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CHANGE IN NITROGEN CONCENTRATIONS AND PERIPHYTON ACCUMULATION RATES DUE TO FOREST FERTILIZATION WITH UREA IN A "SENSITIVE" DRAINAGE ON VANCOUVER ISLAND

by

C.J. Perrin

submitted to:

Ministry of Forests and Lands
4595 Canada Way
Burnaby, B.C.
V5G 4L9

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EXECUTIVE SUMMARY

Changes in N and P concentrations and accumulation rates of benthic algae were monitored in the Gold River from Sept. 1986 to March 1987 to examine combined effects of N loss from forest fertilization upstream in the Heber River drainage and nutrient discharge from the Gold River sewage treatment plant.

Water and periphyton sampling sites were established upstream and downstream of the Heber River - Gold River confluence and in a similar arrangement upstream and downstream of the sewage treatment plant. Sampling was implimented several weeks before forest fertilization which occurred on Nov. 10, 1986 and continued on an irregular basis for 125 days afterwards.

Rainfall throughout the study resulted in frequent freshets and a steady increase in average stream flow from 21 $m^3.s^{-1}$ in Oct. to 153 $m^3.s^{-1}$ in Feb.

Nitrate-N dominated inorganic nitrogen transport after fertilization but changes in concentrations due to forest fertilization were only double the control levels. Concentrations exceeding 100 $ug.L^{-1}$ were rare. Within 16 days after treatment there was no difference in N concentrations between treatment and control sites and levels were near 50 $ug.L^{-1}$. Ammonia concentrations were mostly undetectable at all sites (<10 $ug.L^{-1}$). The use of buffer strips and potential for nitrification between the fertilized blocks and sampling sites can explain the lack of change in ammonia concentrations due to forest fertilization.

Dissolved phosphorus concentrations were low throughout the study and did not differ between sites.

Relatively small or no change in element concentrations is attributed to large dilution effects in relation to mixing of the Heber River and mixing of sewage treatment plant effluent in the Gold River.

The periphyton community was dominated by diatoms and biomass accumulation on substrata was generally low throughout the study. Chemical indicators suggested periphyton growth was P-deficient. Largest accumulations of algae reaching 10 mg. $chl.a.m^{-2}$ were noted before forest fertilization, downstream of the sewage treatment plant. There was no effect of forest fertilization on periphyton accumulation. As the study progressed, periphyton accumulation rates and maximum biomass declined. Sloughing of periphyton at high stream flow was considered most important in winter as a factor controlling biomass accumulation.

Under the present definition of site sensitivity, data from this study does not support the inclusion of Gold River in a list of potentially sensitive sites. Recommendations are presented to reword the definition of a "sensitive site" and to select other potentially sensitive sites using nutrient-deficiency criteria with consideration of physical limitation to algal growth in coastal streams in winter. A modelling approach using dilution criteria is also recommended for site-specific use in determining whether site sensitivity is at all a question for ecosystems downstream of future locations for forest fertilization.

ACKNOWLEDGEMENTS

This study was completed with the assistance of several individuals. Special thanks goes to Cheryl Wardle who completed all sampling in the field. John McClarnon of B.C. Ministry of Forests managed fertilization scheduling and kept field personnel well informed of helicopter activities so that sampling scheduling could be adjusted accordingly. Thanks also goes to Doug Morrison, B.C. Ministry of Environment, Habitat Protection, and John Finnie, Waste Management Branch for discussion of site characteristics.

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INTRODUCTION

The recent Federal-Provincial agreement to increase funding for forest fertilization is regarded as a major boost towards improving the management of second growth Douglas fir Pseudotsuga menziesii stands on Vancouver Island. Fertilization of thinned stands with urea at 200 $Kg.N.ha^{-1}$ is widely regarded as an important silvicultural technique that can be used to enhance growth and merchantable volumes of Douglas fir (Miller et al. 1979, Binkley and Reid 1984, Foster and Morrison 1983). Hence, fertilization is now more extensive than it has been in the past on Vancouver Island.

An important consequence of forest fertilization is that not all fertilizer is retained in forest soils and utilized for tree growth. Depending on site conditions, and the method of fertilizer application, concentrations of all forms of nitrogen can increase in drainage streams after fertilization with urea (Moore 1974, Fredriksen et al. 1974, Perrin et al. 1984). Usual N losses range from 3 to 7% of the applied load and in past studies have not reduced the quality of drainage water when reference is made to drinking water criteria (Nordin 1985, Health and Welfare Canada) or to changes in the biomass of aquatic biota (Stay et al. 1978, Perrin et al. 1984).

In British Columbia, the lack of change in stream functioning after forest fertilization has primarily been due to phosphorus deficiency that limits autotrophic production in streams (Stockner and Shortreed 1978, Bothwell 1985, Perrin et al. 1987). Without a coincident increase in phosphorus concentration, increases in inorganic nitrogen concentrations have been ineffective in changing biological production and aesthetic qualities of streams and lakes.

Recently, the occurrence of combined N and P loading and potential change in algal productivity has been recognized as a real possibility where N losses from forest fertilization may combine with P losses from another user of a fertilized drainage (ie. fish hatchery or sewage treatment plant). New fisheries-forestry guidelines for fertilization on the coast recognize "sensitive" and "non-sensitive" drainages based on potential combinations of N and P loading and water use (Fertilizer Application Guidelines 1986). "Sensitive" drainages are generally defined as those where the addition of fertilizer nitrogen has the potential to cause a negative impact on fish production or on a recreational fishery. For these sensitive sites, important information is lacking on defining limitations to total fertilizer load for a given drainage size. In addition, a quantitative method of predicting change in nitrogen transport due to forest fertilization and in combination with phosphorus, predicting relative change in algal biomass is lacking.

As a first step towards quantifying change in accumulation rates of benthic algae at sensitive sites affected by residual N from forest fertilization and allochthonous P supply, change in nutrient concentrations and accumulation of benthic algae was monitored in the Gold River, Vancouver Island, before and after forest fertilization upstream in the Heber River drainage. The Heber - Gold site is considered "sensitive" in that potential N losses from forest fertilization could combine with N and P in effluent from the Gold River sewage treatment plant and affect benthic algal biomass in the Gold River. Prevention of increased algal biomass to maintain aesthetic quality is considered important in the Gold River in large part because of its valued steelhead sport fishery.

STUDY SITE

The Gold River - Heber River confluence is located within the village boundaries of Gold River, approximately 90 Km west of Campbell River, Vancouver Island (Fig. 1).

The Gold River is a large, fifth order system having a wetted width during this study of about 25 m, an average depth of 1 m and near sampling areas shown in Fig. 1 the river was structured mainly as a series of riffles, runs and deep pools. Gold River has a pristine clarity and is highly valued for its recreational potential and steelhead fishery. A summer run of about 3000 steelhead (Salmo gairdneri) actively migrate and utilize spawning habitat in May through June. Also, a winter run of more than 3000 steelhead support a fishery primarily from December through April, although some winter-run adults have been found in spawning habitat in May and June. The Gold River also supports a small run of about 3000 coho (Oncorhynchus kisutch) that are present in the river at the same time as summer-run steehead but are never intercepted in the sport fishery. Sockeye salmon (Oncorhynchus nerka) are also found in May through June and these are important in the Indian food fishery. Chinook salmon (Oncorhynchus tshawytscha) also migrate in the Gold River but are closed to sport fishing.

The Heber River is a third order system and about a quarter the size of the Gold in annual discharge. It originates in the Mount Heber - Mount Judson drainage and flows for about 40 Km before discharging into the Gold River. Upper reaches of the Heber are characterized mainly by riffle and run sequences having an average width of 2-3m and depth of about 40cm. Lower reaches are steep, having a gradient near 5%. Within the last kilometre before discharging into the Gold River, the Heber cuts through a narrow canyon. Deep pools in the canyon offer excellent holding habitat for summer-run steelhead that spawn in the Gold River. Many of these steelhead migrate upstream for about 10 Km and provide a well known fly fishery before returning to the Gold.

Forest stands fertilized in this study were located on slopes adjacent to the Heber River, 10 Km upstream from the confluence with the Gold. The area is within the dry subzone of the coastal western hemlock biogeoclimatic zone (CWHa1) and is characterized by coarse textured soils derived from glacial - fluvial deposits. All stands were second growth Douglas fir that were planted in 1968-69 after a controlled burn in the early 1960's. All stands were thinned in 1983. Eight blocks of these stands number 28 to 35 were fertilized (Fig. 1). Block areas ranged from 6.9 (block 35) to 31 (block 28) ha. Slope gradients ranged from mostly flat on block 30 to 5%, 40%, and 50% in blocks 28 and 32, blocks 33-35, and blocks 29 and 31 respectively.

