO}_2\text{-N}$ concentrations in all reaches during 1992-93 pre-fertilization monitoring ranged from highs of $30 \mu\text{g} \cdot \text{L}^{-1}$ when monitoring started in July, to between $5\text{-}15 \mu\text{g} \cdot \text{L}^{-1}$ in August (Fig. 12). This indicates that the river was probably nitrogen limited during summer. Since fertilization began in 1994, concentrations in the fertilized T1 and T2 reaches decreased below the detection limit of $5 \mu\text{g} \cdot \text{L}^{-1}$ by August of each year (except 1997), despite the addition of $9\text{-}10 \mu\text{g} \cdot \text{L}^{-1}$ of nitrogen with the fertilizer at each site, indicating a considerable demand and rapid uptake of biologically available nitrogen. Concentrations fluctuated abnormally in 1997, from $60\text{-}180 \mu\text{g} \cdot \text{L}^{-1}$, with concentrations returning to their normal levels at the detection limit in August. Contamination of the field-filtering apparatus was the cause as values returned to normal after a thorough cleaning. NO_{2+3} concentrations recorded in the Nation River were low compared to the Mesilinka, usually below $10 \mu\text{g} \cdot \text{L}^{-1}$, likely indicating co-limitation by nitrogen and phosphorus, as expected in a large lake-headed river.

NH₄ concentrations in both the Mesilinka and Nation rivers were generally below detection limit levels (5 µg · L⁻¹) during most of 1993-97 sampling (Fig. 13). Concentrations between 10-15 µg · L⁻¹ were recorded in the Mesilinka on two sampling dates in 1992, and occasionally in the Nation River where organic nitrogen concentrations were usually higher. Organic nitrogen concentrations in the Mesilinka have generally decreased from 80-100 µg · L⁻¹ in June/July, to below the detection limit of 40 µg · L⁻¹ in August of each year (Fig. 14). Concentrations in the Nation River followed the same trend, but were usually 80 µg · L⁻¹ higher.

Periphyton Accrual: Chlorophyll *a*

Chlorophyll *a* concentrations in the Mesilinka River were similar during pre-fertilization (1992-93) in the three reaches (Fig. 15), with maximum concentrations <16 mg · m⁻² (Table 6) and accrual rates averaging 0.19 mg · m⁻² · day⁻¹ (Table 7). Control reach and Nation River concentrations were also similar in 1994-97 (Fig. 15).

Fertilization of the T1 and T2 reaches began in late-June of 1994 and periphyton accrual remained low through August, but increased substantially in the T1 reach by early September (Fig. 15). Concentrations in the T1 and T2 reaches peaked at 128 and 30 mg · m⁻², respectively, on the September 4th sampling trip, after the blocks had been in the fertilized river for 40 days (Fig. 15). This was the largest periphyton response recorded in either reach during the four years of fertilization (1994-97). In addition, in each year the response was larger in the T1 reach than in the T2. Chlorophyll *a* concentrations increased significantly by an average 4.7 fold in the T1 reach, compared to 1.3-fold in the T2 reach, during 1994-97 (p=0.01).

Table 6. Peak chlorophyll *a* concentration (mg · m⁻²) measured in the Mesilinka River and in the Nation River, during the summers of 1992-97. Sites in bold were fertilized in 1994-97. River km from reservoir confluence is given below station names. Fertilizer inputs were at km 66 for T1 reach and km 46 for T2 reach.

year	Mesilinka River							Nation River
	blackpine 97 km	roadend 67 km	T1 62 km	mid-launch ^a 47 km	T2 34 km	Gratton's 12 km	lower br. 7 km	
1992	15.7	---	12.5	---	13.3	---	---	---
1993	7.3	7.9	13.0	---	8.5	---	---	13.1
1994	10.8	14.7	128.5	---	29.7	---	---	15.3
1995	4.4	---	55.9	8.8	4.8	15.3	8.2	6.0
1996	3.1	---	21.0	10.1	9.9	12.1	17.4	14.5
1997	7.0	---	32.2	21.0	11.7	11.2	10.3	8.9

^a above point of T2 fertilizer additions

The large difference between reaches in 1994 may have resulted from low nitrogen loading to the T2 reach. No nitrogen based fertilizer (28-0-0 solution) was added to the T2 reach in 1994, and NO₂₊₃ concentrations were lower in the T2 reach compared to the T1 (Fig. 12). However, 1994 also had the largest periphyton response in the T2 reach during the 1994-97 fertilization, despite the addition of additional nitrogen to the T2 reach in the following years, and both reaches were near-or-at nitrogen limitation every year of fertilization. The difference between reaches may be partially explained by the difference in distance between the site of fertilizer inputs, and the beginning of each reach. There was a distance of 15 km from the fertilizer site

at mid-launch to the beginning of the T2 reach, and only 4 km from the upper fertilizer site and the beginning of the T1 reach (Fig. 3). There was probably a large and unrecorded periphyton response in the 15 km above the T2 reach, with the T2 reach dependent on spiralling nutrients from upstream which would decrease in availability with distance as they were gradually lost to sedimentation. However, there should have been some nutrient spiralling to the reach, as documented at the Nechako River (Slaney et al. 1994).

Table 7. Chlorophyll *a* accrual rates ($\text{mg} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$) measured in the Mesilinka River and in the Nation River, during the summers of 1992-97. Sites in bold were fertilized in 1994-97. River km from reservoir confluence given below station names, fertilizer inputs at km 66 for T1 reach and km 46 for T2 reach.

year	Mesilinka River							Nation River
	blackpine 100 km	roadend 66 km	T1 62 km	mid-launch ^a 47 km	T2 34 km	Gratton's 12 km	lower br. 7 km	
1992	0.23	---	0.20	---	0.23	---	---	---
1993	0.13	0.17	0.22	---	0.14	---	---	0.28
1994	0.22	0.30	2.60	---	0.61	---	---	0.11
1995	0.11	---	1.40	0.22	0.12	0.38	0.21	0.15
1996	0.06	---	0.45	0.48	0.21	0.26	0.36	0.35
1997	0.13	---	0.59	0.38	0.21	0.20	0.19	0.16

^a above point of T2 fertilizer additions

The periphyton response was more rapid in 1995 as concentrations at the T1 site increased to $16 \text{ mg} \cdot \text{m}^{-2}$ after 12 days in the river, with a maximum concentration of $56 \text{ mg} \cdot \text{m}^{-2}$ recorded after 40 days (Fig. 15). There was no apparent increase in the T2 reach site as concentrations peaked at $4.8 \text{ mg} \cdot \text{m}^{-2}$, similar to control reach levels. Starting in 1995, additional periphyton blocks were added to each reach, one at mid-launch approx. 19 km below the T1 fertilizer addition site, and one each at the Gratton's Camp and Lower Bridge sites, approx. 34 and 39 km below the T2 fertilizer addition site, respectively. Concentrations recorded at the Gratton's Camp and Lower Bridge sites from 1995-97 were equal to or higher than those at the T2 site, which was closer to where the fertilizer was added. However, with no pre-fertilization data from these two sites, it was not possible to determine the extent (or distance) of the periphyton response.

In 1996, periphyton accrual was the lowest recorded since fertilization began. Chlorophyll *a* concentrations at the T1 reach peaked at $21 \text{ mg} \cdot \text{m}^{-2}$ (Table 6), with an accrual rate of $0.45 \text{ mg} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ (Table 7), however, this was still 7-fold greater than the control reach peak concentration of only $3 \text{ mg} \cdot \text{m}^{-2}$. The sites downstream of the T1 reach were slightly elevated, with average maximum concentrations and accrual rates of $12 \text{ mg} \cdot \text{m}^{-2}$ and $0.33 \text{ mg} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$, respectively. Periphyton accrual in 1996 was at least partially limited by the high flows, low visibility/light penetration and low water temperatures explained earlier, but there also was a strong benthic invertebrate response within the fertilized reaches, as explained in the next section, which feed on periphyton.

Following the large periphyton response at the T1 and T2 reach sites in 1994 and at the T1 site in 1995, chlorophyll *a* concentrations and accrual rates the following years were, at best, nominally above pre-fertilization levels as peak concentrations were 8-21 mg · m⁻² (Table 6), at all sites downstream of the fertilizer sites. Several factors probably combined to keep the periphyton concentrations low. As the benthic invertebrate populations generally increased in each reach during fertilization (next section), they probably reduced periphyton growth through increased grazing and detritus uptake, as experimentally confirmed earlier at the Kupark River in Alaska by Peterson et al. (1993a). Additionally, both reaches were nitrogen limited during the fertilization, and nutrient addition rates were approximately 30% below target. The fact that nitrogen limitation occurred despite the addition of approximately 10 µg-N · L⁻¹ with the fertilizer on top of the 15-20 µg · L⁻¹ ambient concentrations, demonstrates the demand for nitrogen generated by the addition of phosphorus to the river, and the movement of nutrients up the food chain.

Benthic Invertebrate Abundance and Diversity

The total density of benthic invertebrates increased on average 2.8-fold in the T1 reach, and a significant (p=0.047) 23-fold increase in the T2 reach during fertilization (1994-97), compared to pre-fertilization values (Table 8). At the same time, biomass values increased 1.5-fold, and a borderline significant (p=0.07) 8-fold increase in the T1 and T2 reaches, respectively.

Values of both were variable, particularly biomass. In the treatment reaches, values doubled following the first summer of fertilization, then decreased to pre-treatment values in the T1 reach in 1995-96 (Fig. 16). The marked decrease also occurred in the control reach and in the Nation River. It could be related to above average river discharge, which in addition to possible effects on the invertebrate community, made sample collection difficult. The baskets had to be moved repeatedly to avoid desiccation or being lost under rising water. This decrease also corresponded to a change in preservation method for the samples from formalin fixation in 1993-94, to ethanol preservation in the following years. Without formalin fixation, the biomass of the preserved invertebrates can decrease, as their viscera is slowly dissolved. However, the decrease in values in 1995-96 was not evident in the T2 reach where biomass increased consistently from 22 to 294 mg per 0.005 m³ between 1993 and 1997, with a corresponding increase in density (Fig. 16). The large fluctuations in density and biomass were also not reflected in ordinal composition which only changed in the treatment reaches during fertilization (Fig. 17).

This variability, whether caused by preservative changes, environmental or in-stream conditions, should not change the results of the statistical analysis, as inferential statistics are applied to the difference between control and treatment values (see Statistical Analysis Section), provided samples from each reach were similarly preserved. The effects of fertilization are obvious based on the magnitude of difference in values compared to the control reach, and both density and biomass increased consistently in the treatment reaches during fertilization (Fig. 18). Density and biomass decreased in the control reach during the study, while values increased in both treatment reaches, to peak values recorded in 1997, following four summers of fertilization (Fig. 16). This response to fertilization by benthic insects was evident in other mesocosm experiments (Mundie et al. 1991; Perrin and Richardson 1997), and field experiments (Peterson et al 1985; Johnson et al. 1990, 1993a).

Table 8. Density and biomass of the dominant orders of benthic invertebrates from the three experimental reaches of the Mesilinka River, and percent change during the pre-fertilization (1993) and fertilization (average of 1994-97) periods. ** denotes $p < 0.05$, and * a $p < 0.1$ using BACI analysis.

	control reach			T1 reach			T2 reach		
	pre-fert	unfert	% change	pre-fert	fert	% change	pre-fert	fert	% change
Density (# per 0.005 m ³)									
Ephemeroptera	114	40	-65%	69	50	-28%	2	23	1,050%
Diptera	49	27	-45%	44	402*	814%	0.8	98**	12,150%
Plecoptera	122	36	-71%	63	42	-33%	5	53*	960%
Trichoptera	30	17	-43%	4	9	125%	0.2	9*	4,400%
Total	315	121	-62%	180	503	180%	8	184**	2200%
Biomass (mg per 0.005 m ³)									
Total	285	133	-53%	212	314*	48%	22	175*	696%

The dominant invertebrate orders (by density) were Ephemeroptera, Diptera, Plecoptera and Trichoptera, which accounted for approximately 98% of the invertebrates collected in each sample. The ordinal composition of invertebrates within the control reach and Nation River were relatively constant during the monitoring period compared to the treated reaches. Ephemeroptera was the dominant order in the unfertilized reaches composing over half of the density in the Nation River and a third in the Mesilinka control reach (Fig. 19). Dipterans composed at most 35%, but typically closer to 20%, of the population in each reach, followed by plecopterans and trichopterans. In the T1 and T2 reaches of the Mesilinka, ordinal composition was similar in the 1993 pre-fertilization assessment to that in the control reach, except that each reach contained more plecopterans. However, dipterans dominated the treatment reaches during fertilization, particularly in the T1 reach where they increased to ~80% of the population. In the T2 reach, dipterans increased to ~50%, with plecopterans at 30%.

Dipterans accounted for the largest density and biomass increases in the fertilized reaches. Control reach densities varied little, with annual averages ranging from 19 to 49 per 0.005 m³, respectively (Fig. 19). The pre-fertilization density in the T1 reach was a comparable 44 per 0.005 m³, yet increased markedly to an average 402 per 0.005 m³ in 1994-97 (Table 8), although not significant at $p=0.08$. In the T2 reach, pre-fertilization dipteran density was only 0.8 per 0.005 m³ which increased two orders of magnitude to an average 98 per 0.005 m³ during fertilization ($p=0.025$). The tube building collector/filtering chironomid larvae were by far the most numerous dipteran (Fig. 20), accounting for ~80 % of their population and were overwhelmingly the one family (subfamily Orthocladiinae) that responded to fertilization. In the T1 reach they increased from 42 in 1993 to an average 384 per 0.005 m³ during fertilization ($p=0.076$), and a large increase in the T2 reach from <1 to an average 89 per 0.005 m³ during fertilization ($p=0.029$). There appeared to be a small increase in the family Tipulidae in the T2 reach, but their density was low and variable (Fig. 20). Other dipteran families were mostly predators and had densities <2 per 0.005 m³, with no distinct changes following fertilization (Fig. 20).

Ephemeropterans increased in the T2 reach during fertilization, but had variable results in the T1 reach. Control reach and Nation River densities decreased from 1993 to 1997, most noteworthy in the control reach where density dropped from over 100 to 25 per 0.005 m³ (Fig. 19). The pre-fertilization density in the T2 reach was 2.3 per 0.005 m³, which increased to an average 23 per 0.005 m³ in 1994-97 (Table 8). Several families increased including Heptageniidae, Ephemerellidae and Baetidae, whereby densities increased from <1 to about 5 per 0.005 m³ (Fig. 21).

Plecopterans showed a smaller response to fertilization. Densities in the Mesilinka River control reach and in the Nation River reach decreased between 1993 and 1997, most notably from 122 to 37 per 0.005 m³ in the former (Fig. 19). In the T1 reach densities also decreased from 1993 to 1995, but rebounded in 1996-97. The largest plecopteran response was seen in the T2 reach where densities increased from 5 per 0.005 m³ pre-fertilization, to an average 53 per 0.005 m³ during fertilization (Table 8), but was marginally significant ($p=0.093$). A marked increase in the Chloroperlidae, a family of known dipteran predators, was responsible for most of the increase (Fig. 22), probably in reaction to the large dipteran population which developed within months of fertilization. There was also a small response among the predatory Perlidae family. Density of the other plecopteran families was low and variable (Fig. 22).

Trichopteran density increased in both fertilized reaches, but not until after the second or third summer of fertilization. Pre-fertilization densities in both reaches were <4 per 0.005 m³, which more than doubled on average in the latter years of fertilization to densities as high as 22 per 0.005 m³ (Fig. 19). During nutrient additions, trichopterans were dominated by Brachycentridae and Hydropsychidae caddisflies, with the former showing the largest increase during fertilization, increasing from <3 to >5 per 0.005 m³ in the last two years of fertilization (Fig. 23).

The sub-dominant orders collected in the sample baskets had densities generally <2 per 0.005 m³, with marginally semi-aquatic families found (Fig. 24). There were several families of predatory beetles (O: Coleoptera), some springtails (O: Collembola) which are usually found 'skating' on the water, and two families from the order Hemiptera, which are predominately terrestrial but found near shore, one of which (F: Saldidae) preys on dipterans. Only one appeared to responded to fertilization, watermites (O: Hydracarina) were found consistently at densities of 1-2 per 0.005 m³ in control or unfertilised reaches. In the T1 and T2 reach, however, their density peaked at 4 per 0.005 m³ in 1997 (Fig. 24).

Overall, both the numbers and biomass of invertebrates increased in both reaches following fertilization. Dipterans showed the largest response (specifically the Chironomid family), but there were increases in the other dominant orders as well. There was no obvious decrease in any family following fertilization, but the densities captured of some families were too low to evaluate their response. In the T1 reach, family richness fluctuated but increased between 1995 and 1997, while in the T2 reach it increased consistently from 4 in 1993 to 9 in 1997 (Appendix D). The number of families captured in the control reach and Nation River sample baskets decreased from 14 to near 8 between 1993 and 1997.

Fish Population Responses - Density

Fish Population Abundance Pre-Fertilization

Two years of count data (1992-93) provide a good indicator of summer (August) fish populations within the Mesilinka River, before fertilizer additions began. Mountain whitefish were by far the most numerous, and the only species counted in the surveys which were most numerous in the control reach I am not sure what you are saying here (Fig. 25). Their density averaged 31 per ha in the control reach, decreasing to 11 per ha in the T2 reach during 1992-93 (Table 9). As a result, total fish density also decreased downstream from 35, 32 and 21 per ha in the control, T1 and T2 reach, respectively. This pattern corresponded to benthic invertebrate density and biomass which was also highest in the control reach during pre-fertilization monitoring (Table 8). Whitefish were most numerous in the 20-30 cm size class, with individuals up to 50 cm seen in each reach (Fig. 26). The whitefish population in the control reach were also consistent during 1994-99, ranging between 14-32 per ha (Fig. 25). Raw counts and fish per kilometre are given in Appendix E.

Arctic grayling were the second most abundant species with their highest densities in the T1 reach, averaging 3.3 per ha in 1992-93, with densities of 2 per ha in both the control and T2 reaches (Table 9). Most of the grayling seen in the control reach were 30-40 cm in length, with more smaller and larger fish seen in the downstream reaches (Fig. 27). The grayling population was also fairly consistent in the control reach during 1994-99, ranging between 1.2-2.9 per ha (Fig. 25). Distribution of grayling tended to vary from year to year with water levels (Blackman 2001); density was positively correlated ($r=0.57$) with average monthly discharge.

Rainbow trout were the third most abundant species overall, and were most numerous in the T2 reach with average densities of 0.78, 1.7 and 3.3 per ha in the control, T1 and T2 reaches, respectively, during 1992-93 (Table 9).

Table 9. Average density (fish per ha) of mountain whitefish, Arctic grayling, rainbow trout, bull trout and suckers, pre-fertilization (1992-93) and with fertilization (1994-99), determined from snorkel surveys of the three experimental reaches of the Mesilinka River, and percent change between pre-fertilization and fertilization periods. (denotes a significant increase at $p<0.05$; * significant at $p<0.1$, using BACI analysis.)**

species	control reach			T1 reach			T2 reach		
	pre-fert	unfert	% change	pre-fert	fert	% change	pre-fert	fert	% change
whitefish	31.0	22.0	-29%	26.0	73.0**	181%	11.0	38.0*	245%
Arctic grayling	2.0	2.2	10%	3.3	4.4	33%	1.9	2.1	11%
rainbow trout	0.78	0.90	15%	1.7	4.1	141%	3.3	6.7	103%
bull trout	0.23	0.30	30%	0.6	1.3	117%	1.1	1.3	18%
suckers	1.20	0.10	-92%	0.7	0.8	14%	3.8	2.8	-26%
total fish	35.0	25.0	-29%	32.0	84.0**	163%	21.0	51.0*	143%
total (rainbow, grayling and bull trout)	3.0	3.5	-17%	5.6	9.8	75%	6.3	10.1	60%

Rainbow trout 20-30 cm in length usually composed half the population in each reach, and individuals larger than 40 cm were sparse in T1 and T2 and were very rare in the control reach, with only a few seen in 1994 (Fig. 28). Bull trout density ranged from 1.1 per ha in the T2 reach to 0.23 per ha in the control reach throughout the study. The size distribution fluctuated due to the few bull trout seen, but large fish made up the largest proportion of their population in the control reach (Fig. 29). The densities of both rainbow and bull trout were relatively consistent in the control reach from 1992-99 (Fig. 25). The density of suckers ranged from 3.8 per ha in the T2 reach to 0.7 per ha in the control, and they were more variable than the other species with a large drop from the 1992 to 1993 populations (Fig. 25).

Density Response to Fertilization

Density of most species increased in the treatment reaches during fertilization, compared to the control reach, particularly in T1 reach where large increases in mountain whitefish and rainbow trout were evident. Whitefish density increased on average 2.8 and 3.5-fold in the T1 and T2 reaches during fertilization, respectively (Table 9). In the T1 reach, the pre-fertilization density of 26 per ha increased about 3-fold ($p=0.02$) to an average 73 per ha in 1994-99, with largest responses in 1995 and 1999 when densities almost reached 100 per ha (Fig. 25). As evident with most species in this reach, density did not increase perceptibly until 1995. In the T2 reach, there was no increase in 1994 and no data collected in this reach in 1995, but density increased from 11 per ha pre-fertilization to an average 38 per ha in 1997 and 1999 ($p=0.064$). Size data was not recorded for whitefish in all years, but using available years it appears the largest whitefish were usually observed in the T1 reach (Fig. 26), where their density was also highest. Whitefish are primarily bottom feeders preferring insect larvae, molluscs, detritus and occasionally small fish (Scott and Crossman 1974), which should position them among the first fish species to respond to a 'bottom-up' increase in productivity.

In the T1 reach there was a modest (33%) increase in total density of Arctic grayling from a pre-fertilization density of 3.3 per ha to an average 4.4 per ha during fertilization (Table 9). As with most other species the increase was not detected until after the second year of fertilization, with a peak density of 5.7 per ha recorded in 1997 occurring after four summers of fertilization (Fig. 25). The largest grayling showed the largest increase in density during fertilization, with a 5-fold increase in grayling 40-50 cm and a 1.5-fold increase in grayling 30-40 cm, with no detectable change in the smaller grayling (Fig. 27). However, total density of Arctic grayling in T2 reach did not change during fertilization, with density remaining at 2 per ha (Fig. 25). There appeared to be a reduction in smaller (<30 cm in length), and an increase in larger sized grayling (Fig. 27).

Density of rainbow trout increased 2.4 and 2.0-fold in the T1 and T2 reaches during fertilization, respectively. In the T1 reach, total density increased from 1.7 per ha during pre-fertilization monitoring to an average 4.1 per ha in 1994-99, while in the T2 reach density increased from 3.3 to 6.7 per ha over the same time periods (Table 9). The numbers increased in all size classes recorded, with the largest increase in the 30-40 cm size class in the T1 reach, from a pre-fertilization average of 0.38 per ha to 1.14 per ha during fertilization 1994-99 (Fig. 28).

Initial densities of bull trout were low, <1 per ha, resulting in small increases until 1999 when the highest densities were recorded in both treatment reaches (Fig. 25). Despite the delayed response, there was an average 2.2-fold increase in T1 reach where density increased from a pre-fertilization average of 0.6 per ha to an average of 1.3 per ha during fertilization (Table 9), with a high of 2 per ha in 1999 (Fig. 25). The response

was not as noteworthy in T2 reach where values recorded in 1994 and 1997 were below pre-fertilization levels, but a density of 2.4 per ha was recorded in 1999, the highest density recorded for this species in the Mesilinka River (Fig. 25). Bull trout generally require 3-6 years to reach sexual maturity (Scott and Crossman 1974), with maturity usually reached at age 4+ in habitats where they grow over 400 mm (McPhail and Baxter 1996), as in the Mesilinka River (Fig. 29). Population densities are generally low (McPhail and Baxter 1996), as their numbers reflect their trophic role as top predators (Bishop 1975). They are voracious predators with adults known to feed on sculpins and mountain whitefish (Bishop 1975, Chisholm et al. 1989), therefore, it is probably no coincidence that their density increased the most in the reach containing the largest whitefish population.

A comparison of peak annual densities recorded during the pre- and fertilization periods show that values for each species increased from 14-350% in the fertilized reaches, compared to a nominal -20% to 92% change in the control reach, during 1994-99 (Table 10), with peak densities usually occurring from 1997-99, after 4 years of fertilization.

Table 10. Peak densities (no. per ha) of mountain whitefish, Arctic grayling, rainbow trout and bull trout determined during pre-fertilization (1992-93), and fertilization (1994-99) snorkel surveys of the three experimental reaches of the Mesilinka River, and percent change between pre-fertilization and fertilization periods.

species	control reach			T1 reach			T2 reach		
	pre-fert	unfert	% change	pre-fert	fert	% change	pre-fert	fert	% change
whitefish	40.0	32.0	-20%	38.0	98.0	158%	12.0	54.0	350%
Arctic grayling	2.6	2.9	12%	3.6	5.7	53%	2.1	2.4	14%
rainbow trout	1.1	1.4	27%	1.9	4.9	158%	3.8	7.1	87%
bull trout	0.26	0.50	92%	0.8	2.0	150%	1.3	2.4	85%

Mark-Recapture Results from Snorkel Surveys

Abundance estimates were calculated for each species in each swim replicate, and appropriate statistics calculated to determine the validity of each population estimate (Appendix F). Only three of the calculations produced valid correction factors. To be statistically valid a mark-recapture procedure requires the initial marking of fish (M) to be 20% or more of the total estimated population (N) (i.e. $M/N \geq 20\%$, Vincent 1972). In only 21 of the 99 individual population estimates were >20% of the fish tagged; grayling were the highest with 15% of grayling usually tagged, followed by rainbow and bull trout usually at 12% each (Appendix F).

In addition, to avoid any bias due to low numbers, the total number of fish marked multiplied by the number of captured fish (C) should be more than 4 times the total estimated population (i.e. $MC > 4N$, or $M+C \geq N$, Robson and Regier 1964). Only 34 of the 99 population assessments were unbiased due to low numbers; again grayling performed best with 55% of their population estimates passing, followed by rainbow at 42% and bull trout at only 6% (Appendix F).

Correction factors were not applied to the Mesilinka snorkel survey results as was attempted earlier (Koning et al. 1995), because most correction factors were not valid. The few correction factors which were (or almost) valid indicated that the snorkel surveys may have underestimated the grayling populations in each reach by approximately a factor of two, and rainbows by a factor of 3-5 (Appendix F), indicating that the true densities of these species may be double what the snorkel swims suggested. Considering the size and complexity of the

river with its deep pools and log jams, and average visibility of 3-4 m during the swims, this was not surprising. The bull trout estimates in the Mesilinka River failed both the minimum number and significance tests more than the other species. Significantly more effort would be required to tag and recapture enough bull trout to make the results meaningful.

No swims were conducted outside the reaches to investigate movement of tagged fish. Work conducted on the Table and Anzac rivers show movement does occur and is highly variable, with as many as one quarter of tagged grayling and bull trout seen outside the 2 km reaches swam (Blackman and Hunter 2001). However, the reaches swum in the Mesilinka River were considerably longer (7-8 km) which should reduce the percentage of fish moving out of the reaches. The potential movement of marked fish combined with the possibility of tags being missed by swimmers would bias the results of the mark-recapture estimates upwards, particularly if tagged fish moved more than those untagged (if they wanted to show off their 'jewellery' to others, for example).

Mark-recapture correction factors typically produce population estimates greater than those from accompanying snorkel surveys. Slaney and Martin (1987) estimated a correction factors of 1.4 for cutthroat trout in the St. Mary River (about half the summer discharge as the Mesilinka). In the Nechako River, correction factors of 2.9 to 5.7 were derived from swim counts for rainbow of different size classes (Godin et al. 2001), similar to factors for the Mesilinka. Correction factors estimated for grayling and rainbow in the Table and Anzac rivers averaged 1.5 and 2.6, respectively, with values in the Table River generally higher than the Anzac (Blackman and Hunter 2001). Values for grayling are usually lower than rainbow as grayling tend to be more visible in rivers as they make less use of cover compared to rainbow.

Fish Population Responses – Size-at-Age

Angling was conducted annually from 1992-99 in all reaches of the Mesilinka River (except 1998), and in the Nation River (except 1998-99). Approximately 1,700 fish (866 rainbow, 593 grayling, 164 bull trout and 31 whitefish, in addition to a few burbot and suckers) were captured from the Mesilinka River, in addition to 866 (684 rainbow, 155 grayling, 13 bull trout and 14 whitefish) angled from the Nation River (Fig. 30). This resulted in an average of almost 250 fish angled per year from the Mesilinka River, with a range of 112 caught in 1996 to 355 in 1997, and 144 angled per year from the Nation River.

Rainbow trout captured ranged in age from 2+ to 7+, with the most common between 3+ to 5+; the number caught averaged 12 per reach per year, and with most being in the T2 reach (Fig. 30). Grayling ranged in age from 1+ to 9+, with the most common between 3+ to 5+; and numbers caught averaged 7 per reach per year (Fig. 31). Bull trout were caught throughout the river, but most were caught in the T2 reach (Fig. 30). The bull trout captured in 1999 are the only bull trout aged to date, and they ranged from 2+ to 11+. The few whitefish caught, an average of 2 per reach per year, ranged in age from 3+ to 10+ and were most numerous in the control reach (Fig. 30). Inferences about density can not be made from this data as fishing effort may have differed.

Fish Size-at-Age Pre-Fertilization

With two years of pre-fertilization data (1992-93) we had a fairly reliable estimate of adult fish size within the Mesilinka River mainstem, before fertilizer additions began. The average size of rainbow trout generally decreased downstream, as the largest average weight and length for each age group was recorded in the control reach (Table 11, Figs. 32, 33). For example, age 2+ rainbow averaged 66, 65 and 58 g in the control through T2 reaches, respectively. However, the difference between the control and T2 reaches for each age class was not significant.

Arctic grayling showed no distinct trend for size-at-age along the length of the Mesilinka River before fertilization began (Figs. 34, 35). They were, however, larger than rainbow trout of the same age (Table 11). Of note, older grayling (age 6+ to 8+) were rarely caught in the T2 reach. They were caught upstream, with slightly more in the T1 reach than the control – particularly in the last few years of the study (Fig. 34). This is a common pattern with grayling in the Williston watershed as larger grayling tend to migrate further upstream (B. Blackman, Senior Fish Biologist, PFWWCP, pers. comm).

Adult Size Response to Fertilization

There was a lot of variation in average weight and length values due to the small sample sizes once angled fish were divided by age class, but some patterns were evident with data grouped by treatment. Rainbow trout weight and length-at-age generally decreased in the control reach between 1992 and 1999, particularly in the most common age classes, a pattern also seen in the Nation River (Figs. 32, 33). In the treatment reaches, however, size either stayed relatively constant (T1 reach) or increased (T2 reach).

Table 11. Average weight and length-at-age of fish, pre-fertilization (1992-93), from the three experimental reaches of the Mesilinka River.

species	age	weight (g)			length (mm)		
		control	T1	T2	control	T1	T2
rainbow	0+	1.3	1.2	0.8	47	46	38
	1+	10.7	---	24.8	98	---	123
	2+	66	65	58	169	165	158
	3+	165	154	123	241	231	216
	4+	232	226	210	266	270	263
	5+	380	302	280	324	306	302
grayling	0+	---	---	0.9	---	---	45
	1+	---	---	---	---	---	---
	2+	114	91	128	201	177	180
	3+	265	197	187	318	258	262
	4+	309	337	283	300	308	284
	5+	380	403	459	330	332	340
	6+	457	523	----	352	373	----

In the T1 reach, the age 2+ rainbow showed the largest increase with a 25% increase in weight and 12% increase in length between the pre-fertilization and fertilization periods (Table 12). The increase was not significant by BACI analysis as no age 2+ rainbow were captured in the control or T1 reaches in 1996-97, limiting the analysis to two years of pre-fertilization and two of fertilization years. The sizes of the older age class rainbow changed little in this reach (Table 12).

In the T2 reach, the average size of age 2+ through 5+ rainbow increased during fertilization. The age 2+ showed the largest increases, and larger rainbow aged 3+ to 5+ also showed notable weight increases from 11-13% and length increases from 2-4% (Table 12). The most numerous age class for angled rainbow was the 3+, which had a significant ($p=0.02$) increase in weight from a pre-fertilization average of 123 g, to an average of 138 g during fertilization, a 12% increase. At the same time, control reach age 3+ rainbow decreased from an average 165 g to 120 g (Table 12). The length of these 3+ rainbows also increased significantly ($p<0.001$). A similar increase was evident among the age 4+ and 5+ rainbows, with a significant increase in both weight ($p=0.02$) and length ($p=0.04$), of the age 5+ rainbows in the T2 reach.

The size of Arctic grayling in the control reach did not decrease during 1992-99 as did the size of the rainbow trout, but increased slightly (Figs. 34 & 36). In the treatment reaches, the percent increase between average pre-fertilization and fertilization size values were slightly larger, but with no statistically significant increase in length or weight in either treated reach. However, samples sizes were small, an average of 7 grayling per reach in the most common age classes, which increased variability in the values, but a pattern of increasing size during fertilization was evident, particularly in the T2 reach (Figs. 34 & 35 and Table 13).

Table 12. Rainbow trout average weight and length-at-age, pre-fertilization (1992-93) and fertilization (1994-99), from angled fish from the three experimental reaches of the Mesilinka River, and percent change. See Fig. 31 for sample sizes. (* denotes a significant ($p<0.05$) increase using BACI analysis.)

	age	control reach			T1 reach			T2 reach		
		pre-fert	unfert	% change	pre-fert	fert	% change	pre-fert	fert	% change
weight	2+	66	71	8%	65	81	25%	58	72	24%
	3+	165	120	-27%	154	130	-16%	123	138*	12%
	4+	232	226	-3%	226	231	2%	210	232	11%
	5+	380	306	-20%	302	315*	4%	280	317*	13%
length	2+	169	179	6%	165	184	12%	158	176	11%
	3+	241	214	-11%	231	225	-3%	216	223*	3%
	4+	266	267	0%	270	267	-1%	263	273	4%
	5+	324	295	-9%	306	303	-1%	302	308*	2%

Table 13. Arctic grayling average weight and length-at-age during pre-fertilization (1992-93) and fertilization (1994-99) from angled fish from the three experimental reaches of the Mesilinka River, and percent change. (* denotes a significant ($p<0.05$) increase using BACI analysis)

	age	control reach			T1 reach			T2 reach		
		pre-fert	unfert	% change	pre-fert	fert	% change	pre-fert	fert	% change
weight	3+	265	274	3.4%	197	201	2.0%	187	205	9.6%
	4+	309	332	7.4%	337	339	0.6%	283	353	25.0%
	5+	380	435	15.0%	403	452	12.2%	459	471	2.6%
	6+	457	427	-6.6%	523	513	-1.9%	---	---	
length	3+	318	283	-11.0%	258	257	-0.4%	262	256	-2.3%
	4+	300	309	3.0%	308	307	-0.3%	284	309	8.8%
	5+	330	337	2.1%	332	339	2.1%	340	340	0%
	6+	352	358	1.7%	373	363	-2.7%	---	---	

Juvenile Size Response to Fertilization

Limited electroshocking was conducted along the river banks and side-channels of the Mesilinka to collect juvenile fish, with the most collected between 1993-95. Juvenile rainbow were the dominant fish collected in all three reaches, with juvenile bull trout similar in numbers in the T2 reach, but absent from the control reach (Paul et al. 1996). The total number captured (per unit shocking time) generally increased downstream 4-fold from the control to T2 reach (Paul et al. 1996). Grayling were captured from shallow riffle regions (5-10 cm deep) of pebble and cobble, in all three reaches. Comparatively low numbers of juvenile longnose dace, mountain whitefish and burbot were also caught. Sculpins were abundant in all reaches.

A brief look at size both before and during fertilization is possible as most of the fish were collected in 1993-95. A total of 148 age 0+ rainbows were captured, which were similar in all reaches before fertilization, averaging 1 g and 44 mm in size (Fig. 38). Their size increased following the start of fertilization, with weight almost doubling to an average of 1.6 g in the T1 reach during 1995. In the T2 reach their size in the first year of fertilization was similar to pre-fertilization values, although in 1997, the next year for which data is available, weight averaged 2.7 g, a 3-fold increase over pre-fertilization size (Fig. 38). Only 33 age 1+ rainbows were captured, which showed no change in size during fertilization (Figs. 39), possibly because of rearing in various tributaries.

Nineteen age 0+ grayling were caught in the mainstem. All those caught in the control reach or before fertilization began in the treatment reaches were <1 g and about 50 mm in size (Figs. 40). The few caught during fertilization were certainly larger, with weights and lengths ranging from 1.5-7.0 g and 57-74 mm, respectively. A total of 3 age 1+ grayling were caught, one in the control reach in 1994 (46 g and 129 mm), and 2 in the T2 reach in 1999 which averaged 31 g and 135 mm (Fig. 41). Overall, not enough juvenile fish were captured to provide meaningful results; however, the size trend of the 0+ fish matches the underyearling trout responses from the Adam and Big Silver rivers (Wilson et al. 2002), and Arctic grayling at the Kuparuk River (Deegan and Peterson 1992).

Juvenile bull trout were captured in the T1 and T2 reaches in 1993-95, almost all in 1994 when most shocking took place. Of the 79 captured, 65 were young-of-the-year averaging 46 mm in length (range 35-56 mm) and 1.2 g (range 0.5-2.7 g). Based size distributions the age 1+ appeared to range from 109-119 mm and 12-16.2 g, with the age 2+ ranging from 146-171 mm and 33-48 g, but there was some overlap using scale ages.

Adult Condition Factor

Fulton's condition factors (Ricker 1975) were calculated for each adult rainbow trout (Fig. 42) and Arctic grayling (Fig. 43) as an additional assessment of fish size. There were no significant differences in the treatment reaches when the values were either grouped by age class or combined. Rainbow trout condition factors averaged 1.24 in the control reach during 1992-93, decreasing to average 1.15 in 1994-97. In the fertilized reaches, factors averaged 1.21 and 1.17 during pre-fertilization (1992-93) monitoring in the T1 and T2 reaches, respectively, which decreased slightly to 1.13 and 1.16 during fertilization, respectively (Fig. 42). Grayling condition factors were more consistent compared to rainbow's, with a very slight increase between pre-fertilization and fertilization values in all reaches, including the control reach (Fig. 43).

Adult Growth Rates

Annual growth rates were calculated for each tagged fish recaptured (Appendix G, H & I). There were insufficient numbers of fish caught, in each age group, to determine pre-fertilization trends along the river, or to compare pre-fertilization rates with those during fertilization for either rainbow or the more numerous grayling. Annual growth rates for Arctic grayling tended to be greater in the fertilized reaches, but sample size was too small to be definitive (Table 14). Growth rates recorded for grayling in other Williston watershed rivers (mostly the Table, Anzac and Parsnip rivers) were similar to those in the Mesilinka River, particularly in the T2 reach (Table 14), however, the Williston rates were calculated from annual average sizes and not from tagged fish so they probably overestimate growth due to size selective mortality among small size fish.

Table 14. Mean growth rates ($\text{mm} \cdot \text{yr}^{-1}$ and $\text{g} \cdot \text{yr}^{-1}$) of aged Arctic grayling from the three experimental reaches of the Mesilinka River, for age of fish at original capture, compared with rates from other parts of the Williston watershed (B. Blackman, unpublished data). Only fish recaptured the following year included in the Mesilinka data. See Appendix G, H and I for details.

age	control reach			T1 reach			T2 reach			Williston Watershed ^a		
	weight	length	n	weight	length	n	weight	length	n	weight	length	n
4+	---	---	0	58	21	2	100	37	4	109	30	169
5+	47	16	4	41	14	10	51	39	1	56	17	234
6+	18	8	2	47	10	2	---	---	0	98	15	149
7+	69	17	1	---	---	0	---	8	1			
8+	---	2	1									

^a mostly the Table, Anzac and Parsnip rivers

Fish Population Responses – Biomass

The biomass of fish in the control reach was relatively constant (within a factor of two) between 1992-99, ranging from 0.90 to $2 \text{ kg} \cdot \text{ha}^{-1}$ (Fig. 44). As with the density values, this reach was dominated by Arctic grayling which averaged $1.1 \text{ kg} \cdot \text{ha}^{-1}$, followed by rainbow and bull trout with each averaging $0.20 \text{ kg} \cdot \text{ha}^{-1}$. Pre-fertilization (1992-93) biomasses were similar in the T1 and T2 reaches, averaging 1.8 and $1.6 \text{ kg} \cdot \text{ha}^{-1}$, respectively, which doubled during fertilization.

