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# A WATER QUALITY STUDY OF THE AKAMINA-KISHINENA WATERSHED AND OTHER TRIBUTARIES TO THE FLATHEAD RIVER IN BRITISH COLUMBIA SUBJECTED TO LOGGING

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March, 1985



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1985

# TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

# LIST OF TABLES

# LIST OF FIGURES

LIST OF FIGURES (Continued)

## SUMMARY

In 1978, salvage logging in the Akamina-Kishinena watershed was proposed to control an infestation of mountain pine beetles. At that time logging was in progress in the adjacent Elder and Sage Creek drainages. Kishinena, Elder and Sage Creeks flow across the International Boundary and into the North Fork of the Flathead River. Because of the potential for adverse transboundary effects of logging, the Water Quality Branch, Inland Waters Directorate, undertook a water quality study of the Canadian portion of these streams. Water chemistry, suspended sediments, and periphytic algae were monitored in Akamina, Kishinena, Elder and Sage Creeks in 1979. Additional samples were collected in 1980 and 1982, after logging had begun in the Kishinena watershed.

Concentrations of chemicals in the water and species composition and abundance of periphytic algae in these streams were similar to those reported from the mainstem and western tributaries of the Flathead River. Suspended sediment and metal levels were low. Periphyton biomass, as well as concentrations of phosphorus and nitrogen, were typical of oligotrophic waters. The algal community was dominated by diatoms, particularly *Achnanthes minutissima* and *Gomphonema olivaceum*.

No deterioration in the water quality of Kishinena Creek was apparent from the limited amount of data collected after logging had commenced. No differences in concentrations of suspended sediments, nutrients, metals, or major ions, which could be attributed to logging, were measured. No major change in the species composition of the periphyton was observed. However, since logging is continuing in the region, continued monitoring of water quality is suggested.

# RESUME

En 1978, la récupération du bois de coupe dans le bassin Akamina-Kishinena a été proposée afin de contrôler une épidémie de dendroctone du pin Ponderosa (Dendroctonus ponderosae, "mountain pine beetle"). A cette époque, l'abattage était déjà en cours dans les bassins adjacents des ruisseaux Elder et Sage. Ces derniers, ainsi que le Kishinena, traversent la frontière internationale pour se jeter dans le bras nord de la rivière Flathead. Comme cet abattage pouvait avoir des effets néfastes outre-frontière, la Direction de la qualité des eaux de la Direction générale des eaux intérieures a entrepris une étude de la qualité des eaux de la portion canadienne de ces cours d'eau. La chimie de l'eau, les particules en suspension et les algues périphytiques des ruisseaux Akamina, Kishinena, Elder et Sage ont été soumis à une surveillance continue en 1979. Des échantillons supplémentaires ont été recueillis en 1980 et en 1982, après que l'abattage ait commencé dans le bassin Kishinena.

Les concentrations de diverses substances dans l'eau, ainsi que l'abondance et la répartition entre les diverses espèces d'algues périphytiques dans ces cours d'eau étaient similaires à celles observées pour la rivière Flathead et ses tributaires occidentaux. Les niveaux de particules en suspension et de métaux étaient peu élevés. La biomasse périphytique et les concentrations en phosphore et en azote étaient typiques des eaux oligotrophes. La communauté des algues était dominée par les diatomées, en particulier Achnanthes minutissima et Gomphonema olivaceum.

Aucune détérioration de la qualité de l'eau du ruisseau Kishinena n'est apparue à partir de la quantité limitée de données recueillies après le début de l'abattage. Aucune différence dans les concentrations de particules en suspension, d'éléments nutritifs, de métaux ou d'ions principaux, attribuable à l'abattage, n'a pu être détectée. De même, aucun changement important de la composition du périphyton n'a été observé. Toutefois, comme l'abattage continue dans la région, nous recommandons une surveillance continue de la qualité des eaux.

# I. INTRODUCTION

In 1978 the British Columbia Forestry Service proposed salvage logging in the Akamina-Kishinena watershed to harvest stands of lodgepole pine (Pinus contorta var. latifolia Engelm.) infested with mountain pine beetles (Dendroctonus ponderosae Hopk.). The beetle infestation had appeared in the Akamina-Kishinena and Flathead watersheds in southeastern British Columbia in 1976. By 1978 salvage logging was in progress in the adjacent Elder and Sage Creek drainages.

Akamina-Kishinena, Elder and Sage Creeks are transboundary waters (Figure 1). All are tributaries to the North Fork of the Flathead River. Kiskinena, Elder, and Sage Creeks flow across the International Boundary into Glacier National Park, Montana, U.S.A.

The United States government expressed concern that logging operations in Canada might impair the water quality in their national park and in the Flathead River. As a result, the Water Quality Branch, Inland Waters Directorate was instructed to describe water quality conditions in the Akamina-Kishinena region so that further impacts of logging on the transboundary water quality could be assessed.

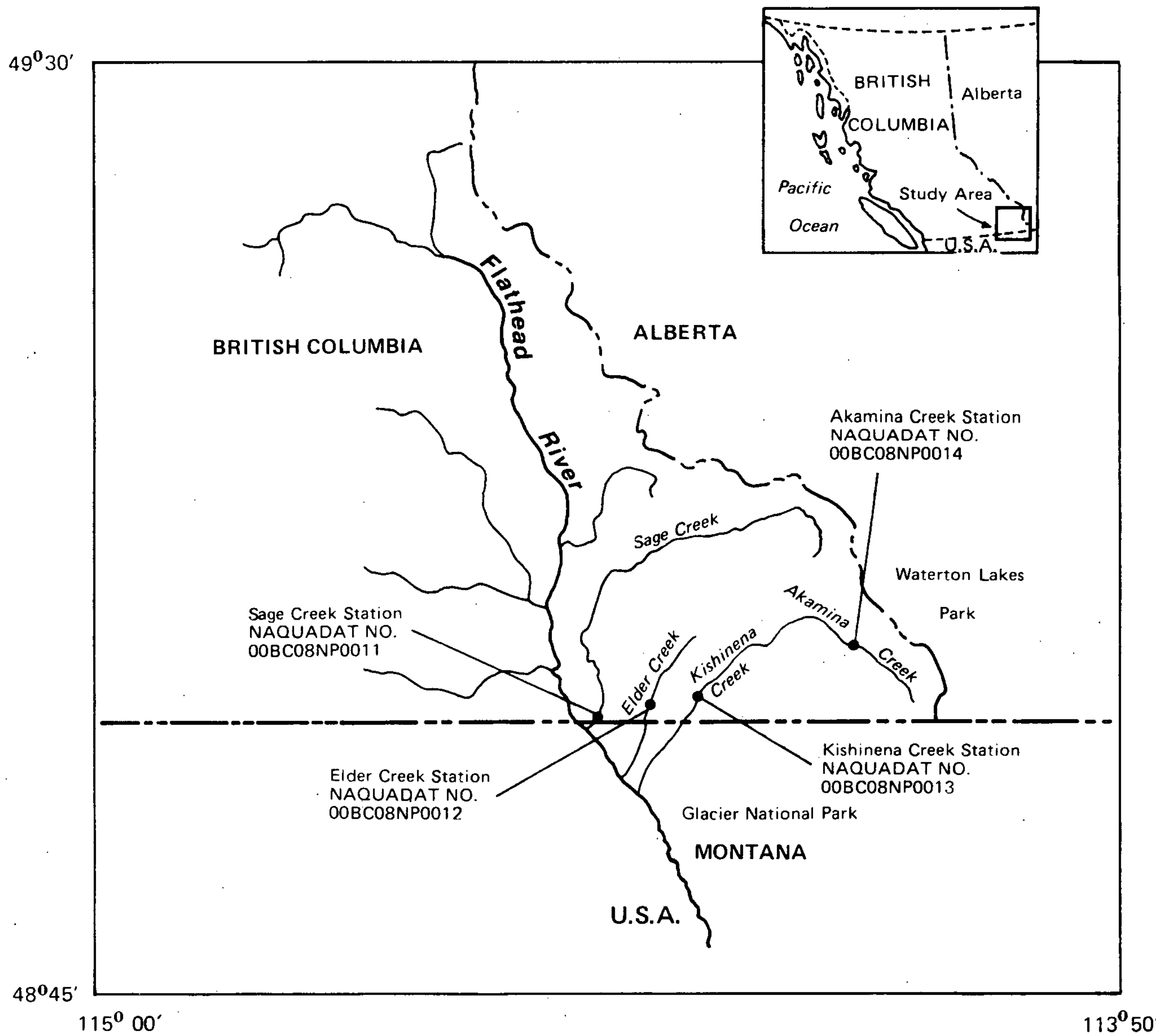


Fig. 1 Sample station locations and NAQUADAT station numbers in the eastern Flathead River Basin, British Columbia. Note that the upstream portion of Kishinena Creek is known as Akamina Creek.

## II. STUDY OBJECTIVES

The major objective of this study was to characterize the hydrology, suspended sediments, water chemistry, and periphytic algal abundance and community structure in Akamina, Kishinena, Elder, and Sage Creeks.

A secondary objective was to use the data collected after the commencement of logging in the Kishinena Creek watershed to identify changes in water quality which might require further study and/or remedial action.

## III. EFFECTS OF LOGGING ON STREAMS - A REVIEW

Logging a watershed can affect water quantity and water quality by:

1) increasing stream flow;
2) increasing sediment concentrations in streams;
3) changing the temperature regime;
4) changing the concentrations of nutrients, ions, and other substances in streams; and
5) altering productivity and species composition of the biota.

The severity of these effects depends upon the logging practices employed as well as the geological structure and soil characteristics of the area. In general, clearcutting results in greater changes to flow patterns and water quality than does patch cutting. The practice of maintaining uncut buffer zones along stream banks usually reduces some of the more serious logging effects on streams.

The removal and disruption of vegetation results in increased annual runoff from the watershed. Vegetation removes water by interception and evaporation of rainfall, by storage and transpiration, and by maintaining the integrity of the soil. Elevated annual stream discharge and flow rates have been observed in devegetated or logged watersheds from New Hampshire to Oregon

(Likens et al. 1970, Verry 1972, Harris 1973, Bateridge 1974). Stream discharge increases more or less in proportion to the percent of the watershed cut (Eschner and Larmoyeux 1963, Rothacher 1970).

The season of maximum effect on stream discharge appears to vary regionally. In streams draining eastern hardwood forests, greatest increases have been measured during the low flow period of the forest growing season, when evapotranspiration should be maximal (Eschner and Larmoyeux 1963, Hornbeck et al. 1970). In the Oregon Cascades, 80% of the increased flow has been recorded during the rainy season (October-March) (Rothacher 1970).

Roads and skid trails have a relatively minor effect on stream discharge. In two studies where roads or skid trails which occupied 2.5% and 8% of the watersheds were constructed one year prior to logging, no effects on discharge were observed (Eschner and Larmoyeux 1963, Rothacher 1970). When roads occupied at least 12% of a watershed, peak flows during storms increased (Harr et al. 1975).

The most serious effect of logging on water quality is the input to streams of sediments which have eroded from logged areas or from roads (Brown 1972). Such inputs result in elevated concentrations of suspended sediments and increased turbidities, as well as increased deposition of sediments in stream beds. Sediment levels doubled after road construction but before logging in one watershed of the Oregon Coast Range, while concentrations tripled after clearcutting and slash burning in a second watershed (Brown and Krygier 1971). The percentage of fine particles (<0.833 mm) deposited in the bed of an Alaska salmon stream increased following landslides from a cut over area, and the increase lasted for somewhat under five years (Sheridan and McNeil 1968). In some cases, careful logging practices, including leaving trees in buffer strips along stream banks and locating roads away from water courses, have protected streams from the effects of erosion (Eschner and Larmoyeux 1963, Moring 1982, Tschaplinski and Hartman 1983). However, Beschta (1978) found that stream buffer strips did not protect a creek from sediment inputs following slumpages and debris avalanches from roads.

Clearcutting causes summer water temperatures to rise. Summer maximum temperatures have been increased by 4-9°C in streams in the Appalachian Mountains and in southwestern British Columbia (Swift and Messer 1971, Lee and Samuel 1976, Feller 1981). In an Oregon stream the summer maximum increased from 13.8°C before to 29.4°C after logging (Brown and Krygier 1970). Diurnal temperature fluctuations also increase after logging. Lee and Samuel (1976) found that complete forest removal more than tripled the weekly range of summer temperatures. All these effects disappear when riparian buffer strips are left (Brown and Krygier 1970, Lee and Samuel 1976).

The effect of logging on winter temperatures has been less studied, and observations have varied. Brown and Krygier (1970) and Swift and Messer (1971) recorded somewhat higher winter water temperatures after clearcutting, but Eschner and Larmoyeux (1963) and Lee and Samuel (1976) found lower winter minumum temperatures after forest removal. In a British Columbia stream, Feller (1981) found increased maximum and minimum temperatures during the first winter after clearcutting, but when slash was burned the following year, winter temperatures decreased significantly.

Changes in concentrations of dissolved substances have frequently been associated with logging. Some of these studies have compared water chemistry in the same stream before and after logging, but many have involved comparisons of streams draining logged and unlogged watersheds in the same region. Chemicals for which changes have been observed and the magnitudes and directions of these changes have been variable.

An increase in the concentration of dissolved nitrate is the water chemical change most frequently observed after logging. In a study of the effect of a large scale change in vegetation on nutrient cycles in the Hubbard Brook watershed, Likens et al. (1970) had the forest cut and treated with herbicides (Bromacil and 2,4,5-T) to prevent vegetation regrowth. Following treatment, nitrate concentrations (after nitrogen input from herbicides had been accounted for) increased up to 56-fold, reaching a maximum concentration of 82 mg/L. Since the disturbance in this study was extreme, Pierce et al. (1972) compared traditionally-logged with unlogged watersheds in the same New Hampshire drainage basin and found nitrate concentrations up to 18 mg/L in streams from logged areas compared with 1-2 mg/L in streams of unlogged watersheds. In Oregon, the stream nitrate level increased from 0.7 mg/L before to 2.1 mg/L after clearcutting and burning on one watershed but did not change significantly in another watershed where patch cutting had occurred (Brown et al. 1973). Nitrate levels were higher and showed greater seasonal variability in streams draining logged than in streams draining unlogged watersheds in the Bitterroot Range, Montana (Bateridge 1974). Making a similar comparsion of logged and unlogged watersheds in the Okanagan Basin, British Columbia, Hetherington (1976) found no differences in nitrate levels.