Sewage from the Gold River townsite is processed through a secondary treatment facility located at the south (downstream) end of the village boundary and after treatment, discharges directly into the Gold River. The treatment plant is equipped with an aerator, clarifier and sludge drying beds and hence the discharge solution is clear and does not visually contaminate the Gold River. Maximum discharge from the plant is $0.011\ m^3.s^{-1}$ having an average total phosphorus (TP) and nitrate nitrogen (NO_3-N) concentration of 4000 $ug.L^{-1}$ and 10,000 $ug.L^{-1}$ respectively.

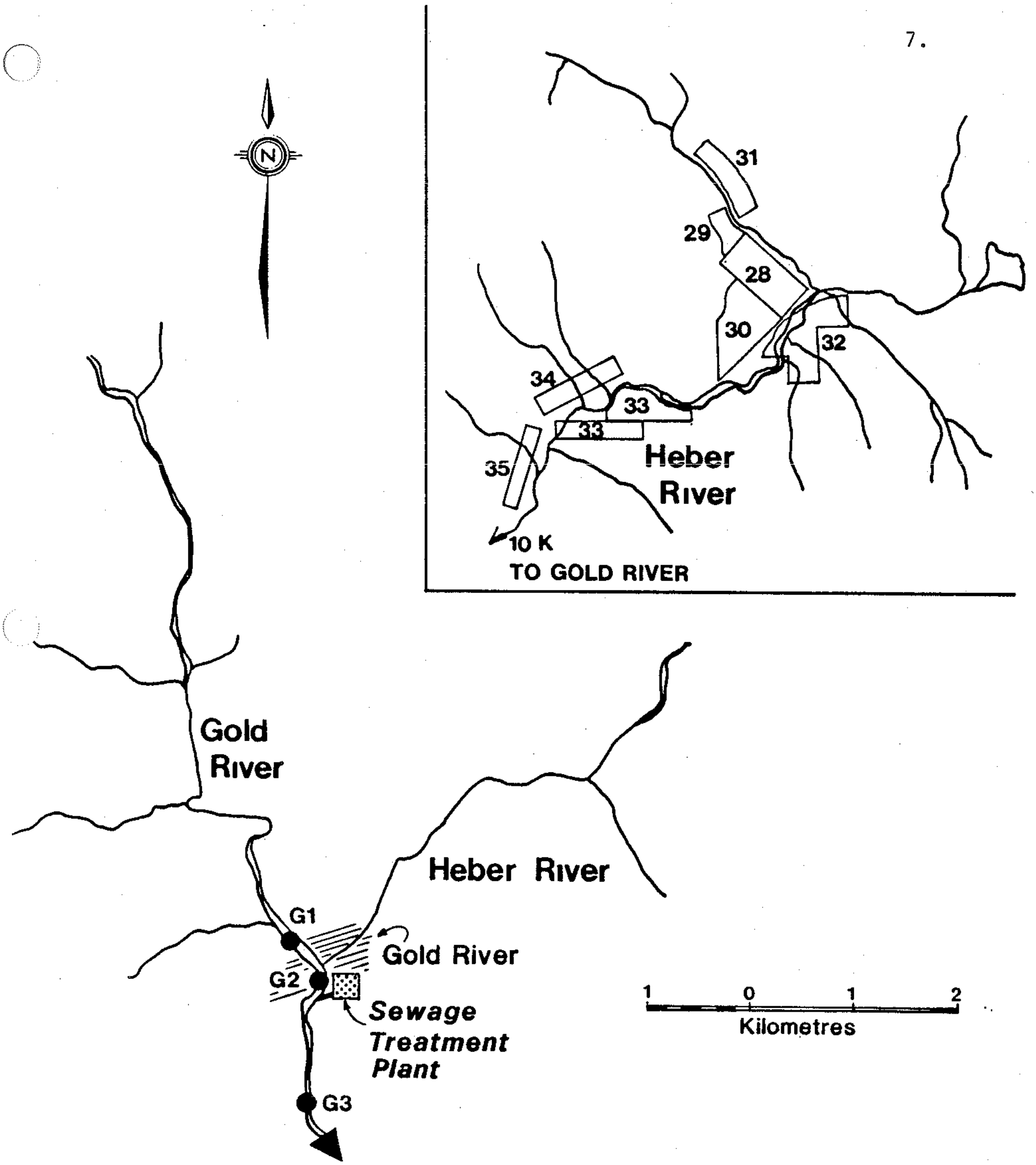

Figure 1. Location of forest fertilization sites (blocks 28 to 35) on the Heber River and water and periphyton sampling sites on the Gold River.

MATERIALS AND METHODS

Prior to fertilization, water and periphyton sampling sites were established upstream and downstream of the Heber - Gold confluence as well as the sewage treatment plant (Fig.1). Site G-1 provided an overall control to establish background variation in both nitrogen concentrations and periphyton accrual. Site G-2 was a treatment location to monitor nitrogen concentrations potentially affected by N loss due to forest fertilization. G-2 also provided a control for any change in the ratio of effluent flow: river flow and hence change in N and/or P concentrations measured at G-3 that could be altered by effluent from the sewage treatment plant.

Water was sampled from each site on four dates over a 50 day period before fertilization and on irregular dates thereafter. After fertilization on Nov. 10, 1986, sites G-1 and G-3 were sampled weekly until mid-January at which time sampling was temporarily stopped. Samples were again collected on a weekly basis in March, 1987. At G-2, daily sampling was started immediately after fertilization for one week to monitor any large pulse of N transport that often occurs immediately after treatment. Thereafter, sampling frequency was gradually reduced to once every 3 days in late November and weekly in December and January at which time sampling was stopped. Sampling at G-2 in

March was the same as that at G-1 and G-3. The final sampling date was March 16, 1987.

All water samples were collected from active water (current velocity >0.10 $cm.s^{-1}$) and filtered in the field using a Millipore apparatus. Nitrocellulose filters having a pore size of 0.45 um were used to ensure results were of the dissolved fraction only. All samples were packed on ice and shipped on the day of sample collection to Cantest Laboratories in Vancouver for analysis within 48 hours of sample collection. All analyses were conducted according to methods outlined in APHA (1985) and MOE (1976). Tests for dissolved nitrogen included nitrate plus nitrite ($NO_3^- + NO_2^-$) and total ammonia ($NH_3 + NH_4^+$), the most biologically available forms of nitrogen. Throughout this report total ammonia will be expressed as NH_4 and the nitrate plus nitrite combination will be expressed as NO_3. Phosphorus tests included total dissolved phosphorus (TDP) and soluble reactive phosphate (SRP). SRP is more frequently accepted as an indication of P available for algal growth than is TDP (Chamberlain and Shapiro 1969, Walton and Lee 1972) although SRP measurements are acknowledged not to represent true phosphate concentrations. Since TDP includes phosphate and organic phosphorus species, it generally overestimates biologically available P (BAP) more than SRP.

Change in nutrient concentrations was examined using a time x location factorial analysis. Time was blocked into 6 categories that were defined on the basis of N transport patterns found in other Vancouver Island studies of N loss after forest fertilization (Perrin et al. 1984, Hetherington 1985): (1) all dates before treatment (Sept.-Nov.9), (2) days 0-3 (Nov. 10-13), (3) days 4-14 (Nov. 14-24), (4) days 15-52 (Nov.25-Jan.2), (5) days 53-66 (Jan.3-16), and (6) a spring period of days 114-125 (March 5-16) after fertilization.

The accumulation of periphyton was measured in riffles at G-1 and G-3. The biomass accrual method was used (Bothwell 1985, Perrin et al. 1987) where biomass measured as chlorophyll-a is followed through a time series of accumulation on styrofoam substrata. Styrofoam DB (Snow Foam Products, El Monte, California) was attached to plywood plates (30x30x6cm) which in turn were anchored to concrete patio blocks. The blocks were secured in riffles to minimize the possibility of washout and tied to trees on the shore to ensure blocks were not lost in case washout did occur. Water depth and current velocities were similar at each site. Parameters used for comparisons of accrual between sites included starting biomass or innocula after an initial colonization phase of 4 days (eg. Bothwell and Jasper 1983), final biomass and rate of accrual determined by least squares analysis of the linear increase in chlorophyll-a concentrations.

