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Development of a Premier Northern River Fishery: Mesilinka River, the Fourth Year of Fertilization (1997)

G. A. Larkin, G. A. Wilson, K. I. Ashley, P. A. Slaney, R. W. Land and S. Biancolin
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Development of a Premier Northern River Fishery:

Mesilinka River, the Fourth Year of Fertilization (1997)

by

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ABSTRACT

G.A. Larkin, G. Wilson, K.I. Ashley, P.A. Slaney, R.W. Land and S. Biancolin. 1999. Development of a premier northern river fishery: Mesilinka River, the fourth year of fertiliztion (1997). B.C. Ministry of Environment, Lands and Parks, Fisheries Project Report No. RD70.

The addition of inorganic nutrients to increase fish production in the Mesilinka River, a northern interior river of British Columbia, is being investigated. Increased production of native stocks is desired to both offset negative impacts following the establishment of the Williston Reservoir and to meet increased angling demands for stream fisheries. 1997 was the fourth of four proposed years of fertilization of the Mesilinka mainstem. Three reaches on the Mesilinka River (an upstream control reach - Blackpine, and two downstream treatment reaches - Tl and T2) and an additional external reference system (the Nation River) were established in 1992 to monitor the effects of added nutrients on stream production. In 1997, inorganic fertilizer was added upstream of each of the two treatment reaches. Actual loading rates of nitrogen (N) and phosphorous (P) were 71 and 64 % of the target loadings of 15 and 5 µg•L^{-1} , respectively. SRP concentrations measured in the Mesilinka River in 1997 were predominantly at or below the detection limit of 1 µg•L^{-1}. Total organic nitrogen (TON) concentrations measured in the Mesilinka River were generally below 100 µg•L^{-1} in all three reaches throughout the sampling period, and declined through the growing season. NO_3+NO_2-N levels were elevated throughout July and early August in 1997 as compared to previous years of the project, particularly in the T2 reach where concentrations of 179 and 134 µg•L^{-1} were measured. Peak periphyton accrual measured in all three reaches of the Mesilinka River in 1997 was greater than that measured in 1996. The greatest accrual and accrual rate was recorded in the Tl reach (32.2 mg•m^{-2}; 0.59 mg•m^{-2}•day^{-1}). Mean biomass of benthic invertebrates collected in sampling baskets during 1997 was greatest in the Tl reach (538 mg•0.005 m^{-3}), followed by the T2 reach (294 mg•0.005 m^{-3}), and the Blackpine (control) reach (174 mg•0.005 m^{-3}). These biomasses all succeed those measured in 1996, and as in noted in previous years, dipterans dominated the invertebrate population in the two treatment reaches. Weight-at-age and length-at-age data for rainbow trout and Arctic grayling angled from the Mesilinka River in 1997 were low when compared to data from previous years, possibly attributable to the less than ideal growing conditions in 1996. Densities for bull trout, Arctic grayling and mountain whitefish were greatest in the Tl reach in 1997 (5.7, 1.0, 71 ha^{-1}, respectively). Rainbow trout densities were greatest in the T2 reach (7.3 ha^{-1}).

Observations since fertilization commenced indicate that the two treatment reaches, Tl and T2, have responded differently to the addition of inorganic nutrients. Two hypotheses were first proposed after the second of the four fertilization years regarding the different responses of Tl and T2. A fish density response would be indicated by an increase in density of fish populations following fertilization. This increase would result in increased predation on benthic invertebrates, and subsequently, a lower invertebrate population would permit standing stocks of periphyton to increase. Little change in fish densities, but an increase in invertebrate population, would indicate a fish growth response. Higher invertebrate abundance would result in better fish growth, and a decrease in standing stocks of periphyton.

In the Tl reach, observations suggest that the addition of inorganic nutrients has produced a fish density response. In the T2 reach, observations indicate that fertilization of this reach has resulted in both a fish growth and a fish density response. The purpose of the Mesilinka River Fertilization Experiment has been to determine whether fertilization is a suitable technique to increase production of native fish species, especially Arctic grayling, bull trout, and rainbow trout, within the Williston Reservoir watershed.

Despite the fact that addition of liquid fertilizer was consistently below target concentrations, increased density and size of rainbow trout are evident in both treatment reaches of the Mesilinka River. As well, increases in mountain whitefish densities have been substantial. Fertilization of the Mesilinka River is continuing for an additional four years, with bi-annual sampling of the fish population. The further response of the fish population will determine the fate of Mesilinka River fertilization, and the proposed fertilization of other candidate systems.

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Taxonomic identification and enumeration of benthic invertebrates was prepared by Fraser Environmental Services, #16 - 9324 126th Street, Surrey, B.C., V3V 6A4.

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INTRODUCTION

Indices of nutrients, including conductivity, dissolved solids and alkalinity, have been reported as positively correlated with salmonid abundance in streams (McFadden and Cooper 1962; Egglishaw 1968). Despite this, inorganic fertilization of streams, as a means to increase the invertebrate food supply to enhance growth and abundance of salmonids in oligotrophic waters, has received only limited attention as a potential habitat restoration, enhancement or mitigation technique (Hall and Baker 1982). This neglect may arise from confusion about the role of allochthonous and autochthonous energy flow in forested stream ecosystems (Johnston *et al.* 1990), regardless of strong evidence that primary production drives food chains in larger streams (Minshall 1978). Also, perhaps a tarnished history of pollution from cultural eutrophication and contaminated waters (Hynes 1971) delayed research on nutrient limitation of the productivity of stream ecosystems, in spite of a very early study by Huntsman (1948), that suggested inorganic fertilization could increase salmonid production by stimulating aquatic insect growth.

Food abundance functions through territory size as a determinant factor affecting the abundance and growth of salmonids, and thus the carrying capacity of streams. Additions of inorganic nutrients to oligotrophic streams increases periphytic production at the base of the food chain (Stockner and Shortreed 1978; Peterson *et al.* 1985; Perrin *et al.* 1987). This in turn can increase 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). As such, controlled seasonal increases in nutrient concentrations, which can be easily controlled and readily reversed, should be beneficial to fish production in oligotrophic streams, similar to the routine fertilization of salmon nursery lakes to enhance commercially important sockeye salmon in British Columbia and Alaska (e.g., Hyatt and Stockner 1985).

The use of nutrients to maintain 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). Non-native invertebrate species introduction (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 and Thompson 1993). 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.* 1993), thus maintaining biodiversity (Quamme 1994).

Research has been conducted on stream fertilization for over a decade on Vancouver Island, British Columbia, firstly at the Keogh River during the 1980s (Slaney *et al.* 1986), and then recently at the Salmon River (Johnston *et al.* 1990), Big Silver Creek (Toth *et al.* 1993, 1996a, 1996b) and the Adam River (Slaney *et al.* 1993; Toth *et al.* 1997a, 1997b; Wilson *et al.* 1997). The primary objective of these studies was to establish the effect of nutrient additions on the growth and abundance of anadromous salmonids in oligotrophic streams, and determine if controlled seasonal enrichments are a cost-effective enhancement or restoration technique. A more recent focus of fertilization work has been as a possible mitigation technique for logging impacts on overwinter survival of juvenile steelhead (Salmon River).

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 *(T. arcticus)*, bull trout *(Salvelinus confluentus)*, and rainbow trout *(O. mykiss)*, within the Williston Reservoir watershed. Nutrient levels in the Mesilinka are extremely low indicating that the river and its main tributaries are highly oligotrophic. Also, 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. Bennett dam in 1968-70 (Blackman 1992). Critical over-wintering refuges and foraging zones were lost, especially for 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 following impoundment. Therefore, increased grayling production through river fertilization may partially offset the loss in grayling stocks from habitat loss. User surveys within the Williston watershed indicate that angling preference favours rivers over small lakes, and especially over the reservoir (B.C. Hydro 1990). Decreased riverine habitats from impoundment will thus be subject to increased angling pressure. Furthermore, stream fisheries are sensitive to overharvest and decreased quality following increased angling pressure (Slaney 1986). Therefore, river fertilization may develop destination fisheries that can support increased angling pressure while alleviating pressure on other unfertilized systems within the watershed.

A sampling program has been conducted on three reaches of the Mesilinka River, several key nursery tributaries, and the Nation River since 1992. The first two years of this study (1992-93) obtained baseline (pre-fertilization) measurements on discharge, temperature, nutrients, periphyton, invertebrates, and fish communities. Mainstem fertilization began in 1994, and field sampling regimes have been conducted annually to assess both chemical and biological responses. In 1993 and 1995, two tributaries of the Mesilinka were also fertilized (Culvert and Golpherhole creeks; liquid fertilizer in 1993, slow release briquettes in 1995). The Nation River has been concurrently but less intensively sampled to serve as an external reference system. This report documents methods and results for the 1997 field season, the fourth year of fertilization, and examines the project results to date.

BACKGROUND AND STUDY AREA

Peace/Williston Fish and Wildlife Compensation Program

Establishment of the Williston Reservoir in 1968-1972 flooded substantial portions of area rivers, resulting in the loss of riverine habitats utilized by salmonids, Arctic grayling and mountain whitefish. The present Mesilinka project is one mitigation option to compensate for loss of fish habitat. Consistent with angler demand, the Peace/Williston Fish and Wildlife Compensation Program places primary emphasis on enhancement of streams and small lakes by means of pilot projects coupled with evaluations. The fish component of the Peace/Williston Fish and Wildlife Compensation Program operates on the basis of a notional fund, of which only the annual interest is utilized to deliver program goals. In this way, funding and program continuance may be possible in perpetuity.

Mesilinka River and Tributaries

The Mesilinka is a large northern river located 280 km north of Prince George, British Columbia (Fig. 1). The headwaters originate in the Omineca mountain range and the river flows for a distance of approximately 120 km to Williston Reservoir. Williston Reservoir was formed behind the W.A.C. Bennett Dam during the 1960s to provide hydroelectric energy, and is part of the Peace-Slave-MacKenzie river system, which ultimately flows north and discharges into the Arctic Ocean.

The mid- to lower portion of the Mesilinka River was used to examine the effects of fertilization (Fig. 2). This section was chosen because (1) temperatures are warmer than upper reaches, (2) nitrogen (N) may not be as limiting in the lower portions due to groundwater input of N, and (3) the lower portion has several road access points making it more suitable for fertilizer delivery (Koning *et al.* 1995). Three study reaches of the mid to lower river were established in 1992, and maintained in subsequent years to facilitate a before and after unreplicated experiment (Stewart-Oaten *et al.* 1986). A control reach (Blackpine) was located approximately 30 km and 60 km upstream of the upper treatment reach (Tl) and lower treatment reach (T2), respectively.

Several tributaries flow into the mid- to lower portion of the Mesilinka River. A number of these tributaries provide rearing habitat for juvenile rainbow trout, bull trout, and mountain whitefish (Koning *et al.* 1995). Five tributaries (Carina, Control, Culvert, Fatfish and Gopherhole creeks) in the vicinity of the two treatment reaches have also been studied to assess their rearing potential for juvenile fish. Two of these creeks (Culvert and Gopherhole) were fertilized in 1993 with liquid fertilizer and in 1995 with slow release fertilizer briquettes to assess whether fertilization could enhance juvenile growth and recruitment.

Wild rainbow trout *(O. mykiss)*, Arctic grayling *(T. arcticus)* and mountain whitefish *(Prosopium williamsoni)* populations inhabit the Mesilinka River, as well as smaller populations of bull trout *(S. confluentus)*. Aside from bull trout, adult salmonid fish are small in size (mean < 30 cm). Salmonid spawning and rearing habitat is found primarily in tributaries of the Mesilinka River and these include 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 northern squawfish *(Ptychocheilus oregonensis)*.

Forests within the Mesilinka watershed (area 3,285 km^2) 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 1970s, with harvesting primarily of white spruce, lodgepole pine *(Pinus contorta)* and subalpine fir. 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. Most activity has occurred in the lower watershed where approximately 30-35% of the area has been logged. In the upper portion of the Mesilinka watershed, only 5% has been logged (J. Thomas, Chief Forester, Finlay Forest Industries Inc., Mackenzie, B.C., pers. comm.). The extent of these impacts in the Mesilinka watershed are undocumented, but past logging to the streambank of some of the tributaries and within sections of the mainstem has likely been detrimental to fish habitat.

Nation River

The Nation River is located approximately 100 km south of the Mesilinka River and also flows southeast into Williston Reservoir, draining a watershed of 5,880 km^2. The river is headed by a chain of five large lakes (the Nation lakes) that are situated at the southern end of the Omineca mountains (Fig. 1). Mean summer water temperatures and flow rates in the Nation 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 flow rates coupled with nitrogen-limitation would necessitate larger (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 produced the desired results in a cost-effective manner, the Nation River would be a candidate for subsequent fertilization in the Peace/Williston Fish and Wildlife Compensation Program.

METHODS AND MATERIALS

Methods utilized in 1997 were consistent with those followed in previous years for the Mesilinka River (Koning *et al.* 1995; Paul *et al.* 1996, 1998; Wilson *et al.* 1999). Mesilinka Fertilization Project methods are similar to those of other fertilization projects conducted by the Fisheries Research and Development Section of the B.C. Ministry of Environment, Lands and Parks, such as on the Adam River (Slaney *et al.* 1993; Toth *et al.* 1997a, 1997b; Wilson *et al.* 1997) and Big Silver Creek (Toth *et al.* 1993, 1996a, 1996b).

Hydrology

Mesilinka River discharges in 1997 were obtained from the Water Survey of Canada (WSC interim data; Lynne Campo, WSC, pers, comm.) for station 07EC003 located upstream of Golpherhole Creek. Nation River discharges were obtained for WSC station 07ED003, located near its mouth. The Mesilinka River on-site discharge, used to calibrate fertilizer drip rates, was determined using a stage-discharge relationship established with 1993-94 WSC flow data and a staff gauge located at the Blackpine station (Paul *et al.* 1996).

Stream discharge was determined for Carina, Control, Culvert, Fatfish, and Golpherhole creeks from water level gauges installed near the mouth of each tributary and associated stage-discharge relationships. In addition, instream discharge was calculated by summing discharges from subsections of the stream's cross section; discharge for each section were determined as the cell depth x cell width x current velocity (as determined by a Marsh-McBirney current meter).

Water Temperatures

To aid in the assessment of salmonid growth potential in the Mesilinka system, water temperatures were measured in the mainstem and tributaries during the 1997 growing season. Onset Instruments Stowaway miniature data loggers were used in the mainstem control reach (Blackpine), and below the T2 reach at Gratton's camp. Temperatures in Carina, Control, Fatfish, and Golpherhole creeks with were also monitored with Onset Stowaway loggers, located at the water chemistry sites near the mouth of each creek. Daily maximum, minimum and average temperatures were calculated from the data records from the loggers (which recorded temperature every 2 h). Annual water temperature data reports were also consulted (Langston 1993-96; Zemlack and Langston, 1997). Nation River temperatures were measured with Ryan TempMentors.

Fertilization

Mesilinka Mainstem

Fertilization of the Mesilinka River was conducted according to the same protocols as previous years, with solutions of phosphorus (ammonium polyphosphate; 10-34-0; % by weight $N-P_2O_5-K_2O$) and nitrogen (urea-ammonium nitrate; 28-0-0) based fertilizers metered into the mainstem. The fertilizers were stored in individual tanks, and dripped into the river through separate valve systems (see Larkin *et al.* 1997 for a review of liquid fertilization technologies). On each site visit (3-4 days apart), river discharge was estimated from the Blackpine staff gauge and the established stage-discharge relationship. Fertilizer drip rates were adjusted manually according to current flow conditions to increase downstream phosphorus and nitrogen concentrations by 5 $\mu g \bullet L^{-1}$ by 15 $\mu g \bullet L^{-1}$, respectively. The drip rates measured both on arrival at the site and after adjustment were recorded and used to calculate fertilizer loading to the river. Drip rates were calculated from the mean of three repeated volumetric measurements of fertilizer taken over 2 min. Table 1 summarizes fertilizer additions to the Mesilinka mainstem during the project.

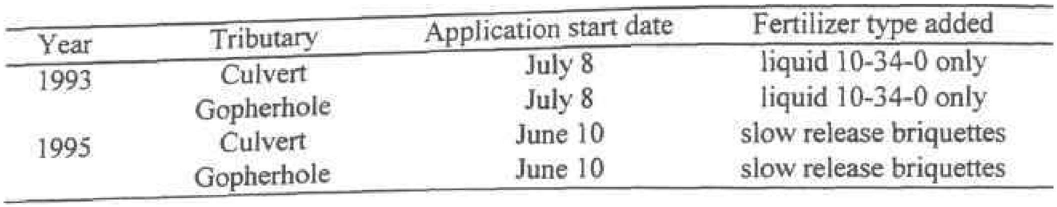
Table 1. History of fertilizer additions to the Mesilinka River mainstem

Year	Application start date	Reach	Fertilizer type added
1994	June 28	Tl	liquid 10-34-0 and 28-0-0
	June 28	T2	liquid 10-34-0 only
1995	June 27	Tl	liquid 10-34-0 and 28-0-0
	June 27	T2	liquid 10-34-0 and 28-0-0
1996	July 5	Tl	liquid 10-34-0 and 28-0-0
	July 5	T2	liquid 10-34-0 and 28-0-0
1997	June 29	Tl	liquid 10-34-0 and 28-0-0
	June 29	T2	liquid 10-34-0 and 28-0-0

Mesilinka Tributaries

Culvert and Gopherhole creeks were initially fertilized in 1993 with liquid phosphorus (ammonium polyphosphate; 10-34-0; % by weight $N-P_2O_5-K_2O$) based 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 too difficult due to the small flows associated with these streams (Koning *et al.* 1994), and therefore did not continue in 1994. In 1995, fertilization of these tributaries was carried out using solid 'slow release' fertilizer briquettes (7-40-0; % by weight $MgNH_4-PO_4-H_2O$) designed to dissolve gradually throughout the summer. 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 and Golpherhole received 111 kg. In each stream, the fertilizer was distributed approximately 4-5 km upstream from its confluence with the Mesilinka River, in riffle areas of approximately 40-50 cm depth. A full report of this experimental product can be found in Mouldey and Ashley (1996). Table 2 summarizes fertilizer additions to Mesilinka tributaries.

Table 2. History of fertilizer additions to Mesilinka River tributaries



Year	Tributary	Application start date	Fertilizer type added
1993	Culvert	July 8	liquid 10-34-0 only
	Gopherhole	July 8	liquid 10-34-0 only
1995	Culvert	June 10	slow release briquettes
	Gopherhole	June 10	slow release briquettes

Water Chemistry

Dissolved nutrients were monitored in the Mesilinka system during the 1997 growing season to determine nutrient loading from the tributaries and nutrient changes in the mainstem in response to fertilizer applications. As in previous years, samples were collected biweekly to monthly from each of the mainstem reaches, as well as from Carina, Control, Culvert, Fatfish, and Golpherhole creeks, and the Nation River. Diurnal samples (samples collected at 4 h intervals over a 24 h period) were also collected at the Gratton's Camp site on August 13, 1997.

All water chemistry samples were collected and processed as described by Perrin *et al.* (1987). Samples collected were immediately placed on ice in a cooler and transported within two days to Zenon Environmental Laboratories in Burnaby, B.C., or the Pacific Environmental Science Center (PESC) in North Vancouver, B.C.. Standard methods of analysis as described in APHA (1992) were conducted to determine soluble reactive phosphorus (SRP), total dissolved phosphorous (TDP), nitrate and nitrite-nitrogen (NO_3+NO_2-N), ammonia-nitrogen (NH_3-N), and total organic nitrogen (TON) concentrations.

Periphyton Accrual

As a measure of primary production, periphyton accrual on an artificial substrate was measured in Mesilinka mainstem reaches, tributaries, and the Nation River. 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 block and placing both (styrofoam side up) in 25-40 cm of water with a moderate velocity (15-30 $cm \cdot sec^{-1}$), as described in Perrin *et al.* (1987). As water levels varied, blocks were moved to ensure they were neither washed away nor left dry. Replicate cores (5.7 cm^2 each) of styrofoam substrata were extracted from each block, at approximately biweekly intervals, and placed in plastic vials. The vials were wrapped in aluminum foil to exclude light, then stored on ice in a cooler for transportation until their extraction with 90% acetone and spectrophotometric determination of chlorophyll *a* (Strickland and Parsons 1972). The chlorophyll *a* value for each site was determined as the mean value from replicate samples. Periphyton accrual rates in each reach were calculated by dividing the peak chlorophyll *a* concentrations recorded during each incubation period by the number days that the periphyton block had spent in the stream.

Benthic Invertebrates

The response of aquatic invertebrates to fertilization was assessed by measuring colonization in artificial substrates (Slaney and Ward 1993). The artificial substrate consisted of a cylindrical plastic basket (22 cm diam.; 13 cm depth; 0.005 m^3 volume) filled with 1-3 cm diameter clean gravel. During the 1997 growing season, groups of baskets were placed in the Nation River and in the Blackpine, Tl, and T2 reaches of the

Mesilinka mainstem. Baskets were placed in approximately 40 cm of water, surrounded by cobbles, and left to colonize with invertebrates for six 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) with invertebrates and detritus collected and placed directly in ethanol. All samples were taken to the Ministry of Environment research facility at the Fraser Valley Trout Hatchery where they were stained with Rose Bengali, and all invertebrates separated from detritus with the aid of a 10X-dissection microscope. After the samples were blotted and allowed to air dry for 2-3 min to remove excess preservative, total wet-weight of invertebrates in each basket was determined with an electronic balance. Invertebrates collected were also identified to the lowest taxonomic group feasible to determine if nutrient addition has caused any shift in population composition.

Estimated Fish Growth, Abundance and Size Distribution

Adults

Fish were sampled and tagged from three reaches of the mainstem Mesilinka River in July and August using standard angling techniques with barbless hooks. Weight, fork length, tag colour, tag number, location and condition of fish at release were recorded for all angled fish. Scale samples (fin rays from bull trout) to determine age were taken, processed, and read as described in Ward and Slaney (1988). Fish >20 cm in fork length were tagged at the base of the dorsal fin with colour coded (Floy) tags. Fish were given tags colour-coded to the reach from which they were captured (Blackpine - orange/white; Tl - blue/white; T2 - fluorescent orange; Table 3 summarizes floy tag colours used throughout the project). The purpose of the different coloured tags was to facilitate mark-recapture population estimation, and allow growth estimation upon recapture. Angling was also conducted in the Nation River during July, with species, weight, fork length, and capture location recorded, and scale samples taken for each fish caught.

Table 3. Floy-tag colors used in mark/recapture population estimates in the Mesilinka River, 1993-1997.

