CHANGE IN INORGANIC NITROGEN CONCENTRATIONS IN MASHITER CREEK, SQUAMISH FOREST DISTRICT, AFTER FOREST FERTILIZATION WITH UREA

by

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SUMMARY

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The change in inorganic nitrogen concentrations in Mashiter Creek was measured before, during, and after forest fertilization of 21 ha of the Mashiter drainage with urea (46-0-0) applied at a rate of 435 $kg \cdot ha^{-1}$ (200 $kgN \cdot ha^{-1}$). A 50 m fertilizer free zone (FFZ) was applied along the stream margin. A water sampling site was established on Mashiter Creek about 1 km downstream of the 21 ha treatment block. A control site was located nearby on the Stawamus River. Both streams were steep, third order systems that drained mountain slopes east of Squamish, B.C. The drainages were dominated by an association of coastal western hemlock, red cedar, and Douglas fir. The fertilized block had been previously thinned, resulting in relative dominance by the fir. The forest floor at all sites was developed to about 1 m in depth. Water sampling continued over 93 days (February 28 through June 13, 1990) in an irregular frequency to monitor concentrations of nitrate and ammonia. Samples were also collected in November, 1989 in anticipation of an earlier treatment date. Ammonia concentrations remained less than the detectable limit of 0.005 $mg \cdot L^{-1}$ throughout the study at both sites. On Mashiter Creek, this finding was attributed to complete hydrolysis and nitrification of the urea. Initial nitrate-N concentrations in the Stawamus River ranged between 0.058 and 0.074 $mg \cdot L^{-1}$ but gradually declined through the rest of the study to reach <0.005 $mg \cdot L^{-1}$ by mid-June. In contrast, NO_3-N levels in Mashiter Creek were <0.005 $mg \cdot L^{-1}$ before fertilization, increased to a peak of 0.037 $mg \cdot L^{-1}$ within 15 days after fertilization, and over the following 9 days declined to a level that stabilized between 0.005 and 0.012 $mg \cdot L^{-1}$. The temporal trends associated with the fertilizer addition were consistent with results from other fertilization monitoring studies conducted at coastal sites. The magnitude of the response, however, was one of the lowest recorded; a finding that was expected since the very small area treated relative to the total drainage area resulted in considerable dilution of the mobilized nitrogen. The change in nitrate concentrations after fertilization in Mashiter Creek was 40% less than the background levels found in the Stawamus River and 250 times lower than Provincial and Federal drinking water quality criteria. Evidence is also presented to show that the nitrogen concentrations were not toxic to aquatic biota and would not have caused increased growth of periphyton.

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1.0 INTRODUCTION

Relationships between nitrogen (N) loading rates to coastal forests from aerial fertilization and changes in inorganic N concentrations in drainage streams is well established from several studies that have been conducted in British Columbia over the past decade. Monitoring and experimental work in the Sayward Forest (Perrin *et al.* 1984), in stagnant cedar-hemlock sites on northern Vancouver Island (Perrin 1987a, 1989), in Douglas Fir sites on southern Vancouver Island (Hetherington 1985), and in sites of the Gold River drainage (Perrin 1987b) and the Rosewall Creek and Qualicum River drainages (Perrin 1990) on Vancouver Island, have all shown that N loss to drainage will occur after forest fertilization with urea. Where fertilizer is applied directly over streams, there can be an immediate increase in N concentrations in the streams by more than two orders of magnitude to briefly reach levels up to 5 $mgN \cdot L^{-1}$. This level declines exponentially to reach pretreatment concentrations within three months after treatment. Where a "fertilizer free zone" (FFZ) is defined around drainages to prevent the direct addition of fertilizer to water courses, the magnitude of change in peak concentrations is less than 10 times the level when a FFZ is not present and the decay of concentrations to pretreatment levels is linear over a period of about three months. Generally, where a FFZ is not present or where there is abundant rainfall over soils that have poor water retention characteristics, the reduced forms of N (NH_4^+ and urea) will dominate the N transport. NO_3^-, the more oxidized form of N, tends to increase in importance in samples collected from sites with a FFZ present. This change in ionic dominance is due to the greater proportion of the N measured in the streams having been from the fertilizer that was nitrified in the forest floor (Otchere-Boateng and Ballard 1978) where a FFZ is present.