Alterations in levels of other dissolved substances following logging have also been reported. In the Hubbard Brook study (Likens et al. 1970), increases in concentrations of dissolved Ca, Mg, K, and Na ranging from 177-1558% were measured in the two years following deforestation. Other workers also have reported increases in K (Brown et al. 1973, Heatherington 1976) and Na (Hetherington 1976) levels. Aubertin and Patric (1974) found "slightly" elevated phosphate levels following clearcutting in West Virginia. Increased concentration of organic compounds, including total organic carbon (Hetherington 1976) and tannin, lignin, humic and fulvic acids (Telang et al. 1981) have been reported. Several researchers have measured increases in total dissolved solids or in electrical conductivity, which indicates the relative abundance of dissolved ions (Likens et al. 1970, Pierce et al. 1972, Hetherington 1976). The only dissolved substance for which decreases have consistently been recorded is sulphate (Likens et al. 1970, Pierce et al. 1972, Aubertin and Patric 1974). Bateridge (1974) reported lower electrical conductivity, total dissolved solids and concentrations of divalent cations in streams draining logged watersheds, which he attributed to dilution by increased runoff. Verry (1972) found no changes in nutrients, major ions, or metals following aspen clearcutting in a Minnesota watershed.

Although the initial effect of logging on a watershed is to increase concentrations of most dissolved substances, as vegetation regrowth proceeds and nutrients are accumulated by the developing forest, levels of these substances in the water decline (Vitousek and Reiners 1975). Streams draining areas that had been logged 45 years earlier had significantly lower nitrate concentrations than streams draining never-logged forests (Silsbee and Larson 1982). Two years after clearcutting, dissolved organic carbon (DOC) levels were lower in a stream draining a logged watershed than in a stream draining an undisturbed watershed because of reduced inputs from leaching of fresh litter and depletion of easily leached DOC in the soil (Meyer and Tate 1983).

While the effects of logging on water chemistry have been well documented, there are only a few reports of effects on lotic algae. Likens et al. (1970) observed a bloom of *Ulothrix zonata* following deforestation of the Hubbard Brook watershed. This species also occurred in streams of logged watersheds but not in streams of unlogged watersheds in the same drainage basin (Pierce et al. 1972). Algal growth rate was somewhat higher in a stream draining a logged watershed than in a stream draining an adjacent unlogged watershed on Vancouver Island (Stockner and Shortreed 1976). This difference was attributed to increased light following clearcutting. Hains (1981) anticipated that algal standing crops would increase in an Appalachian stream after clearcutting due to higher light intensity and higher levels of phosphorus and nitrogen. He speculated that the observed increase was less than predicted because of scouring due to higher sediment levels. Increased grazing by mayflies in the same stream was also observed (Gurtz and Wallace 1984).

Changes in water quality due to logging also affect stream invertebrates and fish, but since these organisms have not been included in the present study, effects on them will not be reviewed.

## IV. STUDY AREA

The study area lies in the eastern portion of the Flathead River Basin in southeastern British Columbia (Figure 1). Creeks in the study area drain a region of the Rocky Mountains where peaks rise to elevations greater than 2400 m.

The vegetation of the region is primarily a mixed coniferous forest dominated by lodgepole pine with spruce (*Picea engelmanii* Parry.) and larch (*Larix occidentalis* Nutt.) plus some Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco.), balsam fir (*Abies lasiocarpa* (Hook.) Nutt.) and whitebark pine (*Pinus albicaulus* Engelm.).

General descriptions of Kishinena and Sage Creeks, including inventories of fish species present have been made by Caw et al. (1976).

### A. Station Selection and Description (Refer to Figure 1)

#### 1. Akamina Creek (NAQUADAT No. 00BC08NP0014)

This station is located near the headwaters of the Akamina-Kishinena watershed at an elevation of approximately 1570 m. The location was selected to act as a control site because, in 1978, it was within the boundary of an area designated for protection from logging. Since the present study was conducted, logging permits have been issued for the headwaters of the Akamina-Kishinena (Figure 2, 3).

2. Kishinena Creek (NAQUADAT No. 00BC08NP0013)

This site is located about 2.5 km north (upstream) of the Canada-U.S. border at an elevation of approximately 1300 m. The stream forms a braided stretch between the station and the border. A road bridge, which was constructed in 1979, crosses the stream immediately downstream from the sampling station. Most of the logging activity has occurred upstream of the site (Figure 2, 3).

3. Elder Creek (NAQUADAT No. 00BC08NP0012)

This station is located about 1 km upstream of the Canada-U.S. border at an elevation of approximately 1330 m. Logging activity had not reached the sampling station when the study began (Figure 2, 3).

4. Sage Creek (NAQUADAT No. 00BC08NP0011)

This site is located just upstream of the international boundary at an elevation of approximately 1200 m. Although active logging was underway in the Sage Creek watershed, monitoring at the border station was undertaken because a substantial area had yet to be logged and because background data from a previous study were available for Sage Creek (Sheehan et al. 1980).

Descriptions of stream characteristics are given in Table 1.

TABLE 1 Station descriptions. Depth and velocity were measured as described by Braybrooks (1978). Flow pattern and stream bed composition were determined by visual observation and reference to stream parameter terms defined in Caw et al. (1976).

| Station | Drainage Area Upstream of Station ($km^2$) | River Bank Description and Stream Flow Pattern | Approximate Light Reaching Water Surface (percent) | Mean Depth Over Study Period (meters) | Velocity Range (m/sec) | Approximate Stream Bed Composition |
|---|---|---|---|---|---|---|
| Akamina Creek | 28.00 | The banks, which slope gradually, support growths of willows and small bushes. Stands of lodgepole pine and spruce are present no more than 5 m from water's edge. The stream flow pattern is uniform. | 50-75 | 0.20 | 0.12-1.03 | 25% small gravel<br>25% large gravel<br>49% large rubble<br>1% boulder |
| Kishinena Creek | 171.46 | Forest cover extends to the right bank, which is about 2 m high and drops steeply. The riparian zone along the left bank consists of gravel bars with willows The flow pattern is uniform. | 75-100 | 0.36 | 0.18-1.30 | 35% small gravel<br>30% large gravel<br>25% small rubble<br>10% large rubble |
| Elder Creek | 29.68 | Forest cover extends to the left bank. The riparian zone of the right bank consists of bars with willows The flow pattern is uniform. | 75-100 | 0.22 | 0.14-0.99 | 20% small gravel<br>40% large gravel<br>5% small rubble<br>10% large rubble<br>25% boulder |
| Sage Creek | 221.65 | Vegetation along the stream banks consists of willows and bushes interspersed with trees and gravel bars. The flow pattern is uniform. | 85-100 | 0.34 | 0.30-1.41 | 30% small gravel<br>45% large gravel<br>10% small rubble<br>5% large rubble<br>10% boulders |

## V. LOGGING IN THE AKAMINA-KISHINENA AND ADJACENT WATERSHEDS

### A. Areas Harvested

Timber harvesting was underway as early as 1973 in the Sage Creek watershed but expanded as the pine beetle infestation spread. Logging began in the Elder Creek watershed in 1978 and in the Kishinena Creek watershed in late 1979 (Figure 2). Initially, the area surrounding Akamina Creek, as well as Starvation and North Kintla Creeks, was designated a special study area to be protected from logging, but when the beetle infestation approached 90%, salvage logging was extended to the Akamina watershed at elevations below 1830 m. Harvesting the Akamina drainage began in 1983. Areas cut and dates of harvesting are summarized in Table 2 and Figure 3.

### B. Road Construction

In all watersheds road building preceded logging. The Sage Creek road was built in the 1960's as a seismic line and was upgraded in the early 1970's to accommodate logging traffic. The Elder Creek road was constructed in 1978. Major road building along Kishinena Creek began in 1979 and was completed in 1980. As of 1983 an existing road along Akamina Creek was being upgraded to handle logging vehicles.

### C. Logging Practices Prior to 1983

In the Akamina-Kishinena watershed the following precautions were

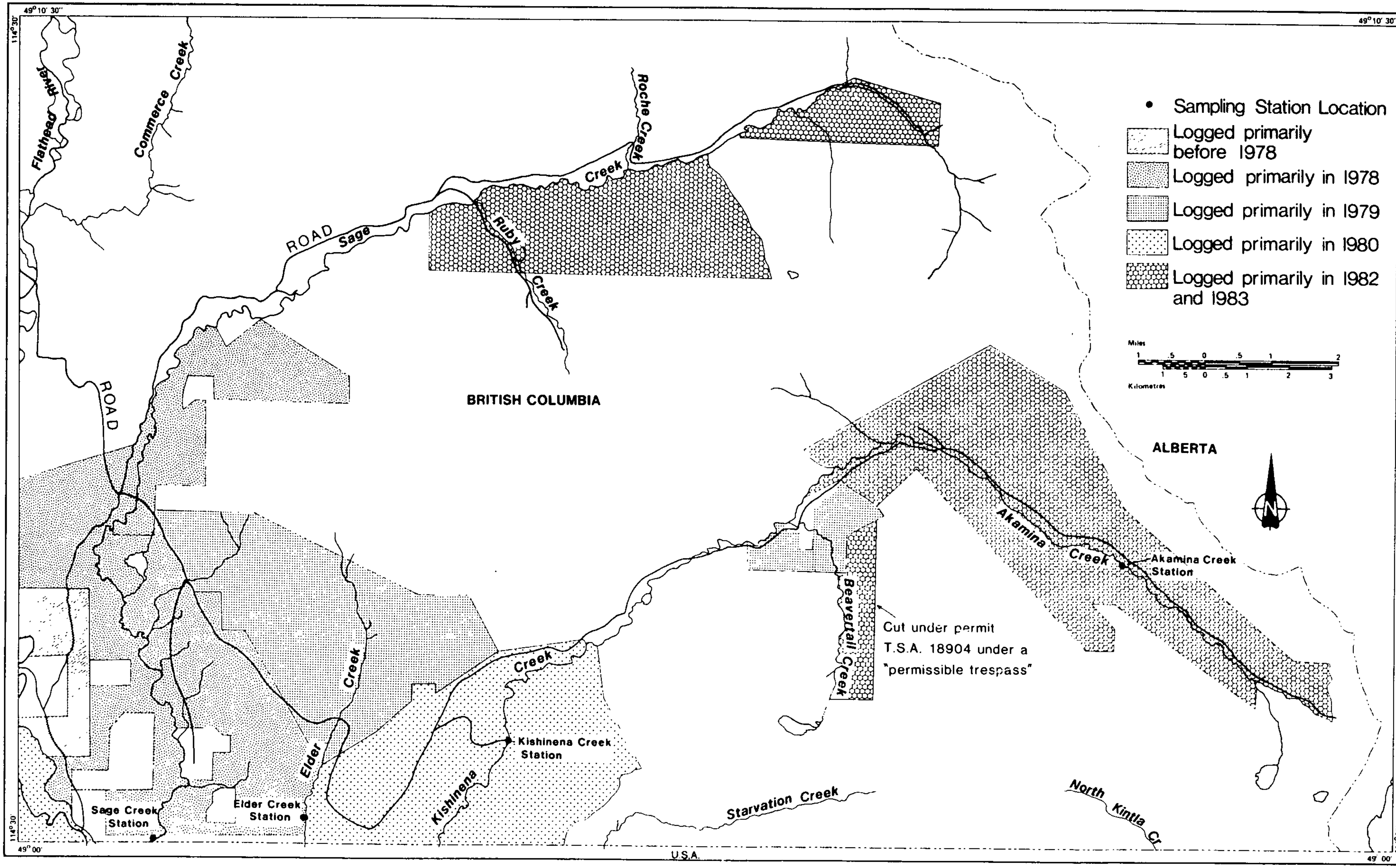


Fig. 2 Areas logged and approximate dates of harvesting in the eastern Flathead River Basin. Note that the area actually logged does not encompass the entire area for which permits were issued.

TABLE 2 Approximate areas of timber cut (by permit number) in the Akamina-Kishinena, Elder, and Sage Creek watersheds, 1973-1983. Locations of cutting permits are illustrated in Figure 3. Areas were calculated from harvest volumes supplied by the B.C. Ministry of Forests, using an average volume of $250m^3$/hectare.

| Permit Number | Year | Area Cut (hectares) |
|---|---|---|
| T.S.H.L. A00243 | | |
| C.P. 49 | 1973 | 91 |
| | 1974 | 32 |
| | 1975 | 79 |
| | 1977 | 29 |
| | 1978 | 27 |
| | TOTAL | 258 |
| C.P. 61 | 1976 | 88 |
| | 1977 | L1 |
| | 1978 | 5 |
| | 1979 | 6 |
| | TOTAL | 99 |
| C.P. 131 | 1978 | 67 |
| | 1979 | L1 |
| | 1980 | L1 |
| | TOTAL | 68 |
| C.P. 133 | 1977 | 94 |
| | 1978 | 150 |
| | 1979 | 50 |
| | TOTAL | 294 |
| C.P. 135 | 1978 | 182 |
| | 1979 | 69 |
| | 1980 | 1 |
| | TOTAL | 252 |
| C.P. 140 | 1978 | 88 |
| | 1979 | 465 |
| | 1980 | 9 |
| | TOTAL | 562 |

TABLE 2 (Continued)

| Permit Number | Year | Area Cut (hectares) |
|---|---|---|
| C.P. 141 | 1979 | 64 |
| | 1980 | 217 |
| | TOTAL | 281 |
| C.P. 142 | 1980 | 167 |
| C.P. 145 | 1979 | 26 |
| | 1980 | 56 |
| | TOTAL | 82 |
| C.P. 146 | 1980 | 94 |
| C.P. 152 | 1980 | 90 |
| C.P. 154 | 1981 | 118 |
| T.S. A18904 | 1983 | 51 [1] |
| T.S. A18920 | 1982 | 28 |
| | 1983 | 60 [1] |
| | TOTAL | 88 [1] |
| T.S. A18921 | 1983 | 1 [1] |
| T.S. A18922 | 1982 | 82 [1] |
| | 1983 | 94 [1] |
| | TOTAL | 176 [1] |