At the end of the second periphyton incubation series (Jan. 8), one sample was collected from each substrata for an examination of community taxonomy. Samples were fixed in Lugol's solution and the percent composition by volume of taxa was estimated on 5-7 transects at 200-500x in Utermohl chambers (Northcote et al. 1975).

Urea (45-0-0) fertilizer was applied to blocks 28 to 35 at a rate of 435 $Kg.ha^{-1}$ (200 $Kg\ N.ha^{-1}$). Fertilizer was spread from a centrifugal-deploying bucket slung beneath a Bell 205 A-1 helicopter that was equipped with navigational equipment known as a Del Norte Transponder MS 12 Flying Flagman. The transponder system was used to maintain accurate flight lines within treatment boundaries. In smaller treatment blocks, visual guidance was preferred. The bucket had an output capacity of 2041 $Kg.min^{-1}$ and covered a swath width of 61m. Leave strips (zones not receiving treatment) of 30m were maintained on all water courses visible from the air. Field measurements indicated that fertilizer landed within 2m of leave strip boundaries (J. McClarnon, Ministry of Forests, Campbell River; pers comm).

Precipitation data were accessed from records of Environment Canada, Atmospheric Environment Service, Climate Services office, Vancouver, B.C. for the Gold River townsite recording station.

Flow records for the Gold River were accessed from Environment Canada, Water Survey of Canada, Vancouver, B.C. records for the recording station below the Ucona River confluence (station #08HC001).

RESULTS

Physical data

Rainfall and stream flow patterns were closely associated throughout the study (Fig. 2 and 3). Snow occurred in only trace amounts and hence is not shown in Fig.2. In late October moderate rain was followed by an increase in stream flow from <10 $m^3.s^{-1}$ to 110 $m^3.s^{-1}$. A subsequent dry period resulted in flows declining to 15 $m^3.s^{-1}$ but a longer period of rain in mid-to-late November increased peak flow to 700 $m^3.s^{-1}$ which again declined to a minimum of 30 $m^3.s^{-1}$ after a relatively dry period. This synchrony between precipitation and flow occurred throughout the study. As rainfall became more consistent in mid-winter, peak flows and minimum flows following the storm hydrograph increased, thus increasing mean flows in the Gold from 21 $m^3.s^{-1}$ in October to 153 $m^3.s^{-1}$ in February. Highest flow of 1450 $m^3.s^{-1}$ occurred on January 11, one day after peak rainfall of 173 mm.

Nutrient concentrations and N:P supply ratios

Throughout the study, inorganic N transport was dominated by NO_3 (Fig.4). NH_4 levels were mostly undetectable both before and after fertilization at all sampling sites (Appendix 1). Before fertilization, NO_3 levels were variable ranging from 20 to 70 $ug.L^{-1}$. There was no significant difference between sites $(p<0.05)$ although levels downstream of the confluence with the Heber River appeared slightly higher than at the control (Fig.4).

Levels upstream and downstream of the sewage treatment plant were virtually identical, indicating no effect on NO_3 concentrations from plant discharge. After fertilization, NO_3-N levels remained between 30 and 60 ug.L^{-1} at G-1 but concentrations doubled at G-2 within the second day after treatment. Over the following 12 days, differences between sites declined and were insignificant by the 16th day after treatment ($p<0.05$). On January 11, however, NO_3-N concentrations at G-2 increased by 7 fold coinciding with the largest flood of the winter of 1,450 m^3.s^{-1}. NO_3-N concentrations at G-3 closely matched those at G-2 ($p<0.05$) after fertilization indicating again that NO_3-N added to the Gold in discharge from the sewage treatment plant did not exceed the variation of upstream concentrations. In early spring, NO_3-N levels were similar between all sites ($p<0.05$) ranging from 50 to 70 ug.L^{-1}.

TDP concentrations were generally low throughout the study and differences between sites were not significant ($p<0.05$) (Fig. 5). Levels ranged between the detectable limit of 1 ug.L^{-1} and an upper level of 6ug.L^{-1}. Only on the first sampling date did the TDP concentration downstream of the sewage treatment plant exceed upstream concentrations.

SRP concentrations were mostly undetectable (<1ug.L^{-1}) throughout the study (Appendix 1) and provide one line of evidence of extreme P deficiency for algal growth in the Gold

River. In aquatic ecosystems of Vancouver Island, P primarily limits autotrophic production (Perrin et al. 1987, Nordin 1985) although there can be a close coupling between N- and P-deficiency. Rhee (1978) has shown that whether or not an algal species is N- or P-limited depends on the dissolved inorganic N (DIN) to dissolved inorganic P (DIP) supply ratio, when all other nutrients are in excess. At low N:P ratios N-limitation will occur, while at high ratios P-limitation will prevail. The particular ratio at which the transition from N- to P-limitation will occur is species dependent, varying from as low as 7:1 for some diatoms (Rhee and Gotham 1980) to as high as 50:1 for some blue-greens (Healey 1985). In streams in which the flow rates are high enough, and the periphyton biomass low enough such that the algae are ineffective in reducing the nutrient concentration, as is typical in large streams, the DIN:DIP supply ratio is closely approximated by the concentrations of DIN and DIP. DIP can be closely approximated by SRP concentrations which unfortunately were not detectable in our samples. Hence, we must assume that changes in TDP reflect changes in DIP, acknowledging that TDP is an overestimate which will cause us to underestimate the N:P supply ratio. Such an approach yields N:P supply ratios at all sites in the Gold River of 35 to 70. Since TDP generally overestimates SRP by about 3 which is typical in the Keogh River (Perrin and Johnston 1985), and we assume SRP is representative of what is biologically available, supply ratios in the Gold River are generally 124 to >200. These values are within the range which are known to indicate extreme P-deficiency in the Thompson River system (Bothwell 1985) and are higher than what is typical in the Keogh River which is also P-deficient (Perrin et al. 1987).

Periphyton taxonomy

Diatoms dominated the periphyton community in the Gold River and all sites were represented by similar species. Generally, Diatoma tenue, Navicula sp., Fragilaria spp., Tabellaria flocculosa, and Achnanthes minutissima each occupied equal proportions of sample volumes. These species are very typical of turbulent coastal streams.

Periphyton accrual

A small difference in net periphyton accrual between G-1 and G-3 was apparent before fertilization (Fig. 6a). Innocula levels at G-3 were 0.51 $mg.m^{-2}$, 3 times the amount at G-1 under the same physical conditions. Differences in innocula represent different rates of passive settlement (Bothwell and Jasper 1983), which is the living biomass that has sloughed from substrata upstream of the sampling location and has subsequently settled. G-3 was located within 1 km of the sewage treatment plant outfall, well within a distance that settlement would be expected from biomass accumulations that may have been relatively high close to the outfall. After the 20 day incubation of series 1, final biomass levels at G-3 were 30% greater than at G-1 and represented a net accumulation rate of 0.55 $mg.m^{-2}.d^{-1}$ compared to 0.19 $mg.m^{-2}.d^{-1}$ at G-1.

These differences in rates of periphyton accrual may be related to nutrients added from the sewage treatment plant despite differences in element concentrations not being apparent in chemical analyses (Fig. 4 and 5). Under extreme P-limitation, for example, Bothwell (Nat. Hydrol. Res. Inst. Saskatoon, Sask.; unpub. data) has shown that P addition at a concentration of less than 1 $ug.L^{-1}$, can saturate P-limited growth of periphyton when other factors are not limiting. Hence, small additions of P from the sewage treatment plant that were not detectable in our chemistry data may have been sufficient to increase growth rates of periphyton downstream of the outfall.

It is important to recognize that even the maximum biomass for the 20 day accrual period shown in Fig. 6 is typical of that found in other P-deficient coastal streams that are unaffected by allocthonous nutrient input. In the Keogh River, for example, (Perrin and Johnston 1985), periphyton biomass after a 20 day incubation consistently reaches 10$mg.m^{-2}$ on styrofoam substrata in April. In May and June, benthic production increases in coastal streams and levels exceeding 20$mg.m^{-2}$ are typical. Additions of P can have pronounced effects, however, in that phosphorus added to achieve SRP concentrations near 5 $ug.L^{-1}$ can increase algal biomass to over 100 $mg.m^{-2}$ (Perrin and Johnston

1985).