A consistent finding in all studies that have measured change in N concentrations in streams after forest fertilization with urea is that increased levels are orders of magnitude less than those known to be toxic to aquatic biota (Perrin 1987a), they are consistently less than criteria that are established for drinking water quality, and despite N being an important nutrient for aquatic plants, the changed concentrations do not affect the growth of algae or other "nuisance" biomass (Perrin 1987b). The lack of change in stream productivity is due to very low levels of phosphorus which primarily limits autotrophic productivity in coastal streams and lakes (Suttle and Harrison 1988, Perrin *et al.* 1984, 1987).

Despite the abundance of data showing little impact of N loss from forest fertilization with urea, there continue to be site-specific concerns related to change in N concentrations in streams. Uncertainty of effects is prevalent in areas where data have not been previously collected and where the systems are considered "sensitive" to chemical change because of high fisheries value or the water is being used for consumption.

The Stawamus River is one system where this uncertainty is particularly important because the river is directly used as a water supply for the District of Squamish. Approximately 3 km upstream of the river estuary a water intake facility is established where large particulates are partially removed in a short-residence-time settling chamber and the water is delivered to the district via a pipeline. To maintain the high quality of the water supplied to the district, it is essential to document changes in water chemistry that may occur in relation to other activities upstream in the Stawamus drainage. This study was implemented to accumulate information on the change in inorganic N concentrations in the Stawamus River in winter and spring months, and to document changes that are associated with forest fertilization with urea in Mashiter Creek, a nearby stream that drains forest cover that is similar to that in the Stawamus drainage.

2.0 STUDY SITE

The study included sample collections from the Stawamus River and Mashiter Creek (Figure 1). Both streams were third order systems, were about 14 km in length, and drained 50-60% slopes east of Squamish. The Stawamus River emptied directly into Howe Sound and Mashiter Creek discharged into the Squamish River estuary (Figure 1). The fertilized block in Mashiter Creek (MF) covered 21 ha. and was located on the north slope, approximately 8.5 km upstream of the Squamish River estuary (Figure 1).

The forest stands in both drainages were dominated by hemlock, red cedar, and Douglas fir. The fir was generally least dominant except in small blocks that had been spaced, resulting in increased relative dominance of the fir to >50% of stem numbers. Spacing was conducted on the fertilized block in Mashiter Creek in 1989 and in 1981 on small blocks in the Stawamus drainage that were targeted for future fertilization. One block shown as SF on Figure 1 was to be fertilized as part of this project, but was omitted because of concerns over potential changes in the quality of the water that is withdrawn for Squamish water supplies.

The forest ecosystem at both sites was part of the coastal western hemlock biogeoclimatic zone. Soils were classified as sandy loams and the forest floors were well developed, having an average depth of 1 m.