The largest increase in biomass following fertilization occurred in the T1 reach, where pre-fertilization values increased from an average $1.8 \text{ kg} \cdot \text{ha}^{-1}$, to an average of $4.2 \text{ kg} \cdot \text{ha}^{-1}$ during fertilization ($p=0.03$, Table 15), peaking at $4.8 \text{ kg} \cdot \text{ha}^{-1}$ in 1995 (Fig. 44). Biomass values in this reach also increased faster, in comparison to the T2 reach, following the start of fertilization. Arctic grayling dominated the biomass in the T1 reach, and increased 2-fold from a pre-fertilization average of $1.0 \text{ kg} \cdot \text{ha}^{-1}$ to $2.1 \text{ kg} \cdot \text{ha}^{-1}$ in 1995-97 (Table 14). However, the rainbow and bull trout values each increased almost 3-fold. Rainbow increased significantly from a pre-fertilization average of $0.38 \text{ kg} \cdot \text{ha}^{-1}$ to $1.0 \text{ kg} \cdot \text{ha}^{-1}$ during the fertilized years ($p=0.008$), and bull trout increased significantly from an average of 0.35 to $1.1 \text{ kg} \cdot \text{ha}^{-1}$ ($p=0.004$, Table 15).

The biomass increase was more gradual in the T2 reach, following the density trend, with a more gradual increase from $1.8 \text{ kg} \cdot \text{ha}^{-1}$ in 1993 to $4.1 \text{ kg} \cdot \text{ha}^{-1}$ in 1997 (Fig. 44). Rainbow and bull trout dominated this reach, with rainbow trout values increasing 2.4-fold from a pre-fertilization average of $0.59 \text{ kg} \cdot \text{ha}^{-1}$ to an

average $1.4 \text{ kg} \cdot \text{ha}^{-1}$ during fertilization. The largest biomass values recorded for rainbow and bull trout in the Mesilinka River were detected in 1999, at 1.7 and $1.3 \text{ kg} \cdot \text{ha}^{-1}$, respectively (Fig. 44). There was also a noted increase in grayling from initial values of 0.31 to $0.89 \text{ kg} \cdot \text{ha}^{-1}$ during fertilization. However, their increases were not statistically significant.

Table 15. The average biomass ($\text{kg} \cdot \text{ha}^{-1}$) of Arctic grayling, rainbow trout and bull trout during the pre-fertilization (1992-93) and fertilization (1994-99) periods in the three experimental reaches of the Mesilinka River, and percent change. (* denotes a significant ($p < 0.05$) increase using BACI analysis.)

species	control reach			T1 reach			T2 reach		
	pre-fert	unfert	% change	pre-fert	fert	% change	pre-fert	fert	% change
Arctic grayling	0.81	1.29	59%	1.05	2.08	98%	0.31	0.89	187%
rainbow trout	0.14	0.23	64%	0.38	1.03*	171%	0.59	1.42	141%
bull trout	0.20	0.18	-10%	0.35	1.05*	200%	0.69	0.87	26%
total	1.15	1.65	44%	1.78	4.16*	134%	1.59	3.18	100%

There were substantial increases in fish density and indications of positive growth leading to increases in fish biomass in both treatment reaches. While there were few statistically significant results in these three measures of fish populations by our methods, the magnitude of the changes and/or the increasing trends within the treatment reaches are indications of increasing fish populations. By plotting the response variables used in the BACI analysis, the log differences in values from the treatment reaches and control reach both before and during fertilization, the increasing trends are clear (Fig. 45). Also evident is the power of the inferential analysis (t-tests) performed on these variables was limited by these increasing trends which were cumulative or delayed, increasing variability during the fertilization period. Additional years of pre-fertilization data would also have strengthened the statistical analysis, which was limited to at most two data points (Fig. 45).

Fish Movements – Observations from Mark-Recapture

A total of 100 bull trout were tagged in 1992-98 as part of both the mark-recapture for snorkel surveys and tagging for growth rates, and only 5 (or 5%) were recaptured in succeeding years (Table 16). Three of the five recaptures had returned to, or had not left the reach in which they were tagged, one had moved from the control to T2 reach, and one had a tag recording error and could not be traced. Of the three recaptured in the same reach, two were recaptured in the control reach (in 1996) where they were tagged the previous year, and one recaptured in the T2 reach in 1993 where it had been tagged a year previous. Bull trout can have a number of life-history forms. The stream resident form lives in small headwater streams, the lacustrine-adfluvial form lives in lakes but migrates to streams to spawning in the fall, and the fluvial form lives in large rivers and spawns in small tributaries (Bruce and Starr 1985; McPhail and Baxter 1996). The latter two, are likely the form encountered during the snorkel surveys and captured during angling efforts.

Rainbow trout were the most numerous tagged fish during the study, with a total of 639, more than half in the T2 reach (Table 16). Despite the numerous tags, only 16 (2.5%) were recaptured in succeeding years. All

recaptured rainbow were from the reaches in which they were originally tagged, and most were recaptured the following year. However, four fish were recaptured two years after they were originally tagged.

Arctic grayling had the highest recapture rate as 79 (18%) of the 451 tagged grayling were recaptured. They also appeared to reside or return to the same stretch of river, as most were recaptured in the same reach they were tagged. Only three (<1%) recaptures strayed to another reach; two recaptured in the control reach in 1999 were originally tagged in the T2 reach in 1997, and one recaptured in the T1 reach in 1997 was tagged in the T2 reach in 1996. Approximately half were recaptured the year after they were tagged; however, a relatively large proportion of grayling were captured several years after tagging. Between 13-31% of the recaptured fish in each reach were caught two years after they were originally tagged, with fish recaptured up to five and seven years after their original tagging, in the control and T2 reach, respectively (Table 17).

Table 16. The number of fish tagged annually, and those recaptured in succeeding years, in the three experimental reaches of the Mesilinka River, 1992-99. Average and total values exclude 1999 numbers, as no angling was conducted in 2000. See Appendix G, H, and I for details.

species	year	control reach			T1 reach			T2 reach		
		tagged	recap.	% recap	tagged	recap.	% recap	tagged	recap.	% recap
bull trout	1992	5	1	20%	9	0	0%	17	1	6%
	1993	7	0	0%	3	0	0%	9	0	0%
	1994	1	0	0%	5	0	0%	6	0	0%
	1995	3	2	67%	9	0	0%	8	0	0%
	1996	1	0	0%	5	0	0%	3	0	0%
	1997	3	0	0%	4	0	0%	2	0	0%
	1999	0	---	---	12	---	---	22	---	---
	ave.	3	0.5	14%	6	0	0%	8	0.2	1%
sum	20	3		35	0		45	1		
rainbow trout	1992	37	0	0%	47	2	4%	69	4	6%
	1993	12	0	0%	16	1	6%	38	1	3%
	1994	6	0	0%	28	0	0%	37	0	0%
	1995	22	3	14%	40	2	5%	66	1	2%
	1996	13	0	0%	13	1	8%	23	0	0%
	1997	17	0	0%	47	1	2%	108	0	0%
	1999	8	---	---	26	---	---	68	---	---
	ave.	18	0.5	2%	32	1.2	4%	57	1	2%
sum	107	3		191	7		341	6		
Arctic grayling	1992	49	6	12%	19	3	16%	25	0	0%
	1993	25	1	4%	19	7	37%	5	1	20%
	1994	12	1	8%	15	3	20%	5	0	0%
	1995	32	9	28%	41	13	32%	19	1	5%
	1996	13	5	39%	51	11	22%	11	5	46%
	1997	20	1	5%	69	11	16%	21	1	5%
	1999	6	---	---	44	---	---	16	---	---
	ave.	25	4	16%	36	8	24%	15	1	13%
sum	151	23		214	48		86	8		

The recapture rate of both Arctic grayling and rainbow trout in the control and fertilized reaches was the same for fish tagged during the fertilizer additions. In the T1 reach, 22% (38 of 176) of grayling tagged in 1994-97 were recaptured in this reach, whereas the recapture rate for grayling in the control reach was about the same at 21% (16 of 77) for fish also tagged in 1994-97. Rainbow recapture rates were 5%, 2% and 5% in the control through T2 reaches, respectively, at the same time with between 2-10 fish recaptured in each reach.

Angling outside the experimental reaches was limited with some occurring between, and downstream of, treatment reaches in 1992-93, 1997 and 1999. Three tagged grayling were captured at the road-end (upper fertilizer site) just above the T1 reach, in 1997. They were all originally tagged in the T1 reach (two in 1995, and one in 1996), and they were captured in close proximity of the fertilized zone so they were included in the recaptures from the T1 reach. Three tagged grayling were also captured at the lower bridge site, approximately 2 km upstream from the reservoir, in 1999 (Fig. 1). One originated from each of the T1 and T2 reaches in 1995, and one had a blue/white tag with an undetermined number, but from the colour code it was either tagged in the control reach in 1995 or the T2 in 1996 (Table 3). These three were recaptured in April while there was still ice cover on the river, and were probably returning after overwintering in the reservoir or another river, a seasonal migratory pattern of Arctic grayling (Northcote 1993).

Table 17. The number and percent of recaptured Arctic grayling and the number of years between original tagging and recapture, Mesilinka River, 1992-99. Only for fish recaptured in the reaches they were originally tagged. Averages do not add to 100% as a few fish were recaptured in another reach or original tagging information was incomplete. (See Appendix H for details.)

years between tagging and recapture	control reach		T1 reach		T2 reach	
	# of fish	%	# of fish	%	# of fish	%
0	2	7%	6	10%	1	13%
1	15	52%	20	35%	6	75%
2	6	21%	18	31%	1	13%
3	0	0%	5	9%	--	---
4	1	3%	2	4%	--	---
5	1	3%	0	0%	--	---
6	--	---	3	5%	--	---
7	--	---	1	2%	--	---

A tagged Arctic grayling was captured in the nearby Osilinka River which also flows into the Onineca Arm of the reservoir, approximately 5 km from the Mesilinka River (captured by angler M. Stanford on Aug. 10, 1998). The fish was originally tagged two years earlier in the Mesilinka control reach, in August of 1995. In two days of limited angling 15 adult grayling were captured by the angler, and in addition to the tagged fish three others had adipose clips, indicating they had been sampled for DNA during 1996-97 in either the Mesilinka or Osilinka rivers. The recapture of the tagged fish may be a chance encounter with a stray, or evidence of a connection between grayling found in each river, perhaps relating to a pre-reservoir condition whereby the larger and deeper downstream portions of these rivers served as overwintering refugia (Northcote 1993). Prior to dam formation, the Mesilinka River flowed into the Osilinka River, then to the Finlay River before joining the Peace River.

Stable Isotope Analysis

This summary is from Paul et al. 1996. The $\delta^{15}\text{N}$ values within biotic and abiotic groups were relatively consistent along the transect stretching from above the first fertilizer station to 15 km below the second fertilizer station (Fig. 46). A slight decline in $\delta^{15}\text{N}$ occurred from 2 km upstream of the first fertilizer station to the other sampling sites (Fig. 46) which is consistent with the negative fractionation of ^{15}N following fertilization as was observed by Peterson et al. (1993b). However, the decrease in $\delta^{15}\text{N}$ values on the Mesilinka River first occurred in the control reach above the fertilizer stations and can not be attributed to fertilization (Fig. 46). The stable $\delta^{15}\text{N}$ values from the Mesilinka River indicate that the level of N fertilizer being added is insufficient to stimulate a negative N isotope fractionation which could be used to trace fertilizers through the food web (B. Peterson, The Ecosystem Center, Woods Hole, Massachusetts, pers. comm.). Higher levels of ammonium-N ($\sim 50 \mu\text{g} \cdot \text{L}^{-1}$), which shows strong fractionation during algal uptake (Peterson et al. 1993b), or spiking the fertilizer with enriched ^{15}N , are required to enable tracing the pathway of added nutrients using stable isotopes (B. Peterson, pers. comm.).

The $\delta^{13}\text{C}$ values mostly lie in between -30 and -25 with no differentiation between terrestrial vegetation and stream algae (Fig. 47). Because $\delta^{13}\text{C}$ fall within 5 - 6 of each other, terrestrial versus stream sources of C can not be distinguished among organisms. Although $\delta^{13}\text{C}$ values have been used to trace C sources in some aquatic systems (Fry and Sherr 1984), its utility in tracing C pathways in stream ecosystems has been questioned (France 1995). The variability observed in $\delta^{13}\text{C}$ values for attached algae often envelops terrestrial $\delta^{13}\text{C}$ values, thereby, obscuring any discrete differences between the two sources that can be traced through the food web (France 1995). These conclusions are supported by our results, in which the $\delta^{13}\text{C}$ values for algae lie between the bounds of the values recorded for terrestrial vegetation (Fig. 47). Although variable, $\delta^{13}\text{C}$ values in biotic and abiotic groupings did not show any observable trends along the fertilization transect.

$\delta^{15}\text{N}$ values for Mesilinka River illustrate the relative trophic position of the sampled organisms in the food web (Fig. 47). Approximately, a 3 part per thousand increase in $\delta^{15}\text{N}$ occurs at each trophic level with rainbow trout and whitefish occupying the role of top consumer from the organisms sampled (Fig. 47). Bull trout were not sampled; however, it is hypothesized that large river resident bull trout would have a $\delta^{15}\text{N}$ of up to 12 parts per thousand (B. Peterson, pers. comm.). Furthermore, invertebrate predators (e.g. Plecopterans) which feed on grazing insects were not sampled and would likely have a $\delta^{15}\text{N}$ similar to dace (~ 6 parts per thousand). This would explain the trophic position of mountain whitefish (Fig. 47) which are unlikely to be piscivorous. Finally, because terrestrial versus stream sources of C are not discernible, the importance of terrestrial insects in the diets of rainbow trout and whitefish can not be ruled out.

Tributary Water Chemistry

Water samples taken from the tributaries were analyzed for several forms of nitrogen and phosphorus in 1992-97, and for additional parameters (pH, alkalinity, conductivity, total dissolved solids and turbidity) in 1995-97 (Appendix J). Values were generally similar among the tributaries, and to mainstem concentrations. Lake headed Carina Ck. stood out with higher dissolved ion and lower nitrate-nitrogen concentrations. All the tributaries had similar pH values which ranged from about 7-8 units. Alkalinity values were $20\text{-}50 \text{ mg} \cdot \text{L}^{-1}$, except in Carina Ck. where they ranged from $48\text{-}80 \text{ mg} \cdot \text{L}^{-1}$. Conductivity ranged from $50\text{-}130 \mu\text{S} \cdot \text{cm}^{-1}$, with values in Carina Ck. ranging from $118\text{-}212 \mu\text{S} \cdot \text{cm}^{-1}$.

SRP concentrations were generally at-or-below their detection limit of $1 \mu\text{g}\cdot\text{L}^{-1}$ in all years except 1994-54 (Fig. 48), when abnormal concentrations were also recorded in the mainstem and the Nation River (Fig. 10). These were determined to be an anomaly, probably resulting from contamination at some point in the field-filtering procedure (see Mainstem Water Chemistry Section). Concentrations did not change in Culvert or Gopherhole creeks during their 1993 and 1995 fertilizations. Total dissolved phosphorus concentrations were also at their detection limit level of $2 \mu\text{g}\cdot\text{L}^{-1}$, except in 1996-97 when concentrations fluctuated as high as $16 \mu\text{g}\cdot\text{L}^{-1}$ in mid-summer (Fig. 49). The reason is unknown, but mainstem concentrations also peaked at this time, although not as high (Fig. 11).

Carina Creek had the lowest NO_{2+3} concentrations of all the tributaries monitored, with concentrations below $10 \mu\text{g}\cdot\text{L}^{-1}$ (Fig. 50). Water in this tributary flows from several lakes which probably experience nitrogen depletion during summer stratification. Gopherhole Creek had the next lowest NO_{2+3} concentrations with values usually $< 20 \mu\text{g}\cdot\text{L}^{-1}$, with the other tributaries between $20\text{--}40 \mu\text{g}\cdot\text{L}^{-1}$ (Fig. 50), suggesting that tributaries undergo nitrogen limitation during the summer. Concentrations fluctuated abnormally in 1997, from $60\text{--}270 \mu\text{g}\cdot\text{L}^{-1}$, with concentrations back to their normal detection limit levels in August. Contamination of the field-filtering apparatus was the cause, as similar values were recorded in the mainstem at the same time, and all values returned to normal after a thorough cleaning of the equipment.

Nitrate concentrations in Culvert and Gopherhole creeks during their 1993 and 1995 fertilizations were similar above and below the fertilizer reach. Concentrations were below $10 \mu\text{g}\cdot\text{L}^{-1}$ in 1993, strongly suggesting nitrogen limitation in the creeks, but SRP concentrations did not increase above detection limit levels (Fig. 48). Nitrate concentrations were higher in the during the 1995 fertilization, but again similar at the above and below sites (Fig. 50). Ammonium concentrations in all creeks were generally at-or-below the detection limit of $5 \mu\text{g}\cdot\text{L}^{-1}$, occasionally increasing to $20\text{--}25 \mu\text{g}\cdot\text{L}^{-1}$ in late-August (Fig. 51).

Tributary Periphyton Accrual: Chlorophyll *a*

Each tributary contained at least one periphyton block which was usually in the stream for two months with samples taken at the minimum of two weeks apart. There was remarkable fluctuation in periphyton accrual (measured as chlorophyll *a*) in the Mesilinka River tributaries monitored, probably resulting from natural variations in ambient nutrient concentrations, light, temperature, benthic invertebrate populations and stream flows. Unfertilized Carina Cr., for example, had peak chlorophyll *a* concentrations (and accrual rates) ranging from $113 \text{ mg}\cdot\text{m}^{-2}$ ($2.8 \text{ mg}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$) in 1992, and $3 \text{ mg}\cdot\text{m}^{-2}$ ($0.06 \text{ mg}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$) in 1996 (Table 18 & 19). Above average discharge was recorded in all tributaries between June and August, 1996 (Fig. 5), coinciding with lowest peak chlorophyll *a* concentrations (Table 18). Carina and Fatfish creeks generally had the highest chlorophyll *a* concentrations of the tributaries, with peaks of 113 and $266 \text{ mg}\cdot\text{m}^{-2}$, respectively, but in different years (Table 18). All the tributaries regularly attained higher chlorophyll *a* concentrations than was found in the unfertilized mainstem.

Table 18. Peak chlorophyll *a* concentrations ($\text{mg} \cdot \text{m}^{-2}$) measured in several Mesilinka River tributaries, and the mainstem control reach, 1992-97. Culvert and Gopherhole creeks fertilized in 1993 and 1995.

Year	Carina Ck.	Control Ck.	Tributaries				Mainstem Control Reach	
			Culvert Ck. abv site	Culvert Ck. blw site	Fatfish Ck.	Gopherhole Ck. abv site		Gopherhole Ck. blw site
1992	113	23	---	11	---	---	36	16
1993	45	40	57	33	33	17	38	7
1994	40	---	---	7	---	27	---	11
1995	32	13	6	14	57 ^a	14	60	4
1996	3	10	---	5	8	---	6	3
1997	19	36	---	20	266	---	16	7

^a may be higher as block broke before final sampling day.

Table 19. Chlorophyll *a* accrual rates ($\text{mg} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$) measured in several Mesilinka River tributaries, and the mainstem control reach, 1992-97. Culvert and Gopherhole creeks fertilized in 1993 and 1995.

Year	Carina Ck.	Control Ck.	Tributaries				Mainstem Control Reach	
			Culvert Ck. abv site	Culvert Ck. blw site	Fatfish Ck.	Gopherhole Ck. abv site		Gopherhole Ck. blw site
1992	2.76	0.39	---	0.28	---	---	0.59	0.23
1993	0.50	0.51	0.76	0.56	0.66	0.23	0.51	0.13
1994	nc ^a	---	---	nc	---	nc	---	0.22
1995	0.61	0.32	0.26	0.58	1.07	0.26	1.13	0.11
1996	0.06	0.21	---	0.10	0.17	---	0.13	0.06
1997	0.34	0.63	---	0.35	4.84	---	0.29	0.13

^a not calculated.

Culvert and Gopherhole creeks were fertilized in 1993 with liquid fertilizer, and in 1995 with solid slow release fertilizer, with mixed results. Peak chlorophyll *a* concentrations were 2- to 4-fold higher below the fertilizer inputs in Gopherhole Creek, with the best response from the solid slow release fertilizer used in 1995 (Table 18). In 1993, visual observations indicated only minor algae growth on the stream substrate, reflecting the difficulty in maintaining target loading concentrations with liquid fertilizer in a small stream (Koning et al. 1995). In Culvert Creek, peak values doubled below the slow release fertilizer in 1995, but concentrations were higher above the fertilizer injector in 1993. Nitrogen limitation may have effected growth in 1993 as nitrate concentrations were $<10 \mu\text{g} \cdot \text{L}^{-1}$ (Fig. 50). A marked periphyton response was observed for a few hundred meters in the mainstem below the confluence with Culvert Creek, suggesting nitrogen may have been less limiting in the mainstem (Koning et al. 1995). There was also difficulty in maintaining the solid fertilizer briquettes in the streams as many were washed out and buried by flash flows (Ewing and Ashley 1996). The slow release fertilizer has been used successfully on numerous creeks with more consistent flows (Mouldy-Ewing et al. 1998).

Tributary Fish Population Density and Size-at-Age

Juvenile fish were collected to varying degrees in five Mesilinka tributaries (Control, Culvert, Fatfish, Gopherhole and Carina creeks) in the vicinity of the mainstem fertilization (Fig. 1). Effort varied between creeks, with electrofishing conducted regularly, and trapping occurring in 1992-93 on Control, Culvert and Gopherhole creeks, the three with similar temperature and flow regimes (see Water Temperature and Discharge Sections). Fatfish and Carina creeks were only assessed in the early years of the project with electrofishing (Table 4). Fatfish Creek was the smallest tributary assessed, and Carina was the largest and warmest. Only Gopherhole and Culvert creeks were fertilized and only in 1993 and 1995.

The traps set in Control, Culvert and Gopherhole during July/August of 1992-93 captured mature whitefish to age 7+, rainbow occasionally to age 3+ and bull trout usually <15 cm fork length (probably age 2+ or 3+, but few ages available). Electrofishing these three tributaries found juvenile rainbow (age 0+ to 1+) and bull trout, but very few juvenile whitefish. Total populations were generally highest in Gopherhole, followed by Culvert and Control creeks.

In most creeks, bull trout dominated both relative catch and density estimates from mark/recapture. Their populations generally increase during the project, with the highest densities in each tributary usually found in 1996 or 1997 (Table 20). Control Creek peaked at 36 fish·100 m² in 1996, Culvert Creek at 13 fish·100 m² in 1995, and while no density estimates are available for Gopherhole in 1997 the number of fish estimated within the enclosure was the highest recorded by a factor of two (Appendix K). However, it must be noted that to be statistically valid a mark-recapture procedure requires the initial marking of fish (M) to be 20% or more of the total estimated population (N) (e.g. $M/N \geq 20\%$, Vincent 1972), and to avoid any bias due to low numbers, the total number of fish marked multiplied by the number of captured fish (C) should be more than 4 times the total estimated population e.g. $MC > 4N$, or $M+C \geq N$, Robson and Regier 1964). Only 35% of the tributary population estimates satisfied both conditions, and are bolded in Table 20, with specific statistics given in Appendix H.

The bull trout populations also appear to fluctuate between years. For example, densities in Control Creek varied from a low of 4 fish·100 m² (1992) to a high of 36 fish·100 m² (1997). The fluctuations in Culvert and Gopherhole creeks noted from 1992 to 1996 do not correspond to years of 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). Bull trout catches in 1997 were dominated by young-of-year cohort, as also noted in previous years (Paul et al. 1998; Wilson et al. 1999c).

No bull trout were captured from Carina Creek, which contained mostly rainbow with some whitefish and grayling. Bull trout are probably excluded from Carina in the summer as it's a warm tributary with summer temperatures averaging 14°C. Bull trout are noted coldwater fish which prefer water temperatures <15°C (Fraleigh and Shepard 1989; Donald and Alger 1993), and only start migrating into spawning tributaries as stream temperatures drop to 7-9°C (Pratt 1992; James and Sexauer 1997).

Table 20. Linear and areal density estimates (no. per 100m and no. per 100m², respectively) for bull trout, rainbow trout and whitefish in three tributaries of the Mesilinka River determined by mark/recapture, 1992–1997. Years in bold are valid estimates, satisfying conditions explained in the text. Gopherhole and Culvert creeks fertilized in 1993 and 1995.

Tributary	Year	Bull Trout		Rainbow Trout		Whitefish		Peak Chloro <i>a</i> (mg · m ⁻²)
		linear	areal	linear	areal	linear	areal	
Gopherhole	1992	3	1	22	6	5	1	36
	1993	21	3	20	3			38
	1994	48	7					---
	1995	110	20	28	5			60
	1996	44	8	6	1			6
	1997	202	na ^a	9	na ^a			16
Culvert	1992	24	5	25	5	7	1	11
	1993	15	2	21	3	17	2	33
	1994	39	5	17	2			7
	1995	89	13	5	1			14
	1996	67	10	8	1			5
	1997	not shocked						
Control	1992	13	4	11	3	6	2	23
	1993	63	11					40
	1994	48	8	1	<1			---
	1995	104	21	3	1			13
	1996	82	19					10
	1997	161	36					36

^a areal estimate unavailable as shocking area not recorded

^b Gopherhole and Culvert creeks values from below (fertilized) sites.

Juvenile whitefish were rarely captured in Gopherhole or Control creeks despite the relative large fishing effort expended on these creeks. Culvert Creek was inhabited by many in 1992-94 but numbers declined notably in 1995-96; however, effort also declined. Juvenile whitefish were also found in great numbers in mainstem side channels.

Arctic grayling were rarely captured in tributaries, with only a few caught in 1992-93. However, as they were found in three tributaries, and in at least two (Culvert and Control) their captures coincided with the time of most fishing effort (Table 4), they may be underrepresented in the data. Three juveniles (ages 0+ to 1+) were captured in 1992 in Carina Creek which was subjected to limited fishing effort, two were captured in Culvert Creek in 1993 (age 1+ and 2+), and one in Control Creek in 1993 (age 1+). The numbers captured were too low to for density calculations.

Rainbow trout densities were usually below 5 fish·100 m⁻², with the highest estimated at 6 fish·100 m⁻² in Gopherhole Creek in 1992. They also had high catches relative to the other species in the warmer water tributaries of Fatfish and Carina, but no mark/recapture population estimates were conducted. Rainbow numbers were lowest in Control Creek. Juveniles were widely captured and regularly aged, allowing some size comparisons between tributaries. The sizes of juvenile rainbow in Carina and Fatfish creeks were

consistent between years. The largest average young-of-the-year rainbow were found in Carina Creek, with age 0+ fish averaging 2 g and 55 mm in length (Fig. 52). Fatfish Creek has not lived up to its name with some of the smallest young-of-the-year rainbows averaging <1 g and around 40 mm in length. The annual average size of the 0+ rainbows in Culvert and Gopherhole creeks appear to have fluctuated widely between years. However, the years with the high averages had small sample sizes of 1-2 fish of larger size, and therefore misrepresent the true population. The age 1+ rainbows averaged 10 g and 80 mm in length, also with some fluctuation between years (Fig. 53). Some of the fluctuation could be attributed to water temperatures, but 1996 was an abnormally cool year (see Water Temperature and Discharge Section), with no apparent corresponding decrease in fish size (Figs. 52-53). There was also overlap in the size ranges of the age 0+ and 1+ rainbows, with some of the age 0+ fish possibly age 1+ fish that didn't have an annulus growth ring due to small growth the previous year. These tributary rainbow were, however, similar in size to those from the mainstem.

WHOLE RIVER RESPONSES TO NUTRIENT ADDITIONS

Fertilization of the Mesilinka River provided an opportunity to determine if nutrient addition is a suitable technique to increase Arctic grayling, bull trout and rainbow trout populations within the Williston Reservoir watershed, to offset losses of riverine habitats by flooding. It was one of three oligotrophic rivers in British Columbia to undergoing fertilization (along with the Big Silver and Adam rivers) and provide a database on the effect of nutrient additions to stream productivity and ecology. The Mesilinka is also the largest river, and the most northern, to undergo intentional low-level nutrient addition, extending the size range of rivers studied. Nutrient additions to the Mesilinka River were approximately 60% of target concentrations, however, the effects were evident at all trophic levels studied. The significant increase in periphyton standing crop combined with the decrease in inorganic nitrogen and phosphorus levels below the fertilizer inputs, despite the addition of nutrients, indicated considerable demand and rapid uptake of biologically available P and N.

Peak values attained in the Mesilinka T1 reach during fertilization, as well as unfertilized values, were similar to those recorded in the Adam and Big Silver rivers (Wilson et al. 1999a; Wilson et al. 199b), undergoing fertilization at similar concentrations. These peak values were half those reported for the fertilized Kuparuk, Nechako, Keogh and Salmon rivers (Perrin et al. 1987; Slaney et al. 1991; Slaney and Ward 1993; Peterson et al. 1993), however, their phosphorus loadings rates were at least double our target concentrations of $5 \mu\text{g-P} \cdot \text{L}^{-1}$, which were generally not attained. The lower periphyton response in the Mesilinka T2 reach may have resulted from incremental nitrogen and phosphorus co-limitation, as nitrate concentrations were often lower in this reach. However, the difference in distance between the site of fertilizer inputs and the beginning of each reach; with a distance of 15 km from the fertilizer site at Mid-launch to the beginning of the T2 reach, and only 4 km from the upper fertilizer site and the beginning of the T1 reach, was significant. There was probably a large and unrecorded periphyton response in the 15 km above the T2 reach. The effects of the fertilization in the T2 study area was dependant on spiralling nutrients from upstream, which is the downstream movement of nutrients as they are gradually lost to sedimentation. An effective distance of at least 8-11 km was found in the Adam and Big Silver rivers, the downstream extent of assessment (Wilson et al. 2002), and 15-20 km in the Salmon River (Slaney and Ward 1993; Larkin et al. 1997). As flow on the

Mesilinka is higher than on the Adam, Big Silver or Salmon, spiralling distance is expected to be higher (Minshall et al. 1985; Mulholland 1996). In addition to sedimentation, the loss of nutrients to the hyporeal zone may also have been a factor. This area in the Mesilinka River basin, while not determined, is probably extensive based on observations such as: sizeable increase in flow between the control and T2 reaches without large tributaries, lateral movements of the river during the course of the study, and the large gravel component of the river bed. A significant amount of nutrients was probably incorporated into the microbial and invertebrate components of this area.

Benthic invertebrate populations also responded differently in the two treatment reaches. Standing crop increased quicker and attained a higher level in the T1 reach, presumably following the periphyton response, compared to the T2 reach where a slow and gradual increase in benthic invertebrates was observed. The eventual increase in the T2 reach suggests an increase in secondary productivity and that nutrients were reaching the T2 reach. Low background populations may have caused the delayed response. Pre-fertilization benthos densities averaged 180 per 0.005 m³ in the T1 reach and just 8 per 0.005 m³ in the T2 reach, compared to 100 on the Adam and 200 per 0.005 m³ on Big Silver rivers (Wilson et al. 2002), and 250 per 0.005 m³ on the Salmon River (Quamme 1994). Following fertilization, results were similar to other fertilization experiments on the Keogh (Johnson et al. 1990), Salmon (Quamme 1994), Adam and Big Silver rivers (Wilson et al. 2002), where major increases were limited to a few families in each order; collectors/gatherer dipterans (family Chironomidae), ephemeropterans (Family Baetidae), and some predatory stoneflies (family Perlodidae).

Ordinal composition of the benthos community shifted as dipterans became numerically dominant in the treatment reaches during fertilization, particularly in the T1 reach where they increased from 30% to approximately 80% of the population. There was no evidence of detrimental effects on the benthos community during fertilization; no groups disappeared, or new groups appeared, based on a non-intensive level of analysis, and fish responded positively in growth and abundance. Extensive sampling in a variety of habitats would be required to effectively extend this conclusion to the entire benthos population. Trough/mesocosm (Mundie et al. 1991; Quamme 1994; Perrin and Richardson 1997) and other instream fertilization experiments (Peterson et al. 1993; Slaney and Ward 1993; Wilson et al. 2002) made no mention of such changes among the benthos. However, a shift in ordinal composition can potentially have important consequences for food chain dynamics and the availability of food to higher trophic levels (Peterson et al. 1993). Benefiting species may reduce density of others through competitive interactions, as seen with the increase in the larval caddisfly *Brachycentrus* which reduced blackfly density in the Kuparuk River (Hershey et al. 1988). At the same time, *Brachycentrus* is an important food for Arctic grayling (Peterson et al. 1993), so an increase would be in concert with the goals of our project. No decrease in black fly (family Simuliidae) larvae, nor any other group, was evident in our data.

There were substantial increases in fish density and biomass and indications of positive growth in both treatment reaches, again with different responses in each reaches. The density of all fish species enumerated increased in the T1 reach, with large increases in whitefish and rainbow trout, and modest increases in grayling and bull trout. The T2 reach showed a large increase in whitefish, with smaller increases in rainbow and grayling density, and a marginal/delayed response in bull trout density. Increases were great enough in magnitude to not be subject to chance or some extraneous factor, especially when supported by the periphyton and insect response during fertilization.

The differential responses may stem from different fish habitats in each reach, and therefore preferences of the different species, in addition to possible treatment effects mentioned above. The different response by Arctic grayling in each reach can be attributed to their habitat preferences. It has been noted that grayling segregate by size class in rivers, with adults in the upper reaches and juveniles in the lower (Reed 1964, Armstrong 1986, Blackman and Hunter 2001), and that different life stages can use different systems all together (Stein et al. 1973; Blackman and Hunter 2001). There was a strong association in this study between older grayling found in the control and T1 reaches, with their density increase in the fertilized T1 reach. Thus, it is possible that the potential for increasing adult and sub-adult grayling density lies more in the upper reaches of the river rather than the lower reaches. The lower portion of the river, including the T2 reach, is probably more favourable to rainbow trout, as they tend to prefer dense log-jam cover and warmer temperatures, as observed in the Table and Anzac rivers (Blackman and Hunter 2001). There may have been a juvenile grayling response that was undetected in T2 reach, as snorkel surveys often underestimate (< 20 cm) small fish abundance (Slaney and Martin 1987). Electroshocking and trapping along the banks and side-channels of the mainstem, while limited, found few juvenile grayling relative to other species. Juveniles may be rearing in another river system, as has been observed in the Anzac/Table/Parsnip rivers system where most juveniles have been found rearing in the Parsnip River (Blackman and Hunter 2001). The small response of grayling compared to rainbow and whitefish responses may also be a reflection of the slow grayling growth rate (min. age to maturity of 4-6 years), it may indicate they are not limited by aquatic food organisms as rainbow or whitefish, or it may be a result of some unknown effect on another portion of the life history, such as overwinter migration to larger riverine refuges (Northcote 1993).

Although the results are promising for rainbow trout and whitefish in this long-term whole-river experiment, it is premature to conclude this technique is applicable to Arctic grayling in northern rivers. Natural variation in the parameters analysed combined with slow fish growth rates have likely resulted in a slow response, which is compounded by the migratory life history of grayling. However, the relatively high recapture rate of tagged grayling is encouraging, as are the small density and biomass increase and indications of size increases. The at-risk status of Arctic grayling in the Williston drainage, with most smaller stocks lost in the past two decades, indicates that restoration efforts such as this are vital.

RECOMMENDATIONS

1. The Mesilinka River was not fertilized in the summers of 2000 and 2001, but should resume in 2002, as should the sampling of fish populations. In addition, the benefits of river fertilization on fish populations in the embayment area of the reservoir receiving outflow from the Mesilinka River should be evaluated. This should be particularly informative, as the reservoir is well into the oligotrophication phase (Stockner et al. 2001), and the links between riverine and lacustrine environments in these migratory fish are poorly understood. Coinciding with these investigations, an adaptive management plan should be implemented because there are few viable large-scale options available to cost-effectively offset impacts of reservoir flooding of numerous riverine habitats.
2. Design the treatment to ensure the large embayment is treated by nutrient spiralling from the Mesilinka River, as there is anecdotal evidence the embayment responded to the 1994-99 treatment.
3. In the interest of assisting at-risk Arctic grayling in the Williston drainage, consider fertilizing the upper portions (control reach) of the river where adult grayling appear to spend summers feeding. This would also benefit other sportfish species, resulting in a destination fishery with significant tourist benefits.
4. Maintain current fishing regulations, that are catch and release for bull trout and grayling, to keep harvest low and minimize the possibility of adult fish loss interfering with the experimental results.
5. Integrate the future treatments with habitat restoration, supported in part from forestry companies with forest tenure holdings (e.g. loss of stream habitat from past riparian logging).
6. Maintain target nutrient loading concentrations by: maintaining adequate site visits to adjust drip rates accordingly, setting the drip rates above target concentrations so they decrease to the target concentration, or using alternate injection methods for controlling drip rates (similar to that at the Adam River).
7. Improve consistency in field procedures (e.g. water chemistry, insect samples, fish counts and sampling) on these long projects with variable field crews through preparation of a standard operating procedures (SOP) manual.
8. Increase nitrogen loading by increasing the addition rate of the nitrogen based fertilizer (28-0-0) above the current target of $15 \mu\text{g-N} \cdot \text{L}^{-1}$. This would prevent potential fertilizer induced nitrogen limitation of the periphyton community, which may favour the development of blue-green algae, but could also result in a reduced utilisation of the phosphorus fertilizer if periphyton growth becomes nitrogen-limited. This is essential to ensure an embayment response, as documented on a smaller scale elsewhere (Milbrink and Holmgren 1981).
9. Implement river-embayment fertilization studies, in addition to the Mesilinka project, as multiple adaptive management components to a comprehensive restoration of fisheries in Williston Reservoir, in an attempt to forestall further losses of endangered (red-listed) Arctic grayling, and declining rainbow stocks in the reservoir. Candidates include Nation, Manson, Carbon and Clearwater rivers with their associated embayments.

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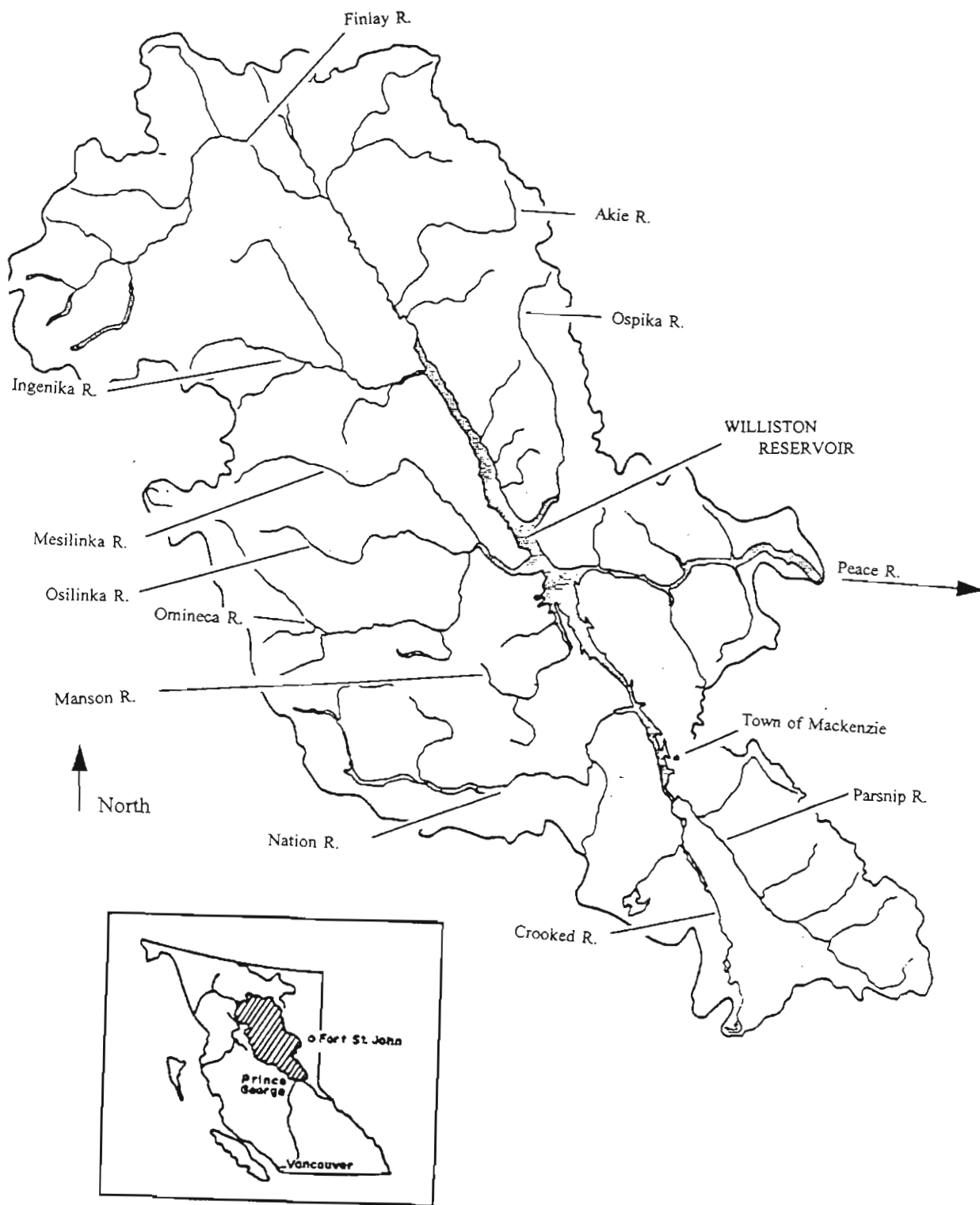


Figure 1. Williston Reservoir and watershed (figure from Koning *et al.* 1995).

