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River Size as a Determinant of Lotic Ecosystem Structure:

The Case for Suspended Algae

by

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Thesis Abstract

Rivers have long been considered physically driven ecosystems, and the physical environment varies between streams and large rivers. The objective of this thesis was to investigate the importance of river size for suspended algal development.

In the first chapter, I examine the seasonal variability of discharge, water chemistry, and suspended algal abundance to evaluate the accepted (but rarely tested) assumption that streams are more temporally variable than large rivers. Temporal variance of discharge and water quality parameters was determined for 114 stations on 104 rivers in eastern United States with data measured between May to October of 1978 by the U.S. National Stream Water Quality Accounting Network (NASQAN). River size explained a suprisingly small portion of the temporal variance of water column parameters even though strong relationships were observed between river size and the hydrological regime. Land use characteristics of the drainage basin (percent crop land, percent forest land) were stronger predictors of absolute seasonal variance of water chemistry and suspended algal abundance than either river size or discharge variability. Seasonal variance in algal abundance was primarily related to the productivity of the water.

In the second chapter, I examine suspended algal communities in 46 rivers in Ontario and Quebec to determine the influence of river size and nutrient status on algal biomass and size structure. Suspended algal biomass was positively related to nutrient concentration and to a lesser extent river size. Physical fractionation of chlorophyll *a* into logarithmic size classes indicated that small-sized algae between 0.2-20 μm dominated community biomass. Chlorophyll *a* estimates of size structure were compared with greatest axial linear dimension estimates (GALD) determined by microscope enumeration of suspended algal samples collected in 31 Ontario and Quebec rivers. GALD measurements similarly estimated that the majority of biomass was less than 20 μm whereas chlorophyll *a* fractionation slightly underestimated biomass in the larger size classes (20-64 μm, >64 μm). Both chlorophyll *a* and GALD estimates of size structure suggested that larger taxa contribute a greater proportion to total biomass in rivers with longer water residence times.

Résumé

Les rivières sont considérées des écosystèmes contrôlés principalement par l'environnement physique, et cet environnement est différent entre les ruisseaux et les grandes rivières. L'objectif de cette thèse était d'examiner l'importance de la grandeur d'une rivière pour le développement des algues suspendues dans l'eau.

Dans le premier chapitre, j'examine la variabilité saisonnière de la décharge et celle des variables chimiques et de l'abondance des algues suspendues pour évaluer la supposition acceptée que les ruisseaux varient plus au cours d'une saison que les rivières. La variabilité temporelle de la décharge et celles des paramètres de qualité de l'eau a été déterminée pour 114 sites sur 104 rivières dans l'est des États-Unis avec des données mesurées entre mai et octobre 1978 par l'organisation américaine appellée National Stream Water Quality Accounting Network (NASQAN). La grandeur de la rivière expliquait très peu la variabilité temporelle des paramètres de qualité de l'eau en comparaison à la forte relation entre la grandeur de la rivière et la variabilité hydrologique. L'impact anthropogénique dans le bassin hydrographique (pourcentage de terre cultivée, pourcentage de forêt) était plus lié à la variabilité temporelle des variables chimiques et de l'abondance algale que la grandeur de la rivière ou la variabilité hydrologique. La variabilité saisonnière des algues suspendues était principalement reliée à la productivité de l'eau.

Dans le deuxième chapitre, j'examine les communautés d'algues suspendues de 46 rivières dans l'Ontario et au Québec pour déterminer l'influence de la grandeur de la rivière et de la concentration des nutriments sur la biomasse et la structure en taille des algues. La biomasse algale était positivement corrélée avec la concentration en nutriments et faiblement corrélée avec la grandeur de la rivière. La filtration de chlorophylle *a* en classes de taille logarithmiques indiquait que les algues de petite taille entre 0.2-20 µm contribuaient majoritairement à la biomasse de la communauté. Les calculs de structure en taille selon la chlorophylle *a* ont été comparés avec des calculs basés sur la dimension maximal des cellules déterminés par énumération microscopique d'échantillons d'algues suspendues de 31 rivières de l'Ontario et du Québec. Les mesures microscopiques ont pareillement estimé que la majorité de la biomasse avait moins de 20 µm mais la chlorophylle *a* a sous-estimé le montant de biomasse dans les plus grandes classes de taille (20-64 µm, >64 µm). Les calculs de la structure en taille selon la chlorophylle *a* et les mesures microscopiques ont tous les deux suggéré que les algues de plus grande taille augmentaient en proportion de la biomasse totale dans les rivières avec de plus longues périodes de rétention.

General Introduction

According to the River Continuum Concept (RCC), the geomorphology of a fluvial ecosystem sets the stage for the structure and function of its aquatic biota (Vannote et al. 1980). As streams enlarge and coalesce into rivers, the physical regime changes; channel dimensions, average water velocity and discharge increase, channel slope flattens out, and bed sediment becomes finer (Kellerhals and Church 1989, Petts and Calow 1996). The biological organization within a river system is believed to conform to this longitudinal gradient of physical conditions (Vannote et al. 1980, Minshall et al. 1985b). The RCC predicts biological attributes of fluvial systems (primarily organic matter cycling/transport, periphyton production, and benthic invertebrate functional groups) based on a gradual change in water volume, turbidity, terrestrial organic input, and riparian shading. Critical to the concept is the coupling of downstream environments with physical and biological processes occurring upstream.

The RCC was written by a group of stream ecologists with a bias towards benthic communities, and suspended algal growth was barely discussed. Suspended algae were expected to develop only in large rivers, and even then remain scarce because of light limitation (Vannote et al. 1980). Since the RCC was published in 1980, river ecologists have clearly demonstrated that 'true' phytoplankton communities develop in rivers (Reynolds and Descy 1996) and can attain high levels of biomass (Basu and Pick 1996, Van Nieuwenhuyse and Jones 1996). Suspended algae are an important source of autochthonous carbon in rivers (Descy and Gosselain 1994, Thorpe and Delong 1994).

Even though planktonic communities are not described in any detail, the RCC nonetheless provides a framework to examine suspended algal development in rivers.

One aspect of stream habitat that is expected to change longitudinally is the temporal variability of environmental conditions (e.g.: discharge, temperature)(Vannote et al. 1980, Minshall et al. 1985b). Groundwater inputs in headwater streams and the large volume of water in high-order rivers act as buffers to temporal change in discharge. Therefore, mid-order streams are believed to exhibit the greatest variance (Vannote et al. 1980, Johnson et al. 1995). Fluctuations in discharge strongly impact suspended algae (Jones 1984), and therefore, seasonal variability may be associated with river size because of a gradient in hydrological variability.

Water residence time is another aspect of the hydrological regime that varies predictably with river size and also regulates the longitudinal development of suspended algae (de Ruyter Van Steveninck et al. 1992, Yang et al. 1997). The water residence time of a system, which is determined by its geomorphology, constrains algal growth by limiting the time available for suspended cells to divide and by preventing the development of algal populations with long doubling rates. Residence times increase as streams enlarge into rivers, and therefore, suspended algal biomass and community structure may change in relation to river size.

The RCC was developed as a conceptual model for temperate forested systems and focuses on physical factors that affect community structure. An underlying assumption of the model is that lotic ecosystems are controlled by physical processes and the importance of water chemistry has only been briefly mentioned in a later revision (Minshall et al. 1985b). However, river ecosystems differ greatly in their water chemistry depending on the geology and land use of the watershed, and longitudinal patterns may be affected by nutrient availability. For suspended algae, comparative studies suggest that differences in biomass among rivers are strongly related to nutrients which must be accounted for when examining effects of geomorphology (Soballe and Kimmel 1987, Van Nieuwenhuyse and Jones 1996).

The objective of this thesis is to describe how river size affects suspended algal development; its seasonal variability (chapter 1) as well as biomass and size structure (chapter 2). Both chapters also consider the importance of river trophic status (measured by nutrient concentration or algal biomass) because both hydrology and resource availability can affect suspended algal development.

River size as a determinant of seasonal variability in discharge, water chemistry, and suspended algal abundance

Abstract

Seasonal variability of discharge, water chemistry, suspended sediment, and suspended algal abundance were examined in temperate rivers of eastern United States to evaluate the accepted (but rarely tested) assumption that streams are more temporally variable than large rivers. Temporal variance of discharge and water quality parameters was determined for 114 stations on 104 rivers with data measured between May to October of 1978 by the U.S. National Stream Water Quality Accounting Network (NASQAN). Three measures of hydrological variability (coefficient of variation of daily discharge, flood frequency, number of months with floods) were negatively correlated with river size estimated by median discharge ($m^3 \cdot s^{-1}$)(r^2=0.28-0.35, $p<0.001$). When rivers were separated into regional drainage basins classified according to the Water Resources Council, hydrological variability was strongly related to median discharge in some regions (r^2=0.46-0.77, $p<0.001$) and not in others ($p>0.05$). Temporal variance of water column parameters increased in relation to the mean estimate of the parameter (r^2=0.69-0.93, $p<0.001$) with the exception of pH ($p=0.614$). Temporal variance of total nitrogen, ammonia, and nitrate-nitrite concentrations and suspended algal abundance decreased in relation to median discharge (albeit weakly) after controlling for the mean value (partial r^2=0.01-0.02, $p<0.05$). Sampling intensity affects temporal variance patterns, and temporal variability of nutrient concentrations was more strongly related to river size (higher r^2, lower p-value) when more sampling dates were used to calculate the variance. However, river size still only explained a very small portion of the temporal variance in water chemistry (<10%). Even though discharge variability was clearly related to river size, land use characteristics of the drainage basin (percent crop land, percent forest land)

were stronger predictors of absolute seasonal variance of water chemistry and suspended algal abundance than either river size or discharge variability. Nutrient concentrations and algal abundance are more temporally variable in eutrophic rivers than oligotrophic ones irrespective of size or hydrology.

Introduction

Patterns of temporal variation in environmental conditions are of ecological significance because variance influences biological structure and processes (Harris and Griffiths 1987, Kolasa and Pickett 1991, Palmer and Poff 1997). The most obvious source of heterogeneity in rivers is discharge which can fluctuate daily. Comparative studies examining stable and flood-prone rivers suggest that the degree of temporal variability in the discharge regime influences communities of fish (Horwitz 1978, Poff and Allen 1995), periphyton (Clausen and Biggs 1997), and benthic invertebrates (Di Maio and Corkum 1995, Townsend et al. 1997).

Hydrological variability tends to decrease with river size (Jowett and Duncan 1990), and in theory, this gradient should create a longitudinal structuring of lotic ecosystems (Vannote et al. 1980). Fluctuations in discharge strongly impact fundamental ecosystem processes occuring in the water column such as element transport and cycling (Rigler 1979, Mullholland et al. 1985, Munn and Prepas 1986) and suspended algal development (Jones 1984, Reynolds and Descy 1996). Suspended algae are an important source of autochthonous carbon in rivers (Descy and Gosselain 1994, Thorpe and Delong 1994), and nutrients are essential resources for their growth. Nutrient concentrations and suspended chlorophyll can increase severalfold during high discharge events (Perkins and Jones 1995) and also vary markedly over a season (Cattaneo and Prairie 1995). Streams generally have more variable hydrological regimes than large rivers, and therefore, river size may affect elemental and suspended algal dynamics. Seasonal variability in water chemistry and suspended algal abundance should be greater in streams than in large rivers.

Empirical models have been developed to predict seasonal variability of phytoplankton chlorophyll and nutrient concentrations in lakes (Knowlton et al. 1984, Marshall et al. 1988, France and Peters 1992) but similar large-scale comparative analyses do not exist for rivers. Cattaneo and Prairie (1995) examined the seasonal variability of water chemistry along the 75 km length of the Rivière de l'Achigan from its headwaters to mouth and found that nutrients (phosphorus, nitrogen, silica) and suspended chlorophyll differed in their relative variability. Interestingly, temporal variance of water chemistry was not related to physical features along the length of the river (river size, distance downstream from nearest lake). Temporal variance of total and dissolved phosphorus concentrations measured in 7 other headwater streams (Prairie and Kalff 1988a, 1988b) fit well models developed for the Rivière de l'Achigan suggesting possible wider applicability of temporal variance models for lotic ecosystems.

The relationship between river size and water column variability warrants closer investigation. From a more practical standpoint, the importance of river size as a determinant of temporal variability in water chemistry and suspended algal abundance has implications for monitoring programs in rivers. Models developed to predict the temporal variance of these parameters can be used to make decisions concerning sampling design. However, an investigation of the importance of river size also tests the theory proposed by many researchers that rivers are physically driven systems and that the variability in the discharge regime is a primary determinant of ecosystem structure (Vannote et al. 1980, Minshall et al. 1985b, Resh et al. 1988, Poff and Ward 1989). River size should be a strong predictor of the temporal variance in water column parameters where a gradient in hydrological variability exists.

Materials and Methods

Discharge, water chemistry, suspended sediment, and suspended algal abundance data were obtained from the comercially available National Stream Water Quality Monitoring Networks CD-ROM (DDS-37) of the U.S. Geological Survey (Alexander et al. 1996). This CD-ROM contains discharge and water quality data collected between 1973-1995 at over 600 river stations throughout the United States by the National Stream Quality Accounting Network (NASQAN). No analogous data base exists for Canadian rivers. In order to minimize inter-annual and geographic effects on temporal variance patterns, I selected discharge and water quality data measured in only 1 specific year (1978) and only in temperate rivers of eastern United States. I chose the year 1978 because the number of river stations sampled by NASQAN was relatively high that year and suspended algal abundance measurements were discontinued after 1981.

Rivers

In the CD-ROM data base, river stations across the United States are organized into 21 regional drainage basins as classified by the Water Resources Council. Each of the 21 regions encompasses either the drainage basin of a major river or the drainage basin of a group of rivers that flow into a particular region such as the Great Lakes. I selected data from the following 6 regional drainage basins: New England (01), Mid-Atlantic (02), Great Lakes (04), Ohio (05), Tennessee (06), and Upper-Mississippi (07) (Fig. 1.1). Rivers in these regions are typically perennial runoff systems with high spring discharge and low flood frequencies but some rivers may have more flashy (high frequency of non-seasonal flooding) or more stable (heavily influenced by groundwater flow) regimes

(Poff and Ward 1989). Within the 6 regions, I only examined river stations where water quality variables were measured. A total of 108 stations on 98 rivers were included in the data set (see Appendix 1a for a list of rivers). The rivers ranged widely in size with median discharges from 1 to 7958 $m^3 \cdot s^{-1}$ and drainage areas from 194 to 1 847 190 km^2. Despite this range, these rivers do not represent a random sample. Because of the water quality mandate of NASQAN, the data set is biased towards larger watersheds (50% of stations have drainage areas >7500 km^2) that are anthropogenically impacted, and the hydrological regime of many of these rivers may be influenced by dams or weirs. Water quality data for small headwater streams were not available but discharge data for an additional 6 streams measured by the U.S. Geological Survey (median discharge ≤0.5 $m^3 \cdot s^{-1}$) were included to compare discharge variability with medium to large rivers.

Water column parameters

Water column nutrient concentrations ($\mu g \cdot L^{-1}$), conductivity ($\mu S \cdot cm^{-1}$), pH, suspended sediment concentration ($mg \cdot L^{-1}$), and suspended algal abundance ($cells \cdot mL^{-1}$) were examined to determine if seasonal variability in these parameters is related to river size. Both total and dissolved concentrations of nutrients were included: total phosphorus (TP), dissolved phosphorus (DP), total nitrogen (TN), nitrate-nitrite (NO_3), ammonia (NH_3). Water chemistry, suspended sediment, and algal cell counts were determined using standard techniques of the U.S. Geological Survey (Alexander et al. 1996). At each river station, water column variables were measured on 5 or 6 sampling dates between May to October of 1978 at approximately monthly intervals. Not all variables were measured at every station and total sample sizes of water quality variables ranged from 73-106 (Table 1.1, Appendix 1b,c).

Hydrological variability

The discharge regime of each river was characterized using daily mean discharge ($m^3 \cdot s^{-1}$) measured over the same time period as water column parameters were sampled (May to October of 1978; n=183 days). The coefficient of variation of daily mean discharge (CV; standard deviation divided by mean discharge as a percent) was calculated as a measure of hydrological variability (Appendix 1d). The CV measures the dispersion of daily discharge around the mean and is a relevant index of overall variability but it does not provide information on the timing or intensity of flooding. Temporal variability in water chemistry is associated with flood events (Munn and Prepas 1986, Perkins and Jones 1994), and therefore, two measures of flooding were also calculated: the frequency of floods (number of peak discharge events exceeding 3 times the median discharge; sensu Clausen and Biggs 1997), and the number of months in which floods occurred (Appendix 1d). When 2 floods occurred within a time interval of ≤ 3 days, both were combined as one flood event. Intermittency was not considered because all rivers in this study have perennial discharge regimes. Median discharge was used as a measure of river size rather than mean discharge because the mean is more influenced by extreme values. Linear regression analysis was performed to determine the relationship between river size and each of the three measures of hydrological variability. ANCOVA analysis was performed to determine if the relationship between river size and each hydrological variable differs among the 6 regional drainage basins.

Mean-variance relationships

The temporal variability of water column variables was examined using mean (*M*) – variance (s^2) relationships (hereafter abbreviated as $M{:}s^2$). $M{:}s^2$ models have also been applied in other studies to describe the temporal variability of nutrient concentrations and phytoplankton chlorophyll in lakes and rivers (Knowlton et al. 1984, Prairie and Kalff 1988a, France and Peters 1992, Cattaneo and Prairie 1995). The variance of replicate samples increases as a function of the mean (Taylor 1961), and therefore $M{:}s^2$ relationships can be used to standardize the variance for comparison among different environments. For each water column variable, I tested the following multiple regression model:

$$(1)\ \log s^2 = a + b\log M + c\log D$$

where s^2 = variance, M = mean, D = median discharge ($m^3 \cdot s^{-1}$), and a, b, and c are fitted constants. I predicted that after controlling for differences in the mean, temporal variance decreases in relation to median discharge. The mean of each water column variable did not covary with median discharge ($p>0.05$) except for NH_3 ($r=-0.25$, $p=0.016$, $n=94$).

Effect of sampling intensity

The effect of sampling intensity on the relationship between temporal variance and river size was investigated because the variability of water column parameters was calculated based on only 5-6 sampling dates. Data from 12 intensively sampled stations on 11 rivers were obtained from the U.S. Geological Survey CD-ROM (10 stations) and the Water Quality Division, Canada Centre for Inland Waters (CCIW, Burlington, Ont., Canada)(2 stations; Appendix 1e). The U.S. Geological Survey sampling stations were located on the Cuyahoga, Illinois, Maumee, Minnesota, Mississippi, Ohio, Sandusky, Susquehanna, and White rivers, and the CCIW sampling stations were on the St. Lawrence and Niagara rivers. The rivers were located in regions 02, 04, 05 and 07 and were sampled intensively (≥ 22 sampling dates) between June to October of either 1980, 1991, or 1993 (Appendix 1f). Temporal variance of TP and TN concentrations were calculated on subsets of the data to correspond with 4 different sampling regimes: monthly, biweekly, weekly, and greater than weekly (all data from that station). Multiple regression model (1) (see above) was fitted to the TP and TN data of each sampling regime and the significance of median discharge as an independent variable in the $M{:}s^2$ model was then compared. I expected that under more intensive sampling, temporal variance of TP and TN concentrations would be more strongly related to median discharge (higher partial r^2, lower p-value, lower standard error of coefficient).

Results

Seasonal variability in discharge and water column parameters

Hydrological variability decreased in relation to river size (Fig. 1.2). Coefficients of variation of daily discharge ranged 3 orders of magnitude among rivers from 7-257%. Flood frequencies were generally low and ranged from 0-11 times over the period of May to October. On average, floods occurred in 2 of the 6 months but in some rivers, floods occurred in all 6 months. The mean CV of discharge decreased by 27% for each order of magnitude increase in median discharge. Large rivers with median discharge greater than 100 $m^3 \cdot s^{-1}$ tended to flood ≤ 2 times while small systems with median discharge of 1 $m^3 \cdot s^{-1}$ flooded an average of 5 times. Predictably, most rivers flooded during the spring

(May and June) but only smaller systems flooded in more months throughout the rest of the summer.

Discharge data for six headwater streams (median discharge $\leq 0.5\ m^3 \cdot s^{-1}$) were included to compare hydrological variability with medium to large rivers (Fig. 1.2). CV of daily discharge for the headwater streams were generally greater than large rivers (e.g.: median discharge $>100\ m^3 \cdot s^{-1}$) and of equal or greater variability than mid-sized rivers. Similar patterns were found when flood frequencies and the number of months with floods were compared except for two headwater streams in the Mid-Atlantic region (02) which had flooding regimes similar to large rivers.

Temporal variance of water column parameters was not related or only very weakly related to river size (Table 1.1). Strong positive correlations were observed between the mean and variance for all variables except pH ($p=0.614$), and coefficients of determination for these relationships ranged from 0.69-0.93 with suspended algal abundance having the highest coefficient. Temporal variance of TN, NH_3, and NO_3 concentrations and suspended algal abundance were negatively correlated with median discharge after controlling for the effect of the mean (Table 1.1). However, although significant, median discharge only explained an additional 1-2% of the variation in the $M{:}s^2$ models. One extreme value from the largest river had a strong influence on the relationship between temporal variance of suspended algal abundance and median discharge (Fig. 1.3). The relationship was non-significant when that point was removed ($p=0.139$). Temporal variance in conductivity, pH, suspended sediment, TP, and DP did not significantly decrease in relation to median discharge ($p>0.05$). Similar patterns were observed with CV for water column variables (Table 1.2). CV of TN, NH_3, and NO_3

concentrations and suspended algal abundance were negatively correlated with median discharge but only 4-6% of the variation was explained (Fig. 1.4). Suspended algal abundance exhibited the highest mean CV (96%) followed by suspended sediment (77%), NH_3 (68%), DP (61%), TP (53%), NO_3 (52%), TN (36%), conductivity (19%), and pH (4%).

Differences among regions

The hydrological regimes differed among the 6 regional drainage basins. ANCOVA analysis revealed that the average CV of daily discharge, flood frequency, and number of months with floods differed significantly among regions (Table 1.3). More importantly, the effect of river size on these hydrological variables depended on the region (Table 1.3). In the New England (01), Mid-Atlantic (02), and Tennessee (06) regions, hydrological variability was not significantly related to median discharge but in the Great Lakes (04), Ohio (05), and Upper Mississippi (07) drainage basins, strong negative correlations were observed (Table 1.4, Fig. 1.5). A significant effect may not have been detected in Tennessee because there was a low sample size (n=6) and all rivers were large (median discharge 124-961 $m^3 \cdot s^{-1}$). In contrast, rivers in New England and the Mid-Atlantic regions ranged 3 orders of magnitude in size but no effect of river size on hydrological variability was observed.

Patterns of temporal variability of water column parameters were similar even when data from regions 01, 02 and 06 were removed. The multiple regression models from Table 1.1 were re-analyzed without the data from these regional drainage basins because hydrological variability in these regions was not correlated with river size (Table

1.4). All significant results observed in the full data set (Table 1.1) were also found after regions 01, 02, and 06 were removed with three exceptions. Temporal variance of TP concentration became negatively correlated with median discharge (p=0.034), temporal variance in NH_3 was no longer significantly correlated with median discharge (p=0.138), and temporal variance in pH became positively correlated with median discharge (p=0.045).