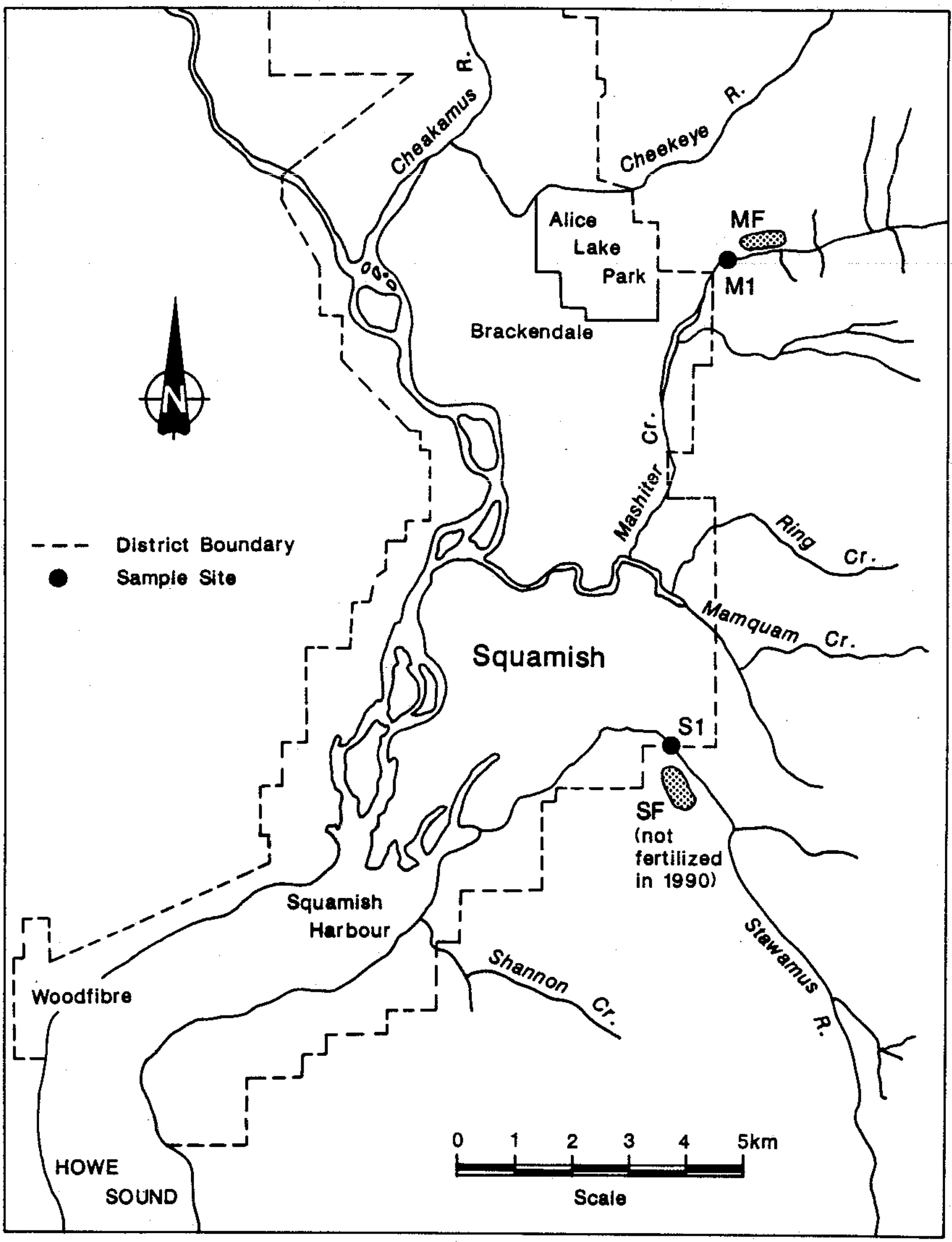

Figure 1. Location of the study area showing the fertilized block and water sampling sites.

3.0 MATERIALS AND METHODS

3.1 Fertilizer Application

Urea forest fertilizer (46-0-0 as N-P-K) was applied at a rate of 435 $kg \cdot ha^{-1}$ (200 $kgN \cdot ha^{-1}$) to the Mashiter Creek block (Figure 1). The fertilizer was spread from a centrifugal-deploying bucket slung beneath a Bell 205 helicopter that was equipped with navigational equipment known as a Del Norte MS 12 Flying Flagman. The guidance system uses transponders to calculate position of the machine on a real time basis and thus helps to maintain accurate flight lines within treatment boundaries.

A 50 m fertilizer-free-zone was established between Mashiter Creek and the south treatment boundary.

The block was fertilized on March 12, 1990.

3.2 Water Sampling

During a reconnaissance before fertilization, water sampling sites were established on Mashiter Creek (M1) and the Stawamus River (S1) (Figure 1). With this layout of sampling sites, M1 was used to monitor changes in N concentrations related only to losses of N from the fertilized block but S1 was used as a control for M1 and provided a site to monitor the spring and early summer changes in N concentrations in the Stawamus River. Because routine access was not available upstream of the fertilized block on Mashiter Creek, a control site on Mashiter Creek was not available. Hence, S1 was used as the control.