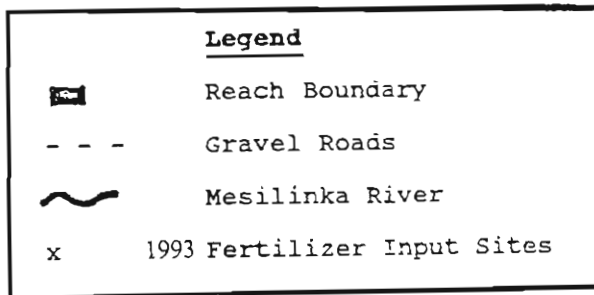
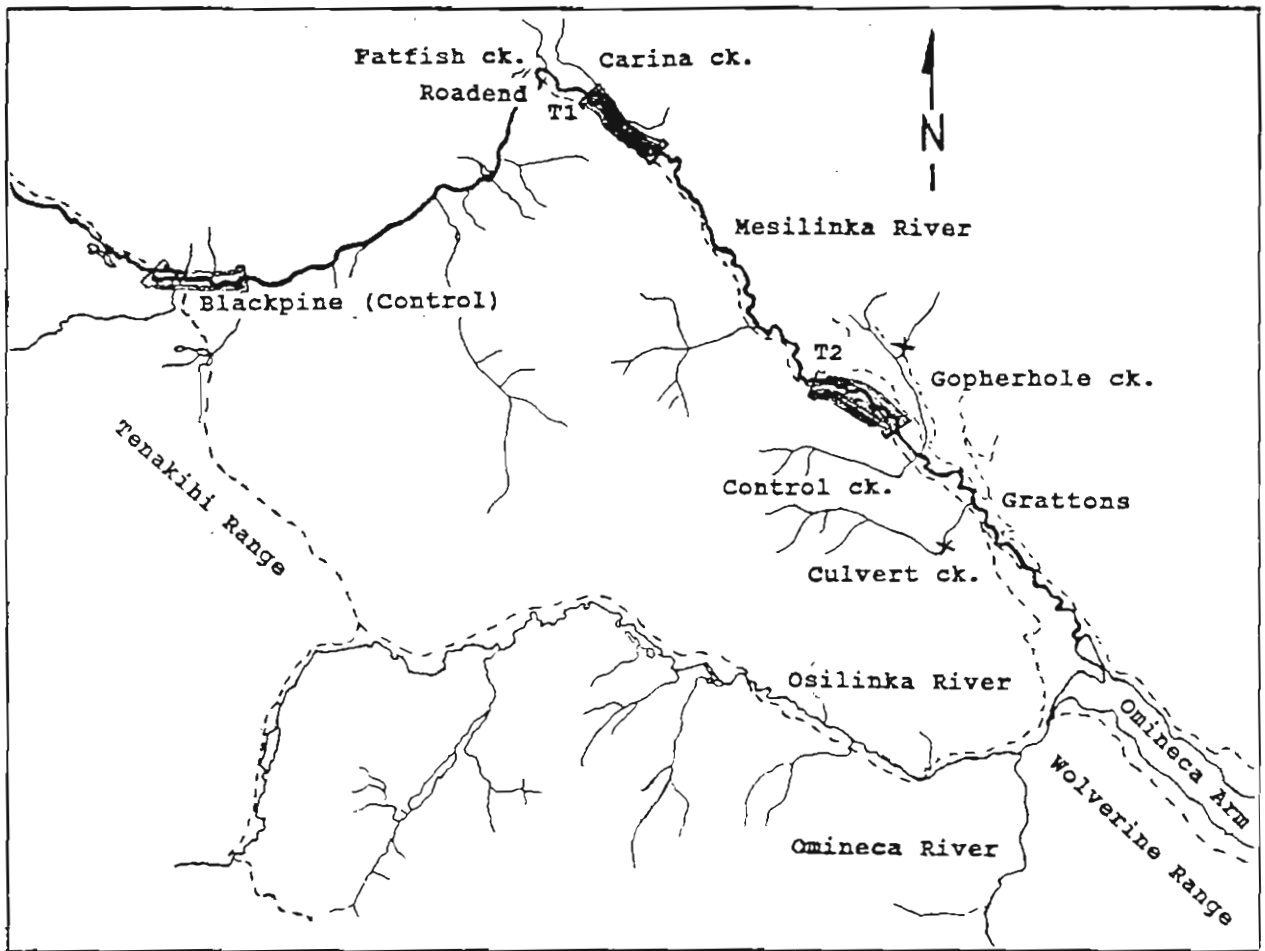


Figure 2. Mesilinka River study area (figure from Koning *et al.* 1995).

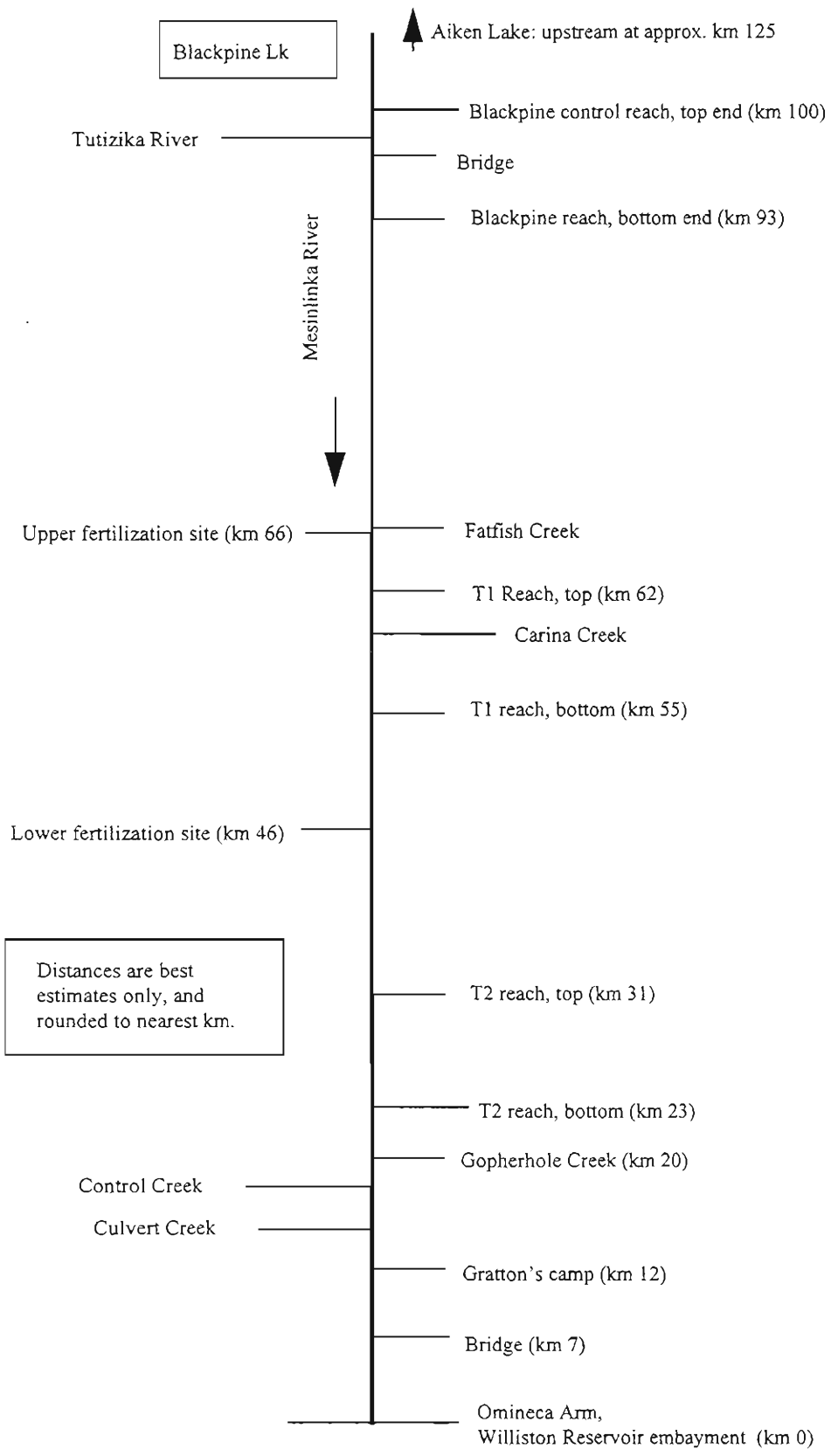


Figure 3. Schematic of the study area on the Mesilinka River (figure from Koning *et al.* 1995).

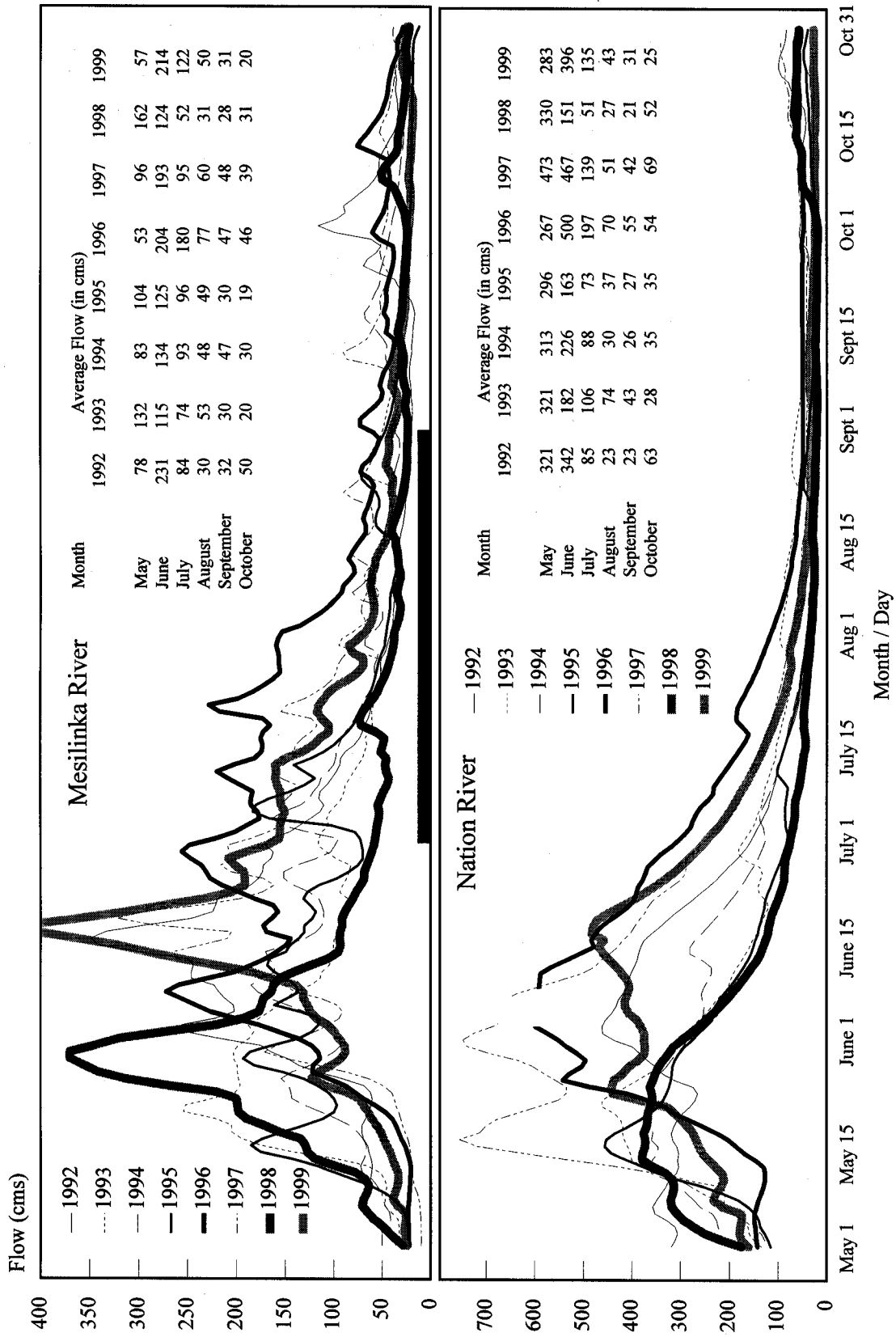


Figure 4. Discharge from the Mesilinka River (top) measured at the WSC station no. 07EC003 located upstream of Gopherhole Creek, and from the Nation River (bottom) measured at WSC station no. 07ED003 located near its confluence with Williston Reservoir, between May and October of 1993-99. Dark line on x-axis of Mesilinka discharge graph indicates approx. time of liquid fertilizer application, 1994-99.

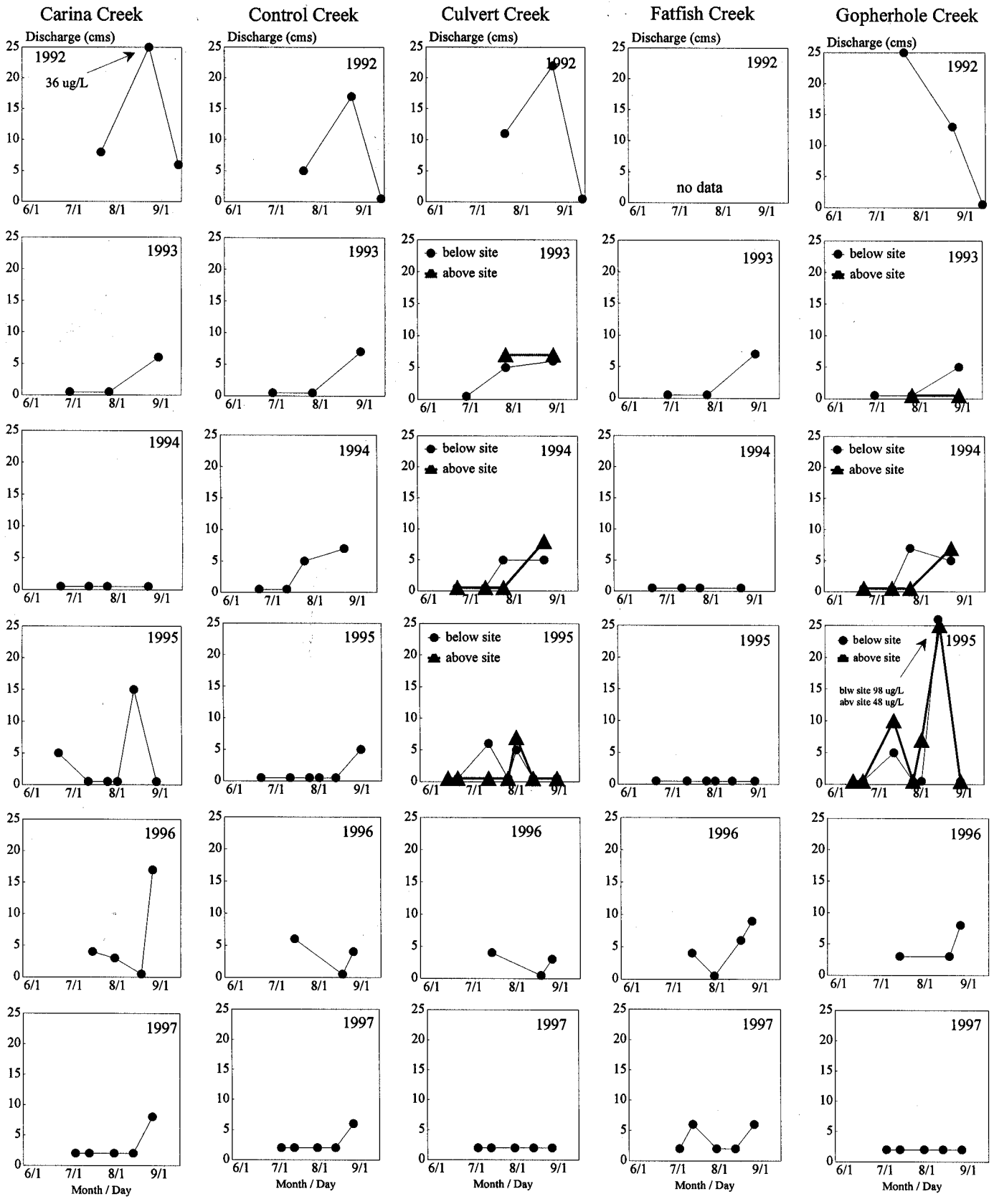
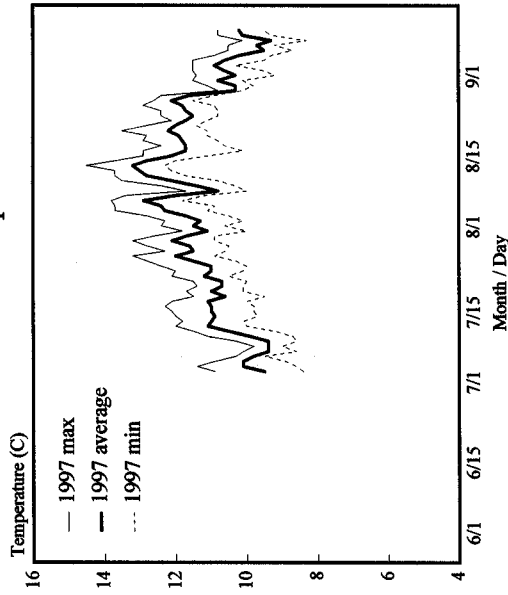
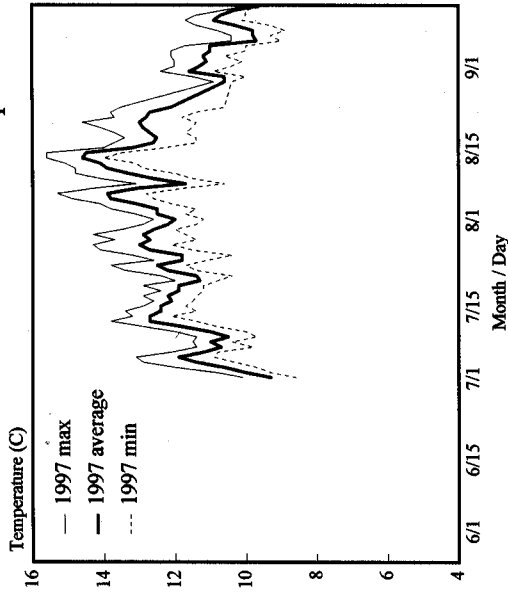


Figure 5. Discharge for tributaries to the Mesilinka River during summers, 1992-97.

Mesilinka at Blackpine



Mesilinka at Gratton's Camp



Nation River

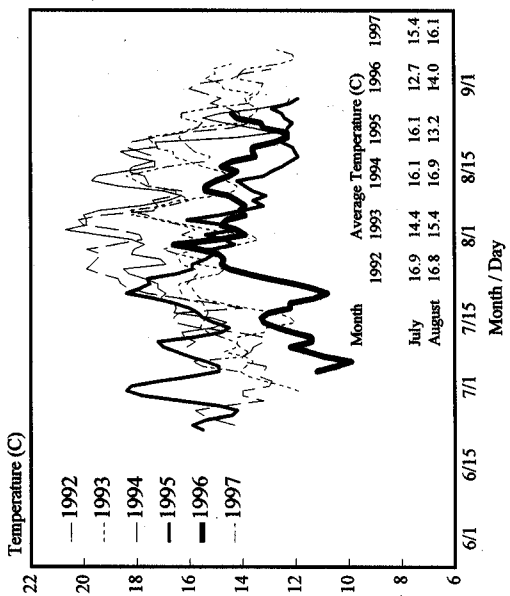
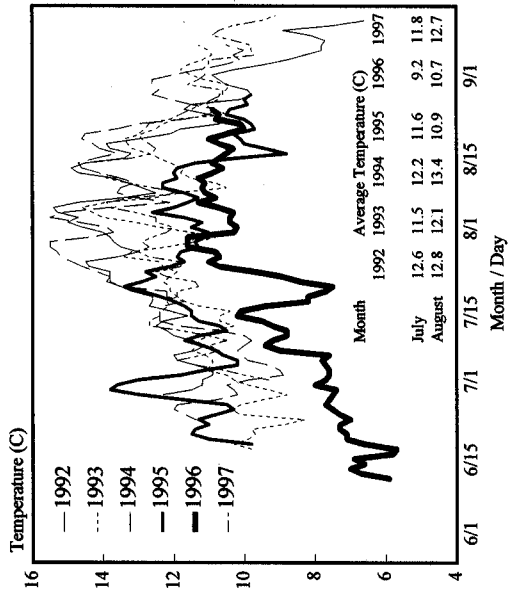
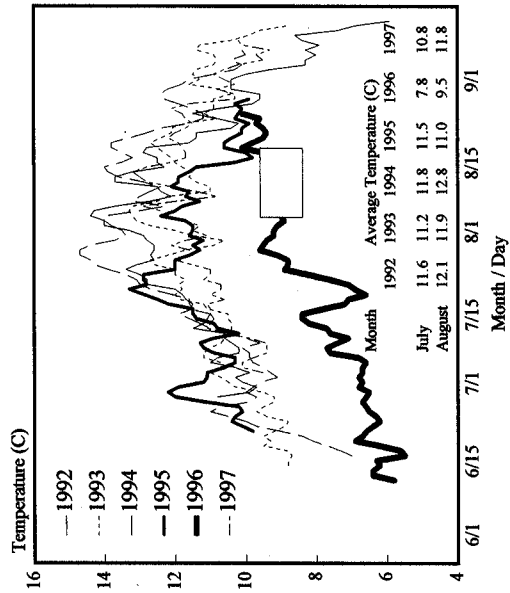
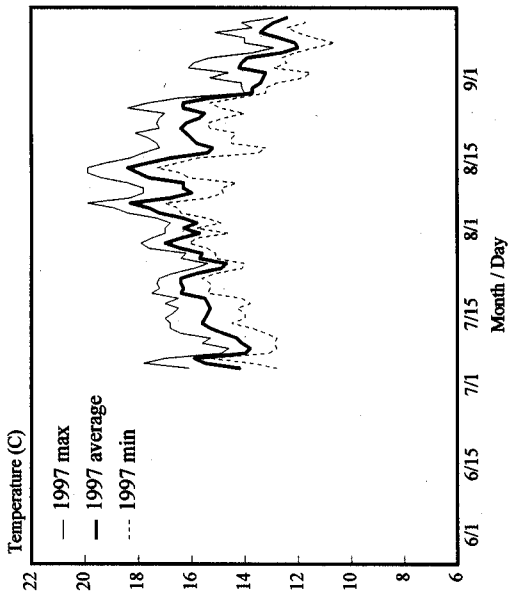


Figure 6. Water temperatures recorded at the Blackpine (control reach) and Gratton's Camp sites of the Mesilinka River, and in the Nation River during summers 1992-97. Dark line on x-axis of Gratton's Camp graph indicates approx. time of 1994-99 liquid fertilizer application. NOTE: Nation River graphs on different scale.

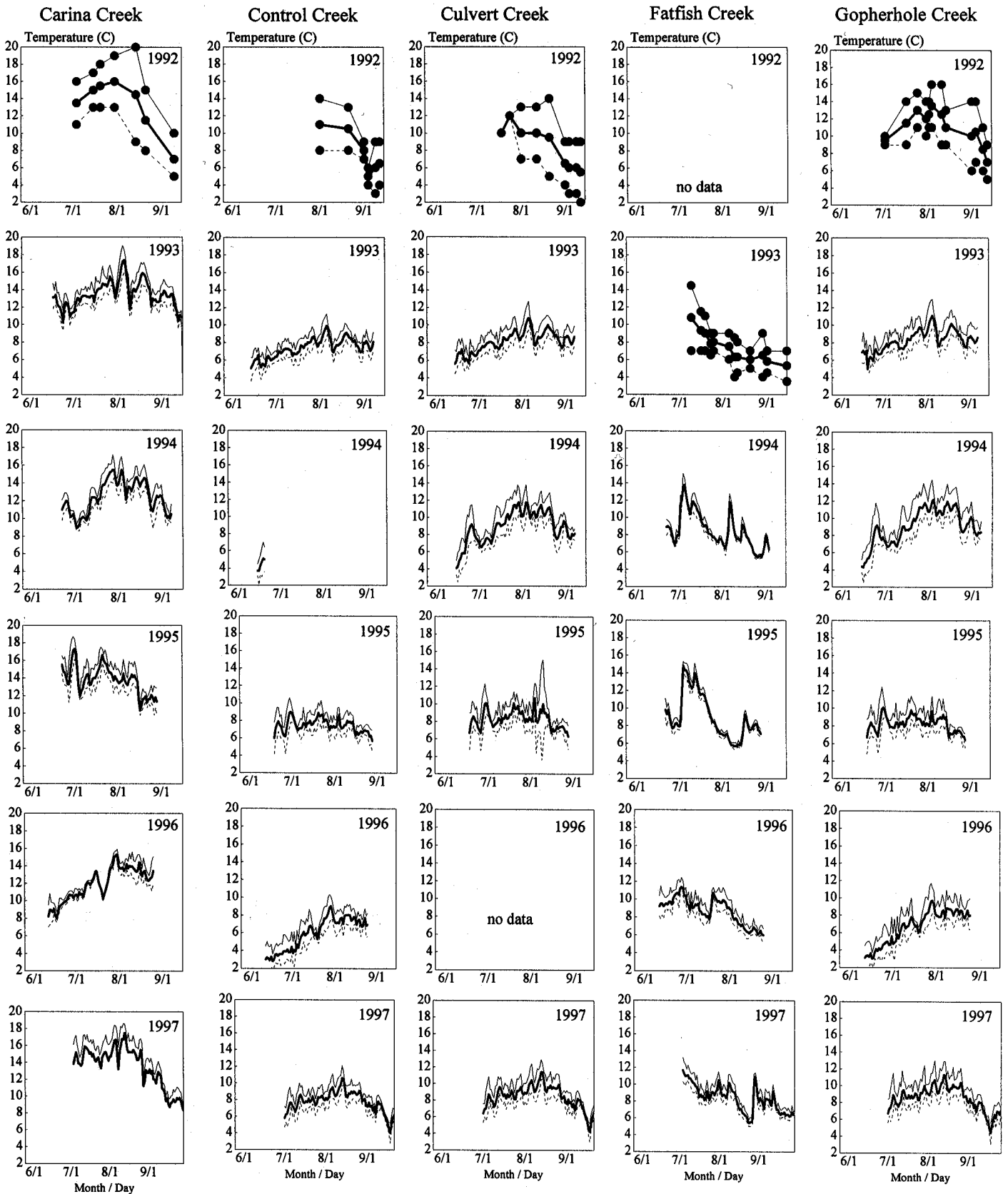


Figure 7. Daily average, maximum and minimum water temperatures recorded in tributaries to the Mesilinka River during summers, 1992-97.

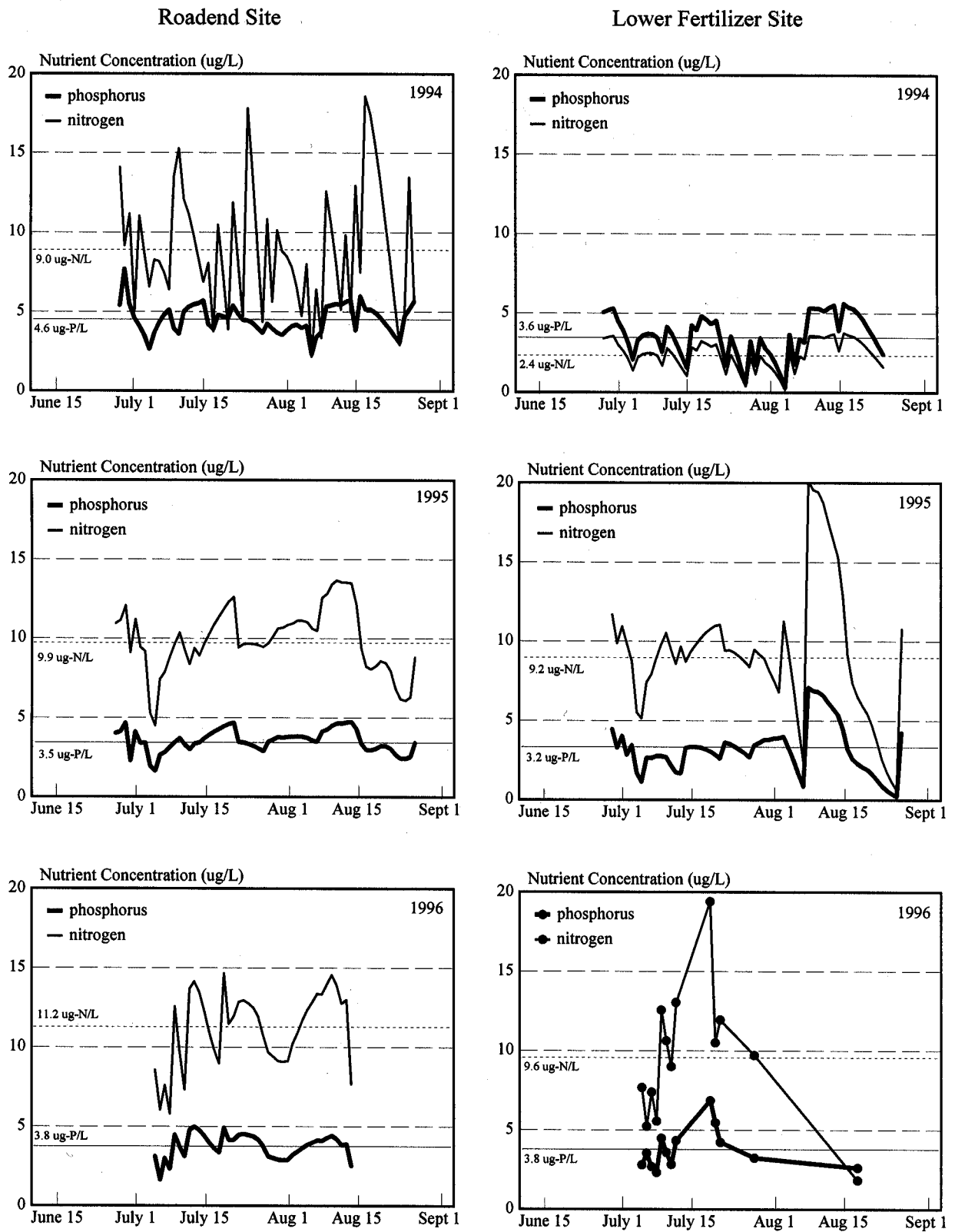


Figure 8. Estimated daily loading rates of fertilizer (phosphorus and nitrogen) added to the Mesilinka River at the Roadend (T1 reach) and Lower Fertilizer (T2 reach) sites during summer 1994-96. Daily values unavailable for the lower fertilizer site in 1996. Horizontal lines indicate average values.

Roadend Site

Lower Fertilizer Site

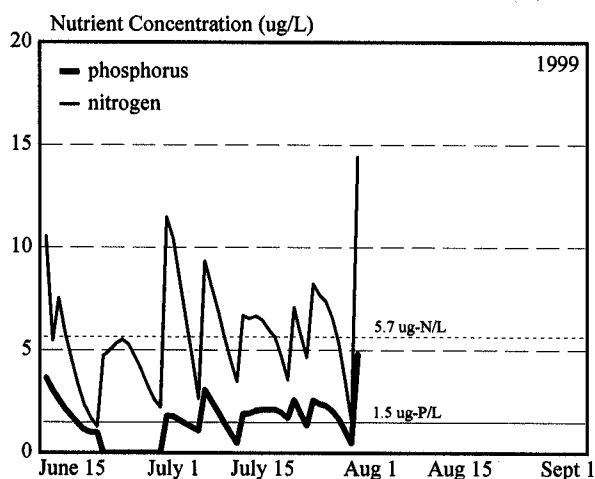
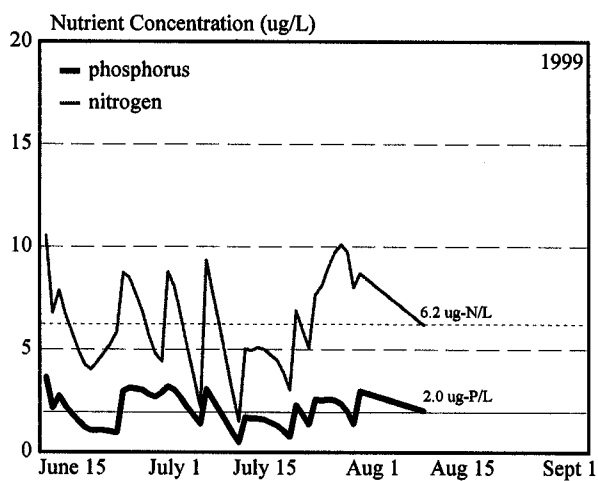
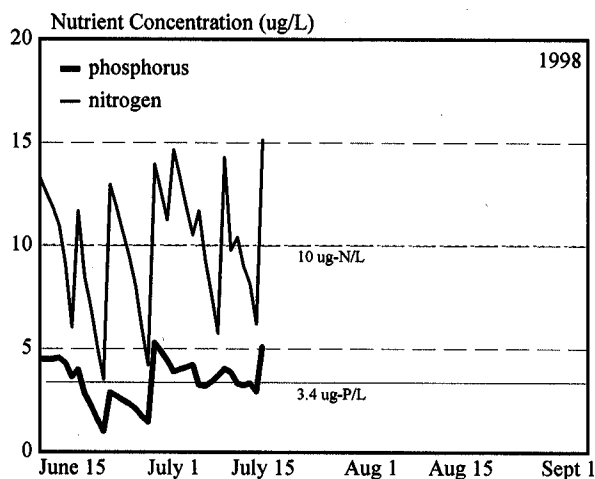
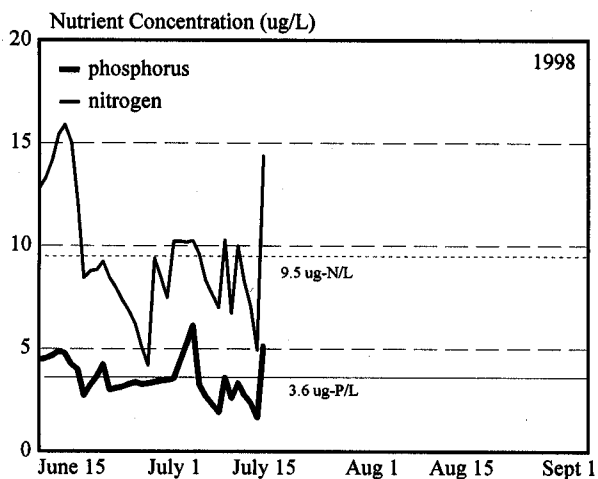
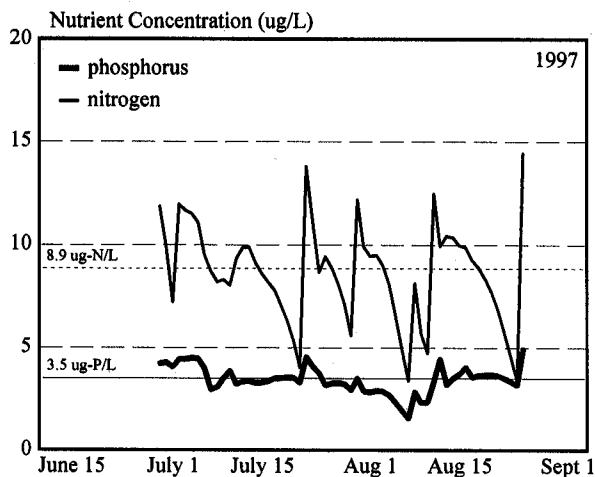
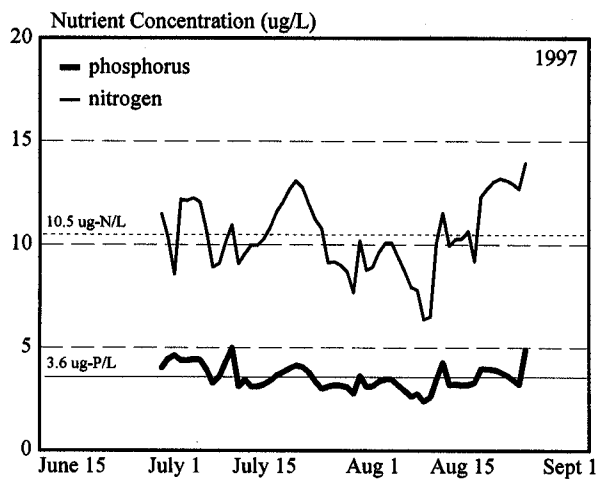


Figure 9. Estimated daily loading rates of fertilizer (phosphorus and nitrogen) added to the Mesilinka River at the Roadend (T1 reach) and Lower Fertilizer (T2 reach) sites during summer 1997-99. horizontal lines indicate average values.