	Reach		
	Blackpine	Tl	T2
1993	Pink	Yellow	White
1994	Green	Orange	Red
1995	Blue/white	Green/yellow	Orange/white
1996	Green/yellow	Orange/white	Blue/white
1997	Orange/white	Blue/white	Fluorescent orange

Peterson mark-recapture estimates of fish population were conducted in 1992-1995 and 1997, employing standardized underwater fish counts as the recapture phase (recapture by observation). No underwater surveys were completed in 1996 due to inclement conditions. Duplicate underwater counts were carried out 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 (Slaney and Martin 1987; Rogers *et al.* 1992). All counts at the Mesilinka River were conducted later in the day (typically 1100 - 1600 h) when temperatures were 12-14 °C, and when visibility was 3-6 m. Also, a minimum 10 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, and attempted to maintain an equal distance from other swimmers while counting fish to the front and to one side of themselves. The four mid-lane counts were expanded over the mid-channel width, then the shore lane counts were added, to get the expanded results. Table 4 summarizes the underwater fish counts conducted during the project.

Table 4. Summary of underwater fish counts conducted in the Mesilinka River, 1992-1997.

Year	Swim dates	Reach	Swim distance (km)	No. of swimmers	Mean reactive distance (m)	Mean wetted width (m)	River discharge $(m^3 \bullet s^3)$
1992	Aug. 22, 23	Blackpine	7.5	6	4.2	37.6	23
	Aug. 20, 21	Tl	7.2	6	4.0	40.8	26
	Aug. 18, 19	T2	8.1	6	4.0	38.7	27
1993	Aug. 16, 17	Blackpine	7.5	6	3.8	37.6	46
	Aug. 18, 20	Tl	7.2	6	4.0	40.8	43
	Aug. 19	T2	8.1	6	4.0	38.7	43
1994	Aug 17, 19	Blackpine	6.5	6	2.3	45.7	43
	Aug. 15, 16	Tl	6.5	6	2.5	52.0	47
	Aug. 18	T2	8.0	6	2.0	37.2	42
1995	Aug. 16	Blackpine[a]	7.5	6	2.5	38.5	50
	Aug. 14, 15	Tl	7.2	6	3.2	43.0	37
		T2	No swims completed				
1996	No swims completed						
1997	Aug. 20	Blackpine	7.5	6	2.8	37.8	43
	Aug. 18, 19	Tl	7.2	6	3.1	43.5	47
	Aug. 21, 22	T2	8.1	6	3.4	40.1	40

[a] no replicate swim conducted due to inclement weather

Juveniles

Size distribution of juvenile fish from the tributaries (Control and Gopherhole creeks) was obtained from electroshocking suitable rearing habitat in each site. All fish captured (except sculpins) were anaesthetized, measured to the nearest 1 mm, 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 of juveniles was estimated using a Pearson mark-recapture technique. Fish captured by electroshocking within a 100-200 m section of good rearing habitat (isolated with up and downstream stop nets) had their lengths and weights recorded and were marked with a clip. 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 h after releasing the fish and was approximately equal in shocking time to the marking phase. Fish captured were weighted, measured, and inspected for clips. Total salmonid abundance (rainbow trout, bull trout, and mountain whitefish) was calculated using Chapman's modification of the Lincoln-Peterson mark-recapture estimation:

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

where M is the number of individuals marked in the first sample, C is the number of individuals captured in the second sample, and R is the number of recaptures (White *et al.* 1982). The area shocked was calculated by multiplying length between stop nets with mean wetted width, then density determined by dividing total abundance by area shocked. Table 5 summarizes the capture of juveniles in Mesilinka River tributaries throughout the project.

Table 5. Overview of juvenile fish collection in Mesilinka River tributaries, 1992-1997

Year	Tributary	Assessment method
1992	Carina	Traps (June - Sept.)
		Electroshocking (open site, Aug. 21; close site, Sept. 10)
	Control	Traps (June - Sept.)
		Electroshocking (open site, Aug. 20; mark/recapture Sept. 6)
	Culvert	Traps (June - Sept.)
		Electroshocking (open site Aug. 20; mark/recapture Sept. 6)
	Gopherhole	Traps (June - Sept.)
		Electroshocking (open site Aug.; mark/recapture Sept. 6)
	Tutuzzi	Electroshocking (open site, Sept. 7)
1993	Carina	Electroshocking (mark/recapture Sept.)
	Control	Traps (July - Aug.)
		Electroshocking (open site July 18, Aug.; mark/recapture Sept)
	Culvert	Traps (July - Aug.)
		Electroshocking (open site July 7, July 18, Aug.; mark/recapture Sept)
	Gopherhole	Traps (July - Aug.)
		Electroshocking (open site July 7, July 18, Aug. 8; mark/recapture Sept)
	Fatfish	Electroshocking (open site Aug.)
1994	Control	Electroshocking (open site July; mark/recapture Sept. 1)
	Culvert	Electroshocking (open site July; mark/recapture Sept. 3)
	Gopherhole	Electroshocking (open site July; mark/recapture Sept. 1)
1995	Control	Electroshocking (mark/recapture Aug. 11)
	Culvert	Electroshocking (mark/recapture Aug. 12)
	Gopherhole	Electroshocking (mark/recapture Aug. 18)
1996	Control	Electroshocking (mark/recapture Aug. 21)
	Culvert	Electroshocking (mark/recapture Aug. 21)
	Gopherhole	Electroshocking (mark/recapture Aug. 20)
1997	Control	Electroshocking (mark/recapture Aug. 22)
	Gopherhole	Electroshocking (mark/recapture Aug. 23)

Stable Isotope Analysis

Stable nitrogen and carbon ratios in food webs from the Mesilinka River were analyzed in 1994 to trace the fate of introduced fertilizers, determine primary carbon sources and examine the trophic relations of organisms. Organisms (algae, invertebrates and fish) at each food web level were collected from 2 sites (2 km and 1 km) upstream of the upper (Tl) 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 (T2) 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 ^{15}N:^{14}N 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 methology and results can be found in the 1994 Mesilinka report by Paul *et al.* (1996)

RESULTS AND DISCUSSION

Hydrology

Discharges measured in the Mesilinka River in 1997 were slightly above means for the previous five years of the study period (Fig. 3). Mean June through September discharges in 1997 were 193.0, 95.1, 59.5 and 48.4 $m^3 \bullet s^{-1}$, respectively; corresponding discharges from 1992-1996 were 161.8, 105.3, 51.5, and 37.3 $m^3 \bullet s^{-1}$. The freshet was largely concentrated over a two-week period in mid-June when peak daily discharges were well above 300 $m^3 \bullet s^{-1}$. Mean June through September discharges over the entire study period (1992-1997) were 167.0, 103.6, 52.8, and 39.2 $m^3 \bullet s^{-1}$.

Spring runoff in the Nation River in 1997 was largely concentrated in two peaks, the first in mid-May, and a second in early June (Fig. 3). The mid-May peak resulted in the largest mean May discharge observed during the project (473.1 $m^3 \bullet s^{-1}$). Mean June to September discharges in 1997 of 466.9, 138.8, 50.5, and 41.6 $m^3 \bullet s^{-1}$ were all above 1992-1996 means for the same months (282.6, 109.7, 47.0, and 34.6 $m^3 \bullet s^{-1}$). Mean June through September discharges over the entire study period (1992-1997) were 313.3, 114.6, 47.6, and 35.8 $m^3 \bullet s^{-1}$.

Discharges determined in Mesilinka River tributaries in 1997 were generally low as compared to previous years (Fig. 4). As monitoring was only conducted from mid-July through August in 1997, the majority of the spring snowmelt contribution to discharges would have already been complete. Discharges in Fatfish and Gopherhole creeks were below 1 $m^3 \bullet s^{-1}$ for the entire period monitored, and discharges in Control and Culvert creeks were below 2 and 3 $m^3 \bullet s^{-1}$, respectively. Only one measurement was available for Carina Creek. Discharge in individual tributaries was quite varied over the course of the project, as would be expected in response to meterological conditions. Variation is also noted among the tributaries in any given year. Discharge in Carina Creek in tempered by an upstream lake. Control, Culvert, and Gopherhole creek discharges fluctuate considerably over the summer. Fatfish Creek discharges measured were relatively constant over the monitoring period, and all below 1 $m^3 \bullet s^{-1}$.

Water Temperatures

In 1997, mean July and August water temperatures in the Mesilinka River were 10.8 °C and 11.8 °C at the Blackpine station, and 11.8 °C and 12.7 °C at the Gratton's Camp site (Fig. 5). These summer water temperatures are a return to typical values (i.e., similar to 1992-1995 observations) after markedly colder values recorded in 1996 (the coldest during the project; July/August 1996 mean = 8.7 °C). Over the six years of the study period, mean July and August water temperatures were 10.8 and 11.5 °C at the Blackpine site, and 11.5 and 12.1 °C and Gratton's Camp site. The temperature difference between the Blackpine and Gratton's Camp stations (approx. 62 km downstream) in July/August 1997 was 0.95 °C; the mean of this difference from 1992-1997 was 0.65 °C.

Water temperatures in the Nation River also returned to typical values in 1997, measured as 15.4 °C in July, and 16.1 °C in August (Fig. 5). Mean July and August water temperatures measured over the entire study period were 15.3 °C and 15.4 °C, respectively. The Nation River has been consistently warmer than the Mesilinka River, due to a chain of five large lakes (the Nation lakes) heading the river above the sampling site.

Tributary summer water temperatures measured in 1997 also rebounded from 1996 lows to more typical values (Fig. 6). Mean July temperatures in Carina, Control, Culvert, Fatfish and Gopherhole creeks were 14.6, 7.6, 8.4, 9.6, and 8.6 °C respectively; mean August temperatures were 15.0, 8.8, 9.5, 8.0, and 9.8 °C. Carina Creek has consistently been the warmest Mesilinka tributary (1992-1997 July/August mean water temperature = 14.0 °C) due to a lake upstream of the sampling site. The remaining four tributaries have similar temperature regimes, with 1992-1997 July/August means of 7.6 °C (Control Creek), 8.9 °C (Culvert Creek), 8.4 °C (Fatfish Creek), and 9.3 °C (Gopherhole Creek).

Fertilization

Mesilinka Mainstem

Phosphorous (P) and nitrogen (N) loading at the Roadend Site (T1) was 3.6 µg P•L^{-1} and 10.5 *µg* N•L^{-1} in 1997, or 72% and 70% of target concentrations. Daily loading estimates at the Lower Fertilizer Site (T2) are 3.5 µg P•L^{-1} and 8.6 *µg* N•L^{-1}, or 69% and 58% of target concentrations, respectively (Fig. 7). At the Roadend site, fertilizer delivery was relatively constant throughout the addition period, with a notable low in its addition in early-mid August, and climbing levels towards the end of the delivery period. At the Lower Fertilizer Site, fertilizer application fluctuated substantially, but concentrations only approached 100% of target concentrations towards the end of the application period. For each of the four years of fertilization, the addition of N and P has been well below target concentrations. Table 6 summarizes fertilizer loading rates throughout the project.

Water Chemistry

Mesilinka Mainstem

Soluble reactive phosphorous (SRP) concentrations measured in the Mesilinka River in 1997 were predominantly at or below the detection limit of 1 µg•L^{-1} (Fig. 8). In the T2 reach, concentrations of 2 µg•L^{-1} were detected in early July and mid August. These low concentrations are similar to those noted in 1996, and in 1992 and 1993 before the river was fertilized. Nation River SRP concentrations were also measured at or below 1 µg•L^{-1} throughout the sampling period. Total dissolved phosphorous (TDP) concentrations are provided in Figure 9, and show increasing concentrations from early to mid-July, subsequent to the start of fertilizer addition. Concentrations declined from mid-July to levels of 4 µg•L^{-1} by the end of the sampling period.

Table 6. Mean daily fertilizer loading rates to the Mesilinka River, 1994-1997

Fertilizer site	Nutrient	Year	Mean loading rate ($\mu g \cdot L^{-1}$)	% of target concentration[a]
Roadend (Tl reach)	Phosphorous	1994	4.6	92
		1995	3.5	70
		1996	3.8	76
		1997	3.6	72
	Nitrogen	1994	9.0	60
		1995	9.9	66
		1996	11.2	75
		1997	10.5	70
Lower site (T2 reach)	Phosphorous	1994	3.6	72
		1995	3.2	64
		1996	3.8[b]	76
		1997	3.5	69
	Nitrogen	1994	2.4[C]	-
		1995	9.2	61
		1996	9.6[b]	64
		1997	8.6	58

[a] target concentrations of 5 $\mu g \cdot L^{-1}$ P and 15 $\mu g \cdot L^{-1}$ N

[b] only an estimate as daily loading values not known

[c] 28-0-0 nitrogen fertilizer not added at lower site in 1994

With the exception of 1995 when SRP concentrations in both the Mesilinka and Nation rivers were elevated, measures have been predominantly below the analytical detection limit. These low concentrations measured in 1992 and 1993 confirmed that the Mesilinka system was P limited and a suitable candidate river for the fertilization project. In mid-July of 1994, a brief increase in SRP concentrations is evident. While the increase was observed in all four study reaches, the increased concentrations detected in the Tl and T2 reaches are coincident with the onset of fertilizer addition. Water chemistry monitoring did not commence until after fertilizer addition in 1996 and 1997, so similar increases in SRP may have also occurred. Regardless, in 1994, 1996 and 1997, concentrations of SRP are below detection limits shortly after fertilizer addition begins, indicating a rapid uptake response from the instream community.

Total organic nitrogen (TON) concentrations measured in the Mesilinka River in 1997 were generally below 100 $\mu g \cdot L^{-1}$ (Fig. 10). In the Blackpine reach, the mid-July sample indicated a peak in TON concentrations to above 160 $\mu g \cdot L^{-1}$. In the Tl and T2 reaches, TON concentrations declined through the growing season; concentrations in the Tl reach were below the analytical detection limit from mid-July to the end of the study period. TON in the Nation River ranged from 50 to 140 $\mu g \cdot L^{-1}$.

Nitrate and nitrite nitrogen (NO_3+NO_2-N) concentrations in the Mesilinka and Nation rivers were elevated throughout July and early August in 1997 as compared to previous years of the project (Fig. 11). Nation River concentrations declined after peaking in mid July at over 75 $\mu g \cdot L^{-1}$, the highest concentrations measured during the project. Above normal concentrations were also noted in the Blackpine reach; NO3+NO2-N is typically below 30 $\mu g \cdot L^{-1}$ for the whole of the summer, but in 1997, concentrations were regularly above 30 $\mu g \cdot L^{-1}$ and peaked at over 70 $\mu g \cdot L^{-1}$. The mid July to early August peak in NO3+NO2-N is also evident in the Tl and T2 reaches. In the T2 reach, mid July and early August measures were 179 and 134 $\mu g \cdot L^{-1}$, respectively. These exceedingly high levels are likely a combination of the system-wide increase in concentrations, coupled with the inorganic fertilizer addition. Ammonia-nitrogen (NH_3-N) concentrations were predominantly below 5 µg•L^{-1} in all three reaches of the Mesilinka River and in the Nation River (Fig. 12).

Throughout the study region in both pre- and post fertilization years, TON concentrations tend to decrease throughout the summer. NO_3+NO_2-N measured before fertilization were predominantly below 30 µg•L^{-1} and relatively constant throughout July and August. Since fertilization has begun, early season peaks are evident, but concentrations decline as the growing season progresses.

Thus, the Mesilinka River appears, in general, to be P limited throughout the summer with a possible N co-limitation after raid-August. Although increases are evident for both nutrients subsequent to the annual commencement of fertilization, the system has largely been able to absorb the added nutrients at the rate at which they have been applied.

Mesilinka Tributaries

In 1997, SRP concentrations in all five Mesilinka River tributaries were measured at or below 3 µg•L^{-1} for the entire sampling period (Fig. 13). In Carina, Culvert, and Gopherhole creeks, concentrations were below detection limits for the first three samples of the season. Concentrations in Control and Fatfish Creeks fluctuated from below the analytical detection limit to 2-3 µg•L^{-1}. TDP concentrations peaked in all five tributaries in mid to late July; peak concentrations above 10 µg•L^{-1} were measured in Carina, Control, Culvert and Fatfish creeks.

NO_3+NO_2-N concentrations fluctuated considerably through the summer of 1997 in the tributaries (Fig. 15). In Fatfish Creek, a NO_3+NO_2-N concentration of 270 µg•L^{-1} was measured, the highest in any tributary over the course of the project. NH_3-N concentrations measured in 1997 were predominantly below the detection limit of 5 µg•L^{-1} (Fig. 16). TON values (determined as total N - inorganic N) generally decreased through the summer in all tributaries.

There has been considerable fluctuation in both P and N concentrations in the tributaries from year to year. Nutrient levels in Carina Creek have been the most consistent, likely a reflection of the lake in its headwaters. For other tributaries, concentrations seem to fluctuate greatly over short periods. These fluctuations may be due to the contribution from groundwater sources in response to local rainfall conditions. This is supported by the observation that nutrient concentrations and fluctuation patterns are relatively similar across the four non-lakeheaded creeks (Control, Culvert, Fatfish and Gopherhole creeks).

Periphyton Accrual

Mesilinka Mainstem

Peak periphyton accrual measured in all three reaches of the Mesilinka River in 1997 was greater than that measured in 1996; Nation River peak accrual was slightly less than 1996, but within the range of values observed during other years of the study period (Table 7). Accrual rates throughout the study area followed similar trends, with Mesilinka reaches showing equal or greater rates as compared to 1996, and the Nation River showing a modest decrease. The greatest periphyton accrual recorded in 1997 was in the Tl reach (32.2 mg•m^{-2}; accrual rate 0.59 mg•m^{-2}•day^{-1}). Peak accrual and accrual rate were greater in both of the two fertilized reaches (Tl and T2) as compared to the Blackpine (control) reach.

Table 7. Peak periphyton accrual and accrual rate in the Mesilinka and Nation rivers, 1992-1997

	Peak periphyton accrual (mg•m^{-2})				Peak periphyton accrual rate (mg•m^{-2}•day^{-1})			
Year	Blackpine	Tl	T2	Nation	Blackpine	Tl	T2	Nation
1992	15.7	12.5	13.3	-	0.23	0.2	0.23	-
1993	7.3	13.0	8.5	13.1	0.13	0.22	0.14	0.28
1994	10.8	127.5	29.7	15.3	0.22	2.60	0.61	0.31
1995	4.4	55.9	4.8	6.0	0.11	1.40	0.12	0.15
1996	3.1	21.0	9.9	14.5	0.06	0.45	0.21	0.35
1997	7.0	32.2	11.7	8.9	0.13	0.59	0.21	0.16

Over the entire study period, the response of periphyton to fertilization has been most pronounced in the Tl reach. Responses to fertilization in the Tl and T2 reaches are presented in Figures 17 and 18 as differences from the Blackpine (control) reach. In 1994, the first year of fertilization, there was a dramatic increase in both peak accrual and accrual rate in the Tl reach. Since 1995, both measures have subsided to modestly elevated levels. Analogous short-term increases have previously been observed (Peterson *et al.* 1993, Slaney and Ward 1993) and are attributed to a response in the grazing insect population. In the T2 reach, only a very modest increase in peak accrual and accrual rate was observed in 1994. In subsequent years, peak accrual and accrual rate have matched pre-fertilization levels. There is no significant difference ($p > 0.1$) between pre- and post-fertilization peak accrual or accrual rate in either the Tl or T2 reach.

Mesilinka Tributaries

Peak periphyton accrual and accrual rates measured in 1997 in Mesilinka River tributaries all recovered from the low levels observed in 1996 (Table 8). Peak accrual in Carina, Control, and Culvert creeks rebounded to within the range measured in previous years. The rebound in Gopherhole Creek was less pronounced with peak accrual measured at only 16.3 mg•m^{-2}, or less than half that observed in previous non-fertilized years (36 mg•m^{-2} in 1992; 33.3 mg•m^{-2} in 1994). Peak accrual in Fatfish Creek in 1997 reached 266 mg•m^{-2}, and was the largest measured in any tributary throughout the project, including below sites on Culvert and Gopherhole creek in fertilization years. Periphyton accrual in Fatfish Creek in 1997 was almost five times the next highest annual peak accrual observed in any tributary (1995, 59.9 mg•m^{-2}, Gopherhole Creek). Recovery of accrual rate in the five tributaries accompanied increases in peak accrual. Accrual rate in Carina, Culvert and Gopherhole creeks all recovered to levels measured in previous years, while Control Creek rose to the highest level observed in that tributary during the study (0.63 mg•m^{-2}•d^{-1}). Accrual rate in Fatfish Creek was the highest measured in any tributary throughout the project, at 4.84 mg•m^{-2}•d^{-1}. Six years of monitoring of Carina, Control and Fatfish creeks indicates that periphyton peak accrual and accrual rates vary greatly from year to year and from creek to creek (Culvert and Gopherhole creeks were fertilized in 1993 and 1995 and thus variations in them may be attributed to fertilization or subsequent responses). While the low accruals and rates that prevailed in 1996 are largely attributable to the atypical runoff year (Wilson *et al.* 1999), there is no obvious explanation for the disparate primary production in the creeks in 1997.

Table 8. Peak periphyton accrual and accrual rate in the Mesilinka River tributaries, 1992-1997

	Peak periphyton accrual (mg•m^{-2})					Peak periphyton accrual rate (mg•m^{-2}•day^{-1})				
Year	Carina	Control	Culvert[a]	Fatfish	Gopherhole[a]	Carina	Control	Culvert[a]	Fatfish	Gopherhole[a]
1992	113.0	23.4	10.8	-	36.0	2.76	0.39	0.28	-	0.59
1993	45.1	39.6	32.9	33	37.8	0.5	0.51	0.56	0.66	0.51
1994	39.2	36.8	-	2.6	33.3	0.55	0.53	-	0.09	0.39
1995	32.3	12.7	14.0	56.7	59.9	0.61	0.32	0.58	1.07	1.13
1996	2.8	10.1	4.6	8.2	6.4	0.06	0.21	0.10	0.17	0.29
1997	18.7	35.9	20.1	266	16.3	0.34	0.63	0.35	4.84	0.29

[a] All Culvert and Gopherhole creek data from lower sites; these creeks were fertilized in 1993 and 1995.

Benthic Invertebrates

Mesilinka Mainstem

Mean biomass of benthic invertebrates collected in sampling baskets during 1997 (Table 9) was greatest in the Tl reach (538 mg•0.005 m^{-3}), followed by the T2 reach (294 mg•0.005 m^{-3}), and the Blackpine (control) reach (174 mg•0.005 m^{-3}). These biomasses all succeed those measured in 1996, but do not progressively increase downstream as noted in 1995 and 1996. Baskets placed in the Nation River indicated slightly increased benthic biomass over 1995 and 1996 measures.