This layout was not ideal in that a control site was not available on Mashiter Creek and thus, temporal and spatial differences in N concentrations between streams could potentially confound treatment effects. In past fertilization studies, however, there has been little argument that a change in stream N levels after forest fertilization is due to the treatment because the magnitude of change usually exceeds background variability by several fold. The degree of change increases with increasing size of the treatment block relative to the size of the drainage area. Any differences in background N levels between streams is unimportant, but the temporal pattern of changes is important with regards to attributing changes in N levels to the forest fertilization. Hence, several fold changes in N concentrations that may occur in Mashiter Creek after fertilization will be attributed to the fertilization if similar changes are not observed in the Stawamus River at the same time. This design is weak but reasonable given the magnitude of change in N levels that is known to occur in other studies.

The water sampling schedule was designed to cover the period before and after fertilization, including the time for concentrations of N to return to pretreatment levels. This design required sampling to continue in irregular intervals over 93 days, beginning on February 28, 1990 and continuing until June 13, 1990. In preparation for the possibility of an earlier treatment, samples were also collected on November 21 and 28, 1989. To monitor rapidly changing concentrations that occur immediately after fertilization, samples were collected daily from March 12 through March 15. Thereafter, the sampling frequency declined to follow the declining phase of the N response curve.

All water samples were filtered in the field through 0.45 μm membrane filters and shipped on the day of sample collection to Cantest Ltd. in Vancouver for analysis within 48 hours of sample collection. All analyses were conducted according to methods outlined in APHA (1985). Tests for dissolved inorganic N included total ammonia (NH_4^+ + NH_3), nitrate (NO_3^-) and nitrite (NO_2^--N). In this report, total ammonia will be expressed as NH_4. Detection limits for NO_3-N, NO_2-N, and NH_4-N were 0.005, 0.002, and 0.005 $mg \cdot L^{-1}$.

4.0 RESULTS

In all samples, only NO_3-N concentrations showed temporal changes associated with the fertilization (Figure 2). NO_2-N and NH_4-N levels were always less than 0.002 and 0.005 $mg \cdot L^{-1}$ respectively. NO_3-N levels in the Stawamus River followed a declining trend beginning near 0.07 $mg \cdot L^{-1}$ in late February, declined slightly during the period that the Mashiter block was being fertilized and then declined further to reach 0.005 $mg \cdot L^{-1}$ by June 13. In contrast, the NO_3-N levels in Mashiter Creek were <0.005 $mg \cdot L^{-1}$ before fertilization. On the day of treatment, the concentrations increased several fold to reach a peak of 0.037 $mg \cdot L^{-1}$ within 15 days after fertilization. Thereafter, the concentrations declined abruptly to background levels and remained between 0.005 and 0.012 $mg \cdot L^{-1}$ for the remainder of the study.