In series 2 and 3, the innoculum and final biomass of periphyton declined to lower levels than in series 1 and differences between G-1 and G-3 were not significant ($p<0.05$). In series 2, the maximum biomass only reached $3mg.m^{-2}$ (Fig. 6b) and in series 3, chlorophyll pigments were not detectable until the 15th day of incubation. After this time levels never exceeded $0.5mg.m^{-2}$ (Fig 6c).

Steadily declining rates of periphyton accrual and maximum biomass at relatively constant inorganic N and TDP concentrations suggests factor(s) other than nutrient supply were important in regulating periphyton accrual in the Gold River as winter progressed. Lower temperatures can play an important role in limiting algal growth (Eppley 1972, Goldman and Carpenter 1974) although Bothwell (unpub data) has found temperature to be of secondary importance to nutrient concentration for growth of periphyton communities in the Thompson River, even near freezing temperatures. Of greater importance, particularly in coastal streams, may be the scouring action of bedload and other particulate transport associated with storm flow in winter (Fig. 3). Throughout series 2 and 3, sand deposits were constantly changing at all sampling sites. On two occasions plate incubations had to be restarted because plates were destroyed during a rising hydrograph or were buried in sand deposits.

Hence, scouring of substrata at high flow rates is likely important in limiting periphyton accrual regardless of nutrient supply contributed from the sewage treatment plant outfall or N loss from forest fertilization.

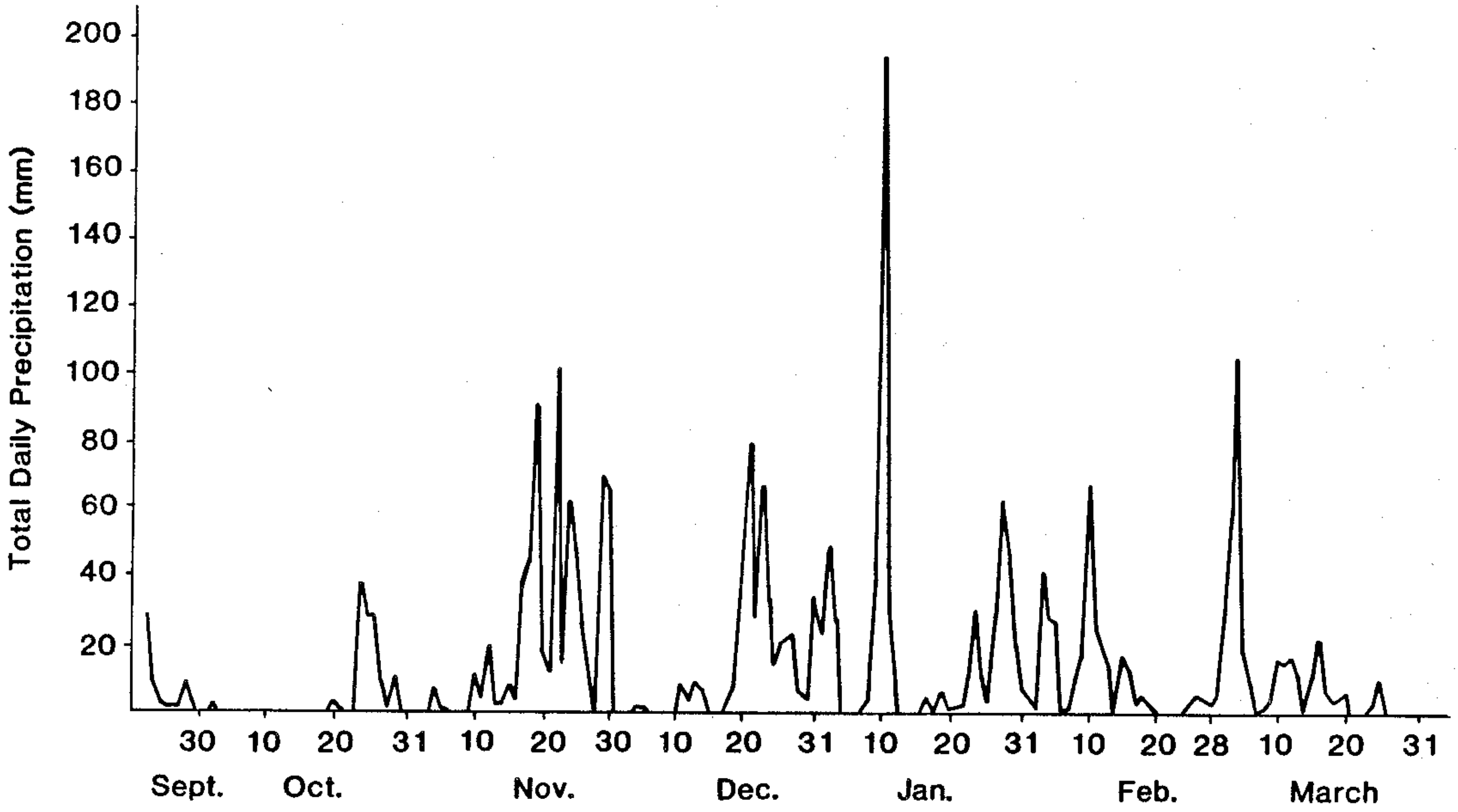

Figure 2. Total daily precipitation as rain at the Environment Canada weather monitoring site in Gold River; Oct. through March, 1986-87.

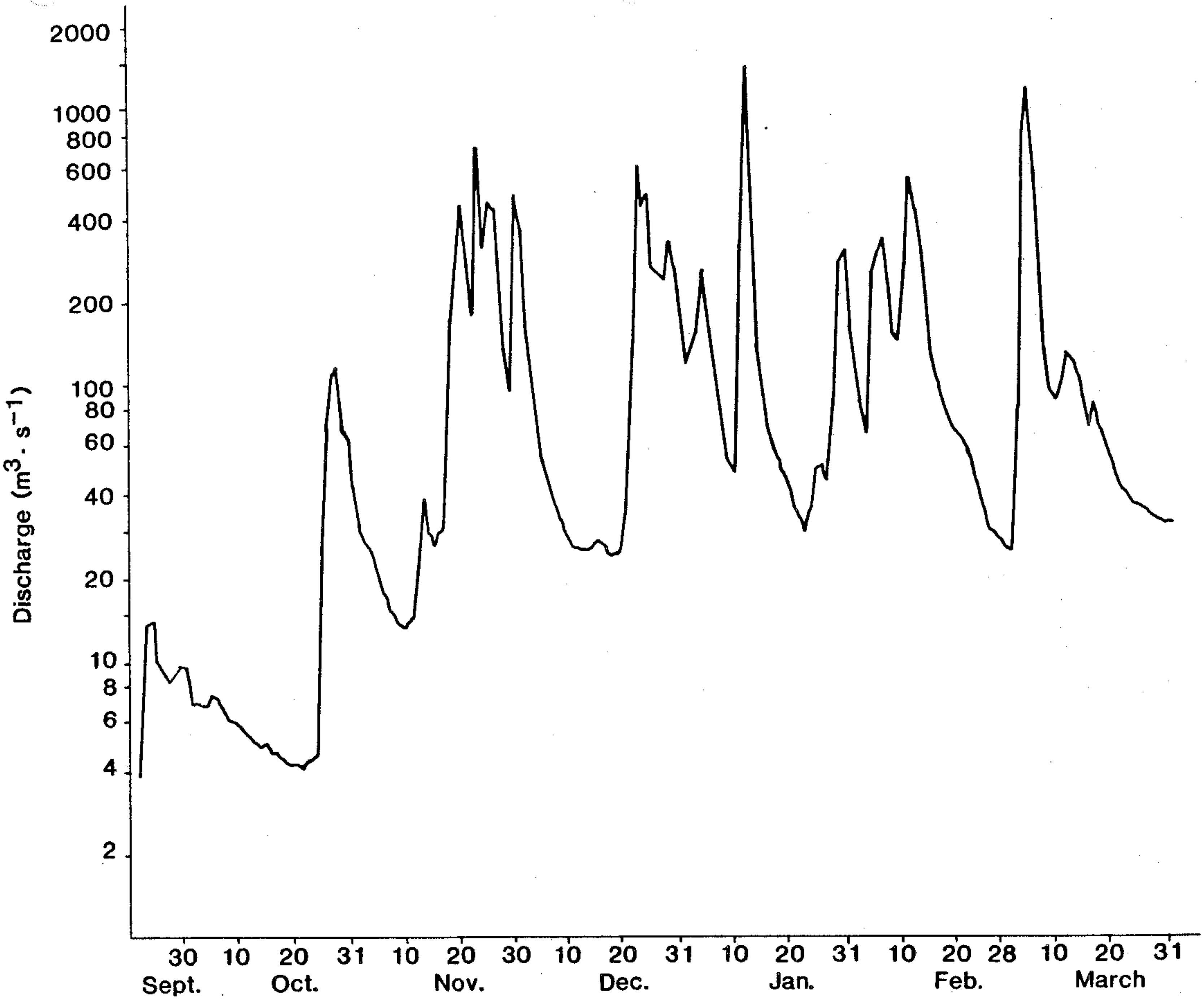

Figure 3. Gold River discharge at Water Survey of Canada recording station #08HC001; Sept. 1986 through March 1987.