Table 9. Mean biomass (wet-weight) of benthic invertebrates (in mg•0.005 m^{-}3 ± SE) from the Mesilinka and Nation rivers, 1993-1997

	Mesilinka River							
	Blackpine		Tl		T2		Nation River	
Year	Biomass	n	Biomass	n	Biomass	n	Biomass	n
1993	285 (± 47)	10	212 (±56)	10	22 (± 10)	10	498 (± 253)	4
1994	262 (± 72)	10	570 (± 273)	10	75 (± 25)	9	3147(±431)	6
1995	34(± 5)	10	54 (± 17)	8	96 (± 24)	10	63 (± 16)	4
1996	61 (±22)	9	95 (± 27)	10	237 (± 68)	9	64 (± 25)	4
1997	174 (±33)	14	538(±51)	13	294(±54)	14	92(± 28)	7

Over the entire study period, benthic invertebrate biomass has fluctuated greatly both within and across reaches within the Mesilinka River, and in the Nation River. In 1993, the only pre-fertilization year for which there is benthic data available, biomass appears to decrease from upstream to downstream in the Mesilinka mainstem (greater biomass observed in the Blackpine reach than the Tl reach than the T2 reach). Responses to fertilization in the Tl and T2 reaches are presented in Figure 19 as differences from the Blackpine (control) reach. Following fertilization, both of the treatment reaches have fluctuated greatly, but with overall increasing trends. The peak invertebrate biomass in Tl in 1994 coincides with the Tl peak in periphyton accrual and accrual rate. The gradual increase in invertebrate biomass following fertilization in the T2 reach is not coincident with fluctuations in periphyton accrual or accrual rate in T2, which have both remained nearly constant since 1992.

Figure 20 illustrates the mean change in biomass in the Tl and T2 reaches from pre- (1993) to post-fertilization (1994-1997) years presented as differences from the Blackpine (control) reach. The biomass increase from pre- to post- fertilization is not significant in either reach independently ($p > 0.1$), but when the reaches are pooled, there is significantly more invertebrate biomass post fertilization (df (1,96), F =13.4, $p < 0.05$).

Figure 21 illustrates the relative abundance of four taxonomic groups of invertebrates from 1993-1997. Taxonomic groups other than dipterans, ephemeropterans, plecopterans and tricopterans are not included as their numerical abundance generally accounted for less than 1% of the total population recovered from the baskets. Fertilization has had the most pronounced effect on dipteran populations, with fluctuations evident in both the Tl and T2 reaches. Relative abundance of dipterans has remained quite steady in the Blackpine control reach, with a range of 12% (1994) to 36% (1996). In the Tl reach, dipteran populations have increased from less than 30% in 1993 to an average of 84% in the four fertilization years (1994-1997). A similar but more moderate response is evident in T2, where the dipteran portion of the population increased from 20% in 1993 to over 60% in 1994 and 1995. Relative abundance dropped in 1996 to just over 30%, but rose again in 1997 to 58%. In both of the treatment reaches, relative abundance of the three other taxomonic groups (ephemeroptera, plecoptera and tricoptera) decreased immediately following fertilization. In the T2 reach, by 1996 and 1997, relative abundance of these groups had increased to approximately the same percent of the invertebrate population held prior to fertilization. Parallel recovery in diversity has not occurred in the Tl reach where relative abundance of the three non-dipteran species are each below 10%.

Estimated Fish Abundance, Growth and Size Distribution

Adults

Weight-at-age and length-at-age data for rainbow trout and Arctic grayling angled from the Mesilinka River in 1997 are presented in Figures 22 and 23. Both weight- and length-at-age for all fish captured were low when compared to data from previous years (Tables 10 and 11). The low size-at-age of fish in 1997 may be attributable to the less than ideal growing conditions in 1996, brought about by high discharges and low water temperatures.

Figures 24 and 25 show responses to fertilization in the Tl and T2 reaches presented as differences from the Blackpine (control) reach. Data are only presented for the most abundant species and ages (rainbow trout, 2+, 3+ and 4+; Arctic grayling (ages 3+, 4+, 5+). For 3+ rainbow trout, weight-at-age appeared to increase from 1992-1995, followed by decreases in 1996 and 1997. Similar patterns are evident in length-at-age data. For both measures of 3+ fish, the decrease noted in 1996 and 1997 appears to have been greater in the Tl reach. Data for 4+ individuals shows greater fluctuation in both weight- and length-at-age in both reaches over the six year study period. For both 3+ and 4+ individuals, the low weight- and length-at-age as noted in 1996 may be linked to the unfavourable discharge and temperature conditions in that year. Six 2+ rainbow trout were caught in 1997, but all were from the T2 reach so no comparative information is available for Fig. 24.

For Arctic grayling, both weight-at-age and length-at-age appear to fluctuate greatly from year to year (Fig. 25). Limited data for the 3+ age class indicate that fish from the Tl and T2 reaches are consistently smaller than those from the control reach. For the 4+ and 5+ size classes, there is considerable variation from year to year.

Table 10. Mean size-at-age data for rainbow trout from 1992 to 1997 collected from three reaches of the Mesilinka River by angling and electrofishing

		Number of fish						Fork length (mm)						Weight (g)					
Age	Reach	1992	1993	1994	1995	1996	1997	1992	1993	1994	1995	1996	1997	1992	1993	1994	1995	1996	1997
0+	Blackpine		7	2					47	45					1	1			
	Tl		6	8	6				51	60	63				1	3	3		
	T2		7	44					42	43					1	1			
1+	Blackpine		2	10					98	106					11	13			
	Tl			9	4					108	97					13	10		
	T2		2	6					123	115					25	24			
2+	Blackpine	3	12	5	3			177	160	175	183			66	66	79	63		
	Tl	10	9	2	2			162	168	174	190			57	73	84	73		
	T2	10	14	9	21	1	6	171	146	172	192	172	177	57	59	81	86	55	64
3+	Blackpine	21	4	5	11	3	3	227	201	210	226	225	207	166	128	130	97	139	112
	Tl	19	4	17	21	2	8	219	244	229	225	208	199	131	177	161	132	101	99
	T2	28	25	25	25	13	42	207	224	218	245	233	214	116	130	134	175	151	124
4+	Blackpine	10	6	2	11	3	8	281	251	292	258	278	243	255	208	309	187	261	165
	TI	6	8	4	17		37	272	268	275	274		239	222	230	252	237		161
	T2	19	29	15	29	4	57	254	273	275	286	292	258	195	214	252	279	258	192
5+	Blackpine	2	3				7	326	323				287	383	378				277
	Tl	7	5	3	5		12	316	296	280	315		288	320	284	258	334		265
	T2	7	6	3	1	5	13	315	294	300	296	308	299	304	236	308	306	277	279
6+	Blackpine					2	2				343	322	310					360	390
	Tl	2		2	1		1	315		331			292	369		386	338		274
	T2	4	1			1	1	311	310			310	301	355	482			350	255
7+	Blackpine					1						320						438	
	Tl																		
	T2	1						342						397					

Table 11. Mean size-at-age data for Arctic grayling from 1992 to 1997 collected from three reaches of the Mesilinka River by angling and electrofishing

		Number of fish						Fork length (mm)						Weight (g)					
Age	Reach	1992	1993	1994	1995	1996	1997	1992	1993	1994	1995	1996	1997	1992	1993	1994	1995	1996	1997
0+	Blackpine			1						55						1			
	T1				1						57						2		
	T2			5						73						7			
1+	Blackpine			1						129						129			
	T1																		
	T2																		
2+	Blackpine		3		1				201		220				114		124		
	T1		5	1	2		2		177	224	253		185		91	156	152		42
	T2	2	4	1	6	4	2	198	162	183	223	210	166	128	57	90	119	94	55
3+	Blackpine	5	1	1	0	1		269	367	275		292		227	304	276		273	
	T1	4	3	2	9	7	18	268	249	226	269	270	261	206	189	151	222	213	206
	T2	14	2	3	8	5	11	253	270	235	257	261	261	176	199	166	211	200	213
4+	Blackpine	19	14	6	18	1	6	302	298	299	309	298	313	333	279	346	334	317	332
	T1	6	5	3	19	8	23	305	311	286	308	311	316	317	357	269	342	364	355
	T2	5	2		4	1	10	285	283		296	318	312	255	312		311	353	360
5+	Blackpine	12	5	4	12	6	14	328	333	320	345	329	347	409	352	397	466	428	392
	T1	5	5	7	9	13	38	338	326	318	349	336	344	442	363	397	505	415	446
	T2	3	1	2	0	2		333	348	313		357		406	511	369		525	
6+	Blackpine	6	4		5	3	6	366	354		336	364	376	489	483		445	538	559
	T1	2	3	1	3	7	11	378	368	369	360	357	366	554	492	546	557	503	533
	T2						1						361						590
7+	Blackpine	3	2	1		2	1	375	366	365		380	376	489	482	506		593	620
	T1	1	1	1		4	2	360	382	379		373	382	454	425	606		572	612
	T2						2						381						595

Figures 26 through 29 illustrate the mean changes in size-at-age in the Tl and T2 reaches from pre- (1992-1993) to post-fertilization (1994-1997) years presented as differences from the Blackpine (control) reach. For rainbow trout, length of 2+ and 3+ individuals has increased in the Tl reach following fertilization, but length of 4+ individuals has decreased (Fig. 26). These changes in the Tl reach have not been statistically significant ($p > 0.01$). In the T2 reach, length of 2+, 3+, and 4+ individuals has increased subsequent to fertilization. This increase is significant for 3+ rainbow trout (df (1,216), $F = 33.0$, $p < 0.05$). Weight-at-age of rainbow trout show similar responses to length-at-age, with increases noted for 2+ and 3+ individuals in the Tl reach, and for 2+, 3+, and 4+ individuals in the T2 reach (Fig. 27). These increases are significant for 3+ individuals in the Tl and T2 reaches (df (1, 216), $F = 38.8$, $p < 0.05$), and for 4+ individuals in the T2 reach (df (1, 204), $F = 4.9$, $p < 0.05$). Pre-fertilization rainbow trout in the Tl and T2 reaches were generally smaller those from the Blackpine reach; fertilization has increased the size-at-age of rainbow trout in the Tl and T2 reaches to the extent that they are now generally larger.

For Arctic grayling, length-at-age has increased post-fertilization for 3+, and 4+ individuals in Tl, and in all three age classes in T2 (Fig. 28). The decrease noted in length at age in 5+ individuals in the Tl reach is very small. None of the changes in length-at-age following fertilization noted for Arctic grayling are significant ($p > 0.01$). Weight-at-age of Arctic grayling has decreased slightly for 3+ and 5+ age classes in the Tl reach, and for 3+ fish in the T2 reach (Fig. 29). However, substantial (not significant; $p > 0.01$) increases in weight-at-age were measured in 4+ and 5+ fish in the T2 reach. Since fertilization, little change overall in size-at-age has been noted for Arctic grayling in the Tl reach. In the T2 reach, 4+ and 5+ individuals have increased substantially in both length- and weight-at-age since pre-fertilization. Throughout the study period, 3+ individuals from both treatment reaches have been consistently smaller than those in the Blackpine (control) reach.

Underwater counts were successfully conducted in 1997, and values determined for all underwater surveys conducted during the study are provided in Tables 12 and 13.

Table 12. Density of fishes (no. per ha) in three reaches of the Mesilinka River as determined from underwater counts, 1992-1997. No counts were conducted in 1996 or in the T2 reach in 1995.

	1992			1993			1994			1995		1997		
	BP	Tl	T2	BP	Tl	T2	BP	Tl	T2	BP	Tl	BP	Tl	T2
Rainbow trout	0.5	1.5	2.8	1.1	1.9	3.8	1.2	3.4	5.6	0.6	4.9	0.7	4.6	7.3
Bull trout	0.2	0.8	1	0.3	0.5	1.3	0.4	0.8	0.8	0.5	1.3	2.6	5.7	2.0
Arctic grayling	2.6	3.6	2.1	1.4	3	1.7	1.3	2.1	2	2.9	5.2	0.2	1.0	0.9
Mountain whitefish	40	38	9.5	21	14	12	10	27	14	32	98	26	71	47
Suckers	1.9	0.9	5.3	0.4	0.6	2.2	0.1	0.9	4	0.1	0.7	0	0	0
Squawfish	0	0	0	0	0	0.2	0	0	0	0	0	0	0	0

Table 13. Density of size classes of rainbow trout, Arctic grayling, and bull trout (no. per ha) observed in Mesilinka River snorkel surveys, 1992-1997

		Rainbow trout			Arctic grayling			Bull trout		
Reach	Year	20-30 cm	30-40 cm	> 40 cm	20-30 cm	30-40 cm	>40cm	20-30 cm	30-40 cm	>40cm
Blackpine	1992	0.24	0.13	0.00	0.56	1.81	0.15	0.00	0.00	0.15
	1993	0.30	0.16	0.00	0.25	1.09	0.09	0.04	0.08	0.10
	1994	0.61	0.40	0.08	0.00	2.01	0.15	0.11	0.02	0.31
	1995	0.37	0.00	0.00	0.23	1.91	0.77	0.00	0.12	0.38
	1996	No swim completed								
	1997	0.53	0.09	0.00	0.19	1.98	0.47	0.07	0.00	0.09
Tl	1992	0.72	0.67	0.03	1.27	1.90	0.24	0.16	0.30	0.31
	1993	1.01	0.09	0.03	0.87	1.08	0.07	0.07	0.17	0.14
	1994	1.90	0.74	0.21	1.24	1.03	0.11	0.11	0.15	0.57
	1995	2.50	1.14	0.04	1.10	3.05	0.85	0.33	0.56	0.44
	1996	No swim completed								
	1997	1.84	1.54	0.03	1.36	2.99	0.88	0.19	0.42	0.38
T2	1992	1.62	0.48	0.00	1.05	0.28	0.02	0.23	0.37	0.34
	1993	1.97	0.49	0.03	0.86	0.23	0.00	0.23	0.43	0.54
	1994	2.05	0.67	0.07	1.17	1.12	0.07	0.28	0.23	0.12
	1995	No swim completed								
	1996	No swim completed								
	1997	3.28	2.32	0.15	0.56	1.21	0.10	0.05	0.40	0.41

Increases in rainbow trout density increased in the Tl and T2 reaches are evident, particularly from 1993 to 1994 and 1995, coincident with the onset of fertilization (Fig. 30). Increases in bull trout density are also evident, but this change has occurred later, from 1995 to 1997 (no data for 1996). Arctic grayling populations have fluctuated through the six year study period, with elevated densities noted for 1995. Densities observed in 1997 were the lowest during the study program at less that 1 fish per ha. Mountain whitefish densities show an increase from 1993 to 1995, consequent to the onset of fertilization (as also observed for rainbow trout).

Figures 31 and 32 illustrate the mean changes in density in the Tl and T2 reaches from pre- (1992-1993) to post-fertilization (1994-1997) years presented as differences from the Blackpine (control) reach. In the Tl reach, density of rainbow trout, Arctic grayling and bull trout have all increased following fertilization (Fig. 31). This increase is significant for rainbow trout (df (1, 14), $F = 18.2$, $p < 0.05$). In T2, rainbow trout have increased in density, but Arctic grayling and bull trout have decreased. Mountain whitefish densities have increased significantly in both the Tl and T2 reaches (df (1, 14), $F = 21.5$, $p < 0.05$); these substantial increases are illustrated in Figure 32 with rainbow trout increases included for scale. Mountain whitefish measured in all three reaches are predominantly in the 10-30 cm size range. Sucker densities have not substantially changed during the study period, with small (not significant; $p > 0.01$) increases in density in the Tl reach, and decreases in the T2 reach. Insufficient squawfish were counted during the study to determine density changes due to fertilization.

Juveniles

Bull trout dominated juvenile fish captured by electroshocking in Control and Gopherhole creeks in 1997, as has been the case in previous year (Table 14). While data are unavailable in 1997 for Gopherhole Creek, areal density of bull trout measured in Control Creek was the highest during the study at 37 fish•100 m^{-2}; juvenile bull trout densities in Control Creek varied from a low of 1 fish•100 m^{-2} (1995) to a high of 37 fish•100 m^{-2} (1997). The fluctuations in bull trout population 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 appeared to be dominated by young-of-year cohort, as also noted in 1995 and 1996 (Paul *et al.* 1998; Wilson *et al.* 1999; Fig. 33).

Only one rainbow trout was captured in Control Creek in 1997. In Gopherhole Creek, eight rainbow trout in total were caught, but an areal density measure is unavailable. Only three mountain whitefish were caught in 1997, all in Control Creek. Table 15 summarizes rainbow trout densities determined for all of the years of the project. In general, rainbow trout densities were below 5 fish•100 m^{-2}, with the highest estimated at 12 fish•100 m^{-2} in Culvert Creek in 1996.

Table 14. Areal density estimates for bull trout in three tributaries of the Mesilinka River determined by mark/recapture, 1992-1997.[a]

Tributary	Year	M	C	R	N	Areal Density (#•100 m^2)
Gopherhole	1992	2	3	2	3	1
	1993	10	7	3	21	3
	1994	6	7	1	27	7
	1995	35	26	11	110	20
	1996	29	19	8	67	8
	1997	55	35	7	252	n/a b
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	99
	1997				Not shocked	
Control	1992	13	4	4	13	4
	1993	11	15	2	63	11
	1994	17	9	2	59	8
	1995	2	2	1	3	1
	1996	31	33	10	99	19
	1997	22	8	0	207	37

[a] population estimates are only unbiased if both of the conditions $(M+C) \geq N$ and $R > 7$ were met
[b] areal estimate unavailable as shocking area not recorded

Table 15. Areal density estimates for rainbow trout in three tributaries of the Mesilinka River determined by mark/recapture, 1992-1997.[a]

Tributary	Year	M	C	R	N	Areal Density (#•100 m^2)
Gopherhole	1992	16	6	4	22	6
	1993	6	5	1	30	3
	1994	0	1	0		
	1995	7	10	2	28	5
	1996	6	3	2	9	1
	1997	3	7	2	11	n/a[b]
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	12
	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] population estimates are only unbiased if both of the conditions $(M+C) \geq N$ and $R > 7$ were met

[b] areal estimate unavailable as shocking area not recorded

CONCLUSIONS

1997 was the final of six intensive years of study of the Mesilinka and Nation rivers, and the fourth of four years of planned fertilization. The comparative study of control and treatment reaches in the Mesilinka River is validated by parallel monitoring of the Nation River, acting as an external control.

Observations since fertilization commenced indicate that the two treatment reaches, Tl and T1, have responded differently to the addition of inorganic nutrients. Two hypotheses were first proposed after the second of the four fertilization years (1995; Paul *et al.* 1998) regarding the different responses of Tl and *Tl.* A fish density response would be indicated by an increase in density of fish populations following fertilization. This increase would result in increased predation on benthic invertebrates, and subsequently, a lower invertebrate population would permit standing stocks of periphyton to increase. Little change in fish densities, but an increase in invertebrate population, would indicate a fish growth response. Higher invertebrate abundance would result in better fish growth, and a decrease in standing stocks of periphyton.

In the Tl reach, an initial increase in periphyton has since abated, and stocks have remained at modestly elevated levels for the past two years. The invertebrate population also showed an immediate response to fertilization, with populations remaining elevated since. With regard to size-at-age, there has been no widespread increases noted; however, there have been increases within restricted age classes for some species. However, fish density has increased for all notable species, modestly for Arctic grayling and bull trout, but more substantially for rainbow trout and especially mountain whitefish. Combined, these observations suggest that the addition of inorganic nutrients to Tl has produced a fish density response.

However, this density increase has not been of sufficient magnitude, through predation, to impact upon the increased invertebrate community to such an extent that standing stocks of periphyton increase.

In the T2 reach, the response of periphyton to the addition of nutrients consisted of only a minor increase in stocks in the initial year of fertilization. Benthic invertebrates displayed gradual increase following fertilization, rather than an immediate positive response. Size-at-age of Arctic grayling and particularly rainbow trout have increased. Rainbow trout density has also increased; however, density increases were not noted for Arctic grayling and bull trout. Mountain whitefish also increased substantially in density as noted in Tl. Combined, these observations indicate that fertilization of this reach has resulted in both a fish growth and a fish density response. Also, as was noted for Tl, the cumulative increases in the fish population have not been of sufficient magnitude, through predation, to impact upon the increased invertebrate community to such an extent that standing stocks of periphyton increase.

The purpose of the Mesilinka River Fertilization Experiment has been to determine whether fertilization is a suitable technique to increase production of native fish species, especially Arctic grayling, bull trout, and rainbow trout, within the Williston Reservoir watershed. Despite the fact that addition of liquid fertilizer was consistently below target concentrations, increased density and size of rainbow trout are evident in both treatment reaches of the Mesilinka River. Increases of Arctic grayling and bull trout have been modest and noted only for the Tl reach. Other changes to the system subsequent to fertilization have been the shift in the invertebrate population to favor dipterans, and the large increase in mountain whitefish density. The consequences of these changes to the system is yet unknown.

Although 1997 marks that last year of intensive monitoring of the Mesilinka River, fertilization is due to continue for an additional four years. In 1999 and 2001 (at the conclusion of years 6 and 8 of fertilization), sampling of the fish population will take place to add to the existing database. Further to these results, the long-term fate of Mesilinka River fertilization, and the proposed fertilization of other candidate systems, will be determined.

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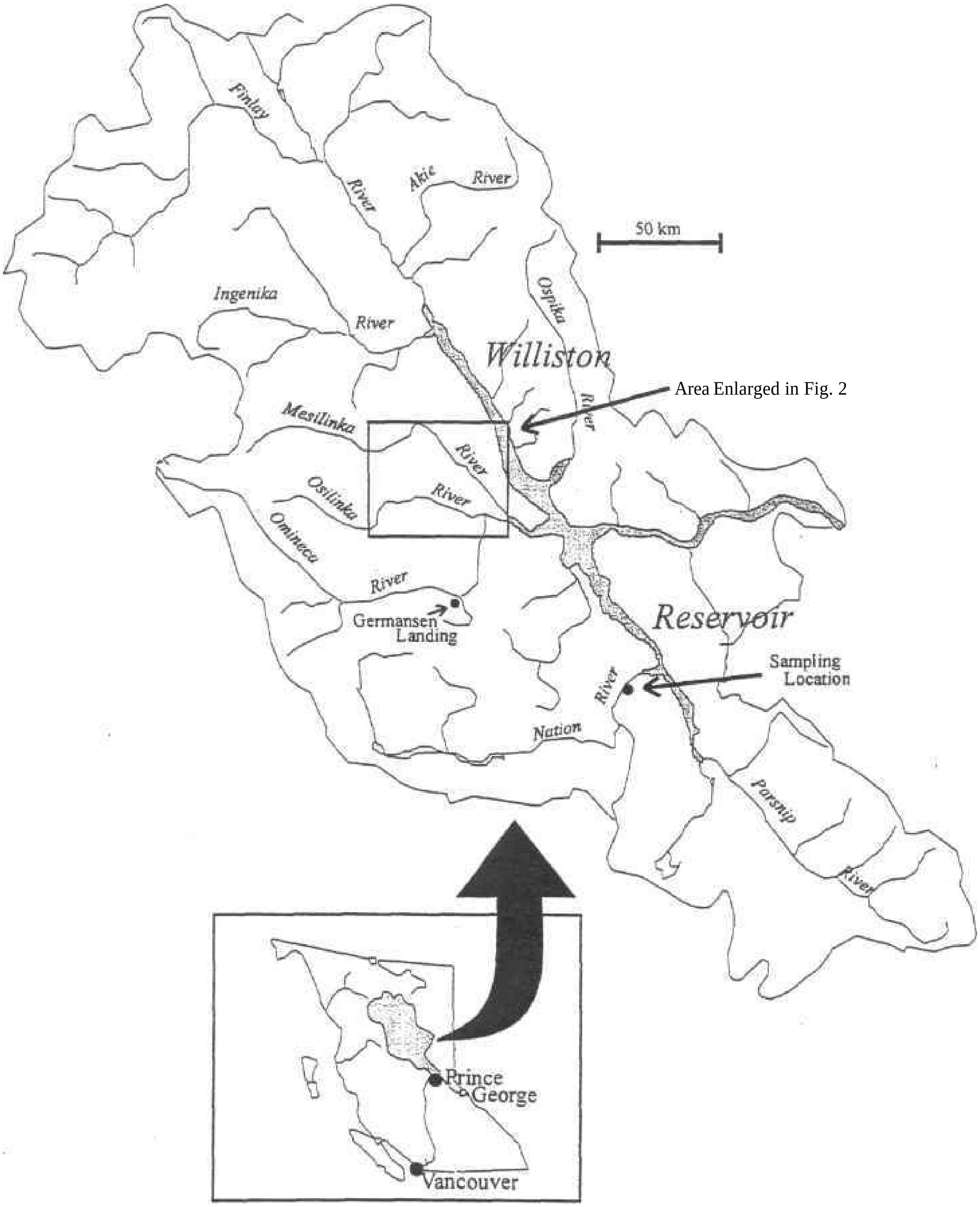


Figure 1. The Williston Reservoir Watershed (from Langston 1993).