[1] Values to the end of July, 1983

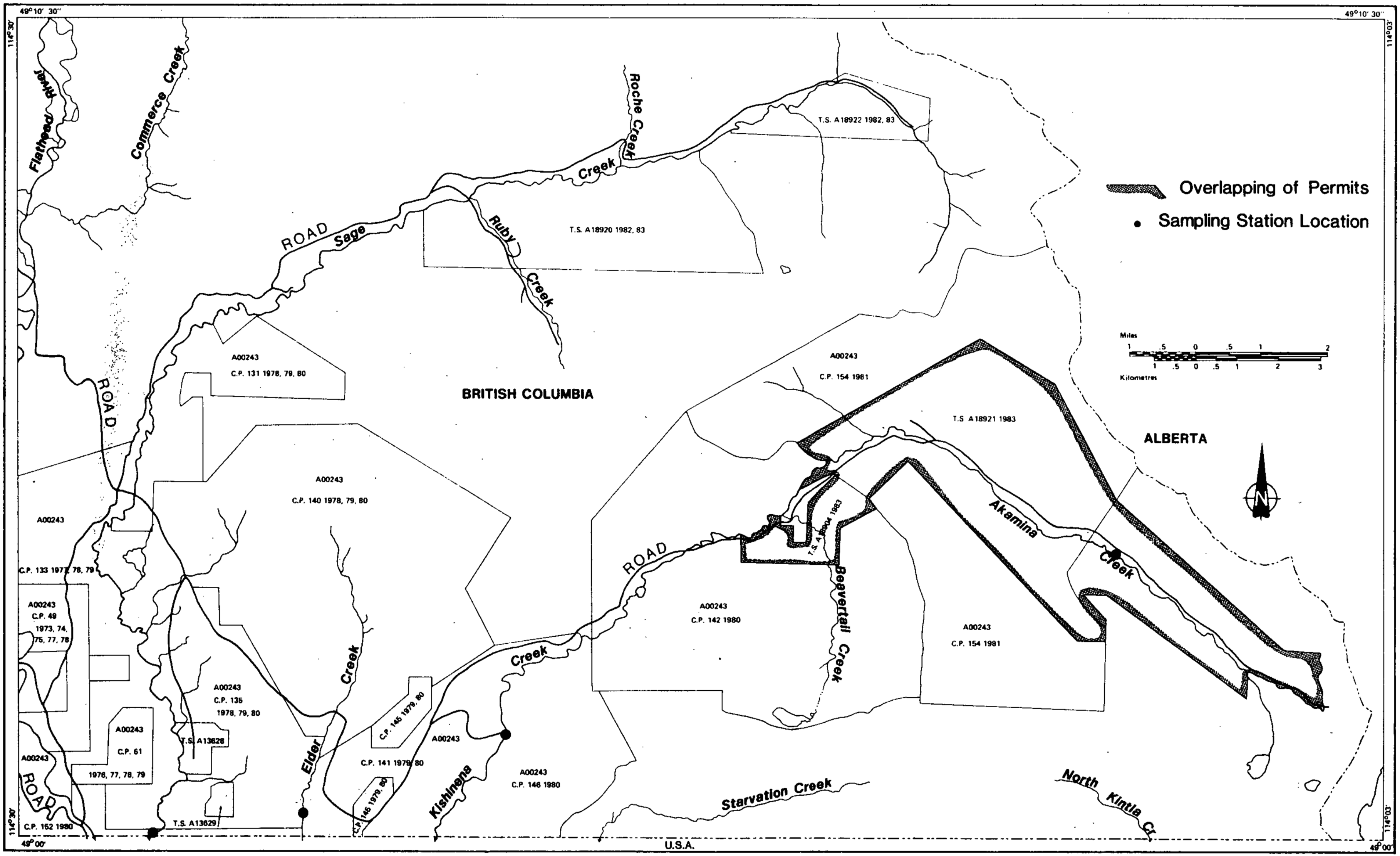


Fig.3 Locations of timber permits and date of harvesting under each permit in the eastern Flathead River Basin.

taken to reduce the impacts of logging and associated road construction on the environment:

1) Only lodgepole pine were harvested. Spruce, larch, and deciduous trees remained uncut.
2) Neither machines nor timber harvesting were allowed within riparian buffer zones. These zones extended the width of the historic flood plain along stream banks and around marsh areas.
3) An attempt was made to keep logging debris out of stream channels. Any logging debris which did enter a stream channel was removed.
4) Machines selected for road construction and log skidding were types which cause minimal erosion. These included hydraulic shovels for road building and FMC (light flotation) vehicles instead of skidders when slope gradients exceeded 40-50%.
5) The number of skid trails was limited.
6) Upon completion of operations, skid trails were water-barred and all areas where mineral soil had been exposed (eg. skid trails and the cut banks of roads) were seeded with grass.

Areas of the Sage Creek drainage logged during the early 1970's were not protected as vigorously as was the Akamina-Kishinena watershed. Selective cutting of both pine and spruce prevailed in some areas, while clearcutting or patch cutting occurred in others.

## D. Logging Practices in 1983 and Following

Because of an infestation of spruce bark beetle (*Dendroctonus rufipennis* Kirby) which had been declared epidemic in 1982, the following changes in logging practices were agreed to in 1983:

1) Spruce were to be cut in addition to pine. Although larch and deciduous trees were to be left standing, removal of pine and spruce would result in clearcutting in many blocks.
2) Since harvesting both pine and spruce would leave creek banks covered with only thin strips of trees, which are unstable in high winds, clearcutting in patches on alternate sides of streams was to be allowed. One bank was to remain uncut to provide shading and protect against increased water temperature. Sections to be clearcut would be determined locally depending on bank stability and accessibility. Buffer strips were to remain machine-free; timber was to be cut by hand and removed with cables.

## VI. SAMPLING SCHEDULE

Preliminary chemical sampling and qualitative evaluation of algal species composition was conducted at Kishinena, Elder, and Sage Creeks in August, 1978.

Detailed sampling at all four stations in 1979 was designed to measure the flow and collect water and algal samples during prefreshet (April), freshet (May and June) and postfreshet (August and November) periods.

Two days of detailed sampling were conducted at the Kishinena station during the August, 1979, trip, when that location was accessible by road rather than by helicopter.

Sampling in subsequent years was scheduled for times of presumed peak algal abundance. Sampling of water chemistry and algae was carried out at Akamina and Kishinena Creeks in August, 1980, and July, 1982. Water chemistry only was measured at Sage Creek in 1980.

Water samples were collected for suspended sediment analyses, and flow was measured on all occasions except the 1980 sampling trip.

Kishinena Creek is the only station which was sampled both before (1979) and after (1980, 1982) commencement of logging. Logging continued after the 1982 sample date (see Section V, Table 2 and Figures 2 and 3).

In August, 1983, an aerial reconnaissance of the Akamina-Kishinena Valley was flown, but no samples were collected.

# VII. METHODS

## A. Hydrographic Methods

Stream water velocity and discharge rates were determined using a Price No. 622 current meter and the wading measurements technique outlined by Braybrooks (1978).

## B. Analysis for Suspended Sediments

One to four replicate samples were collected and returned to Vancouver for analysis of suspended sediments. Samples were gathered using a depth-integrating suspended sediment hand sampler. In the laboratory the samples were settled for 3-4 weeks. Each bottle was weighed so that the total volume of the sample could be calculated. Then 100 ml was pipetted off and evaporated to determine the quantity of dissolved solids. Most of the remaining supernatant was siphoned off leaving about 50 ml stream water plus sediment. The bottle with the sample was weighed; then the sample was washed into a tared evaporating dish. The bottle was weighed again to calculate the exact volume of stream water plus sediment. The sediment was dried and weighed. The weight was corrected for dissolved solids.

## C. Water Chemistry Methods

### 1. Field Sampling

Samples for determination of nutrients, metals and major ions were collected, preserved as necessary in the field, and returned to Vancouver for analysis. Usually three replicates were collected for analyses of nutrients and metals, while single samples were taken for determination of major ions. Samples were gathered by dipping appropriate collecting bottles into the streams. Details of sampling for specific parameters are summarized in Table 3.

2. Laboratory Analytical Methods

Water chemistry analyses were performed in the Water Quality Branch Laboratory in Vancouver according to methods described in the NAQUADAT Dictionary (Inland Waters Directorate, Water Quality Branch 1983) and the Analytical Methods Manual (Inland Waters Directorate, Water Quality Branch 1979). All analyses used, with their identifying NAQUADAT code numbers and limits of detection, are listed in Table 4.

D. Aerial Reconnaissance and Photography

A pilot study was conducted in April, 1979, (Schreier 1979) to evaluate the use of photography for monitoring algal abundance and stream bank erosion. Sequential colour photographs were taken from a helicopter flown at low level above the Kishinena station. A Hasselblad camera with a 70-mm cassette attachment was used for the photography.

In order to determine whether the photographs could be used to estimate algal abundances or identify dominant species, the following experiment was conducted. Four ropes were set up across

TABLE 3. Field sampling procedures for water chemistry

| Parameter | Field Procedures and Sample Preservation |
|---|---|
| Total Phosphorus | Samples were collected in 50-ml sovirel glass bottles. The bakelite caps had teflon liner inserts to prevent phosphate contamination. Samples were packed in an ice-filled cooler. |
| Dissolved Phosphorus | Samples were collected in 100-ml sovirel glass bottles capped with teflon-lined bakelite caps. Each sample was filtered through a 47-mm Millipore HA (0.45μm pore diameter) filter which had been pre-soaked in distilled water. The filtering apparatus consisted of a Sartorius polycarbonate filter holder (47 mm diameter, Model SM 165 11). Positive pressure was provided by a hand pump. The filtrate was collected in a 50-ml soivrel glass bottle and packed in ice. |
| Nitrate and Nitrite, Ammonia, Total Dissolved Nitrogen, Particulate Carbon, Particulate Nitrogen | Samples were collected in 1-L polyethylene bottles. Each sample was filtered as soon as possible through a Whatman GF/F glass fibre filter which had been pre-cooked for 6 hours at 460 C. The filtering apparatus consisted of a glass filter holder coupled to a 1-L erlenmeyer flask, both of which had been prewashed in HCl. The vacuum was provided by a hand pump. The filtrate was collected in a 250-ml polyethylene bottle and packed in ice. The filter was transferred to a petri dish and placed in the cooler. In April and June, 1979, nitrogen samples were not filtered. |
| Metals (Ba, Cd, Cu, Fe, Mn, Ni, Pb, Zn) | Samples were collected in polyethylene bottles which which had been pre-washed in chromic acid cleaning solution. One milliliter of $HNO_3$ was added to each bottle prior to sampling. Care was taken so that acid was not lost during sampling. |
| Hg | Samples were collected in 100-ml teflon bottles which had been pre-washed with chromic acid cleaning solution. Two milliliters of 50% $HNO_3$ and 2.5% $K_2Cr_2O_7$ was added to each bottle prior to sampling. Care was taken so that acid was not lost during sampling. |
| As, Se | Samples were collected in 100-ml polyethylene bottles which had been pre-washed in chromic acid cleaning solution. |
| Major Ions, Residues, Physical Parameters | Two 1-L polyethylene bottles were filled with water. In the laboratory, aliquots were taken for analyses. |
| Total Inorganic Carbon/Total Organic Carbon (TIC/TOC) | Samples were collected in 100-ml polyethylene bottles and packed in ice. |

TABLE 4

NAQUADAT Code Numbers and Limits of Detection for the Water Chemistry Parameters Measured in the Akamina-Kishinena Watershed Study

| Parameter | NAQUADAT Number | Detection Limit |
|---|---|---|
| Colour | 02011 | 5.0 |
| Specific Conductance | 02041 | 0.2 µsie/cm |
| Water Temperature (Lab) | 02061 L | |
| Water Temperature (Field) | 02061 S | |
| Turbidity | 02073 | 0 jtu |
| Total Organic Carbon | 06001 | Variable |
| Total Inorganic Carbon | 06051 | 0.5 mg/L |
| Particulate Carbon | 06903 | Variable |
| $NO_3/NO_2$ (dissolved) | 07110 | 0.002 mg/L |
| Ammonia (dissolved) | 07557 | 0.002 mg/L |
| Total Nitrogen (unfiltered) | 07651 | 0.01 mg/L |
| Total Dissolved Nitrogen (filtered) | 07655 | 0.01 mg/L |
| Particulate Nitrogen | 07903 | Variable |
| Fluoride (dissolved) | 09106 | 0.05 mg/L |
| Alkalinity (total) | 10101 | 0.5 mg/L $CaCO_3$ |
| Alkalinity (phenolphthalein) | 10151 | 0.5[1] mg/L $CaCO_3$ |
| pH (Lab) | 10301 L | |
| Nonfilterable residue | 10401 | 10.0 mg/L |
| Filterable residue | 10451 | 10.0 mg/L |
| Nonfilterable residue (fixed) | 10501 | 10.0 mg/L |
| Filterable residue (fixed) | 10551 | 10.0 mg/L |
| Hardness (total) | 10603 | 0.5 mg/L $CaCO_3$ |
| Sodium (dissolved) | 11103 | 0.2 mg/L |
| Magnesium (dissolved) | 12101 | Calculated |
| Silica (reactive) | 14105 | 0.2 mg/L |
| Phosphorus (dissolved) | 15102 | 0.002 mg/L |

[1]This limit of detection applies at pH greater than 8.3. At lower pH phenolphthalein alkalinity = 0

Table 4 (Continued)

| Parameter | NAQUADAT Number | Detection Limit |
|---|---|---|
| Total phosphorus | 15406 | 0.002 mg/L |
| Sulphate (dissolved) | 16306 | 0.5 mg/L |
| Chloride (dissolved) | 17206 | 0.2 mg/L |
| Potassium (dissolved) | 19103 | 0.2 mg/L |
| Calcium (dissolved) | 20101 | 0.5 mg/L |
| Manganese (total) | 25004 | 0.01 mg/L |
| Manganese (extractable) | 25304 | 0.01 mg/L |
| Iron (total) | 26005 | 0.001 mg/L |
| Iron (extractable) | 26305 | 0.001 mg/L |
| Nickel (total) | 28002 | 0.001 mg/L |
| Nickel (extractable) | 28302 | 0.001 mg/L |
| Copper (total) | 29005 | 0.001 mg/L |
| Copper (extractable) | 29305 | 0.001 mg/L |
| Zinc (total) | 30005 | 0.001 mg/L |
| Zinc (extractable) | 30305 | 0.001 mg/L |
| Arsenic (extractable) | 33304 | 0.0001 mg/L |
| Selenium (extractable) | 34302 | 0.0001 mg/L |
| Cadmium (extractable) | 48302 | 0.0005 mg/L |
| Barium (extractable) | 56301 | 0.01 mg/L |
| Mercury (extractable) | 80311 | 0.05 µg/L |
| Lead (total) | 82002 | 0.001 mg/L |
| Lead (extractable) | 82302 | 0.001 mg/L |

the creek at 5-7 m intervals. The locations of these transects were marked with survey tape on tree trunks along the west bank of the creek so that the same sites could be identified for future sampling. Four random-length, brightly coloured survey tapes were attached at random intervals along each rope. At the end of each survey tape a metal spike was attached and anchored in the riverbed to identify individual rocks which were to be sampled for algal species composition. After the photography had been completed, the rock immediately downstream of each spike was collected and treated as described in Section VII-E. The sampling design is illustrated in Figure 4.