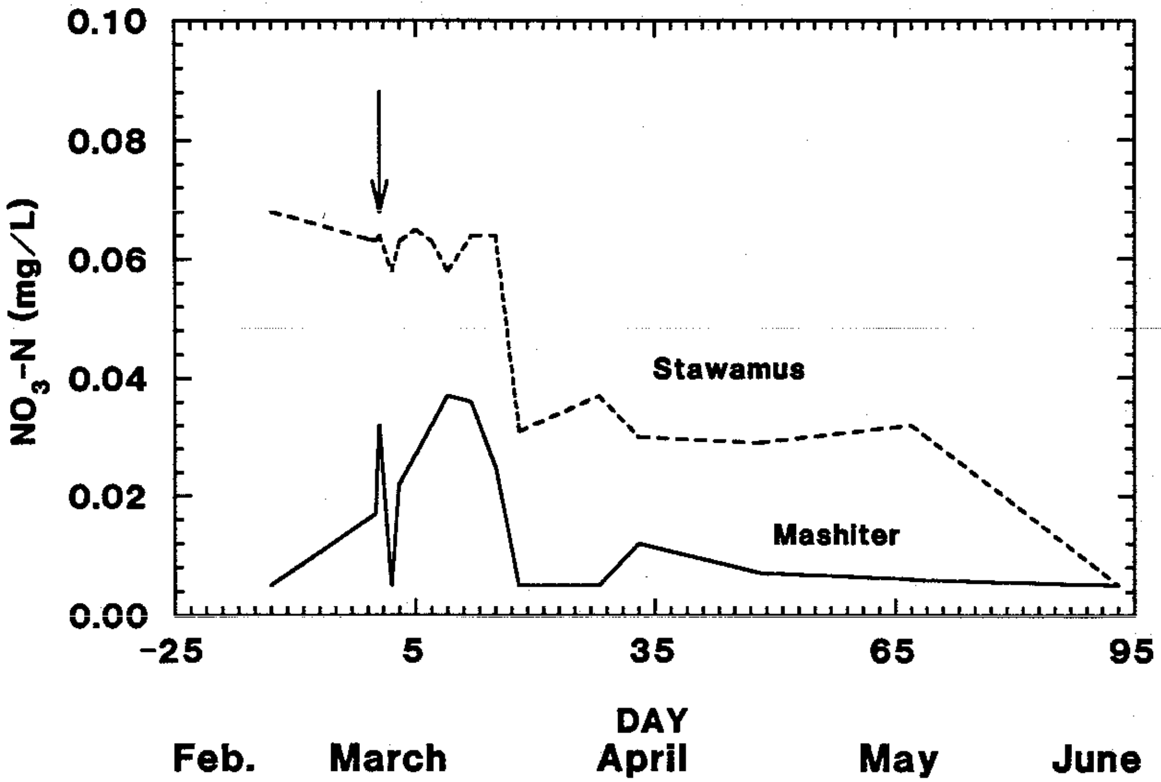

Figure 2. Change in NO_3-N concentrations in Mashiter Creek and the Stawamus River during and after forest fertilization in March 1990. The Arrow indicates March 12, the day of fertilization on Mashiter Creek.

5.0 DISCUSSION

The temporal trend of change in N concentrations in this study was consistent with that from earlier work at other sites where a FFZ was present. Immediately after fertilization inorganic N concentrations increased rapidly to reach peak levels within two weeks after fertilization. After some volatility, concentrations then declined rapidly and reached pretreatment levels by the end of March.

The response in stream N levels to fertilizer addition can be summarized in terms of three indices; peak concentration, the number of days to reach peak concentration, and the number of days required to return to control levels. Values for these indices as they pertain to changes in NO_3-N in this study, show some variation compared to other findings (Table 1).

The magnitude of peak NO_3-N concentrations was less than what has been measured at other sites, but is expected since the total size of the treated areas relative to that of the drainage areas was small. Perrin (1989, 1987b) found differences in nitrogen transport after fertilization in relation to the ratio between these respective areas and has hypothesized that a quantitative relationship can be determined to predict various indices of nitrogen transport as a function of this areal ratio. The ratio is essentially an index of dilution of fertilizer that is lost from the forest and enters surface drainage. That dilution is high where the treated area is small relative to the drainage area given the assumption that stream flow is directly proportional to drainage area.

Table 1. Comparison of indices of inorganic N concentrations in drainage following forest fertilization with urea between this and other studies in which fertilizer-free-zones were present. All units are $mg \cdot L^{-1}$

Response Index	NH_4-N This Study	NH_4-N Other Studies[1]	NO_3-N This Study	NO_3-N Other Studies
Control	<0.005	<0.005	<0.005-0.068	<0.005-0.060
Peak[2]	<0.005	<0.005-0.472	0.037	0.057-0.19
Day_A[3]	N/A	11-19	9	3-75
Day_B[4]	N/A	20-136	10	4-51

[1] Other studies are from Vancouver Island sites treated with urea where FFZ were present and include Perrin et al. (1984), Perrin (1987b) and Perrin (1990).
[2] Highest concentration measured after fertilization.
[3] The number of days to reach peak concentration after fertilization.
[4] The number of days required for the concentrations to decline to and stay at control levels.