Effect of sampling intensity

Temporal variance of TP and TN concentrations was more strongly related to river size when samples were taken more frequently. The effect of sampling intensity was tested by examining $M{:}s^2$ models calculated from 4 different subsets of data (monthly, biweekly, weekly, and full data set) from 12 intensively sampled river stations. In this dataset, hydrological variability measured by the CV of discharge decreased strongly with median discharge (r^2=0.61, p=0.003, n=12). Temporal variance of TP and TN was more strongly correlated with median discharge (higher partial r^2, lower p-value) when more sampling dates were used to calculate the temporal variability but the relationship was not necessarily linear (Table 1.5). For TP concentration, the highest partial r^2 (r^2=0.07), the lowest p-value (p=0.032), and the lowest standard error (SE=0.122) were observed for the weekly rather than the greater than weekly sampling frequency. The coefficient *c* for the effect of median discharge in the multiple regression model was relatively constant (compared to the standard error) under different sampling intensities. The standard error of the coefficient *c* decreased with increasing sampling intensity for TP but not for TN.

Temporal variance of TP concentration in streams, rivers, and lakes

$M{:}s^2$ models for TP concentration were compared between headwater streams of Missouri (data from Lohman 1988), temperate rivers of eastern United States (this study) and north-temperate lakes of Europe and North America (France and Peters 1992). For a given mean concentration of TP, temporal variance was similar between headwater streams (mean discharge 0.04-2.44 $m^3 \cdot s^{-1}$) and temperate rivers (mean discharge 1-8158 $m^3 \cdot s^{-1}$) but higher in lotic than in lentic systems (Fig. 1.6). Caution is required when making comparisons between models because the number of replicates, sample size, and range of data influence $M{:}s^2$ coefficients (Downing 1986). However, for each model, temporal variance of TP was calculated based on monthly estimates during the summer (5-7 replicates) and sample sizes were sufficiently large (streams n=44, rivers n=104, lakes n=65). These results suggest that temporal $M{:}s^2$ models are specific to particular environments and that seasonal variability in TP concentration is lower in lakes than in streams and rivers.

Discussion

River size was a strong predictor of hydrological variability in some regional drainage basins and not in others. Similarly, Horwitz (1978) found that discharge variability decreased longitudinally in some undisturbed temperate streams and not in others. River size is only one of several determinants of hydrological variability, and other factors such as precipitation (intensity, duration), vegetation cover (extent, type), soil character (infiltration capacity), and landscape topography (slope, shape)(Mosley and McKerchar 1993) may have an overiding effect. Large rivers are generally rather stable but smaller systems have either flashy or stable discharge regimes (Horwitz 1978, Richards 1990, this study). Flashy regimes occur in rivers fed largely by surface run-off and are typical in poorly vegetated catchments with fine-grained heavy soils (Richards 1990). Longitudinal gradients in discharge variability are likely stronger in drainage basins with these characteristics. Conversely, river size is likely a weak predictor of discharge variability in forested drainage basins with headwater streams fed by groundwater. The lack of a relationship between river size and hydrological variability in the Mid-Atlantic (02) may have been due to stable groundwater streams which are common in parts of this region (Poff 1996). Likewise, drainage basins in New England (01) were largely forested (on average 71% forest cover in contrast with less than 50% for all other regions) which may account for the stability of discharge in smaller rivers of this region. Undoubtedly, some of the rivers in this study were regulated by dams or weirs but this is unlikely to account for the regional differences in hydrological variability because river regulation is common throughout eastern United States (Cuff and Young 1980).

Temporal variance of water column parameters was only weakly related to river size. Median discharge explained 1-2% of the temporal variance in only 4 of 9 water column parameters. Temporal variance of a fifth parameter, TP concentration, was also negatively related to median discharge when a subset of the data was examined. Coefficients of variation of water column parameters were also weakly related to median discharge (highest r^2=0.06). Cattaneo and Prairie (1995) found no relationship between temporal variability of water chemistry and river size along the length of the Rivière de l'Achigan. In this study, seasonal variability of water column parameters was likely underestimated because extreme fluctuations in water chemistry, suspended sediment, and algal abundance occur during flood events which would have been missed under a monthly sampling regime. A test of the effect of sampling intensity indicated that median discharge explained a greater percentage of the variance in nutrient concentrations (up to 7%) when temporal variability was calculated with weekly replicates (Table 1.5). However, river size still only explained a suprisingly small portion of the temporal variance of water column parameters relative to the strong relationships observed between river size and the hydrological regime.

Fluctuations in discharge do not exert consistent effects on element concentrations in rivers (Meyer et al. 1988) which may explain the weak relationship observed between river size and temporal variance of water column parameters. Meyer et al. (1988) reviewed several studies of discharge effects on element dynamics and found that the behaviour of elements varied widely among streams. For example, nitrate and soluble reactive phosphorus concentrations either increased, decreased, or remained constant with rising discharge depending on the study. Even particulate fractions are not necessarily predictable as, for example, particulate phosphorus concentration can increase or decrease during rain events depending on the forest cover and channel gradient of the catchment (Prairie and Kalff 1988b). Cation concentrations increase during periods of high discharge when the dominant source of cations is surface runoff (Kerekes and Freedman 1989) but decrease during high discharge when the dominant source is groundwater (Caissie et al. 1996). In contrast with most elements, suspended sediment concentration predictably increases with rising discharge (Leopold 1994) but in this study, temporal variance of suspended sediment was not related to river size and only marginally related to the CV of daily discharge ($p=0.055$). Suspended sediment increases with discharge because of sediment resuspension from the riverbed, bank erosion, and transport from the drainage basin by overland flow. However, sediment load varies widely among regional drainage basins depending on the topography, geology, and land use of the watershed (Leopold 1994). Watershed characteristics play a strong role in determining the behaviour of elements in relation to discharge (Meyer et al. 1988) and likely also exert control over their seasonal variability.

The mean estimate of each water column parameter explained the majority of the temporal variance (69-93%) suggesting that, on a landscape scale, factors determining the supply of nutrients to rivers also influence their temporal variability. Fluctuations in discharge play a key role in the sequence or timing of temporal changes in nutrient concentrations, but watershed geology and land use determine the average concentrations of nutrients entering a river and therefore also limit the absolute magnitude of their temporal variance. In fact, land use characteristics of the drainage basin are stronger predictors of absolute seasonal variance than either river size or discharge variability (Table 1.6). Rivers flowing through agricultural watersheds tend to have higher concentrations of suspended sediment, nutrients, and algal biomass than forested regions, and therefore, the absolute temporal variance of these variables increases with the proportion of crop land in the drainage basin. Likewise, the temporal variance of water column parameters decreases with the proportion of forested land because forested drainage basins export smaller loads of nutrients (Dillon and Kirchner 1975, Prairie and Kalff 1988b) and develop lower concentrations of suspended chlorophyll (Lohman and Jones 1999). Biological processes and sorption/desorption reactions can also affect the temporal variability of nutrient concentrations but these factors are probably more significant at smaller temporal and spatial scales (Meyer et al. 1988).

Seasonal variability in suspended algal abundance was only weakly related to river size and strongly related to mean abundance suggesting that trophic status is a more important determinant of the magnitude of temporal variance than the physical regime. Productive waters have greater seasonal variability perhaps because algal blooms tend to occur at certain times during the summer in eutrophic rivers (Soballe and Bachmann 1984, Gosselain et al. 1998a) but not in oligotrophic ones (Hudon et al. 1996). Seasonality of phytoplankton chlorophyll in lakes also depends on trophy with eutrophic lakes exhibiting greater temporal variation and more distinct blooming periods than unproductive waters (Marshall and Peters 1989). In the present study, the CV of suspended algal abundance increased with the mean ($r=0.26$, $p=0.023$, $n=73$) indicating that a more intensive sampling regime is required to obtain the same level of estimate precision in more productive rivers. The sample size required to obtain a mean abundance with a standard error of 25% or less was estimated with the equation $n = 2.183[X]^{0.190}$ following the method of Downing (1979) and Morin (1985). The $M{:}s^2$ relationship used to calculate this equation did not include the parameter median discharge because it only explained an additional 1% of the temporal variance. Based on the $M{:}s^2$ model, 8 samples are required to obtain a mean with an error of 25% or less for a river with an average abundance of 1000 cells·mL^{-1} while 15 samples are required for a river with an average abundance of 30 000 cells·mL^{-1}. Trophy rather than river size or hydrological regime should be the primary concern when deciding a sampling frequency for algal abundance in rivers.

Suspended algal abundance was the most variable water column parameter relative to the mean (average CV=96%). Cattaneo and Prairie (1995) observed that suspended chlorophyll in the Rivière de l'Achigan varied more throughout the season than dissolved and total nitrogen concentrations, silica, alkalinity, conductivity, and pH but varied less than total and dissolved phosphorus concentrations. Coefficients of variation of suspended chlorophyll measured on a monthly basis during two summers in 22 Missouri streams were comparable to CV of algal abundance in this study, averaging 84% (data from Lohman 1988). Coefficients of variation for summer chlorophyll can be considerably lower such as in the Madawaska (25%), Rideau (44%), and Trent (72%), but CV were always greater than those for TP and TN concentrations (B.K. Basu, unpublished data, 1993). Since suspended algae in lotic ecosystems tend to vary more throughout the season than other water chemistry parameters, sampling regimes should be designed with the precision of algal biomass estimates as a first priority. The same recomendation has been made for phytoplankton biomass in lakes (France and Peters 1992).

Although temporal variability of water column parameters was little affected by the type of hydrological regime, a comparison of $M{:}s^2$ models suggests that TP concentration is more variable in lotic than in lentic systems (this study, Cattaneo and Prairie 1995). Greater riparian inputs in rivers than lakes (higher ratio of shoreline length to water surface area) may partly account for this difference. $M{:}s^2$ models for nutrient concentrations may also be specific to lakes and rivers because discharge is a greater and more constant advective force than mixing in lake epilimnia. To my knowledge, no temporal $M{:}s^2$ model exists in the literature for lake phytoplankton abundance to compare with the algal abundance model from this study.

Mid-order rivers are expected to exhibit the greatest temporal variability (Vannote et al. 1980, Johnson et al. 1995), and although this may be so for diel temperature variation in undisturbed streams (Minshall et al. 1985a), it does not appear to be the case for other water column parameters. Vannote et al. (1980) suggested that groundwater inputs in headwater streams and the large volume of water in high-order rivers act as buffers to temporal change in discharge and other water column characteristics. Contrary to assumptions, river size does not appear to influence strongly temporal variance in water chemistry parameters and suspended algal abundance, although it is clear that hydrological parameters are tightly correlated with river size. Nutrient concentrations and algal abundance are more temporally variable in eutrophic rivers than in oligotrophic ones irrespective of size or the hydrological regime.

Table 1.1 Multiple regression models relating the temporal variance (s^2) of 9 water column parameters to their mean (M) and to median discharge (D). Coefficients and their standard error (SE), probability values (p), sample size (n), partial coefficients of determination (partial r^2) for each independent variable, and the full coefficient of determination (model r^2) are presented for each model. All variables were log transformed. NS = non-significant ($p>0.05$).

Water Column Variable	**Range of M**	**Independent Variable**	**Coefficient**	**SE**	**p**	**Partial r^2**	**n**	**Model r^2**
Conductivity ($\mu S\cdot cm^{-1}$)	35-4150	Intercept	-1.592	0.324	<0.001		106	0.69
		Log M	2.002	0.133	<0.001	0.69		
		Log D			NS			
pH	4.4-8.8	Intercept			NS		103	
		Log M			NS			
		Log D			NS			
Suspended sediment ($mg\cdot L^{-1}$)	2-413	Intercept	-0.661	0.140	<0.001		99	0.86
		Log M	2.218	0.093	<0.001	0.86		
		Log D			NS			
TN ($\mu g\cdot L^{-1}$)	328-8680	Intercept	-1.312	0.423	0.003		100	0.73
		Log M	2.168	0.135	<0.001	0.71		
		Log D	-0.138	0.054	0.012	0.02		
NH_3 ($\mu g\cdot L^{-1}$)	13-3495	Intercept	-0.044	0.151	NS		94	0.91
		Log M	1.891	0.066	<0.001	0.90		
		Log D	-0.087	0.036	0.020	0.01		
NO_3 ($\mu g\cdot L^{-1}$)	28-4020	Intercept	-0.087	0.262	NS		106	0.78
		Log M	1.851	0.096	<0.001	0.77		
		Log D	-0.139	0.061	0.024	0.01		
TP ($\mu g\cdot L^{-1}$)	13-1182	Intercept	-0.379	0.223	NS		104	0.73
		Log M	1.835	0.111	<0.001	0.73		
		Log D			NS			
DP ($\mu g\cdot L^{-1}$)	12-1085	Intercept	-0.485	0.147	0.002		88	0.86
		Log M	1.985	0.087	<0.001	0.86		
		Log D			NS			
Algal abundance ($cells\cdot mL^{-1}$)	394-228560	Intercept	-0.759	0.270	0.006		73	0.94
		Log M	2.226	0.068	<0.001	0.93		
		Log D	-0.138	0.050	0.008	0.01		

Table 1.2 **Pearson correlation coefficients for pairwise comparisons between log transformed median discharge ($m^3 \cdot s^{-1}$) and log transformed coefficients of variation (CV) of 9 water column parameters. *$p<0.05$**

	Log median discharge	n
Log CV conductivity	-0.11	106
Log CV pH	0.13	103
Log CV suspended sediment	-0.10	99
Log CV TN	-0.24*	100
Log CV NH_3	-0.21*	94
Log CV NO_3	-0.24*	106
Log CV TP	-0.17	104
Log CV DP	-0.09	88
Log CV algal abundance	-0.23*	73

Table 1.3 ANCOVA models testing for differences in hydrological variability among the 6 regional drainage basins. F-statistics (F) and probability values (p) are presented for the effect of log transformed median discharge ($m^3 \cdot s^{-1}$) and river location on three measures of hydrological variability (CV of discharge, flood frequency, number of months with floods). (n=114)

Dependent Variable	**Independent Variable**	**F**	**p**
CV of discharge	Log *D*	11.6	<0.001
	Region	4.7	<0.001
	Region x Log *D*	6.1	<0.001
Flood frequency	Log *D*	8.5	0.004
	Region	12.6	<0.001
	Region x Log *D*	6.2	<0.001
Months with floods	Log *D*	12.8	<0.001
	Region	8.6	<0.001
	Region x Log *D*	4.9	<0.001

Table 1.4 **Pearson correlation coefficients for the relationship between log transformed median discharge ($m^3 \cdot s^{-1}$) and three measures of hydrological variability (CV of discharge, flood frequency, number of months with floods). Coefficients were calculated separately for each regional drainage basin (01-07). Sample sizes are provided in parentheses.** *$p<0.05$, **$p<0.01$, ***$p<0.001$

	Log median discharge					
Region	**01** (15)	**02** (19)	**04** (31)	**05** (28)	**06** (6)	**07** (15)
CV of discharge	-0.01	0.02	-0.71***	-0.88***	-0.46	-0.72**
Flood frequency	-0.24	-0.07	-0.68***	-0.84***	0.43	-0.82***
Months with floods	-0.62*	-0.13	-0.73***	-0.81***	0.43	-0.83***

Table 1.5 Effect of sampling intensity on the relationship between median discharge and temporal variance of TP and TN concentrations. The following multiple regression model: $\log s^2 = a + b\log M + c\log D$ (where s^2 = variance, M = mean, D = median discharge ($m^3 \cdot s^{-1}$), and a, b, and c are constants) was fit to temporal variance data of TP and TN calculated using a range of sampling intensities at 12 river stations. The coefficient (c), standard error (SE), partial r^2, and probability value (p) for log median discharge as a second independent variable in the M:s^2 model are presented for each sampling regime.

Variable	**Sampling Intensity**	**# Sampling Dates**	**Coefficient of Log Median Discharge (c)**	**SE**	**Partial r^2**	**p**
TP	monthly	5	-0.313	0.217	0.04	0.184
	biweekly	10-11	-0.332	0.150	0.07	0.054
	weekly	19-22	-0.311	0.122	0.07	0.032
	>weekly	22-157	-0.215	0.132	0.05	0.137
TN	monthly	5	-0.188	0.165	0.02	0.284
	biweekly	10-11	-0.211	0.175	0.03	0.258
	weekly	19-22	-0.219	0.171	0.04	0.233
	>weekly	22-157	-0.226	0.158	0.05	0.187

Table 1.6 Pearson correlation coefficients for pairwise comparisons between log transformed temporal variance of water column parameters, log transformed median discharge ($m^3 \cdot s^{-1}$), CV of discharge (%), arcsine transformed percent of drainage area as crop land, and arcsine transformed percent of drainage area as forest land. Percent crop land and forest land area for the drainage basin of each river station were obtained from the U.S. Geological Survey CD-ROM. *p<0.05, **p<0.01, ***p<0.001

	Log median discharge	CV of discharge	Arcsine % Crop[a]	Arcsine % Forest[a]	n
Log Var conductivity	-0.05	0.36***	0.50***	-0.43***	106
Log Var pH	0.17	-0.03	0.14	-0.13	103
Log Var suspended sediment	0.08	0.30**	0.40***	-0.40***	99
Log Var TN	-0.07	0.23*	0.54***	-0.56***	100
Log Var NH_3	-0.31**	0.34***	0.34***	-0.36***	94
Log Var NO_3	0.04	0.19	0.72***	-0.73***	106
Log Var TP	-0.15	0.38***	0.45***	-0.50***	104
Log Var DP	-0.13	0.19	0.44***	-0.54***	88
Log Var algal abundance	0.11	0.03	0.34**	-0.25*	73

[a] Drainage basin land use was estimated for 1987 while discharge and water column parameter variance were measured in 1978. I assumed that changes in land use between 1978 and 1987 were small given the broad range in percent forest and crop land among watersheds.

Figure 1.1 NASQAN river stations examined in this study were located in 6 hydrologic drainage basins as classified according to the Water Resources Council: New England (01), Mid-Atlantic (02), Great Lakes (04), Ohio (05), Tennessee (06), and Upper Mississippi (07).

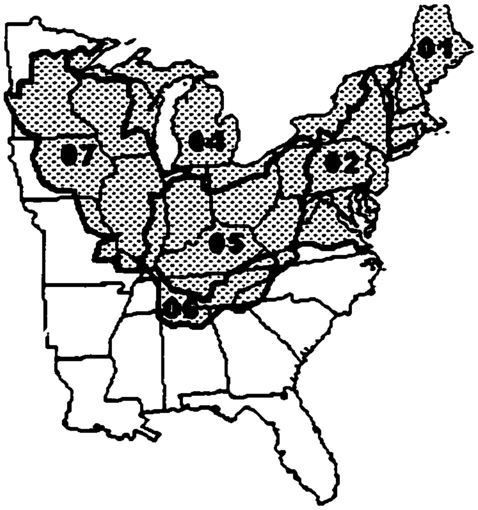
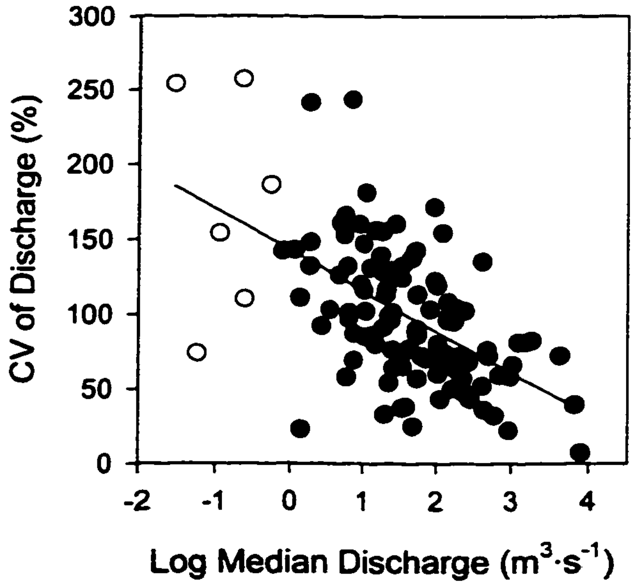
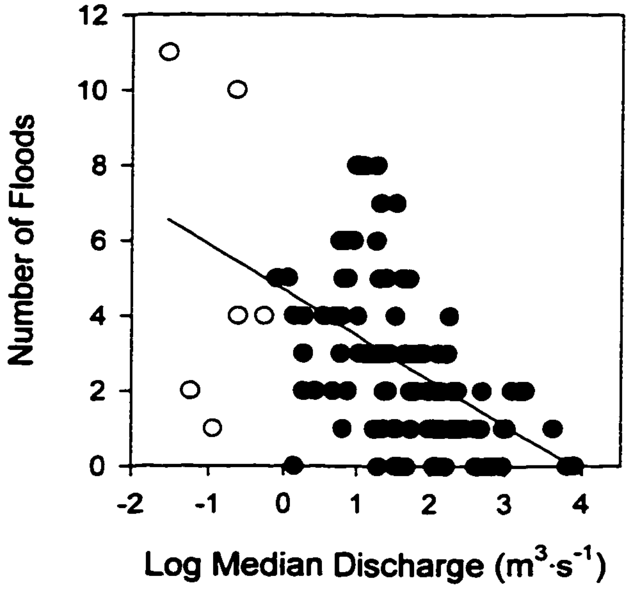

01
07
04
02
05
06

Figure 1.2 Effect of median discharge on CV of daily discharge (r^2=0.32, $p<0.001$, n=114), flood frequency (r^2=0.28, $p<0.001$, n=114), and number of months with floods (r^2=0.35, $p<0.001$, n=114). Headwater streams (median discharge ≤0.5 $m^3 \cdot s^{-1}$; open circles) with no corresponding water quality data were included to compare discharge variability with medium to large rivers (median discharge ≥1 $m^3 \cdot s^{-1}$; closed circles).