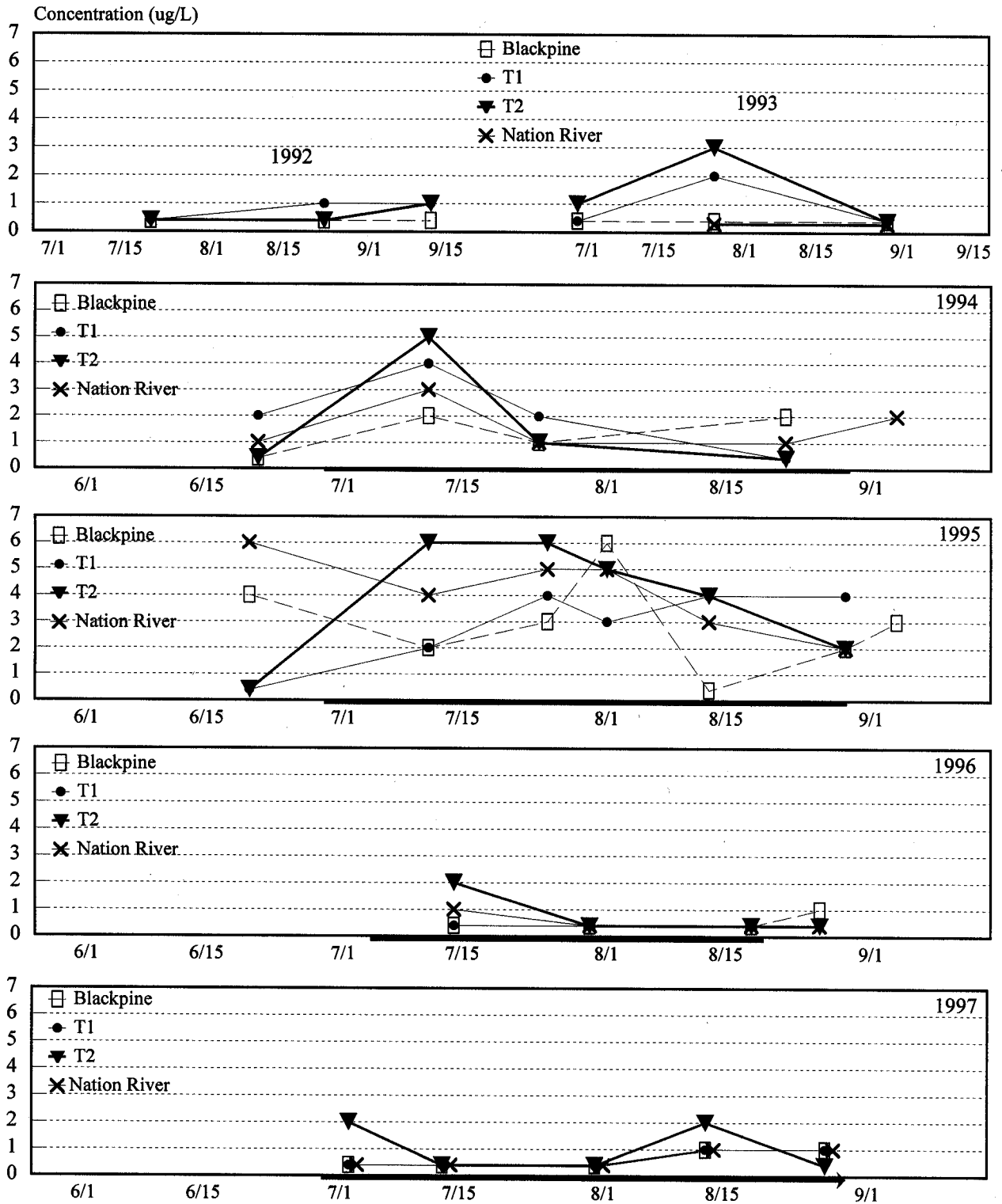


Figure 10. Soluble reactive phosphorus concentrations measured in the control, T1 and T2 reaches of the Mesilinka River, and in the Nation River during the summers of 1992-97. Determinations made below the detection limit are shown at half the detection limit value of 1 $\mu\text{g/L}$. Dark lines on x-axes indicate approximate time of liquid fertilizer application to the T1 and T2 reaches.

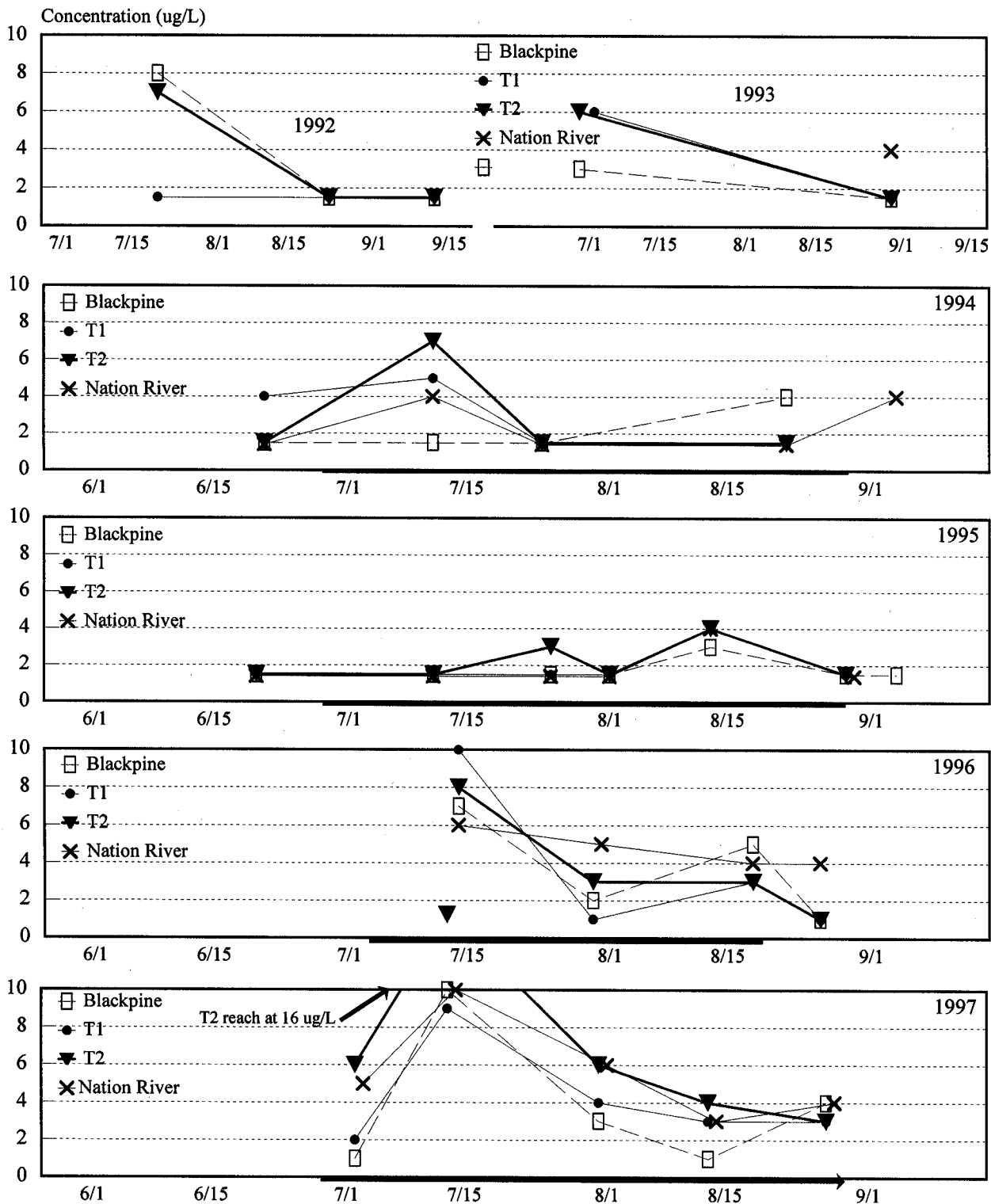


Figure 11. Total dissolved phosphorus concentrations measured in the control, T1 and T2 reaches of the Mesilinka River, and in the Nation River, during the summers of 1992-97. Determinations made below the detection limit are shown at half the detection limit value of 3 ug/L for 1992-95 data, and 2 ug/L for 1996-97 data. Dark lines on x-axes indicate approximate time of liquid fertilizer application to the T1 and T2 reaches.

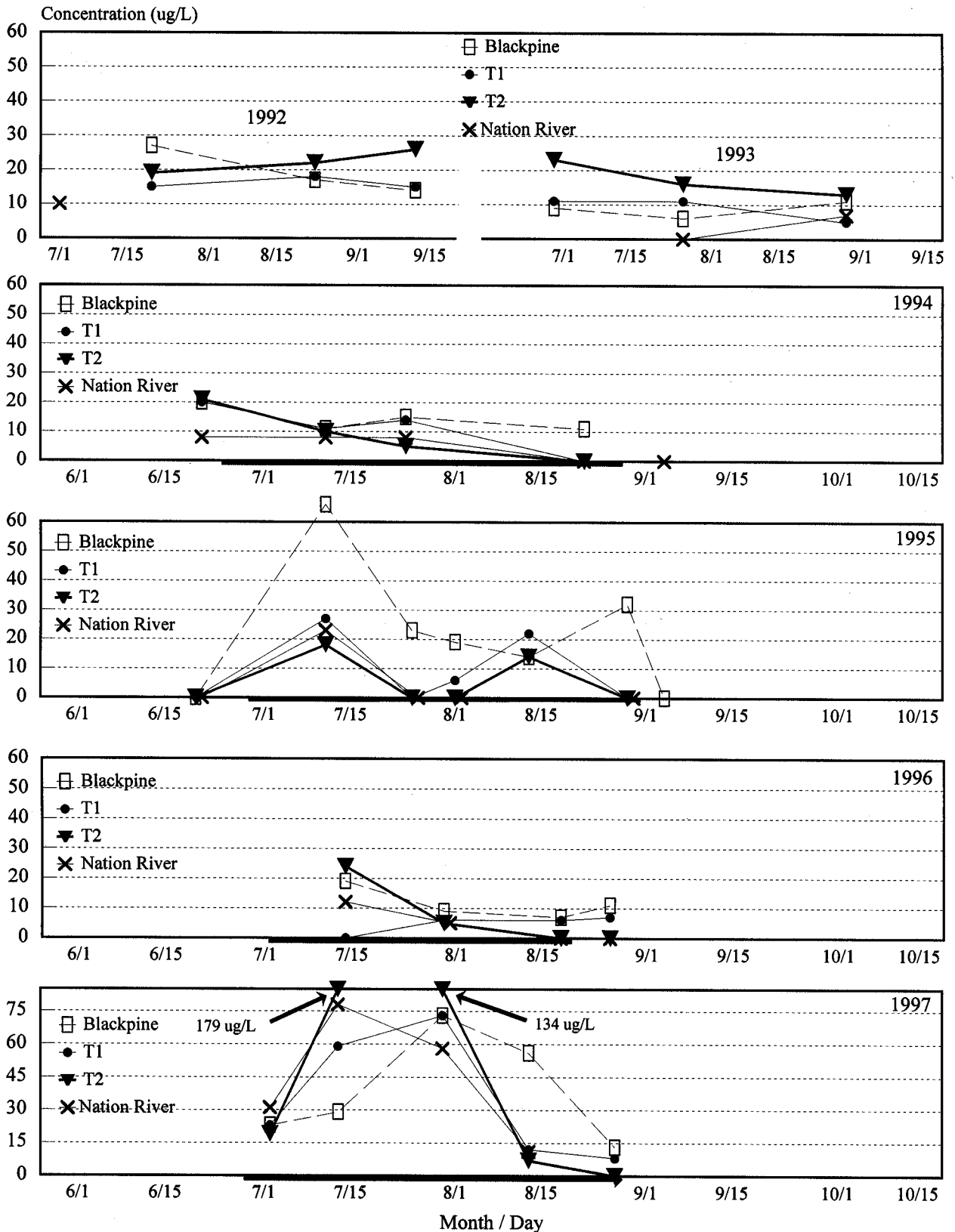


Figure 12. Nitrate+nitrite-nitrogen concentrations measured in the control, T1 and T2 reaches of the Mesilinka River, and in the Nation River, during the summers of 1992-97. Determinations made below the detection limit are shown at 0 ug/L for 1992-95 data, and 2 ug/L for 1996-97 data. Dark lines on x-axes indicate approximate time of liquid fertilizer application to the T1 and T2 reaches.

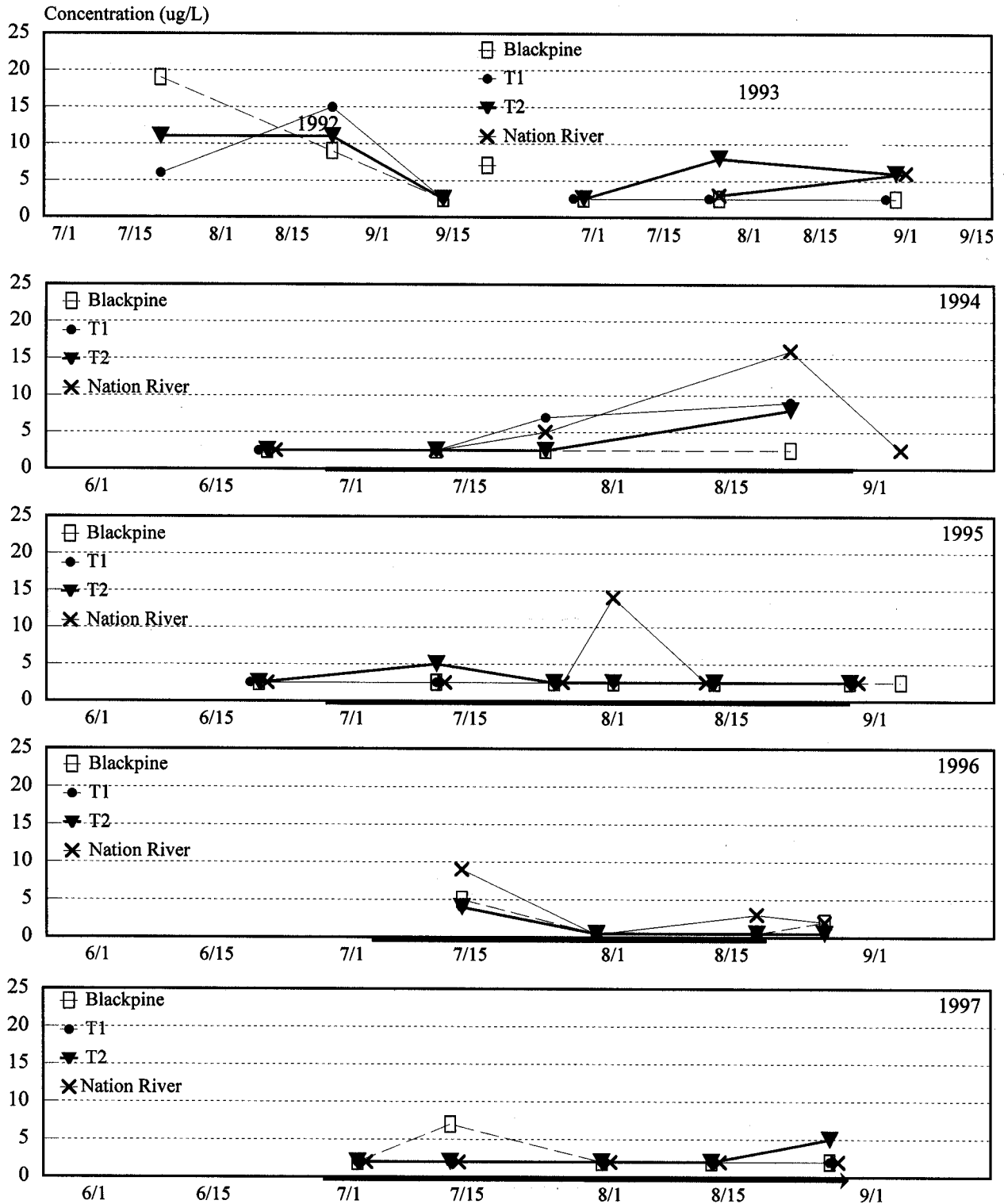


Figure 13. Ammonia-nitrogen concentrations measured in the control, T1 and T2 reaches of the Mesilinka River, and in the Nation River, during the summers of 1992-97. Determinations made below the detection limit are shown at half the detection limit value of 5 ug/L for 1992-95 data, and 2 ug/L for 1996-97 data. Dark lines on x-axes indicate approximate time of liquid fertilizer addition to the T1 and T2 reaches.

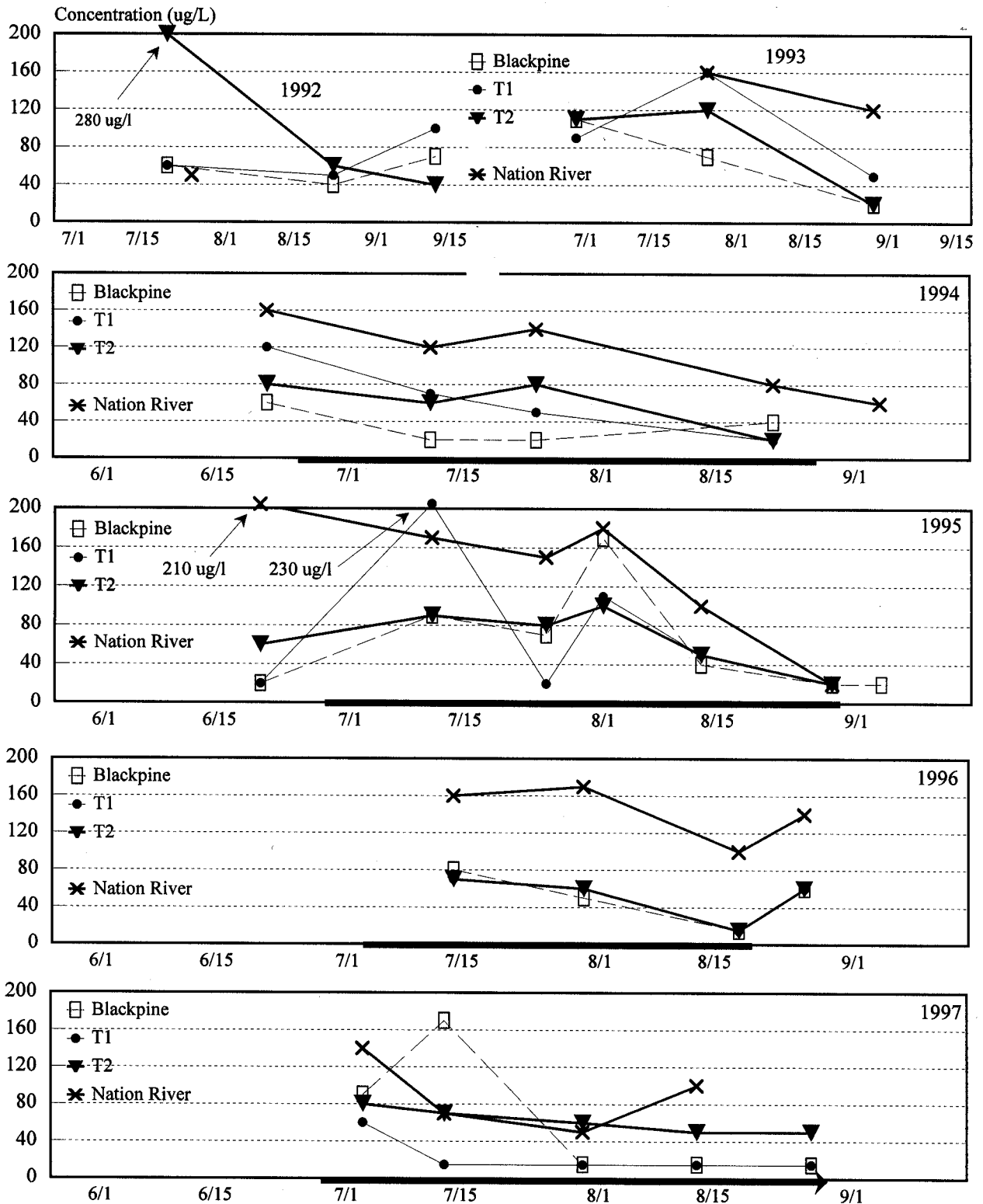


Figure 14. Total organic nitrogen concentrations measured in the control, T1 and T2 reaches of the Mesilinka River, and in the Nation River, during the summers of 1992-97. Determinations made below the detection limit are shown at half the detection limit value of 40 ug/L. Dark lines on x-axes indicate approximate time of liquid fertilizer application to the T1 and T2 reaches.

Mesilinka River

Nation River

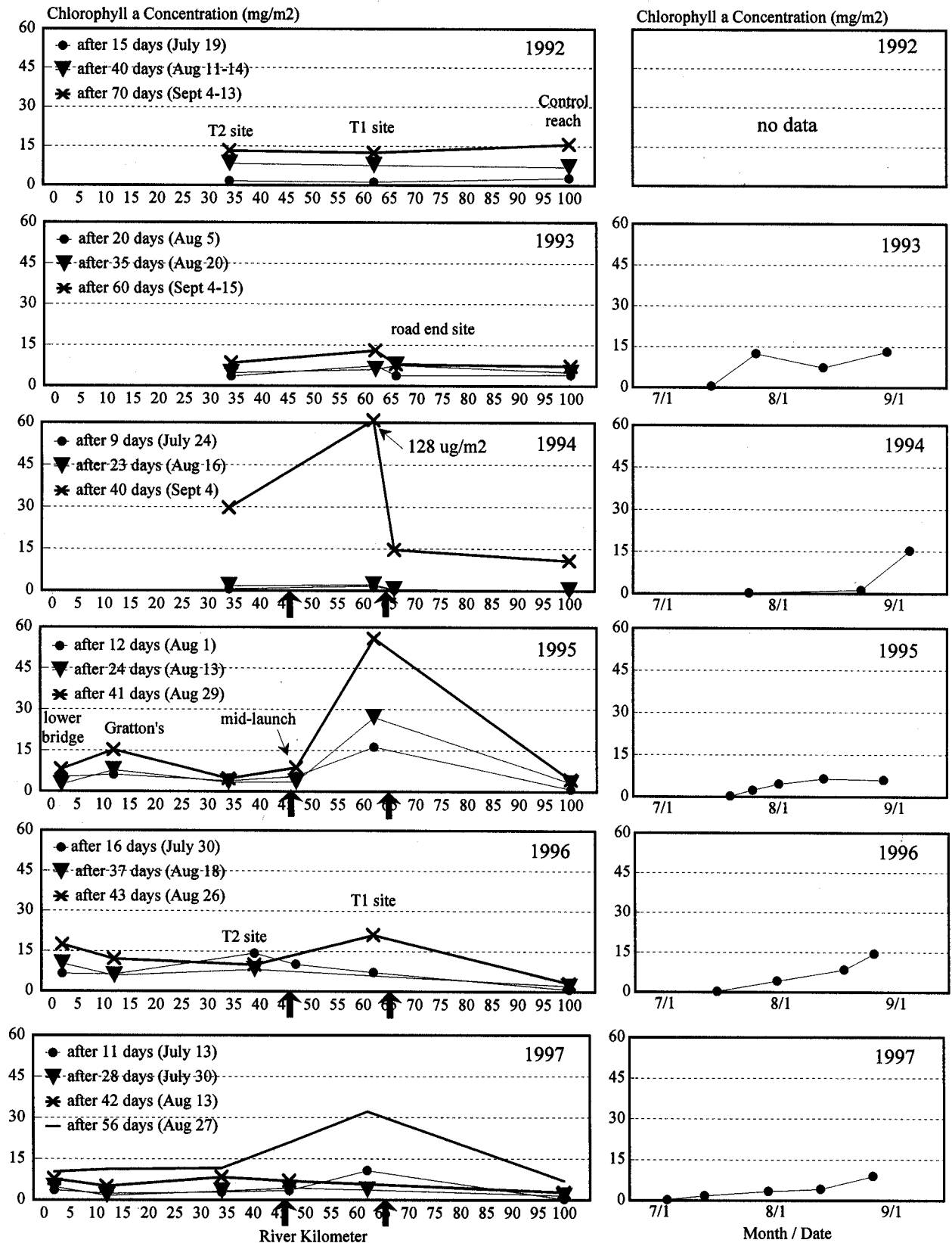


Figure 15. Chlorophyll a concentrations on artificial substrate measured at different sites (river kilometers) in the Mesilinka River, after different numbers of days in the river, summers of 1992-97. Also, concentrations from the one site in the Nation River. Arrows on x-axes indicate approximate location of liquid fertilizer addition to the T1 and T2 reaches of the Mesilinka River.

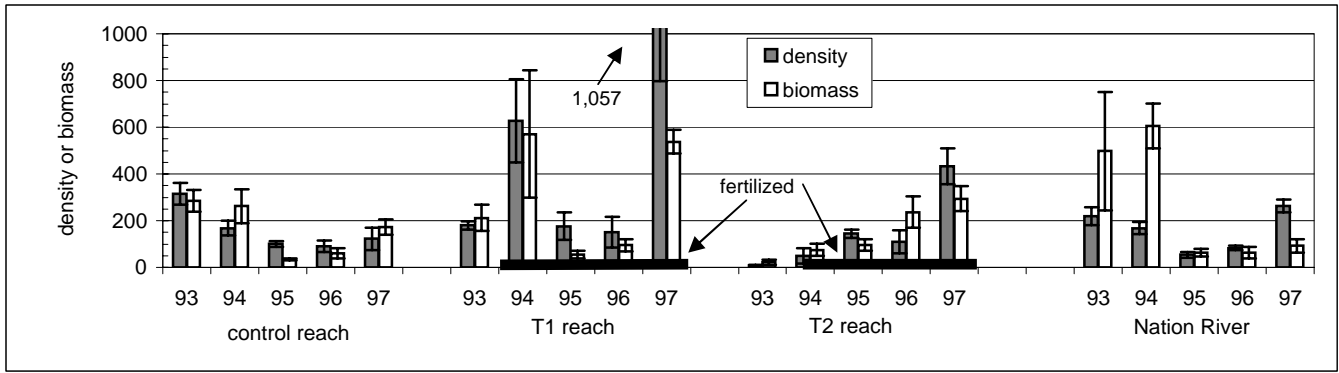


Figure 16. Benthic invertebrate density (# per 0.005 m³) and biomass (mg per 0.005 m³) measured in the three experimental reaches of the Mesilinka River and in the Nation River, summers 1993-97. Error bars are +/- SE. Note: T1 and T1 reaches were fertilized during the summers of 1993-1997.

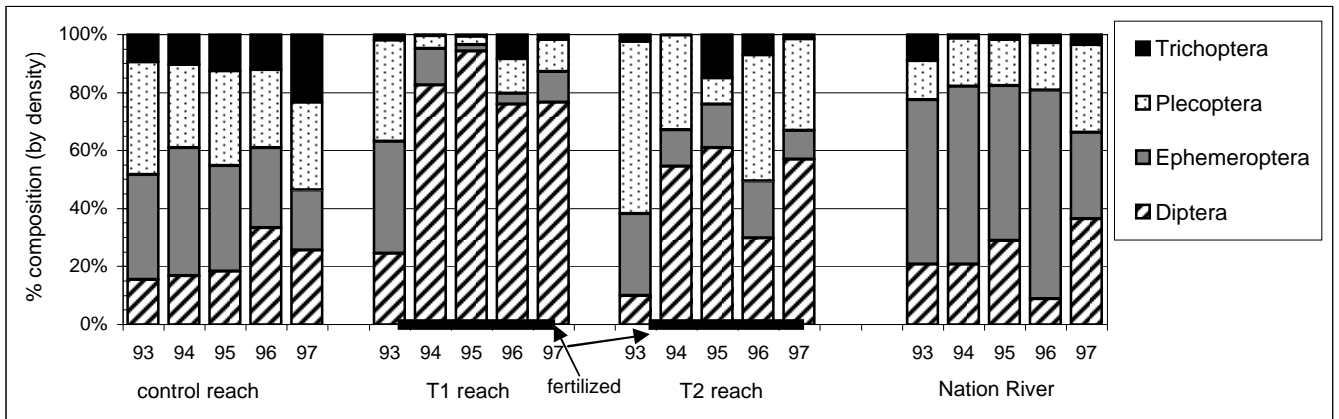


Figure 17. Ordinal composition of benthic invertebrates (by density) from the three experimental reaches of the Mesilinka River and in the Nation River, summer of 1993-97. Note: T1 and T2 reaches were fertilized during the summers of 1994-1997.

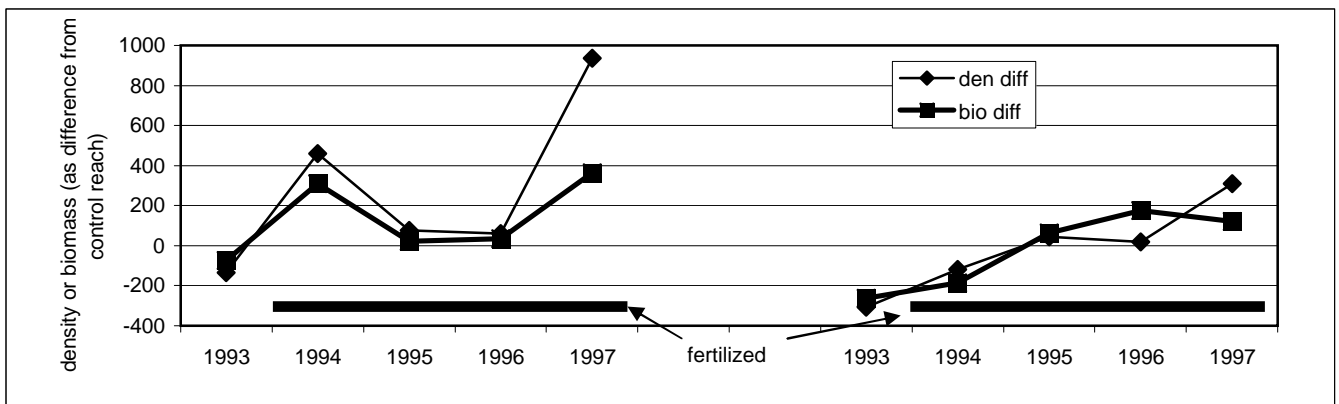


Figure 18. Benthic invertebrate density (# per 0.005 m³) and biomass (mg per 0.005 m³) in the fertilized T1 and T2 reaches of the Mesilinka River, shown as the difference from control reach values, summers 1993-97.

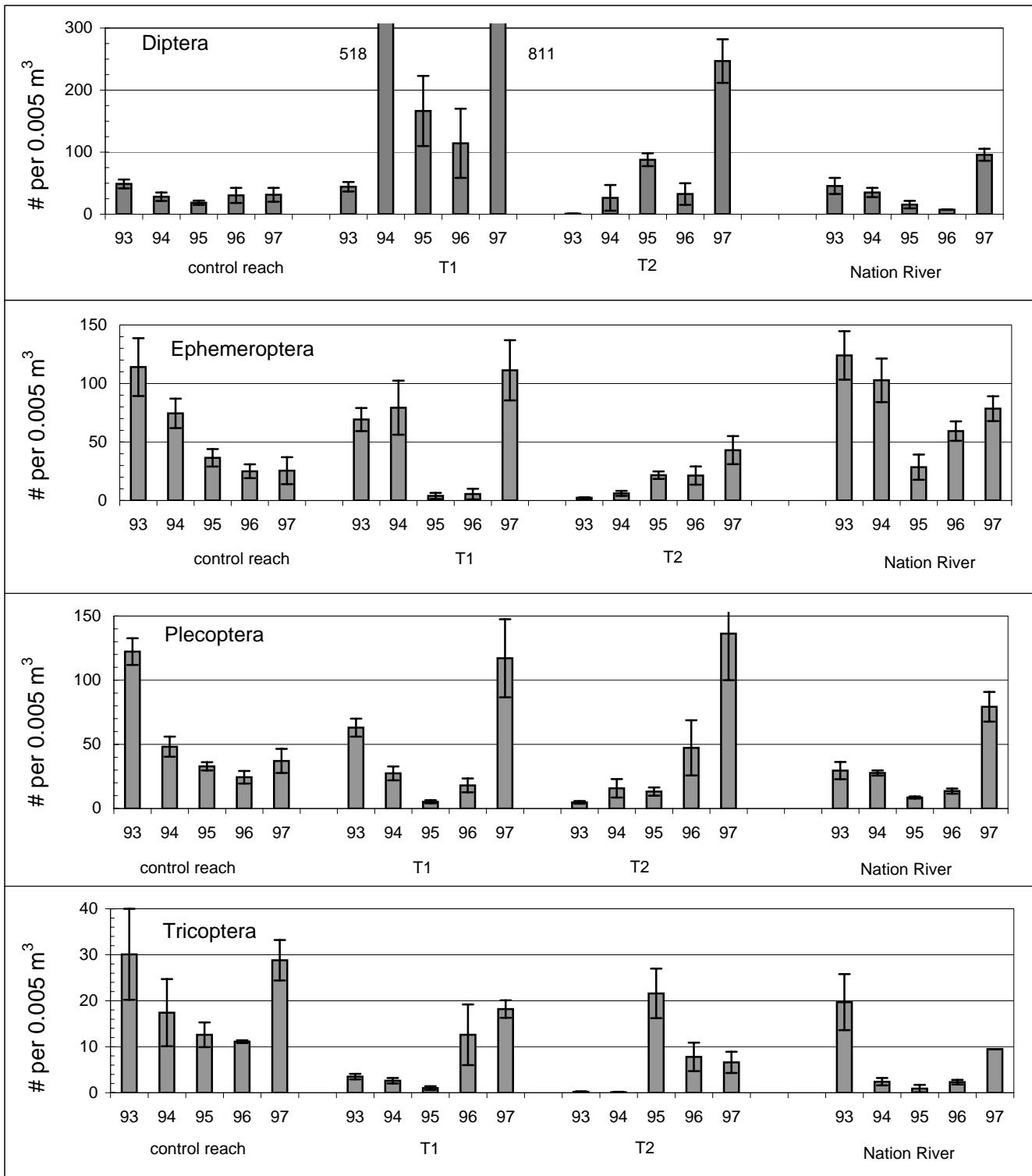


Figure 19. The density of dominant orders of benthic invertebrates in the three experimental reaches of the Mesilinka and Nation rivers during 1993-97. Error bars +/- 1 standard error of the mean. Note: T1 and T2 reaches were fertilized during the summers of 1994-97.

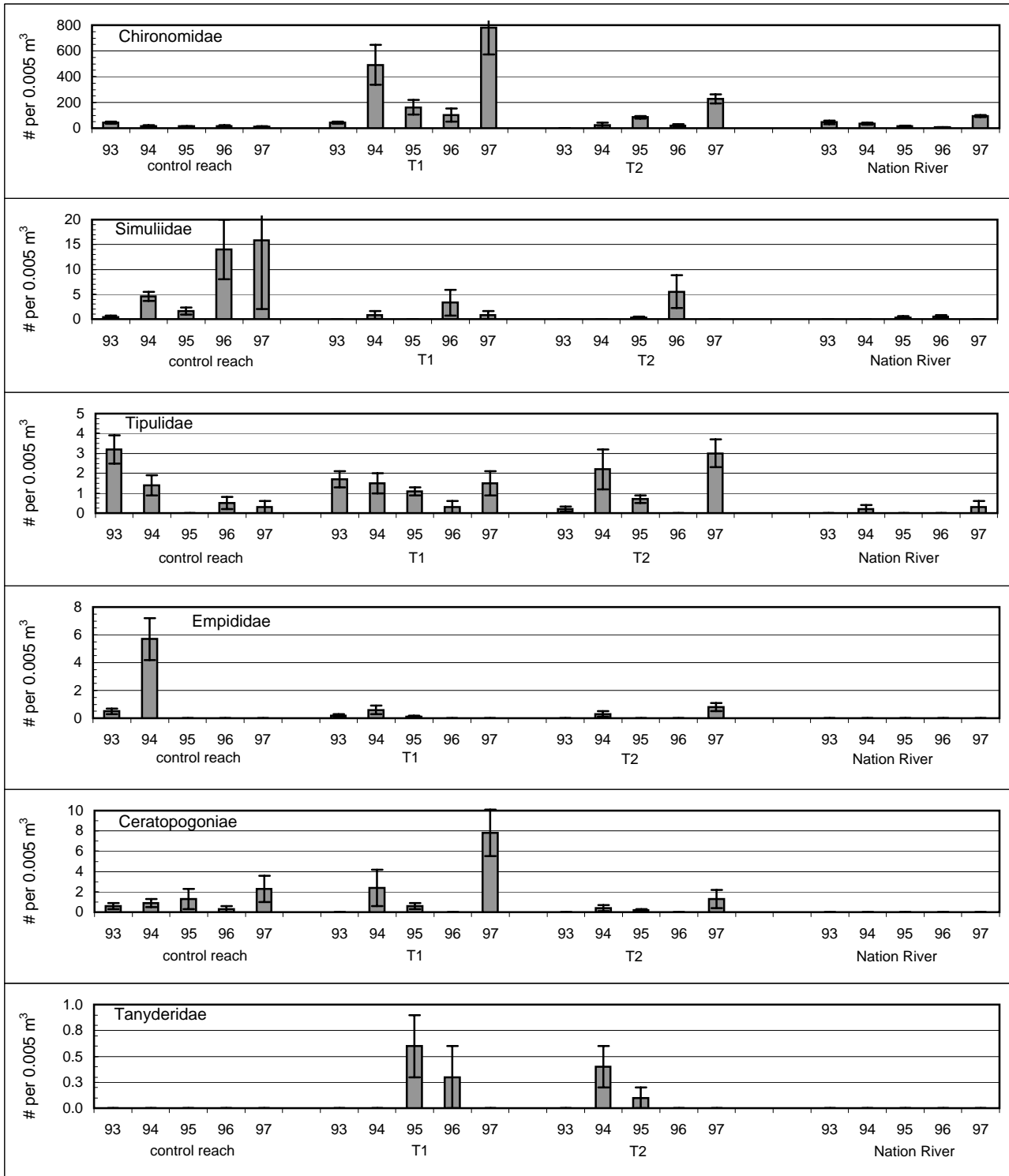


Figure 20. Density of Dipteran families identified in the three experimental reaches of the Mesilinka and Nation Rivers during 1993-97. Error bars ± 1 SE. Note: T1 and T2 reaches were fertilized during the summers of 1994-97.

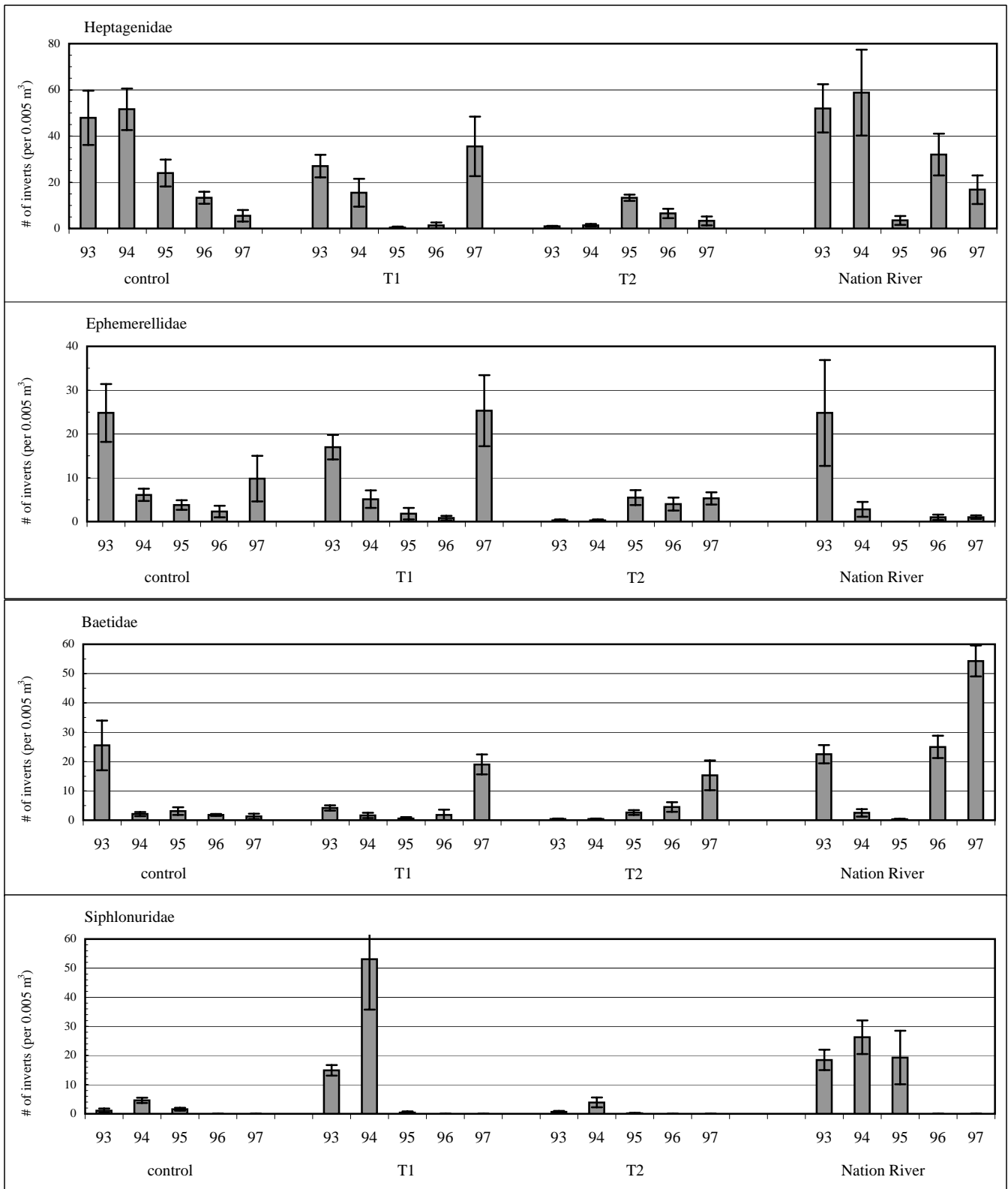


Figure 21. Density of Ephemeropteran families identified in the three experimental reaches of the Mesilinka and Nation rivers during 1993-97. Error bars +/- 1 SE. Note: T1 and T2 reaches were fertilized during the summers of 1994-97.