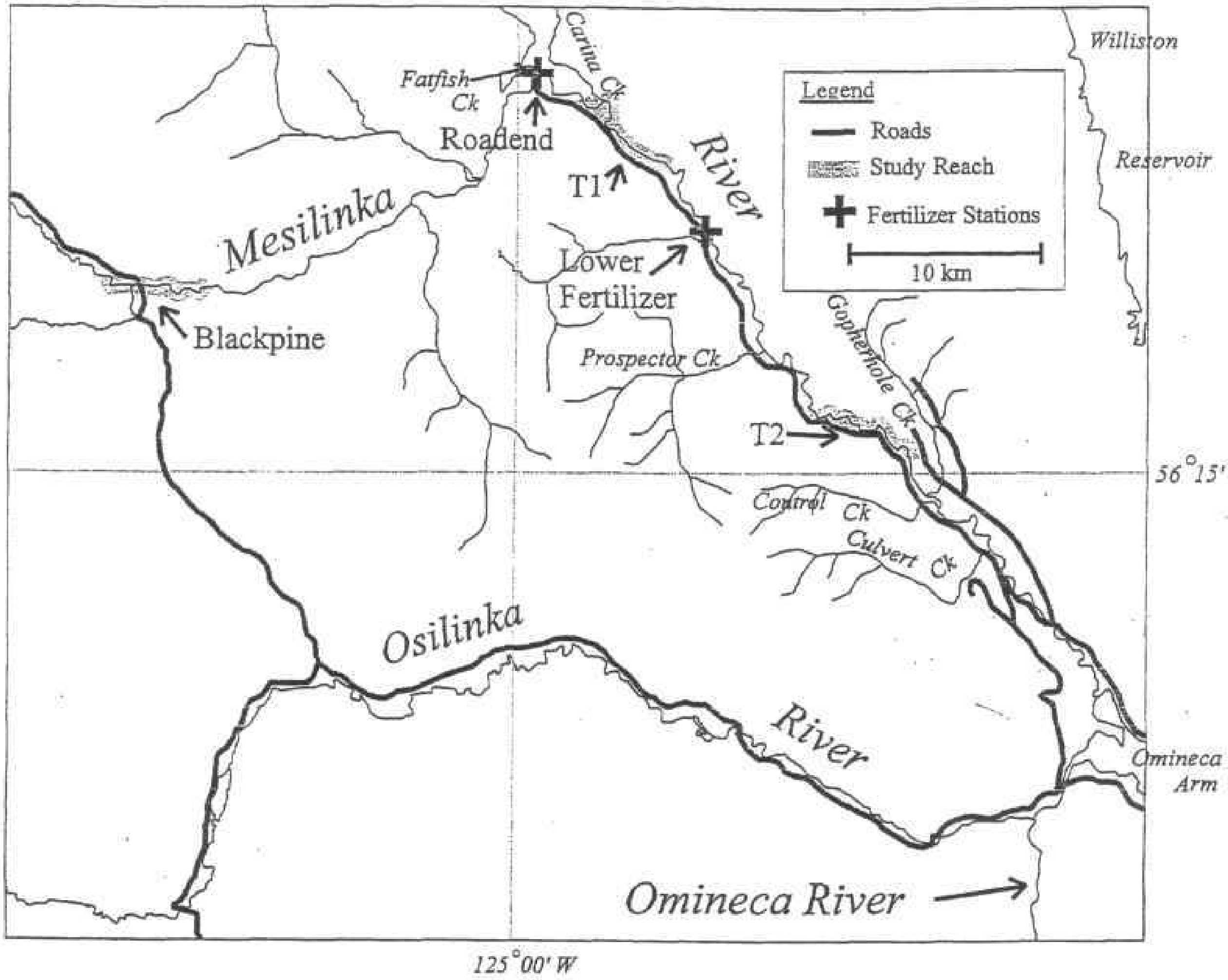
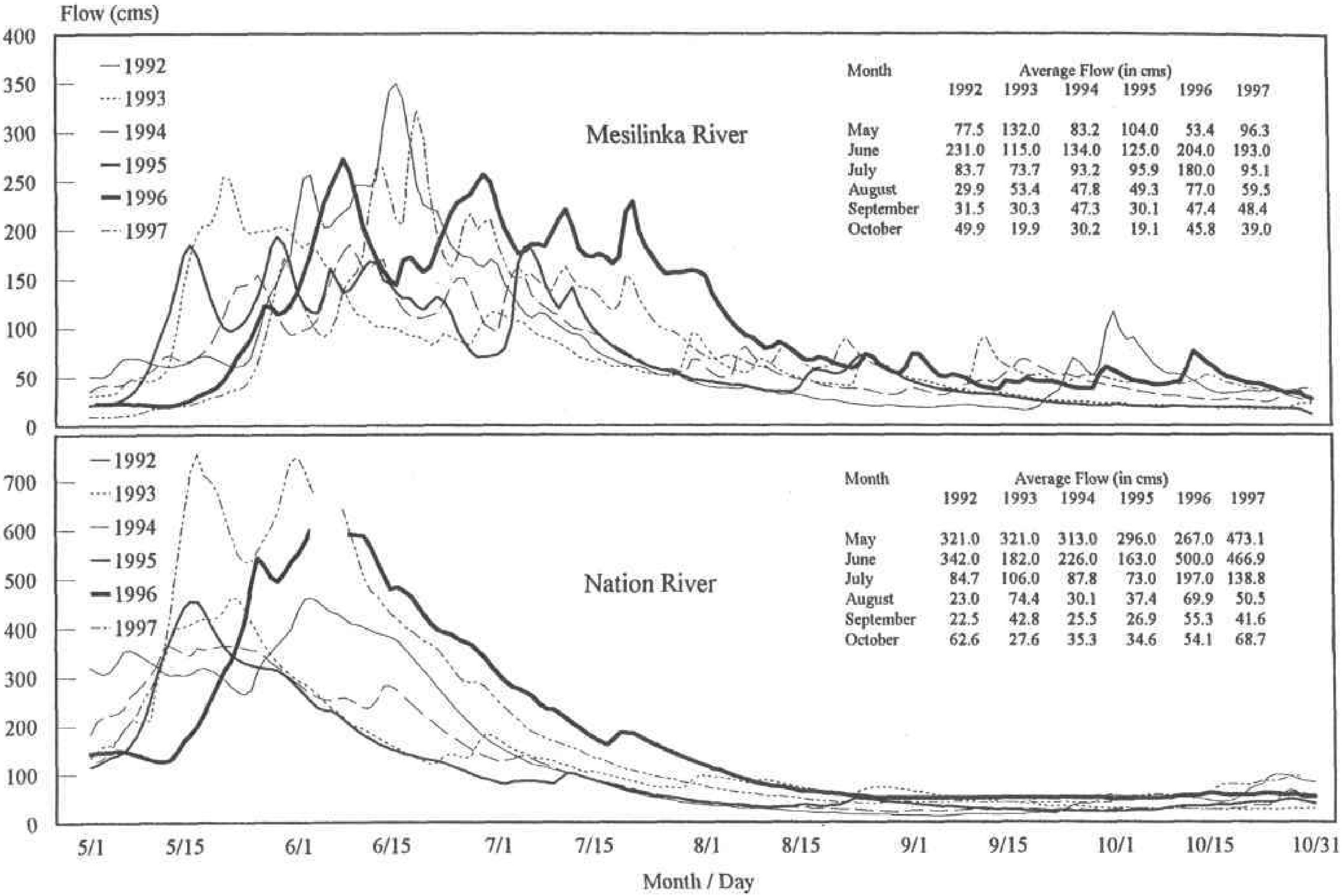


Figure 2. Mid- to lower portion of the Mesilinka River.



Mesilinka River

Month	Average Flow (in cms) 1992	1993	1994	1995	1996	1997
May	77.5	132.0	83.2	104.0	53.4	96.3
June	231.0	115.0	134.0	125.0	204.0	193.0
July	83.7	73.7	93.2	95.9	180.0	95.1
August	29.9	53.4	47.8	49.3	77.0	59.5
September	31.5	30.3	47.3	30.1	47.4	48.4
October	49.9	19.9	30.2	19.1	45.8	39.0

Nation River

Month	Average Flow (in cms) 1992	1993	1994	1995	1996	1997
May	321.0	321.0	313.0	296.0	267.0	473.1
June	342.0	182.0	226.0	163.0	500.0	466.9
July	84.7	106.0	87.8	73.0	197.0	138.8
August	23.0	74.4	30.1	37.4	69.9	50.5
September	22.5	42.8	25.5	26.9	55.3	41.6
October	62.6	27.6	35.3	34.6	54.1	68.7

Figure 3. Discharge from the Mesilinka and Nation rivers between May and October, 1992-1997.

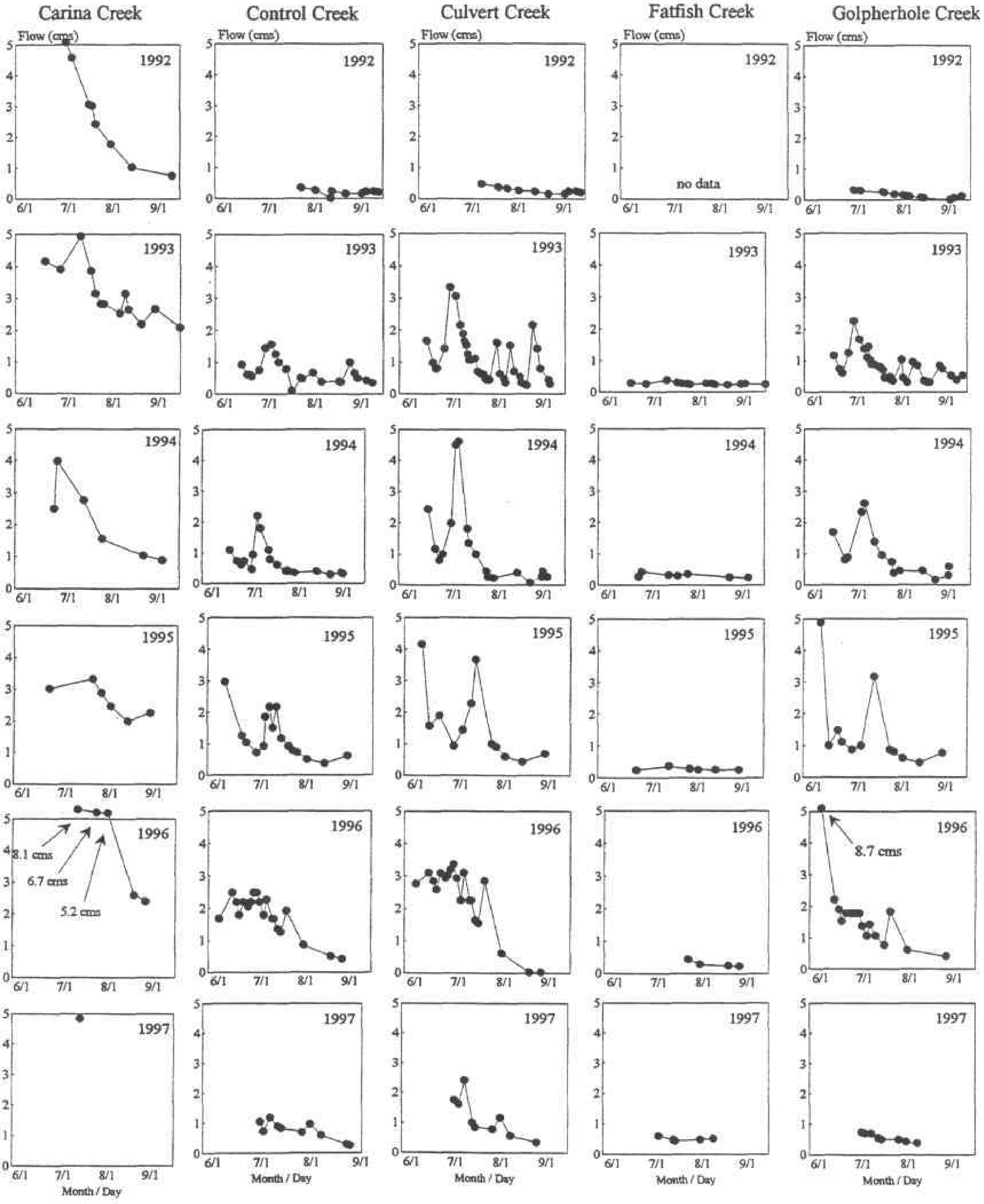


Figure 4. Discharge from tributaries of the Mesilinka River during summers of 1992-1997.

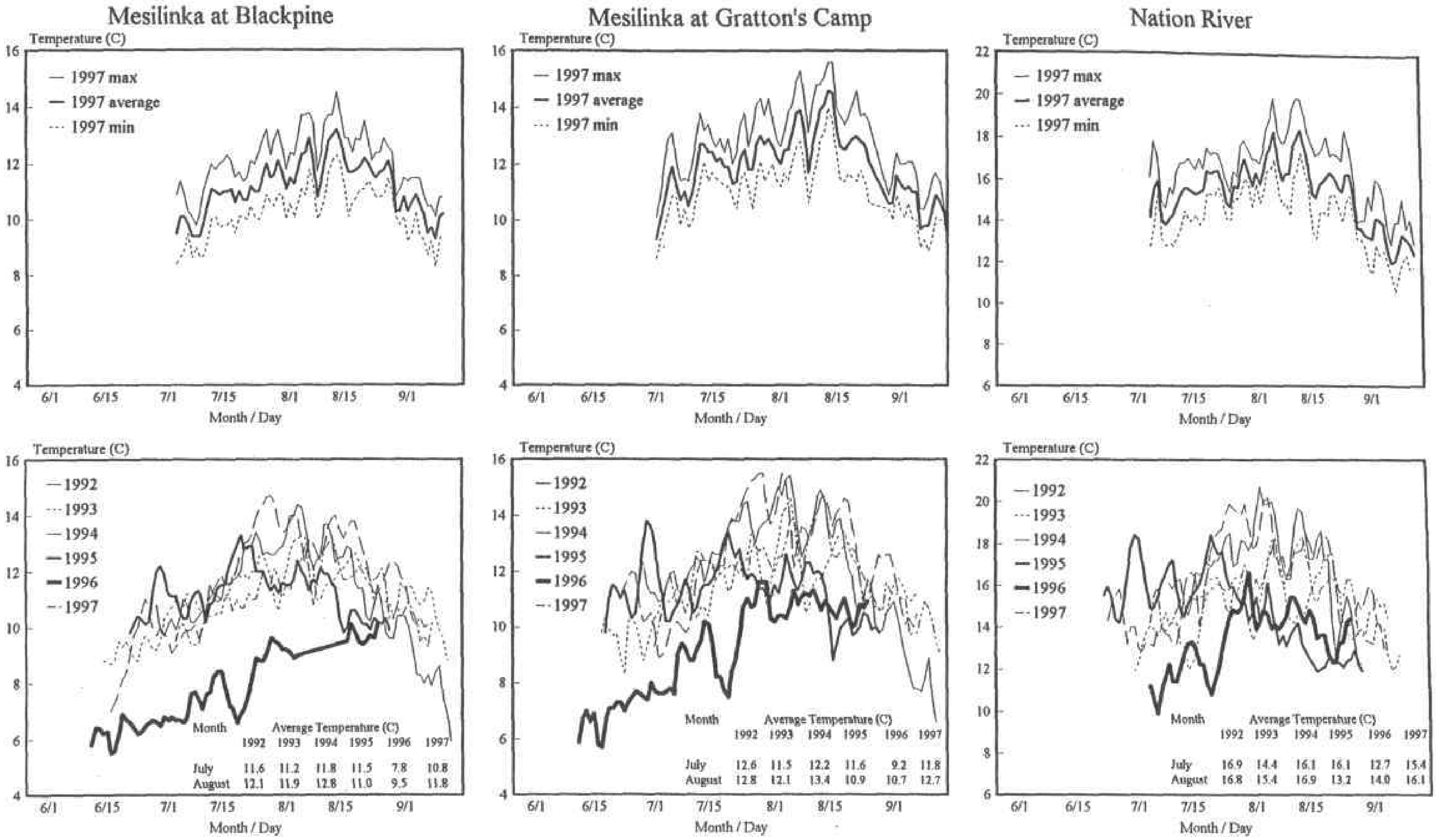


Figure 5. Mesilinka and Nation river water temperatures, 1992-1997.

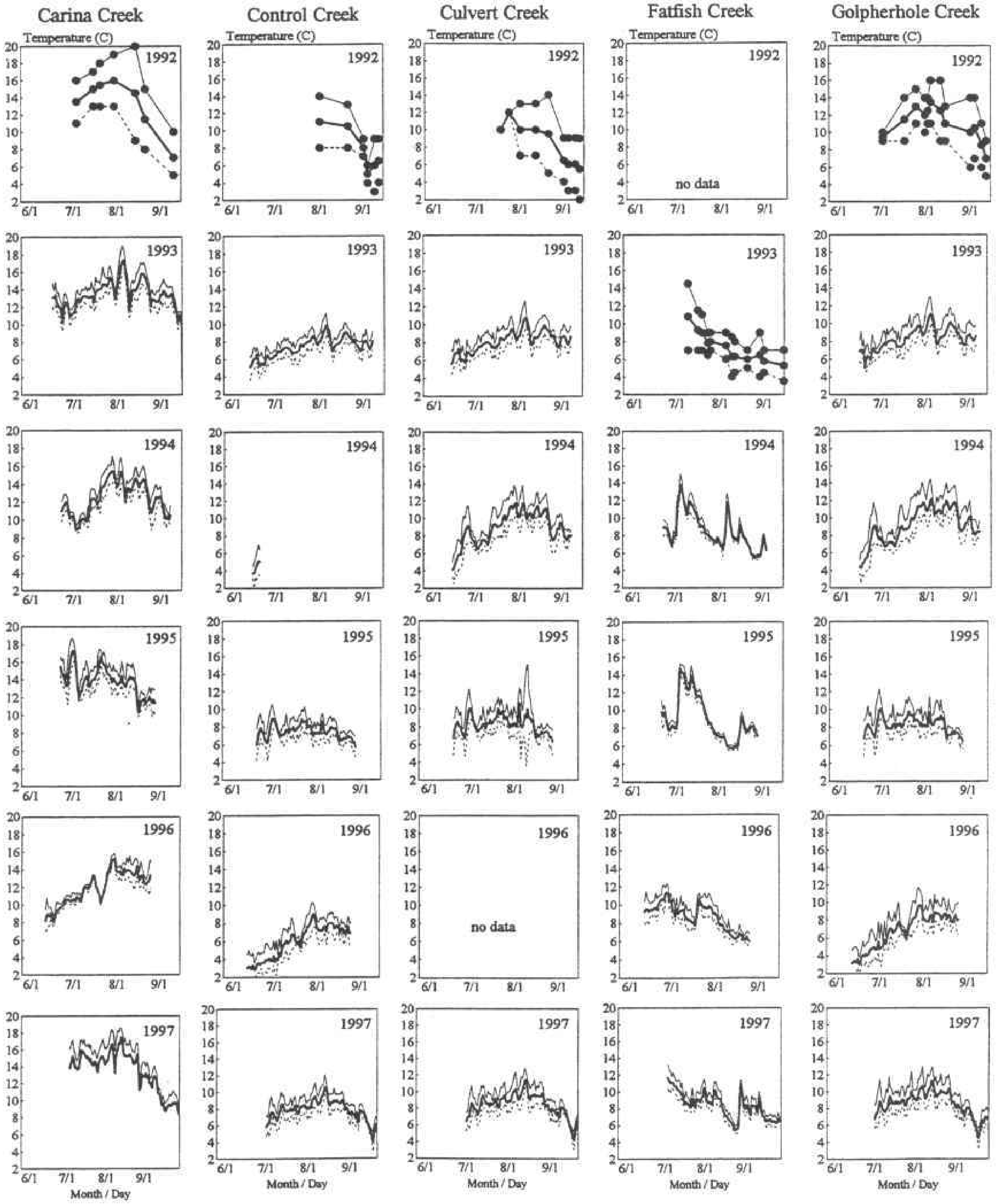
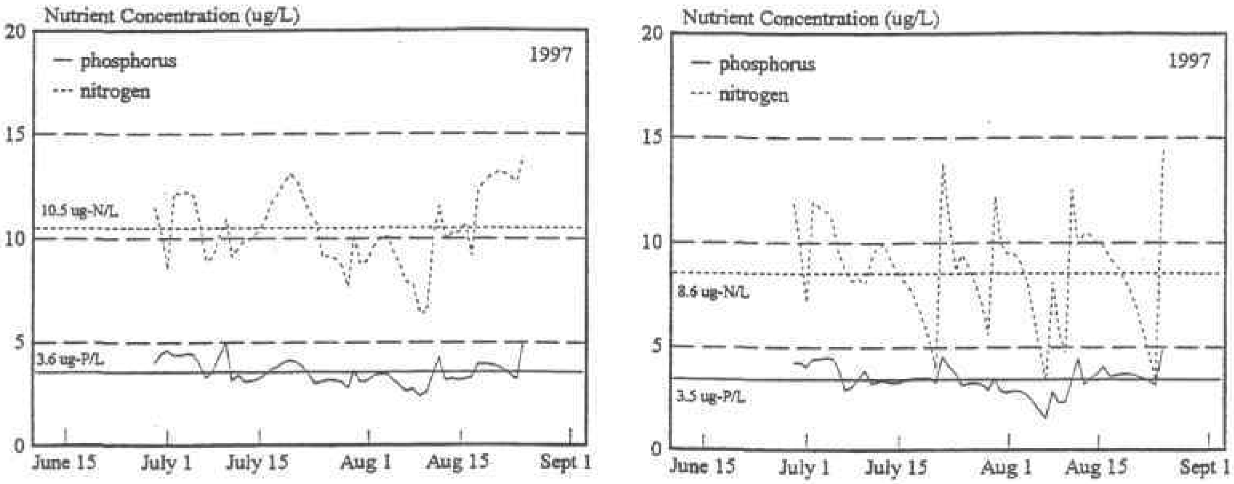


Figure 6. Mesilinka River tributary water temperatures, 1992-1997.