CV of Discharge (%)
300
250
200
150
100
50
0
-2
-1
0
1
2
3
4
Log Median Discharge ($m^3 \cdot s^{-1}$)


Number of Floods
12
10
8
6
4
2
0
-2
-1
0
1
2
3
4
Log Median Discharge ($m^3 \cdot s^{-1}$)

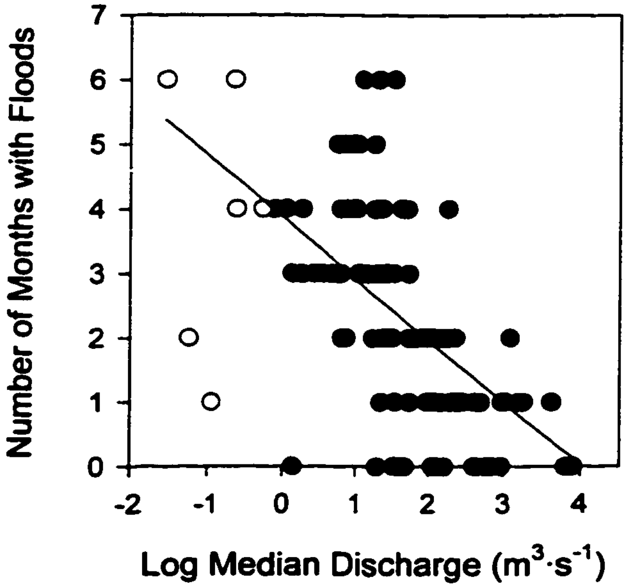
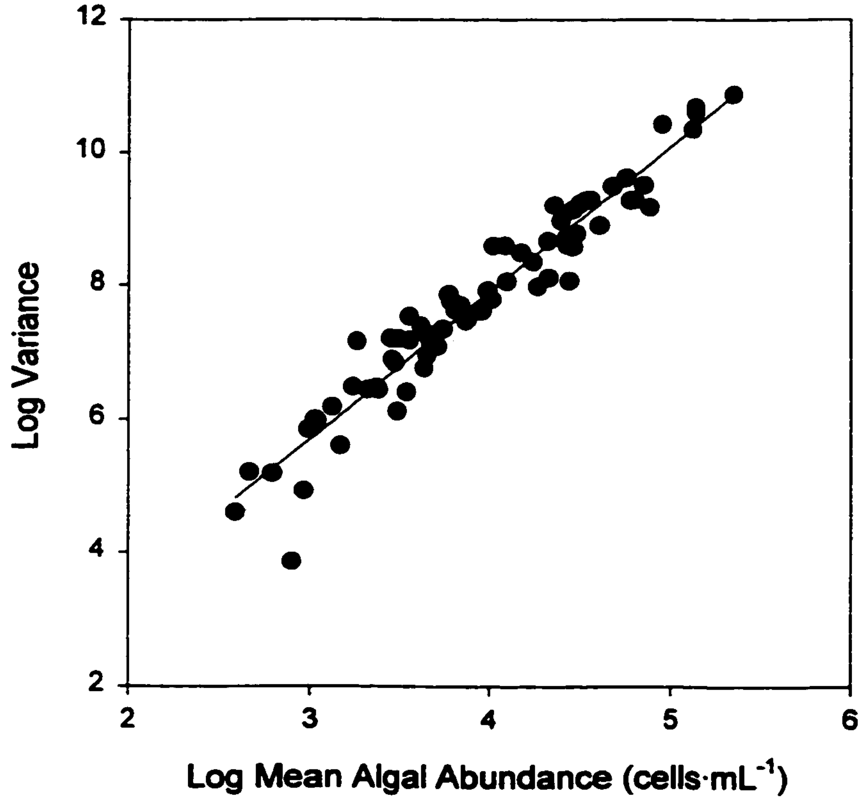

Number of Months with Floods
7
6
5
4
3
2
1
0
-2
-1
0
1
2
3
4
Log Median Discharge ($m^3 \cdot s^{-1}$)

Figure 1.3 Relationship between the mean estimate and the temporal variance of suspended algal abundance (r^2=0.93, p<0.001, n=73), and the effect of median discharge ($m^3 \cdot s^{-1}$) on the temporal variance of algal abundance after controlling for the mean (partial r^2=0.01, p=0.008, n=73).


12
10
8
6
4
2
Log Variance
2
3
4
5
6
Log Mean Algal Abundance (cells·mL^{-1})

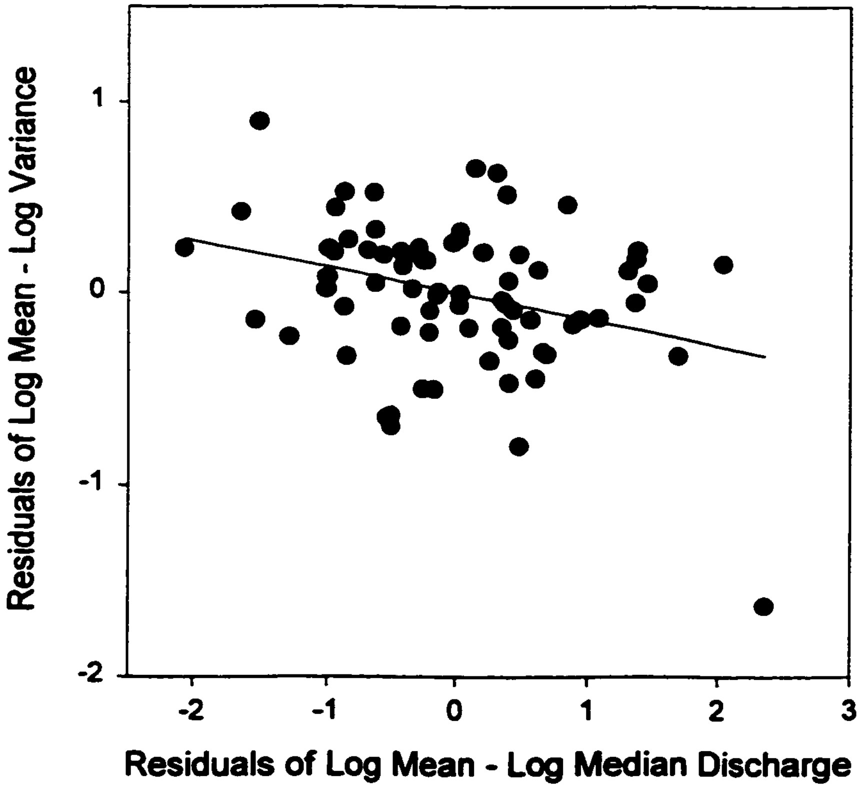

1
0
-1
-2
Residuals of Log Mean - Log Variance
-2
-1
0
1
2
3
Residuals of Log Mean - Log Median Discharge

Figure 1.4 Relationship between CV of suspended algal abundance and median discharge (r^2=0.05, p=0.049, n=73).

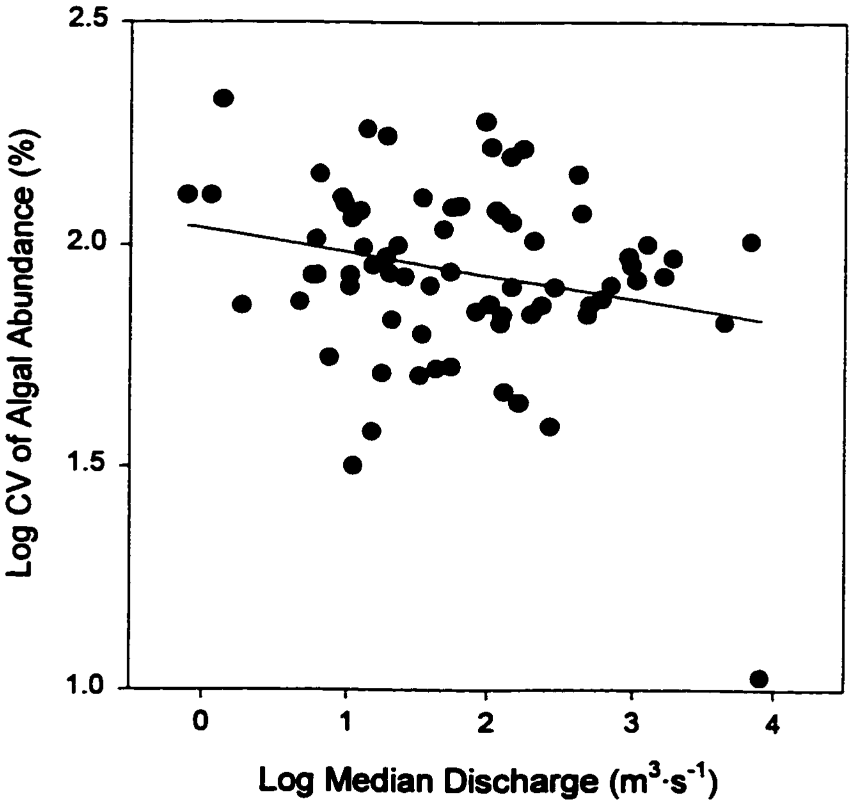

2.5
2.0
1.5
1.0
0
1
2
3
4
Log CV of Algal Abundance (%)
Log Median Discharge (m^3·s^{-1})

Figure 1.5 Relationship between median discharge and CV of discharge in each of the six regional drainage basins. See Table 4 for correlations coefficients, probability values, and sample sizes of each relationship. Headwater streams (median discharge ≤ 0.5 $m^3 \cdot s^{-1}$; open circles) with no corresponding water quality data were included to compare discharge variability with medium to large rivers (median discharge ≥ 1 $m^3 \cdot s^{-1}$; closed circles).

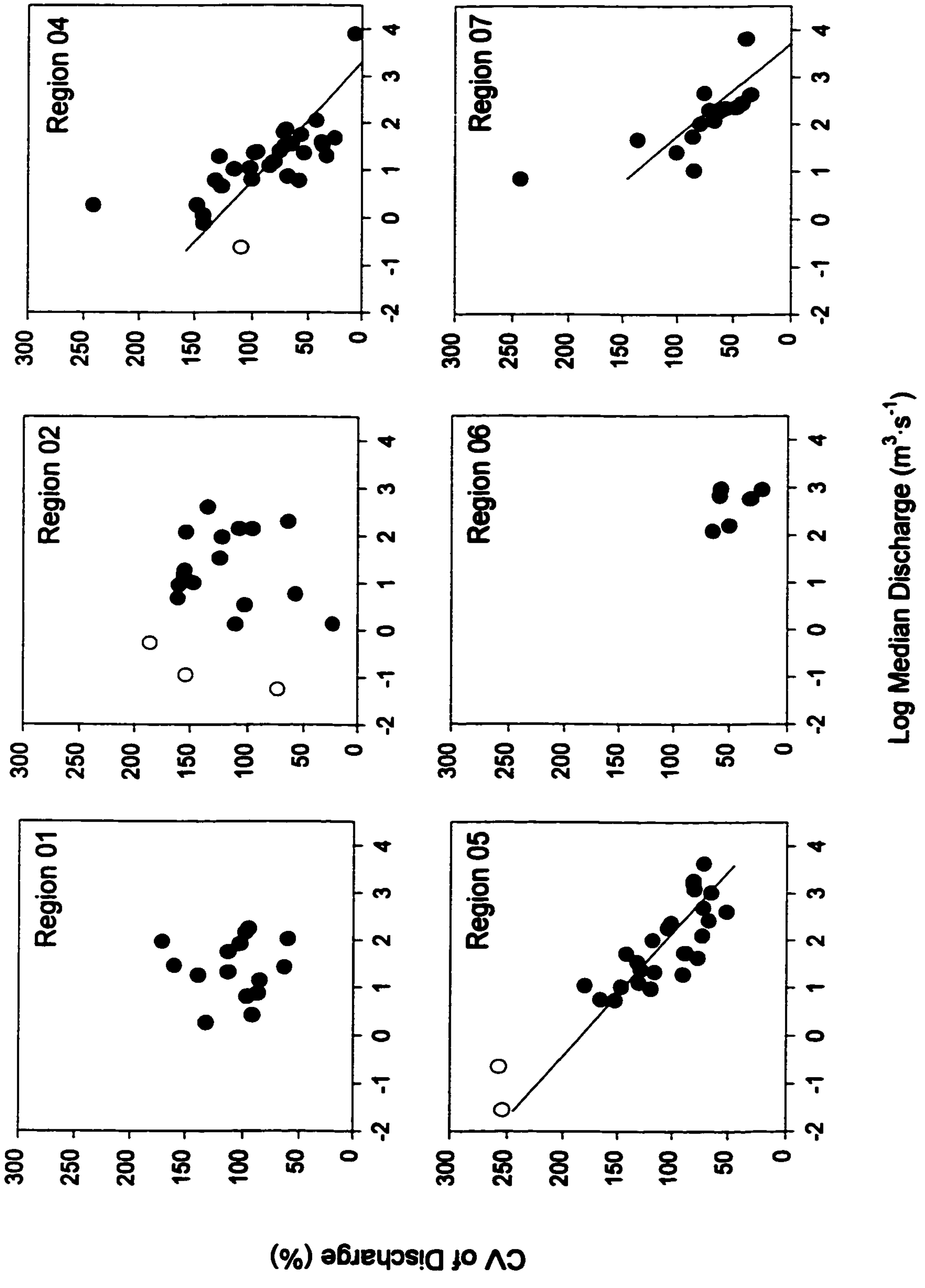
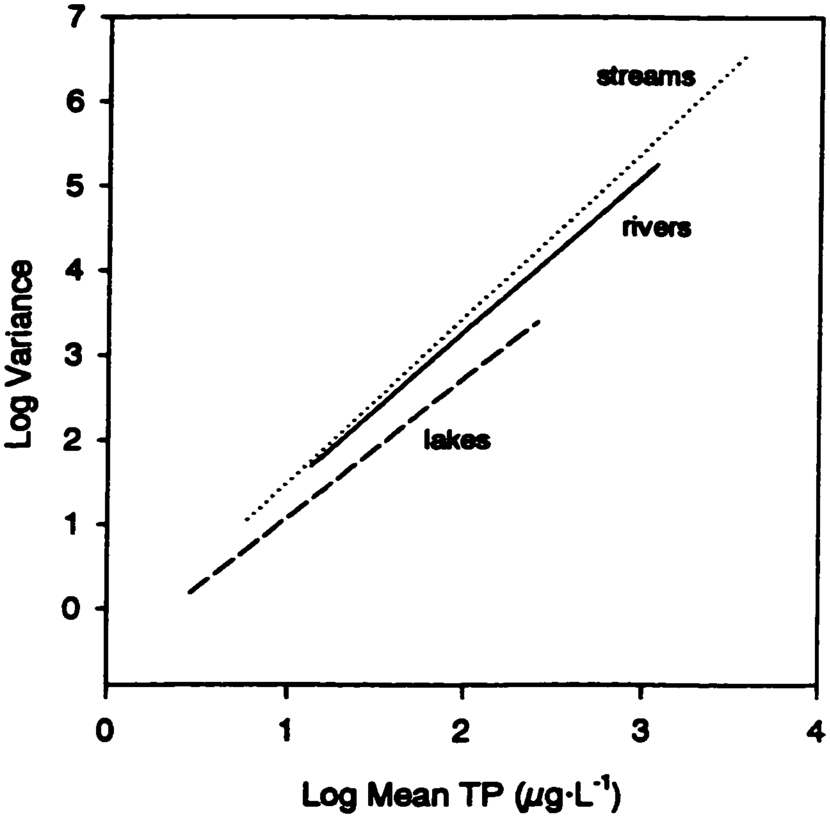

Region 01
Region 02
Region 04
Region 05
Region 06
Region 07
CV of Discharge (%)
Log Median Discharge (m^3·s^{-1})
300
250
200
150
100
50
0
-2
-1
0
1
2
3
4

Figure 1.6 Comparison of log mean – log variance relationships for TP concentration in streams of Missouri (data from Lohman 1988), rivers of eastern United States (this study), and north-temperate lakes of Europe and North America (France and Peters 1992).


7
6
5
4
3
2
1
0
Log Variance
streams
rivers
lakes
0
1
2
3
4
Log Mean TP (μg·L^{-1})

Influence of river size and nutrient concentration on the biomass and size structure of suspended algae

Abstract

The biomass and size structure of suspended algae were examined in 46 rivers in Ontario and Quebec to determine the influence of river size and nutrient status on algal development. Suspended algal biomass was expected to increase in relation to ambient nutrient concentration and water residence time, and larger-sized algae were expected to contribute a greater proportion to community biomass with increasing water residence time and trophy. Suspended algal biomass estimated by chlorophyll *a* (Chl *a*, $\mu g \cdot L^{-1}$) was positively correlated with total phosphorus and total nitrogen concentrations (r^2=0.41-0.44, $p<0.001$) and weakly related to water residence time over the range of 1-39 days only after controlling for nutrient concentrations (partial r^2=0.07, p=0.012). Algal size structure was estimated by physical fractionation of Chl *a* into 4 size classes (0.2-2.0 µm, 2.0-20 µm, 20-64 µm, >64 µm), and on average, smaller size classes contributed the greatest portion to community biomass (32% in 0.2-2.0 µm, 50% in 2.0-20 µm). Chl *a* size spectra were determined for each river site by plotting the proportion of Chl *a* retained on the filter against the logarithm of the filter size. Size spectra regression slopes were steeper in rivers with greater total Chl *a* indicating that larger algae contributed less to total biomass in more productive waters. This trend was due to a greater proportion of biomass in the 2.0-20 µm size class. A non-linear relationship was observed between size spectra slopes and river size. Slopes were steepest at intermediate water residence times indicating that larger algae contributed more to total biomass in the smallest and largest systems. Chl *a* estimates of size structure were compared with greatest axial linear dimension (GALD) estimates determined by microscope enumeration of suspended algal samples collected in 31 Ontario and Quebec rivers. GALD measurements similarly

estimated that the majority of biomass was below 20 μm (57%) whereas Chl *a* fractionation slightly underestimated biomass in the larger size classes (20-64 μm, >64 μm). The proportion of biomass in size classes based on GALD measurements was not related to trophy but the proportion of algal biomass >64 μm increased with water residence time ($r^2=0.25$, $p=0.004$). These observations suggest that differences in suspended algal biomass among rivers are primarily related to nutrients and that small-sized algae dominate community biomass although larger taxa contribute a greater proportion to total biomass in rivers with longer water residence times.

Introduction

Downstream flow is an unavoidable constraint on the growth of algae suspended in river waters. Water residence time regulates the longitudinal development of suspended algae by determining the time available for growth (Reynolds and Descy 1996). In many rivers such as the Rhine (de Ruyter van Steveninck et al. 1992), Rideau (Basu and Pick 1997), Severn (Reynolds and Glaister 1993), and Waikato (Lam 1981), algal biomass tends to increase downstream as the water parcel ages. Even over reaches as short as 8 km, variation in suspended chlorophyll is associated with residence times (Basu and Pick 1995). Most evidence supporting advective control of suspended algal development is based on observations over reaches of a single watercourse. Less emphasis has been placed on the role of river size in regulating suspended algae even though water residence times vary widely among rivers. The importance of river size as a large-scale determinant of algal biomass is still unresolved because conflicting observations have been reported (Soballe and Kimmel 1987, Basu and Pick 1996, Van Nieuwenhuyse and Jones 1996).

Advective forces limit the time available for growth while nutrients, temperature, and light determine the growth rate of algae. Phytoplankton photosynthesis is related to water temperature over an annual cycle, and maximum photosynthetic rates and biomass occur during summer water temperatures (Baker and Baker 1979). Insufficient light may also regulate suspended algal growth in large turbid rivers when the mixing depth is much greater than the photic depth (Cole et al. 1992). Nutrient enrichment stimulates algal growth in temperate freshwaters (Wetzel 1983), and comparative studies suggest that differences in biomass among rivers are strongly related to nutrients (Basu and Pick 1996, Van Nieuwenhuyse and Jones 1996). Suspended algal development is related to the time available for growth as well as the growth rate of algae, and therefore, temperature, light conditions, and nutrient availability must also be considered when examining the influence of water residence time.

Water residence time may also play a role in determining the community structure of suspended algae. The growth rate of algae is inversely related to cell size (Malone 1980, Reynolds 1984), and therefore, small sized algae with faster growth rates may dominate in systems with short residence times, and larger cells contribute a greater proportion to total biomass with increasing residence times. Few studies have focused on the size structure of suspended algae in rivers (Rojo et al. 1994) although several review articles predict that small cells with high surface to volume ratios hold advantages for growth in turbulent and turbid fluvial waters (Reynolds 1994, Reynolds and Descy 1996). Algal size distributions provide relevant information on community structure because algal physiology (e.g., growth rates, nutrient uptake rates) and many ecological processes involving algae (e.g., sedimentation rates, grazing) are a function of cell size (Malone 1980, Reynolds 1984). Yang et al. (1997) observed longitudinal changes in phytoplankton size structure in the Rideau River where larger size classes (22-64 µm and >64 µm fractions) increased in proportion downstream. However, these size structure patterns may have reflected longitudinal increases in both residence time and ambient nutrient concentrations (Yang et al. 1997).

The size structure of suspended algae in rivers may also be related to the productivity of the system. For temperate lakes, smaller algae (nanoplankton <20-35 µm) typically dominate in oligotrophic waters while the relative contribution of larger algae increases with eutrophication (Kalff 1972, Malone 1980, Watson and Kalff 1981, Harris

1986). Photosynthetic picoplankton (<2.0 µm) can also represent an important component of the phytoplankton in oligotrophic lakes (Pick and Caron 1987). Shifts in size structure associated with nutrient enrichment may be the result of differences in the competitive abilities of various sized taxa under different nutrient regimes (Tilman et al. 1982) or may be due to changes in grazing pressure (Watson and McCauley 1988). Similar patterns could be expected in rivers where smaller algae dominate in oligotrophic systems and decrease in importance with eutrophication. However, to my knowledge, relationships between community size structure and trophic status have not been explored in rivers.

The objective of this study was to investigate the role of river size and nutrients in suspended algal development. I hypothesized that (1) suspended algal biomass is positively related to ambient nutrient concentration and water residence time, and (2) larger sized algae contribute a greater proportion to total biomass with increasing water residence time and trophy. I tested these hypotheses empirically by examining the biomass and size structure of suspended algae in rivers of different size and nutrient status.

Materials and Methods

Field sampling

A total of 46 rivers were sampled in Ontario and Quebec over a period of one month in June and July of 1998. River discharges and catchment areas ranged 5 orders of magnitude, and water residence times varied 2 orders (Table 2.1, Appendix 2a). Almost half of the rivers (n=21) were located in forested catchments on the Canadian Shield around Georgian Bay, Lake Nipissing, Lac St. Jean, and the Ottawa Valley. These systems were typically oligotrophic with total phosphorus and chlorophyll concentrations averaging 13 $\mu g \cdot L^{-1}$ and 3 $\mu g \cdot L^{-1}$respectively. The remaining rivers sampled (n=25) were located in partly forested or agricultural catchments in the Great Lakes/St. Lawrence lowlands of southern Ontario and southern Quebec. These systems were moderately to highly enriched with total phosphorus and chlorophyll concentrations averaging 48 $\mu g \cdot L^{-1}$ and 12 $\mu g \cdot L^{-1}$ respectively. Sampling locations were close to discharge gauging stations of the Water Survey of Canada (WSOC 1990) and were a minimum of 10 km downstream of the nearest lake or major tributary.

Water samples were obtained from each river site at 3 distances along a transect perpendicular to the shoreline (one-third, mid-channel, and two-thirds distances)(Basu and Pick 1996). Water samples were collected with a 5 m long integrated tube sampler except at shallow sites where water was collected as surface grab samples. Four water samples were collected in 4 L Nalgene bottles for suspended chlorophyll, one from each of the one-third and two-thirds distances and 2 from mid-channel. Three water samples were collected in 300 mL bottles for nutrient analyses, one from each of the one-third, mid-channel and two-thirds distances. Depth was determined at all 3 distances along the transect with a measurement rope and weight. Light attenuation in the water column was calculated by measuring irradiance (μmol photons$\cdot m^{-2} \cdot s^{-1}$) mid-channel at depth intervals of 0.25 or 0.5 m with a LiCor Photometer (model LI-185B). Water conductivity and temperature were measured with a YSI probe (model 33 S-C-T meter).