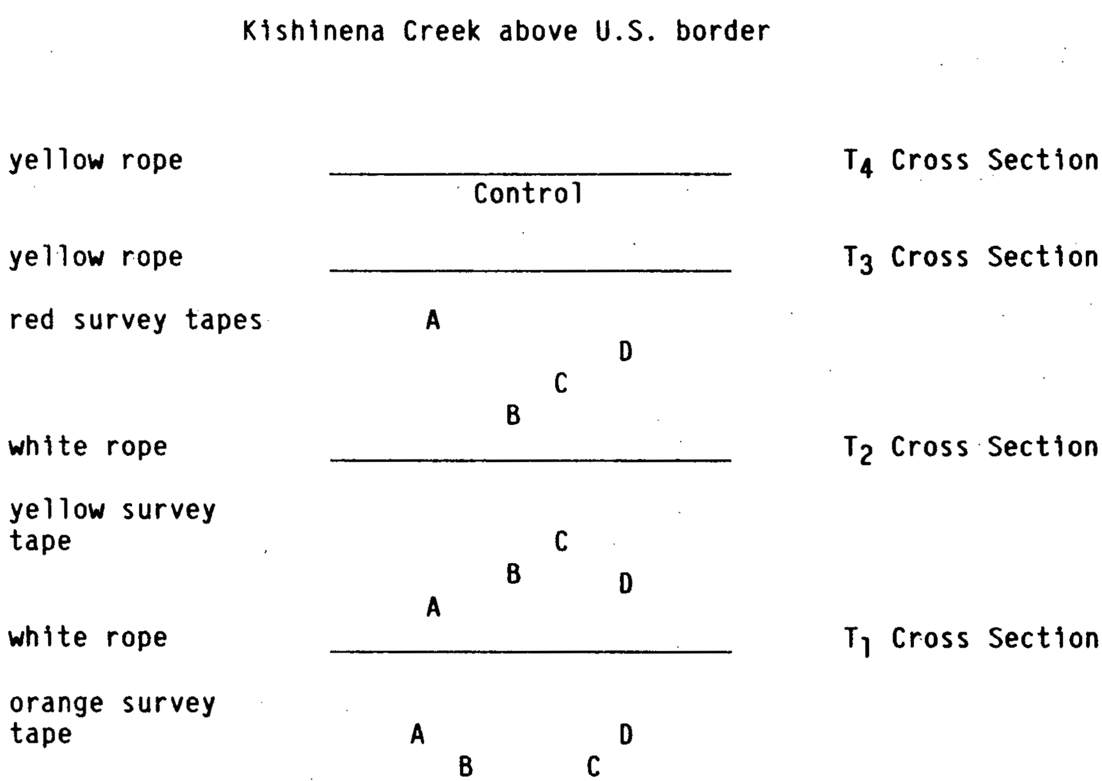


Figure 4. Sampling design for Kishinena Creek algae and photography

A more intensive study of stream morphology was undertaken in September, 1979. Sequential stereo, colour photographs were taken from a C-FC2A helicopter flown at altitudes ranging from 46 m - 610 m. Two Hasselblad MK 70 cameras with a 100-mm lens were mounted on a boom under the aircraft. The effort resulted in continuous photographic coverage of Kishinena Creek from the border to the sampling station. Additional photographs were taken at Kishinena Creek upstream from the sampling station and at the Akamina Creek station. Detailed photographic monitoring was not continued after the pilot studies but observations were made from the helicopter on all subsequent trips, and photographs were taken to document stream bank stability and any other notable conditions.

## E. Algal Methods

The algal sampling methods were based on experience gained in other sections of the Flathead River Basin (Sheehan et al. 1980). Periphyton were collected from whole rocks, which had provided the best estimates of abundance. Phytoplankton were not sampled, because in the western tributaries of the Flathead, phytoplankton abundances had been low and species composition suggested that the cells were mainly detached periphyton.

### 1. Sample Collection and Preservation

Rocks with surface areas approximately 50-300 $cm^2$ (occasionally larger or smaller) were collected for quantitative algal analyses. Usually four rocks were chosen randomly at each station. In addition, rocks with unusual growths were collected as qualitative samples.

More intensive sampling occurred at Kishinena Creek, April - August, 1979. Collection of the April samples has been described in Section VII-D. In May and June, four rocks were chosen randomly from each of the transects illustrated in Figure 4. For the August samples, 23, 4, and 27 rocks were collected from transects 1, 2, and 3, respectively.

Quantitative sampling of periphyton has been described in detail by Sheehan et al. (1980). Briefly, rocks were scraped with a toothbrush to remove algae, which were then washed into collecting bins with distilled water. Following transfer to glass jars, algal samples were placed in a dark cooler for transportation. Rock surface areas were determined by making templates with aluminum foil and tracing the shapes onto paper for later measurement with a polar planimeter.

In the evening following collection, samples were divided and preserved for several laboratory analyses. The 1978-1980 samples were wet filtered as described by Sheehan et al. (1980). Each filter was subdivided using a razor blade: 1/2 for chlorophyll a analysis, 1/4 for estimates of abundances of major algal groups and non-diatom species, and 1/4 for diatom counts. Chlorophyll a subsamples were treated with magnesium carbonate, filtered until dry, and then frozen. Diatom and non-diatom subsamples were washed into glass jars and preserved with acid Lugol's solution. In 1982, samples were subdivided using a plankton splitter instead of filtration. Subsamples were preserved in acid Lugol's solution for diatom and non-diatom identifications. Chlorophyll a analyses were not done.

## 2. Analytical Procedures

### a. Chlorophyll a

Samples for chlorophyll a determinations were extracted in 90% acetone with a High Speed Polytron Homogenizer and measured on a Technicon autoanalyzer (Sheehan et al. 1980; G. Kan, personal communication).

### b. Algal Division Abundance

The relative abundance (by volume) of each algal division was measured with an inverted microscope as detailed by Northcote et al. (1975). Non-diatom species were identified using the descriptions of Prescott (1962), and Bourrelly (1966 - 1970).

### c. Diatom Enumeration

From 1978-1980, diatoms were prepared for enumeration by cleaning with nitric acid (Patrick and Reimer 1966), followed by evaporation of drops of known volume onto cover slips. The cover slips were then mounted onto microscope slides with Hyrax mounting media (refractive index 1.63). The 1982 samples were prepared by cleaning with sulfuric acid, potassium permanganate, and oxalic acid (Hasle and Fryxell 1970). Subsamples of known volume were pipetted into evaporation dishes, each of which contained four circular cover slips. The samples were evaporated onto the cover slips as described by Battarbee (1973) and mounted onto slides with Hyrax Media. Only one slide from each sample was examined. Diatoms were counted by examining transects using a phase contrast microscope at 1000X magnification. All diatoms encountered were identified and counted until a minimum of 100 frustules of the dominant species and a total of at least 300 frustules had been counted. Because high magnification can produce errors in the counts of large diatoms, e.g. Gomphonema geminatum, the sample was re-examined at 200X magnification and only the large diatoms counted. Suitable conversion factors were used to transform counts to cells/$cm^2$.

Numerous references were consulted for identification and classification of diatoms. Keys employed were Patrick and Reimer (1966), Cleve-Euler (1951-1955), Hustedt (1930, 1931-1959), Huber-Pestalozzi (1942), Sreenivasa and Duthie (1973) and Weber (1966). Bourrelly's (1968) taxonomic scheme was followed to place the diatoms into orders, and the species classification outlined by Van Landingham (1967-1979) was followed, except that Cymbella caespitosa was recognized as a distinct species.

d. Statistical Procedures

Diatom species diversities were calculated for each rock using the Shannon-Wiener formula (Shannon and Weaver 1949):

$$H' = -\sum_{i=1}^{n} p_i \log_2 p_i$$

where $H'$ = diversity index

$p_i$ = proportion of total sample belonging to the ith species

$n$ = total number of species

Composite species diversities for each station at each time were also calculated as follows:

The number of each species per square centimeter on each rock was multiplied by the surface area of the rock to give the total number of cells. Cell counts of each species were summed over all rocks and the numbers obtained were used to calculate overall proportional abundances and the diversity index.

Two-way factorial analyses of variance were used to compare 1979 chlorophyll a concentrations, total diatom cell density, number of diatom species, and diatom diversity per rock among stations and times. In order to balance sample sizes, four rocks were selected at random from the April-August Kishinena Creek data, and only values from those rocks were used in the ANOVAS, although means of all samples were graphed (Fig. 14, 17, 18, 19). Statistical tests were performed using the BMDP:P7D statistical software (Dixon 1983).

All data were tested for homogeneity of variance using Levine's test (as described by Brown and Forsythe 1974), which is included in the BMDP:P7D program. In all cases, Levene's test showed significant heteroscedasticity ($P<0.001$). However, the $V_{max}$ test (Sokal and Rohlf 1969) showed no significant differences in variance. Sokal and Rohlf argue, "The consequences of moderate heterogeneity of variances are not too serious for the overall test of significance [in the ANOVA], but single degree of freedom comparisons may be far from accurate". Thus, overall significances, which will be reported in Section VII-F, should be valid, but detailed comparisons of group means are impossible.

# VIII. RESULTS AND DISCUSSION

## A. Hydrology

Discharge measurements for Akamina, Kishinena, Sage, and Elder Creeks suggested that the 1979 sampling dates encompassed pre-freshet, freshet and post-freshet periods (Figure 5). Highest flows were recorded on June 14 at all stations except Elder Creek, where maximum discharge was measured on May 15. More detailed hydrographic data measured at gauging stations on the Flathead River and several of its western tributaries suggest that maximum discharge actually occurred sometime between the May and June sampling dates (Inland Waters Directorate, Water Survey 1979). Measurements were not made in the eastern tributaries during the period of ice cover, which probably occurred between December and March (Sheehan et al. 1980).

Discharge rates appear more closely related to drainage area (Table 1) than to presence or absence of logging activity in the watersheds. Discharge rates of Akamina and Elder Creeks are similar as are those of Kishinena and Sage Creeks.

There are not enough hydrographic data to determine whether logging had any effect on the discharge in Kishinena Creek. The single post-logging measurement, made in July, 1982, is within the range of the 1979 values, implying that no drastic change occurred, but a single measurement taken during summer low flow is inadequate for

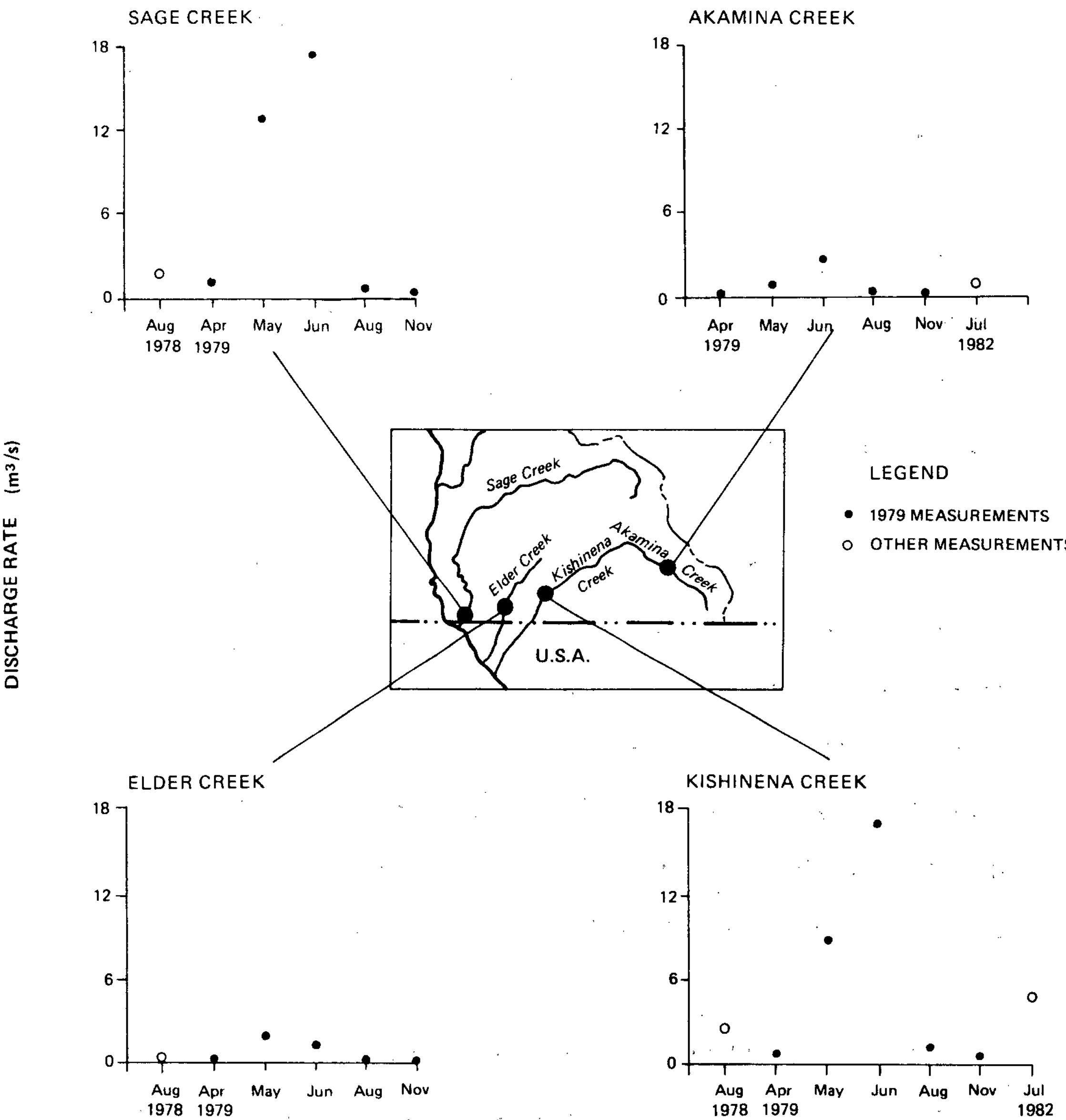


Fig. 5 Discharge rates measured at four stations in the eastern Flathead River Basin, August 1978 - July 1982.

drawing conclusions. Logging-induced changes in discharge of Pacific Northwest streams are most pronounced during fall and winter storms (Rothacher 1970) and may be difficult to demonstrate in summer.