Roadend Site (Tl)

Lower Fertilizer Site (T2)

Figure 7. Estimated daily loading rates of fertilizer (nitrogen and phosphorus) added to the Mesilinka River at the Roadend and Lower Fertilizer sites during 1997.

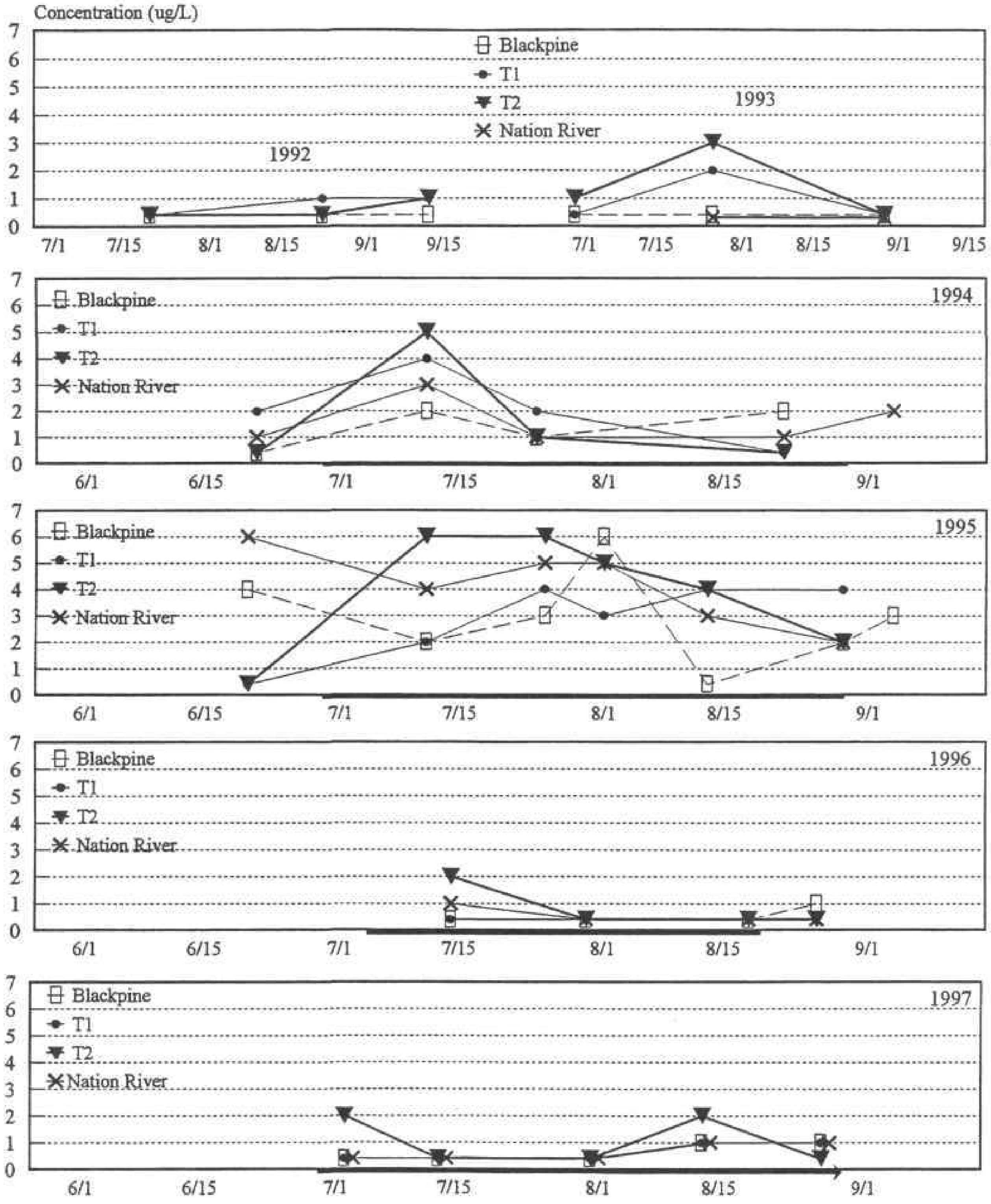


Figure 8. Soluble reactive phosphorous (SRP) concentration measured in the Mesilinka and Nation rivers, 1992-1997. Concentrations determined as below the analytical detection limit are shown at half the detection limit value of 1 $\mu g \cdot L^{-1}$. Dark lines on the x-axes indicate approximate time of liquid fertilizer addition to the Tl and T2 reaches.

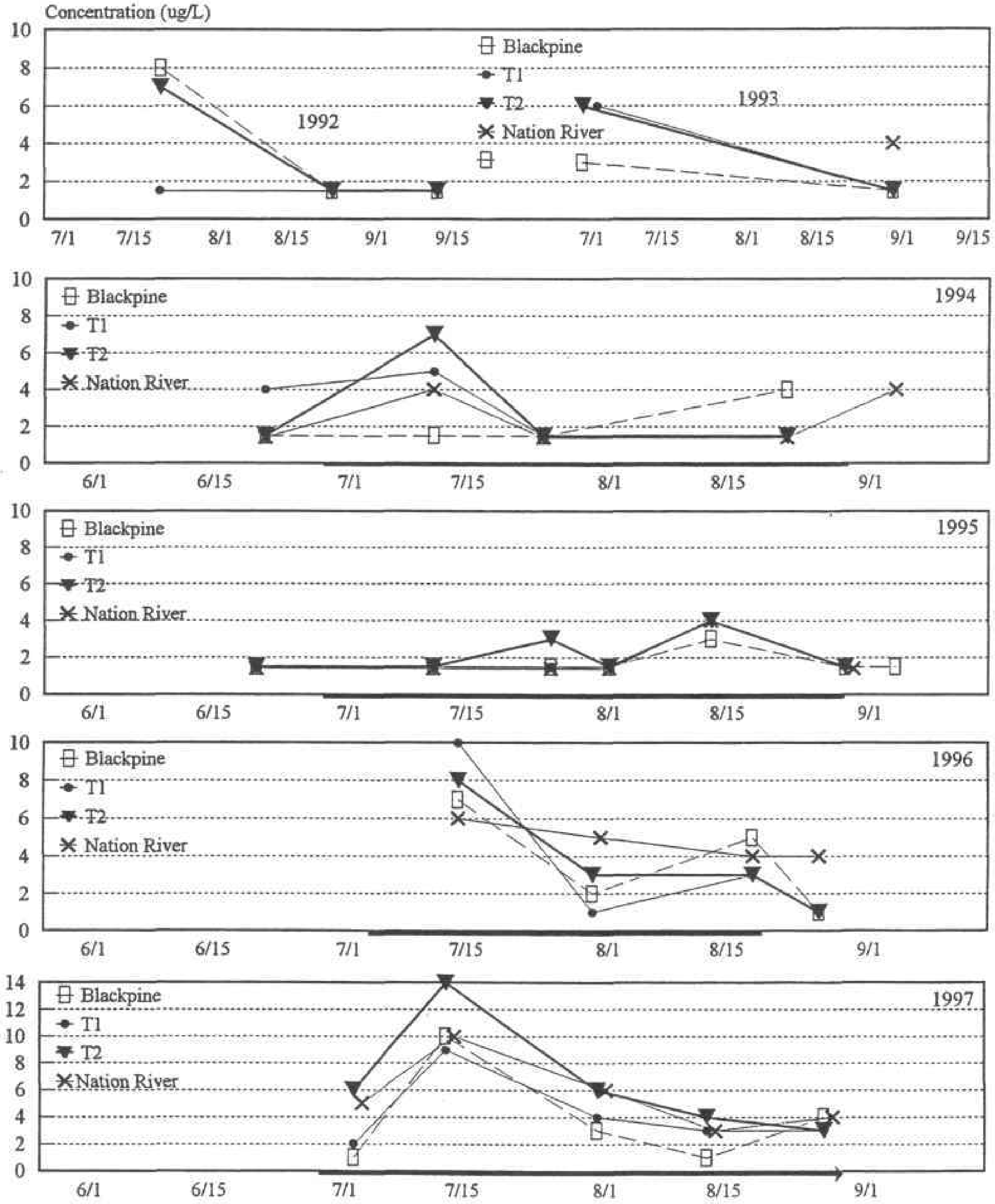


Figure 9. Total dissolved phosphorous (TDP) concentration measured in the Mesilinka and Nation rivers, 1992-1997. Concentrations determined as below the analytical detection limit are shown at half the detection limit value of 3 μg•L^{-1} for 1992-1995 data, and 2 μg•L^{-1} for 1996 and 1997 data. Dark lines on the x-axes indicate approximate time of liquid fertilizer addition to the Tl and T2 reaches.

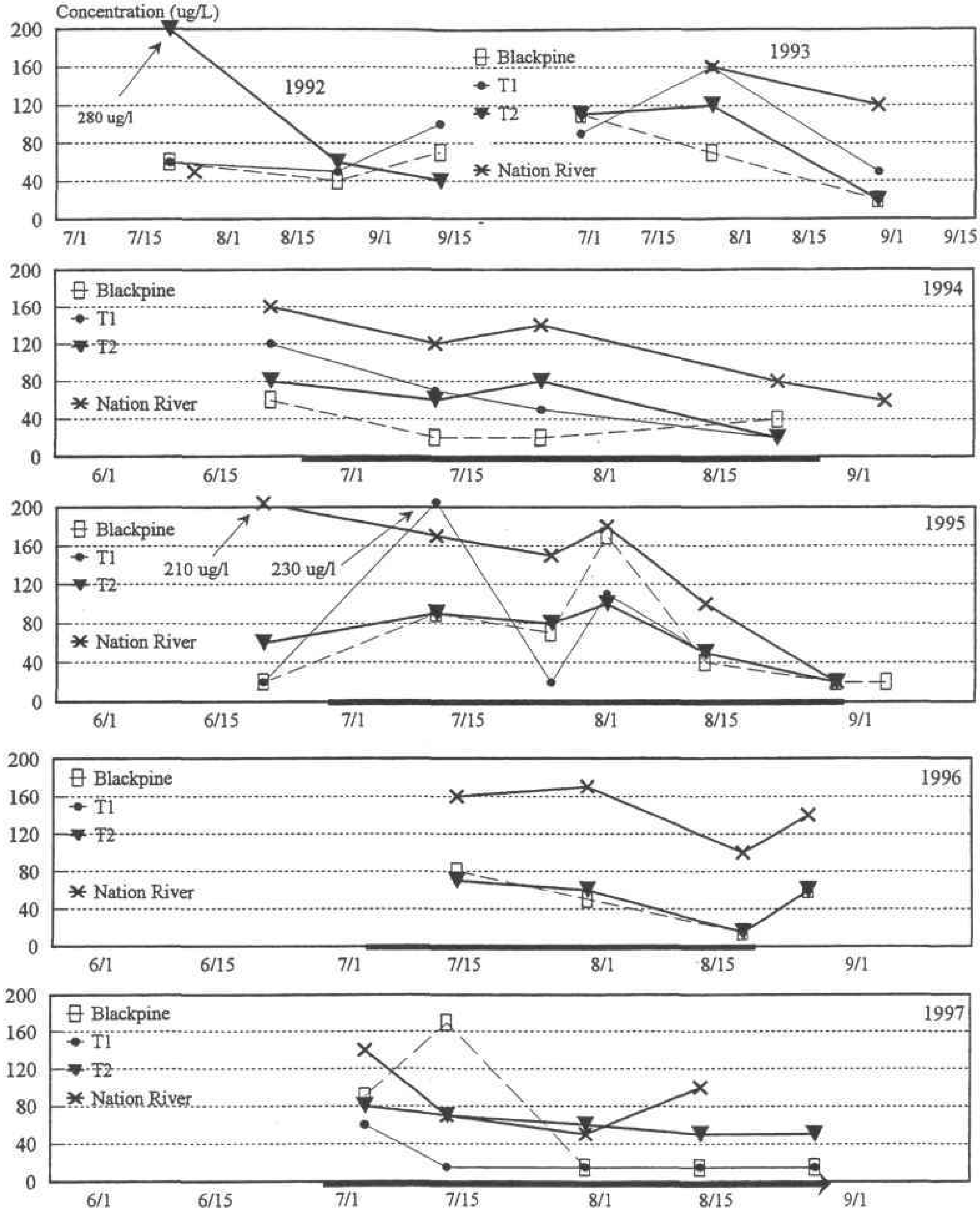


Figure 10. Total organic nitrogen (TON) concentration measured in the Mesilinka and Nation rivers, 1992-1997. Concentrations determined as below the analytical detection limit are shown at half the detection limit value of 40 µg•L^{-1}. Dark lines on the x-axes indicate approximate time of liquid fertilizer addition to the Tl and T2 reaches.

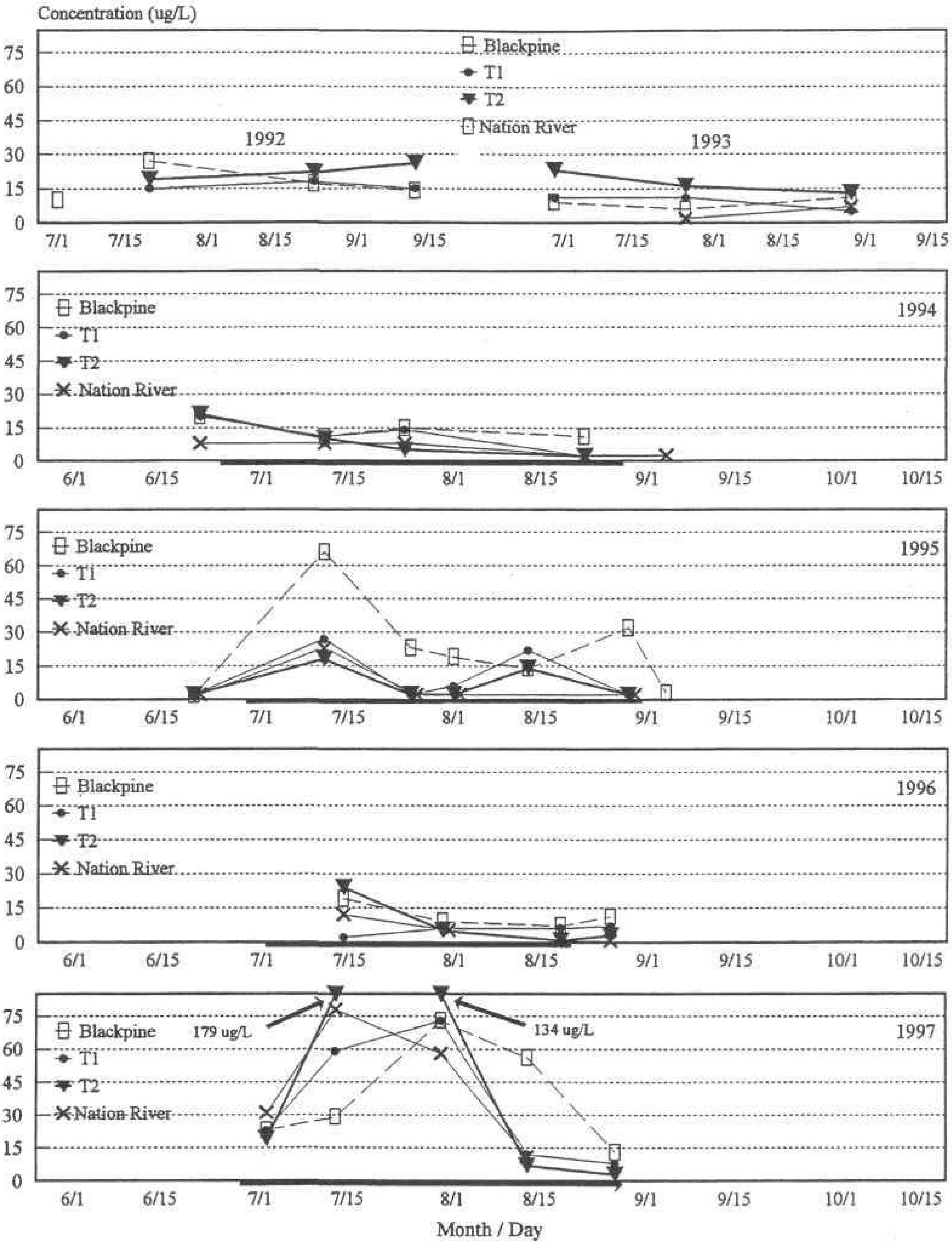


Figure 11. Nitrate and nitrite nitrogen (NO_3+NO_2-N) concentration measured in the Mesilinka and Nation rivers, 1992-1997. Concentrations determined as below the analytical detection limit are shown at half the detection limit value of 5 $\mu g \cdot L^{-1}$ for 1992-1995 data, and 2 $\mu g \cdot L^{-1}$ for 1996 and 1997 data. Dark lines on the x-axes indicate approximate time of liquid fertilizer addition to the Tl and T2 reaches.

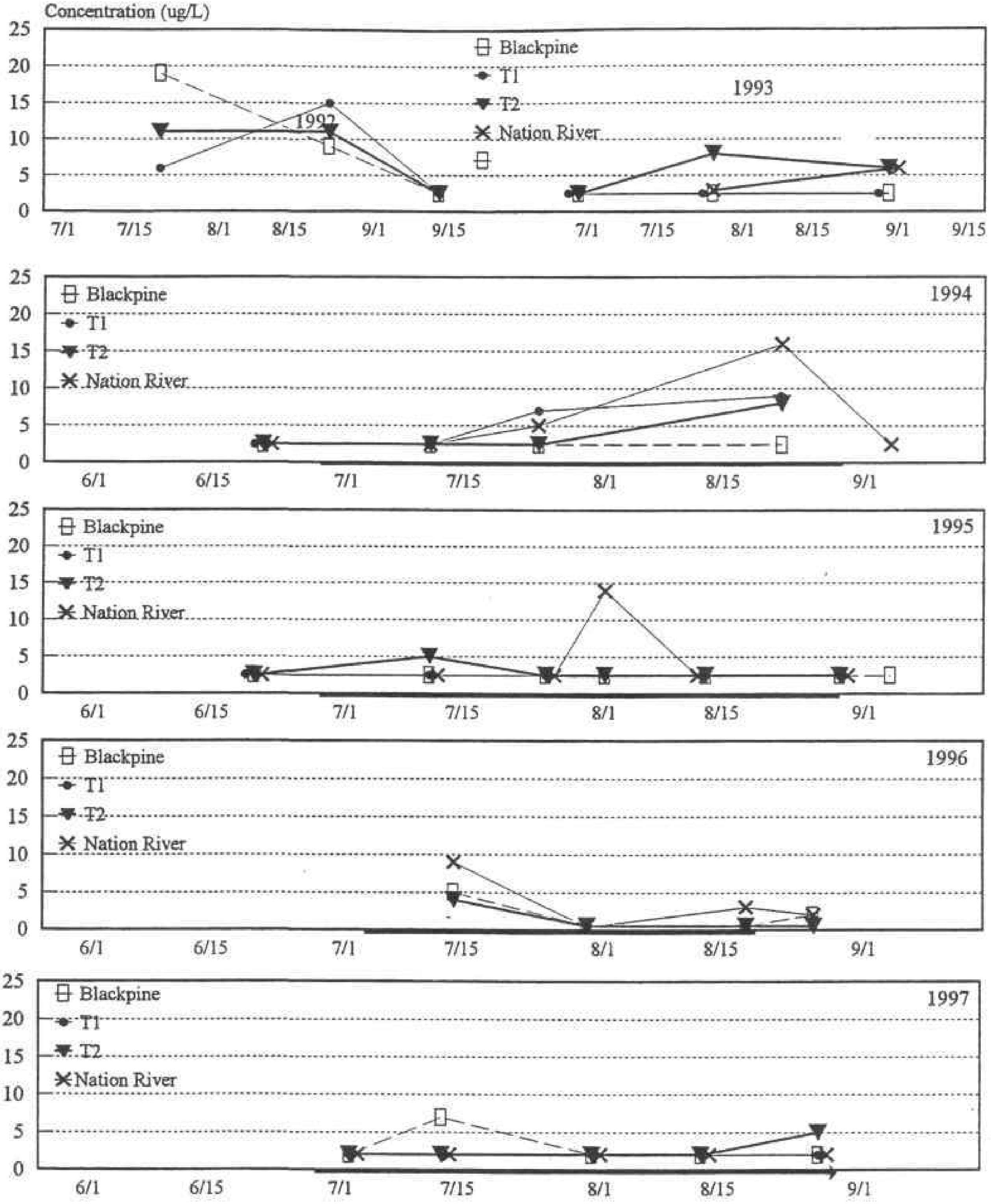


Figure 12. Ammonia nitrogen (NH_3-N) concentration measured in the Mesilinka and Nation rivers, 1992-1996. Concentrations determined as below the analytical detection limit are shown at half the detection limit value of 5 $\mu g \cdot L^{-1}$ for 1992-1995 data, and 2 $\mu g \cdot L^{-1}$ for 1996 and 1997 data. Dark lines on the x-axes indicate approximate time of liquid fertilizer addition to the T1 and T2 reaches.