Measurement of total chlorophyll *a* and chlorophyll size fractions

Water samples were filtered for chlorophyll *a* (Chl *a*) on the same day of field collection. Total Chl *a* was estimated by filtering water through Poretics 0.2 μm polycarbonate membranes. To estimate Chl *a* in 4 size fractions, water was also filtered in parallel through 2.0 μm and 20 μm Poretics polycarbonate membranes and 64 μm Nitex mesh. Chl *a* in each size fraction was calculated as the difference in Chl *a* between filters of successively larger pore size (0.2-2.0 μm, 2.0-20 μm, 20-64 μm, >64 μm; Appendix 2b). This logarithmic size classification of microorganisms was proposed by Dussart (1965) and is now widely adopted by plankton ecologists (Malone 1980, Pick and Caron 1987). Chl *a* estimates were based on 4 water samples collected at each site. Vacuum pressure for filtration was maintained below 15 mm Hg to minimize cell breakage. Filtered Chl *a* samples were frozen at –25 °C for later processing. Chl *a* was extracted with DMSO and acetone (Burnison 1980), and concentrations were estimated with a Turner Designs fluorometer (American Public Health Association 1992).

Nutrient concentrations

Nutrient analyses were performed by the Regional Municipality of Ottawa Carleton, Surface Water Quality Laboratories using standard methods (Basu and Pick 1995). Water samples were analyzed for total phosphorus (TP), soluble reactive phosphorus (SRP), total Kjeldahl nitrogen (unfiltered), ammonia (NH_3), and nitrate-nitrite (NO_3-NO_2) (Appendix 2c). Total nitrogen (TN) was calculated as the sum of total Kjeldahl nitrogen and nitrate-nitrite.

Determination of discharge, catchment area, and water residence time

Estimates of mean daily discharge ($m^3 \cdot s^{-1}$) for each river were obtained from the following government agencies and private industries operating gauging stations close to sampling sites: Water Survey of Canada, Ontario Hydro, Hydro-Québec, Environment Canada, Environement Canada Québec, MQPC Maclaren, and Alcan. Gauging stations on 8 small rivers (discharge $<5\ m^3 \cdot s^{-1}$) were not operational so an estimate of discharge was obtained on the day of sampling by employing the velocity-area method (Herschy 1985). Discharge was computed by dividing a stream cross-section into a minimum of 12 cells of equivalent width and then measuring the average depth and average current velocity (with a hand-held Gurley current meter) in each cell (Appendix 2d). Mean daily discharge was not measured in 1998 for the South Nation and North Branch South Nation rivers and was estimated using the historical average for June (Water Survey of Canada 1990). Catchment areas were obtained from the Water Survey of Canada (1990) and were determined for the area upstream of the gauging station. The theoretical water residence time (WRT) for each river was calculated as a function of discharge (Q, $m^3 \cdot s^{-1}$) and catchment area (A_c, km^2) with the following equation: $WRT = 0.08 \cdot A_c^{0.6} \cdot Q^{-0.1}$ (Soballe and Kimmel 1987).

Size structure indices

The size structure of suspended algal communities was evaluated by examining size spectra and size classes. Size spectra are models of the distribution of community biomass in relation to organism size (Sheldon et al. 1972) and parameters of the models (slope, intercept) provide descriptors of community size structure (Sprules and Munawar

1986). Size spectra parameters can effectively identify differences in phytoplankton communities resulting from experimental stresses (Cottingham 1999). Size classes also provide a simple descriptor of size structure by dividing community biomass into 2 or more fractions based on organism size.

Size spectra of suspended Chl *a* were determined for each river site by plotting the proportion of Chl *a* retained on the filter against the logarithm of the filter size (Fig. 2.1., Appendix 2e)(Mazumder et al. 1988). The slope of the linear relationship between these two variables was used to characterize the size distribution of suspended Chl *a*. A decrease in the steepness of the regression slope indicated that larger algae contributed a greater proportion to total biomass of the community.

The biomass of suspended algae was estimated in 4 size classes (0.2-2.0 μm, 2.0-20 μm, 20-64 μm, >64 μm) by physical fractionation of Chl *a*. Measurements of size structure based on physical fractionation with filters can bias estimates because filters retain algae smaller than the official pore size (Malone et al. 1979). The use of Chl *a* as a measure of standing crop may further introduce bias because smaller cells tend to have higher chlorophyll per unit biomass (Malone et al. 1979, Malone 1980). To account for potential biases, Chl *a* fractionation data were compared with unpublished size structure data measured by microscope enumeration (Appendix 2f). Jing-Rong Yang enumerated duplicate Lugol's preserved samples of suspended algae collected in a previous survey of 31 Ontario and Quebec rivers (Basu and Pick 1996). Twenty-three of the rivers were also sampled in the present study. Suspended algae were enumerated following the Utermöhl method on a Wild M40 inverted microscope at 125x, 250x, and 500x magnifications. Cell dimensions were measured in each sample and cell volumes estimated by approximation to geometric shapes of known volume. Algal biomass ($\mu g \cdot L^{-1}$) was determined by converting calculated cell volumes to biomass assuming a specific density of unity. The biomass of each taxon was assigned to 1 of 3 size classes (2.0-20 μm, 20-64 μm, >64 μm) based on its mean greatest axial linear dimension (GALD).

Data analysis

Statistical analyses consisted of parametric correlations and regressions. Pearson correlation coefficients were calculated to examine relationships between physical and chemical variables and algal biomass. Correlations were performed by pairwise comparisons because of non-uniform sample sizes among variables (n=46 for all variables except temperature n=45, light attenuation coefficients n=42, ratio of euphotic depth:total depth n=42). Multiple regression models were developed to predict (1) total Chl *a* as a function of nutrient concentrations and WRT, (2) size spectra slopes as a function of total Chl *a* and WRT, and (3) the proportion of Chl *a* in each size class as a function of total Chl *a* and WRT. Variables were log transformed or arcsine transformed to satisfy the assumptions of the parametric test.

Results

Total Chl *a*

Of the 4 measured factors that can affect algal biomass (temperature, light availability, nutrients, WRT), suspended Chl *a* was most strongly correlated with ambient nutrient concentrations (Table 2.2). Chl *a* was positively correlated with TP, SRP, and TN concentrations ($r=0.60-0.66$, $p<0.001$) and to a lesser extent NO_3-NO_2 ($r=0.37$, $p<0.05$).

Suspended Chl *a* was less correlated with water temperature ($r=0.30$, $p<0.05$) and unrelated to WRT or light availability (estimated by the ratio of the euphotic depth to total depth; $Z_{eu}:Z_t$). The positive relationship between Chl *a* and light attenuation in the water column probably reflects the contribution of algal biomass to light absorption.

The ratio of TN:TP concentrations in the water was low in a few eutrophic rivers suggesting the possibility of nitrogen limitation. The mean TN:TP ratio was 37 (Table 2.1) indicating that on average phosphorus was more likely to be limiting than nitrogen. However, TN:TP ratios varied widely among rivers from 3-250, and ratios were <15 in 3 rivers (Little Castor, Thames, and Trent) and <20 in 11 rivers. TN:TP ratios decreased with increasing TP concentration ($r=-0.64$, $p<0.001$) but were not related to TN ($r=0.06$, $p=0.68$). The ratio of ambient concentrations of dissolved nitrogen (NO_3-NO_2 + NH_3):SRP was positively correlated with TN:TP ratios ($r=0.78$, $p<0.001$).

Suspended Chl *a* was positively related with water residence time (albeit weakly) after controlling for the effect of nutrient concentrations. Rivers with the shortest WRTs tended to contain less Chl *a* per unit TP than larger systems (Fig. 2.2). A multiple linear regression model predicting suspended Chl *a* as a function of TP, TN, and WRT revealed that WRT explained 7% of the variabilility in Chl *a* after accounting for the effect of nutrient concentrations (Table 2.3). WRT was not a significant predictor variable when TN concentration was excluded from the model ($p=0.109$). That TP and TN concentrations were both significant variables in the model may reflect the importance of varying ambient nitrogen to phosphorus ratios on algal biomass.

Size spectra

Size spectra models adequately described the size distribution of Chl *a*. A linear regression fit to the relationship between the proportion of Chl *a* retained on the filters and the logarithm of filter size explained the majority of the variance (r^2>0.90 for 75% of sites, $p<0.05$ for all sites). The size distribution of Chl *a* differed among rivers with regression slopes ranging from –0.212 to –0.500.

The size distribution of suspended Chl *a* was related to the trophic status and size of the river. Size spectra regression slopes were steeper in rivers with greater total Chl *a* (r^2=0.19, p=0.003) indicating that larger algae contributed less to total biomass in more productive waters (Fig. 2.3). Regression slopes were also related to WRT but a locally weighted smoothing technique (LOWESS) suggested that the relationship was non-linear (Fig. 2.3). This non-linear effect of WRT was approximated with a quadratic equation (r^2=0.14, p= 0.038). Regression slopes were steepest at intermediate WRTs indicating that larger algae contributed more to total biomass in the smallest and largest rivers. The Trent River was an outlier in the data set with a much shallower slope (-0.212) than other rivers (Fig. 2.3) probably because of the biomass contribution of a *Gloeotrichia* bloom, a the large colonial alga greater than 64 µm. When total Chl *a*, WRT, and WRT ^{2} were included in a multiple regression model as predictors of size spectra slope, total Chl *a* explained the most variance (partial r^2=0.19, p=0.019), and WRT and WRT ^{2} were only marginally correlated (partial r^2=0.06, $p<0.09$)

Size classes

Chl *a* fractionation estimates of the proportion of biomass in individual size classes were consistent with estimates based on microscope enumerations (Fig. 2.4). According to Chl *a* measurements, the majority of biomass was in the 0.2-2.0 μm and 2.0-20 μm size classes, representing on average 32% and 50% of total biomass. GALD measurements similarly indicated that the majority of biomass was in the 2.0-20 μm fraction (57%). Because picoplankton (0.2-2.0 μm) were not enumerated by microscope, percent Chl *a* in the 2.0-20 μm, 20-64 μm, and >64 μm size classes were recalculated using total Chl *a* >2.0 μm for direct comparison with GALD estimates (Fig. 2.4). Relative to the GALD data, Chl *a* measurements slightly overestimated the proportion of biomass in the 2.0-20 μm fraction and slightly underestimated biomass in the larger fractions.

The proportion of Chl *a* in individual size classes changed in relation to trophic status (Table 2.4). Higher total Chl *a* was primarily associated with greater biomass in the 2-20 μm fraction (Fig. 2.5). Proportions of Chl *a* in the 0.2-2.0 μm and >64 μm fractions decreased in importance in more productive waters and proportions in the 20-64 μm fraction were not related to total Chl *a* ($p=0.93$) (Table 2.4). These results suggest that the proportional shift in biomass towards smaller algae with increasing trophy observed by size spectra analysis (Fig. 2.3) was due to higher biomass in the 2.0-20 μm fraction. Relationships between the proportion of biomass in size classes and total biomass were not observed with GALD estimates ($p>0.05$).

The proportion of biomass in individual size classes was also related to river size (Table 2.4). Percent Chl *a* in the 0.2-2.0 μm fraction increased with WRT while percent Chl *a* in the 20-64 μm fraction decreased. Percent Chl *a* in the >64 μm fraction decreased with WRT in the smallest systems and then increased again in larger rivers (Fig. 2.6). This trend was approximated with a quadratic function (Table 2.4). The proportion of total Chl *a* in the 2.0-20 μm fraction was not related to WRT ($p=0.17$). Although the proportion of biomass in size classes was signficantly correlated with WRT, no consistent effect was observed (e.g.: the biomass of larger algae either increased or decreased in importance with increasing WRT). The contribution of larger algae (>64 μm) increased in rivers with the longest WRTs (Fig. 2.6) but this fraction still remained a minor component of suspended Chl *a* (<10%). However, greater increases in percent contribution were observed with GALD estimates of biomass >64 μm. The proportion of biomass >64 μm increased linearly with WRT by up to 20% ($r^2=0.25$, $p=0.004$, Fig. 2.6) while the proportion of 2.0-20 μm biomass decreased with WRT ($r^2=0.17$, $p=0.021$). The contribution of biomass in the 20-64 μm size class did not change with WRT ($p=0.64$).

Discussion

Although nutrients explained only half the variation in total biomass of suspended algae (Table 2.3), relative to other factors (temperature, light availability, water residence time), nutrient concentration was the best predictor variable. There are divergent views in the literature over the importance of physical and chemical processes for suspended algal development in rivers. Several ecologists studying large rivers have emphasized the role of physical factors in phytoplankton dynamics (discharge, light availability, water residence time) and have discounted nutrient limitation because of high nutrient concentrations observed in many rivers (Descy 1987, Reynolds and Descy 1996, Wehr and Descy 1998). A contradictory view is supported by a strong positive relation between algal chlorophyll and nutrients in a wide range of rivers (Basu and Pick 1996, Van Nieuwenhuyse and Jones 1996). This study supports the latter view that nutrients are a key regulator of algal biomass but in a sense, the debate represents a lack of integration between community and ecosystem level approaches. Ecological processes are scale dependent (Harris 1980), and therefore the relative importance of physical and chemical factors will also depend on the temporal and spatial scale of interest. Large-scale comparative studies indicate that the average biomass observed in a river is primarily related to nutrients. Furthermore, nutrient-enriched rivers tend to have higher algal biomass irrespective of whether retention times are short or light conditions are limiting (Basu and Pick 1996, Van Nieuwenhuyse and Jones 1996, present study) perhaps because of inoccula from other environments. Systems with short water residence times approaching cell division rates can develop high suspended biomass because nutrient enrichment stimulates periphyton biomass (Lohman et al. 1992, Chételat et al. 1999) which then detaches from the riverbed. Large turbid rivers with light-limiting conditions such as the lower Hudson can also still develop high biomass (>50 µg Chl $a{\cdot}L^{-1}$) probably because of algal inputs from upstream reaches and shallow backbays (Cole et al. 1992). Clearly, suspended algal development cannot be reduced to nutrient-biomass relationships because physical factors (discharge, temperature, light) determine seasonal and longitudinal variation of standing crops (Reynolds and Descy 1996). However, an overemphasis in the literature of the importance of physical processes has lead to the claims that nutrient-biomass relationships do not apply to rivers and have little value in river management and that eutrophication may arise from increased light transparency in the water column (Wehr and Descy 1998). Nutrient-biomass relationships may poorly predict seasonal or longitudinal variation but published models strongly suggest that nutrient loading should be the primary focus to reduce eutrophication in rivers.

Water residence time is a weak predictor of suspended algal biomass. Only 7% of the variation in suspended Chl *a* was explained by WRT even though the study rivers ranged 2 orders of magnitude from 1-39 days. Similarly, Van Nieuwenhuyse and Jones (1996) found that catchment area (a geomorphic variable reflecting the flushing rate of the system) explained only 6% of the variation in suspended Chl *a* among 116 temperate rivers when the effect of TP concentration was controlled for. Lohman and Jones (1999) found that catchment area explained a greater amount of Chl *a* variance (12-14%) in northern Ozark streams while Basu and Pick (1996) observed no effect of residence time on algal biomass in medium sized rivers (WRT=3-19 days). The weak relationship between suspended algal biomass and WRT is counter-intuitive considering biomass tends to increase as a water parcel ages downstream and flushing rates in small rivers are rapid relative to algal growth rates. But the hypothesis that suspended algal biomass increases with WRT assumes that planktonic algae consist of a single community developing as it flows downstream. This assumption has come into question because algal populations increase and decrease along the length of a river suggesting that community composition is affected by local factors (e.g., depth, velocity) and local populations in dead zones (Reynolds and Glaister 1993). Therefore the size of a river may poorly reflect time constraints for algal growth along its watercourse if dead zones contribute substantially to the main channel community. The WRT of a river has a minor effect on suspended algal biomass which is probably only relevant when comparing systems of very different size.

The size structure patterns observed in rivers contradict present theory of trophic effects on phytoplankton in lakes. Smaller algae (nanoplankton <20-35 µm) tend to decrease in importance with lake eutrophication as larger non-edible algae become more abundant (Malone 1980, Watson and Kalff 1981, Harris 1986). In contrast, this study suggests that larger algae (20-64 µm, >64 µm) generally do not contribute a greater proportion to total biomass in more eutrophic rivers. Smaller algae actually increased in importance in eutrophic rivers according to Chl *a* estimates of standing crop but this pattern was not observed with GALD estimates. Suspended algal communities in productive rivers are often dominated by small centric diatoms (e.g., *Cyclotella*, *Stephanodiscus*) with maximum linear dimensions less than 20-25 µm (Rojo et al 1994, Reynolds and Descy 1996). Although large colonial cyanobacteria can develop in eutrophic rivers (Ha et al. 1998, Train and Rodrigues 1998), these blooms are not common and tend to occur for only short periods of time in the summer (Wehr and Descy 1998). In one of the few river studies examining seasonal changes in phytoplankton size structure, Gosselain et al. (1998b) found that algae <20 µm dominated the community throughout most of the summer in the eutrophic River Meuse.

The difference in trophic patterns between lakes and rivers may be related to the physical environment or zooplankton grazing. Short water residence times, low light conditions, and shallow depths in rivers likely favour smaller cells with faster growth rates, greater photosynthetic efficiency, and lower sedimentation rates (Reynolds and Descy 1996). Lower proportions of nanoplankton (<20-35 µm) in eutrophic lakes have been attributed to increased zooplankton grazing on small edible algae which favours larger taxa (Watson and McCauley 1988, Cottingham 1999), and alternatively, the lack of dominance of large algae in eutrophic rivers could be attributed to low grazing pressure. Downstream flow limits zooplankton growth and rivers typically have lower zooplankton biomass than lakes (Pace et al. 1992, Basu and Pick 1996). Zooplankton grazing may occasionally have a significant impact on the size structure of suspended algae in large rivers but only over brief periods during summer low flows (Gosselain et al. 1998a).

Large-sized algae contributed a greater proportion to community biomass in larger rivers. The proportion of algal biomass >64 µm estimated by GALD measurements increased with WRT (3-19 days) primarily due to greater abundance of colonial taxa (*Asterionella formosa*, *Aulacoseira* sp., *Dinobryon* sp., *Fragilaria crotonensis*, *Tabellaria* sp.) but also large unicells (*Synedra ulna*). Large colonial phytoplankton have slow growth rates which may prevent these taxa from developing in small rivers with short retention times. However since suspended algal biomass was weakly related to WRT, increased biomass of colonial taxa may be more due to other physical characteristics associated with large rivers (depth, vertical mixing patterns). Sedimentation rates increase with cell size, and large colonial taxa may be restricted to deeper waters of large rivers. The proportion of Chl *a* in size classes was examined over a wider range of WRTs than GALD measurements (1-39 days) and the contribution of Chl *a* >64 µm was greatest in the largest and smallest rivers. Suspended algae in the smallest systems (WRT<3 days) were largely of benthic or epiphytic origin consisting of pennate diatoms such as *Achnanthes*, *Navicula*, *Cocconeis*, *Cymbella*, *Amphora*, *Gomphonema*, and *Synedra* and the chlorophytes *Spirogyra*, *Mougeotia*, and *Scenedesmus*. The contribution of Chl *a* >64 µm in these small rivers was often due to *Synedra* and filaments of *Spirogyra* and *Mougeotia*.

Patterns of size structure of suspended algae varied somewhat depending on the method used to estimate algal standing crop. The proportion of biomass in size classes estimated by GALD measurements were not related to the total biomass of the community (in contrast with significant relationships for Chl *a* estimates) perhaps because community biomass <2.0 μm was excluded. Chl *a* in the 0.2-2.0 μm size class contributed on average 32% to total biomass and decreased in importance in more productive waters. Percent biomass >64 μm estimated by GALD measurements increased more with WRT than percent Chl *a* >64 μm probably also because biomass <2.0 μm was not included. Furthermore, chlorophyll fractionation tended to underestimate biomass in the larger size classes (20-64 μm, >64 μm) perhaps because chlorophyll to biomass ratios are lower in larger cells (Malone 1980). Size class estimates based on filtration may be more representative of average sizes rather than the greatest axial linear dimension. However, despite these differences, both methods suggest that smaller algae dominate community biomass even in productive waters and that larger algae increase in importance in larger rivers.

Unexplained variation in total Chl *a* among rivers may be related to zebra mussel grazing or discharge conditions prior to sampling. Several rivers examined in this study are canal systems (Otonabee, Richelieu, Rideau, Trent) which are known to support substantial zebra mussel populations (Francine McDonald, Ontario Federation of Anglers and Hunters, personal communication; Yves de Lafontaine, Centre St. Laurent, personal communication). Suspended algal biomass in these rivers was surprisingly low (<3 μg Chl $a\cdot L^{-1}$) considering water column nutrient concentrations (18-42 μg $TP\cdot L^{-1}$) as well as biomass measured in previous years (Basu and Pick 1996, unpublished data). These observations suggest that zebra mussel grazing may have impacted algal biomass in these systems. Fluctuations in river discharge also affect suspended algae (Jones 1984) and increases in discharge a few days prior to sampling may have reduced observed biomass.

Patterns of size structure in relation to trophic status and water residence time were weak suggesting that, not surprisingly, other factors affect community structure. Empirical studies examining phytoplankton size structure in lakes have also found significant but weak relationships between algal biomass in size fractions and trophic variables (r^2=0.18-0.46; Watson and Kalff 1981, Paloheimo and Zimmerman 1983, Watson and McCauley 1988). I examined relationships between algal size structure and large-scale river characteristics but recent evidence suggests that community structure may also be determined by local physical conditions at a river site (Reynolds and Glaister 1993, Shermann et al. 1998). Even in larger rivers where suspended algae are predominantly planktonic forms, up to 30% of diatom biomass (Yang et al. 1997) or up to 30% of algal taxa (Hamilton and Duthie 1987) can be benthic and epiphytic. Sedimentation of mainchannel populations and local inputs of algae from deadzones, weedbeds, and benthos may represent important processes determining community structure.

In conclusion, suspended algal biomass was most strongly related to nutrient concentration and weakly related to river size. Communities were dominated by smaller taxa <20 μm, and larger algae did not contribute a greater proportion to total biomass in eutrophic rivers. The size structure of suspended algae varied in relation to river size, and larger algae contributed a greater proportion to total biomass in systems with longer water residence times.

Table 2.1 Medians and ranges of river size parameters, water temperature, light conditions (Z_{eu}=euphotic depth at 1% of surface irradiance, Z_t=total depth), water conductivity, nutrient concentrations, and suspended Chl *a* measured in 46 rivers in Ontario and Quebec.