B. Suspended Sediments

Suspended sediment levels were low at all stations (Figure 6). Maximum concentrations were measured during freshet (May-June), but mean values never exceeded 10 mg/L.

No increase in sediment concentrations at the Kishinena station was shown by the post-logging measurement in July, 1982. However, based on the 1979 hydrograph, it appears this sample was taken after freshet. Increases in sedimentation and turbidity may be apparent only during storms or other periods of high flow (Aubertin and Patric 1974, Beschta 1978), and Beschta (1978) cautions that monitoring during low flow is of little use.

Although high sediment loads were not measured in the present study, it is possible that sediments will become a problem in the future. Increases in suspended sediments and other particulate matter may not become apparent until 2 - 7 years after the construction of logging roads (Beschta 1978, Gurtz et al. 1980). However, the delayed mass failures of logging roads that Beschta (1978) observed may never occur in the Akamina-Kishinena Valley due to the logging methods described in Section V-C.

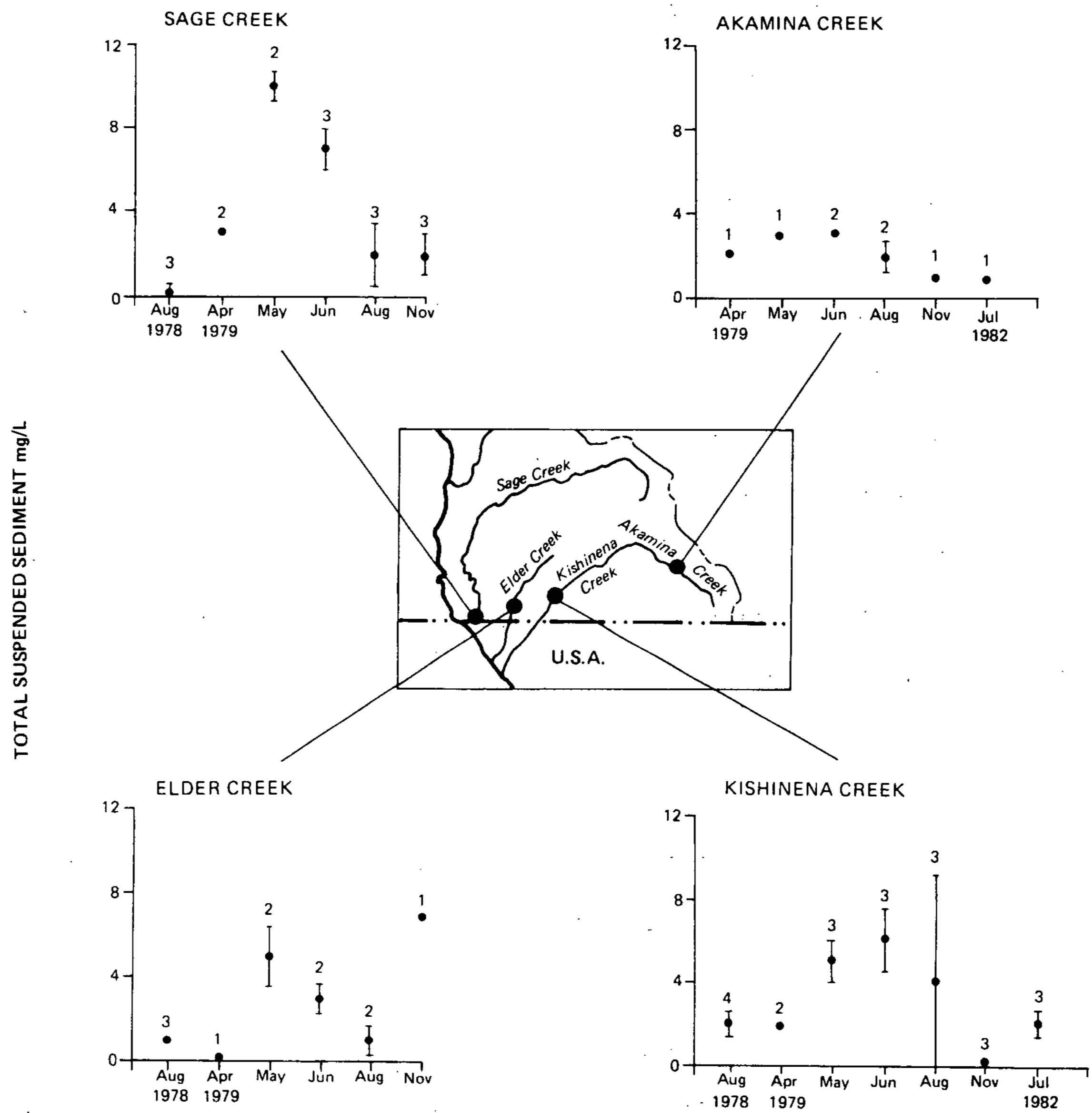


Fig. 6 Concentrations of total suspended sediments in the eastern Flathead River Basin, August, 1978 - July, 1982. The solid circle and vertical bars represent the mean ± one standard deviation. The number of replicates is indicated above each point.

## C. Water Chemisty

Detailed water chemistry data may be obtained from the Akamina-Kishinena data report (Smith et al. 1984).

### 1. Nutrients

Concentrations of nutrients were low at all stations. The maximum concentration of total phosphorus, 0.01 mg/L, recorded at Sage and Elder Creeks (Figure 7) was equal to or lower than most values measured elsewhere in the Flathead River Basin (Sheehan et al. 1980). Total dissolved nitrogen and nitrate plus nitrite levels (Figures 8 and 9) were similar to, while ammonia concentrations (Figure 10) were somewhat lower than levels measured in the western Flathead Basin (Sheehan et al. 1980). These nutrient levels suggest that the term "ultraoligotrophic", which Sheehan et al. applied to the Flathead River and its western tributaries, is also applicable to the eastern tributaries.

Nutrient limitations have often been discussed by researchers in terms of nitrogen and phosphorus ratios. In the eastern Flathead basin we measured only total phosphorus (TP), because the phosphorus levels were so low that measurements of dissolved phosphorus or orthophosphate would have been inaccurate; therefore, our data can only be compared with ratios based on TP. Sakamoto (1966) modelled the relationship between chlorophyll yield and the ratio (based on weights) of

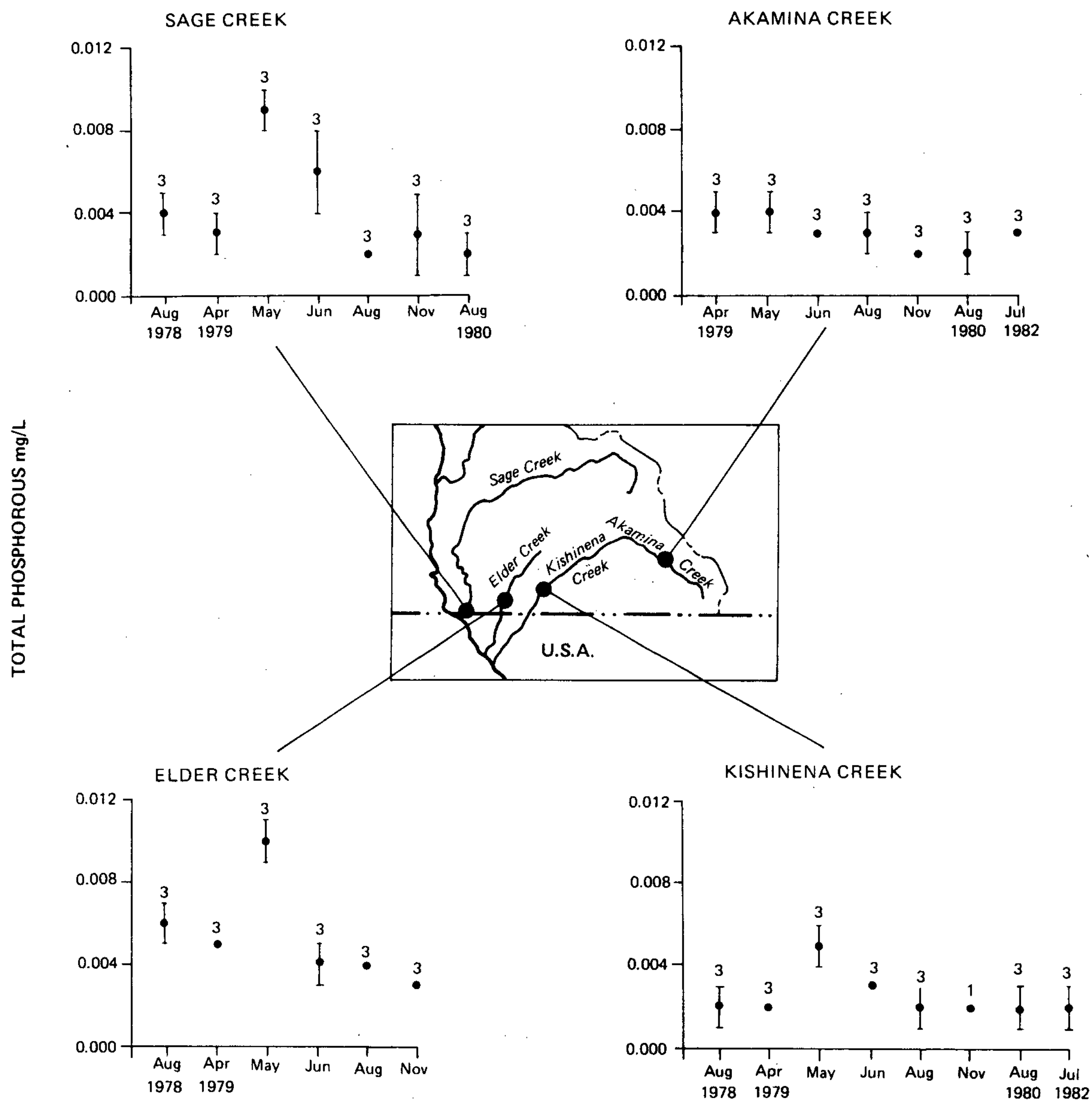


Fig. 7 Concentrations of total phosphorus in the eastern Flathead River Basin, August, 1978 - July, 1982. The solid circle and vertical bars represent the mean ± one standard deviation. The number of replicates is indicated above each point.

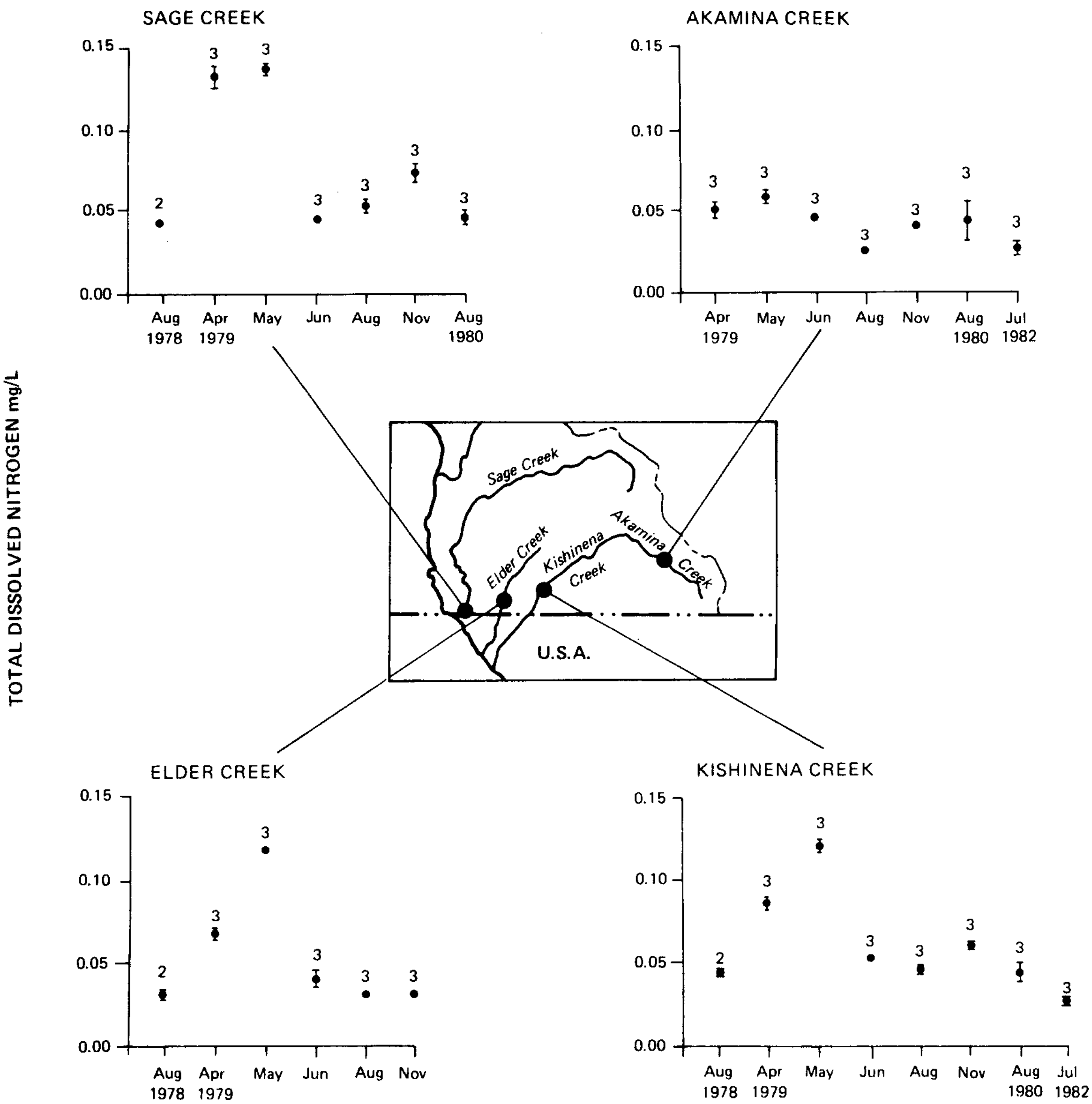


Fig. 8 Concentrations of total dissolved nitrogen in the eastern Flathead River Basin, August, 1978 - July, 1982. The solid circle and vertical bars represent the mean ± one standard deviation. The number of replicates is indicated above each point.