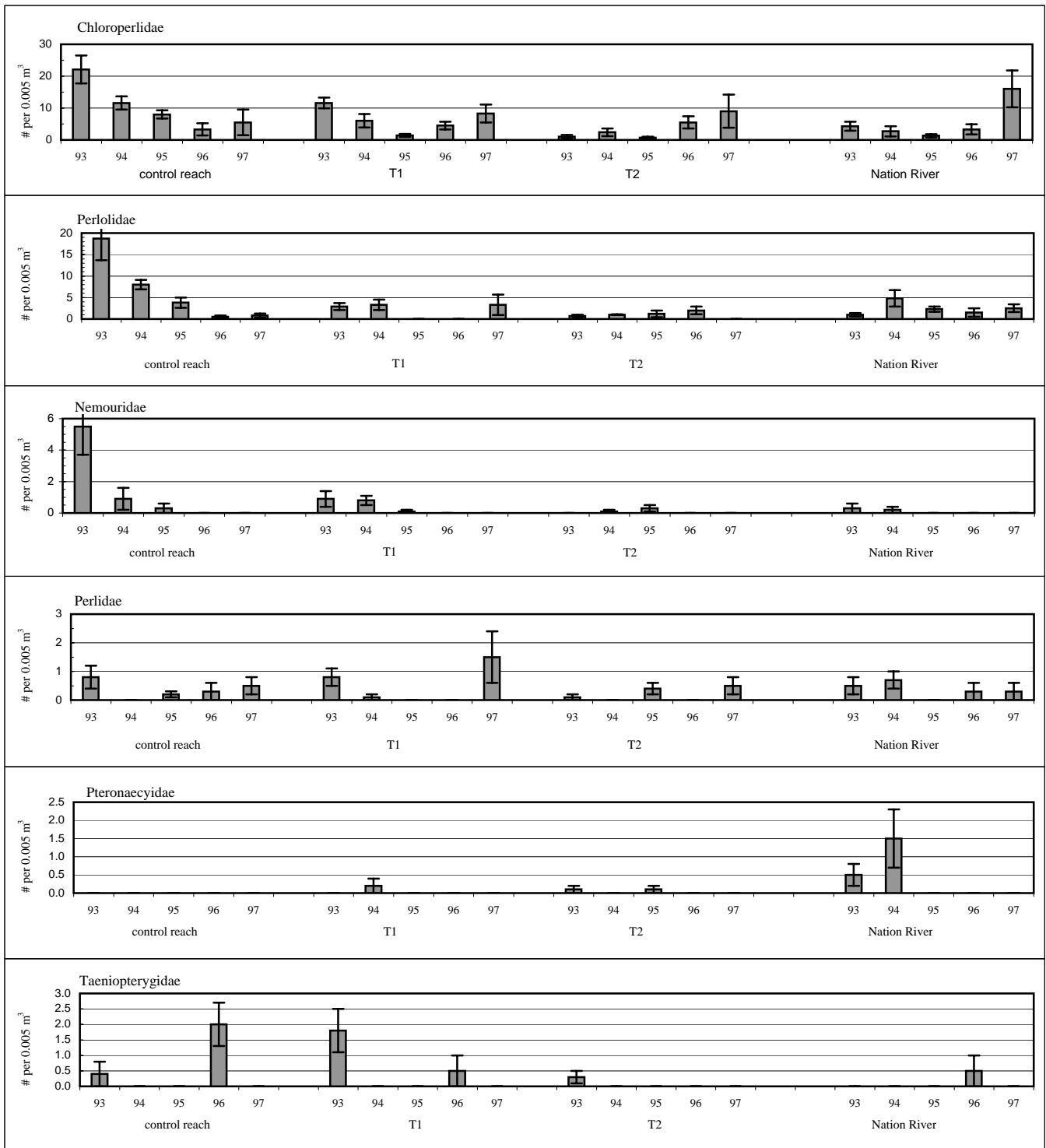


Figure 22. Density of Plecopteran families identified in the three experimental reaches of the Mesilinka and Nation rivers during 1993-97. Error bars +/- 1 SE. Note: T1 and T2 reaches were fertilized during the summers of 1994-97.

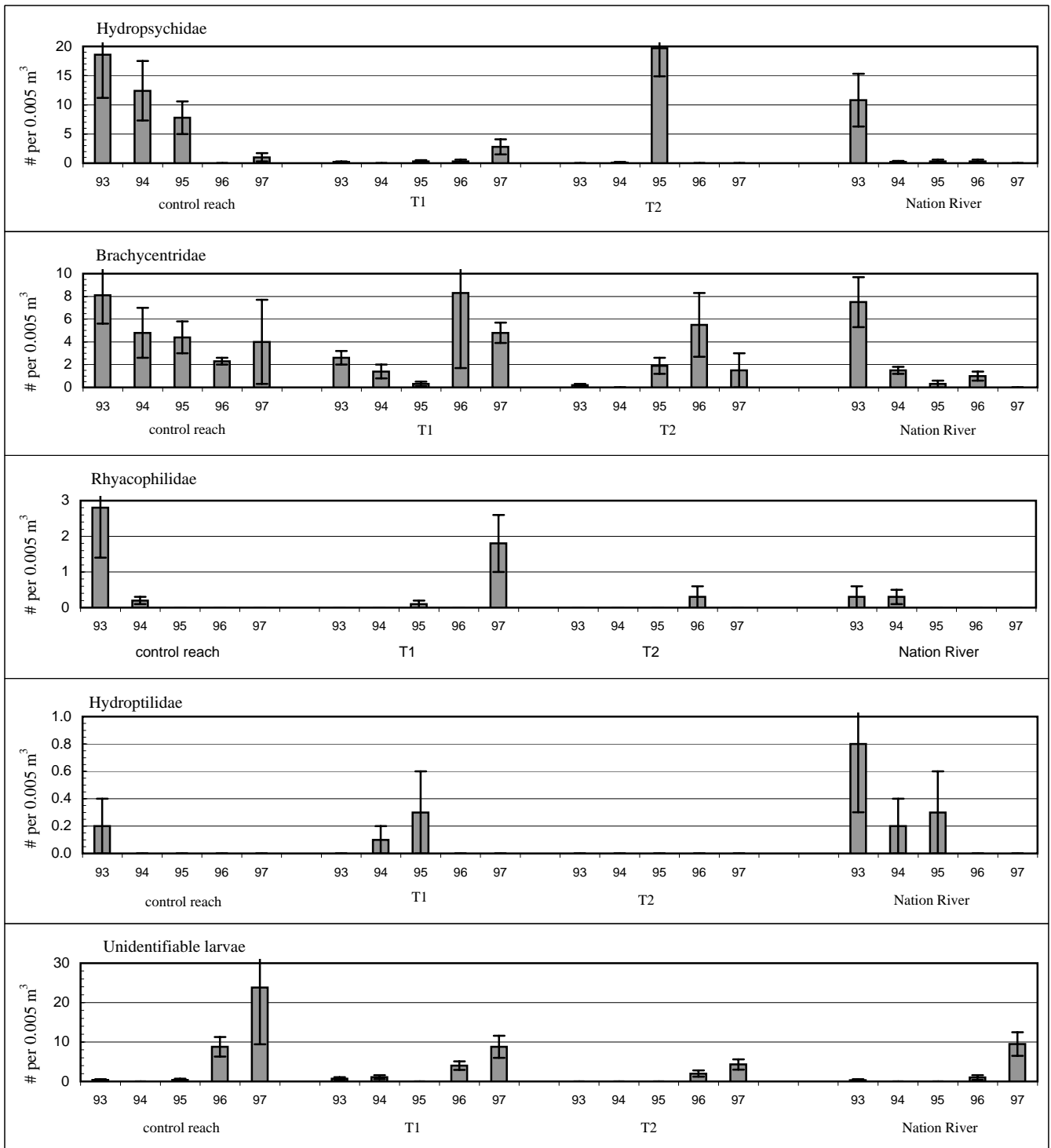


Figure 23. Density of Tricopteran families identified in the three experimental reaches of the Mesilinka and Nation rivers during 1993-97. Error bars +/- 1 SE. Note: T1 and T2 reaches were fertilized during the summers of 1994-97.

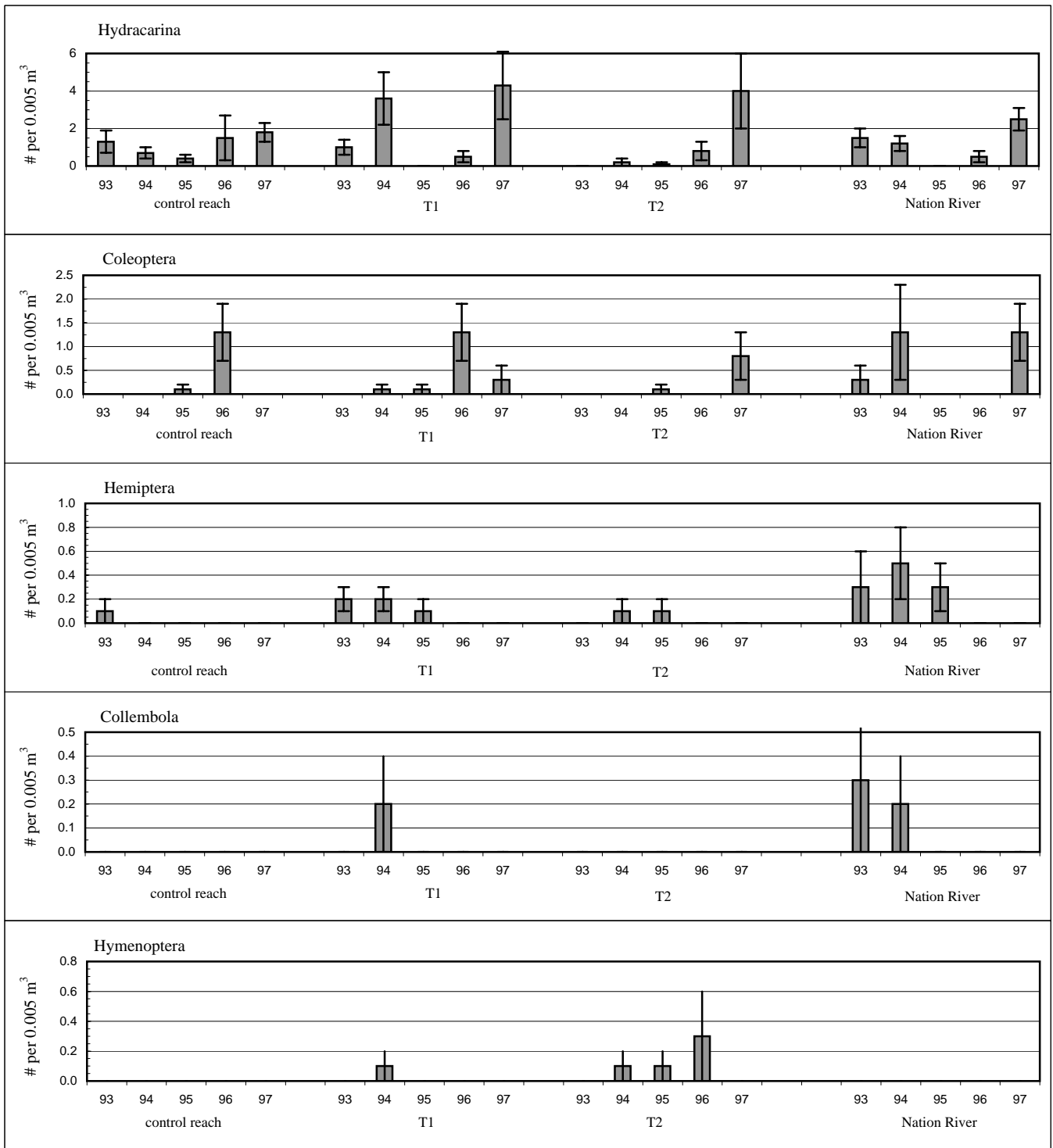


Figure 24. Density of sub-dominant benthic invertebrate orders identified in the four experimental reaches of the Mesilinka and Nation rivers during 1993-97. Error bars +/-1 standard error of the mean. Note: T1 and T2 reaches were fertilized during the summers of 1994-97.

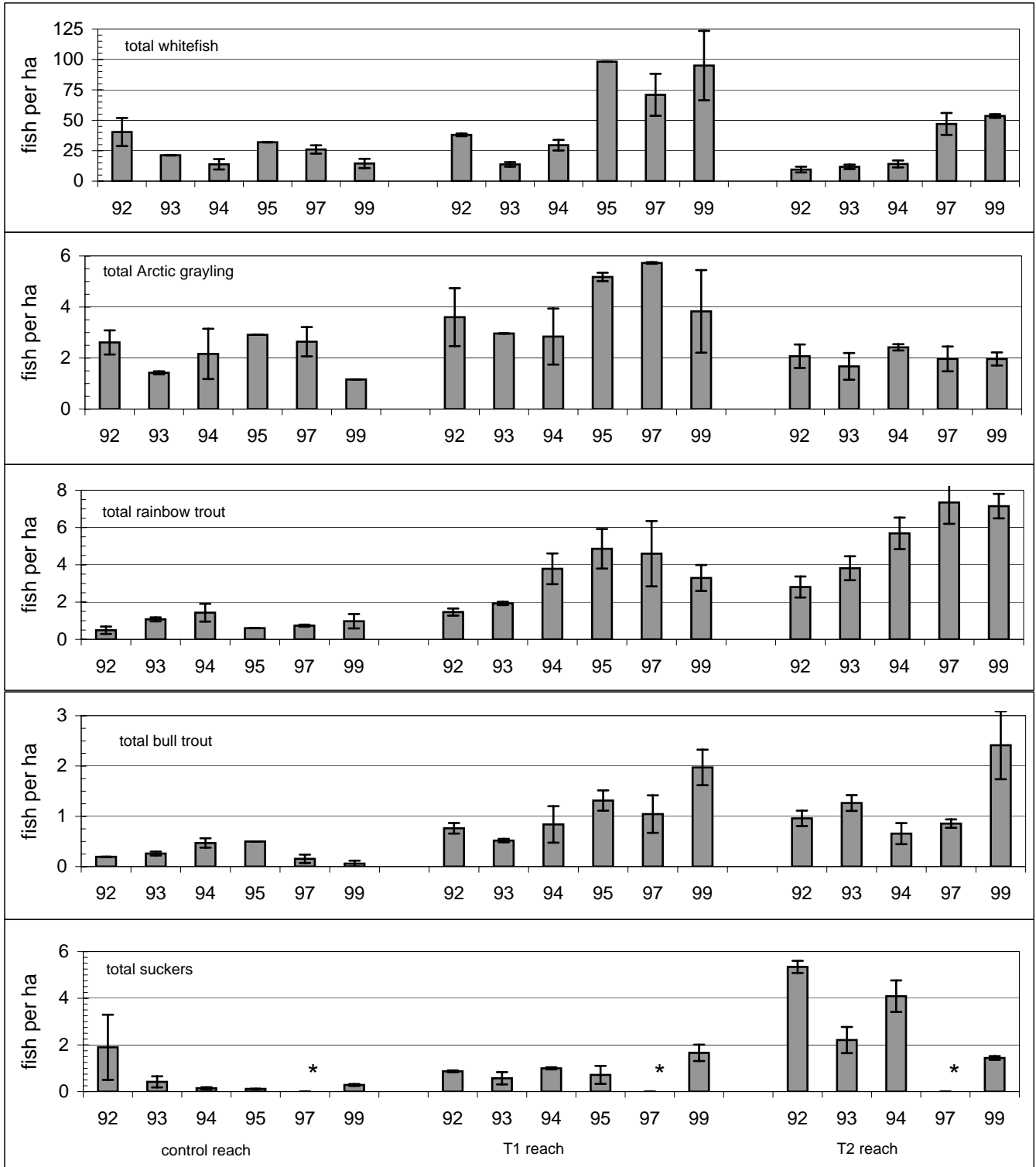


Figure 25. Density of the different fish species counted during underwater snorkel surveys of the Mesilinka River experimental reaches during Aug, 1992-99. Error bars are +/- 1 SE, and "*" indicates no data collected.

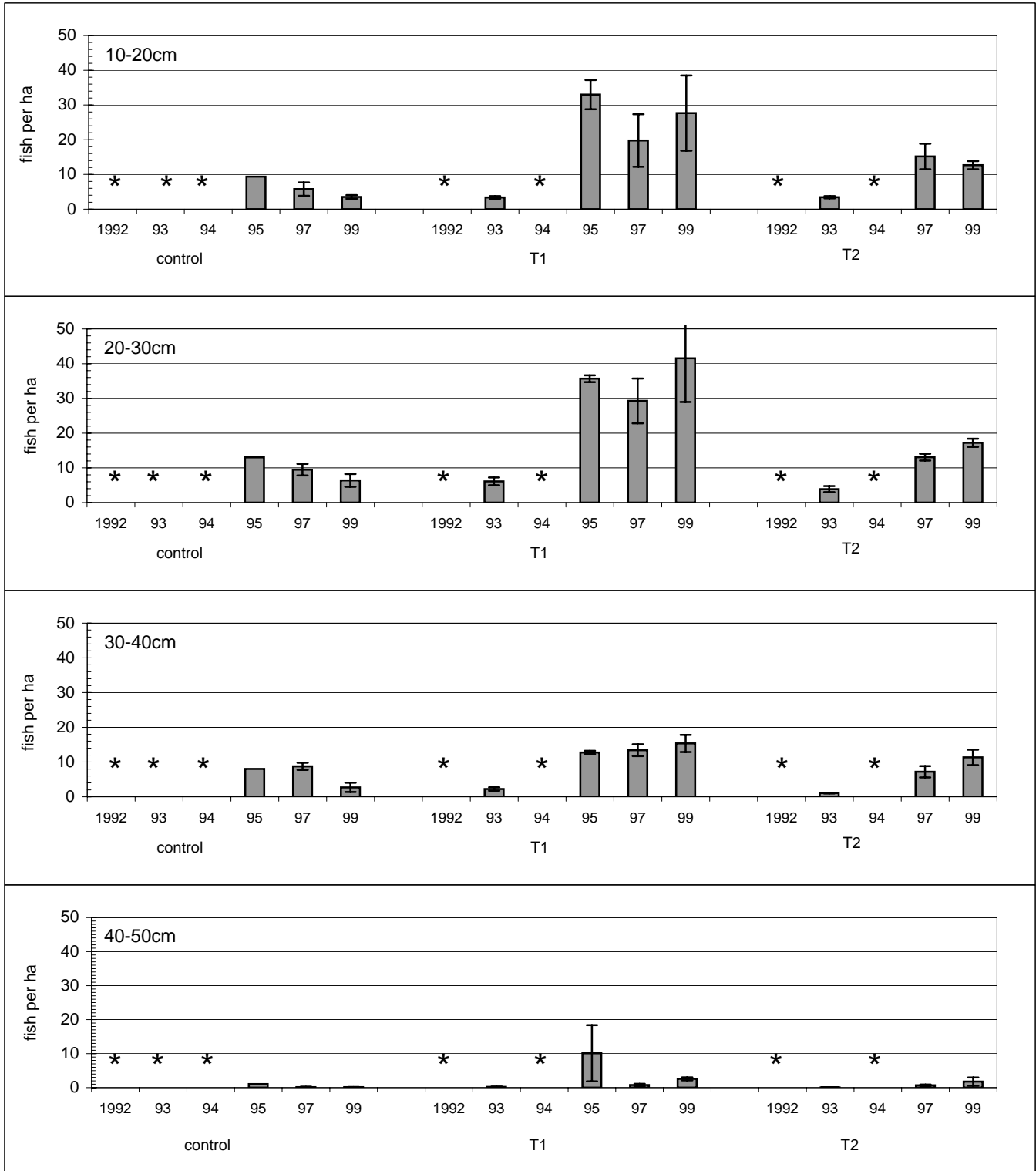


Figure 26. Mountain whitefish density in different size classes from underwater snorkel surveys of the Mesilinka River, August 1992-99. Error bars are +/- 1 SE. Note: "*" indicates no data collected.

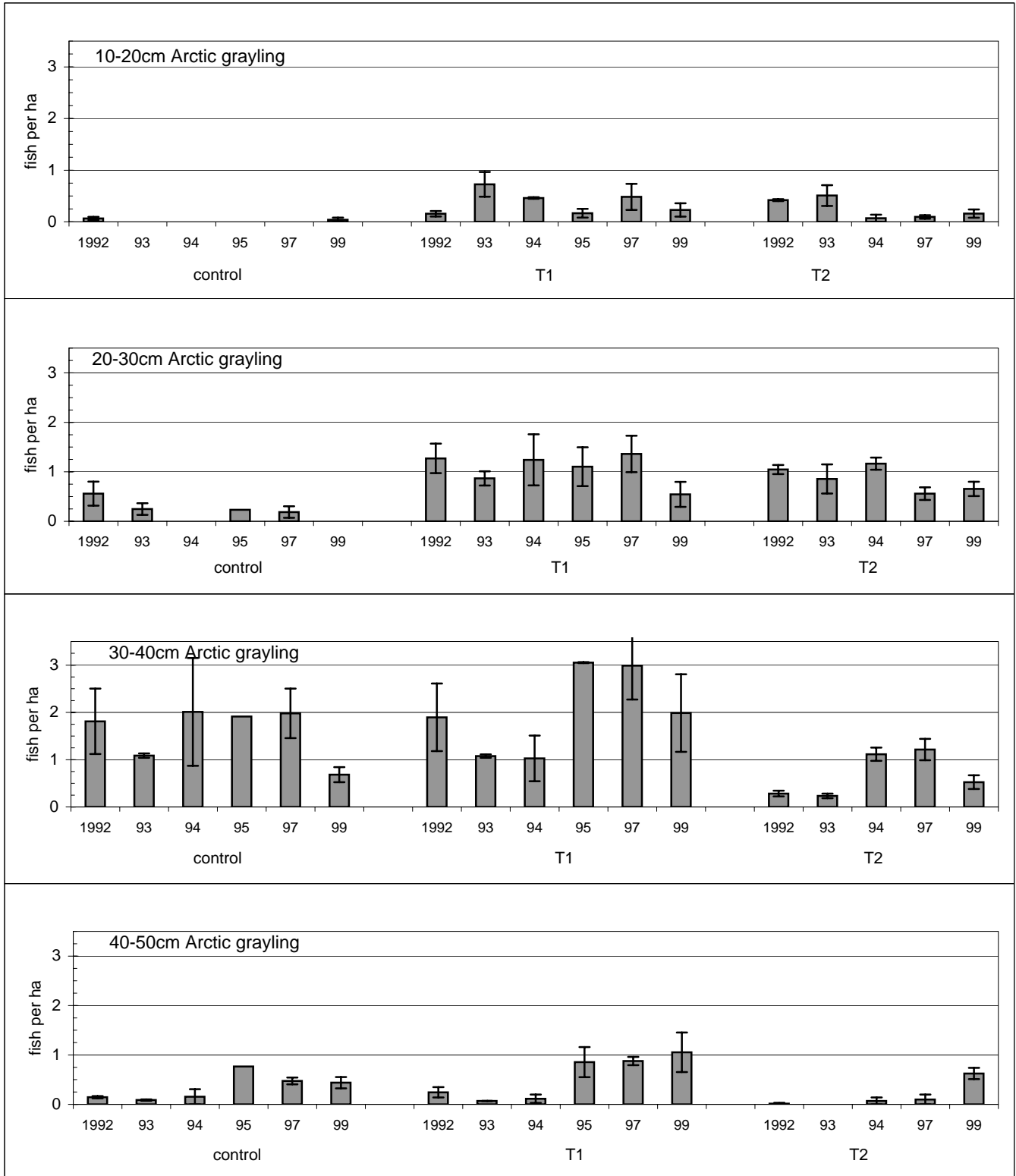


Figure 27. Arctic grayling density in different size classes from underwater snorkel surveys of the Mesilinka River, August 1992-99. Error bars are +/- 1 SE.

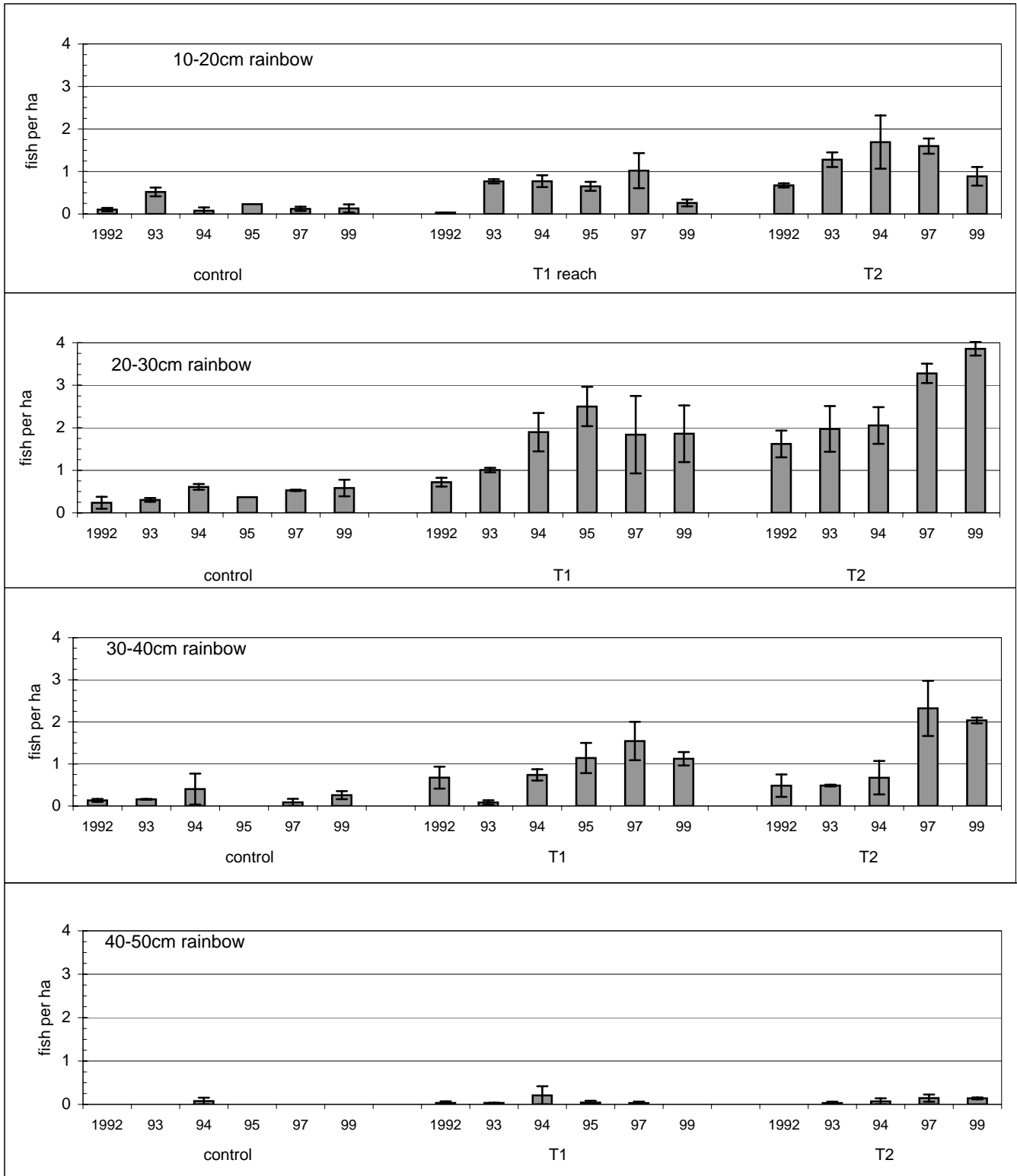


Figure 28. Rainbow trout density in different size classes from underwater snorkel surveys of the Mesilinka River, August 1992-99. Error bars are +/-1 SE.

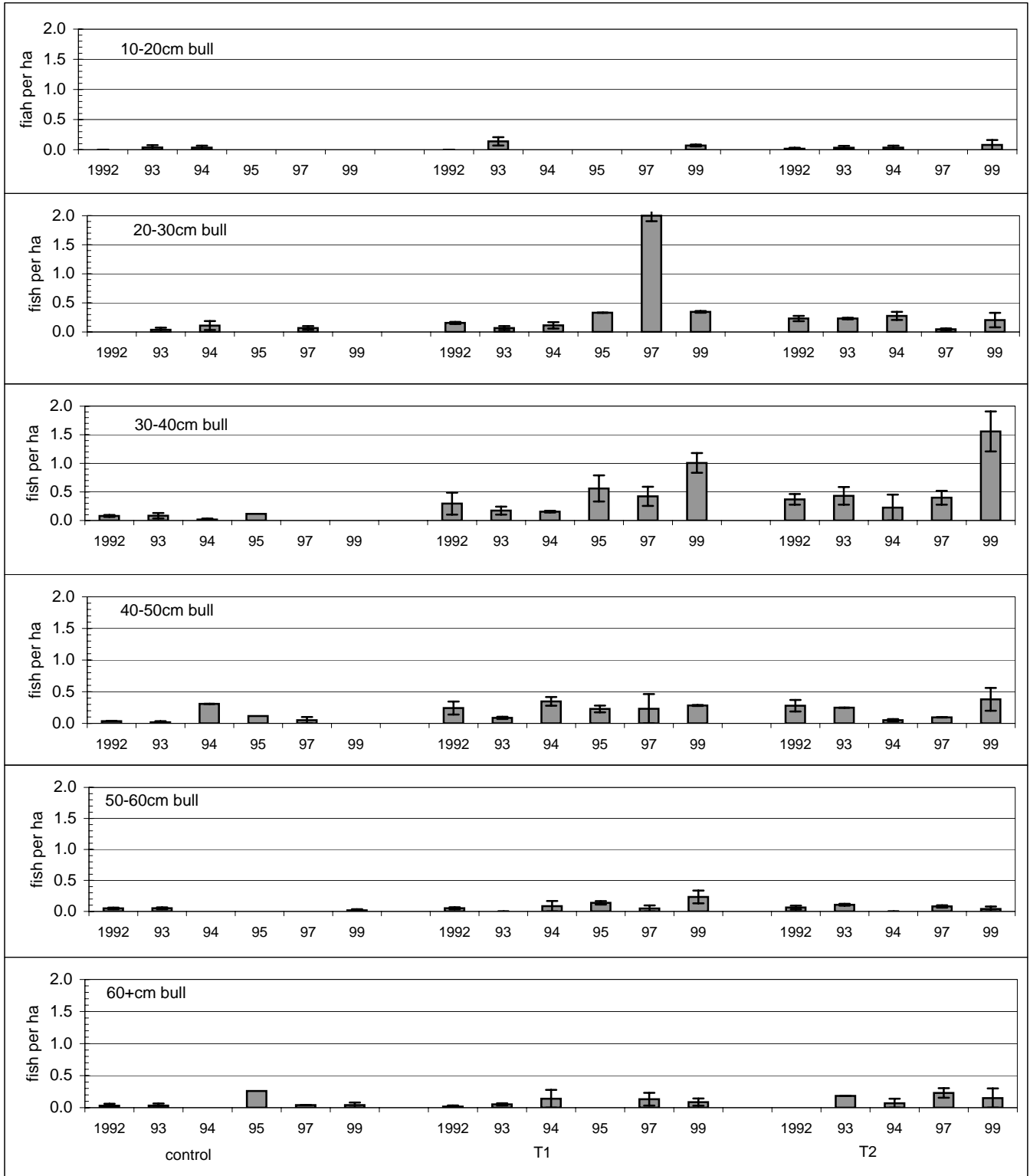


Figure 29. Bull trout density in different size classes from underwater snorkel surveys of the Mesilinka River, August 1992-99. Error bars are +/- 1 SE.

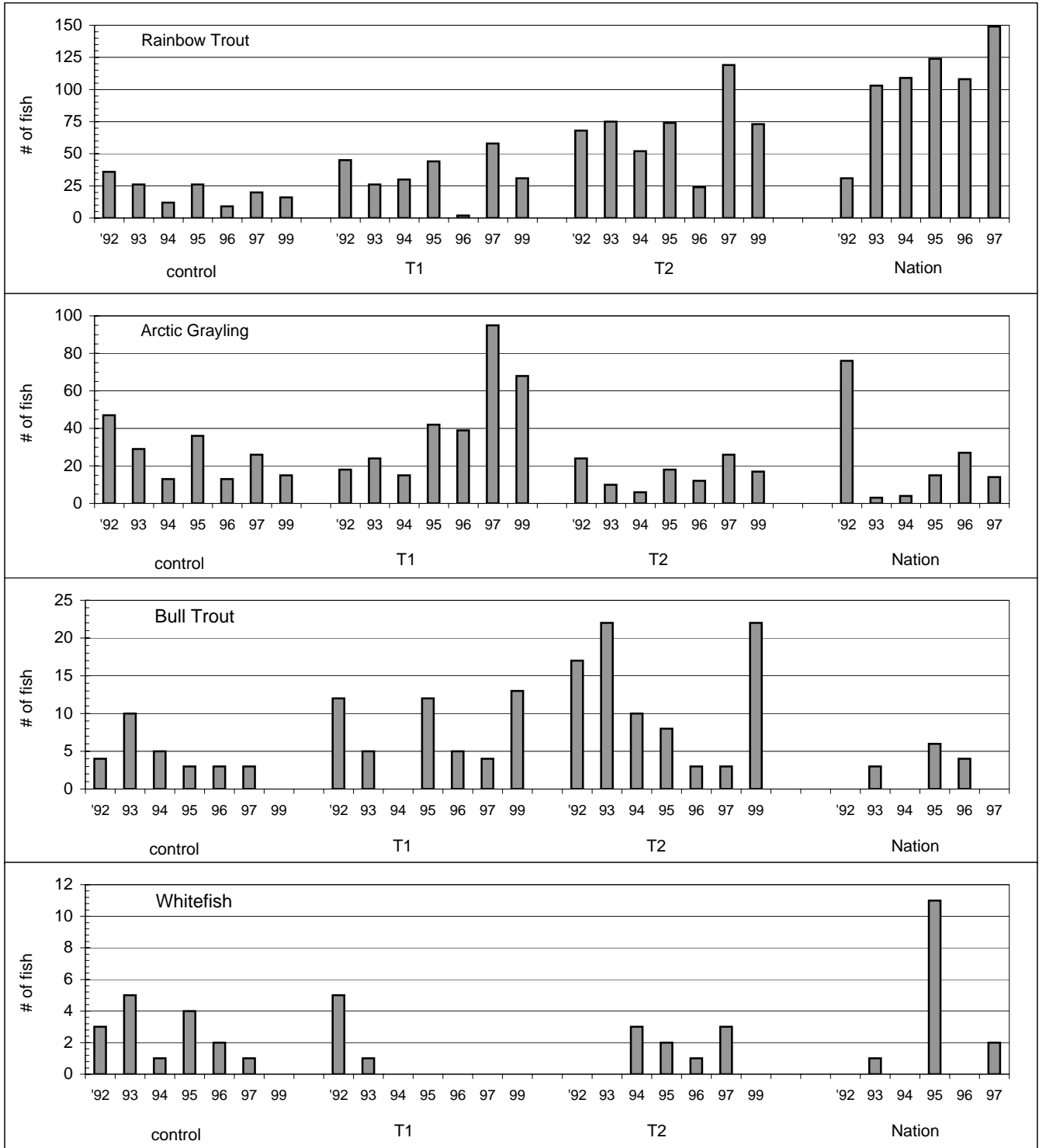


Figure 30. Total number of each species of fish captured by angling in the three reaches of the Mesilinka and Nation (no angling 1998-99) rivers, during summer 1992-99.

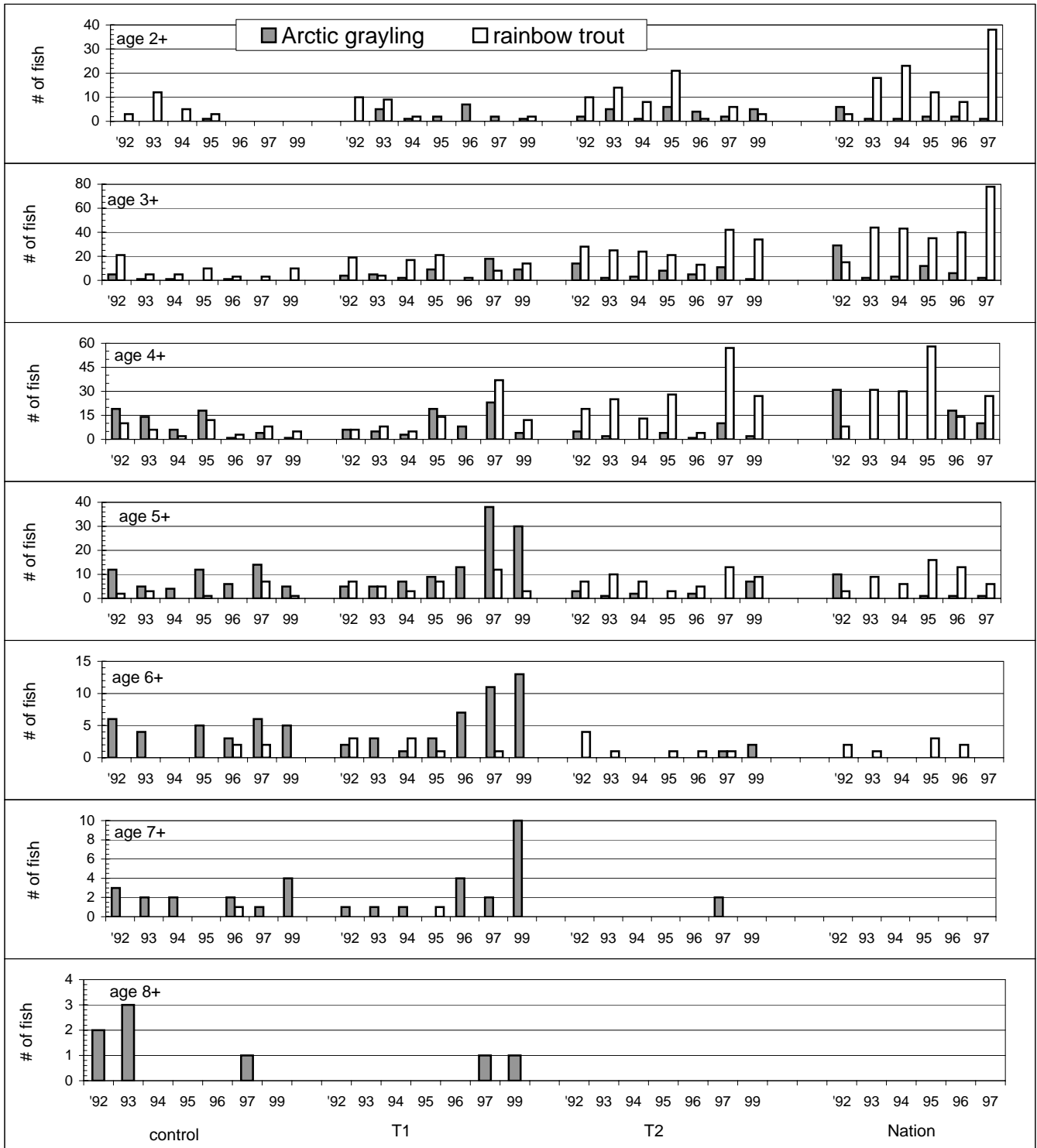


Figure 31. Number of Arctic grayling and rainbow trout angled in each age class from the three experimental reaches of the Mesilinka River, and Nation River (no angling 1998-99), during summers 1992-99.