Variable	**Median**	**Range**
Discharge ($m^3 \cdot s^{-1}$)	8.9	0.1-1143
Catchment area (km^2)	2395	45-90900
Depth (m)	2.1	0.2-23
WRT (days)	7	1-39
Temperature (°C)	22	18-28
Light attenuation coefficient (m^{-1})	1.5	0.6-6.1
Z_{eu}:Z_t	1.4	0.1-32.9
Conductivity ($\mu S \cdot cm^{-1}$)	210	21-1354
TP ($\mu g \cdot L^{-1}$)	18	5-280
SRP ($\mu g \cdot L^{-1}$)	6	2-157
TN ($\mu g \cdot L^{-1}$)	541	203-6633
NO_3-NO_2 ($\mu g \cdot L^{-1}$)	81	3-5400
TN:TP	29	3-257
Chl *a* ($\mu g \cdot L^{-1}$)	2.5	1.4-133.1

Table 2.2 Pearson correlation coefficients for pairwise comparisons of physical variables (catchment area, discharge, depth, WRT), water temperature, light attenuation coefficients (LA), ratio of euphotic depth:total depth (Z_{eu}:Z_t), water conductivity, TP, SRP, TN and NO_3-NO_2 concentrations, ratio of TN:TP, and suspended Chl *a* among rivers (n=41-46). All variables were log transformed. *p<0.05, **p<0.01, ***p<0.001

	Catchment	Discharge	Depth	WRT	Temp	LA	Z_{eu}:Z_t	Cond	TP	SRP	TN	NO_3-NO_2	TN:TP
Discharge	0.953***												
Depth	0.830***	0.813***											
WRT	0.997***	0.925***	0.821***										
Temp	-0.261	-0.366*	-0.368*	-0.229									
LA	-0.253	-0.291	-0.301	-0.239	-0.058								
Z_{eu}:Z_t	-0.701***	-0.658***	-0.856***	-0.702***	0.357*	-0.233							
Cond	-0.618***	-0.657***	-0.661***	-0.597***	0.508***	0.201	0.561***						
TP	-0.412**	-0.498***	-0.504***	-0.383**	0.323*	0.276	0.482**	0.718***					
SRP	-0.399**	-0.468**	-0.462**	-0.374*	0.286	0.188	0.491***	0.686***	0.952***				
TN	-0.506***	-0.576***	-0.559***	-0.479***	0.367*	0.376*	0.339*	0.793***	0.730***	0.651***			
NO_3-NO_2	-0.230	-0.256	-0.236	-0.219	0.076	0.282	0.006	0.502***	0.367*	0.301*	0.784***		
TN:TP	0.030	0.076	0.105	0.018	-0.060	0.001	-0.387*	-0.153	-0.636***	-0.656***	0.063	0.349*	
Chl *a*	-0.129	-0.287	-0.253	-0.085	0.295*	0.559***	-0.010	0.520***	0.661***	0.598***	0.640***	0.369*	-0.242

Table 2.3 Summary of multiple regression model predicting log suspended Chl *a* (µg·L^{-1}) as a function of log TP concentration (µg·L^{-1}), log TN concentration (µg·L^{-1}), and log WRT (days)(n=46).

Independent Variable	**Coefficient**	**Standard Error**	**p**	**Partial R^2**	**R^2**	**Residual Variance**
log TP	0.437	0.150	0.006	0.44	0.56	0.077
log TN	0.609	0.205	0.005	0.05		
log WRT	0.283	0.108	0.012	0.07		
intercept	-1.895	0.498	<0.001			

Table 2.4 Summary of regression models predicting the proportion of suspended Chl *a* (arcsine transformed) in 4 size classes as a function of log total Chl *a* (µg·L^{-1}) and log WRT (days). *$p<0.05$, **$p<0.01$, ***$p<0.001$

Size Class	**log Chl *a***	**log WRT**	**log WRT ^{2}**	**Intercept**	**Model p**	**Model r^2**
0.2-2.0 µm	-0.224**	0.171**		0.577***	<0.001	0.32
2.0-20 µm	0.221***			0.659***	<0.001	0.31
20-64 µm		-0.114**		0.455***	0.001	0.21
>64 µm	-0.109*	-0.299*	0.188*	0.331***	0.001	0.31

Figure 2.1 Method used to estimate the size distribution of Chl *a* by measuring the slope of the linear relationship between the proportion of Chl *a* retained on the filter and the logarithm of the filter size. The slope is steeper for suspended algae in the Grand River (open circles; slope ± SE = -0.437 ± 0.031) than in the Saguenay River (closed circles; slope ± SE = -0.339 ± 0.011) indicating that smaller algae contribute a greater proportion to total biomass in the Grand. Four replicates were measured for each filter size.

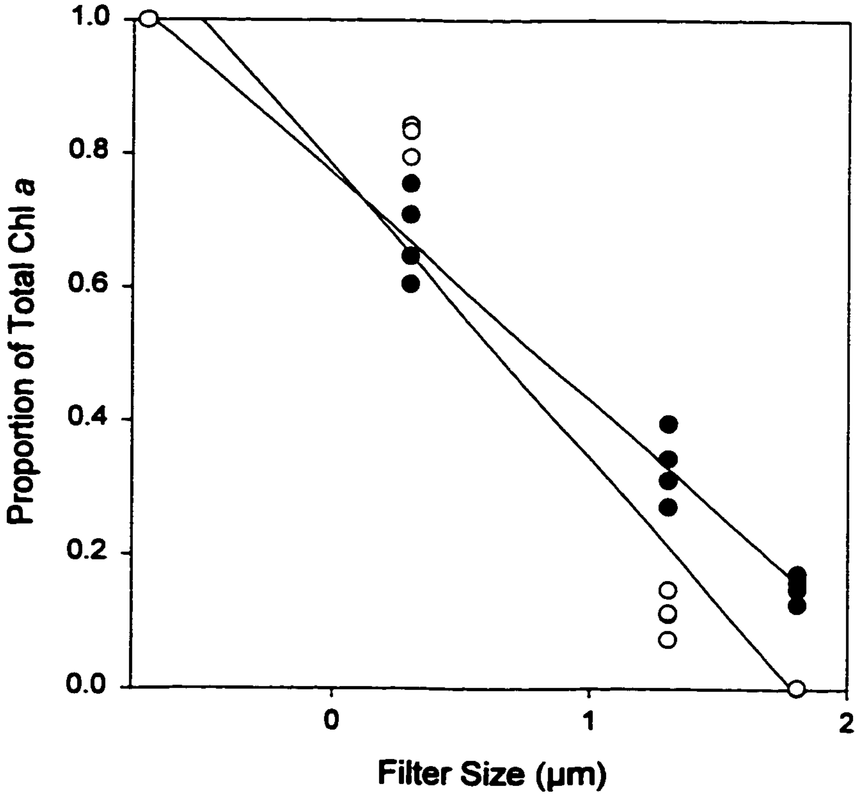

1.0
0.8
0.6
0.4
0.2
0.0
Proportion of Total Chl *a*
0
1
2
Filter Size (µm)

Figure 2.2 Relationship between suspended Chl *a* and TP concentration in 46 rivers in Ontario and Quebec ($r^2=0.44$, $p<0.001$). Rivers are divided according to size by WRT less than 3 days (open circles) and greater than 3 days (filled circles).

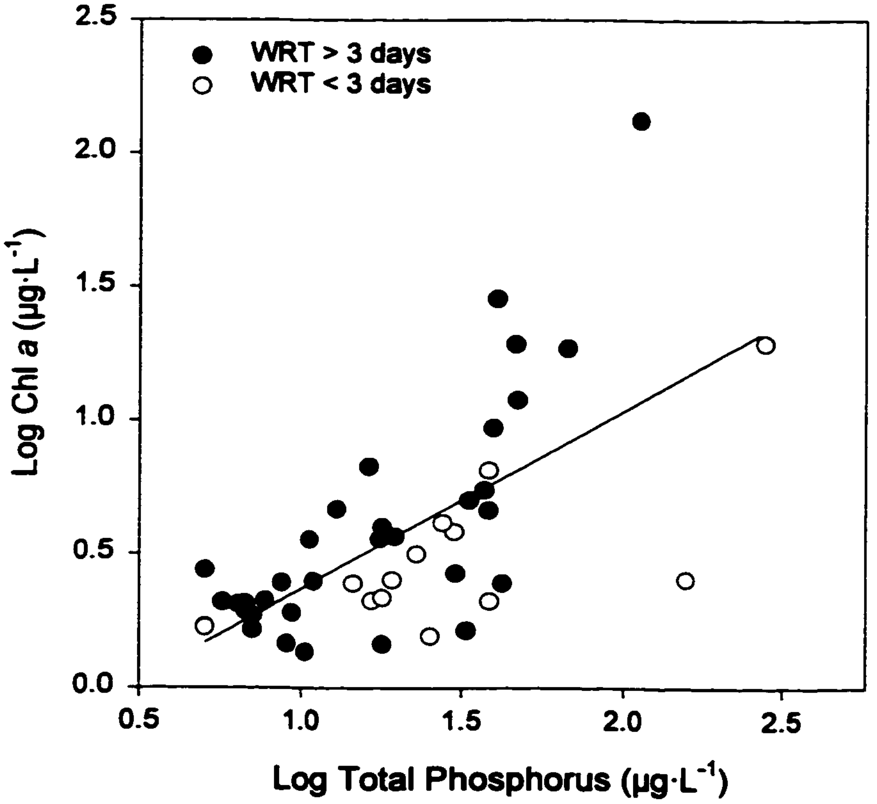
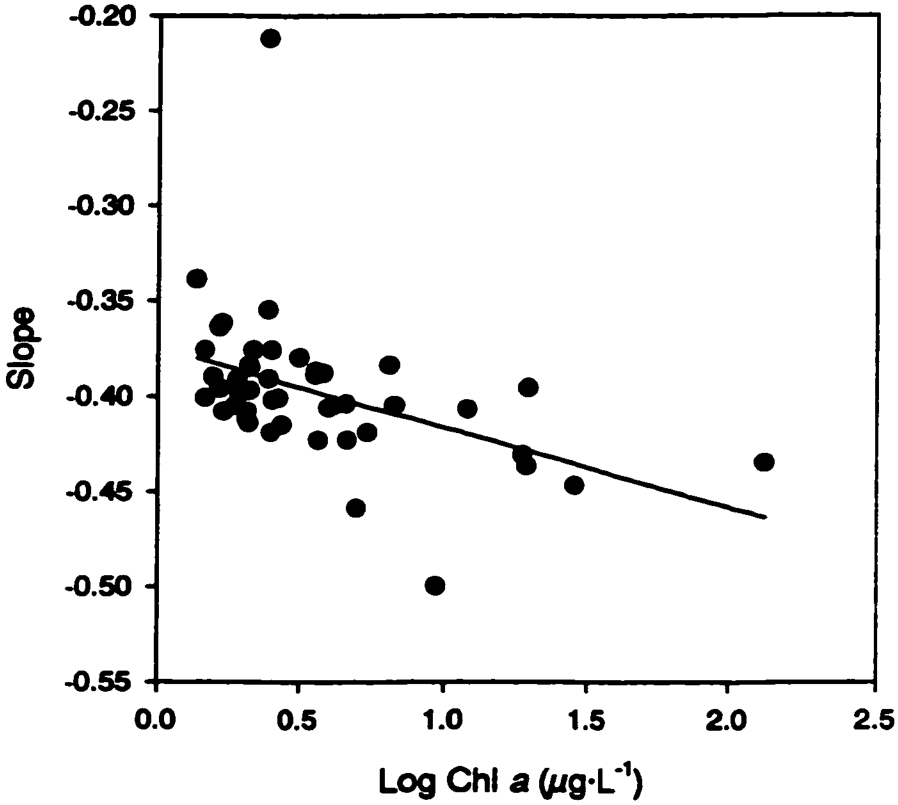
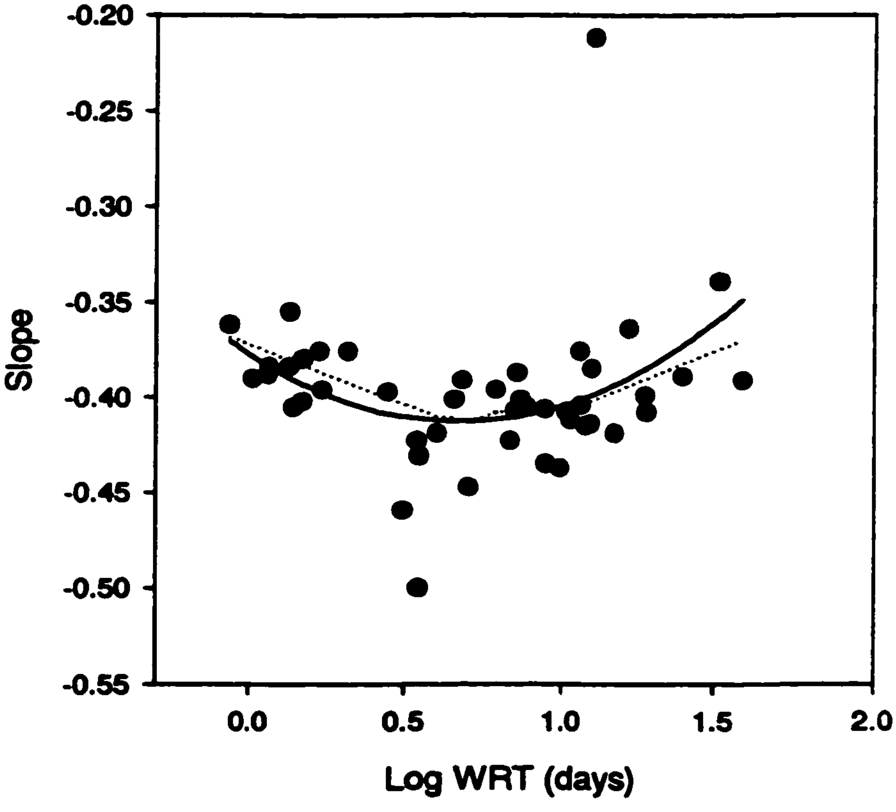

● WRT > 3 days
○ WRT < 3 days
2.5
2.0
1.5
1.0
0.5
0.0
Log Chl a (µg·L-1)
0.5
1.0
1.5
2.0
2.5
Log Total Phosphorus (µg·L-1)

Figure 2.3 Shifts in the size distribution of Chl *a* in relation to total Chl *a* (r^2=0.19, p=0.003) and WRT (r^2=0.14, p= 0.038). The size distribution of Chl *a* was estimated for suspended algae in each river (n=46) with linear size spectra slopes. A locally weighted sequential smoothing technique (LOWESS) provided a model-free assessment of the non-linear trend (dotted line) which was subsequently approximated with a quadratic model (solid line).



-0.20
-0.25
-0.30
-0.35
-0.40
-0.45
-0.50
-0.55
Slope
0.0
0.5
1.0
1.5
2.0
2.5
Log Chl *a* (μg·L-1)



-0.20
-0.25
-0.30
-0.35
-0.40
-0.45
-0.50
-0.55
Slope
0.0
0.5
1.0
1.5
2.0
Log WRT (days)

Figure 2.4 **Comparison of percent contributions of biomass in 4 size classes based on Chl *a* fractionation (n=46) and greatest axial linear dimension (GALD) measurements (n=31). Percent Chl *a* in each size class was calculated using total Chl *a* >0.2 µm and >2.0 µm because biomass in the 0.2-2.0 µm size class was not estimated by microscope enumeration. Estimates include the standard error.**

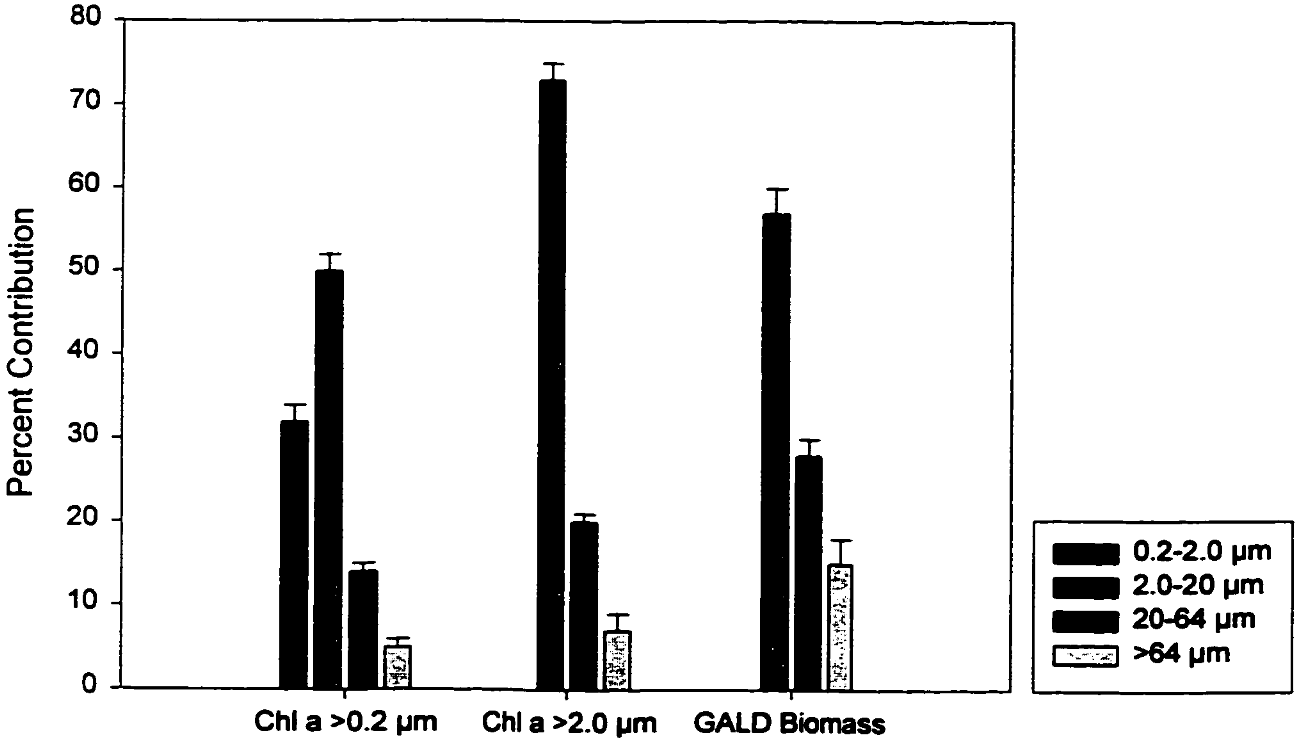

80
70
60
50
40
30
20
10
0
Percent Contribution
Chl a >0.2 µm
Chl a >2.0 µm
GALD Biomass
0.2-2.0 µm
2.0-20 µm
20-64 µm
>64 µm

Figure 2.5 Relationship between the proportion of suspended Chl *a* in the 2.0-20 μm size class and total Chl *a* in 46 rivers in Ontario and Quebec.

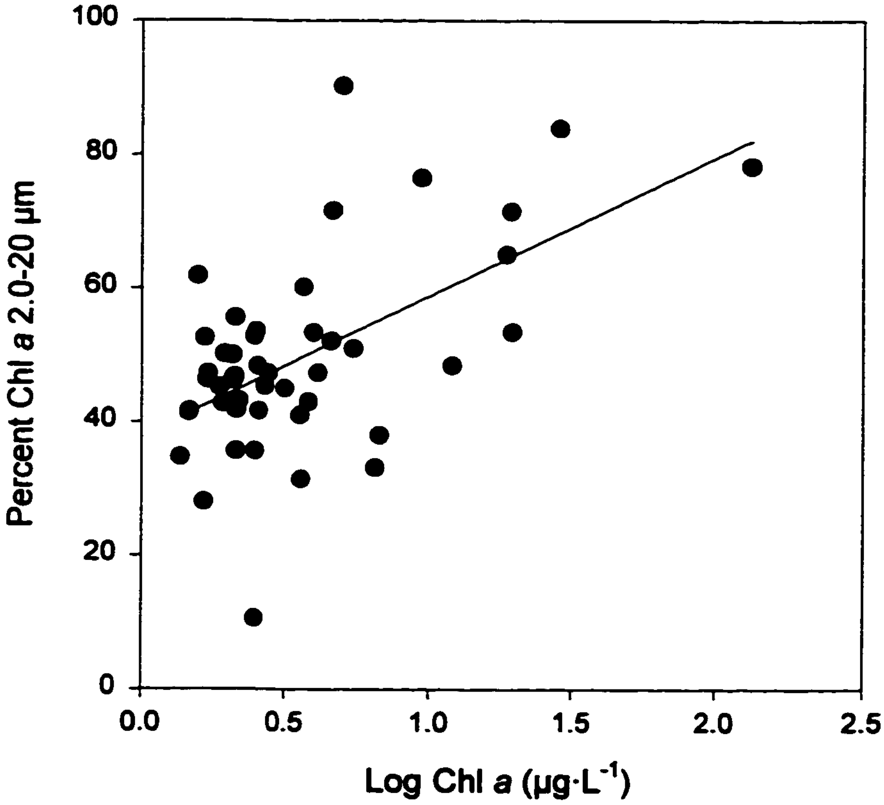
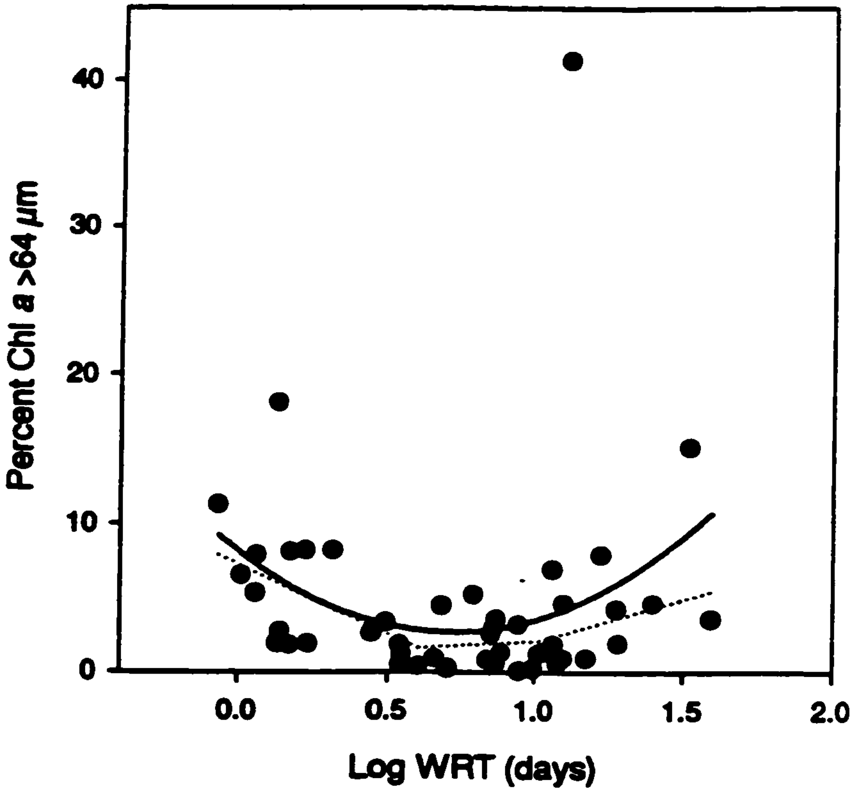
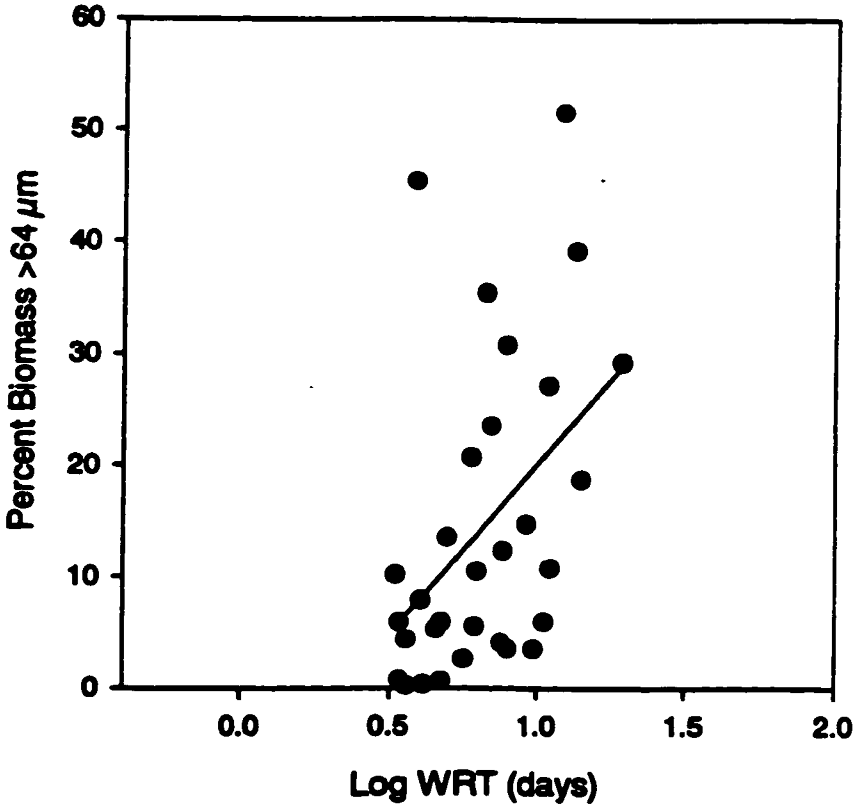

Percent Chl *a* 2.0-20 µm
0
20
40
60
80
100
0.0
0.5
1.0
1.5
2.0
2.5
Log Chl *a* (µg·L⁻¹)

Figure 2.6 Relationship between WRT and the proportion of suspended algal biomass in the >64 µm size class estimated by Chl *a* fractionation (n=46) and microscope enumeration (n=31). A locally weighted sequential smoothing technique (LOWESS) provided a model-free assessment of the non-linear trend (dotted line) which was subsequently approximated with a quadratic model (solid line).