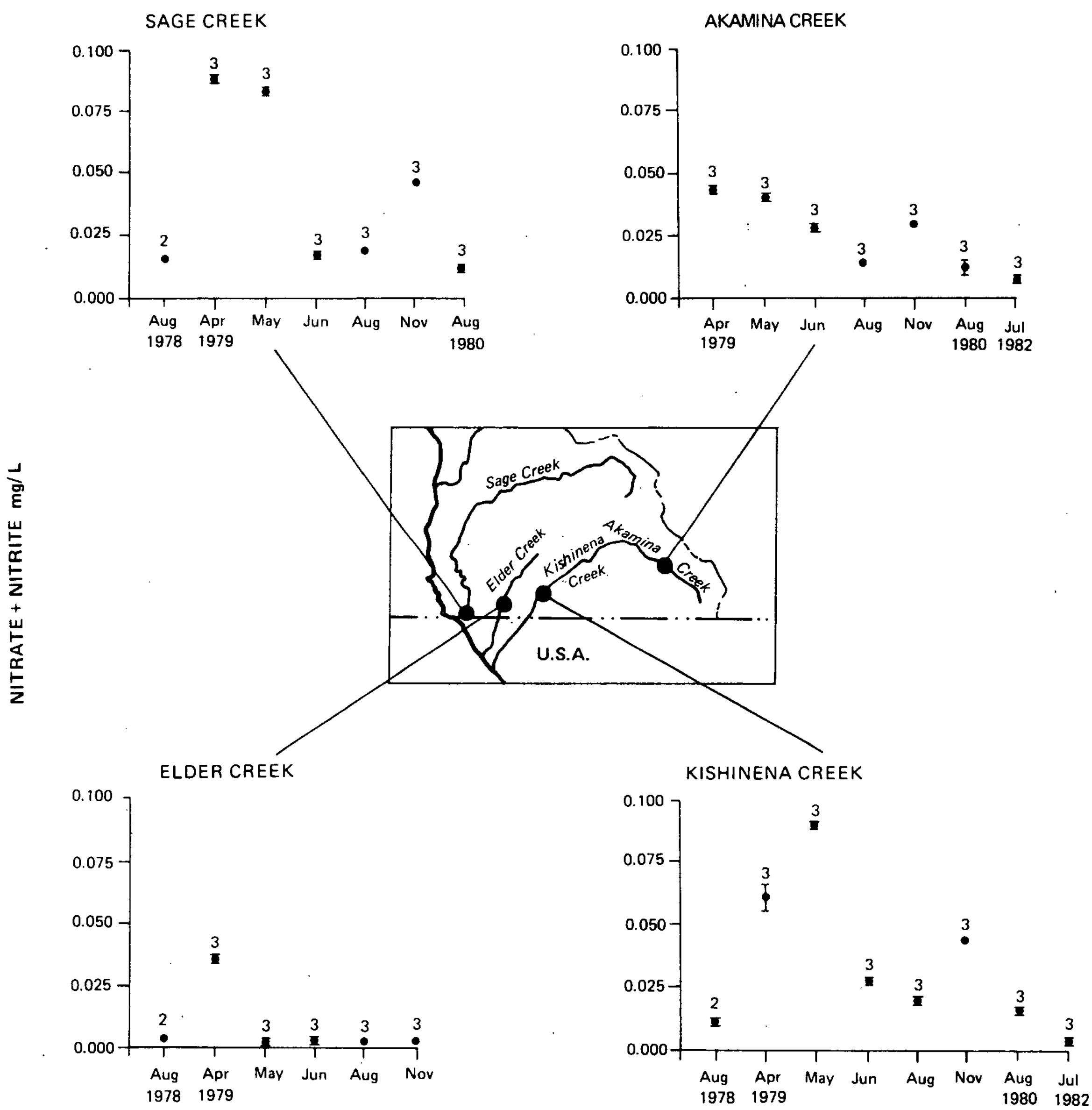


Fig. 9 Concentrations of nitrate ($NO_3$) plus nitrite ($NO_2$) in the eastern Flathead River Basin, August, 1978 - July, 1982. The solid circle and vertical bars represent the mean ± one standard deviation. The number of replicates is indicated above each point.

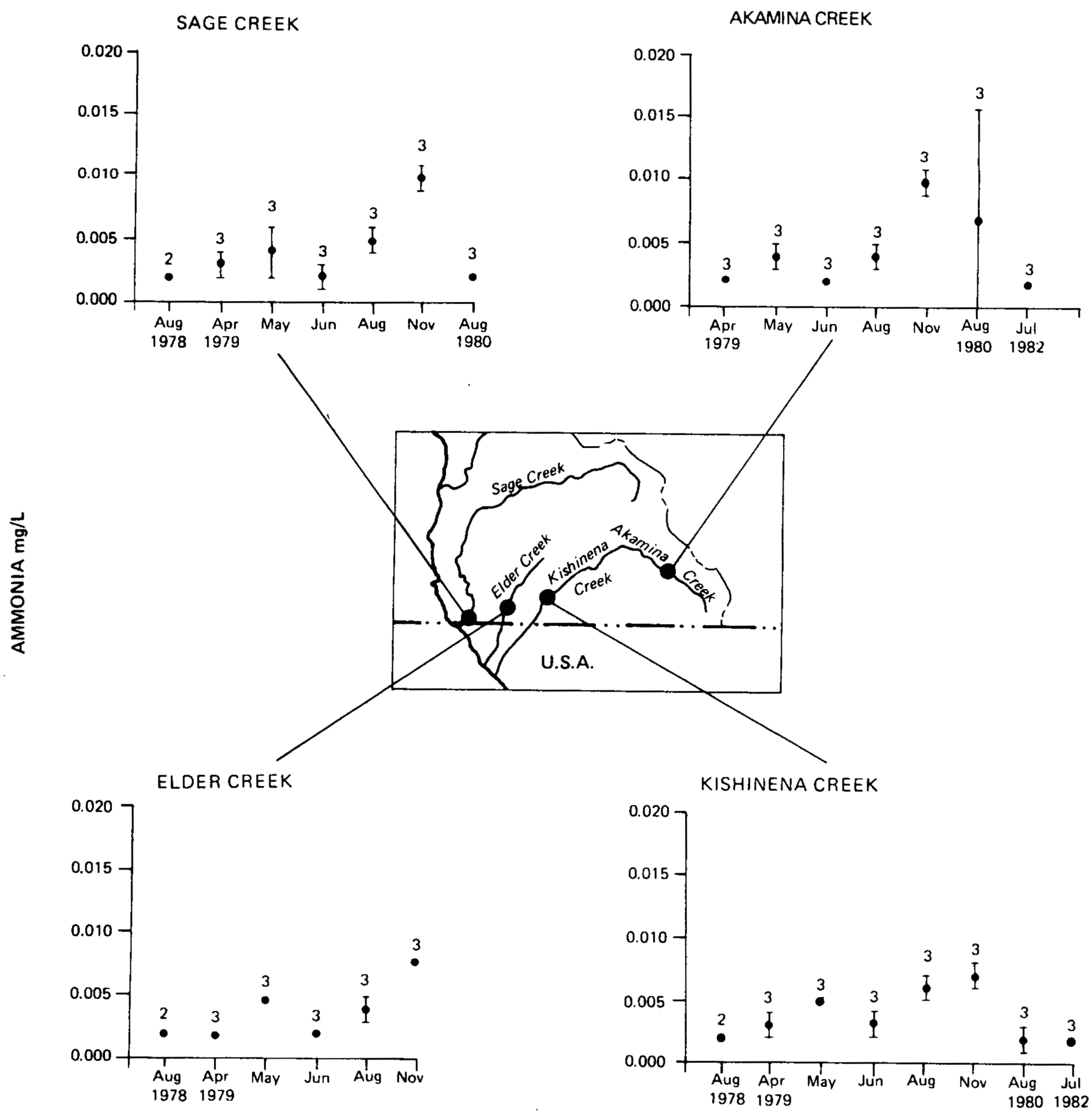


Fig. 10 Concentrations of ammonia in the eastern Flathead River Basin, August, 1978 - July, 1982. The solid circle and vertical bars represent the mean ± one standard deviation. The number of replicates is indicated above each point.

total nitrogen (TN) to TP in Japanese lakes. He concluded that when TN:TP ratios were between 9-10 to 15-17, nitrogen and phosphorus were nearly balanced. At TN:TP≥15-17 phosphorus was the limiting nutrient, while for TN:TP≤9-10 nitrogen became critical. Forsberg et al. (1978) derived the same critical TN:TP ratios using calculations based on samples from Swedish lakes and data from algal assays. Since optimum N:P ratios for different algal species vary widely (Rhee and Gotham 1980), Smith (1982) argued that with changes in the TN:TP ratio, species shifts should occur, and algal biomass should be dependent on both nitrogen and phosphorus over an even wider range of ratios.

In the eastern Flathead basin, the ranges of mean TN: mean TP (where TN = total dissolved nitrogen plus particulate nitrogen) over the study period were: Akamina Creek 9.2-53, Kishinena Creek 14.8-51, Elder Creek 6.8-13.6, Sage Creek 7.5-44.3. It is not possible to use these ratios to conclude that either nutrient alone always limits algal growth in these streams because the range of variability encompasses both nitrogen and phosphorus limitation as defined by Sakamoto (1966) and Forsberg et al. (1978). Further, it is unclear whether ratios derived for lakes can be applied to streams. Additional study, preferably including in situ growth experiments, would be needed to resolve the question of nutrient limitation.

The nutrient chemistry of Elder Creek differed somewhat from that of the other streams. On most dates TN:TP ratios were lower at Elder Creek than elsewhere, but these ratios do not reflect the full extent of the difference. Inorganic nitrogen (nitrate plus nitrite plus ammonia), which is usually considered most readily available to algae, comprised on average only 18% of the total nitrogen at Elder Creek, while at the other stations inorganic nitrogen represented 47-58% of the total. This difference is the result of exceptionally low nitrate plus nitrite concentrations in Elder Creek (Figure 9).

Few post-logging (1980 and 1982) differences in nutrient concentration were observed at the Kishinena station. No changes in total phosphorus or ammonia levels were measured in either year. In 1980 total dissolved nitrogen and nitrate-nitrite concentrations were within the range of previous measurements. These results are similar to those of a study in the Okanagan Basin, where total phosphorus, total dissolved nitrogen, and nitrate plus nitrite levels were not significantly different in control streams than in a stream draining a watershed which had been patch cut one year earlier (Hetherington 1976). In 1982 total dissolved nitrogen and nitrate-nitrite levels were somewhat lower than any previous measurements, but not enough data are available to interpret the significance of this change.

2. Carbon

Total organic carbon concentrations were similar in both the eastern and western tributaries to the Flathead, but total inorganic carbon concentrations were usually lower in the eastern drainage (see Sheehan et al. 1980, 1984). All total inorganic carbon levels in Akamina, Kishinena, and Elder Creeks were below the minimum values measured at five of the eight western stations and less than the maxima recorded in each of the western tributaries (Sheehan et al. 1983). The concentrations recorded at Sage Creek fell within the range measured in the earlier study (Figure 11).

Hetherington (1976) measured higher total organic carbon concentrations in a stream draining a logged area than in control streams in the Okanagan Basin but found no change in total inorganic carbon levels which could be attributed to logging. Inorganic and total organic carbon concentrations measured at Kishinena Creek following logging were no higher than those measured previously. Total organic carbon was below detection limits at the Kishinena station in both 1980 and 1982, but whether this represents an actual decline in concentration is difficult to assess since variable detection limits of the analytical method make comparisons of low levels on different dates impossible.