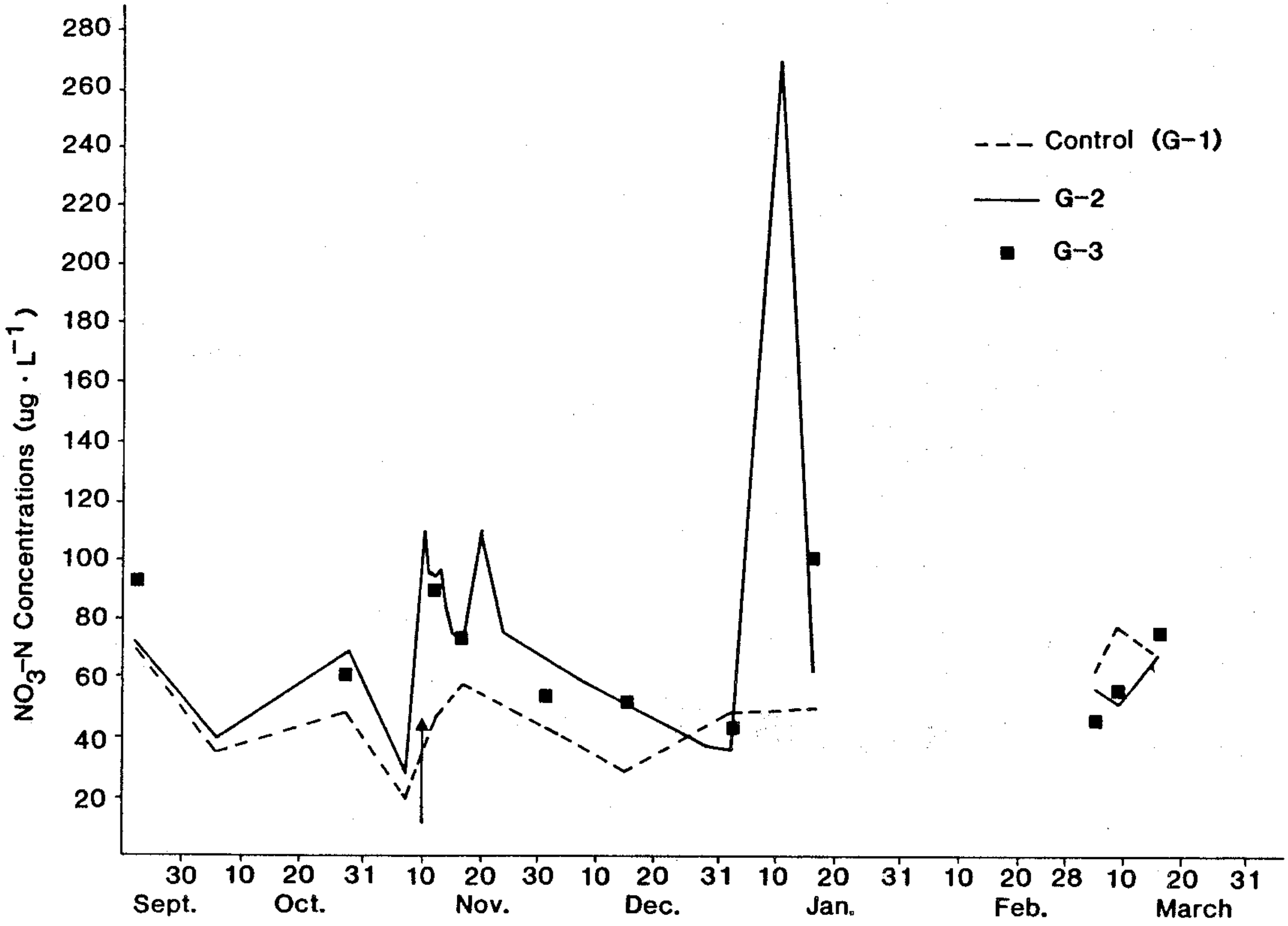

Figure 4. NO_3-N concentrations at sampling sites, G-1, G-2, and G-3; Sept. 1986 through March, 1987. The arrow indicates the day of forest fertilization.

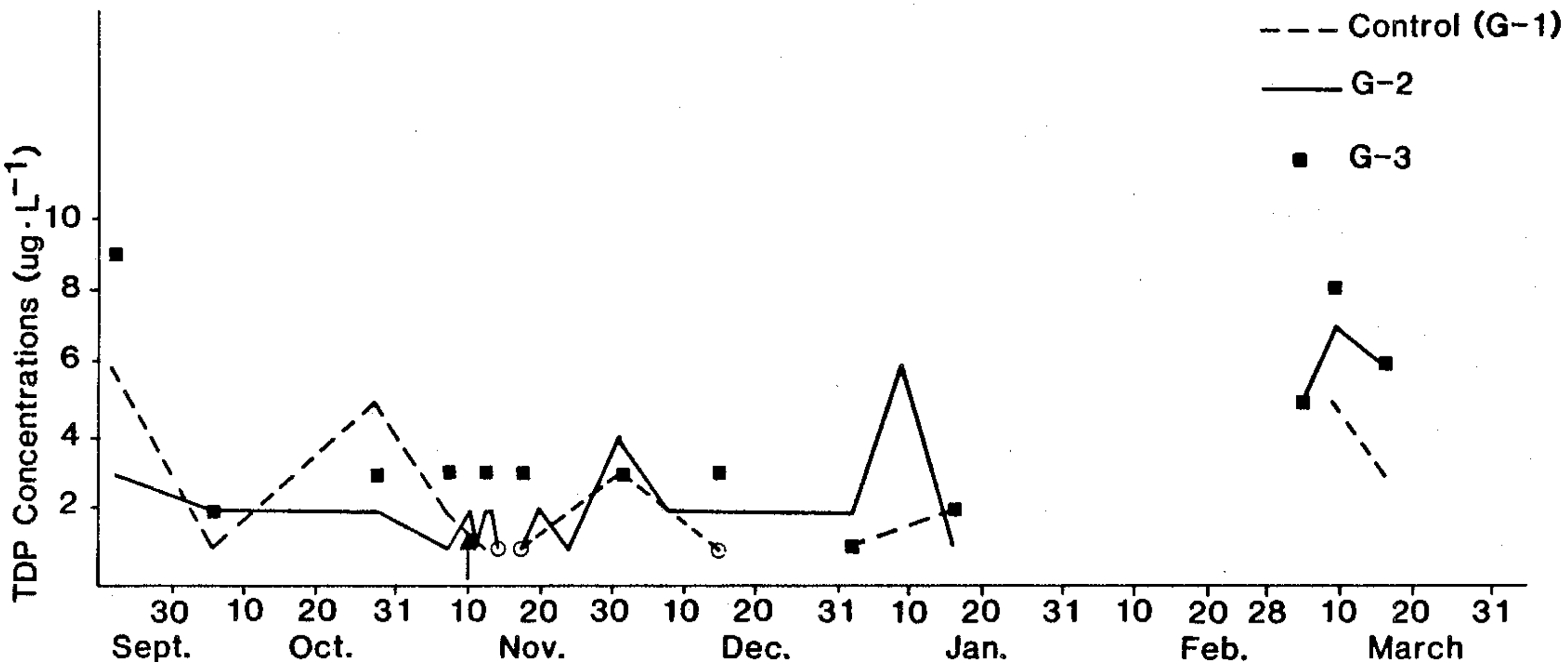

Figure 5. TDP concentrations at sampling sites, G-1, G-2, and G-3; Sept. 1986 through March, 1987. The vertical arrow indicates the day of forest fertilization. Open circles indicate values less than the detection limit of 1 ug.L^{-1}.