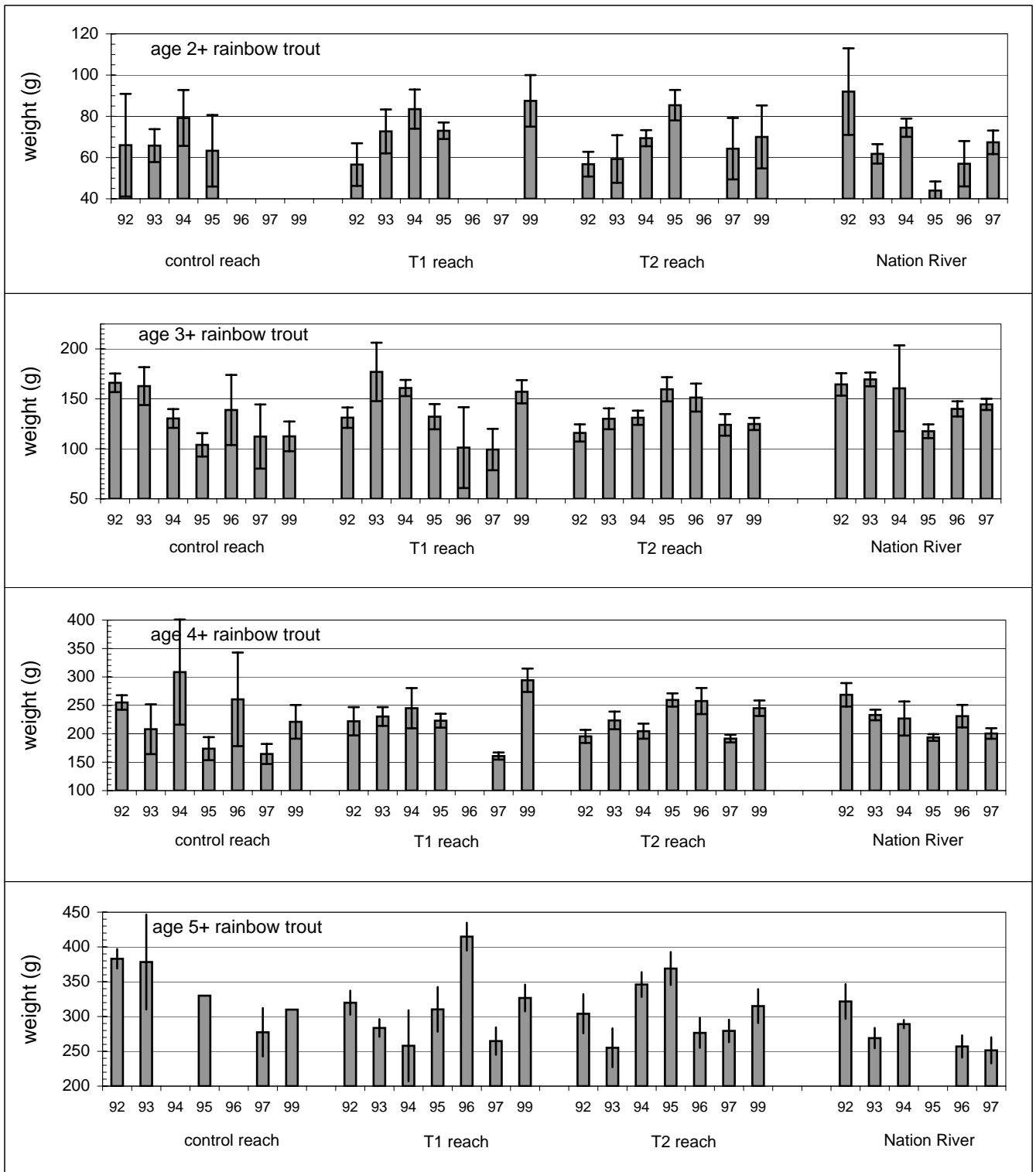


Figure 32. Average weight of age rainbow trout angled from the three experimental reaches of the Mesilinka and Nation (no angling 1998-99) rivers, during summer 1992-99. Error bars are +/- 1 SE.

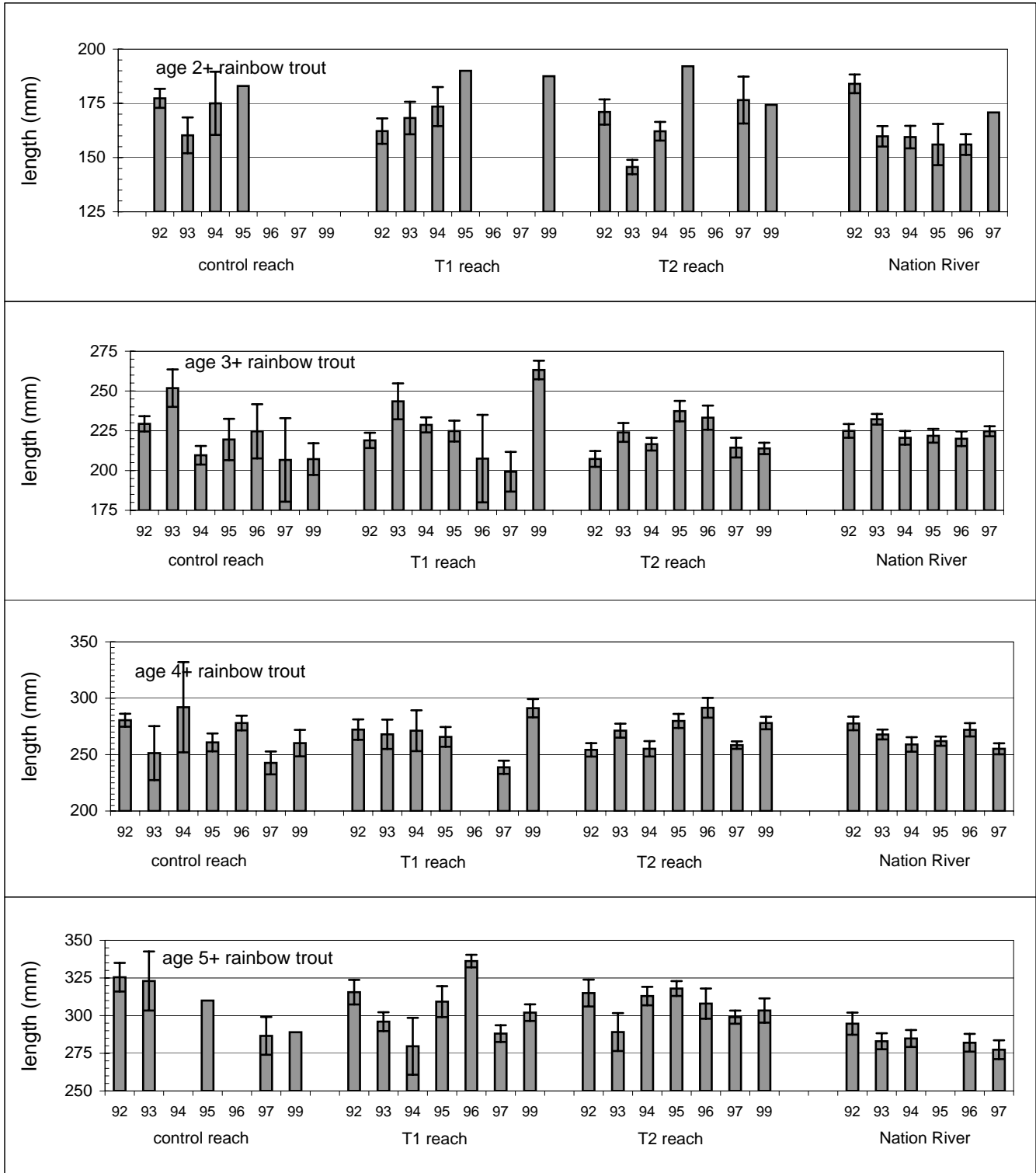


Figure 33. Average length of aged rainbow trout angled from the three experimental reaches of the Mesilinka and Nation (no angling 1998-99) rivers, during summer 1992-99. Error bars are ± 1 SE.

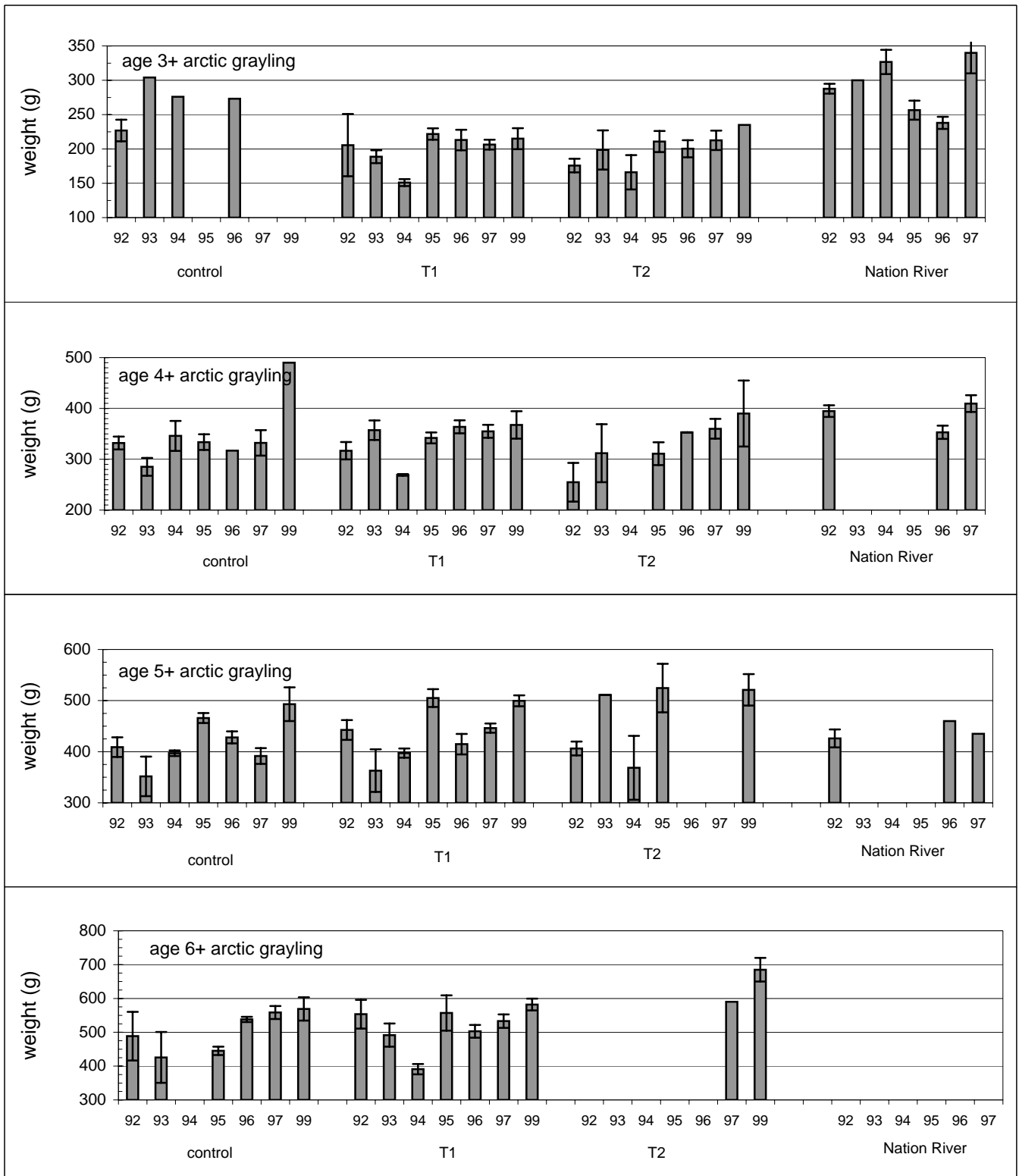


Figure 34. Average weight of aged Arctic grayling angled from the three experimental reaches of the Mesilinka River, and the Nation River (no angling 1998-99), summer 1992-99. Error bars are +/- 1 SE.

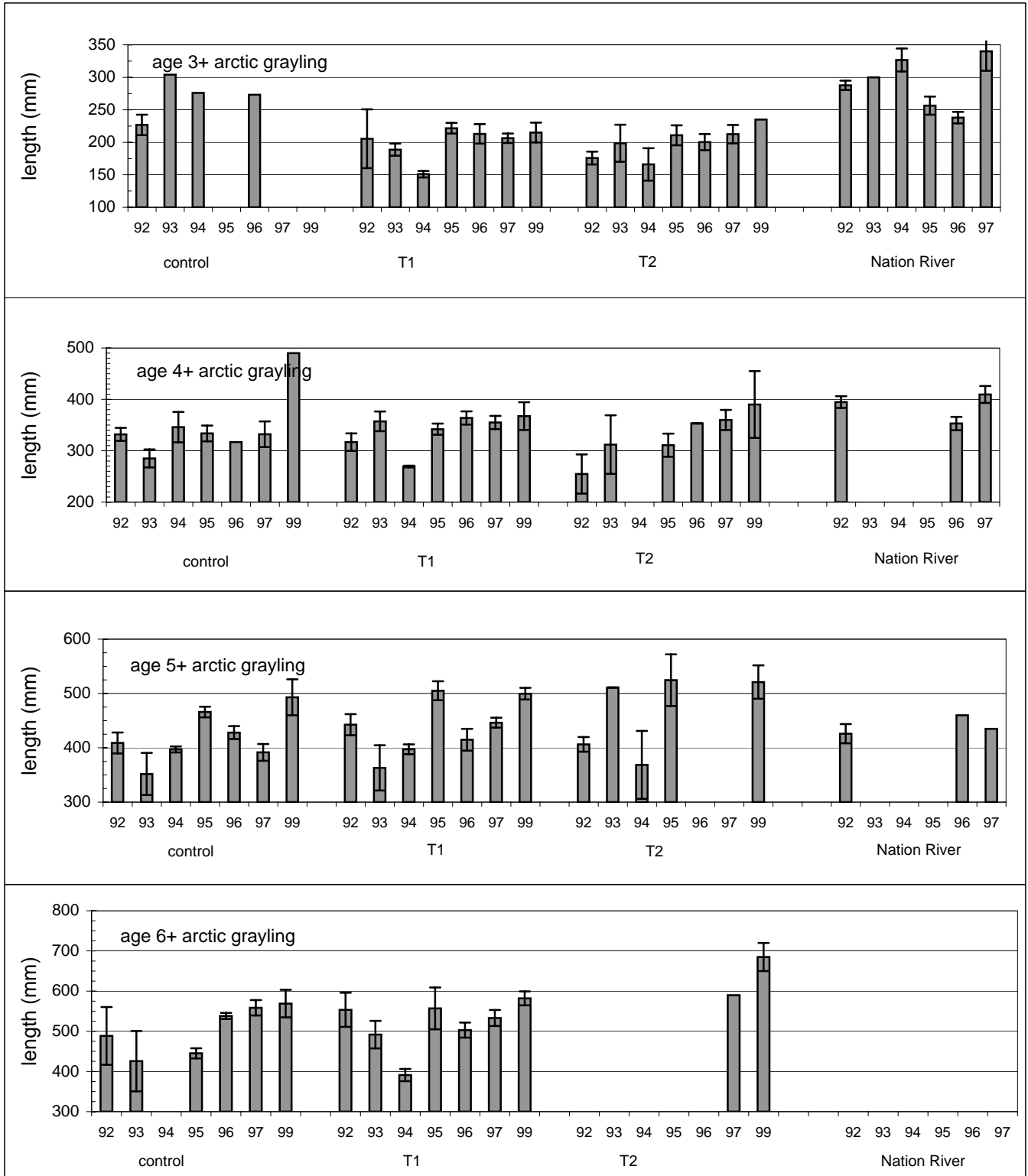


Figure 35. Average length of aged Arctic grayling angled from the three experimental reaches of the Mesilinka River, and the Nation River (no angling 1998-99), summer 1992-99. Error bars are +/- 1 SE.

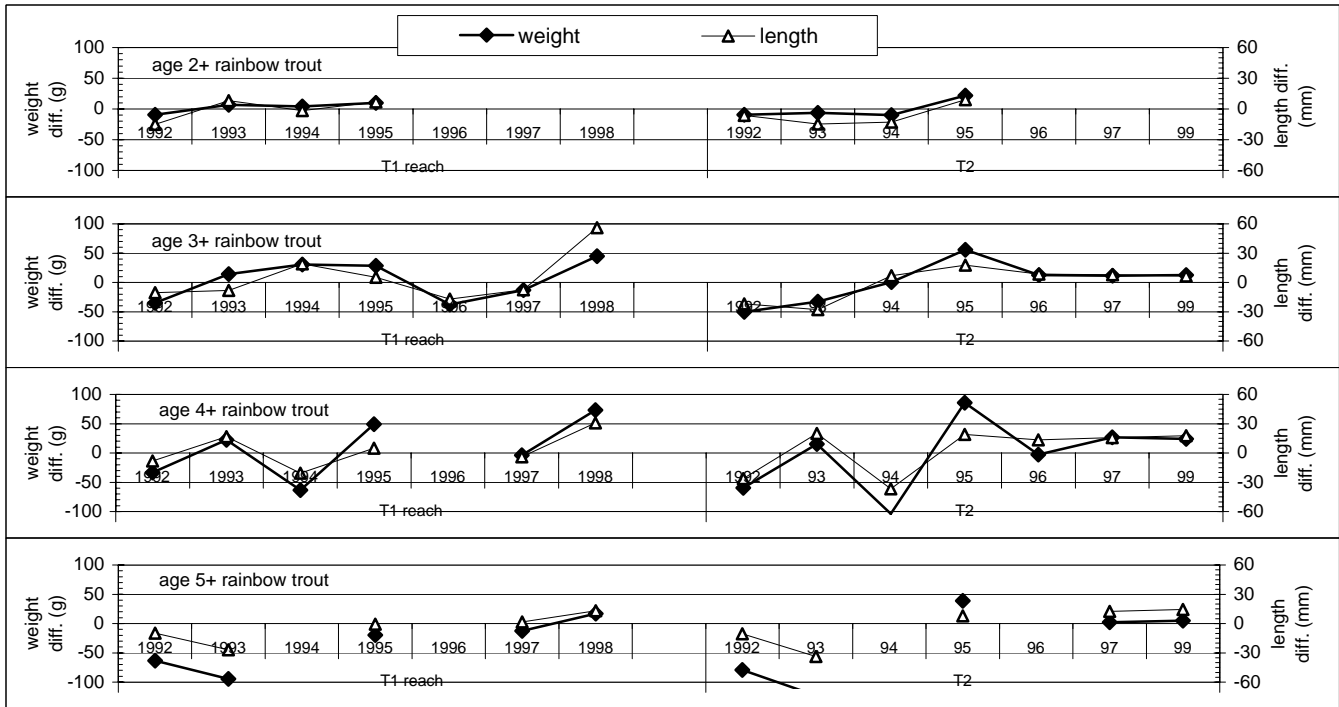


Figure 36. The length and weight difference of aged rainbow trout in the T1 and T2 reaches of the Mesilinka River, compared to control reach values, 1992-97.

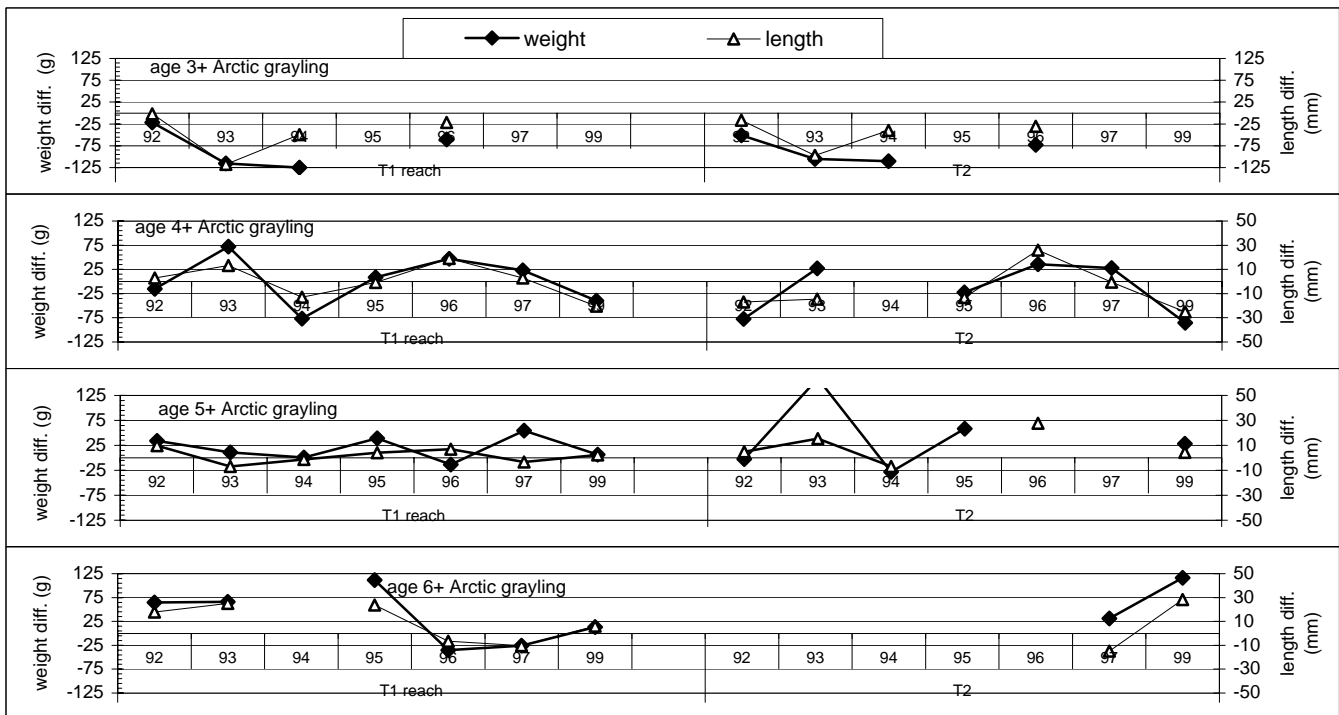


Figure 37. The weight and length difference of aged Arctic grayling in the T1 and T2 reaches of the Mesilinka River, compared to control reach values, 1992-99.

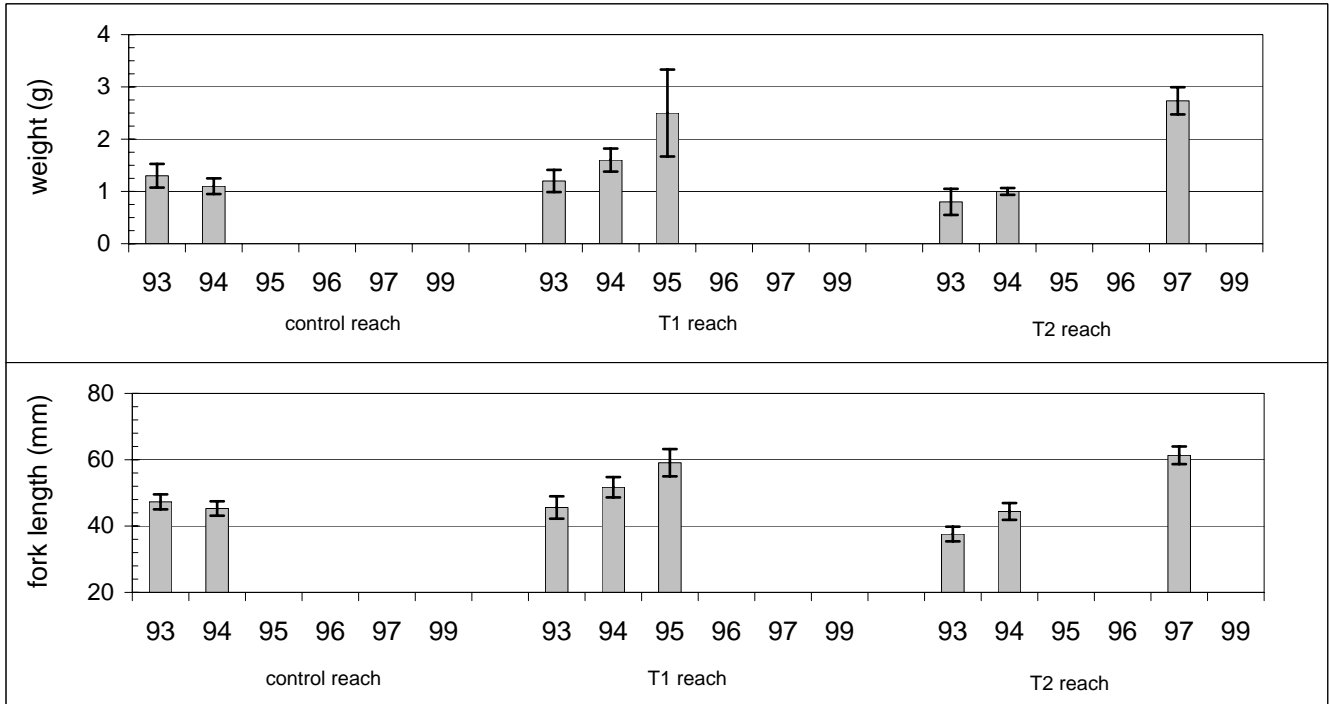


Figure 38. The average weight (top) and length (bottom) of age 0+ rainbow trout from the three reaches of the Mesilinka River, sampled during summers of 1993-97. Error bars are +/-1 SE.

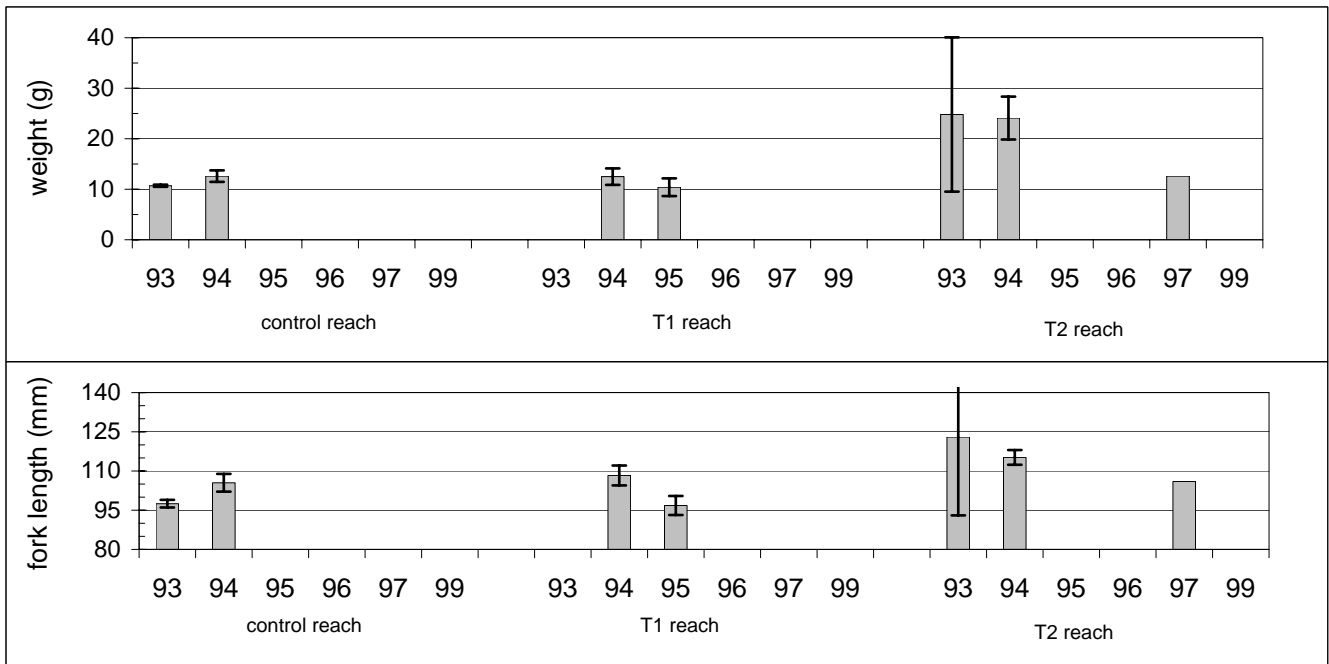


Figure 39. The average weight (top) and length (bottom) of age 1+ rainbow trout from the three reaches of the Mesilinka River, sampled during summers of 1993-97. Error bars are +/-1 SE.

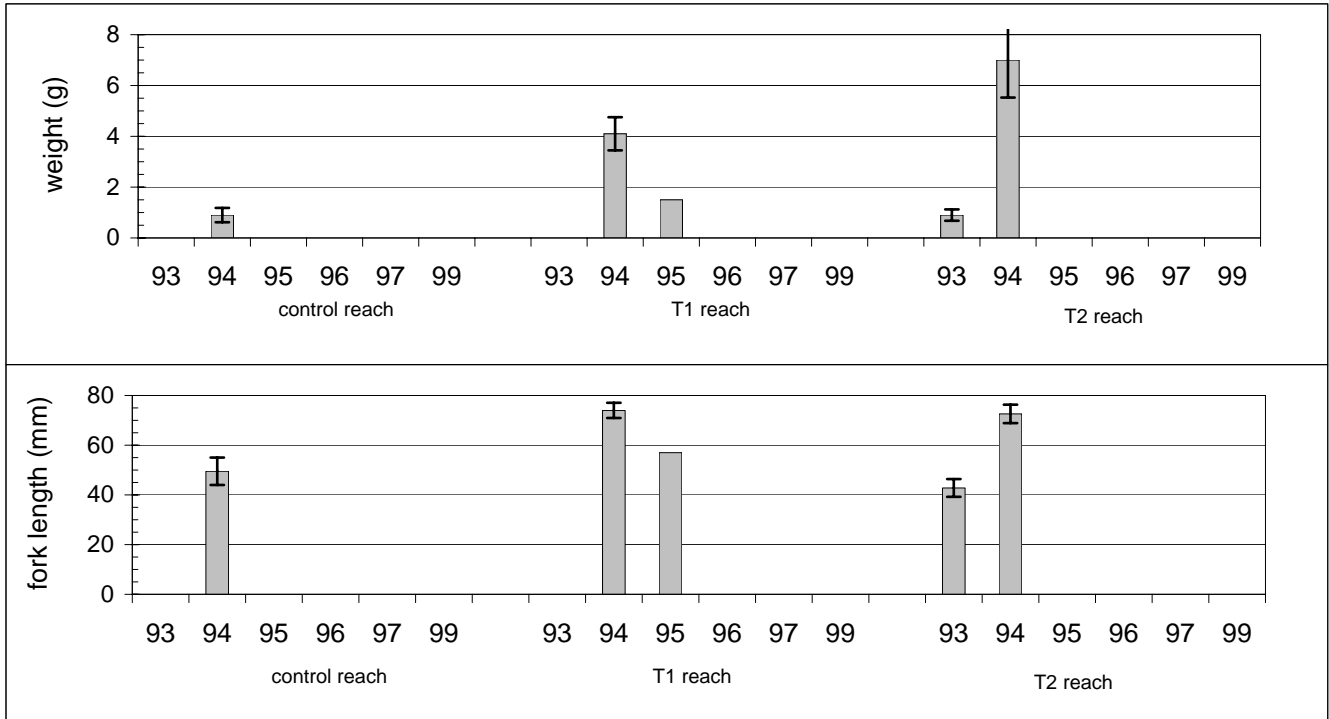


Figure 40. The average weight (top) and length (bottom) of age 0+ Arctic grayling from the three reaches of the Mesilinka River, sampled summers of 1993-97. Error bars are ± 1 SE.

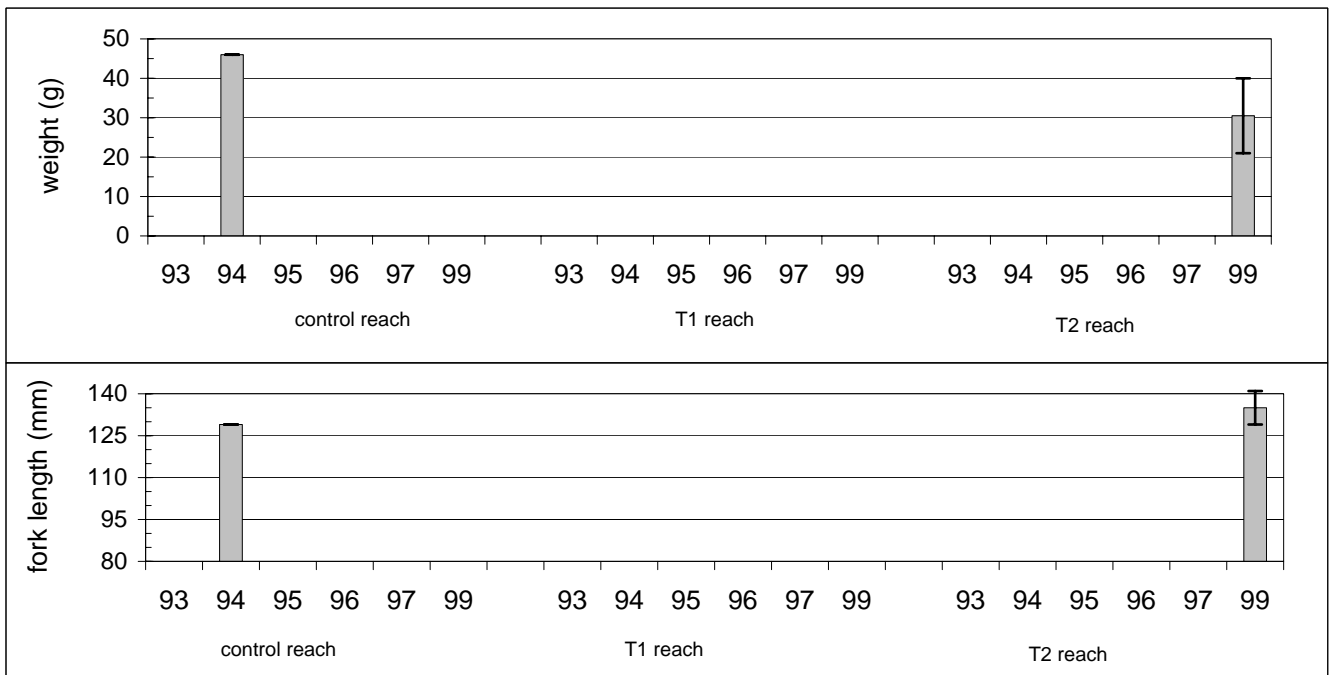


Figure 41. The average weight (top) and length (bottom) of age 1+ Arctic grayling from the three reaches of the Mesilinka River, sampled summers of 1993-97. Error bars are ± 1 SE.

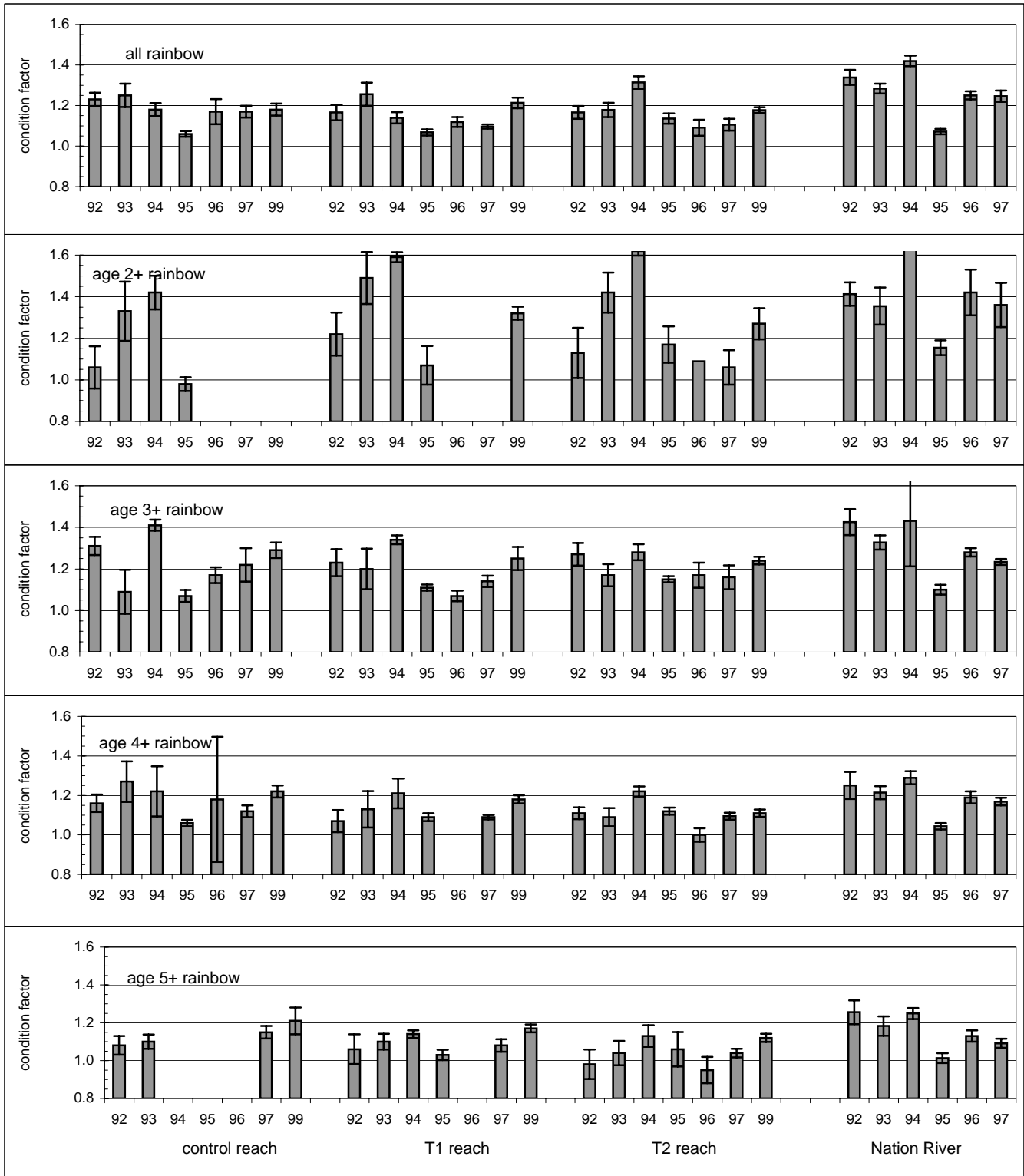


Figure 42. Fulton's condition factor for all rainbow trout (top), and for aged rainbow from the Mesilinka and Nation rivers, angled in 1992-99. Error bars are ± 1 SE.

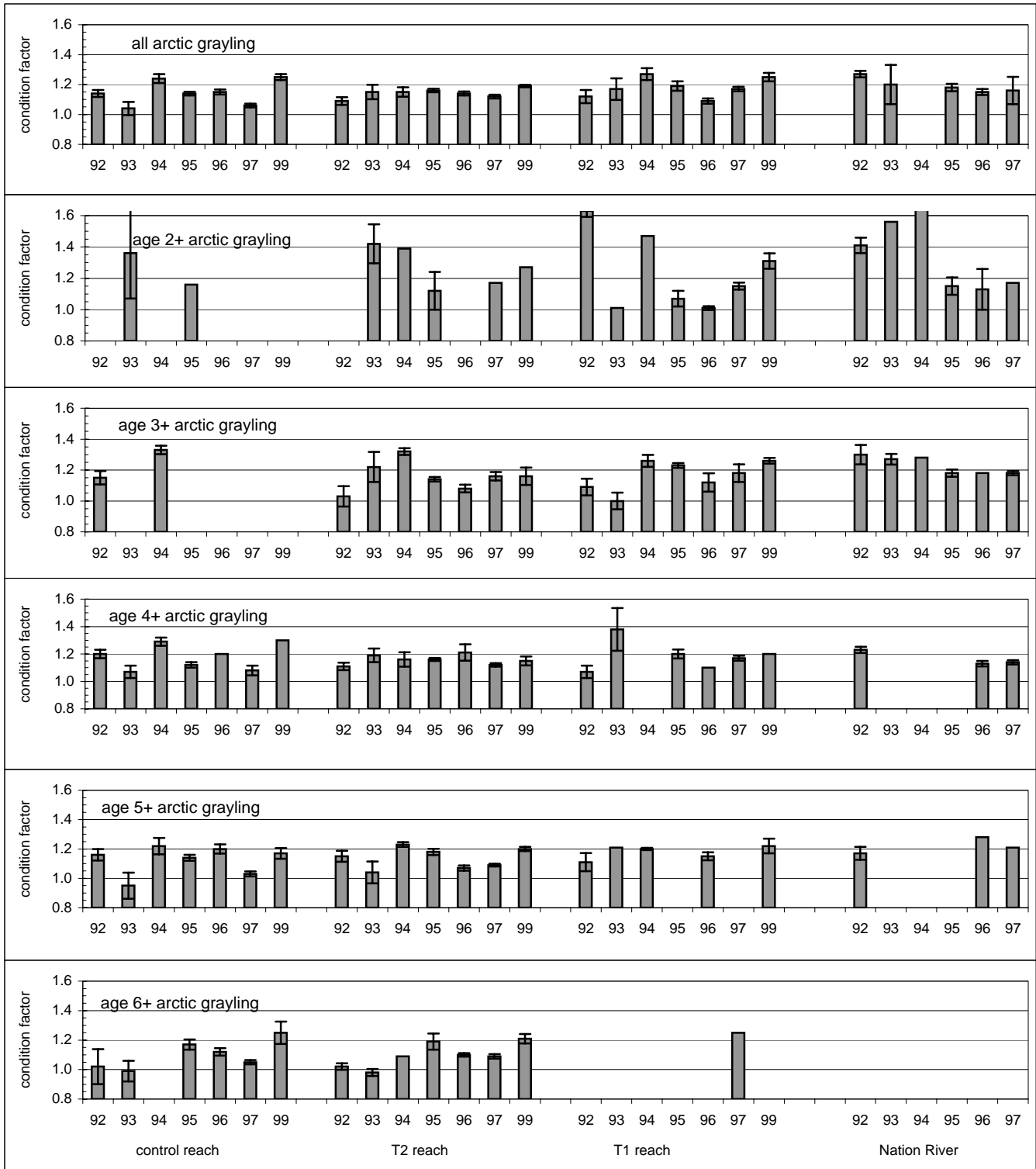


Figure 43. Fulton's condition factor for all Arctic grayling (top), and for aged grayling from the Mesilinka and Nation rivers, angled in 1992-99. Error bars are ± 1 SE.