Particulate carbon may increase after forest harvesting due to

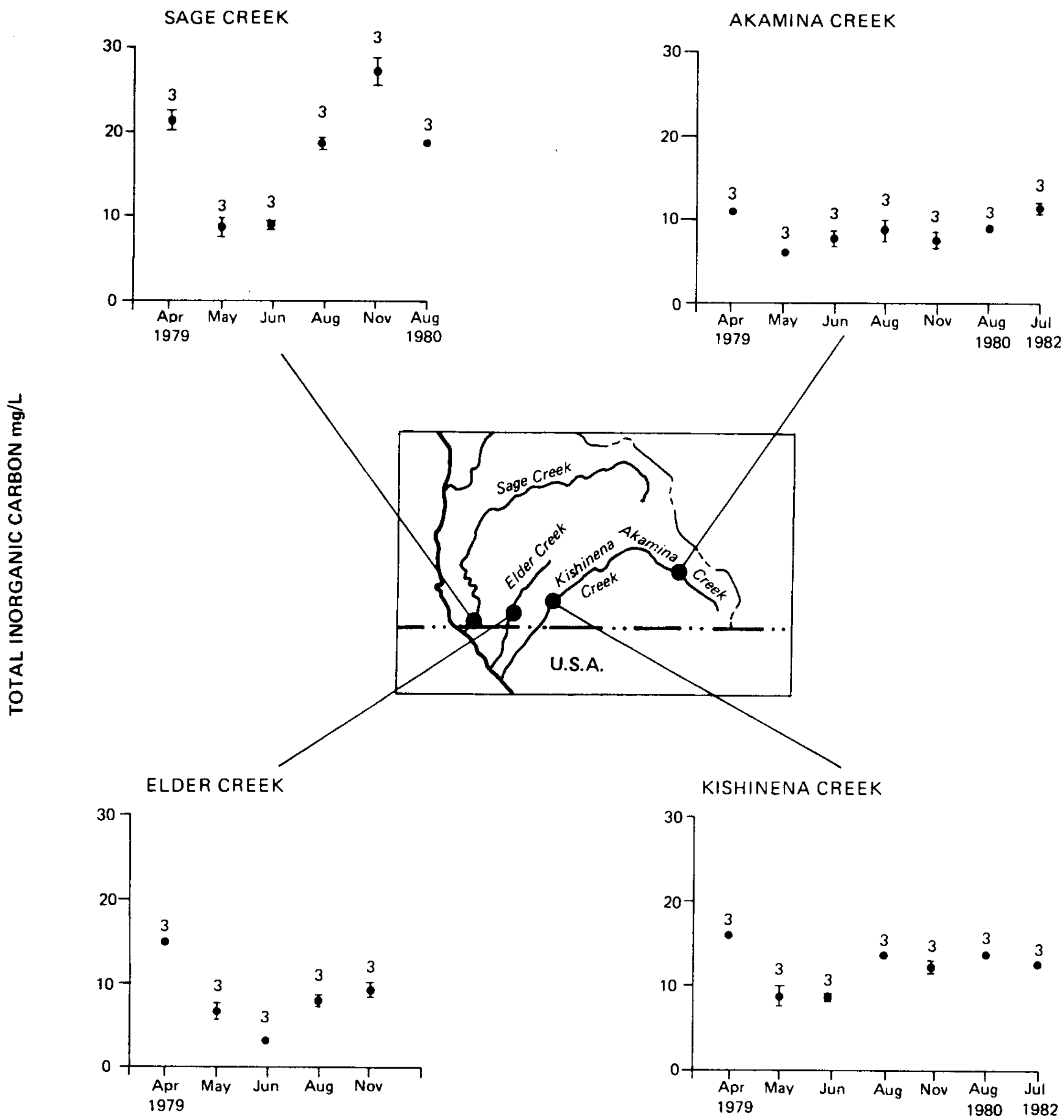


Fig. 11 Concentrations of total inorganic carbon in the eastern Flathead River Basin, April, 1979 - July, 1982. The solid circle and vertical bars represent the mean ± one standard deviation. The number of replicates is indicated above each point.

intrusion of logging debris (Gurtz et al. 1980), but no increase was observed in 1980 or 1982 in Kishinena Creek (Figure 12).

3. Metals

Metal levels were generally low at all stations. Mercury and cadmium levels were always below the limits of detection, 0.05 µg/L and 0.0005 mg/L respectively. Mean concentration ranges of other metals (for total and/or extractable, unless indicated otherwise) at the four stations were total iron 0.018-0.165 mg/L, extractable iron 0.018-0.092 mg/L, copper 0.002-0.004 mg/L, manganese 0.010-0.014 mg/L, nickel <0.001-0.001 mg/L, zinc <0.001-0.004 mg/L, arsenic 0.0001-0.0002 mg/L, selenium <0.0001 mg/L, barium <0.10-0.16 mg/L, lead <0.001-0.001 mg/L. No values higher than Canadian Drinking Water Standards (Canada Department of National Health and Welfare 1968) were ever recorded. Metal levels following logging at Kishinena Creek were within the range of previous measurements.

4. Major Ions and Other Parameters

Calcium was the dominant major cation in the watersheds studied. Its concentration was at least double that of any other cation measured (Table 5).

Concentrations of most major ions (Table 5) fell within the ranges measured in the western Flathead Basin (Sheehan et al. 1980). However, the reactive silica ($SiO_2$) level at Elder

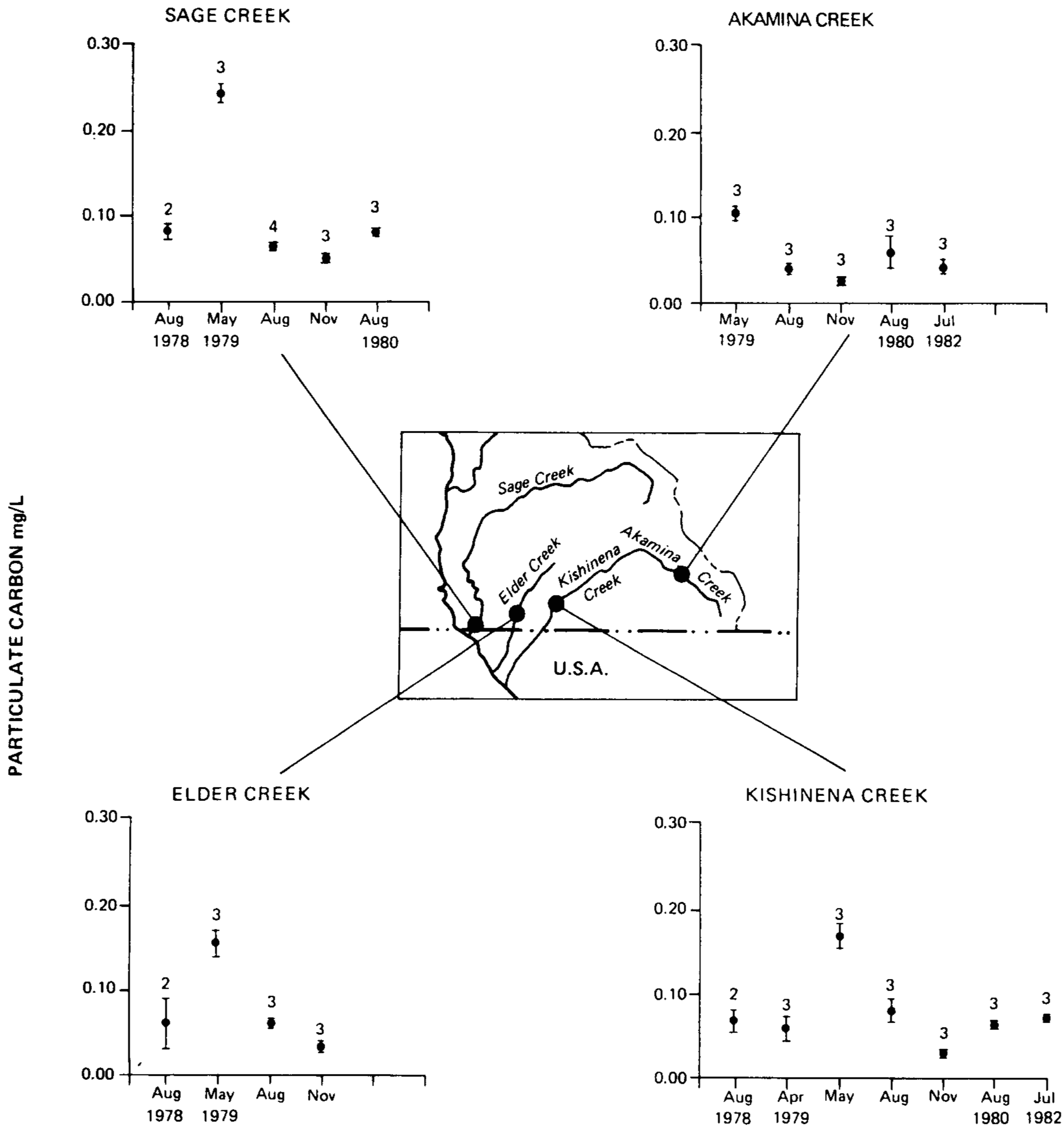


Fig. 12 Concentrations of particulate carbon in the eastern Flathead River Basin, August, 1978 - July, 1982. The solid circle and vertical bars represent the mean ± one standard deviation. The number of replicates is indicated above each point.

Creek and the sulfate levels at Akamina and Kishinena Creeks were higher than any values measured in the earlier study.

Total alkalinity and pH fell within or below the lower range of values measured by Sheehan et al. (1980) in the western Flathead drainage (Table 6).

Changes in concentrations of many dissolved substances have been reported following logging. Total dissolved solids and electrical conductivity (specific conductance), which both reflect the relative abundance of ions in water, were higher in streams draining a logged watershed than in control streams in the Okanagan Basin (Hetherington 1976). Higher concentrations of potassium, sodium, and chloride, which apparently had resulted from logging, and elevated calcium, silica, and hardness not directly attributable to logging were also observed (Hetherington 1976). In the Bitterroot Range, Montana, conductivity and levels of divalent cations were lower in streams draining clearcut watersheds than in streams draining unlogged watersheds. Levels of these parameters in Kishinena Creek in 1980 and 1982 were similar to previous levels (Figure 13, Smith et al. 1984).

D. Temperature

All water temperature values are listed in the data report (Smith et al. 1984).

TABLE 5 Means and ranges of concentrations for major dissolved ions (mg/L), based on the entire sampling period.

| Ion | | Akamina | Kishinena | Elder | Sage |
|---|---|---|---|---|---|
| F | Max | 0.05 | 0.14 | 0.06 | 0.07 |
| | Mean | 0.05 | 0.06 | 0.05 | 0.05 |
| | Min | <0.05 | <0.05 | <0.05 | <0.05 |
| Na | Max | 3.9 | 2.2 | 2.1 | 2.1 |
| | Mean | 1.3 | 1.3 | 1.5 | 1.6 |
| | Min | 0.7 | 0.7 | 0.8 | 0.8 |
| $SiO_2$ | Max | 5.0 | 5.1 | 7.3 | 6.0 |
| | Mean | 4.5 | 4.5 | 6.7 | 5.3 |
| | Min | 4.2 | 4.0 | 5.6 | 4.2 |
| $SO_4$ | Max | 27.0 | 26.0 | 9.0 | 15.6 |
| | Mean | 17.8 | 14.5 | 5.0 | 9.7 |
| | Min | 9.1 | 5.9 | 2.6 | 3.8 |
| Cl | Max | 0.3 | 0.8 | 0.4 | 0.7 |
| | Mean | 0.2 | 0.4 | 0.2 | 0.5 |
| | Min | <0.2 | <0.2 | 0.1 | 0.3 |
| K | Max | 0.4 | 0.4 | 0.3 | 0.6 |
| | Mean | 0.2 | 0.3 | 0.2 | 0.4 |
| | Min | <0.2 | 0.2 | 0.1 | 0.2 |
| Ca | Max | 16.2 | 23.9 | 16.9 | 33.4 |
| | Mean | 13.2 | 18.9 | 11.3 | 24.4 |
| | Min | 9.5 | 12.1 | 5.2 | 11.5 |
| Mg (calculated) | Max | 7.7 | 6.9 | 4.5 | 8.6 |
| | Mean | 5.9 | 5.2 | 3.1 | 6.0 |
| | Min | 4.2 | 3.8 | 1.7 | 3.4 |

TABLE 6 Means and ranges of some physical water quality parameters over the entire sampling period.

| Parameter | | Akamina | Kishinena | Elder | Sage |
|---|---|---|---|---|---|
| | Max | 5 | 5 | 20 | 5 |
| Colour | Mean | <5 | <5 | 7 | <5 |
| (relative units) | Min | <5 | <5 | <5 | <5 |
| | Max | 140.0 | 181.0 | 125.0 | 209.0 |
| Specific Conductance | Mean | 119.2 | 140.5 | 83.6 | 167.7 |
| (μsiemens/cm) | Min | 94.2 | 93.9 | 40.4 | 84.2 |
| | Max | 0.8 | 1.5 | 1.3 | 1.9 |
| Turbidity | Mean | 0.5 | 0.5 | 0.7 | 0.8 |
| (jtu) | Min | 0.2 | 0.2 | 0.4 | 0.3 |
| | Max | 43.3 | 64.0 | 59.7 | 106.0 |
| Total Alkalinity | Mean | 41.0 | 55.9 | 38.7 | 78.4 |
| (mg $CaCO_3$/L) | Min | 37.2 | 41.0 | 18.2 | 39.2 |
| | Max | 7.8 | 8.0 | 7.9 | 8.2 |
| pH | Mean | 7.7 | 7.9 | 7.7 | 8.1 |
| | Min | 7.5 | 7.7 | 7.5 | 7.9 |
| | Max | 68.0 | 88.1 | 60.6 | 119.0 |
| Hardness | Mean | 57.3 | 68.7 | 40.9 | 85.5 |
| (mg $CaCO_3$/L) | Min | 45.6 | 46.0 | 20.0 | 42.8 |

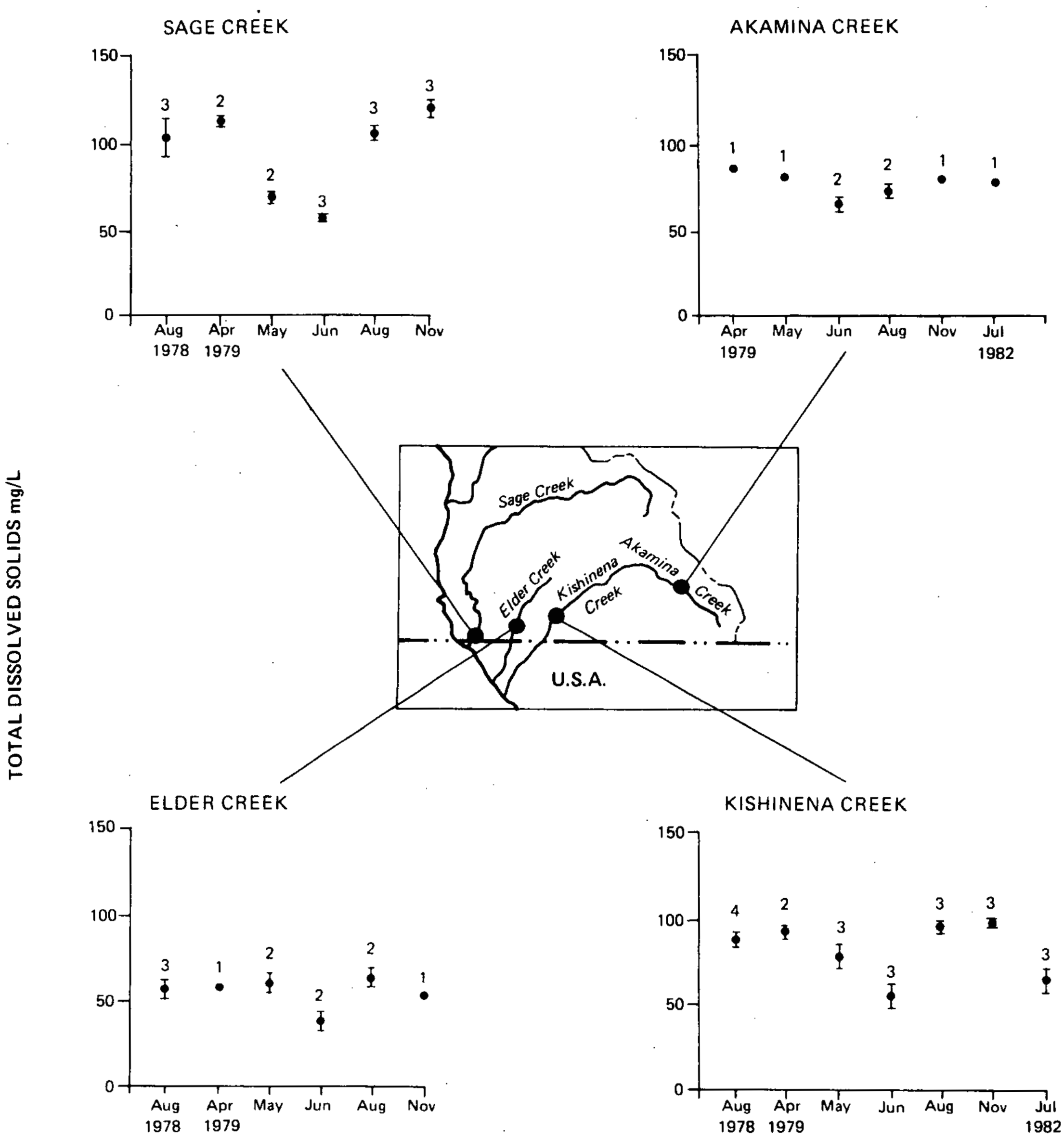


Fig. 13 Concentrations of total dissolved solids in the eastern Flathead River Basin, August, 1978 - July, 1982. The solid circle and vertical bars represent the mean ± one standard deviation. The number of replicates is indicated above each point.