The lack of an ammonia response supports the findings from monitoring N losses after fertilization in the Heber River drainage (Perrin 1987b) and at Rosewall Creek (Perrin 1990) but differs from findings in the Sayward Forest (Perrin *et al.* 1984), both being Vancouver Island sites. Since the relative concentrations of NO_3 and NH_4 are a function of the proportion of urea that enters hydrolysis and oxidation reactions, the lack of an ammonium response indicates complete nitrification of the N lost from the forest. At the Sayward Forest sites, an abundance of macropore channelling was observed which would have reduced the proportion of ammonium that could be completely nitrified because of rapid throughput of surface water to streams. Water tended to bypass chemical and microbial processing in the forest floor. At the Heber River sites, there was several km between the treatment area and sampling sites, which allowed nitrification to proceed not only in the forest floor but also via the stream substrata, thus increasing the potential for complete nitrification of the fertilizer lost to surface drainage. In Rosewall Creek and the upper Qualicum River that were monitored in 1990 (Perrin 1990), an ammonium response was also not found, yet stream sampling sites were relatively close to fertilized areas. This outcome was explained by complete microbial processing of the added fertilizer in the forest floor.

The toxic effects of urea fertilizer lost to streams has been raised as an important concern in Squamish area streams and particularly in the Stawamus River which is being used for domestic water supplies. The present data suggest that NO_3 levels in the Stawamus River decline through the spring months, a pattern that is typical in developing forests where spring growth tends to retain nutrients during the growing season. It is important that the N concentrations measured in Mashiter Creek after forest fertilization were less than these background levels in the Stawamus River. Even the peak concentration measured after fertilization was 40% less than levels in the Stawamus River and more than 250 times lower than the criterion for NO_3-N that is established in

Provincial (Nordin and Pommen 1986) and Federal (CCREM 1990) water quality guidelines. That level is 10 mg·L^{-1} in both guidelines. Clearly, the changes in NO_3 levels that were measured in Mashiter Creek after forest fertilization were well within the background variability that can occur in drainages in the Squamish area. They are also within ranges that are typical of "pristine" water that has been examined in other streams (Table 1).

Other toxicity concerns may be associated with fish resources in the Squamish area streams. Fish can develop pathological symptoms under exposure to increased levels of unionized ammonia, the form that always exists in equilibrium with ionized ammonia (NH_4^+). The proportion of total ammonia that is of the unionized fraction is a function of temperature and pH (Emerson *et al.* 1975). At ambient temperatures of about 8°C or less in a coastal stream in spring and circumneutral pH, the concentration of unionized ammonia will be 0.159% of measured ammonia levels, or about 0.0000079 mg·L^{-1} in Mashiter Creek and the Stawamus River. This concentration is more than four orders of magnitude less than levels that are know to produce pathological symptoms in trout including the development of lesions, reduced growth rates, reduced fecundity, increased egg mortality, or increased susceptibility to other disease (USEPA 1985). Since total ammonia levels did not change in this study in relation to fertilization, it is obviously expected that ammonia toxicity would also not occur.

Like the rationale of fertilizing forests with nitrogen, N enrichment of streams may have the potential to increase stream productivity if N deficiency occurs in the benthic flora. Unlike the nutritional characteristics of coastal forests, however, where N is primarily deficient, it is phosphorus that primarily limits the growth and biomass of algae and other periphytic biota in streams. This phenomenon has been clearly established in bioassay experiments (Stockner and Shortreed 1978) and river enrichment studies (Perrin *et al.* 1987). While additions of inorganic nitrogen to Mashiter Creek may have produced a very small change in autotrophic production, as has been observed after controlled N additions to streams (Stockner and Shortreed 1978), a large increase in periphyton biomass is not possible without additional phosphorus input. Although biologically available phosphorus was not measured in this study, there is no evidence of phosphorus enrichment during the period of increased N levels after forest fertilization in the Mashiter Creek drainage. Without a phosphorus source, it is unlikely that any change in algal production occurred in Mashiter Creek due to the increased NO_3 levels after forest fertilization.

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