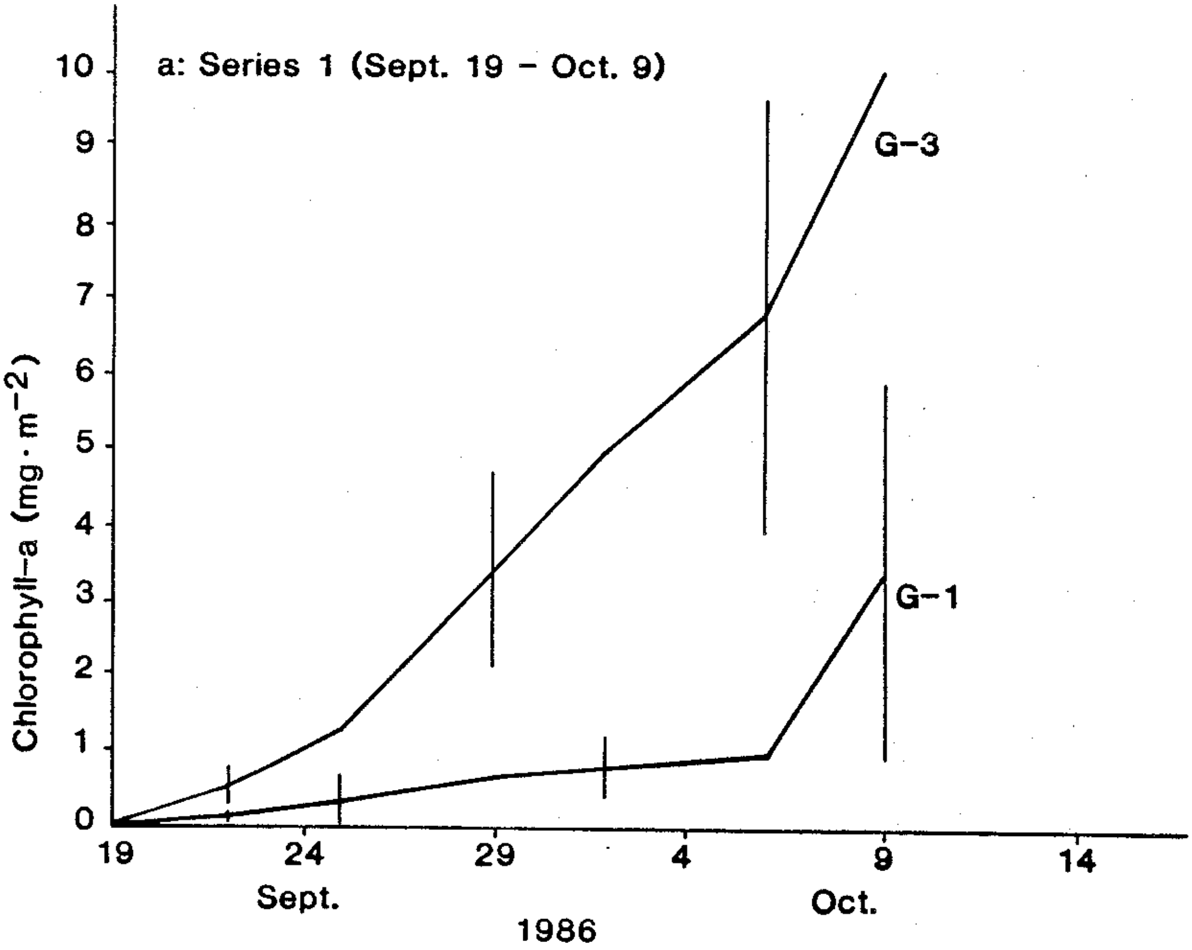

Figure 6. Accumulation of periphyton biomass (measured as chlorophyll-a) on styrofoam substrata at G-1 and G-3

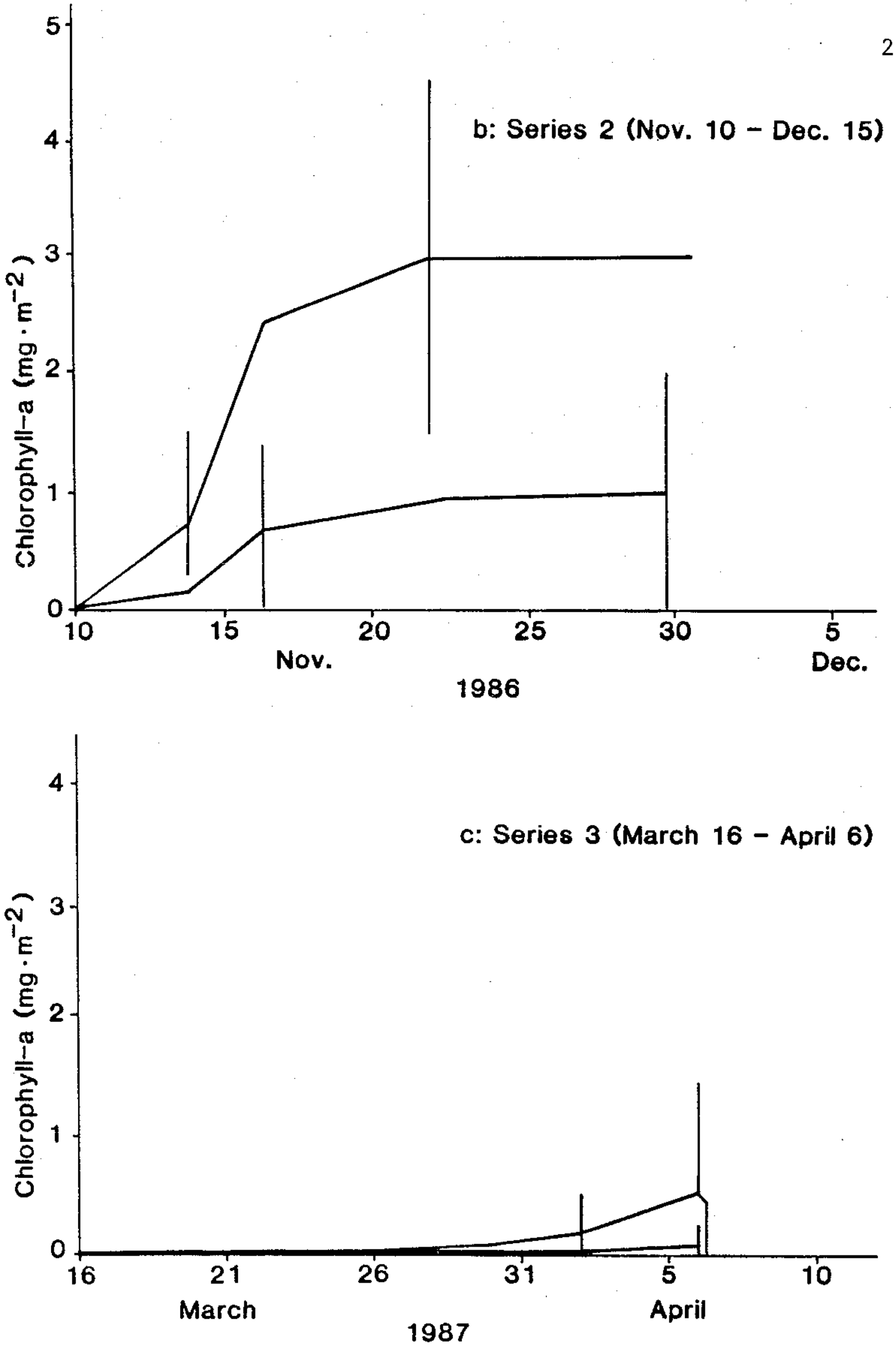

Figure 6. Accumulation of periphyton biomass (measured as chlorophyll-a) on styrofoam substrata at G-1 and G-3.

DISCUSSION

N Transport After Forest Fertilization

Change in inorganic N concentrations in the Gold River after fertilization in the Heber drainage differed in two major ways from other studies on Vancouver Island.