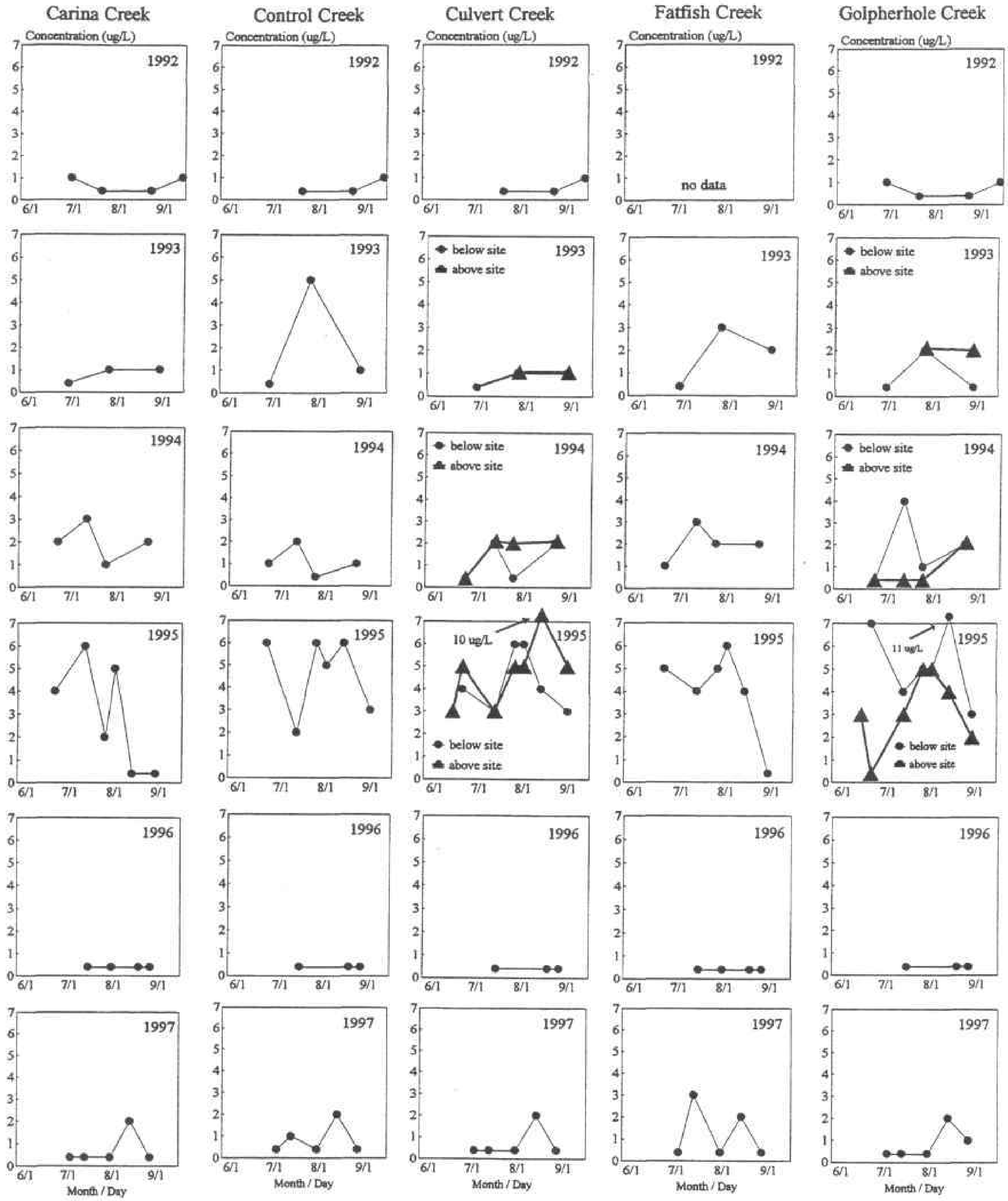


Figure 13. Soluble reactive phosphorous (SRP) concentration measured in 5 Mesilinka tributaries, 1992-1997. Dark lines on x-axes of 1993 and 1995 Culvert and Gopherhole creeks indicate approximate time of 1993 liquid fertilizer addition, and dissolution of slow release briquettes in 1995. Concentrations determined as below the analytical detection limit are shown at half the detection limit value of 1 µg•L^{-1}.

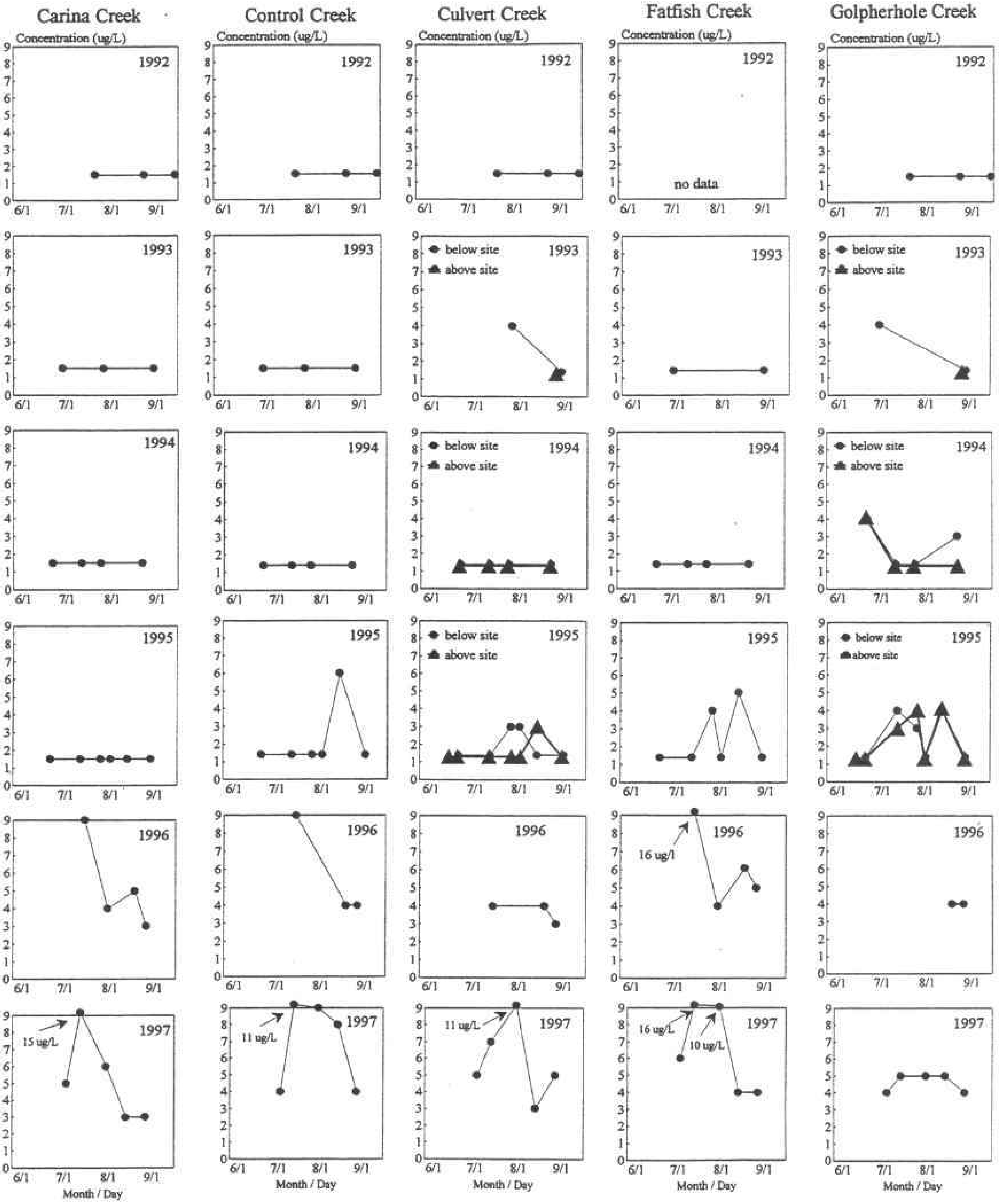


Figure 14. Total dissolved phosphorous (TDP) concentration measured in Mesilinka River tributaries, 1992-1997. Dark lines on x-axes of 1993 and 1995 Culvert and Gopherhole creeks indicate approximate time of 1993 liquid fertilizer addition, and dissolution of slow release briquettes in 1995. Concentrations determined as below the analytical detection limit are shown at half the detection limit value of 3 $\mu g \cdot L^{-1}$ for 1992-1995 data, and 2 $\mu g \cdot L^{-1}$ for 1996 and 1997 data.

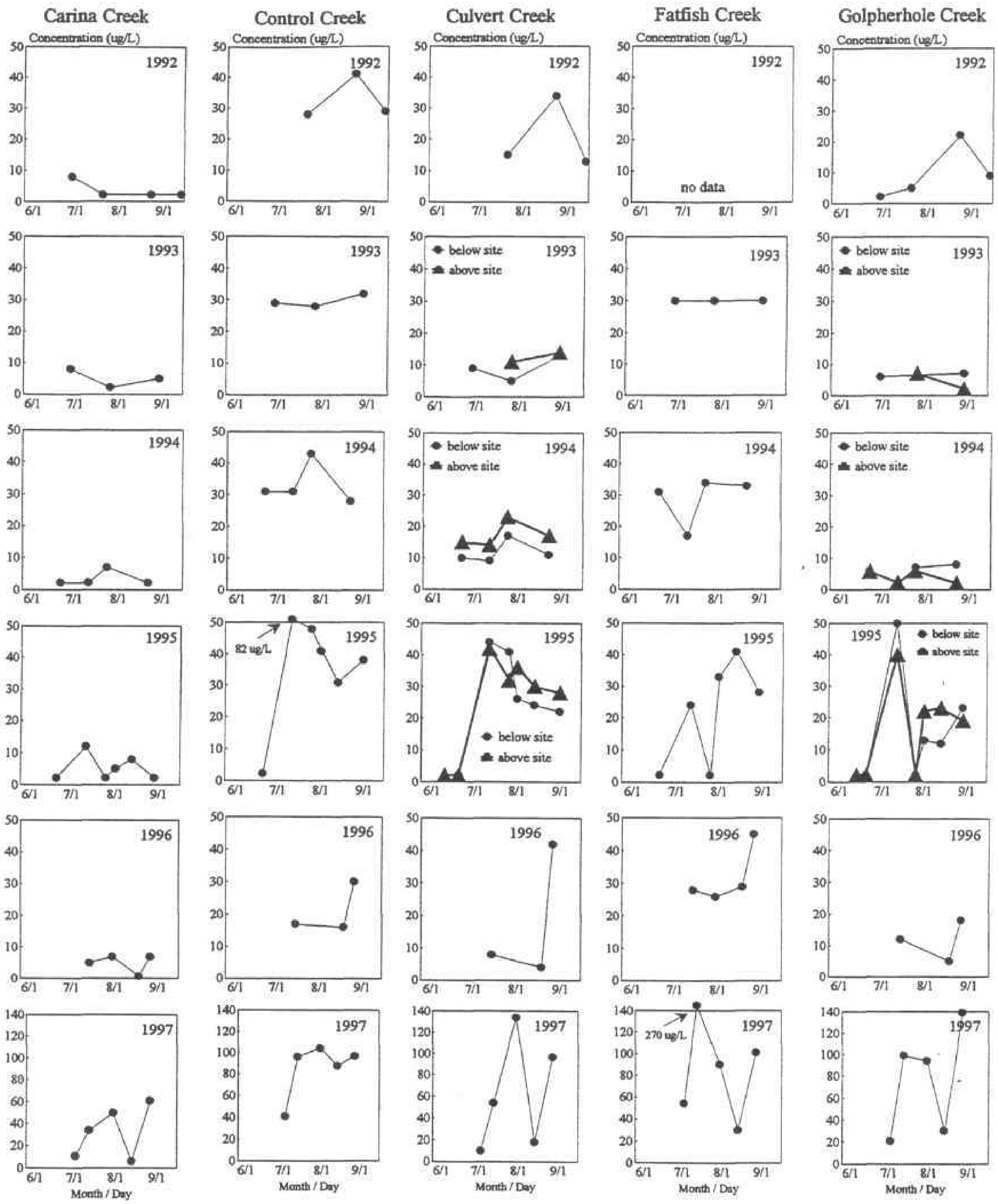


Figure 15. Nitrate and nitrite nitrogen (NO_3+NO_2-N) concentration measured in 5 Mesilinka tributaries, 1992-1997. Dark lines on x-axes of 1993 and 1995 Culvert and Gopherhole creeks indicate approximate time of 1993 liquid fertilizer addition, and dissolution of slow release briquettes in 1995.

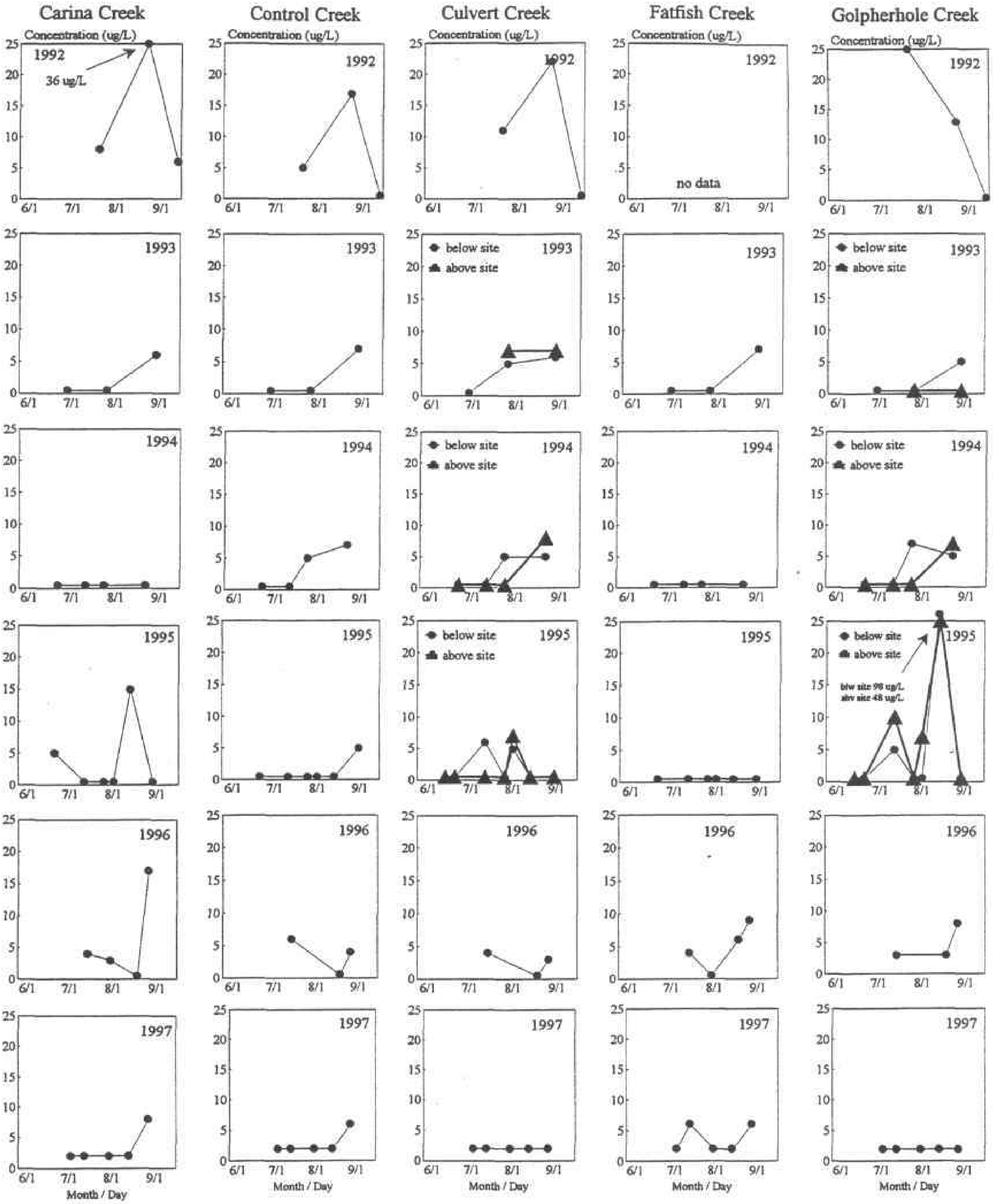


Figure 16. Ammonia nitrogen (NH_3-N) concentration measured in Mesilinka River tributaries, 1992-1997. Dark lines on x-axes of 1993 and 1995 Culvert and Gopherhole creeks indicate approximate time of 1993 liquid fertilizer addition, and dissolution of slow release briquettes in 1995. Concentrations determined as below the analytical detection limit are shown at half the detection limit value of 5 µg•L^{-1} for 1992-1995 data, and 2 µg•L^{-1} for 1996 and 1997 data.

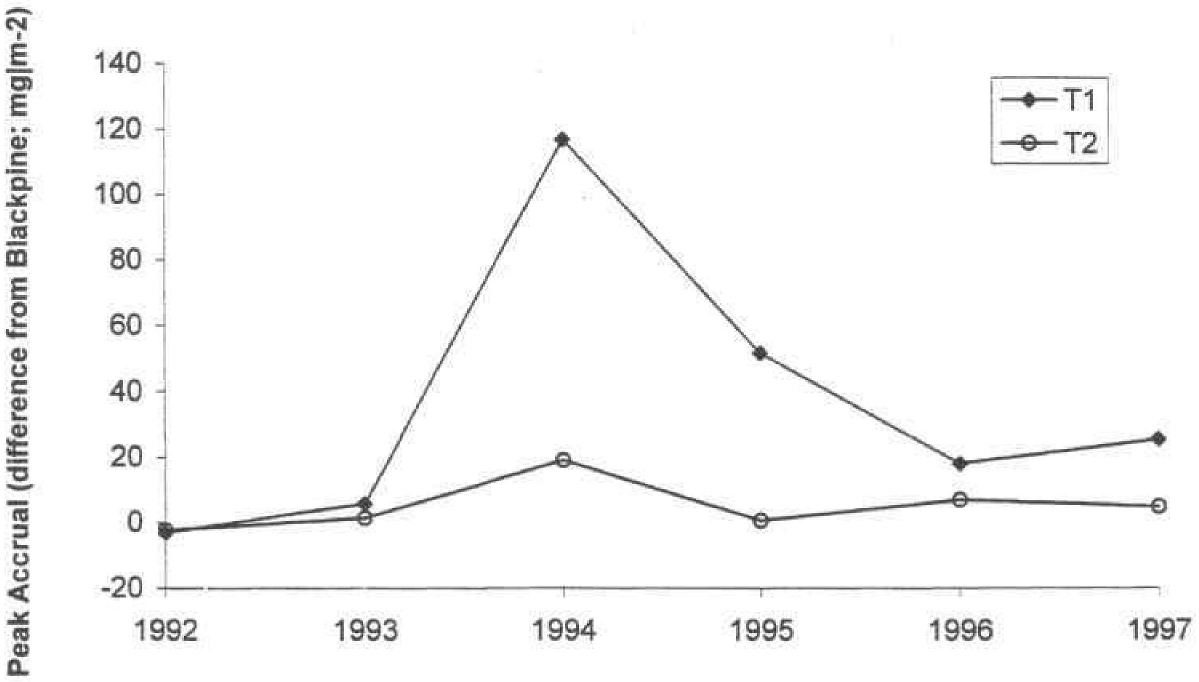


Figure 17. Peak periphyton accrual in the Tl and T2 treatment reaches, as difference from the Blackpine (control) reach, 1992-1997.

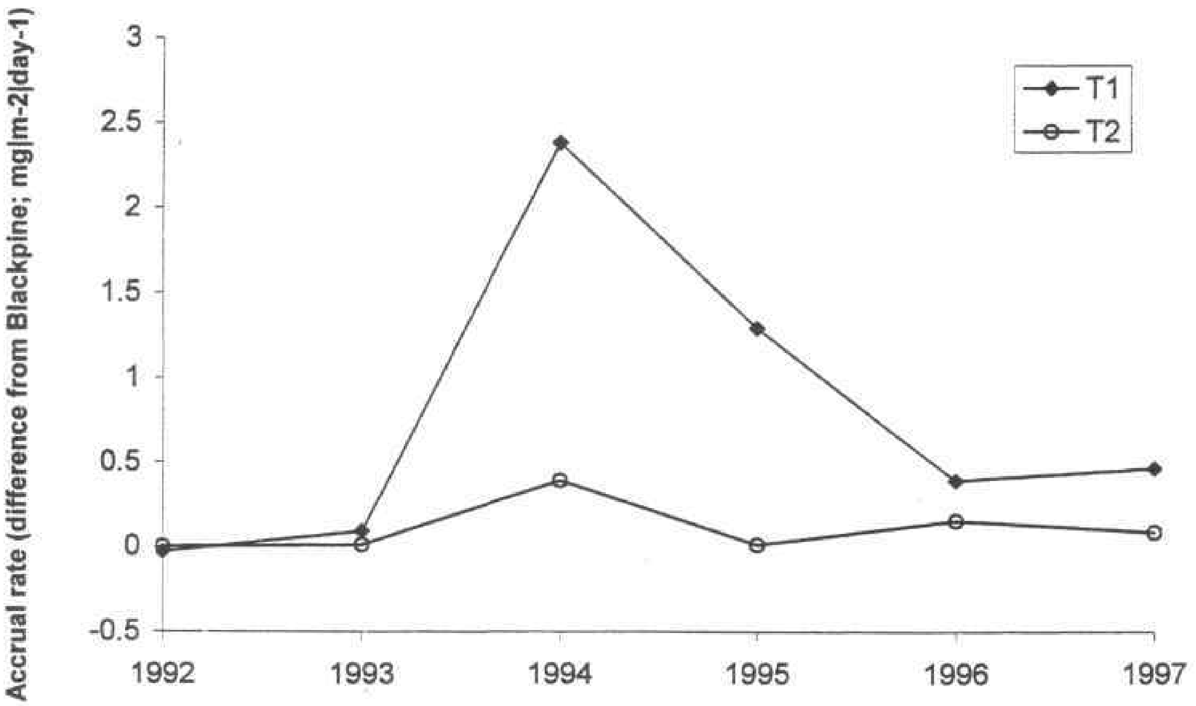


Figure 18. Periphyton accrual rate in the Tl and T2 treatment reaches, as difference from the Blackpine (control) reach, 1992-1997.