Percent Chl a >64 μm
40
30
20
10
0
0.0
0.5
1.0
1.5
2.0
Log WRT (days)


Percent Biomass >64 μm
60
50
40
30
20
10
0
0.0
0.5
1.0
1.5
2.0
Log WRT (days)

Summary and Conclusions

Contrary to theoretical predictions, suspended algal development was only weakly controlled by river size. Seasonal variability in algal abundance was primarily related to the productivity of the water even the variability of discharge was strongly related to river size. Suspended algal biomass was positively related to nutrient concentration and to a lesser extent river size. Small-sized algae dominated community biomass although larger taxa contributed a greater proportion to total biomass in rivers with longer water residence times. River size weakly predicted the seasonal variability and biomass of suspended algae explaining less than 10% of the variation. Community structure was related more to river size although water residence time still only explained up to 25% of the variation.

In contrast, trophic variables were more strongly related to suspended algal development. Total phosphorus and total nitrogen concentrations together explained 49% of the variation in suspended algal biomass. Seasonal variability in algal abundance was primarily related to the productivity of the water measured as mean abundance (r^2=0.93). Total biomass explained a similar amount of the variation in community structure as water residence time (up to 31%). Lotic ecosystem theory focuses largely on physical characteristics as determinants of ecosystem structure (Vannote et al. 1980, Minshall 1988, Resh et al. 1988, Poff and Ward 1989) but, at least with respect to suspended algae, empirical models do not support this theoretical emphasis because trophic status (measured as nutrient concentration or algal biomass) is a more important large-scale determinant of suspended algal development than river geomorphology.

There are several topics stemming from this thesis which may warrant further research. First, the importance of discharge regime as a large-scale determinant of seasonal variance in suspended algal abundance was rejected suggesting that, at least for temperate rivers, empirical models of biomass phenology may be fruitful. Models of phytoplankton succession and seasonal development have been published for lakes (Sommer et al. 1986, Marshall and Peters 1989) but no general empirical models exist for rivers. Admittedly, differences in hydrological regimes could affect the timing of biomass maxima but high discharge events are usually of short duration relative to the growing season (except for the spring flood period which is common to most temperate rivers). An investigation of the generality of spring blooms and possible late summer maxima (Garnier et al. 1995) could lead to temporal models that compliment existing empirical models predicting average biomass in rivers. Second, river size affects the community structure of suspended algae and in the smallest rivers, phytoplankton populations do not develop in the water column. Despite all the debate over whether rivers support 'true' potamoplankton communities, little empirical data exists describing how large a river must be for potamoplankton to develop (e.g.: where contributions of benthic and epiphytic algae to the plankton are minimal). A model predicting the relative contribution of benthic and planktonic taxa to community biomass in relation to river size or other geomorphic variables would help to shed light on the origin of suspended communities.

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Appendix 1a: Drainage basin characteristics of NASQAN water quality monitoring stations examined for seasonal variability of discharge, water chemistry, and suspended algal abundance.

Station #	River	Regional Drainage Basin Code	Year	Drainage Area (km^2)	% Crop Land	% Forest Land
1015000	ST. JOHN RIVER	1	1978	21171	7.38	82.04
1017100	AROOSTOOK RIVER	1	1978	5032	7.17	81.51
1021050	ST. CROIX RIVER	1	1978	3768	1.56	81.07
1034500	PENOBSCOT RIVER	1	1978	16633	2.2	85.42
1046500	KENNEBEC RIVER	1	1978	7032	3.19	87.69
1059400	ANDROSCOGGIN RIVER	1	1978	8894	5.09	76.88
1066000	SACO RIVER	1	1978	3349	2.01	67.11
1096550	MERRIMACK RIVER	1	1978	10101	3.73	65.45
1103500	CHARLES RIVER	1	1978	474	1.1	30.77
1118500	PAWCATUCK RIVER	1	1978	764	3.78	60.54
1122610	SHETUCKET RIVER	1	1978	1057	7.35	66.42
1127000	QUINEBAUG RIVER	1	1978	1847	5.39	67.51
1184000	CONNECTICUT RIVER	1	1978	25019	6.08	71.74
1205500	HOUSATONIC RIVER	1	1978	3999	5.96	64.39
4296000	BLACK RIVER	1	1978	316	8.82	74.51
4024430	NEMADJI RIVER	4	1978	1088	9.23	70.55
4027595	BAD RIVER	4	1978	2512	1.46	64.81
4040000	ONTONAGON RIVER	4	1978	3471	4.98	54.36
4045500	TAHQUAMENON RIVER	4	1978	2046	2.88	75.96
4057004	MANISTIQUE RIVER	4	1978	3743	1.3	45.99
4059000	ESCANABA RIVER	4	1978	2253	0.46	74.33
4059500	FORD RIVER	4	1978	1166	8.65	71.51
4085000	FOX RIVER	4	1978	15670	37.61	29.63
4087000	MILWAUKEE RIVER	4	1978	1803	47.98	16.52
4108690	KALAMAZOO RIVER	4	1978	5232	47.04	24.74
4122030	MUSKEGON RIVER	4	1978	6268	15.39	51.81
4126520	MANISTEE RIVER	4	1978	4994	5.2	56.85
4132052	CHEBOYGAN RIVER	4	1978	3885	12.61	61.23
4137500	AU SABLE RIVER	4	1978	3989	5.58	56.56
4142000	RIFLE RIVER	4	1978	829	19.75	53.18
4165500	CLINTON RIVER	4	1978	1901	20.21	6.11
4176500	RIVER RAISIN	4	1978	2699	65.63	7.07
4193500	MAUMEE RIVER	4	1978	16395	77.04	7.48
4198000	SANDUSKY RIVER	4	1978	3240	80.62	6.83
4208000	CUYAHOGA RIVER	4	1978	1831	18.28	25.94
4212200	GRAND RIVER	4	1978	1816	29.54	41.6
4213500	CATTARAUGUS CREEK	4	1978	1129	22.87	48.99
4217000	TONAWANDA CREEK	4	1978	443	43.68	28.74
4232006	GENESEE RIVER	4	1978	6364	31.61	39.61
4249000	OSWEGO RIVER	4	1978	13209	33.92	34.63
4250750	SANDY CREEK	4	1978	332	20	39.2
4260500	BLACK RIVER	4	1978	4828	10.98	69.36
4263000	OSWEGATCHIE RIVER	4	1978	2499	13.63	63.85
4264331	ST. LAWRENCE RIVER	4	1978	773892	30.35	37.04
4269000	ST. REGIS RIVER	4	1978	1585	9.79	69.02

Station #	River	Regional Drainage Basin Code	Year	Drainage Area (km^2)	% Crop Land	% Forest Land
1304500	PECONIC RIVER	2	1978	194	6.25	18.75
1358000	HUDSON RIVER	2	1978	20953	12.13	66.84
1404100	RARITAN RIVER	2	1978	2233	21.12	32.34
1408500	TOMS RIVER	2	1978	319	1.91	47.77
1409815	WB WADING RIVER	2	1978	223	6.98	51.16
1463500	DELAWARE RIVER	2	1978	17560	12.39	60.43
1474500	SCHUYLKILL RIVER	2	1978	4903	28.42	32.53
1491000	CHOPTANK RIVER	2	1978	293	47.22	28.7
1540500	SUSQUEHANNA RIVER	2	1978	29060	21.49	51.43
1553500	WB SUSQUEHANNA RIVER	2	1978	17734	15.11	70.72
1570500	SUSQUEHANNA RIVER	2	1978	62419	20.49	58.29
1594440	PATUXENT RIVER	2	1978	901	17.16	25.47
1668000	RAPPAHANNOCK RIVER	2	1978	4134	17.64	43.94
1673000	PAMUNKEY RIVER	2	1978	2800	14.19	65.83
2035000	JAMES RIVER	2	1978	16206	8.19	54.77
2041650	APPOMATTOX RIVER	2	1978	3481	12.25	66.99
3049625	ALLEGHENY RIVER	5	1978	29785	15.08	56.91
3085000	MONONGAHELA RIVER	5	1978	19003	10.19	58.98
3107500	BEAVER RIVER	5	1978	8045	26.31	33.23
3150000	MUSKINGUM RIVER	5	1978	19223	34.06	32.43
3155000	LITTLE KANAWHA RIVER	5	1978	3924	5.91	74.24
3159510	HOCKING RIVER	5	1978	2479	20.7	41.08
3201300	KANAWHA RIVER	5	1978	30585	5.62	63.89
3204000	GUYANDOTTE RIVER	5	1978	3170	1.43	86.33
3215000	BIG SANDY RIVER	5	1978	10093	1.11	78.91
3216600	OHIO RIVER	5	1978	160580	13.71	56.42
3234500	SCIOTO RIVER	5	1978	13289	68.94	8.05
3245500	L MIAMI RIVER	5	1978	3116	60.54	8.28
3254000	LICKING RIVER	5	1978	8767	14.84	38.64
3274600	G MIAMI RIVER	5	1978	9878	63.69	10.11
3276500	WHITEWATER RIVER	5	1978	3170	58.08	19.74
3277200	OHIO RIVER	5	1978	215410	21.68	48.32
3290500	KENTUCKY RIVER	5	1978	16006	9.58	49.07
3301630	ROLLING FORK	5	1978	3561	29.09	19.83
3303280	OHIO RIVER	5	1978	251230	21.39	46.69
3321230	GREEN RIVER	5	1978	21896	28.44	30.69
3374100	WHITE RIVER	5	1978	29280	52.93	20.31
3378500	WABASH RIVER	5	1978	75716	66.53	13.79
3381500	LITTLE WABASH RIVER	5	1978	8034	74.21	10.32
3425000	CUMBERLAND RIVER	5	1978	27687	11.5	52.4
3609750	TENNESSEE RIVER	5	1978	104455	13.17	47.26
3612500	OHIO RIVER	5	1978	526029	27.67	39.95
3438220	CUMBERLAND RIVER	6	1978	45579	17.42	44.26
3470500	FRENCH BROAD RIVER	6	1978	13212	8.6	39.5
3495500	HOLSTON RIVER	6	1978	9705	7.87	38.73
3543005	TENNESSEE RIVER	6	1978	44833	7.39	44.39
3571850	TENNESSEE RIVER	6	1978	58638	6.96	46.38

Station #	River	Regional Drainage Basin Code	Year	Drainage Area (km^2)	% Crop Land	% Forest Land
3593005	TENNESSEE RIVER	6	1978	85004	12.25	45.98
5330000	MINNESOTA RIVER	7	1978	41958	78.41	1.81
5331570	MISSISSIPPI RIVER	7	1978	95830	51.73	18.33
5340500	ST. CROIX RIVER	7	1978	16162	12.37	56.05
5369500	CHIPPEWA RIVER	7	1978	23336	26.56	45.99
5407000	WISCONSIN RIVER	7	1978	26936	28.53	44.18
5446500	ROCK RIVER	7	1978	24732	65.51	6.68
5465500	IOWA RIVER	7	1978	32372	81.29	3.35
5508000	SALT RIVER	7	1978	6423	53.39	12.45
5543500	ILLINOIS RIVER	7	1978	21391	63.88	4.74
5583000	SANGAMON RIVER	7	1978	13191	86.01	2.32
5586100	ILLINOIS RIVER	7	1978	69264	71.62	5.74
5594100	KASKASKIA RIVER	7	1978	11378	75.25	10.11
5599500	BIG MUDDY RIVER	7	1978	5618	49.86	17.4
7019000	MERAMEC RIVER	7	1978	9811	9.55	47.79
7022000	MISSISSIPPI RIVER	7	1978	1847188	39.33	7.24

Headwater Streams (no water quality data available)

Station #	River	Regional Drainage Basin Code	Year	Drainage Area (km^2)	% Crop Land	% Forest Land
1466500	MCDONALDS BRANCH	2	1978	5		
1545600	YOUNG WOMANS CREEK	2	1978	119		
2038850	HOLIDAY CREEK	2	1978	23		
3237280	UPPER TWIN CREEK	5	1978	31		
3276700	SOUTH HOGAN CREEK	5	1978	98		
4001000	WASHINGTON CREEK	4	1978	34		

Appendix 1b: Means and variances of water conductivity, pH, suspended sediment, and suspended algal abundance measured on 5-6 sampling dates between May to October of 1978.

Station #	Cond. (µS/cm)	Variance Cond.	PH	Variance PH	Sus. Sed. (mg/L)	Variance Sus. Sed.	Algal Abu. (cells/mL)	Variance Algal Abu.
1015000	103	1517	6.8	0.03	17	337		
1017100	91	1066	7.2	0.15	10	20		
1021050	106	1023	6.6	0.01	6	8		
1034500	55	84	6.7	0.02	5	8	7274	34654380
1046500	35	21	6.6	0.01	2	1	3551	34845155
1059400	100	2644	6.7	0.02	13	81	9098	41817520
1066000	42	76	6.5	0.04	9	64	394	40980
1096550	117	1552	6.5	0.01	37	630	36180	1948762000
1103500	188	861	6.8	0.15	32	800		
1118500	97	338	6.6	0.06	5	10	2786	16208180
1122610	109	613	6.9	0.06				
1127000	109	348	7.1	0.20	11	12	89420	26563692000
1184000	116	646	7.0	0.04	15	94	12250	405662500
1205500	223	1493	7.5	0.21	5	28	5162	12313720
4296000	194	1560	6.8	0.04	17	444		
4024430	199	1054	7.9	0.0	112	40683	472	164270
4027595	142	456	7.8	0.0	14	49	924	86130
4040000	123	366	7.6	0.1	31	478		
4045500	110	722	7.0	0.1	6	8		
4057004	145	520	7.6	0.1	6	4		
4059000	166	1243	7.8	0.2	5	9		
4059500	254	682	8.0	0.0	10	101		
4085000	358	1417	8.6	0.1	32	301	228560	75579268000
4087000	650	18520	8.4	0.1	44	2016	17520	225652000
4108690	566	533	8.5	0.1	20	47	76200	1499700000
4122030	347	689	8.2	0.1	11	46	4704	14647080
4126520	429	1125	8.0	0.2	8	7	3572	15122920
4132052	306	54	8.2	0.0	2	2	976	714330
4137500	295	276	8.1	0.0	4	10	626	156680
4142000	439	739	8.1	0.0	39	2697	1698	3078970
4165500	736	23962	8.0	0.0	112	38650	4340	5878000
4176500	796	12791	8.5	0.1	30	467	27000	406000000
4193500	653	32278	8.8	0.1	34	293		
4198000	729	14404	8.2	0.2	34	185		
4208000	984	64054	7.6	0.0	25	299	4160	24743000
4212200	4150	803000	7.6	0.1	22	70	7440	29648000
4213500	409	1794	7.6	0.0	13	85		
4217000	494	2364	7.5	0.0	7	21	3092	16042520
4232006	715	52910	7.3	0.1	45	4137	6536	42791480
4249000	1202	229937	7.3	0.0	13	127		
4250750	380	5720	7.7	0.1	8	70	31880	1708157000
4260500	85	200	7.2	0.1	9	21	6182	57891028.8
4263000	102	207	7.2	0.1	8	34		
4264331	323	107	7.8	0.1	6	19	798	7270
4269000	69	133	6.9	0.1	8	54	1082	954370

Station #	Cond. (µS/cm)	Variance Cond.	PH	Variance PH	Sus. Sed. (mg/L)	Variance Sus. Sed.	Algal Abu. (cells/mL)	Variance Algal Abu.
1304500	94	13	6.3	0.1				
1358000	186	1244	7.3	0.3	9	16		
1404100	459	45483	7.7	0.1	28	753	28980	1381262000
1408500	59	19	4.9	0.4	13	35		
1409815	36	45	4.4	0.1	12	11		
1463500	199	874	8.7	0.5	5	9	138860	48165778000
1474500	358	10410	7.7	0.4			34280	1933817000
1491000	137	277	6.9	0.3	6	18	1794	14484819
1540500	275	1960	8.0	0.3	95	28141	133420	22610432000
1553500	229	6164	7.4	0.3	49	2315	4496	9026080
1570500	286	2854	8.2	0.3	49	5809	139200	40196700000
1594440	216	1094	7.2	0.0	51	1479		
1668000	71	131	7.0	0.5	134	82142	1062	1004989
1673000	71	163	6.6	0.1	29	496	2068	2790920
2035000	156	2554	6.8	0.2	32	837	10500	396790050
2041650	75	59	6.7	0.1	28	136	3040	1328000
3049625	310	7319	6.7	0.1	43	3237		
3085000	384	10959	7.2	0.1	27	45		
3107500	438	8127	7.2	0.0	37	1682		
3150000	782	18367	7.9	0.1	29	43	3440	2578000
3155000	122	1707	7.2	0.0	72	6896		
3159510	804	32144	7.5	0.1	92	11033	24920	952012000
3201300	223	3467	7.3	0.0	16	36		
3204000	438	17147	7.8	0.2	226	227960		
3215000	467	14847	7.5	0.0	94	5844		
3216600	425	11020	7.2	0.0	55	1754	4400	19615000
3234500	651	12806	8.0	0.0	94	2838	26920	554437000
3245500	671	11598	8.1	0.0	87	2382	2840	7893000
3254000	241	2084	7.4	0.1	96	7336		
3274600	772	8948	8.2	0.1	95	5881	18560	95708000
3276500							22998	1634590020
3277200	377	6817	7.3	0.1	40	3265	12550	114963000
3290500	283	817	7.4	0.1	75	7106		
3301630	349	874	7.3	0.1	131	5399		
3303280	384	1814	7.3	0.1	42	5139	9803	84387267
3321230	297	2467	7.4	0.4	61	2980	2335	2983750
3374100	488	8158	8.0	0.1	194	16501	27800	117700000
3378500					108	1849	59520	1919852000
3381500	388	13183	7.7	0.2	129	4717	5528	22404920
3425000	177	95	7.4	0.2	36	436	5964	74282480
3609750	166	224	7.7	0.1	18	47	26627	496894667
3612500	355	3150	7.9	0.3	86	2134	29067	381306667
3438220	223	5338	7.7	0.1	17	32	30183	602889667
3470500	159	564	7.1	0.1	20	811	1448	407870
3495500	279	304	7.4	0.5	7	1	2382	2771120
3543005	178	377	6.7	0.1	7	2	10360	61793000
3571850	166	304	6.7	0.1	14	38	1310	1533650

Station #	Cond. (µS/cm)	Variance Cond.	PH	Variance PH	Sus. Sed. (mg/L)	Variance Sus. Sed.	Algal Abu. (cells/mL)	Variance Algal Abu.
3593005	173	748	7.3	0.1	16	77	2946	7087280
5330000	764	8514	8.4	0.0	238	17646		
5331570	487	7035	8.0	0.2			47500	3151500000
5340500	155	410			17	451	15000	312395000
5369500	123	168			20	128	7560	30813000
5407000	189	764	8.0	0.5			70800	3252700000
5446500	592	4577	8.4	0.1	212	3019	62800	1938700000
5465500	450	7900	8.2	0.7				
5508000	297	13200	7.8	0.1				
5543500	745	1470	7.8	0.0	102	1093	21140	469448000
5583000	643	9347						
5586100	657	7787	8.2	0.0	413	228870	40420	798982000
5594100	439	3043	7.7	0.1	120	1535	21400	130300000
5599500	893	106347	7.9	0.2	104	550	56400	4214800000
7019000	331	3485	8.1	0.0	36	933	5036	18354480
7022000	484	2649	7.9	0.0	367	54410	6960	50828000

Appendix 1c: Means and variances of nutrient concentrations measured on 5-6 sampling dates between May to October of 1978.