First, N transport was dominated by NO_3 immediately after treatment whereas measurements in the Mohun drainage (Perrin et al. 1984), at Lens Creek (Hetherington 1985) and more recently in the Keogh River drainage (Perrin 1987) show that NH_4 and urea dominate within the first few days after fertilization. In the preceding studies, discussion emphasized the importance of stream buffers and nitrification in regulating species flux. Samples were collected near treatment boundaries and were sensitive to direct introduction of urea. Since ureolysis proceeds rapidly in wet coastal conditions in winter, large increases in ammonia concentrations in drainage streams were also not surprising. Sampling sites in the Gold River, however, were more than 10 km downstream of treatment boundaries and all stream margins were buffered within treatment areas. Hence, direct introduction of fertilizer to streams and thus, peaks of urea and ammonia concentrations on the day of fertilization were not a factor in this study. More important was the potential contribution to the nitrate pool from nitrification of ammonia in the forest floor and in the 10 km of stream substrata prior to collection of water samples. The importance of nitrification is also shown with the large increase in NO_3-N concentrations on the date of peak rainfall and highest river flow rates, two months following fertilization. Hetherington (1985) attributed similar results in Lens Creek to the relatively high mobility of NO_3 that accumulates in the forest floor due to nitrification but can be subsequently mobilized during large rainfall events particularly from steep slopes having high soil permeability as was typical in the Heber drainage.

A second important difference between studies is the magnitude of change in N concentrations. NO_3 levels only doubled in the Gold River within a few days after treatment and only increased 6 times during the peak flood, whereas changes of an order of magnitude were reported by Perrin et al. (1984) and Hetherington (1985).

There is little doubt that dilution rate at sampling sites is an important factor here. Shortly before the Heber drainage was fertilized, a preliminary analysis proposed a very simple model (Appendix 2) which described relations between river flow (Q), load of fertilizer-N lost to the river (F_N) and the DIN concentration at full mixing (N_C):

$$N_C = F_N . Q^{-1} \qquad (1)$$

where F_N was determined from the percent loss of fertilizer-N derived in previous studies (Appendix 2) and total fertilizer load to the Heber drainage (known to be 31,725 kg. N). Using historic average flow data, equation 1 indicated that flow of the Gold River in winter may dilute N losses from forest fertilization in the Heber drainage to a level where N added from fertilization would be either less than the detectable limit for analyses of water samples or would be within the range of background variability and hence statistically indistinguishable from background levels. The nature and result of equation 1 is entirely based on variation in dilution rates since F_N is generally consistent between sites (7% of fertilizer load over about 100 days).

Equation 1 generally corroborated actual findings of N_C when flow rates of the Gold River during the study were inserted. For example, for days 1-3, 4-8, 9-15, and 16-34 after fertilization, equation 1 predicts N_C to average 60, 47, 2, and 1 ug.L^{-1} respectively. The latter two values are below detection limits and cannot be distinguished from background variability but predicted concentrations in the first two time periods approximate concentrations that were actually measured (Fig. 4). At constant F_N (which seems reasonable from past studies on Vancouver Island), N concentrations will be inversely proportional to stream flow rates and hence are expected to be higher in smaller streams that were monitored in previous studies.

The importance of dilution rate can be quantified in an index (let us call it I_{NC}) that rates the area fertilized (A_F) to the area of drainage at the location of interest in the watershed (A_W):

$$I_{NC}=A_F/A_W \qquad (2)$$

I_{NC} in this study was 0.002 compared to values generally ranging from 0.05 to 0.5 at Mohun Lake and at Lens Creek. Since A_W can be assumed to be directly related to stream discharge, I_{NC} is simply another means of quantifying dilution. Hence, INC may be considered to be directly proportional to NC and could provide the basis for modelling fertilizer-N loss rates for coastal watersheds.

Mixing Of Sewage Treatment Plant Effluent

The concept of dilution rate can also explain the lack of change in DIN and TDP concentrations downstream of the sewage treatment plant. Average NO_3-N concentrations in the plant discharge of 0.01 $m^3.s^{-1}$ were about 10,000 $ug.L^{-1}$. At a minimum dilution rate of 0.001 that occurred in October, the concentration of NO_3-N added due to effluent discharge at full mixing would not be expected to exceed 11 ug.L^{-1}. Similarly, the average total phosphorus (TP) concentration in effluent discharge was 5,000 ug.L^{-1}, which at full mixing in the Gold River would be reduced to 5 ug.L^{-1}. Although variation in the proportion of TP that includes TDP is often large, 30% of TP or 1.5 ug.L^{-1} is a reasonable approximation of the amount of TDP. This added amount of N and P from effluent is well within the background variation of the Gold River and is consistent with the finding of no significant change in concentrations downstream of the plant.

Sensitivity Of The Gold River Drainage

Results from this study question the allocation of the Gold River as a sensitive site in the context of fish-forestry guidelines for forest fertilization (Fertilizer Application Guidelines, 1986). N:P supply ratios are one line of evidence that algal growth is nutritionally P-limited regardless of discharge from the sewage treatment plant. In addition, very high dilution ratios virtually eliminated any impact from either the sewage treatment plant or N loss from forest fertilization in drainages upstream of the townsite in winter. Finally, periphyton "growth" may be limited by P concentrations, but in winter and early spring the "net accumulation" of algae which primarily impacts on recreational potential and aesthetics of the river were more likely controlled by abrasion and physical sloughing of substrata at high stream flows. The combination of these biological and physical factors do not support the concept of site sensitivity to N loss from forest fertilization in the Gold River drainage in the winter through early spring period. If we maintain the assumption that the Gold River is P-limited from a nutritional point of view, then extensive accumulations of benthic algae that have been reported in prime fishing areas which are all downstream of the sewage treatment plant (D. Morrison, Ministry of Environment, Nanaimo, B.C., pers comm.) are likely related both to reduced physical limitations as river flows decline in April and to additions of phosphorus from the sewage treatment plant in concentrations that may be low but still adequate to saturate P-limited growth of algae.

RECOMMENDATIONS

In anticipation that forest fertilization with urea will continue on Vancouver Island, this study can be used as a basis for discussion of fertilization strategies in potentially "sensitive" sites. To improve management of forest fertilization at these sites, three recommendations are proposed:

1. The existing definition of "sensitive sites" is presently inadequate in that it does not consider limitations to algal productivity within the sensitive areas. It simply states,"If a municipal, industrial, or hatchery outfall or a nutrient-rich agricultural discharge is present on a system with the potential for a negative impact on fish production or a recreational fishery through the addition of fertilizer nitrogen, then the watershed is considered to be sensitive." The basic problem with this definition is that the phrase, "potential for a negative impact" is ambiguous. In the context of the present study, "negative impact" infers that <u>N-deficiency</u> characterizes a site in question and that increases in inorganic N concentrations due to N lost from forest fertilization will increase benthic productivity within the sensitive area. Hence, an important recommendation is that sensitive sites be defined on the basis of N-deficiency: a potentially sensitive site is N-deficient and a non-sensitive site is P-deficient regardless of presence or

absence of multiple nutrient discharges to the system.

Some confusion may arise in determining whether a site is N- or P-deficient and this where I see additional work required. In coastal British Columbia, aquatic ecosystems are generally recognized as being P-deficient (Stockner and Shortreed 1978, Perrin et al. 1987) or there can be a close coupling between N- and P-deficiency where very small additions of one element will drive the system into limitation by the other. Clearly, the main concern is at sites affected by P inputs alone since it is here that N-deficiency will most likely prevail. It is important to locate these sites that are downstream of targets for future forest fertilization and to characterize nutrient deficiency at these locations by either using chemical parameters including N/P supply ratios and nutrient concentrations as indicators of nutrient-deficiency or by running multi-treatment bioassays (Stockner and Shortreed 1978, Bothwell 1985). With these data, the potential for increased benthic productivity at increased concentrations of N due to N transport from forest fertilization can be determined on a site specific basis and used in defining forest fertilization strategies.

2. The definition of site-sensitivity based on characteristics of nutrient-deficiency ignores the role of physical limitations to algal accumulation on substrata. Where aesthetics are a concern, this view should be maintained. Winter

streamflows on the coast are highly variable both in time and within single reaches of a stream. During flood conditions, for example, scouring may be important at mid-channel locations but where stream power is lower near stream margins, nutrient-deficiency factors may be more important in regulating accumulations of algae.

If aesthetics are not a concern and there is no potential confounding of downstream research or other fertilization activities, I would suggest that even N-deficient sites be considered non-sensitive because of the importance of physical limitation to algal accumulation. During the late fall through winter period when freshets are frequent, there is sufficient physical disturbance to prevent large accumulations of algae. It is important to recognize that even during spring and summer months, algal accumulations associated with nutrient addition can lead to improved growth of juvenile salmonids in coastal streams (Slaney et al. 1986) and oxygen deficits that are often associated with algal mats do not occur (Perrin and Johnston 1985). In addition, reported concentrations of NH_4 and NO_3 in streams after forest fertilization are less than those known to cause a chronic toxicological risk to fish (USEPA 1984) or affect drinking water quality (Health and Welfare Canada 1979).