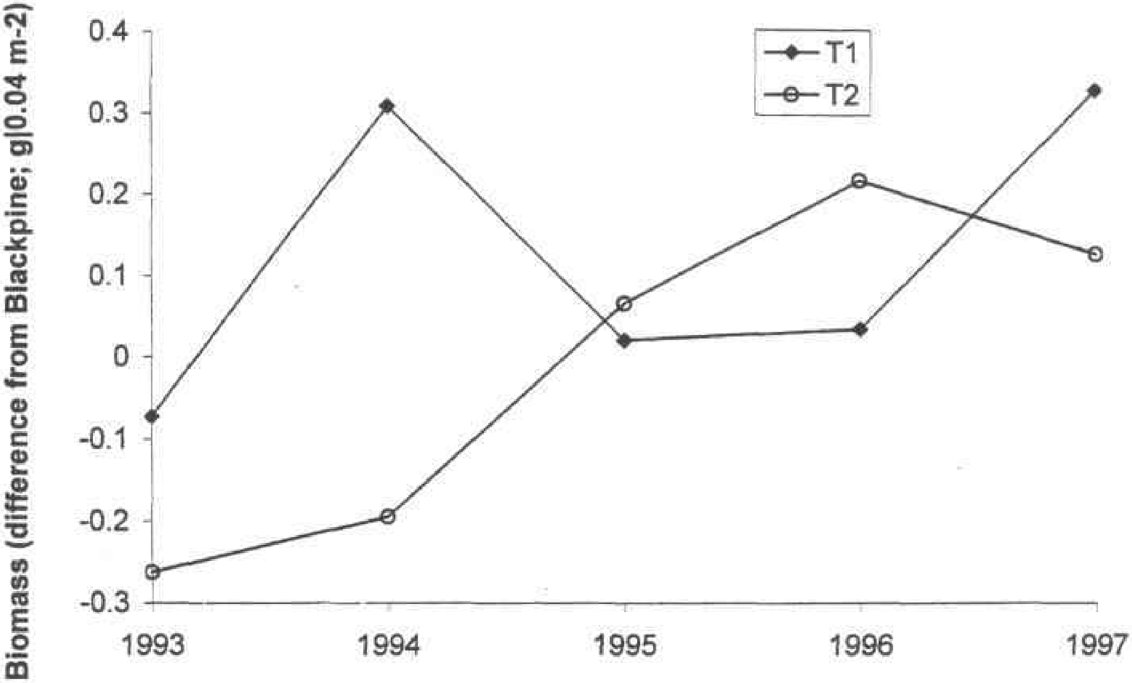


Figure 19. Benthic invertebrate biomass in baskets recovered from the Tl and T2 treatment reaches, as difference from the Blackpine (control) reach, 1993-1997.

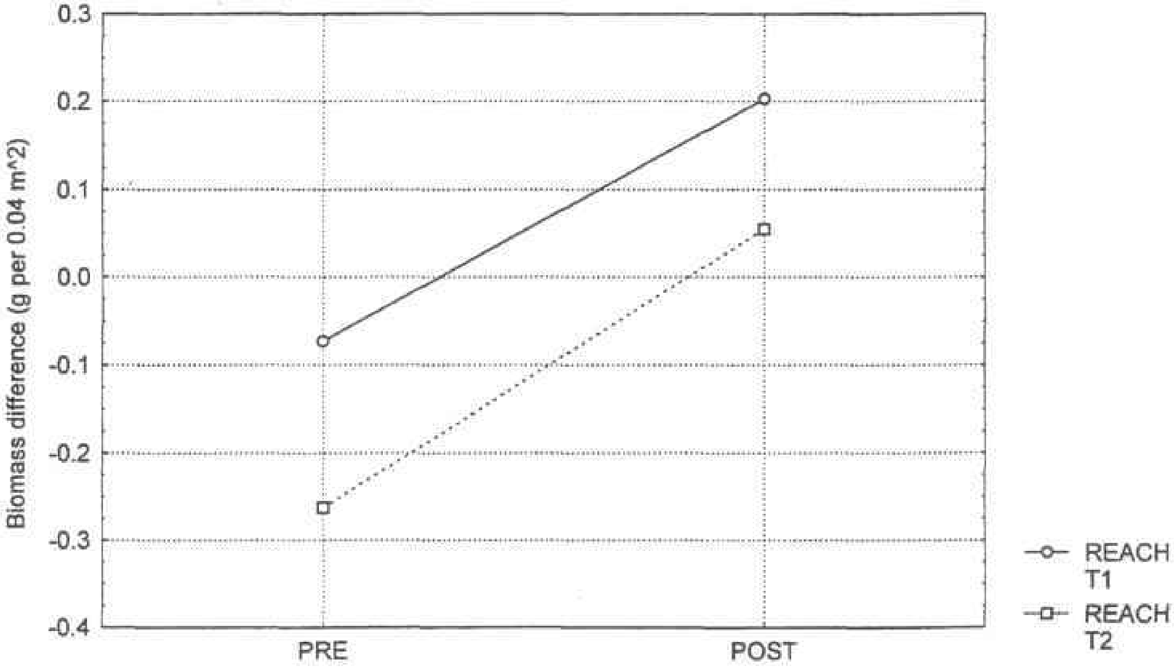
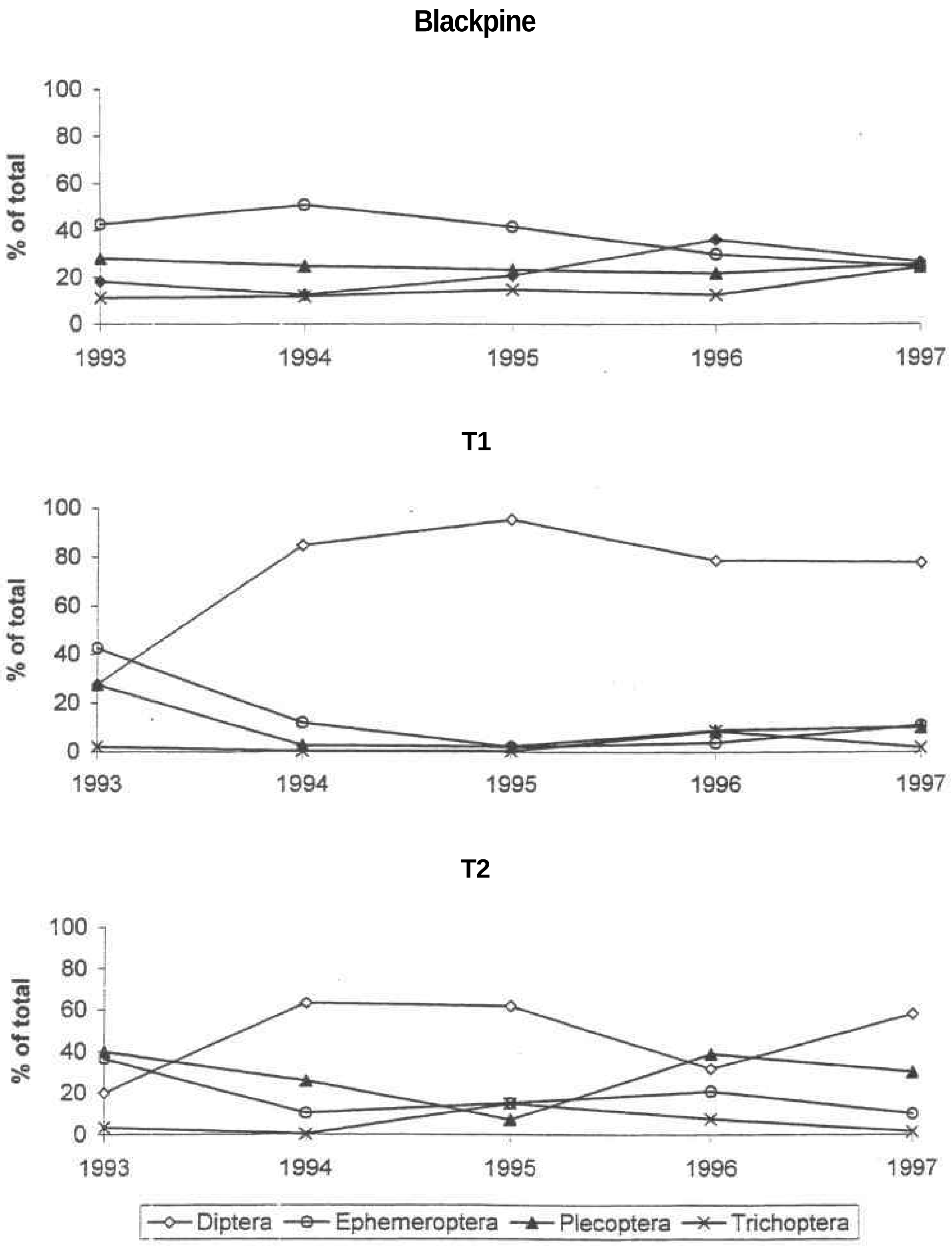


Figure 20. Benthic invertebrate biomass in baskets recovered from the Tl and T2 treatment reaches, as difference from the Blackpine (control) reach, pre- versus post-fertilization.



Blackpine

T1

T2

Figure 21. Relative abundance of four taxonomic groups of benthic invertebrates in the Mesilinka River, 1992-1997.

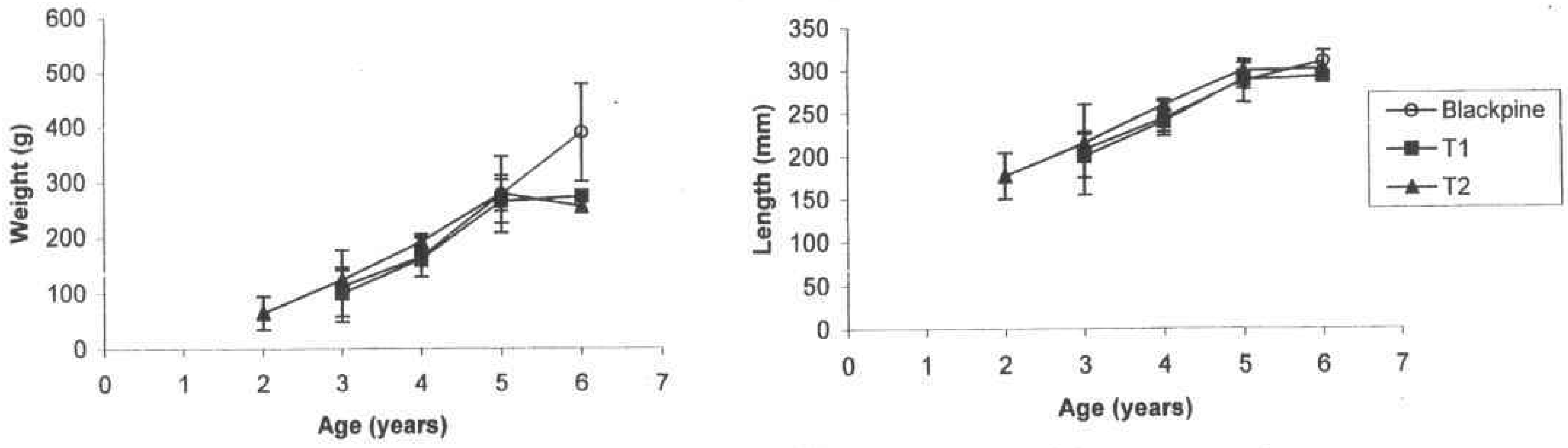


Figure 22. Weight-at-age and length-at-age for Mesilinka River rainbow trout captured by angling in 1997. Error bars are 2 standard errors of the mean.

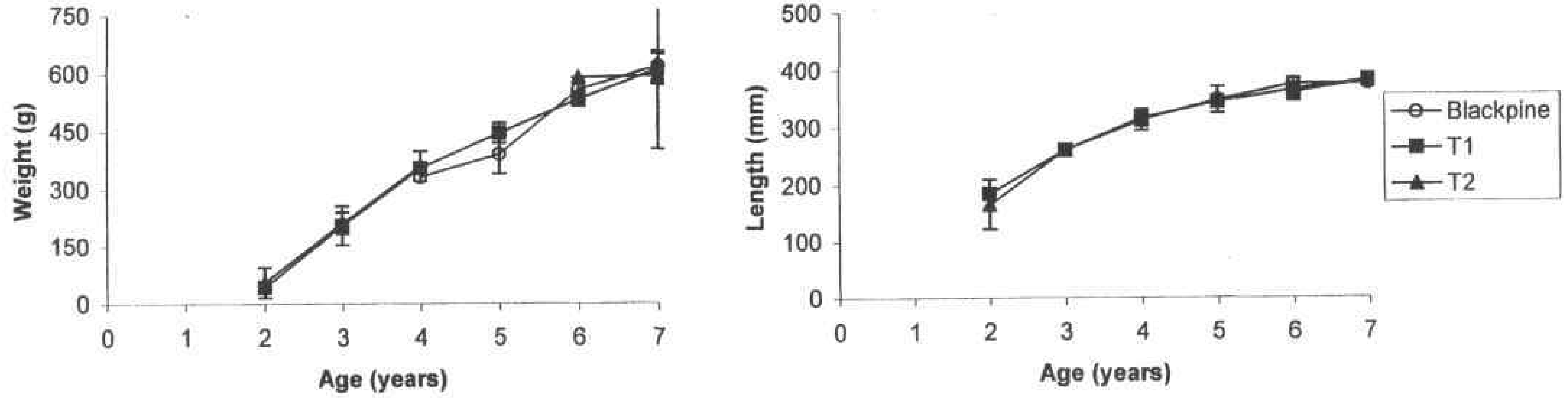


Figure 23. Weight-at-age and length-at-age for Mesilinka River Arctic grayling captured by angling in 1997. Error bars are 2 standard errors of the mean.

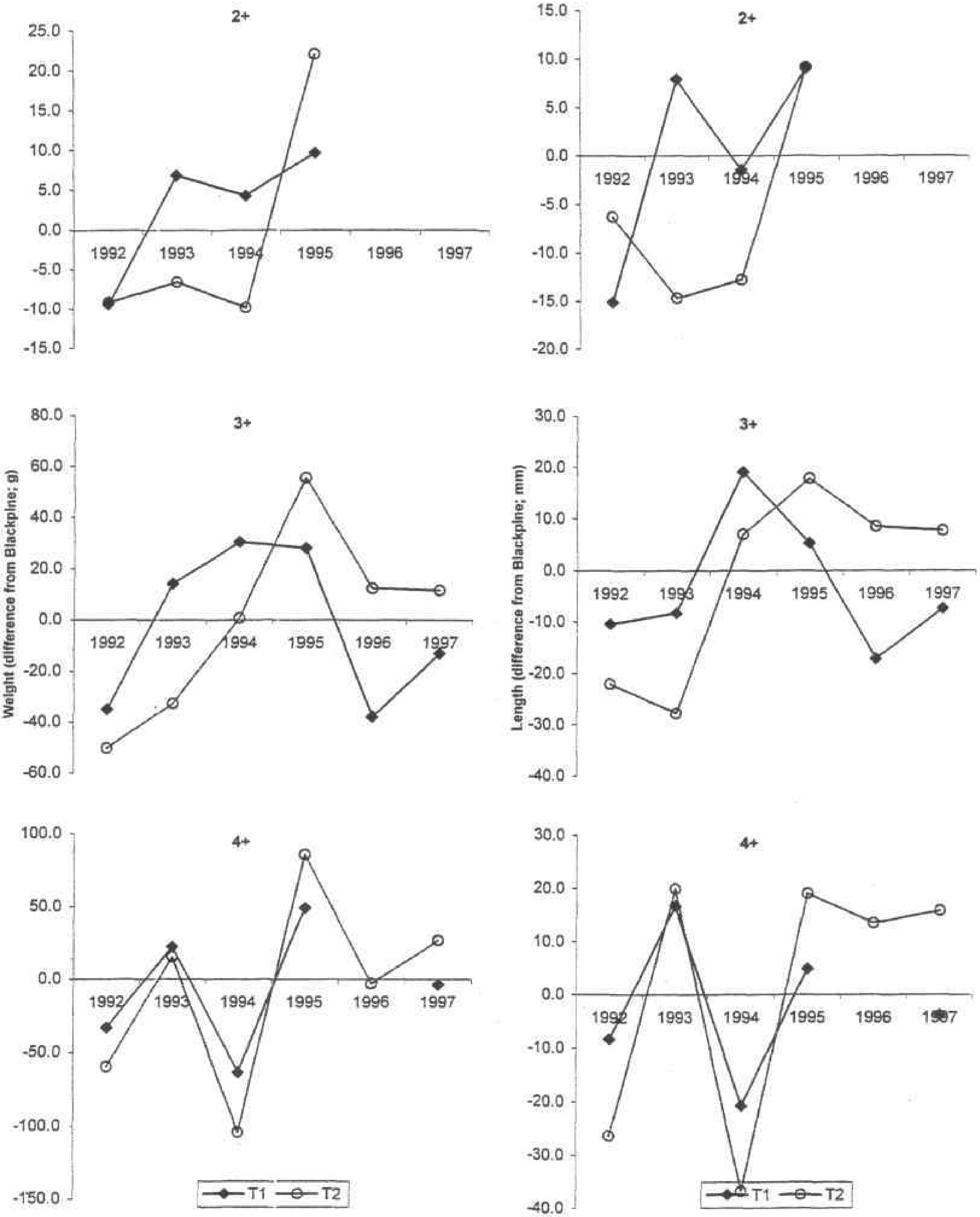


Figure 24. Responses of 2+, 3+ and 4+ rainbow trout to fertilization in the Tl and T2 reaches of the Mesilinka River, presented as differences from the Blackpine (control) reach.

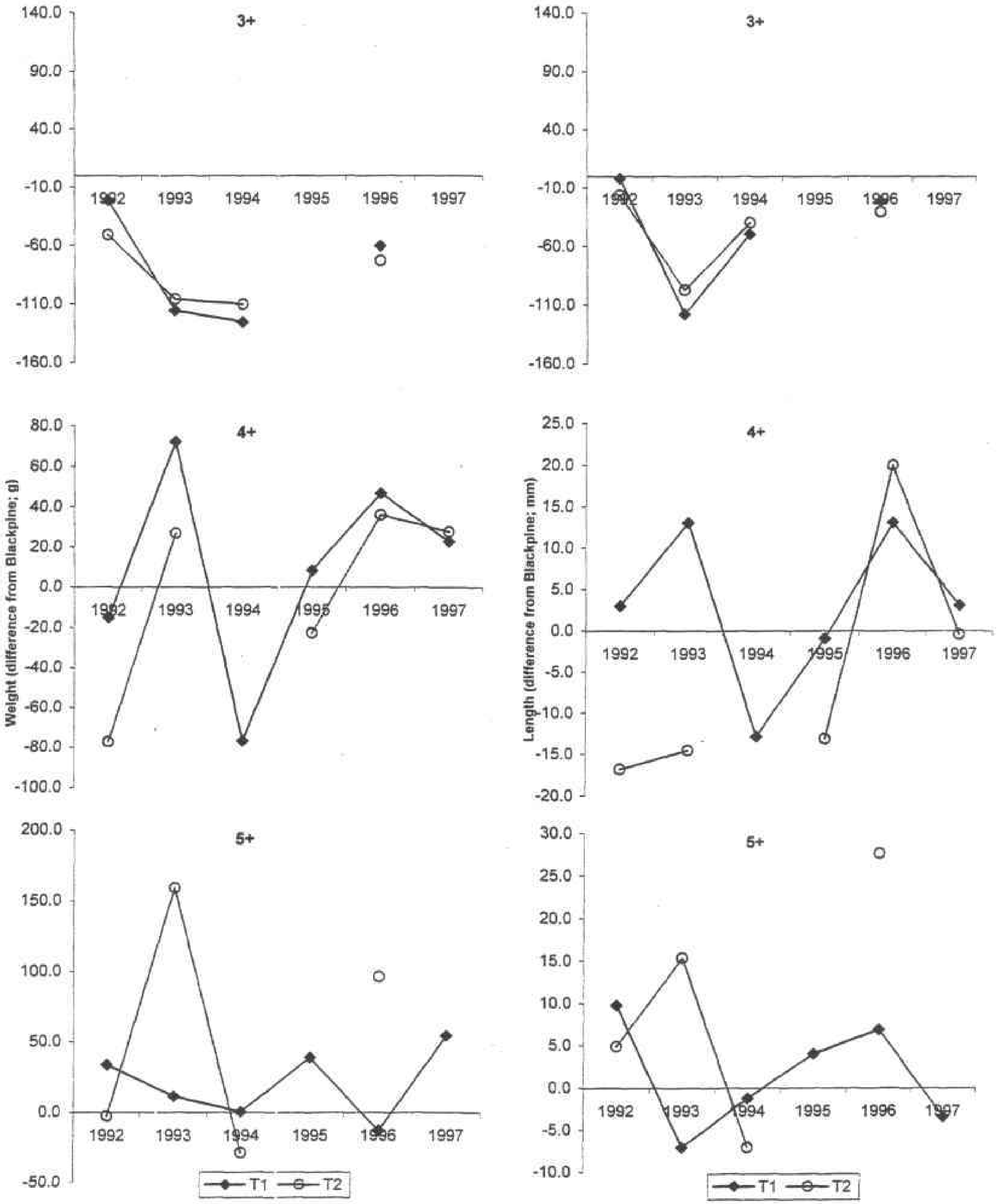


Figure 25. Responses of 3+, 4+ and 5+ Arctic grayling to fertilization in the Tl and T2 reaches of the Mesilinka River, presented as differences from the Blackpine (control) reach.

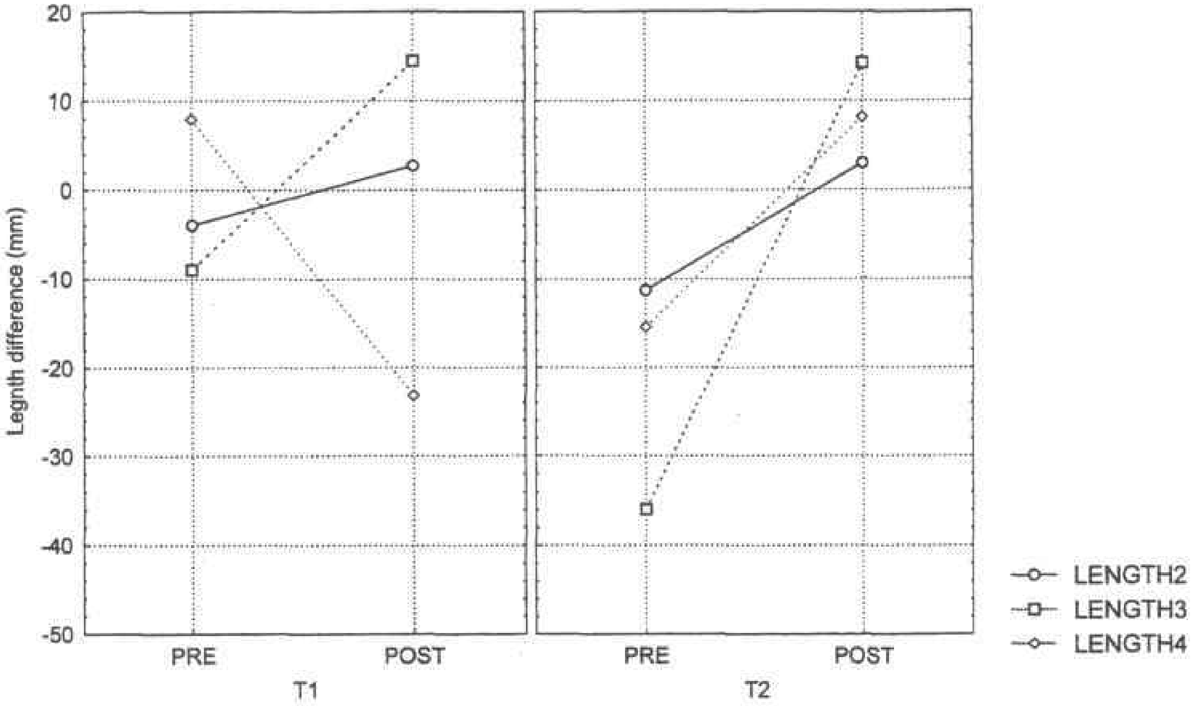


Figure 26. Length-at-age of 2+, 3+ and 4+ rainbow trout in the Tl and T2 reaches of the Mesilinka River, presented as differences from the Blackpine (control) reach, pre- versus post-fertilization.