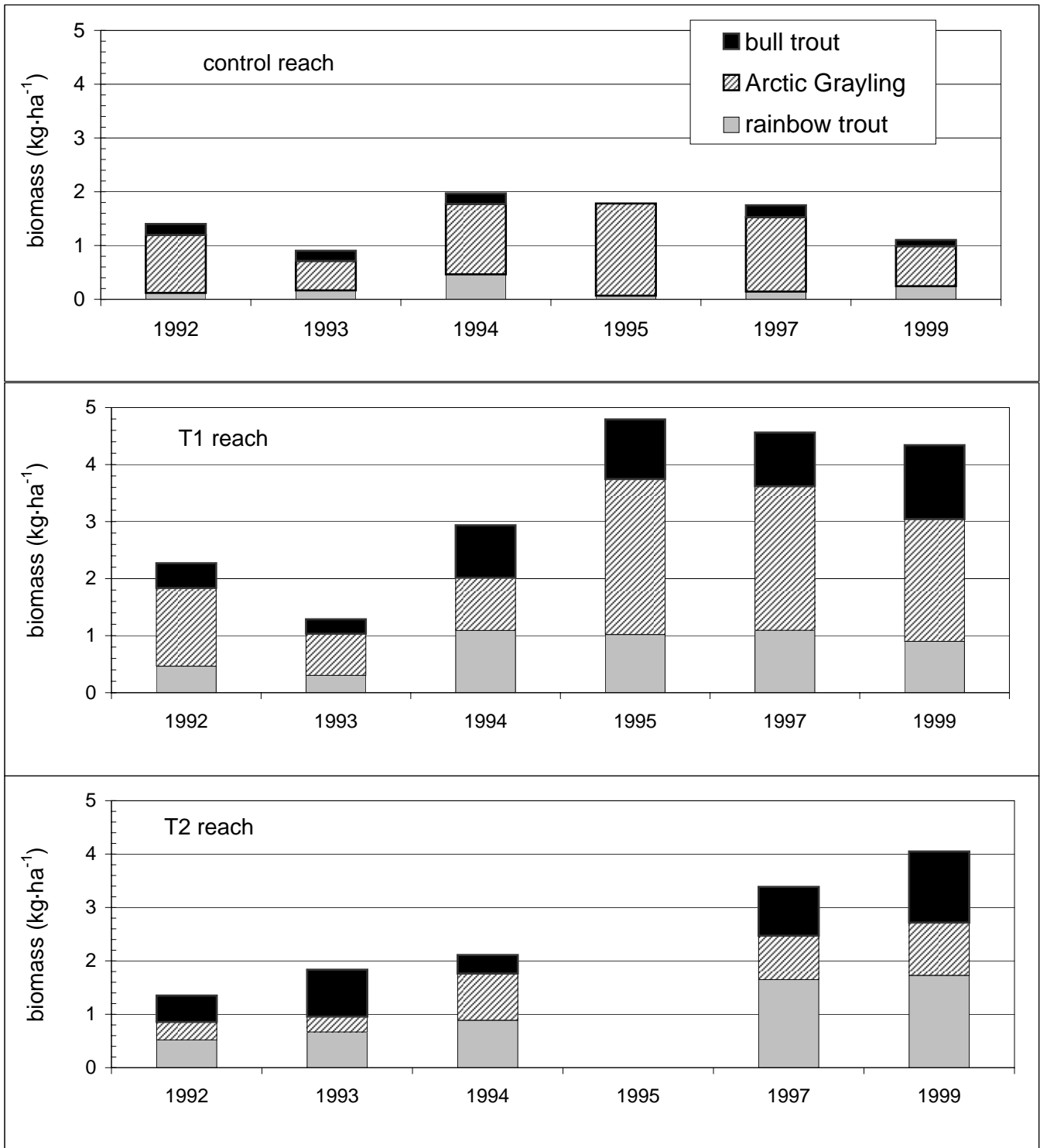


Figure 44. Biomass of rainbow trout, Arctic grayling, and bull trout in the three experimental reaches of the Mesilinka River, recorded during August 1992-99.

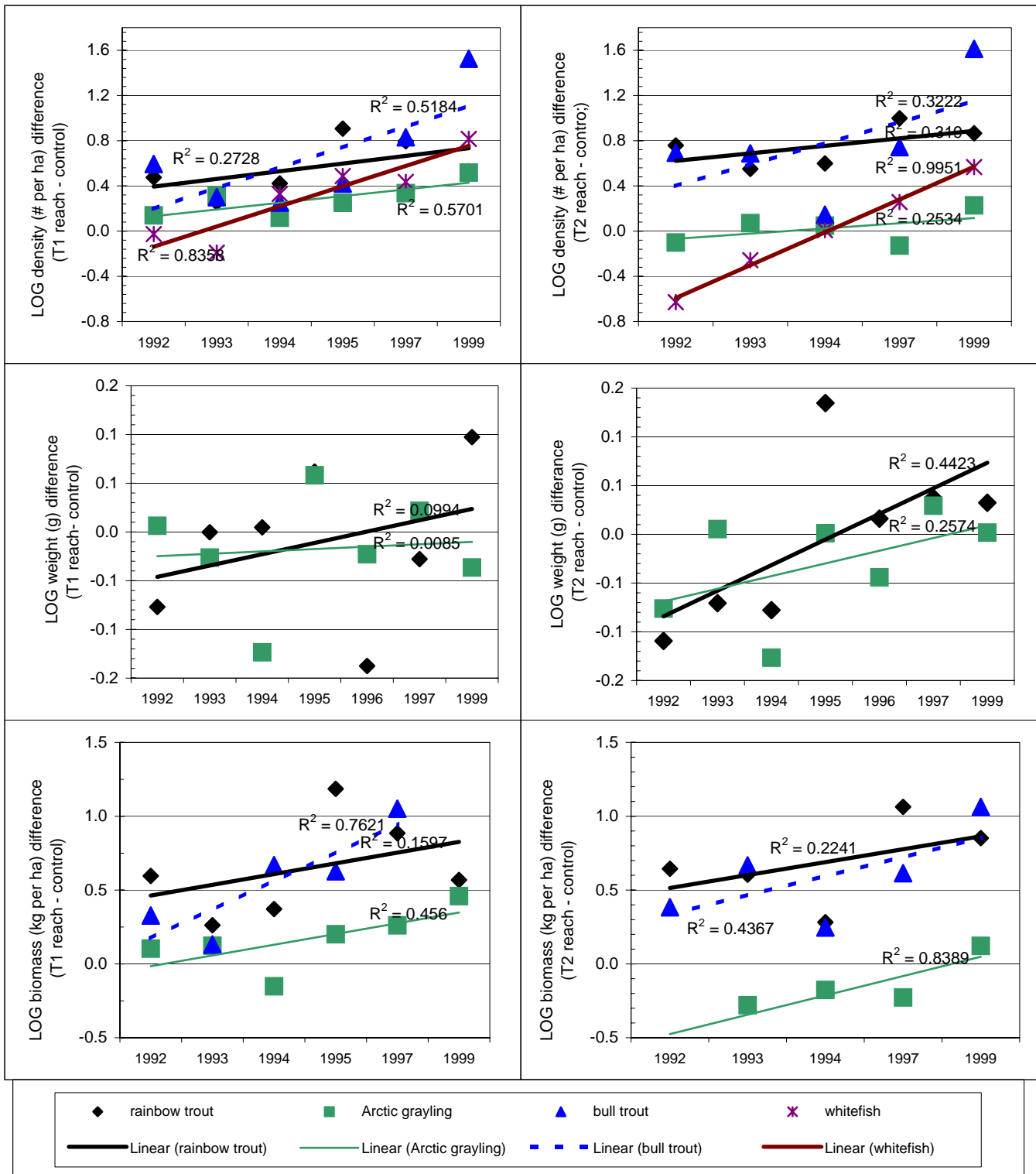


Figure 45. The response variables used in BACI analysis of fish density, weight and biomass responses to the 1994-99 fertilization; the log difference in values from the T1 reach less control reach (left side), and T2 reach less control reach (right side), for density (top), weight (middle) and biomass (bottom)

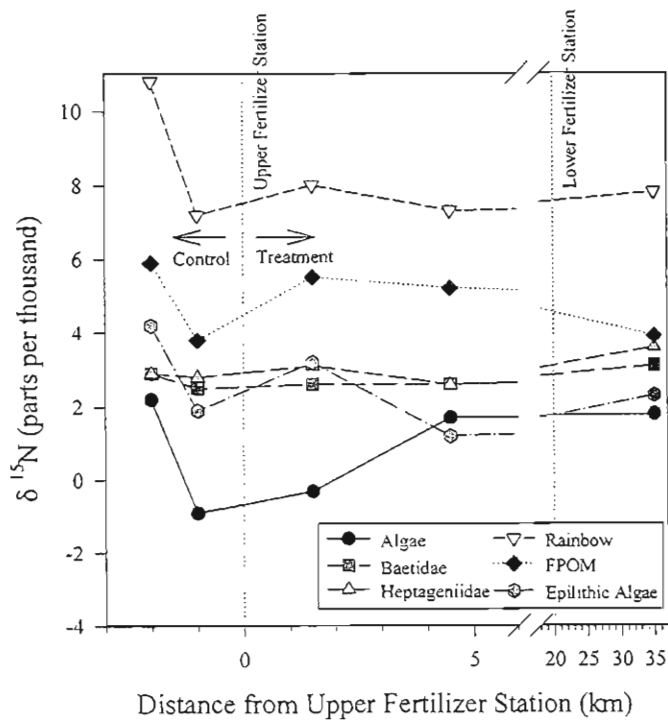


Figure 46. The $\delta^{15}\text{N}$ values for 5 biotic groups and fine particulate organic matter (FPOM).

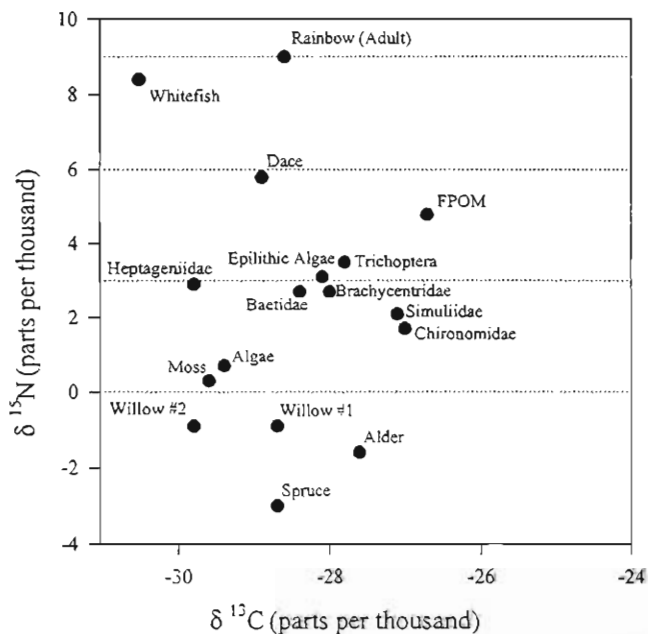


Figure 47. Stable isotope diagram for the Mesilinka River including terrestrial vegetation. Values represent averages from the 2 pre-fertilization sites. Lines are at 3ppt intervals.

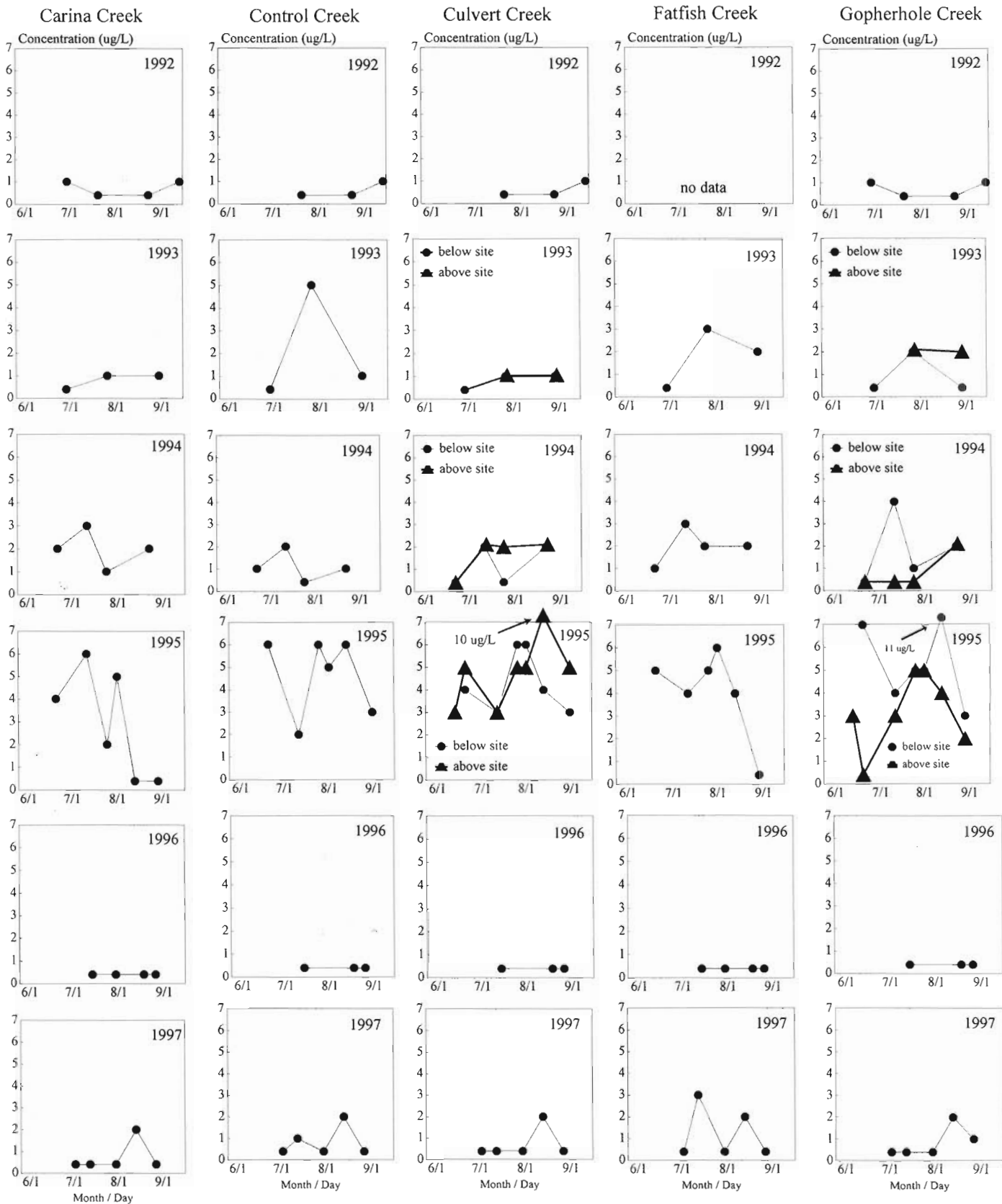


Figure 48. Soluble reactive phosphorus concentrations measured in 5 Mesilinka River tributaries, summers of 1992-97. Determinations made below the detection limit are shown at half the detection limit value of 2 $\mu\text{g/L}$.

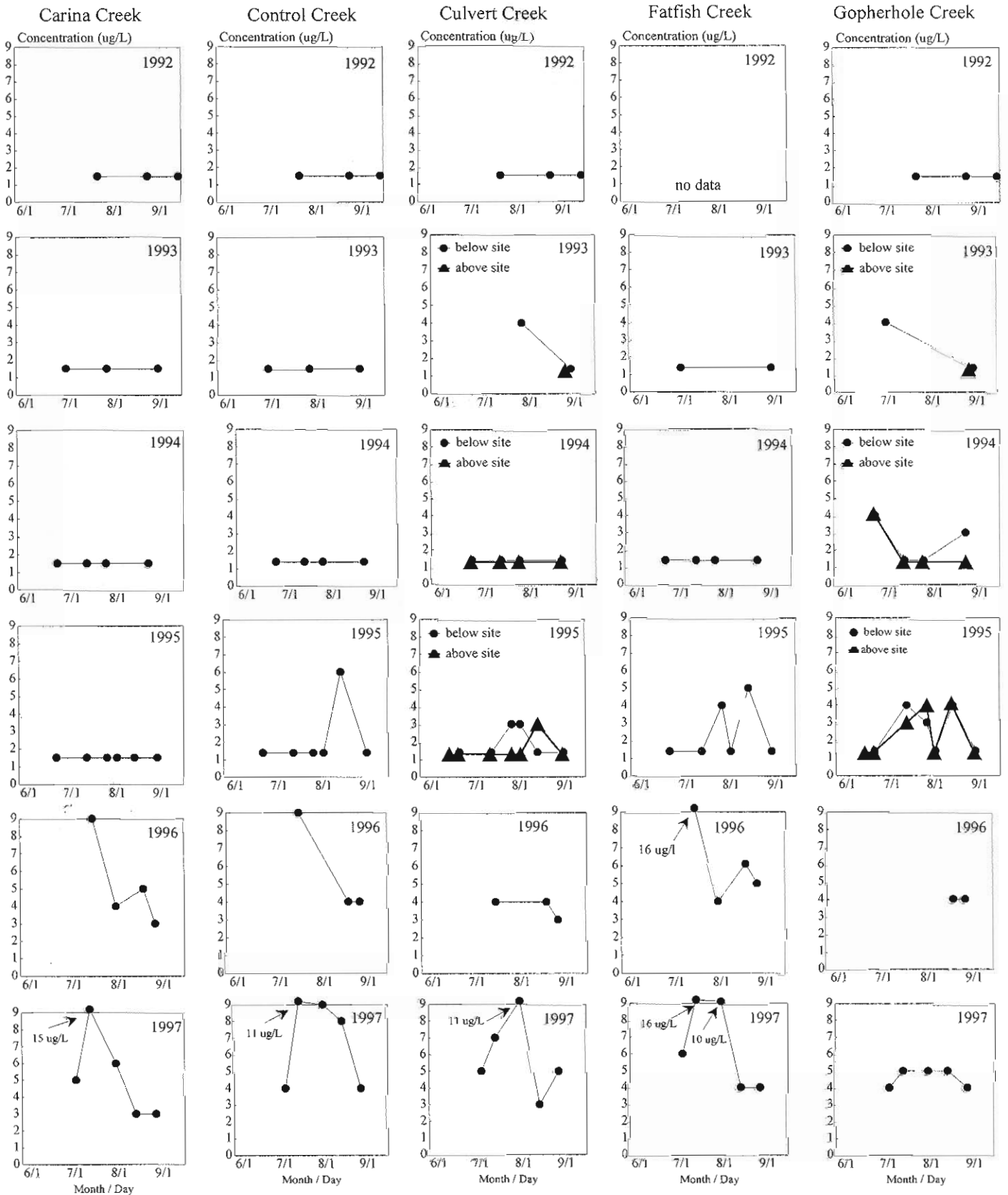


Figure 49. Total dissolved phosphorus concentrations measured in 5 Mesilinka River tributaries, summers of 1992-97. Determinations made below the detection limit are shown at half the detection limit value of 2 ug/L.

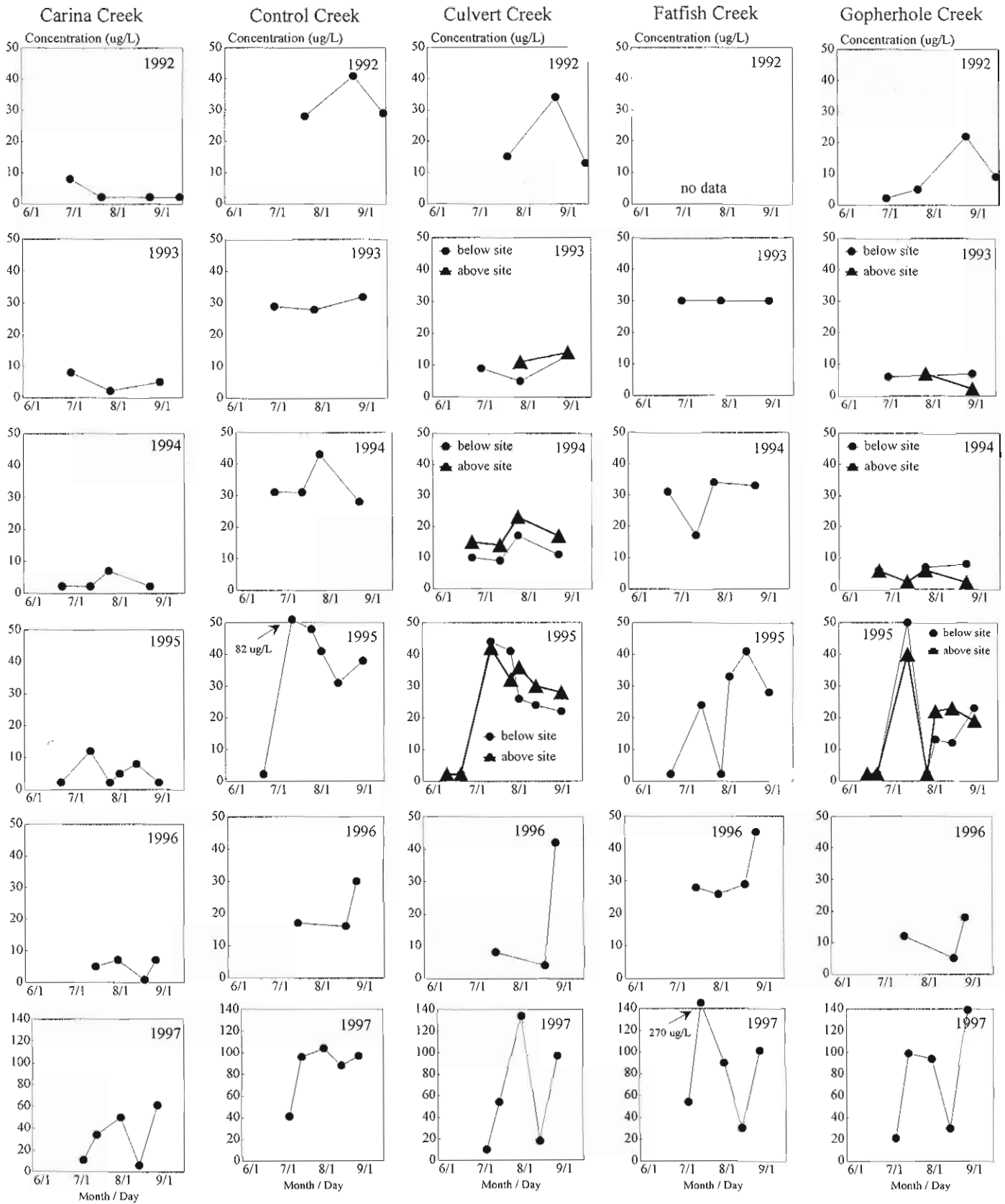


Figure 50. Nitrate+nitrite nitrogen concentrations measured in 5 Mesilinka River tributaries, summers of 1992-97. Determinations made below the detection limit are shown at half the detection limit value of 2 ug/L.

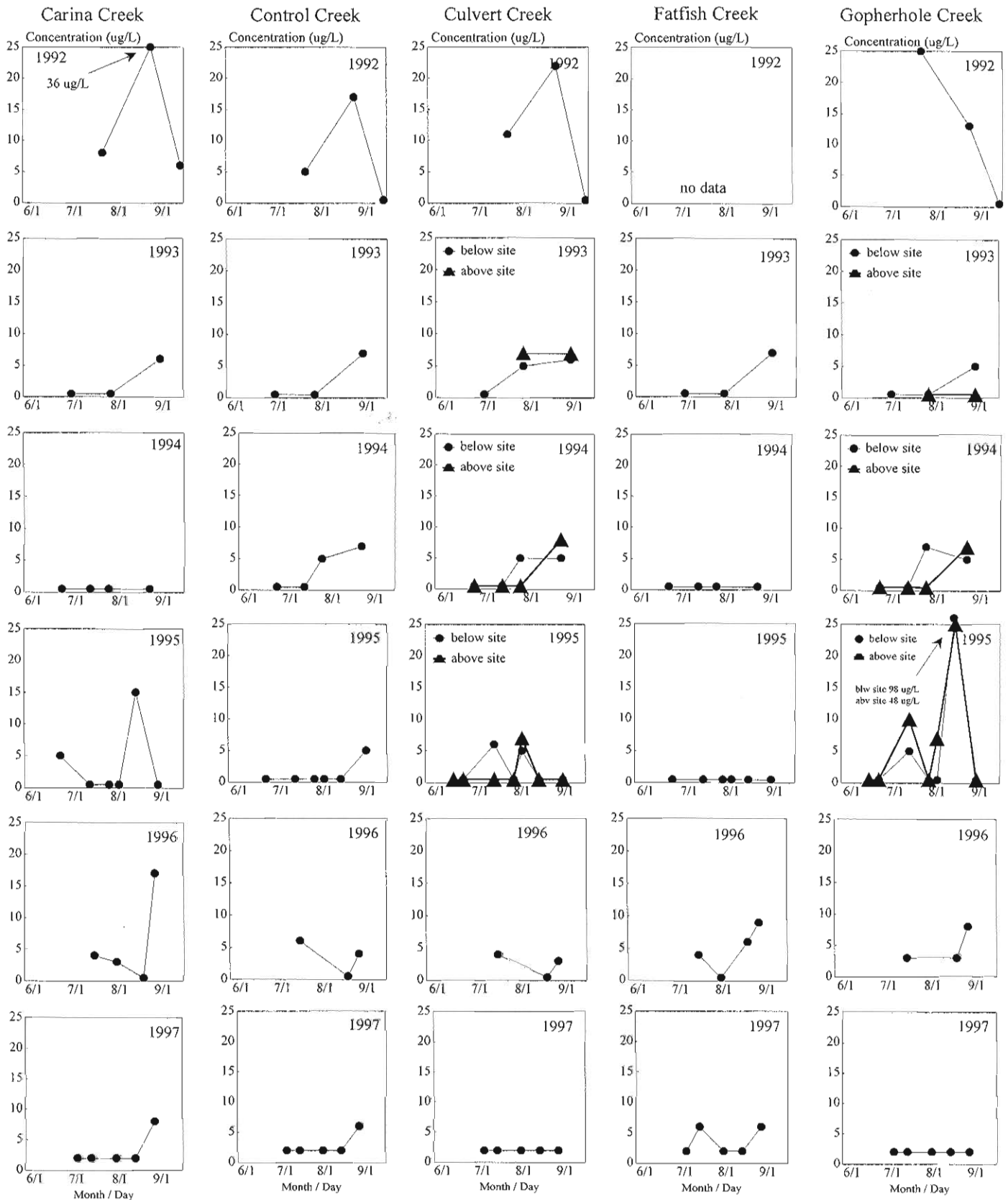


Figure 51. Ammonia nitrogen concentrations measured in 5 Mesilinka River tributaries, summers of 1992-97. Determinations made below the detection limit are shown at half the detection limit value of 2 ug/L.

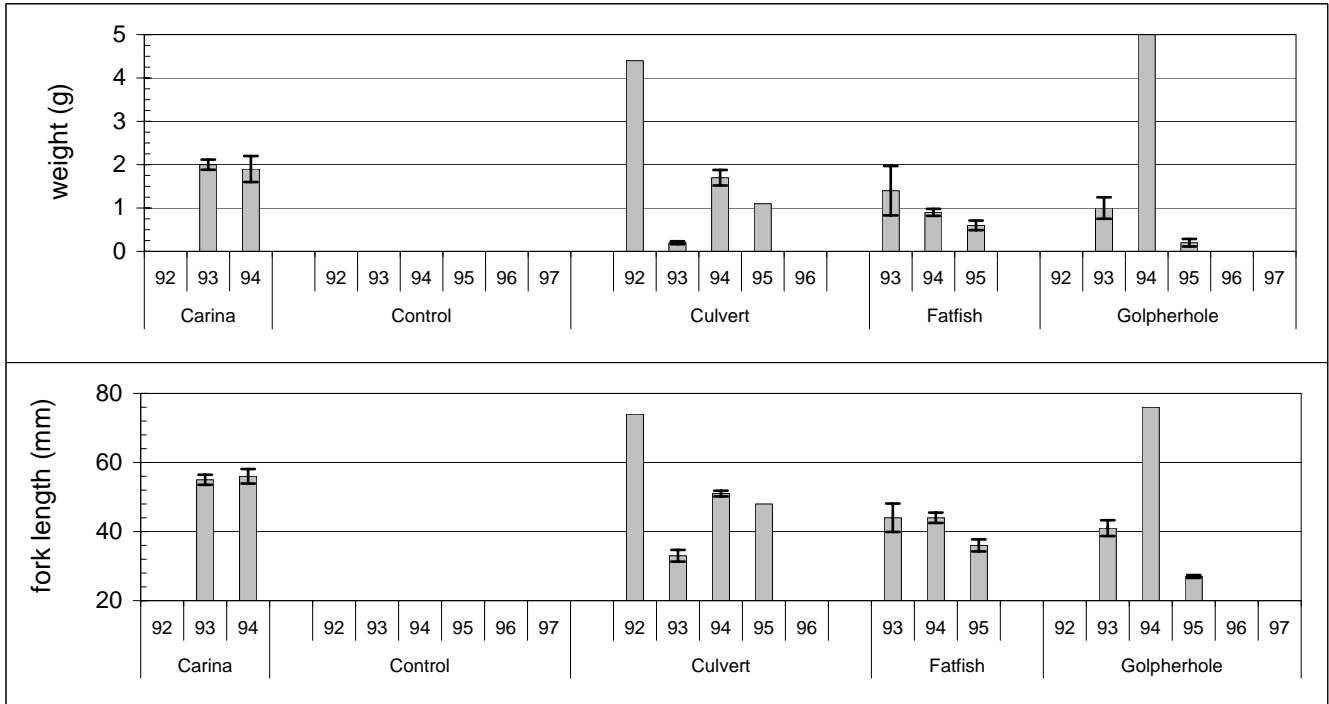


Figure 52. The average weight (top) and length (bottom) of age 0+ rainbow trout from tributaries to the Mesilinka River, sampled during August/Sept. of 1992-97. Error bars are +/- 1 SE.

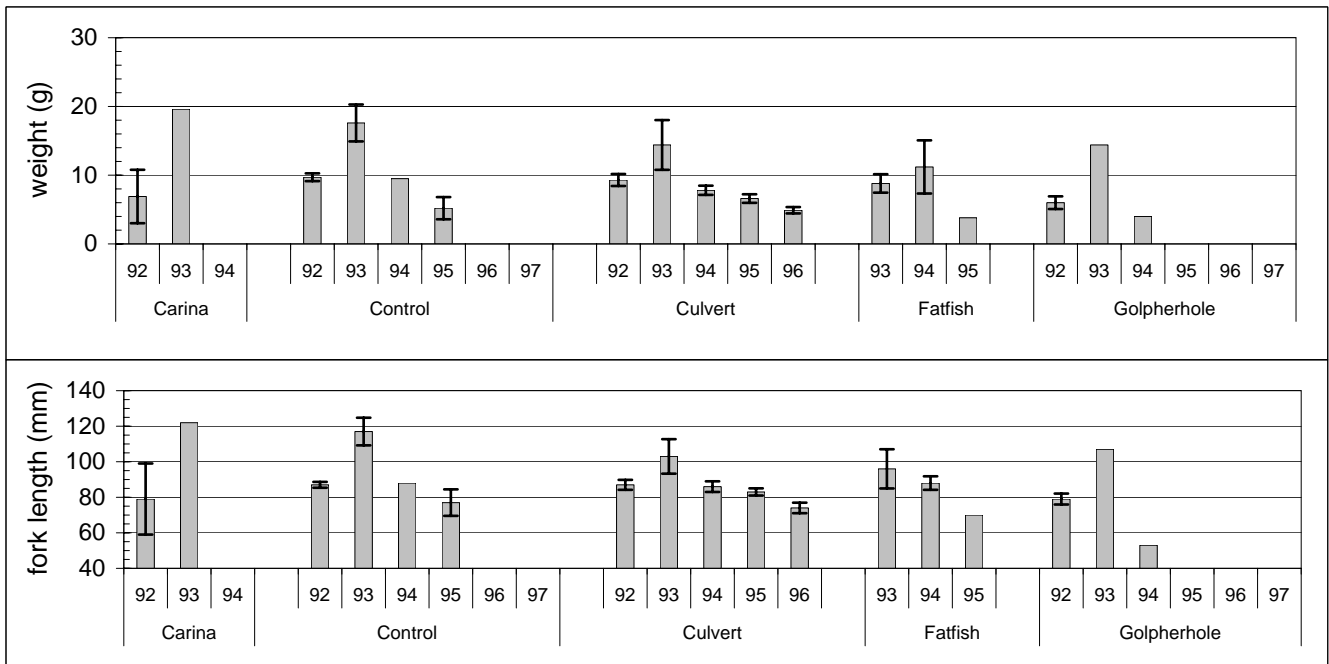


Figure 53. The average weight (top) and length (bottom) of age 1+ rainbow trout from tributaries to the Mesilinka River, sampled during August/Sept. of 1992-97. Error bars are +/- 1 SE.

APPENDIX A:

Fertilizer drip rates vs river discharge for the Mesilinka River.

for target concentrations of: 5 ug-P/L

15 ug-N/L

River Discharge (cms)	10-34-0 drip rate		28-0-0 drip rate		River Discharge (cms)	10-34-0 drip rate		28-0-0 drip rate	
	(ml/sec)	(ml/20sec)	(ml/sec)	(ml/20sec)		(ml/sec)	(ml/20sec)	(ml/sec)	(ml/20sec)
150	3.6	72	5.0	100	72	1.7	35	2.4	48
148	3.6	71	4.9	98	70	1.7	34	2.3	47
146	3.5	70	4.9	97	68	1.6	33	2.3	45
144	3.5	69	4.8	96	66	1.6	32	2.2	44
142	3.4	68	4.7	94	64	1.5	31	2.1	43
140	3.4	67	4.7	93	62	1.5	30	2.1	41
138	3.3	66	4.6	92	60	1.4	29	2.0	40
136	3.3	65	4.5	90	58	1.4	28	1.9	39
134	3.2	65	4.5	89	56	1.3	27	1.9	37
132	3.2	64	4.4	88	54	1.3	26	1.8	36
130	3.1	63	4.3	86	52	1.3	25	1.7	35
128	3.1	62	4.3	85	50	1.2	24	1.7	33
126	3.0	61	4.2	84	48	1.2	23	1.6	32
124	3.0	60	4.1	82	46	1.1	22	1.5	31
122	2.9	59	4.1	81	44	1.1	21	1.5	29
120	2.9	58	4.0	80	42	1.0	20	1.4	28
118	2.8	57	3.9	78	40	1.0	19	1.3	27
116	2.8	56	3.9	77	38	0.9	18	1.3	25
114	2.7	55	3.8	76	36	0.9	17	1.2	24
112	2.7	54	3.7	74	34	0.8	16	1.1	23
110	2.6	53	3.7	73	32	0.8	15	1.1	21
108	2.6	52	3.6	72	30	0.7	14	1.0	20
106	2.6	51	3.5	71	28	0.7	13	0.9	19
104	2.5	50	3.5	69	26	0.6	13	0.9	17
102	2.5	49	3.4	68	24	0.6	12	0.8	16
100	2.4	48	3.3	67	22	0.5	11	0.7	15
98	2.4	47	3.3	65	20	0.5	10	0.7	13
96	2.3	46	3.2	64	18	0.4	9	0.6	12
94	2.3	45	3.1	63	16	0.4	8	0.5	11
92	2.2	44	3.1	61	14	0.3	7	0.5	9
90	2.2	43	3.0	60	12	0.3	6	0.4	8
88	2.1	42	2.9	59	10	0.2	5	0.3	7
86	2.1	41	2.9	57	8	0.2	4	0.3	5
84	2.0	40	2.8	56	6	0.1	3	0.2	4
82	2.0	39	2.7	55	4	0.1	2	0.1	3
80	1.9	39	2.7	53	2	0.0	1	0.1	1
78	1.9	38	2.6	52					
76	1.8	37	2.5	51					
74	1.8	36	2.5	49					

APPENDIX B:

Mesilinka River mainstem supplemental water chemistry data.

Date	Alkalinity (mg/l)	pH (std. units)	Conductivity (uS/cm)	Filterable Residu (TDS) (mg/L)	Nonfilterable Residu (mg/L)	Turbidity (NTU)	Secchi Depth (m)
Control Reach (Blackpine)							
20-Jul-92	29.1	7.4		52			
23-Aug-92	42.4	7.5		78			
13-Sep-92	42.4	7.5		72			
28-Jun-93					< 4	0.3	
26-Jul-93					< 4	0.1	
20-Jun-95	30	7.2	83	183		0.6	
11-Jul-95	35.8	7.3	91	62		0.9	
25-Jul-95	40.9	7.3	91	92		0.4	
01-Aug-95	43.2	7.3	107	90		0.4	
13-Aug-95	42.5	7.3	102	98		0.4	
29-Aug-95	35.4	6.9	124	74		0.6	
14-Jul-96	27.8	7.6	60	10		1.0	
30-Jul-96	34.8	7.6	81	50		1.2	
18-Aug-96	34.8	7.9	92	60		0.3	
26-Aug-96	34.6	7.8	93	70		0.4	
02-Jul-97	34.6	7.6	84	60		1.9	
13-Jul-97	37.2	7.8	90	60		1.9	
30-Jul-97	47.6	7.6	107	70		0.9	
13-Aug-97	37.5	7.8	91	60		0.9	
27-Aug-97	45.1	7.9	109	60		0.4	
Roadend Site							
28-Jun-93					5	0.6	
26-Jul-93					< 4	0.3	
T1 Reach							
20-Jul-92	42	7.8		48			
23-Aug-92	53.7	7.9		82			
13-Sep-92	52.9	7.8		84			
28-Jun-93					< 4	0.9	
26-Jul-93					< 4	0.3	
20-Jun-95	31.7	7.4	88	84		0.5	
11-Jul-95	36.8	7.4	82	56		0.6	
25-Jul-95	43.3	7.4	98	74		0.4	
01-Aug-95	49.6	7.7	114	92		0.3	
13-Aug-95	50.4	7.6	113	82		0.4	
29-Aug-95	39	7.2	118	94		0.3	
14-Jul-96	32.9	7.9	78	60		2.5	
30-Jul-96	38.8	7.8	81	50		1.0	
18-Aug-96	41.5	8.0	103	70		0.4	
26-Aug-96	40.1	8.0	102	60		0.4	
02-Jul-97	39.8	7.8	90	60		1.5	
13-Jul-97	44	7.9	100	50		1.0	
30-Jul-97	44.8	7.8	101	60		2.1	
13-Aug-97	44.6	8.0	101			0.6	
27-Aug-97	50.2	8.0	115	60		0.6	
T2 Reach							
20-Jul-92	45.1	7.8		72			
23-Aug-92	55.8	7.7		74			
13-Sep-92	60.2	7.8		90			

APPENDIX B:

Mesilinka River mainstem supplemental water chemistry data.