3. This study has highlighted the importance of dilution in regulating the magnitude of change in element concentrations

after full mixing of a pollutant in receiving water (eg. equations 1 and 2). Further analysis is recommended that would involve development of a model that quantifies relations between N_C and I_{NC} through a time series. Results could be used to actually predict change in N concentrations in drainage due to forest fertilization at any point in time and hence would be used to decide whether downstream sensitivity is at all a question for a target location for forest fertilization.

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APPENDICES

Appendix 1: Ammonia and SRP concentrations at sites G-1, G-2, and G-3 in the Gold River, September, 1986 through March, 1987. "U" indicates the value is less than the detectable limit (10 ug.L^{-1} NH_4-N; 1 ug.L^{-1} SRP).

	G-1		G-2		G-3	
	NH_3-N	SRP	NH_3-N	SRP	NH_3-N	SRP
Sept. 22	16	2	17	U	10	5
Oct. 6	U	1	U	U	U	2
Oct. 28	10	U	12	U	U	U
Nov. 7	U	U	14	U	U	2
Nov. 10			11	U		
Nov. 11			U	U		
Nov. 12	U	1	30	U	U	U
Nov. 13			10	U		
Nov. 14			U	U		
Nov. 15			U	U		
Nov. 17	U	U	U	U	U	2
Nov. 20			U	U		
Nov. 24			U	U		
Dec. 1	13	U	U	U	U	U
Dec. 8			11	U		
Dec. 15	U	U	U	U	U	U
Dec. 29			12	U		
Jan. 2	12	U	15	U	17	U
Jan. 9			U	3		
Jan. 16	15	U	11	U	U	U
March 5	U	U	U	U	U	U
March 9	U	U	U	U	U	U
March 16	U	U	U	U	U	U

Appendix 2

A Preliminary Analysis of Change in N Concentrations and Algal Production Due To Forest Fertilization in the Heber Drainage, Vancouver Island

LIMNOTEK RESEARCH
AND DEVELOPMENT INC.

22 October 1986

Mr. G. Kennah, R.P.F.
Silviculture Officer
Ministry of Forests
4595 Canada Way
BURNABY, B.C.
V5G 4L9

Dear Gerry:

Re: A prediction of change in algal production due to forest fertilization in the Heber drainage, Vancouver Island.

As a follow-up to our meeting of August 12, 1986, and conversations thereafter, I have prepared an estimate of expected change in dissolved inorganic nitrogen (DIN: NO_3-N + NO_2-N + NH_3-N) concentrations at full mixing in the Gold River over a time series after forest fertilization of the Heber drainage (Table 1). I emphasize that these are estimates that must be compared to real change to be measured over the next several months and hence should not be distributed until the study is complete. As I have mentioned in the past, however, I believe we have sufficient data from previous studies to make time series predictions of N loss where data on stream flow is available. The Heber offers an ideal opportunity to run through some of these numbers and compare predicted and actual change. The development of similar predictive procedures may be useful for setting fertilizer loading limits in other "sensitive" drainages.

It is important to recognize that Table 1 is not the outcome of a rigorous modelling exercise. In particular, I have estimated percent loss of fertilizer through time from "ball park" change in N transport measured during the Mohun study. A model could be more precise by integrating losses (area under fertilizer loss curves from more than one study) in weekly or even daily time windows.

I have been very conservative by estimating a 7% loss of applied fertilizer. This is more than what has been reported in any study that has examined N loss after forest fertilization. I have partitioned that loss into seven time "windows" and the proportionate loss in each "window" is based on relative magnitude of N transport through time from buffered drainages at Mohun Lake. You will note from the Mohun study that greatest loss in buffered areas occurred between Day 4 and 18 after fertilization. The characteristic peak noted on Days 1-3 in drainages that are not buffered does not occur because of negligible direct introduction of fertilizer to streams.

Calculations of expected DIN concentrations in the Gold River due to fertilizer loss from the Heber drainage show a range of 0.018 mg $N.L^{-1}$ in the first few days to levels that are essentially undetectable after the first week using present analytical techniques. Our preliminary sampling in the Gold River has shown that background DIN levels downstream of the sewage treatment plant vary between 0.039 and 0.093 $mg.L^{-1}$ with a mean of 0.060 $mg.L^{-1}$ and at the upstream control they vary from 0.035 to 0.070 $mg.L^{-1}$ with a mean of 0.053 $mg.L^{-1}$.

There are two observations from a comparison of Table 1 estimates to results of preliminary sampling that provide evidence of what may be expected in algal production. First, a detectable increase in DIN concentrations due to fertilization is expected to last only for the first few days after treatment. Thereafter, DIN concentrations are analytically undetectable (<0.010 $mg.N.L^{-1}$) and hence we would expect no significant difference in DIN concentrations between the control and treatment sites. We expect, then, to have a critical period of detectable change in DIN concentrations and potential influence on algal growth only within the first few days after treatment. Our observations of trends in algal growth during nutrient manipulation at the Keogh River, Vancouver Island, suggest that this length of time would be inadequate to sustain any enhanced algal growth for more than 2-3 weeks. It is also important to note that a detectable increase in DIN concentrations does not imply a coincident increase in accumulation of benthic algae. Algal growth will increase due to increased DIN concentrations only if growth was previously N-deficient. Although a bioassay is best used to examine nutrient-deficient growth, I can say than background DIN levels downstream of the sewage treatment plant discharge are only within the range of potential N-deficiency reported from literature values part of the time. Hence, growth of benthic algae downstream of the sewage discharge may not always be limited by N. This possibility of N-sufficiency in combination potentially with a very temporary increase in DIN concentrations, reinforces my view that we will see no net change in accumulation of benthic algae due to forest fertilization.

The real value of this prediction will be to compare Table 1 to actual field measurements to be completed over the next several months. At that time we may be in a good position to recommend a procedure to calculate expected change in N transport due to forest fertilization in "sensitive" drainages. As far as settng critical fertilizer loading limits is concerned, I believe we could also be quite accurate by working backwards in Table 1 ($F_N = Q*N_c$). The important variable in this relation is N_c, the acceptable N concentration added from fertilization. N_c will be dependent on the presence or absence of N-deficiency at any specific site. For example, N_c at sites where N is not deficient may be much higher (regulated to health or toxicity standards) than at sites where N does limit algal growth (regulate to no significant change in N transport over a sustained period). The presence or absence of N-deficiency can be determined for any site in the future with standard bioassay procedures. Hence, the use of field testing in combination with calculations from previous data could yield estimates of loading rates and/or relative change in algal production at other sensitive sites with confidence.

If you have any questions about these comments, please feel free to give me a call. Many details have been necessarily left out since these are only interim comments. I will elaborate in the final report. In the meantime, I will keep you updated as to results as they come in.

Yours sincerely

Limnotek Research & Development Inc.

Chris Perrin

cc. D. Morrison
J. Hume
S. Samus
J. Boateng
J. McLarnon

Table 1. Estimated change in DIN concentrations in the Gold River after forest fertilization of the Heber drainage.

Date	Oct.27-29	Oct.30-Nov.13	Nov.14-30	Dec.1-31	Jan.1-31	Feb.1-28	March 1-31	TOTAL
Days	1-3 (3)	4-18 (15)	19-34 (16)	36-65 (31)	68-96 (31)	100-124 (28)	125-155 (31)	
Average total[1] discharge (m^3) (Q)	26,876,448	175,582,080	198,993,024	318,542,112	217,994,976	215,381,376	189,282,528	
Percent loss of[2] fertilizer-N	1.5	2	1.5	0.8	0.6	0.4	0.2	7
Load of fertilizer-[3] N lost (kg) (F_N)	475.875	634.5	475.875	253.80	190.35	126.90	63.45	2,220.75
N concentration added[4] to Gold River due to fertilizer losses (N_c) ($mg.L^{-1}$)	0.018	0.004	0.002	0.001	0.001	0.001	0.0004	

Notes:
1. Calculated from 10 year average of daily discharge of the Gold River monitored by Water Survey of Canada near the Ucona River confluence.
2. Estimated from results of the Mohun Lake study (Perrin et al. 1984).
3. Based on a total load of 67,500 kg Urea (31,725 kg N) applied to the Heber.
4. $N_c = F_N \cdot Q^{-1}$.