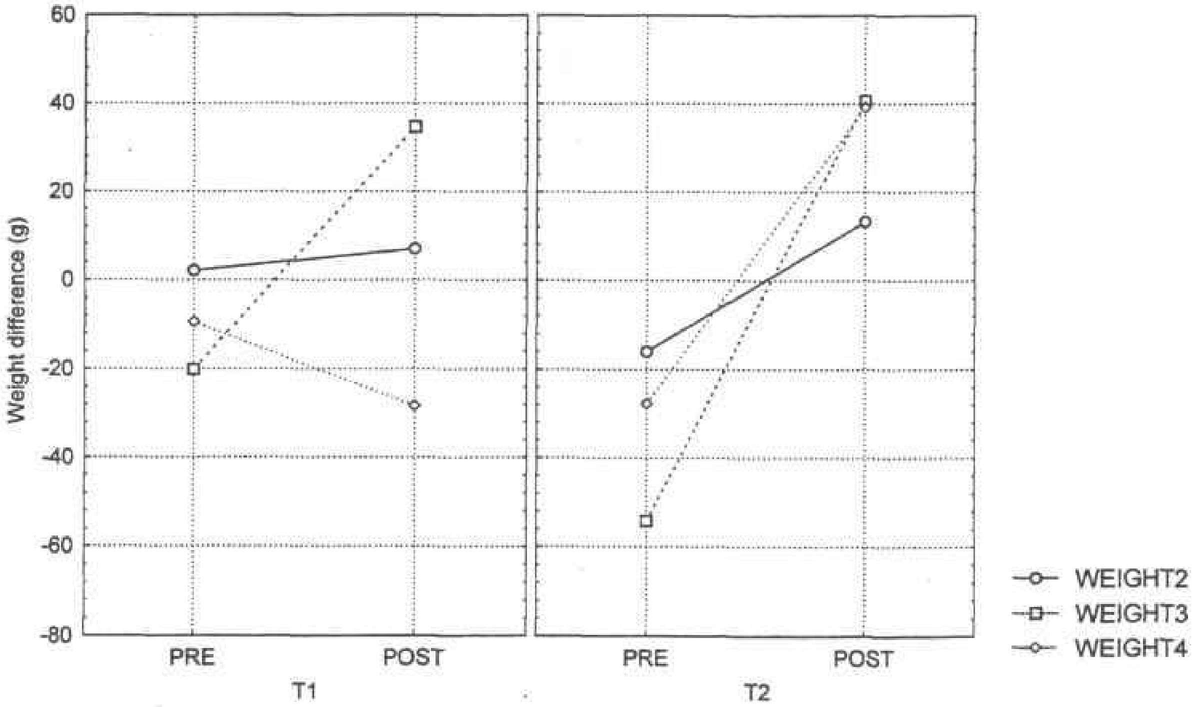


Figure 27. Weight-at-age of 2+, 3+ and 4+ rainbow trout in the Tl and T2 reaches of the Mesilinka River, presented as differences from the Blackpine (control) reach, pre- versus post-fertilization.

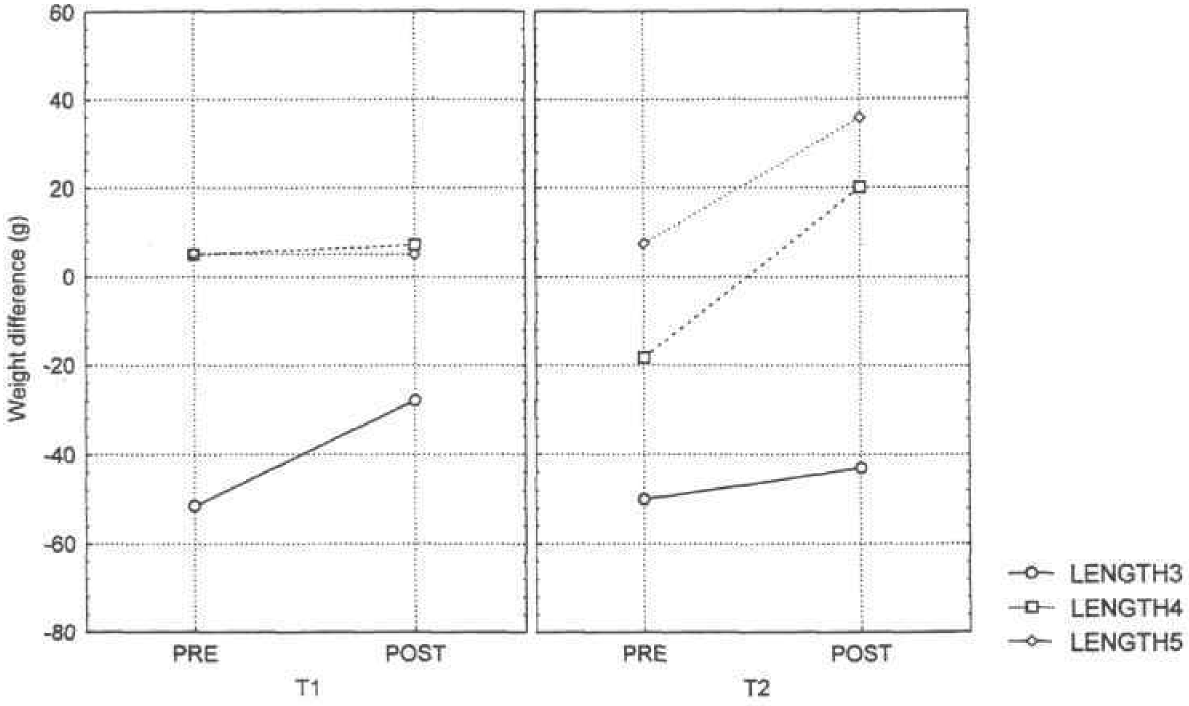


Figure 28. Length-at-age of 3+, 4+ and 5+ Arctic grayling in the Tl and T2 reaches of the Mesilinka River, presented as differences from the Blackpine (control) reach, pre- versus post-fertilization.

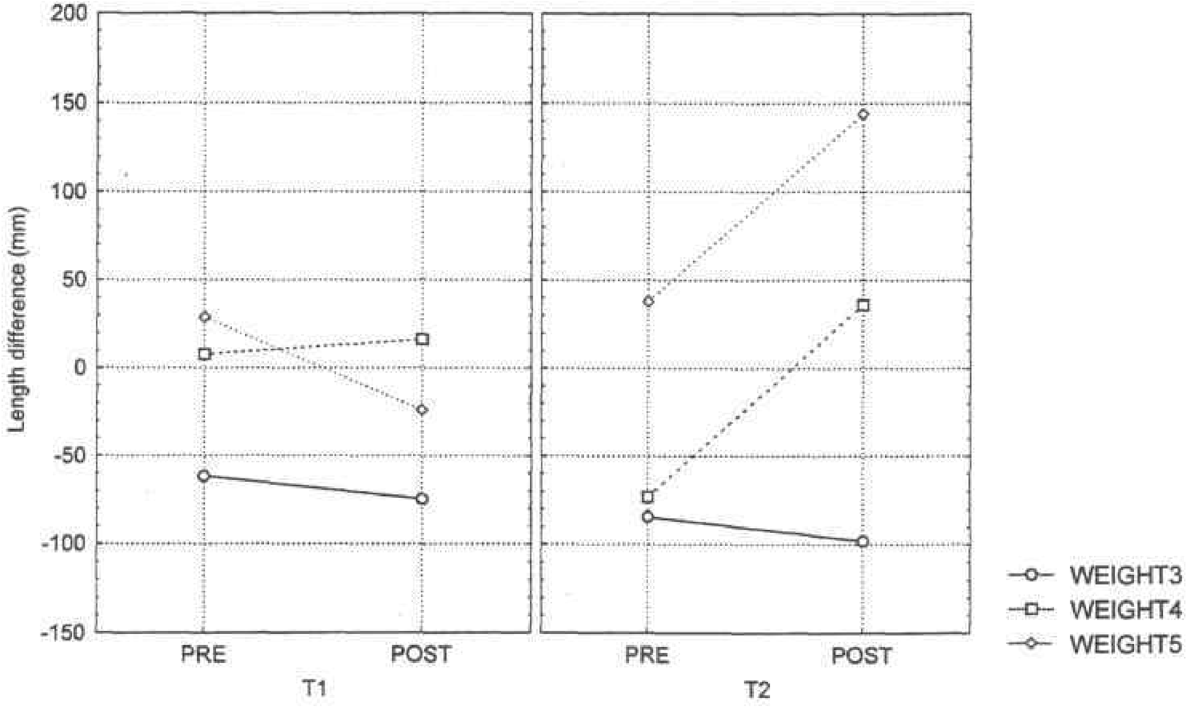


Figure 29. Weight-at-age of 3+, 4+ and 5+ Arctic grayling in the Tl and T2 reaches of the Mesilinka River, presented as differences from the Blackpine (control) reach, pre- versus post-fertilization.

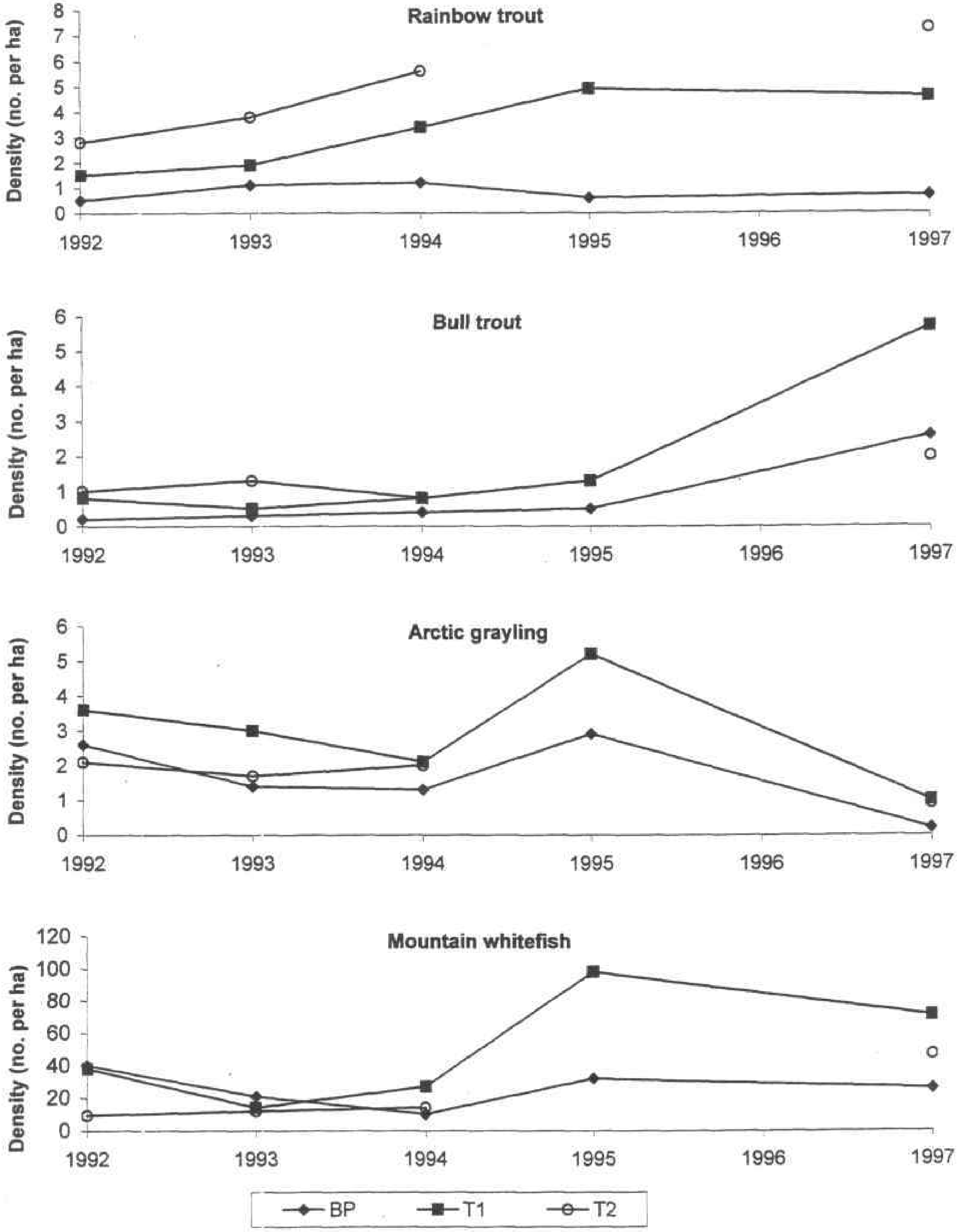


Figure 30. Densities of fishes in three reaches of the Mesilinka River from 1992 to 1997 as determined from underwater counts. No counts were conducted in 1996 or in the T2 reach in 1995.

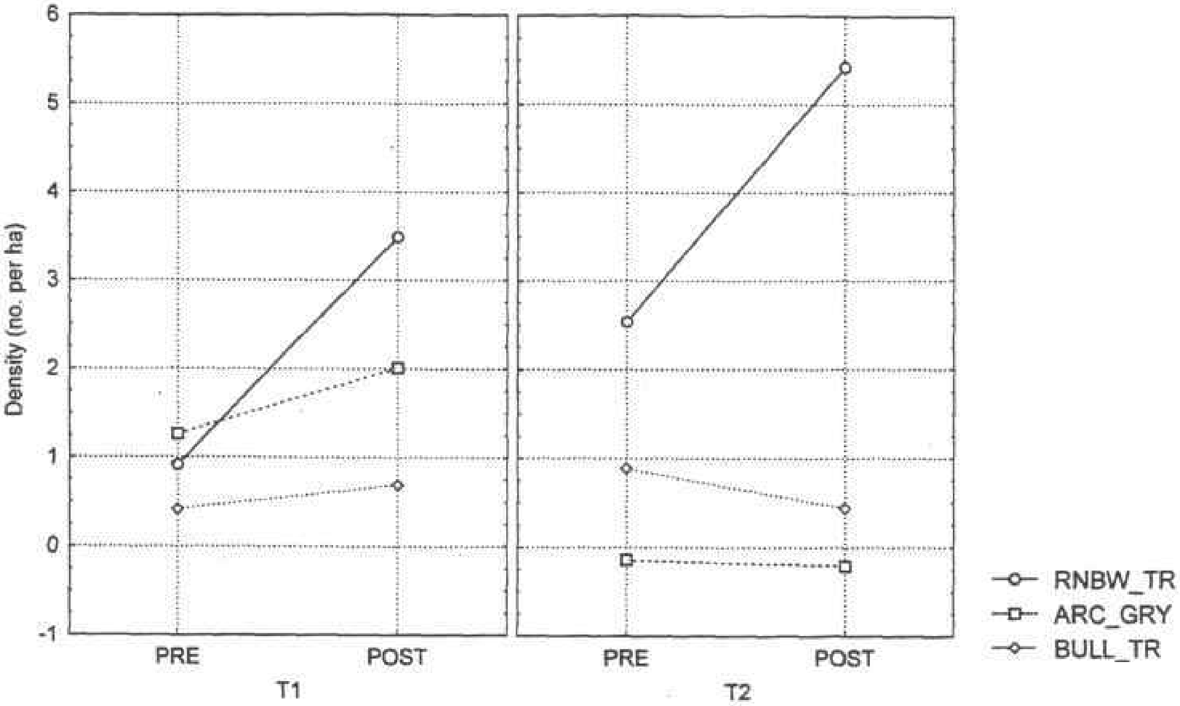


Figure 31. Density of rainbow trout, arctic grayling and bull trout in the Tl and T2 reaches of the Mesilinka River, presented as differences from the Blackpine (control) reach, pre- versus post-fertilization.

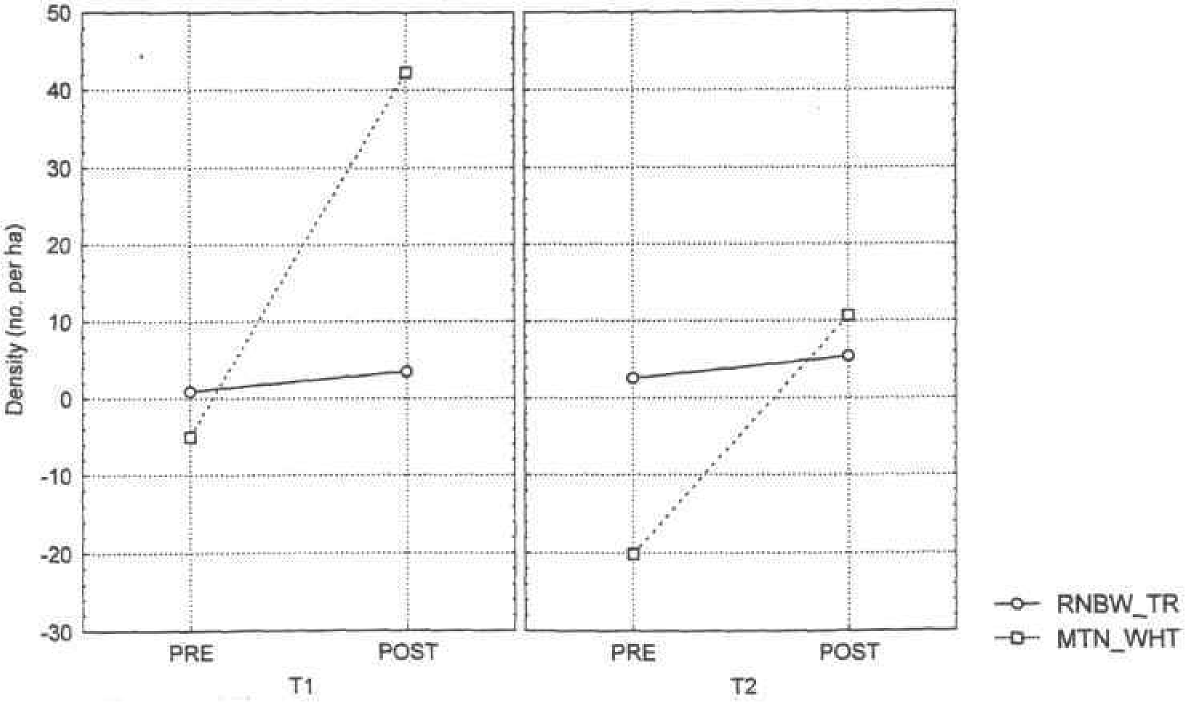
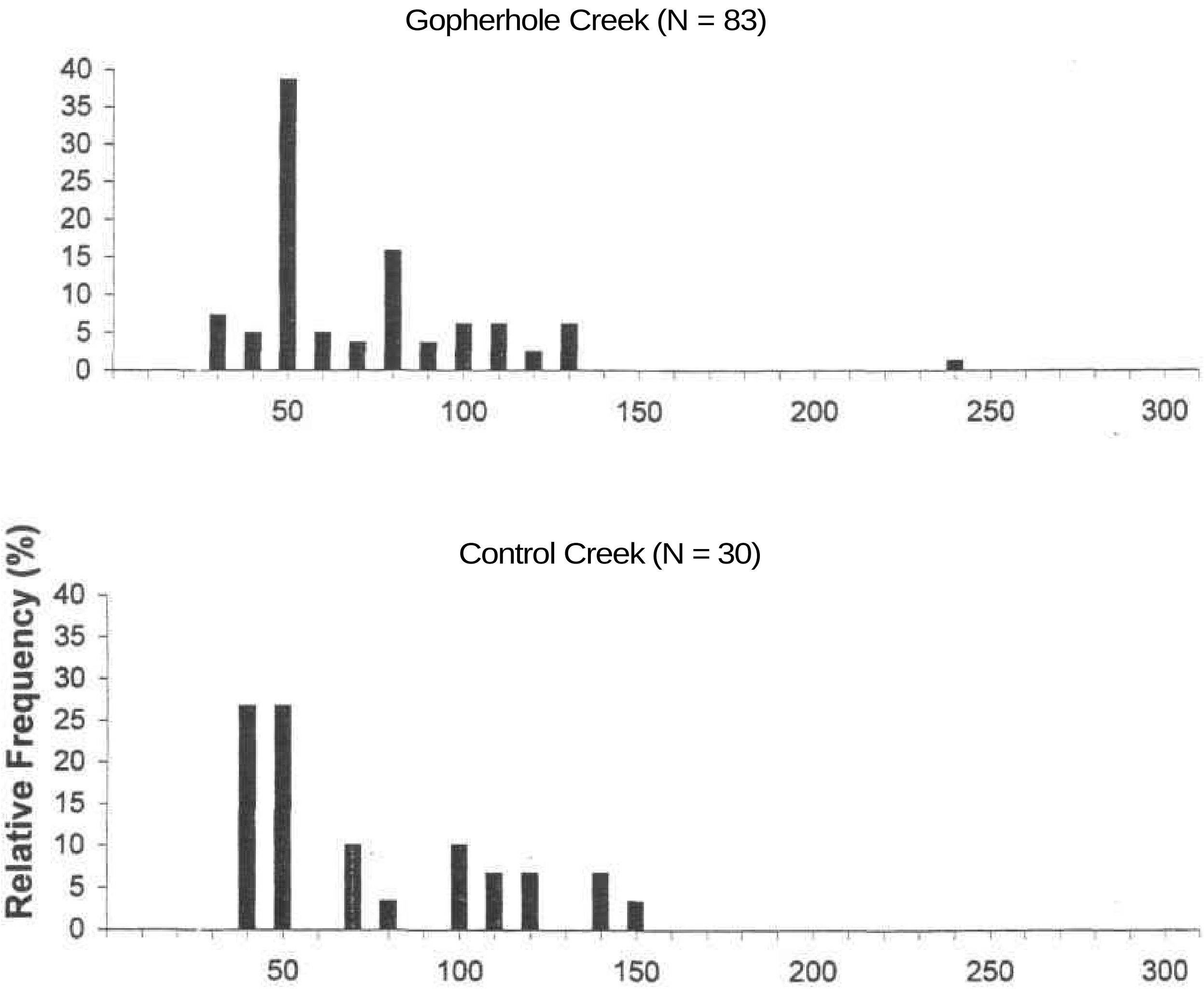


Figure 32. Density of rainbow trout and mountain whitefish in the Tl and T2 reaches of the Mesilinka River, presented as differences from the Blackpine (control) reach, pre- versus post-fertilization.


Gopherhole Creek (N = 83)

Control Creek (N = 30)

Figure 33. Length-frequency plots for all bull trout captured in two tributaries of the Mesilinka River, 1997.