Date	Alkalinity (mg/l)	pH (std. units)	Conductivity (uS/cm)	Filterable Residu (TDS) (mg/L)	Nonfilterable Residu (mg/L)	Turbidity (NTU)	Secchi Depth (m)
13-Aug-95	52.3	7.5	116	88		0.3	
29-Aug-95	43.4	7.2	128	84		0.5	
14-Jul-96	36.6	7.8	85	80		3.3	
30-Jul-96	38.9	7.8	85	50		1.4	
18-Aug-96	42	8.0	104	70		0.4	
26-Aug-96	40.4	8.0	102	60		0.4	
02-Jul-97	39.4	7.8	88	60		1.6	
13-Jul-97	43.5	8.0	99	60		1.5	
30-Jul-97	45.2	7.9	102	60		0.7	
13-Aug-97	46.6	8.0	106	70		0.8	
27-Aug-97	54	8.0	122	70		0.6	
Gratton's Camp							
27-Jun-92					24	5.0	0.7
03-Jul-92					18	2.7	0.9
10-Jul-92					16	1.5	1.0
17-Jul-92					18	2.6	1.1
24-Jul-92					30	2.6	2.0
31-Jul-92					6	2.9	
12-Jun-93					6	0.9	1.3
19-Jun-93					<4	0.6	1.8
27-Jun-93					<4	0.2	2.0
28-Jun-93					17	2.8	
03-Jul-93					4	0.6	1.7
10-Jul-93					4	0.6	1.7
17-Jul-93					<4	0.4	
31-Jul-93					<4	0.4	
25-Jul-93					4	1.1	1.2
11-Jun-94					15	0.5	
21-Jun-94					<4	0.9	
26-Jun-94				34	<4	2.9	
03-Jul-94				44	14	4.5	
11-Jul-94				52	<4	1.5	
17-Jul-94				92	5	0.7	
24-Jul-94				68	<4	0.8	
31-Jul-94				52	<4	0.6	
20-Jun-95	34.2	7.4	91	130		0.8	
11-Jul-95	37.6	7.4	80	60		0.8	
01-Aug-95	52.4	7.5	119	96		0.5	
13-Aug-95	53.4	7.4	117	90		0.3	
14-Jul-96	37.1	7.79	88	80		3.5	
30-Jul-96	38.1	7.77	88	50		1.6	
26-Aug-96	41.9	8.04	104	60		0.42	
02-Jul-97	39.4	7.78	89	60		1.9	
13-Jul-97	45.5	7.96	100	60		1.4	
30-Jul-97	48.2	7.75	105	60		1	
Nation River							
26-Jul-93					25	0.5	
12-Jul-94				44	<4	0.8	
25-Jul-94				72	<4	0.4	
20-Jun-95	37.8	7.4	83	88		0.5	
12-Jul-95	40.5	7.3	76	68		0.6	
25-Jul-95	40.5	7.4	90	72		0.7	
01-Aug-95	47	7.4	86	84		0.3	
13-Aug-95	49.4	7.4	99	76		0.5	
30-Aug-95	44.8	7.2	91	100		0.6	
14-Jul-96	41	7.85	82	80			

APPENDIX B:**Mesilinka River mainstem supplemental water chemistry data.**

Date	Alkalinity (mg/l)	pH (std. units)	Conductivity (uS/cm)	Filterable Residu (TDS) (mg/L)	Nonfilterable Residu (mg/L)	Turbidity (NTU)	Secchi Depth (m)
31-Jul-96	4.9	7.84	85	60		1.0	
18-Aug-96	49.4	7.99	97	70		0.4	
26-Aug-96	47.8	8.04	101	70		0.4	
02-Jul-97	39.4	7.82	89	70		1.9	
13-Jul-97	44.9	7.93	87	60		1.8	
30-Jul-97	50.5	7.91	98	80		0.7	
13-Aug-97	53.1	8.06	105	80		0.6	
27-Aug-97	57	8.08	113	80		0.4	

APPENDIX C:

Diurnal water chemistry data from the Mesilinka River, 1995-97.

Date	Time	Alkalinity (mg/l)	pH (std. units)	Conductivity (uS/cm)	Filterable Res: (mg/L)	Turbidity (NTU)	Nitrogen			Phosphorus			
							ammonia (ug/L)	NO ₂ +NO ₃ (ug/L)	total (ug/L)	SRP (ug/L)	total diss. (ug/L)	total (ug/L)	
25-Jul-95	6:00							72			4		
25-Jul-95	10:00							10			4		
25-Jul-95	14:00							5			5		
25-Jul-95	18:00							< 5			4		
25-Jul-95	22:00							< 5			4		
26-Jul-95	2:00							10			4		
29-Aug-95	8:00							7			5		
29-Aug-95	12:00							< 5			5		
29-Aug-95	16:00							< 5			5		
29-Aug-95	20:00							< 5			5		
30-Aug-95	4:00							5			4		
18-Aug-96	8:15							6			< 1		
18-Aug-96	13:10							5			< 1		
18-Aug-96	19:35							2			< 1		
18-Aug-96	24:00							3			< 1		
12-Aug-97	20:05	47.0	7.82	107	80	0.84	<5	8	40	2	3	15	
13-Aug-97	0:05	46.9	7.97	108	80	0.78	<5	54	50	2	<2	13	
13-Aug-97	6:05	47.1	7.85	108	60	0.67	<5	3	50	2	2	15	
13-Aug-97	11:30	47.2	7.93	110	70	0.79	<5	12	40	2	3	13	
13-Aug-97	17:30	47.9	8.04	110	60	0.66	<5	3	40	2	3	13	

APPENDIX D:

Benthic invertebrate biomass, density, and family richness measured in the three reaches of the Mesilinka River, 1993-97 (\pm SE).

reach	year	biomass (mg per 0.005 m ³)	density (# per 0.005 m ³)	family richness ^a
control	1993 pre-fert	285 (\pm 47)	315 (\pm 46)	14 (\pm 1)
	1994 un-fert	262 (\pm 72)	168 (\pm 32)	13 (\pm 1)
	1995 un-fert	34 (\pm 5)	100 (\pm 12)	11 (\pm 1)
	1996 un-fert	61 (\pm 22)	91 (\pm 25)	10 (\pm 1)
	1997 un-fert	174 (\pm 33)	177 (\pm 48)	8 (\pm 2)
	mean un-fert	163 (\pm 53)	120 (\pm 17)	11 (\pm 1)
T1	1993 pre-fert	212 (\pm 56)	180 (\pm 18)	13 (\pm 1)
	1994 fertilized	570 (\pm 273)	627 (\pm 187)	10 (\pm 1)
	1995 fertilized	54 (\pm 17)	177 (\pm 60)	6 (\pm 1)
	1996 fertilized	95 (\pm 27)	150 (\pm 65)	7 (\pm 2)
	1997 fertilized	538 (\pm 51)	1,058 (\pm 260)	12 (\pm 1)
	mean fertilized	314 (\pm 139)	503 (\pm 214)	10 (\pm 1)
T2	1993 pre-fert	22 (\pm 10)	8 (\pm 2)	4 (\pm 1)
	1994 fertilized	75 (\pm 25)	48 (\pm 31)	5 (\pm 1)
	1995 fertilized	96 (\pm 24)	144 (\pm 19)	9 (\pm 1)
	1996 fertilized	237 (\pm 68)	109 (\pm 50)	8 (\pm 1)
	1997 fertilized	294 (\pm 54)	433 (\pm 76)	10 (\pm 1)
	mean fertilized	175 (\pm 54)	184 (\pm 85)	7 (\pm 1)
Nation River	1993 un-fert	498 (\pm 253)	219 (\pm 38)	13 (\pm 1)
	1994 un-fert	3,147 (\pm 431)	168 (\pm 26)	13 (\pm 1)
	1995 un-fert	63 (\pm 16)	54 (\pm 13)	9 (\pm 1)
	1996 un-fert	64 (\pm 25)	83 (\pm 10)	8 (\pm 1)
	1997 un-fert	92 (\pm 28)	263 (\pm 28)	9 (\pm 1)
	mean un-fert	773 (\pm 670)	142 (\pm 44)	10 (\pm 1)

^a the number of families represented in the samples

Appendix E:

Population estimates (# counted, #/km and #/ha) of fish counted during snorkle surveys of the three experimental reaches of the Mesilinka River, Augusts of 1992-99. Per ha numbers are expanded to cover mid-sections of the river not observed during the swims. For fish >20cm fork length (except whitefish).

Year	bull trout			rainbow trout			Arctic grayling			whitefish		
	# counted	# per km	# per ha	# counted	# per km	# per ha	# counted	# per km	# per ha	# counted	# per km	# per ha
Control Reach												
1992	6	0.7	0.20	10.5	1.4	0.4	71	9.5	2.5	1138	152	40
1993	6	0.8	0.20	13.1	1.7	0.5	40	5.3	1.4	600	80	21
1994	13	2.0	0.44	32.4	5.0	1.1	64	9.9	2.2	411	63	14
1995	14	1.9	0.50	10.7	1.4	0.4	84	11.2	2.9	923	123	32
1996	swim cancelled due to inclement weather											
1997	4	0.6	0.15	17.4	2.3	0.6	75	10.0	2.6	738	98	26
1999	2	0.2	0.06	23.2	3.5	0.8	31	4.6	1.1	399	60	15
T1 reach												
1992	22	3.1	0.80	42.0	5.8	1.4	100	13.9	3.4	1117	155	38
1993	11	1.5	0.40	33.1	4.6	1.1	59	8.2	2.0	403	56	14
1994	28	4.4	0.84	96.2	14.8	2.8	81	12.4	2.4	999	154	30
1995	41	5.6	1.31	114.0	15.8	3.7	155	21.5	5.0	3041	422	98
1996	swim cancelled due to inclement weather											
1997	33	4.5	1.04	106.9	14.8	3.4	164	22.7	5.2	2222	309	71
1999	65	9.0	1.96	99.3	13.8	3.0	119	16.6	3.6	3162	439	95
T2 reach												
1992	30	3.7	0.90	66.0	8.1	2.1	42	5.2	1.3	298	40	9
1993	38	4.6	1.20	78.1	9.6	2.5	34	4.2	1.1	369	46	12
1994	19	2.3	0.62	83.3	10.4	2.8	70	8.7	2.4	420	52	14
1995	swim cancelled due to inclement weather											
1996	swim cancelled due to inclement weather											
1997	28	3.4	0.86	186.6	23.0	5.7	61	7.5	1.9	1526	188	47
1999	78	9.7	2.33	202.4	25.0	6.0	61	7.5	1.8	1796	222	54

Appendix F:

Mark-recapture results and correction factors for underwater fish counts, Mesilinka River, 1992-99.

Reach	Sp. ^a	Year	Total marked	Swim 1				Swim 2				Mark Recapture Population Estimate ^b				Snorkel Swim Pop. Est. ^f		Corr. ^g Fact. for swims	
				Total Recapt. capt. w/mark		Min. Num. ^c (%)	Sign. Test ^d	Total Recapt. capt. w/mark		Min. Num. ^c (%)	Sign. Test ^d	Swim # 1	Swim # 2	Average	Std Err	Density ^e (per ha)	Density (per ha)		
				C1	R1	M/N	(MC>4N)	C2	R2	M/N	(MC>4N)	N1	N2	N ave			(# of fish)		(# of fish)
Control	RB	1992	21	4	0	---	---	11	1	16%	failed	---	132	132	---	4.68	11	0.37	12.6
		1993	12	6	1	26%	failed	12	1	14%	failed	46	85	65	20	2.30	13	0.46	5.0
		1994	6	19	0	---	---	9	0	---	---	---	---	---	---	---	32	1.09	---
		1995	14	6	0	---	---	---	---	---	---	---	---	---	---	---	11	0.37	---
		1997	16	7	1	24%	failed	11	3	31%	failed	68	51	60	9	2.10	17	0.62	3.4
		1999	8	20	2	13%	failed	9	1	18%	failed	63	45	54	9	1.96	23	0.80	2.5
	AG	1992	28	54	13	25%	passed	34	5	17%	passed	114	169	142	28	5.02	71	2.52	2.0
		1993	25	24	7	31%	passed	24	6	27%	passed	81	93	87	6	3.09	40	1.42	2.2
		1994	12	10	0	---	---	12	0	7%	failed	---	169	169	---	5.69	64	2.16	2.6
		1995	29	30	5	19%	passed	---	---	---	---	155	---	155	---	5.36	84	2.91	1.8
		1997	17	33	1	6%	failed	23	4	20%	passed	306	86	196	110	6.91	75	2.64	2.6
		1999	9	16	4	26%	passed	16	3	21%	failed	34	43	38	4	1.39	31	1.10	1.3
	BT	1992	3	4	0	---	---	4	0	---	---	---	---	---	---	---	6	0.23	---
		1993	3	3	2	56%	failed	5	1	25%	failed	5	12	9	---	---	6	0.22	---
		1994	1	4	0	---	---	3	0	---	---	---	---	---	---	---	13	0.44	---
		1995	3	5	0	---	---	---	---	---	---	---	---	---	---	---	14	0.50	---
		1997	3	3	0	---	---	2	0	---	---	---	---	---	---	---	4	0.15	---
		1999	0	2	0	---	---	0	0	---	---	---	---	---	---	---	2	0.10	---
T1	RB	1992	32	28	5	20%	passed	34	4	14%	passed	160	231	195	36	6.64	42	1.43	4.6
		1993	16	29	1	6%	failed	34	2	8%	failed	255	198	227	28	7.71	33	1.13	6.8
		1994	11	49	1	4%	failed	36	1	5%	failed	300	222	261	39	7.72	96	2.84	2.7
		1995	28	92	6	7%	passed	56	5	10%	passed	385	276	330	55	10.66	114	3.68	2.9
		1997	37	43	5	13%	passed	87	8	10%	passed	279	372	325	46	10.39	107	3.41	3.0
		1999	26	53	3	7%	failed	99	2	3%	failed	365	900	632	268	18.99	99	3.00	6.3
	AG	1992	21	69	3	5%	failed	38	2	7%	failed	385	286	336	50	11.41	100	3.41	3.3
		1993	19	35	5	16%	passed	36	5	15%	passed	120	123	122	2	4.14	59	2.01	2.1
		1994	3	32	1	5%	failed	18	0	4%	failed	66	76	71	5	2.10	81	2.38	0.9
		1995	33	71	13	19%	passed	54	13	25%	passed	175	134	154	21	4.97	155	5.01	1.0
		1997	45	71	9	14%	passed	68	8	13%	passed	331	353	342	11	10.92	164	5.23	2.1
		1999	44	35	10	30%	passed	85	13	16%	passed	147	276	212	65	6.36	119	3.60	1.8
	BT	1992	7	16	2	15%	failed	13	0	---	---	45	---	45	---	1.54	22	0.76	2.0
		1993	3	8	1	17%	failed	9	0	---	---	18	---	18	---	0.61	11	0.38	1.6
		1994	4	11	0	---	---	5	0	---	---	---	---	---	---	---	28	0.84	---
		1995	6	14	1	11%	failed	18	0	---	---	53	---	53	---	1.69	41	1.33	1.3
		1997	3	13	0	---	---	21	3	14%	failed	---	22	22	---	0.70	33	1.03	0.7
		1999	12	28	0	---	---	50	4	9%	passed	---	133	133	---	3.98	65	2.00	2.0
T2	RB	1992	46	34	6	20%	passed	64	15	24%	passed	235	191	213	22	6.80	66	2.11	3.2
		1993	38	50	4	10%	passed	74	6	9%	passed	398	418	408	10	13.03	78	2.49	5.2
		1994	28	34	1	6%	failed	38	1	5%	failed	508	566	537	29	18.00	83	2.80	6.4
		1997	105	114	20	18%	passed	114	16	15%	passed	580	717	649	68	19.96	187	5.75	3.5
		1999	69	152	11	8%	passed	133	11	9%	passed	893	782	837	55	24.91	202	6.00	4.2
		AG	1992	13	26	0	---	---	29	1	6%	failed	---	210	210	---	6.71	42	1.35
	1993		5	20	1	8%	failed	28	0	---	---	63	---	63	---	2.01	34	1.09	1.8
	1994		3	17	0	---	---	19	1	8%	failed	---	40	40	---	1.34	70	2.35	0.6
	1997		21	29	7	25%	passed	26	3	14%	failed	83	149	116	33	3.55	61	1.87	1.9
	1999		17	26	6	24%	passed	26	5	21%	passed	69	81	75	6	2.24	61	1.80	1.2
	BT		1992	8	16	1	10%	failed	22	0	---	---	77	---	77	---	2.44	30	0.94
		1993	9	19	4	23%	passed	26	3	13%	failed	40	68	54	14	1.72	38	1.20	1.4
		1994	4	10	0	---	---	5	0	---	---	---	---	---	---	---	19	0.62	---
		1997	2	15	0	---	---	16	0	---	---	---	---	---	---	---	28	0.86	---
		1999	21	33	2	8%	failed	46	2	6%	failed	249	345	297	48	8.84	78	2.30	3.8

- mark recapture population estimate = $N_x = (M_x + 1)(C_x + 1) / (R_x + 1)$

where M = number of fish marked

C = total number of fish seen during swim

R = number of fish seen with tag during swim

- numbers in bold are significant based on M/N > 20% and MC > 4N

- no corrections made for tagging losses, or tagging / hooking mortality

^a RB - rainbow trout, AG - Arctic grayling, BT - bull trout

^b for the Mark Recapture population estimate to be statistically valid:

^c the initial marking of fish (M) should be >20% of the total estimated population (M/N > or = 20%) (Vincent 1972)

^d the number of fish marked (M) multiplied by the number of captured fish © should be more than 4 times

the total estimated population (MC>4N) (Robson and Regier 1964)

^e mark recapture density estimated based on: control reach, 7.5 km and 28.2 ha; T1 reach, 7.2 km and 33.8 ha; T2 reach, 8.1 km and 29.8 ha

^f snorkle swim population estimates from snorkle survey results (Appendix F), and are included for comparison

^g correction factor = mark-recapture population estimate / snorkle swim population estimate

APPENDIX H:

Mesiinka River T1 Reach angling recaptures and calculated growth rates

Year	date	sp.	ln (mm)	wt (grams)	cf	age	1992 tag #	1993 tag #	1994 tag #	1995 tag #	1996 tag #	1997 tag #	original capture info					growth rates						
													date	reach	ln	wt	cf	age	days between	ln (mm/day)	wt (g/day)	ln (mm/year)	wt (g/year)	
1993	11-Aug	GR	325	340	0.99	5+	red 060	yel 00030					01-Aug-92	T1	302	340	1.23	3+	375	0.06	0.00	23.0	0.0	
1993	19-Jul	RB	299	312	1.17	5+	or 06184						????											
1993	25-Jul	RB	297	284	1.08	5+	or 06184						????											
1994	02-Aug	GR	369	546	1.09	6+		yel 00016					09-Aug-93	T1	374	511	0.98	6+	358	-0.01	0.10	-5.0	35.0	
1994	14-Jul	RB	322	401	1.20	6+ (5S)		yel 00027					10-Aug-93	T1	228	255	2.15	4+	338	0.28	0.43	94.0	146.0	
1994	02-Aug	GR	324	421	1.24	5+			bl 19				14-Jul-94	T1	323	416	1.23	5+						
1995	16-Jul	GR	363	552	1.15	5+		yel 00006					19-Jul-93	T1	356	425	0.94	6	727	0.01	0.17	7.0	127.0	
1996	25-Jul	GR	370	546	1.08	6+	green 359						17-Jul-92	T1	334	425	1.14	p/s	1469	0.02	0.08	9.0	30.3	
1996	25-Jul	GR	342	438	1.10	6+ (5s)		pink/or 5137					02-Aug-94	T1	242	157	1.11	5+	723	0.14	0.39	50.0	140.6	
1996	25-Jul	GR	377	600	1.12	7+ (6s)		orange 5126					09-Aug-93	T1	374	511	0.98	6+	1081	0.00	0.08	1.0	29.8	
1996	25-Jul	GR	315	336	1.07	4+			qr/yell 37				30-Jul-95	T1	293	277	1.10	4+	361	0.06	0.16	22.0	58.6	
1996	25-Jul	GR	349	455	1.07	5+			qr/yell 38				30-Jul-95	T1	328	391	1.11	4+	361	0.06	0.18	21.0	64.0	
1996	26-Jul	GR	352	498	1.14	5+ (4s)			qr/yell 52				08-Aug-95	T1	329	421	1.18	4+	353	0.07	0.22	23.0	77.1	
1996	15-Aug	RB	270	230	1.17				yel/gr 60				08-Aug-95	T1	232	145	1.16	4+	373	0.10	0.23	38.0	84.8	
1996	15-Aug	GR	343	490	1.21				qr/yell 51				08-Aug-95	T1	319	397	1.22	4+	373	0.06	0.25	24.0	93.0	
1996	26-Jul	GR	361	535	1.14	6+			qr/yell 19				08-Aug-95	T1	353	565	1.28	6+	353	0.02	-0.09	8.0	-30.3	
1996	25-Jul	GR	357	499	1.10	6+ (5s)			green 4117				16-Jul-95	T1	330	441	1.23	4+	375	0.07	0.15	27.0	57.9	
1996	15-Aug	GR	331	425	1.17					or/wt 205			26-Jul-96	T1	327	407	1.16	5+ (4s)						
1996	15-Aug	GR	309	340	1.15					or/wt 151			25-Jul-96	T1	304	318	1.13	4+						
1996	15-Aug	GR	359	520	1.12					or/wt 169			25-Jul-96	T1	356	495	1.10	5+ (4s)						
1997	23-Jul	GR	364	494	1.02	5+	yellow 6						19-Jul-93	T1	356	425	0.94	6	1465	0.01	0.05	2.0	17.2	
1997	23-Jul	GR	352	462	1.06	5+		blue grow 30					14-Jul-94	T1	317	386	1.21	5+	1105	0.03	0.07	11.7	25.2	
1997	06-Aug	GR	335	414	1.10	4+			green/yellow 26				30-Jul-95	T1	297	302	1.15	4+	738	0.05	0.15	19.0	56.0	
1997	23-Jul	GR	334	393	1.05	5+			green/yellow 26				30-Jul-95	T1	297	302	1.15	4+	724	0.05	0.13	18.5	45.5	
1997	23-Jul	GR	324	357	1.05	5+			green/yellow 37				30-Jul-95	T1	293	277	1.10	4+	724	0.04	0.11	15.5	39.9	
1997	27-Jul	GR	344	403	0.99				green/yellow 27				30-Jul-95	T1	290	270	1.11	4+	728	0.07	0.18	27.0	66.7	
1997	23-Jul	GR	343	422	1.05	5+			green/yellow 14				08-Aug-95	T1	305	317	1.12	4+	715	0.05	0.15	19.0	52.6	
1997	06-Aug	GR	337	435	1.14	5+			green/yellow 27				30-Jul-95	T1	290	270	1.11	4+	738	0.06	0.22	23.5	82.5	
1997	27-Jul	RB	291	243	0.99	5+			green/yellow 00001				30-Jul-95	T1	235	145	1.12	3+	728	0.08	0.13	28.0	48.9	
1997	23-Jul	GR	327	407	1.16	5+				or/wt 209			26-Jul-96	T1	321	389	1.17	4+	362	0.02	0.05	6.0	18.7	
1997	23-Jul	GR	368	477	0.96	5+				or/wt 208			26-Jul-96	T1	374	586	1.12	7+ (6s)	362	-0.02	-0.30	-6.0	-109.2	
1997	27-Jul	GR	340	409	1.04	5+				or/wt 156			25-Jul-96	T1	325	387	1.13	5+	367	0.04	0.06	15.0	22.4	
1997	27-Jul	GR	345	466	1.14	5+				or/wt 236			15-Aug-96	T1	340	490	1.25	?	346	0.01	-0.07	5.0	-23.7	
1997	27-Jul	GR	333	421	1.14	5+				or/wt 238			15-Aug-96	T1	318	410	1.27	?	346	0.04	0.03	15.0	11.2	
1997	27-Jul	GR	303	314	1.13	5+				blue/white 116			24-Jul-96	T2	264	199	1.08	3+	368	0.11	0.31	39.0	115.2	
1997	06-Aug	GR	362	522	1.10	5+				or/wt 153			25-Jul-96	T1	340	417	1.06	5+	377	0.06	0.28	22.0	105.2	
1997	08-Aug	GR	332	447	1.22	5+				or/wt 209			26-Jul-96	T1	321	389	1.17	4+	378	0.03	0.15	11.0	58.5	
1997	27-Jul	GR	292	266	1.07	4+				or/wt 240			15-Aug-96	T1	261	210	1.18	?	346	0.09	0.16	31.0	56.2	
1997	27-Jul	GR	327	377	1.08					blue/white 00031			23-Jul-97	T1	327	377	1.08	4+						
1997	08-Aug	GR	315	365	1.17					blue/white 00053			27-Jul-97	T1	313	350	1.14	4+						
1997	08-Aug	GR	323	435	1.29					blue/white 00052			27-Jul-97	T1	324	423	1.24	4+						
1997	27-Jul	RB	273	235	1.16					blue/white 00030			23-Jul-97	T1	267	200	1.05	4+						
1997	23-Jul	GR	381	577	1.04	6+							found with orange tag 06179, origin unknown (but possibly T2)											
1997	08-Aug	GR	329	620	1.74	8+							found with yellow tag 6172, origin unknown (possibly T1 in 1993)											
1999	25-Jul	GR	388	730	1.25	9	or 6172						15-Aug-92	T1	333	425	1.15	5+	2535	0.02	0.12	7.9	43.6	
1999	20-Jul	GR	340	430	1.09	6							30-Jul-95	T1	293	277	1.10	4+	1451	0.03	0.11	11.8	38.3	
1999	30-Jul	GR	359	580	1.25	7			yellow/green 37				30-Jul-95	T1	297	302	1.15	4+	1461	0.04	0.19	15.5	69.5	
1999	25-Jul	GR	386	640	1.11	9			yellow/green 26				08-Aug-95	T1	368	560	1.12	5+	1447	0.01	0.06	4.5	20.1	
1999	25-Jul	GR	369	585	1.16	6			orange/white 156				25-Jul-96	T1	325	387	1.13	5+	1095	0.04	0.18	14.7	66.0	
1999	25-Jul	GR	369	570	1.13	6			orange/white 152				25-Jul-96	T1	280	222	1.01	3+	1095	0.08	0.32	29.7	115.9	
1999	04-Aug	GR	388	685	1.17	7			orange/white 153				25-Jul-96	T1	340	417	1.06	5+	1105	0.04	0.24	16.0	89.4	
1999	08-Aug	GR	357	550	1.21	5				blue/white 24			08-Aug-97	T1	275	243	1.17	3+	730	0.11	0.42	41.0	153.5	
1999	30-Jul	GR	323	400	1.19	5				blue/white 177			08-Aug-97	T1	251	195	1.23	3+	721	0.10	0.28	36.0	102.5	
1999	23-Jul	GR	353	525	1.19	5				blue/white 32			23-Jul-97	T1	320	361	1.10	4+	730	0.05	0.22	16.5	82.1	
1999	02-Aug	GR	355	510	1.14	6				blue/white 139			08-Aug-97	T1	339	435	1.12	5+	724	0.02	0.10	8.0	37.5	
1999	04-Aug	GR	346	590	1.42	6				blue/white 52			27-Jul-97	T1	324	423	1.24	4+	738	0.03	0.23	11.0	83.7	
1999	30-Jul	GR	384	670	1.18	6				blue/white 54			27-Jul-97	T1	349	488	1.15	4+	733	0.05	0.25	17.5	90.9	
1999	30-Jul	GR	389	680	1.16	7				blue/white 56			27-Jul-97	T1	378	578	1.07	6+	733	0.02	0.14	5.5	51.3	
1999	20-Jul	GR	308	350	1.20					blue/white 60			27-Jul-97	T1	245	176	1.20	3+	723	0.09	0.24	31.5	87.0	
1999	23-Jul	RB	301	305	1.12	4																		

APPENDIX I:

Mesilinka River T2 Reach angling recaptures and calculated growth rates

Year	date	sp.	In (mm)	wt (grams)	cf	age	1992 tag #	1993 tag #	1994 tag #	1995 tag #	1996 tag #	1997 tag #	original capture info				growth rates						
													date	reach	In	wt	cf	age	days between	In (mm/day)	wt (g/day)	In (mm/year)	wt (g/year)
1993	06-Aug	BT	670	2750	0.91		red 06125						11-Aug-92	cont.	620	2154	0.90	360	0.14	1.66	50	596	
1993	06-Aug	BT	570	1786	0.96		red 06091						10-Aug-92	T2	583	1530	0.77	361	-0.04	0.71	-13	256	
1993	24-Jun	RB	270			4+	gr 00345						31-Jul-92	T2	256	227	1.35	328	0.04		14		
1993	03-Jul	RB	339			5+	gr 00227						11-Jul-92	T2	330	397	1.10	357	0.03		9		
1993	24-Jun	RB	310	482	1.62	6+	gr 00220						11-Jul-92	T2	205	284	4+						
1993	18-Jul	RB	346	397	0.96	regen	reg 06096						10-Aug-92	T2	342	397	0.99	342	0.01	0.00	4	0	
1994	12-Jul	BT	660	2025	0.70		red 06081						no such tag number found										
1994	12-Jul	GR	294	306	1.20	5+	white 00001						18-Jul-93	T2	255	255	1.54	359	0.11	0.14	39	51	
1994	01-Aug	RB	265	241	1.30	4+	white 00042						06-Aug-93	T2	224	142	1.26	360	0.11	0.28	41	99	
1996	24-Jul	GR	318	353	1.10	4+			green 4098				15-Jul-95	T2	268	246	1.28	375	0.13	0.28	50	106.7	
1997	28-Jul	RB	265	162	0.87	4+			orange/white 00030				31-Jul-95	T2	191	69	0.99	728	0.10	0.13	37	46.25	
1997	09-Jul	GR	291	270	1.10	4+			blue/white 00104				24-Jul-96	T2	249	175	1.13	350	0.120	0.272	42	95.1	
1997	06-Aug	GR	304	315	1.12	4+			blue/white 00106				24-Jul-96	T2	264	206	1.12	378	0.106	0.288	40	108.8	
1997	11-Aug	GR	330	430	1.20	4+			orange/white 00151				25-Jul-96	T1	304	318	1.13	382	0.068	0.293	26	112	
1997	09-Jul	GR	373	500	0.96	7+			blue/white 00103				24-Jul-96	T2	365	572	1.18	350	0.023	-0.205	8	-71.6	
1997	11-Aug	GR	243	155	1.08				or 05144				06-Aug-97	T2	244	155	1.07	3+					
1997	11-Aug	RB	293	250	0.99	4+			or 05187				28-Jul-97	T2	293	263	1.05	3+					
1997	11-Aug	RB	267	200	1.05	4+			or 05272				06-Aug-97	T2	270	205	1.04	4+					
1997	11-Aug	RB	276	220	1.05	4+			or 05149				06-Aug-97	T2	278	247	1.15	4+					
1997	11-Aug	RB	260	200	1.14	4+			or 05148				06-Aug-97	T2	261	185	1.04	4+					
1997	11-Aug	RB	301	255	0.94	6+			or 05352				28-Jul-97	T2	300	268	0.99	4+					
1997	28-Jul	RB	302	242	0.88				or 05178				09-Jul-97	T2	299	237	0.89	4+					
1997	06-Aug	RB	340	348	0.89				or 05188				28-Jul-97	T2	333	372	1.01	5+					
1997	06-Aug	RB	263	200	1.10				or 05190				28-Jul-97	T2	261	187	1.05	3+					
1997	06-Aug	RB	282	245	1.09				or 05180				09-Jul-97	T2	280	230	1.05	3+					
1999	27-Jul	GR	342	500	1.25								06-Aug-97	T2	265	230	1.24	3+	720.0	0.107	0.375	38.5	135

APPENDIX J:

Mesilinka tributary supplemental water chemistry data.

Date	Alkalinity (mg/l)	pH (std. units)	Conductivity (uS/cm)	Filterable Residu (TDS) (mg/L)	Nonfilterable Residu (mg/L)	Turbidity (NTU)
Gopherhole Creek Site 1 (below fertilizer)						
28-Jun-93					13	0.7
26-Jul-93					< 4	0.2
20-Jun-95	38.2	7.4	85	88		0.3
11-Jul-95	35.3	7.3	81	68		0.4
25-Jul-95	51.2	7.4	105	94		0.4
01-Aug-95	57.0	7.3	103	90		0.5
13-Aug-95	63.1	7.5	135	110		0.3
29-Aug-95	43.8	7.0	125	78		0.2
14-Jul-96	36.6	7.8	70	70		0.6
18-Aug-96	53.1		102			0.1
26-Aug-96	53.1	8.0	111	80		0.2
02-Jul-97	43.3	7.8	88	70		0.4
13-Jul-97	49.9	8.0	98	70		0.2
30-Jul-97	55.7	7.9	108	80		0.4
13-Aug-97	58.6	7.9	116	80		0.2
27-Aug-97	60.7	8.1	121	80		0.6
Gopherhole Creek Site 2 (above fertilizer)						
26-Jul-93					5	0.1
13-Jun-95	32.0	7.0	68	52		0.2
20-Jun-95	30.9	7.4	65	152		0.3
11-Jul-95	28.7	7.2	68	58		0.3
25-Jul-95	33.7	7.3	88	92		0.5
01-Aug-95	43.6	7.4	82	86		0.5
13-Aug-95	49.3	7.3	109	98		0.4
29-Aug-95	37.0	6.9	112	76		0.2
Control Creek						
28-Jun-93					8	0.6
26-Jul-93					< 4	0.3
20-Jun-95	19.4	7.1	51	66		0.3
11-Jul-95	16.1	6.8	47	50		2.4
25-Jul-95	23.5	6.9	55	60		0.6
01-Aug-95	26.2	7.2	58	78		0.3
13-Aug-95	26.1	7.1	68	64		0.4
29-Aug-95	22.8	6.8	76	68		0.3
14-Jul-96	19.5	7.5	47	50		1.0
18-Aug-96	25.3	7.8	62	40		0.2
26-Aug-96	23.7	7.7	65	60		0.2
02-Jul-97	19.5	7.4	50	50		0.5
13-Jul-97	24.7	7.7	60	40		0.2
30-Jul-97	24.4	7.6	58	50		2.6
13-Aug-97	29.9	7.7	71	60		0.3
27-Aug-97	26.8		69	50		1.1
Carina Creek						
28-Jun-93					15	1.3
26-Jul-93					7	0.3
20-Jun-95	65.1	7.8	162	112		0.6
11-Jul-95	62.3	7.7	124	86		0.6
25-Jul-95	47.5	7.6	143	102		1.2
01-Aug-95	61.8	7.5	138	156		0.7
13-Aug-95	70.8	7.6	147	120		0.5
29-Aug-95	71.1	7.4	212	122		0.7
14-Jul-96	65.7	8.0	145	110		1.0
30-Jul-96	71.9	8.0	153	100		1.0
18-Aug-96	75.9	8.2	161	100		0.4
26-Aug-96	75.1	8.2	167	110		0.4
02-Jul-97	67.2	8.0	148	100		1.2
13-Jul-97	75.2	8.1	160	90		1.1

APPENDIX J:

Mesilinka tributary supplemental water chemistry data.

Date	Alkalinity (mg/l)	pH (std. units)	Conductivity (uS/cm)	Filterable Residu (TDS) (mg/L)	Nonfilterable Residu (mg/L)	Turbidity (NTU)
30-Jul-97	77.1	8.1	160	100		1.0
13-Aug-97	80.4	8.1	173	100		0.6
27-Aug-97	79.1	8.2	118	100		1.5
Culvert Creek Site 1 (above fertilizer)						
20-Jul-92				52		
23-Aug-92				78		
13-Sep-92				72		
28-Jun-93					12	0.8
26-Jul-93					< 4	0.2
20-Jun-95	22.4	7.2	62	64		0.2
11-Jul-95	14.9	6.8	44	44		1.3
25-Jul-95	32.1	7.1	61	76		0.4
01-Aug-95	34.2	7.2	66	66		0.5
13-Aug-95	34.9	7.0	86	70		0.3
29-Aug-95	26.1	6.5	94	74		0.3
14-Jul-96	22.6	7.5	55	50		0.6
18-Aug-96	34.4	7.9	78	40		12.0
26-Aug-96	31.2	7.9	80	50		0.2
02-Jul-97	22.5	7.5	55	50		0.8
13-Jul-97	29.3	7.8	69	60		0.2
30-Jul-97	33.0	7.7	72	60		2.6
13-Aug-97	37.3	7.8	74	60		0.3
27-Aug-97	36.3	7.8	84	70		3.1
Culvert Creek Site 2 (above fertilizer)						
26-Jul-93					< 4	0.1
13-Jun-95	16.1	7.1	44	41		0.2
20-Jun-95	17.3	7.1	53	122		0.2
11-Jul-95	11.8	6.7	36	46		0.7
25-Jul-95	22.3	7.0	58	68		0.6
01-Aug-95	26.3	7.0	55	122		0.3
13-Aug-95	25.7	6.7	72	74		0.3
29-Aug-95	19.3	6.3	81	64		0.3
Fatfish Creek						
28-Jun-93					< 4	0.6
26-Jul-93					< 4	0.4
20-Jun-95	38.1	7.3	95	92		0.3
11-Jul-95	25.3	7.0	62	50		0.4
25-Jul-95	29.7	7.1	92	74		0.7
01-Aug-95	45.3	7.2	103	124		0.6
13-Aug-95	49.6	7.3	108	94		0.4
29-Aug-95	41.0	7.1	134	76		0.5
14-Jul-96	51.5	7.7	105	100		1.0
30-Jul-96	48.8	7.7	105	80		0.8
18-Aug-96	52.7	7.9	112	80		0.6
26-Aug-96	51.5	7.8	120	80		0.4
02-Jul-97	32.3	7.5	75	60		1.1
13-Jul-97	42.9	7.8	96	60		1.2
30-Jul-97	40.1	7.6	90	60		2.5
13-Aug-97	44.9	7.7	103	70		0.7
27-Aug-97	52.6	7.8	118	80		0.7

APPENDIX K

Mark-recapture results and statistics for tributary mark-recapture, 1992-97. (see Methods Section for explanation of values)

Bull Trout

Tributary	Year	M	C	R	N	Areal Density (# per 100 m ²)
Gopherhole	1992	2	3	2	3	1
	1993	10	7	3	21	3
	1994	6	7	1	27	7
	1995	35	35	11	110	20
	1996	29	19	8	67	8
	1997	55	35	7	252	n/a ^a
Culvert	1992	9	4	1	24	5
	1993	7	5	2	15	2
	1994	16	7	1	67	5
	1995	35	39	15	89	13
	1996	24	19	4	100	10
	1997	Not shocked				
Control	1992	13	4	4	13	4
	1993	11	15	2	63	11
	1994	17	9	2	59	8
	1995	33	27	8	104	21
	1996	31	33	10	99	19
	1997	22	8	0	207	36

^a areal estimate unavailable as shocking area not recorded

Rainbow Trout

Tributary	Year	M	C	R	N	Areal Density (# per 100 m ²)
Gopherhole	1992	16	6	4	22	6
	1993	6	5	1	20	3
	1994	0	1	0		
	1995	7	10	2	28	5
	1996	6	3	2	9	1
	1997	3	7	2	11	n/a ^a
Culvert	1992	7	9	2	25	5
	1993	3	16	2	21	3
	1994	16	8	4	29	2
	1995	2	3	1	5	1
	1996	8	8	6	12	1
	1997	Not shocked				
Control	1992	9	10	8	11	3
	1993	6	1	0		
	1994	1	1	1	1	<1
	1995	2	2	1	3	1
	1996	0	0	0		
	1997	1	0	0		

^a areal estimate unavailable as shocking area not recorded

Mountain Whitefish

Tributary	Year	M	C	R	N	Areal Density (# per 100 m ²)
Gopherhole	1992	3	5	3	5	1
	1995	1	0	0		
Culvert	1992	3	3	1	7	1
	1993	5	11	3	17	2
	1994	8	3	0		
Control	1992	5	5	4	6	2
	1993	1	2	0		
	1994	1	0	0		
	1995	1	0	0		
	1996	0	1	0		
	1997	1	0	0		