Station #	TN (µg/L)	Variance TN	NH_3 (µg/L)	Variance NH_3	NO_3 (µg/L)	Variance NO_3	TP (µg/L)	Variance TP	DP (µg/L)	Variance DP
1015000	658	222297	15	150	70	2640	22	257		
1017100	588	43297	33	587	120	3840	65	2270	27	347
1021050	328	8417			47	1947	40	40		
1034500	458	41697	25	110	60	1680	27	27	12	17
1046500					96	30				
1059400	1013	291467	52	1057	405	80350	50	640	20	400
1066000	422	99657			112	577				
1096550	1237	141827	210	21040	383	25227	140	4720	92	4220
1103500	1290	114480	80	1680	287	40947	230	3160	147	3947
1118500	983	46827			410	33840	43	307	37	427
1122610	1023	67787			368	9257	93	587		
1127000	1048	60897			390	2440	123	827	85	4670
1184000	840	45960			287	4627	50	480	23	67
1205500	820	74840			308	25657	32	97	20	160
4296000	343	43027	30	1000	143	4027	20	400		
4024430	977	78507	32	897	58	737	100	16360	15	30
4027595	613	71267	22	257	63	547	30	160	12	17
4040000	654	51830	17	67	52	1337	53	1187	15	150
4045500	777	45467	18	177	58	1577	20	40		
4057004	682	31920	27	227	60	320	18	17	12	17
4059000	842	45337	13	27	115	1790	22	137	15	70
4059500	635	16990	23	547	28	777	13	27		
4085000	2080	607000	97	4427	128	21897	188	2337	48	217
4087000	2060	423000	67	1187	767	314627	155	2470	80	1960
4108690	1733	10667	123	3627	423	89307	137	347	33	707
4122030	663	20667	37	227	147	9267	32	217	17	267
4126520	492	7937	45	430	130	2520	23	67	13	27
4132052	415	17710	13	27	52	1217	22	417	22	417
4137500	385	19190	22	417	63	1707	25	630	23	467
4142000	746	276280	25	190	147	11427	42	1857	12	17
4165500	4433	2262667	178	18697	3167	2758667	283	20507	113	2827
4176500	2850	2735000	165	13070	1590	2190800	235	1830	130	1720
4193500	4417	15653667	90	4960	2783	13669667	178	2297	73	1547
4198000	3883	5313667	128	5897	2452	4174817	133	2347	25	110
4208000	4317	2373667	665	191870	2333	418667	422	39977	303	67347
4212200	2300	216000	952	65857	370	141920	92	1257	12	17
4213500	1450	63000	330	25800	848	97497				
4217000	903	62947	45	910	495	22550	52	617	23	387
4232006	1715	392550	437	125187	585	48150	180	16000	126	15180
4249000	1283	73667	200	6160	360	35480	82	897	46	430
4250750	1017	673787	135	23230	68	7377	1182	1109457	1085	890950
4260500			22	320	192	16857	33	307	18	97
4263000	550	16800			180	8700	32	1470		
4264331	473	13067	23	227	145	5070	13	67		
4269000	477	13987			107	1907	27	1307	12	17

Station #	TN (µg/L)	Variance TN	NH_3 (µg/L)	Variance NH_3	NO_3 (µg/L)	Variance NO_3	TP (µg/L)	Variance TP	DP (µg/L)	Variance DP
1304500	772	105937	133	8867	182	4870	120	2410	67	790
1358000	1192	74417	83	3987	545	20750	52	217	13	27
1404100	8680	30607000	3495	6604150	1883	157667	298	10617	223	14627
1408500	754	49430	86	2030	258	29497	43	307	13	27
1409815	376	20080	18	70	58	2137	22	57		
1463500	1547	135467	25	550	1010	116480	95	2150	57	787
1474500			214	9730	2360	473000	266	15030	228	13970
1491000	1580	167000	48	2097	1005	25670	68	857	28	497
1540500	1362	72417	60	640	445	56750	147	19267	35	1510
1553500	1107	67947	47	587	608	80137	50	1000	20	600
1570500	1548	201617	53	1027	823	62907	83	5427	20	160
1594440	3640	2088000	516	153630	2426	1334380	904	232330	668	251120
1668000	1072	1206670	45	1790	532	217817	137	61027	20	400
1673000	710	23080	65	7510	332	47937	53	787	18	57
2035000	652	32417	27	507	315	5510	78	577	45	990
2041650	592	71270	62	1697	148	5937	45	670	22	377
3049625	1015	45430	150	4720	528	12937	38	1617	30	1120
3085000	1667	86667	442	28497	792	5217	100	6520	32	1217
3107500	3050	659000	442	45017	1683	241667	332	36817	133	2227
3150000	8217	242469667	118	8257	1048	52417	82	177	25	270
3155000	974	567780	32	770	488	488120	58	2570	12	20
3159510	1917	893667	153	10267	1090	509560	168	5417	37	3667
3201300	1135	112390	182	12217	475	58270	62	1217	27	267
3204000	943	1144267	83	5187	280	74600	67	13107	12	17
3215000	1016	109530	20	160	550	91720	60	800	18	417
3216600	1580	167000	50	950	988	391720	43	187	12	17
3234500	4133	410667	173	42267	2783	529667	538	26057	388	28457
3245500	4283	4293667	65	430	3433	3974667	417	9707	295	16750
3254000	1243	386267	37	587	590	129400	180	15960	67	3467
3274600	4650	343000	175	5230	3333	282667	518	8937	278	9537
3276500										
3277200	1720	52000	84	2330	1193	39347	103	4427	48	817
3290500	1467	170667	65	7470	1013	171787	212	15817	98	3137
3301630	1430	74200	88	1937	730	10760	252	18897	94	2130
3303280					1300	20000	136	3930		
3321230	1377	64067	23	387	972	28617	75	2710	34	1430
3374100	3040	263000	92	4520	1940	453000	224	13730	38	570
3378500	2840	733000	100	1000	1784	720280	166	2580	38	370
3381500	2200	140000	323	84267	842	95097	272	9897	108	1177
3425000			17	147	402	6217	45	750	15	70
3609750	567	28227	48	617	170	27200	65	350		
3612500	1733	166667	23	67	1033	103947	140	1760		
3438220	667	35107	72	937	210	38880	87	547		
3470500	590	33350	28	697	368	20177	17	67	12	17
3495500	885	94070	28	870	530	46600	198	154020	14	30
3543005	628	25870	30	450	318	5070	22	20		
3571850	586	7380	62	377	310	1400	35	70	15	70

Station #	TN (µg/L)	Variance TN	NH_3 (µg/L)	Variance NH_3	NO_3 (µg/L)	Variance NO_3	TP (µg/L)	Variance TP	DP (µg/L)	Variance DP
3593005			57	907	325	13390	57	707	30	680
5330000	5480	26167000	14	80	4020	23707000	250	15750	80	5500
5331570	3640	5803000	248	13977	1905	3313270	210	2320	100	1720
5340500	1075	125750	35	630	125	2110	58	697	33	507
5369500	1152	37617	27	387	360	10720	97	347	57	627
5407000	1267	34667	55	3870	312	27377	92	257	40	320
5446500	4650	1819000	70	2200	3000	1312000	383	3147	173	2187
5465500	5940	6608000			4004	8141080	394	39830		
5508000					740	263000	258	26620		
5543500	5050	1283000	668	144777	3217	1073667	480	8600	335	12110
5583000	917	116227	170	15379			363	28067	225	45750
5586100	4433	1522667	50	3040	3133	1406667	398	15737	180	2400
5594100	2017	193667	80	4600	1067	286667	197	17347	67	2867
5599500	1153	88267	137	11507	293	34027	177	2187	67	667
7019000	740	42280	25	430	168	23697	52	897	18	97
7022000	2580	547000	13	27	1878	1000017	367	12427	130	680

Appendix 1d: Hydrological characteristics of river stations calculated using mean daily discharge measured between May to October of 1978.

Station #	Discharge (May-Oct) (m^3/s)	Median Discharge (m^3/s)	CV Discharge (%)	Flood Frequency	# of Months with Floods
1015000	316	93	171	2	2
1017100	65	28	160	3	3
1021050	40	26	64	2	2
1034500	240	144	98	1	1
1046500	142	104	60	1	1
1059400	164	82	103	3	2
1066000	66	18	139	1	2
1096550	128	56	113	1	2
1103500	5	3	92	2	3
1118500	12	6	97	1	2
1122610	11	7	87	5	4
1127000	23	14	86	3	3
1184000	308	172	95	3	2
1205500	41	21	113	5	4
4296000	4	2	132	3	3
4024430	11	6	132	4	4
4027595	15	11	102	3	3
4040000	33	24	96	2	3
4045500	39	35	65	1	1
4057004	62	56	57	1	1
4059000	33	25	76	3	2
4059500	18	14	82	3	3
4085000	129	113	43	0	0
4087000	18	10	116	4	4
4108690	42	33	72	1	2
4122030	44	39	38	0	0
4126520	50	48	25	0	0
4132052	21	20	33	0	0
4137500	38	34	37	0	0
4142000	7	6	58	3	3
4165500	9	7	69	2	2
4176500	11	5	126	2	3
4193500	48	19	128	3	3
4198000	6	2	148	4	4
4208000	16	12	85	3	3
4212200	6	2	241	2	3
4213500	9	6	101	5	3
4217000	2	1	143	5	4
4232006	39	23	99	1	2
4249000	95	72	70	3	2
4250750	2	1	142	5	4
4260500	85	63	72	2	2
4263000	26	23	54	1	1
4264331	8158	7958	7	0	0
4269000	22	15	80	3	3

Station #	Discharge (May-Oct) (m^3/s)	Median Discharge (m^3/s)	CV Discharge (%)	Flood Frequency	# of Months with Floods
1304500	1	1	23	0	0
1358000	256	201	64	2	1
1404100	23	9	160	6	5
1408500	7	6	58	3	3
1409815	5	3	103	4	3
1463500	234	142	96	2	2
1474500	64	34	124	4	3
1491000	3	1	111	4	3
1540500	231	143	108	2	2
1553500	252	121	154	2	2
1570500	690	408	135	1	1
1594440	9	5	161	4	3
1668000	35	19	155	6	4
1673000	25	10	147	8	5
2035000	147	95	122	1	1
2041650	40	15	156	3	3
3049625	345	238	102	1	1
3085000	294	184	104	4	4
3107500	82	54	88	2	2
3150000	188	129	74	3	2
3155000	39	21	117	7	6
3159510	19	10	120	8	4
3201300	15	6	153	4	5
3204000	26	10	147	4	4
3215000	46	24	129	3	4
3216600	1635	1239	81	2	2
3234500	78	54	90	3	3
3245500	23	13	131	8	6
3254000	86	35	132	7	6
3274600	58	43	77	5	4
3276500	30	19	91	8	5
3277200	2146	1618	81	2	1
3290500	153	52	142	5	4
3301630	37	11	181	8	5
3303280	2477	1871	82	2	1
3321230	173	102	119	2	2
3374100	333	266	68	1	1
3378500	670	493	72	2	1
3381500	29	6	166	6	5
3425000	402	408	52	0	0
3609750	1169	1049	66	1	1
3612500	5583	4319	72	1	1
3438220	715	691	59	0	0
3470500	168	163	50	0	0
3495500	134	124	65	0	0
3543005	605	593	32	0	0
3571850	914	922	22	0	0

Station #	Discharge (May-Oct) (m^3/s)	Median Discharge (m^3/s)	CV Discharge (%)	Flood Frequency	# of Months with Floods
3593005	1056	961	58	1	1
5330000	107	105	80	1	1
5331570	449	429	36	0	0
5340500	160	121	67	1	1
5369500	263	230	48	2	2
5407000	319	282	43	1	1
5446500	246	196	62	1	1
5465500	274	224	57	1	1
5508000	54	7	243	6	5
5543500	263	205	72	2	2
5583000	87	47	137	3	4
5586100	634	472	76	1	1
5594100	64	55	86	2	1
5599500	16	11	85	3	4
7019000	42	25	101	5	3
7022000	6596	6655	39	0	0
Headwater Streams (no water quality data available)					
1466500	0.065	0.057	74	2	2
1545600	1.4	0.5	186	4	4
2038850	0.179	0.113	154	1	1
3237280	0.324	0.028	254	11	6
3276700	1.32	0.23	257	10	6
4001000	0.47	0.24	110	4	4

Appendix 1e: TP and TN concentrations and discharge measured in the St. Lawrence and Niagara rivers between June to October of 1993. Data were obtained from the Water Quality Division, Canada Centre for Inland Waters, Burlington, Ont., Canada and were used to test the effect of sampling intensity on the relationship between temporal variance of TP and TN concentrations and river size.

Niagara River, Station ON02HA0019

Date	Discharge (m^3/s)	TP (µg/L)	TN (µg/L)
6/1/93	6965	13.1	575
6/2/93	6883		
6/3/93	6768	10.7	636
6/4/93	6576		
6/5/93	6270	5	665
6/6/93	6279		
6/7/93	6698		
6/8/93	6624	13.2	685
6/9/93	6717		
6/10/93	6867	17.9	634
6/11/93	6546		
6/12/93	6118	19.1	766
6/13/93	5798		
6/14/93	6523		
6/15/93	6549	15.6	681
6/16/93	6365		
6/17/93	6381	19.6	694
6/18/93	6456		
6/19/93	5988	22.1	703
6/20/93	5924		
6/21/93	6663		
6/22/93	6676	20.6	670
6/23/93	6595		
6/24/93	6462	11.1	725
6/25/93	6600		
6/26/93	6310	18.1	637
6/27/93	6362		
6/28/93	6759		
6/29/93	6739	25.5	663
6/30/93	6575		
7/1/93	6452	16.3	575
7/2/93	6591		
7/3/93	6550	21.8	598
7/4/93	6070		
7/5/93	6505		
7/6/93	6830	29.8	558
7/7/93	6881		
7/8/93	6760	214.8	592
7/9/93	6677		
7/10/93	6454	19.6	582
7/11/93	6258		
7/12/93	6856		

St. Lawrence River, Wolfe Island

Date	Discharge (m^3/s)	TP (µg/L)	TN (µg/L)
6/1/93	10700	7.7	544
6/2/93	9930		
6/3/93	9870		
6/4/93	9940		
6/5/93	9890		
6/6/93	9900		
6/7/93	9900		
6/8/93	9890	7.7	579
6/9/93	9910		
6/10/93	9890	8.8	551
6/11/93	9900		
6/12/93	9920		
6/13/93	9880		
6/14/93	9900		
6/15/93	9890	6.7	561
6/16/93	9890		
6/17/93	9910		
6/18/93	9900		
6/19/93	9920		
6/20/93	9910		
6/21/93	9870		
6/22/93	9900	8.3	519
6/23/93	9400	8.4	559
6/24/93	9400		
6/25/93	9410		
6/26/93	9400		
6/27/93	9400		
6/28/93	9400		
6/29/93	9380	8.2	495
6/30/93	8790		
7/1/93	8780		
7/2/93	8780		
7/3/93	8780		
7/4/93	8780		
7/5/93	8780		
7/6/93	8790	8.2	539
7/7/93	8780		
7/8/93	8780	7.6	499
7/9/93	8780		
7/10/93	8780		
7/11/93	8770		
7/12/93	8800		

Niagara River, Station ON02HA0019

Date	Discharge (m^3/s)	TP (µg/L)	TN (µg/L)
7/13/93	6750	22.8	548
7/14/93	6740		
7/15/93	6701	20	614
7/16/93	6680		
7/17/93	6285	25.5	450
7/18/93	6045		
7/19/93	6566		
7/20/93	6817	19.1	522
7/21/93	6646		
7/22/93	6615	13.3	554
7/23/93	6616		
7/24/93	6180	16.9	572
7/25/93	6010		
7/26/93	6538		
7/27/93	6752	29.5	487
7/28/93	6672		
7/29/93	6843	19.6	480
7/30/93	6817		
7/31/93	6466	59	302
8/1/93	6011		
8/2/93	6714		
8/3/93	6736	34.7	332
8/4/93	6765		
8/5/93	6464	17	411
8/6/93	6387		
8/7/93	6106	15	419
8/8/93	5872		
8/9/93	6459		
8/10/93	6493	13.3	401
8/11/93	6427		
8/12/93	6337	18.1	463
8/13/93	6318		
8/14/93	5772		
8/15/93	5999	14.8	362
8/16/93	6395		
8/17/93	6311	12.4	351
8/18/93	6326		
8/19/93	6340	8.9	471
8/20/93	6468		
8/21/93	5657	10.1	404
8/22/93	5850		
8/23/93	6353		
8/24/93	6527	15.9	380
8/25/93	6225		
8/26/93	6385	9.7	425
8/27/93	6432		
8/28/93	5888	16.1	832

St. Lawrence River, Wolfe Island

Date	Discharge (m^3/s)	TP (µg/L)	TN (µg/L)
7/13/93	8780	4.1	583
7/14/93	8780		
7/15/93	8790		
7/16/93	8780		
7/17/93	8790		
7/18/93	8770		
7/19/93	8780		
7/20/93	8780	5.9	475
7/21/93	8790	5.7	503
7/22/93	8780		
7/23/93	8770		
7/24/93	8800		
7/25/93	8780		
7/26/93	8780		
7/27/93	8780	12.9	461
7/28/93	8780		
7/29/93	8790		
7/30/93	8780		
7/31/93	8780		
8/1/93	8780		
8/2/93	8780		
8/3/93	8780	13.5	487
8/4/93	8700		
8/5/93	8700		
8/6/93	8700		
8/7/93	8700		
8/8/93	8700		
8/9/93	8690		
8/10/93	8700	11.2	432
8/11/93	8650		
8/12/93	8660	11.5	452
8/13/93	8620		
8/14/93	8610		
8/15/93	8610		
8/16/93	8480		
8/17/93	8320	6.9	436
8/18/93	8320		
8/19/93	8300		
8/20/93	8320		
8/21/93	8310		
8/22/93	8310		
8/23/93	8310		
8/24/93	8290	7	755
8/25/93	7980		219
8/26/93	7970		
8/27/93	7970		
8/28/93	7970		

Niagara River, Station ON02HA0019

Date	Discharge (m^3/s)	TP (µg/L)	TN (µg/L)
8/29/93	5729		
8/30/93	6216		
8/31/93	6392	21.3	812
9/1/93	6187		
9/2/93	6266	6.3	850
9/3/93	6426		
9/4/93	6095	27.6	601
9/5/93	6174		
9/6/93	5870		
9/7/93	6340	15.8	381
9/8/93	6395		
9/9/93	6375	6.9	449
9/10/93	6707		
9/11/93	6116	10.7	520
9/12/93	5920		
9/13/93	6380		
9/14/93	6367	19.8	408
9/15/93	6379		
9/16/93	5808	14	458
9/17/93	6104		
9/18/93	5797	16.9	460
9/19/93	5443		
9/20/93	6017		
9/21/93	5960	16	450
9/22/93	6054		
9/23/93	6141	10.4	415
9/24/93	6223		
9/25/93	5567	16.9	400
9/26/93	5873		
9/27/93	6418		
9/28/93	7026	21.2	470
9/29/93	6564		
9/30/93	5992	28.5	515
10/1/93	6233		
10/2/93	5982	27.7	555
10/3/93	6169		
10/4/93	6824		
10/5/93	6282	40.7	476
10/6/93	6081		
10/7/93	6159	23.6	512
10/8/93	6095		
10/9/93	5603	8.8	464
10/10/93	5586		
10/11/93	6077		
10/12/93	6387		
10/13/93	6036		
10/14/93	5958	8.2	669

St. Lawrence River, Wolfe Island

Date	Discharge (m^3/s)	TP (µg/L)	TN (µg/L)
8/29/93	7970		
8/30/93	7980		
8/31/93	7970	6.6	396
9/1/93	7910		
9/2/93	7910		
9/3/93	7920		
9/4/93	8050		
9/5/93	7970		
9/6/93	7910		
9/7/93	7910		381
9/8/93	7810	6.9	409
9/9/93	7820		
9/10/93	7820		
9/11/93	7820		
9/12/93	7820		
9/13/93	7820		
9/14/93	7810	9.7	448
9/15/93	7500		
9/16/93	7500		
9/17/93	7500		
9/18/93	7500		
9/19/93	7510		
9/20/93	7500		
9/21/93	7500	8.9	390
9/22/93	7530		
9/23/93	7780	10.5	434
9/24/93	7650		
9/25/93	7470		
9/26/93	7460		
9/27/93	7470		
9/28/93	7460	8	441
9/29/93	7480		
9/30/93	7470		
10/1/93	7490		
10/2/93	7460		
10/3/93	7460		
10/4/93	7470		
10/5/93	7490	8.9	397
10/6/93	7580		
10/7/93	7570	7.9	501
10/8/93	7570		
10/9/93	7580		
10/10/93	7590		
10/11/93	7580		
10/12/93	7600	8.2	423
10/13/93	7710		
10/14/93	7700		

Niagara River, Station ON02HA0019

Date	Discharge (m³/s)	TP (µg/L)	TN (µg/L)
10/15/93	6063		
10/16/93	5645	24.1	435
10/17/93	5720		
10/18/93	6254		
10/19/93	6007	31.7	470
10/20/93	5921		
10/21/93	6827	12.7	467
10/22/93	6631		
10/23/93	5756	50	521
10/24/93	6024		
10/25/93	5898		
10/26/93	5986		
10/27/93	6145		
10/28/93	6296	25.4	521
10/29/93	6487		
10/30/93	5637	49.3	382
10/31/93	5281		

St. Lawrence River, Wolfe Island

Date	Discharge (m³/s)	TP (µg/L)	TN (µg/L)
10/15/93	7710		
10/16/93	7580		
10/17/93	7530		
10/18/93	7710		
10/19/93	7690	7.6	439
10/20/93	7580		
10/21/93	7490		
10/22/93	7260	8.8	440
10/23/93	7420		
10/24/93	7550		
10/25/93	7560		
10/26/93	7560	10.7	
10/27/93	7390		
10/28/93	7380		
10/29/93	7380		
10/30/93	7380		
10/31/93	7380		

Appendix 1f: Data used to test the effect of sampling intensity on the relationship between temporal variance and river size. TP and TN concentrations were measured intensively at 12 river stations from June to October by NASQAN (10 stations) and the Water Quality Division, Canada Centre for Inland Waters, Burlington, Ont., Canada (2 stations). Temporal variance of TP and TN concentrations were calculated on subsets of the data to correspond with 4 different sampling regimes: monthly, biweekly, weekly, and > weekly (all data from that station).

Sampling Intensity	n	River	Station #	Drainage Basin Code	Year	TP (µg/L)	TN (µg/L)	Variance TP	Variance TN	Median Discharge (m^3/s)
monthly	5	Maumee	4193500	4	1991	311	3840	138996	17573000	13
monthly	5	Sandusky	4198000	4	1991	522	4756	670117	72630880	1
monthly	5	Cuyahoga	4208000	4	1991	280	5020	17750	1537000	5
monthly	5	White	3374100	5	1991	184	2220	6030	4972000	59
monthly	5	Ohio	3612500	5	1991	107	932	3170	218170	2433
monthly	5	Mississippi	5420500	7	1991	210	3260	900	1823000	1631
monthly	5	Illinois	5586100	7	1991	314	4060	830	3488000	263
monthly	5	Mississippi	7022000	7	1991	238	3780	16720	4932000	3852
monthly	5	Minnesota	5330000	7	1980	298	6620	17870	11507000	39
monthly	5	Susquehanna	1570500	2	1980	38	878	70	73620	204
monthly	5	St. Lawrence		4	1993	9	475	7	4860	8480
monthly	5	Niagara		4	1993	20	577	131	33761	6362
biweekly	11	Maumee	4193500	4	1991	237	3373	61654	11948182	13
biweekly	11	Sandusky	4198000	4	1991	280	3143	321832	33362882	1
biweekly	11	Cuyahoga	4208000	4	1991	195	4564	4725	462545	5
biweekly	11	White	3374100	5	1991	190	2191	6320	2510909	59
biweekly	11	Ohio	3612500	5	1991	84	970	765	137140	2433
biweekly	11	Mississippi	5420500	7	1991	222	3109	1916	1140909	1631
biweekly	10	Illinois	5586100	7	1991	310	3630	3578	1997889	263
biweekly	11	Mississippi	7022000	7	1991	270	3282	27012	3717636	3852
biweekly	11	Minnesota	5330000	7	1980	267	4882	15942	9027636	39
biweekly	11	Susquehanna	1570500	2	1980	55	847	1547	104682	204
biweekly	11	St. Lawrence		4	1993	8	497	5	11835	8480
biweekly	11	Niagara		4	1993	22	501	82	10975	6362
weekly	22	Maumee	4193500	4	1991	208	3214	32438	9831710	13
weekly	22	Sandusky	4198000	4	1991	193	2636	162500	22383129	1
weekly	22	Cuyahoga	4208000	4	1991	193	4700	4970	534286	5
weekly	21	White	3374100	5	1991	187	1967	11041	1631333	59
weekly	22	Ohio	3612500	5	1991	79	947	1199	209499	2433
weekly	20	Mississippi	5420500	7	1991	205	3040	2394	1018316	1631
weekly	20	Illinois	5586100	7	1991	335	3605	6037	1752079	263
weekly	21	Mississippi	7022000	7	1991	267	3214	18621	3490286	3852
weekly	19	Minnesota	5330000	7	1980	253	5142	11609	8337018	39
weekly	22	Susquehanna	1570500	2	1980	54	932	843	90101	204
weekly	22	St. Lawrence		4	1993	8	486	5	7518	8480
weekly	22	Niagara		4	1993	20	523	65	16732	6362

Sampling Intensity	n	River	Station #	Drainage Basin Code	Year	TP (µg/L)	TN (µg/L)	Variance TP	Variance TN	Median Discharge (m^3/s)
>weekly	153	Maumee	4193500	4	1991	191	3201	16261	10248475	13
>weekly	129	Sandusky	4198000	4	1991	149	2438	44990	16288130	1
>weekly	144	Cuyahoga	4208000	4	1991	229	4821	11715	589493	5
>weekly	36	White	3374100	5	1991	170	1851	7537	1327044	59
>weekly	22	Ohio	3612500	5	1991	79	948	1199	209218	2433
>weekly	25	Mississippi	5420500	7	1991	194	3244	2642	1004233	1631
>weekly	25	Illinois	5586100	7	1991	328	3848	5217	2214267	263
>weekly	26	Mississippi	7022000	7	1991	278	3681	23386	3924015	3852
>weekly	25	Minnesota	5330000	7	1980	242	4980	9372	7914167	39
>weekly	23	Susquehanna	1570500	2	1980	54	931	817	86012	204
>weekly	30	St. Lawrence		4	1993	8	476	4	8188	8480
>weekly	64	Niagara		4	1993	23	533	700	16080	6362

Appendix 2a: Physical characteristics of 46 Ontario and Quebec rivers sampled in June and July of 1998.

River	Latitude	Longitude	Drainage Area (Km^2)	Discharge (m^3/s)	WRT (days)	Temp (°C)	Depth (m)	LA (m^{-1})	Z_{eu}:Z_{tot}
Jock	45°14.97	75°47.44	559	1.12	3.5	19.0	2.3	2.7	0.7
Rideau	45°13.92	75°40.87	3120	20.2	7.4	19.5	3.1	0.9	1.7
Kemptville	44°59.09	75°40.08	409	1.63	2.8	22.0	1.1	2.9	1.4
NB South Nation	44°58.79	75°32.45	69.2	0.29	1.2	20.5	1.2	2.8	1.4
South Nation	45°17.56	75°07.36	2410	6.7	7.1	20.0	5.3	2.5	0.3
Rouge	45°44.45	74°41.40	5460	97.54	8.8	18.0	1.2	2	1.9
Lievre	45°35.64	75°25.22	9560	82	12.6	18.0	6.7	1.6	0.4
Mississippi	45°19.68	76°17.27	2900	12	7.5	21.5	2.5	1.1	1.7
Ottawa	45°30.88	76°13.02	90900	711	39.2	20.0	14.3	1	0.3
Gatineau	45°38.78	75°55.21	22500	233	19.0	19.0	11.0	1.1	0.4
Bonnechere	45°30.06	76°33.60	2380	8.68	6.8	21.5	2.7	1.9	0.9
Madawaska	45°14.54	77°10.74	5800	29.4	10.3	20.0	3.7	0.7	1.8
Blue Springs	43°35.26	80°05.92	44.5	0.47	0.8	22.5	0.4		
Grand	43°05.92	80°14.40	5210	23.9	9.9	25.5	0.9	2.3	2.2
Thames	42°43.92	81°34.66	3760	9.91	8.9	26.5	1.2	5.5	0.7
Ausable	43°04.65	81°36.59	865	0.43	5.0	27.5	0.9	5.1	1.0
Nith	43°23.66	80°43.51	552	0.468	3.8	23.5	0.5	2.7	3.4
Avon	43°19.75	81°07.77	144	0.39	1.7	23.5	0.4	1.3	8.9
Maitland	43°54.23	81°16.99	528	0.93	3.5	27.0	0.3		
Conestogo	43°34.87	80°38.45	578	2.85	3.3	20.5	0.8	2.2	2.6
Moira	44°16.60	77°21.94	2620	9.15	7.2	25.0	3.2	1.4	1.0
Parks	44°17.08	77°19.50	199	2.64	1.7	23.0	0.5	3.3	2.8
Otonabee	44°11.08	78°20.10	7360	67.6	11.0	24.0	5.2	0.8	1.1
Ganaraska	44°00.76	78°26.85	67.3	0.856	1.0	18.5	0.6	1.2	6.4
Burnley	44°11.30	77°56.44	82.3	0.7	1.2	22.0	0.6	1.3	5.9
Trent	44°23.67	77°52.53	9090	49.0	12.9	26.0	2.9	0.6	2.6
Wilton	44°14.38	76°50.95	112	0.35	1.5	25.0	0.4	1.4	8.2
Amable du Fond	46°14.60	78°55.13	1130	3.39	4.8	22.0	1.8		
La Vase	46°16.18	79°23.25	70.4	0.06	1.4	24.0	1.1		1.6
Duchesnay	46°20.01	79°30.57	90.4	0.24	1.4	18.5	0.4	6.1	1.9
Sturgeon	46°29.97	79°58.81	6660	49.8	10.7	22.0	8.7	1.1	0.5
Temagami	46°36.39	80°09.66	2360	23.5	6.2		2	0.9	2.6
Veuve	46°25.54	80°12.53	741	1.87	4.0	22.0	3.6	3.3	0.4
Magnetewan	45°46.45	80°30.06	2850	7.78	7.7	24.0	4.4	0.9	1.2
Indian	45°14.78	76°15.58	203	0.49	2.1	23.5	0.5	1	9.2
Chamouchouane	48°41.59	72°29.92	15300	235.7	15.0	19.0	2.2	2.7	0.8
Mistassini	48°53.44	72°14.72	9870	107.48	12.5	20.0	1.9	2.7	0.9
Mistassibi	48°55.44	72°11.82	9320	114.48	12.0	20.0	7.0	0.8	0.8
Peribonca	48°45.95	71°35.66	26900	595	19.2	19.0	23.0	1.6	0.1
Saguenay	48°26.00	71°03.01	73800	1143	33.0	19.5	7.2	2	0.3
St. Maurice	46°40.96	72°43.70	42000	581	25.2	22.0	9.7	0.7	0.7
St. Francois	45°51.70	72°25.25	9630	186	11.6	22.0	4.7	2.6	0.4
Richelieu	45°19.62	73°15.67	22000	683	16.8	23.0	3.1	0.8	1.9
La Peche	45°38.53	76°04.38	117	1.15	1.4	24.5	0.9	1.5	3.4
Picanoc	46°04.49	76°04.63	1290	9.243	4.7	27.0	3.8	1.3	0.9
Little Castor	45°16.24	75°13.08	76.1	0.05	1.5	25.0	0.2	0.7	32.9

Appendix 2b: Total suspended Chl *a* and Chl *a* in 4 size classes measured in 46 Ontario and Quebec rivers in June and July of 1998.

River	Total Chl a (µg/L)	Chl a 0.2-2.0 µm (µg/L)	Chl a 2.0-20 µm (µg/L)	Chl a 20-64 µm (µg/L)	Chl a >64 µm (µg/L)
Jock	18.7	5.0	12.1	1.3	0.22
Rideau	2.7	1.2	1.2	0.2	0.09
Kemptville	2.1	0.9	0.9	0.3	0.06
NB South Nation	3.8	1.2	1.6	0.7	0.20
South Nation	12.0	5.0	5.8	0.9	0.30
Rouge	4.0	1.2	2.1	0.5	0.13
Lievre	2.1	1.1	0.8	0.2	0.10
Mississippi	6.8	3.7	2.6	0.4	0.04
Ottawa	2.5	1.3	0.9	0.2	0.09
Gatineau	1.9	0.6	1.0	0.2	0.08
Bonnechere	3.7	1.1	2.2	0.3	0.03
Madawaska	2.1	0.9	1.0	0.2	0.03
Blue Springs	1.7	0.3	0.8	0.4	0.19
Grand	19.3	3.3	13.8	2.1	0.04
Thames	133.1	0.0	104.4	32.2	0.12
Ausable	28.6	1.9	24.0	2.6	0.05
Nith	9.4	1.3	7.2	0.8	0.05
Avon	19.6	1.9	10.5	6.8	0.37
Maitland	4.7	0.2	3.3	1.0	0.08
Conestogo	5.0	0.0	4.5	1.0	0.17
Moira	3.6	2.0	1.1	0.4	0.11
Parks	2.5	0.5	1.2	0.6	0.21
Otonabee	1.5	0.5	0.6	0.3	0.10
Ganaraska	1.6	0.0	1.0	0.6	0.10
Burnley	2.1	0.2	1.2	0.6	0.17
Trent	2.4	0.9	0.3	0.3	1.01
Wilton	3.2	1.0	1.4	0.5	0.26
Amable du Fond	1.9	0.8	0.8	0.2	0.08
La Vase	6.5	2.6	2.2	1.6	0.13
Duchesnay	4.1	1.7	2.0	0.3	0.11
Sturgeon	2.1	0.8	1.0	0.2	0.03
Temagami	1.6	0.5	0.9	0.2	0.09
Veuve	5.5	2.4	2.8	0.3	0.02
Magnetewan	1.9	0.8	0.8	0.2	0.02
Indian	2.2	0.7	0.9	0.3	0.18
Chamouchouane	2.5	1.0	1.3	0.2	0.02
Mistassini	2.1	1.0	1.0	0.1	0.02
Mistassibi	2.7	1.3	1.3	0.1	0.02
Peribonca	1.7	0.7	0.8	0.1	0.03
Saguenay	1.4	0.4	0.5	0.2	0.21
St. Maurice	3.6	1.5	1.5	0.5	0.16
St. Francois	4.6	1.2	2.4	1.0	0.08
Richelieu	1.6	0.9	0.5	0.2	0.13
La Peche	2.4	0.5	1.3	0.2	0.44
Picanoc	1.5	0.6	0.6	0.3	0.01
Little Castor	2.5	1.2	1.1	0.2	0.05

Appendix 2c: Water chemistry parameters measured in 46 Ontario and Quebec rivers in June and July of 1998.

River	Cond (µS/cm)	NH_3 (µg/L)	NO_3+NO_2 (µg/L)	SRP (µg/L)	TKN (µg/L)	TP (µg/L)	TN (µg/L)
Jock	538	90	253	21	847	67	1100
Rideau	222	42	20	16	540	30	560
Kemptville	406	35	186	4	673	17	859
NB South Nation	388	35	263	14	527	30	790
South Nation	481	54	201	23	697	47	898
Rouge	53	11	89	5	200	18	289
Lievre	54	18	96	4	217	8	313
Mississippi	210	30	60	4	447	16	507
Ottawa	69	13	99	2	270	9	369
Gatineau	43	13	87	2	243	7	330
Bonnechere	209	49	81	10	470	20	551
Madawaska	97	7	42	2	270	7	312
Blue Springs	596	4	993	2	290	5	1283
Grand	839	47	1207	18	613	46	1820
Thames	651	113	14	85	1027	113	1040
Ausable	481	25	1027	21	600	40	1627
Nith	454	41	527	10	617	39	1143
Avon	1354	273	5400	157	1233	280	6633
Maitland	456	13	737	2	510	13	1247
Conestogo	355	11	1370	8	600	33	1970
Moira	285	11	36	3	433	18	469
Parks	406	6	13	5	507	19	520
Otonabee	227	39	141	7	400	18	541
Ganaraska	356	11	387	11	253	25	640
Burnley	389	15	150	24	500	38	650
Trent	231	78	63	20	550	42	613
Wilton	609	9	28	9	620	23	648
Amable du Fond	37	3	5	2	220	9	225
La Vase	185	370	947	12	1247	38	2193
Duchesnay	49	7	102	8	590	28	692
Sturgeon	61	3	13	2	190	6	203
Temagami	62	4	3	2	210	7	213
Veuve	112	9	45	14	617	37	662
Magnetewan	45	6	73	2	260	7	333
Indian	277	4	3	5	527	18	530
Chamouchouane	29	9	5	2	277	11	282
Mistassini	31	10	18	2	250	6	268
Mistassibi	24	9	3	2	233	5	236
Peribonca	21	12	25	2	227	5	252
Saguenay	35	25	81	3	283	10	364
St. Maurice	29	14	48	2	307	11	355
St. Francois	126	33	156	6	540	38	696
Richelieu	156	58	168	21	373	33	541
La Peche	163	13	23	6	360	15	383
Picanoc	102	3	17	2	320	9	337
Little Castor	502	23	3	155	537	159	540

Appendix 2d: Cross sectional profiles of depth and depth-averaged current velocity measured in 8 small rivers to esimate discharge using the velocity-area method.

River	Distance from Shore (m)	Depth (cm)	Depth-averaged Current Velocity (cm/s)	Discharge of Cell (m^3/s)	River Discharge (m^3/s)
Parks	0.6	22	24	0.032	
	1.2	31	25	0.046	
	1.8	34	26	0.053	
	2.4	38	26	0.059	
	3.0	42	27	0.067	
	3.6	42	31	0.079	
	4.2	50	30	0.091	
	4.8	51	35	0.107	
	5.4	45	34	0.092	
	6.0	41	42	0.102	
	6.6	39	46	0.108	
	7.2	36	45	0.098	
	7.8	40	52	0.124	
	8.4	37	54	0.119	
	9.0	40	46	0.111	
	9.6	41	52	0.127	
	10.2	40	47	0.113	
	10.8	43	43	0.112	
	11.4	43	42	0.107	
	12.0	46	44	0.123	
	12.6	41	44	0.109	
	13.2	43	42	0.107	
	13.8	45	40	0.107	
	14.4	41	30	0.075	
	15.0	37	30	0.068	
	15.6	37	30	0.066	
	16.2	30	26	0.047	
	16.8	27	30	0.048	
	17.4	28	37	0.062	
	18.0	28	24	0.040	
	18.6	23	24	0.033	2.64
Burnley	0.6	11	2	0.001	
	1.2	23	6	0.009	
	1.8	38	18	0.042	
	2.4	48	10	0.029	
	3.0	50	12	0.036	
	3.6	52	16	0.049	
	4.2	52	13	0.040	
	4.8	67	13	0.052	
	5.4	65	17	0.068	
	6.0	61	18	0.067	
	6.6	64	18	0.071	
	7.2	52	18	0.057	
	7.8	60	17	0.063	
	8.4	64	18	0.071	

River	Distance from Shore (m)	Depth (cm)	Depth-averaged Current Velocity (cm/s)	Discharge of Cell (m^3/s)	River Discharge (m^3/s)
Burnley cont.	9.0	46	16	0.043	0.70
Amable du Fond	0.5	16	23	0.037	
	1.5	34	41	0.138	
	2.5	41	47	0.193	
	3.5	44	27	0.118	
	4.5	39	40	0.155	
	5.5	40	25	0.100	
	6.5	48	9	0.044	
	7.5	42	29	0.120	
	8.5	41	37	0.152	
	9.5	35	53	0.185	
	10.5	42	39	0.163	
	11.5	40	18	0.074	
	12.5	23	33	0.077	
	13.5	15	45	0.068	
	14.5	22	22	0.049	
	15.5	26	30	0.077	
	16.5	35	7	0.026	
	17.5	30	16	0.047	
	18.5	41	20	0.083	
	19.5	40	19	0.077	
	20.5	41	36	0.148	
	21.5	37	8	0.030	
	22.5	39	38	0.148	
	23.5	30	47	0.142	
	24.5	38	43	0.162	
	25.5	34	45	0.154	
	26.5	27	53	0.142	
	27.5	32	35	0.112	
	28.5	41	7	0.030	
	29.5	29	27	0.078	
	30.5	24	17	0.042	
	31.5	24	10	0.024	
	32.5	19	18	0.035	
	33.5	16	15	0.024	
	34.5	27	30	0.080	
	35.5	19	19	0.037	
	36.5	12	8	0.010	
	37.5	11	6	0.007	
	38.5	7	2	0.001	3.39
Duchesnay	0.5	8	8	0.003	
	1.0	10	23	0.012	
	1.5	17	29	0.024	
	2.0	23	25	0.029	
	2.5	24	26	0.031	
	3.0	23	26	0.030	
	3.5	26	22	0.029	

River	Distance from Shore (m)	Depth (cm)	Depth-averaged Current Velocity (cm/s)	Discharge of Cell (m^3/s)	River Discharge (m^3/s)
Duchesnay cont.	4.0	24	24	0.029	
	4.5	22	9	0.010	
	5.0	18	13	0.012	
	5.5	26	15	0.019	
	6.0	29	9	0.013	0.24
Veuve	1.0	25	12	0.030	
	2.0	30	12	0.036	
	3.0	41	43	0.178	
	4.0	50	43	0.213	
	5.0	55	78	0.428	
	6.0	48	67	0.320	
	7.0	40	32	0.129	
	8.0	40	33	0.133	
	9.0	41	25	0.102	
	10.0	33	25	0.082	
	11.0	27	11	0.030	
	12.0	29	39	0.113	
	13.0	30	23	0.069	
	14.0	33	4	0.012	1.87
Indian	1.0	38	1	0.003	
	2.0	41	1	0.003	
	3.0	45	5	0.024	
	4.0	47	5	0.026	
	5.0	45	9	0.041	
	6.0	48	8	0.039	
	7.0	43	10	0.043	
	8.0	53	7	0.039	
	9.0	56	6	0.036	
	10.0	46	8	0.038	
	11.0	48	12	0.057	
	12.0	47	10	0.047	
	13.0	47	10	0.047	
	14.0	47	9	0.043	
	15.0	35	1	0.003	0.49
Lapeche	1.0	30	8	0.025	
	2.0	80	11	0.088	
	3.0	90	17	0.149	
	4.0	95	17	0.166	
	5.0	94	20	0.191	
	6.0	86	19	0.166	
	7.0	86	12	0.103	
	8.0	86	13	0.111	
	9.0	80	10	0.081	
	10.0	74	8	0.061	
	11.0	35	4	0.013	1.15

River	Distance from Shore (m)	Depth (cm)	Depth-averaged Current Velocity (cm/s)	Discharge of Cell (m^3/s)	River Discharge (m^3/s)
Little Castor	0.3	6	3	0.000	
	0.6	10	7	0.002	
	0.9	14	8	0.003	
	1.2	18	8	0.004	
	1.5	20	6	0.004	
	1.8	23	8	0.006	
	2.1	24	8	0.006	
	2.4	23	9	0.006	
	2.7	23	8	0.006	
	3.0	22	7	0.005	
	3.3	15	8	0.004	
	3.6	14	6	0.003	
	4.1	7	5	0.001	0.05

Appendix 2e: Slope and regression stastics for the linear relationship between the proportion of Chl *a* retained on the filter and the logarithm of the filter size.

River	Slope	Standard Error	r^2	p
Jock	-0.431	0.035	0.92	<0.001
Rideau	-0.401	0.017	0.98	<0.001
Kemptville	-0.397	0.014	0.98	<0.001
NB South Nation	-0.388	0.018	0.98	<0.001
South Nation	-0.407	0.015	0.98	<0.001
Rouge	-0.406	0.015	0.98	<0.001
Lievre	-0.385	0.016	0.98	<0.001
Mississippi	-0.405	0.021	0.96	<0.001
Ottawa	-0.391	0.020	0.97	<0.001
Gatineau	-0.399	0.014	0.98	<0.001
Bonnechere	-0.423	0.022	0.97	<0.001
Madawaska	-0.408	0.014	0.98	<0.001
Blue Springs	-0.362	0.019	0.96	<0.001
Grand	-0.437	0.031	0.93	<0.001
Thames	-0.435	0.051	0.84	<0.001
Ausable	-0.447	0.046	0.87	<0.001
Nith	-0.500	0.220	0.27	0.039
Avon	-0.396	0.035	0.90	<0.001
Maitland	-0.423	0.043	0.88	<0.001
Conestogo	-0.459	0.150	0.40	0.008
Moira	-0.387	0.023	0.95	<0.001
Parks	-0.376	0.046	0.82	<0.001
Otonabee	-0.376	0.017	0.97	<0.001
Ganaraska	-0.390	0.121	0.43	0.006
Burnley	-0.384	0.050	0.81	<0.001
Trent	-0.212	0.061	0.47	0.004
Wilton	-0.380	0.012	0.98	<0.001
Amable du Fond	-0.391	0.011	0.99	<0.001
La Vase	-0.384	0.012	0.99	<0.001
Duchesnay	-0.405	0.014	0.98	<0.001
Sturgeon	-0.412	0.014	0.99	<0.001
Temagami	-0.396	0.024	0.95	<0.001
Veuve	-0.419	0.016	0.98	<0.001
Magnetewan	-0.405	0.010	0.99	<0.001
Indian	-0.376	0.013	0.98	<0.001
Chamouchouane	-0.419	0.016	0.98	<0.001
Mistassini	-0.414	0.019	0.97	<0.001
Mistassibi	-0.415	0.018	0.97	<0.001
Peribonca	-0.408	0.014	0.98	<0.001
Saguenay	-0.339	0.011	0.99	<0.001
St. Maurice	-0.389	0.013	0.98	<0.001
St. Francois	-0.404	0.017	0.98	<0.001
Richelieu	-0.364	0.020	0.96	<0.001
La Peche	-0.355	0.050	0.78	<0.001
Picanoc	-0.401	0.023	0.96	<0.001
Little Castor	-0.402	0.014	0.98	<0.001

Appendix 2f: Total suspended algal biomass and biomass in 3 size classes based on the average greatest axial linear dimension (GALD) of taxa measured in 31 Ontario and Quebec rivers in July 1994.

River	WRT (days)	Total Biomass (µg/L)	Biomass 2.0-20 µm (µg/L)	Biomass 20-64 µm (µg/L)	Biomass >64 µm (µg/L)
Amable	4.0	847	475	306	67
Ausable	4.7	4117	3753	340	24
Bonnechere	5.6	583	372	195	15
Bumt	4.9	323	208	72	43
Conestogo	3.4	529	420	78	31
Lievre	10.9	416	247	55	113
French	14.1	1102	528	368	206
Gatinueau	19.4	482	193	149	141
Grand	9.8	1592	1001	535	55
Madawaska	10.6	475	374	73	29
Magnetewan	6.6	760	260	231	269
Missisippi	7.9	686	482	180	24
Moira	5.9	335	156	110	70
Maitland	3.3	680	381	230	69
Mattawa	7.5	587	399	164	24
Napanee	3.8	545	177	121	247
Nith	3.6	2389	1838	446	106
North Thames	4.7	4899	2180	2429	291
Otonabee	12.1	946	244	214	488
Picanoc	4.5	865	455	364	46
Rouge	9.2	521	290	155	77
Rideau	7.8	1281	451	435	395
Salmon	3.4	338	294	42	2
Saugeen	6.1	1180	585	530	65
Skootamata	4.1	1873	1255	612	6
South Nation	6.2	2261	1517	506	237
Sturgeon	11.1	209	117	69	23
Temagami	6.9	182	100	39	43
Thames	7.6	5727	3971	1049	707
Trent	13.5	2984	455	1359	1170
Veuve	3.6	426	251	174	1