Because water temperatures were measured at different times of day and under different weather conditions, it is impossible to make comparisons among stations or times. However, it may be possible to infer post-logging changes in stream water temperature from the algal data. Patrick (1977) predicts that a change in algal species composition should result from a temperature shift. For example, a rise in stream temperature should cause a loss of cold-loving species. This possibility will be discussed further in Section VIII-F-3C.

E. Aerial Observation and Photography

Colour photographs taken from the helicopter proved inadequate for monitoring periphytic algae. Wind created by the helicopter produced ripples on the water surface which reduced the quality of the photos. Individual rocks could be identified in the photographs, but it was impossible to analyze in detail the algal species present. Interpretation of the photographs was further complicated because rocks present in the stream bed ranged in colour from grey to green to red.

Aerial observation was useful for assessing stream bank and related conditions. During the April pilot study (prior to any logging) active natural stream bank erosion was noted in several places along Kishinena Creek. Stereo photographs also provided clear documentation of stream morphology and bank conditions. The photographic sequence has never been repeated, but these photographs could be used to assess morphological changes in Kishinena Creek between the border and the sampling station, if in the future such a study becomes necessary.

On more recent sampling trips some changes in stream conditions have been noted. In 1983, a major log jam was observed in the Kishinena Canyon. This debris appeared to have originated from natural events such as snow avalanches or insect infestations, rather than from any activity associated with logging.

## F. Algal Data

### 1. Chlorophyll a

Although chlorophyll a concentrations varied greatly among rocks (Figure 14), all values measured fell within the range reported for oligotrophic waters. These values were less than or equal to the mean 19.1-51.0 $mg/m^2$ found in oligotrophic Lake Superior (Stokes et al. 1970) and well below levels of 300 $mg/m^2$ of a stream in the Rocky Mountains of Utah (McConnell and Sigler 1959) and the 220-1200 $mg/m^2$ reported from several other flowing water systems (Moss 1968). However, chlorophyll a concentrations in this study were generally higher than the 1.6 $mg/m^2$ and 2.3 $mg/m^2$ reported from Carnation and Ritherdon Creeks on Vancouver Island (Stockner and Shortreed 1976).

Chlorophyll a concentrations measured in Akamina, Kishinena,

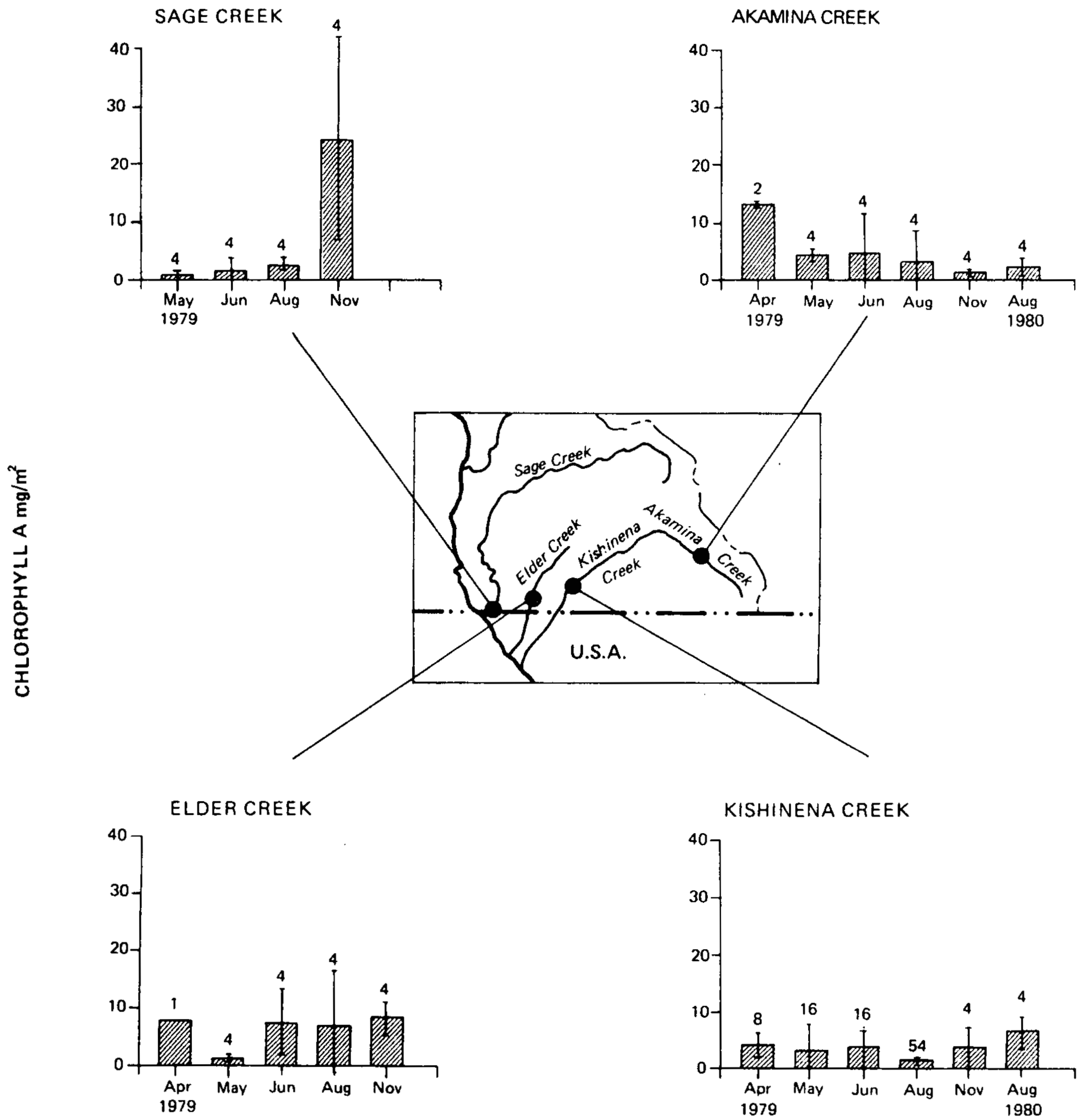


Fig. 14 Mean chlorophyll *a* concentrations measured in periphytic algae from the eastern Flathead River Basin, April, 1979 - August, 1980. Vertical lines represent standard deviations. Numbers above the bars indicate the number of rocks sampled.

Elder, and Sage Creeks were usually higher than the 1.0 $mg/m^2$ which Sheehan et al. found on most whole rocks in the western Flathead basin. The reason for this difference is unclear, since nutrient levels were somewhat lower in the eastern tributaries than in the western section (see Section VIII-C-1). Other factors such as turbidity, light availability and flow velocity could account for the difference. The apparent difference may be an artifact, because the low number of whole rock samples in the Flathead study may not have encompassed the entire range of variation.

Analysis of variance revealed no significant differences in chlorophyll a levels among the four eastern sampling stations ($P>0.05$). Differences among sampling dates and the interaction were significant ($P<0.01$). Because of heteroscedasticity, valid comparisons among individual sampling dates could not be done, but it appears (Figure 14) that most of the difference is due to the high chlorophyll values recorded at Sage Creek in November.

It is unclear why chlorophyll a levels should have been high at Sage Creek in November, 1979. The total phosphorus level was not elevated (Figure 7). Total nitrogen and nitrate/nitrite concentrations were higher than those measured in the summer months but not as high as the pre-freshet peaks (Figures 8 and 9). The proportions of these nutrients which were biologically available is not known. Differences in factors such as light, scouring, and grazing were not measured but could have limited algal standing crop at other sampling times. Higher nutrient levels prior to the sampling date may have been reflected in the November chlorophyll values.

A flush of nutrients into a watershed following logging can increase algal productivity (Stockner and Shortreed 1976, Meyer and Tate 1983). No such flush was measured in Kishinena Creek (see Section VIII-C-1), but no samples were taken between November, 1979 and August, 1980. Had nutrient levels risen during that period the change might have been shown indirectly by increased chlorophyll a levels. However, no increase in biomass was apparent in the 1980 samples (Figure 14).

2. Algal Division Abundance

The dominant periphytic algae at all four stations were diatoms (Chrysophyta-Bacillariophyceae). They comprised >50% by volume of the algae in all collections except the April samples at Elder Creek, when green algae (Chlorophyta) were dominant, the May samples at Sage Creek when Chrysophyceae were most abundant, and the November samples at Elder Creek, when diatoms and blue-green algae (Cyanophyta) each made up 45% of the periphyton (Figure 15).

The marked seasonal succession from diatoms to *Hydrurus*

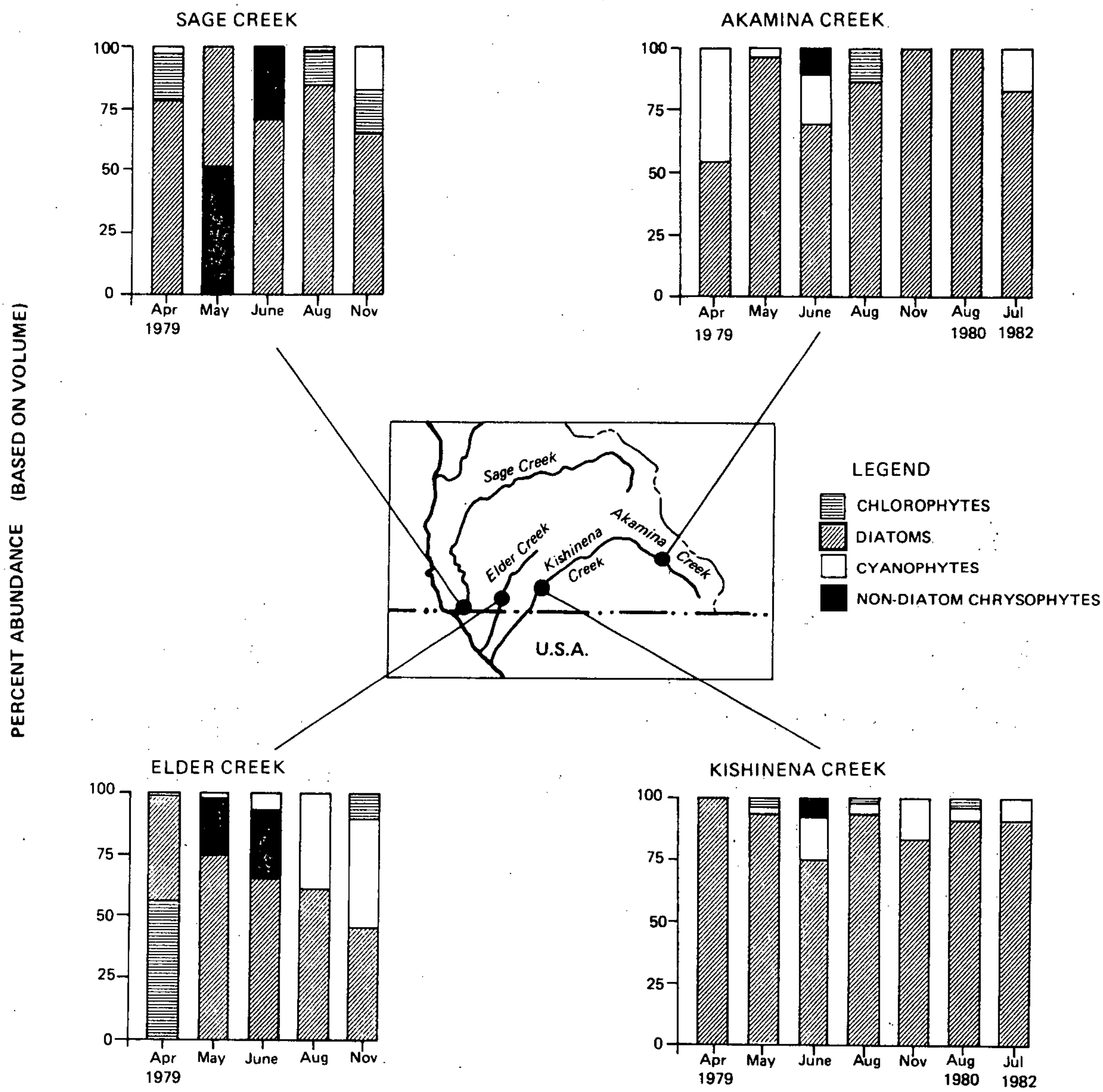


Fig. 15 Average percent abundance (by volume) of major periphytic algal groups collected from the eastern Flathead River Basin, April, 1979 - July, 1982.

foetidus (Chrysophyta - Chrysophyceae) to green algae, which Sheehan et al. (1980) described in the western Flathead basin, was not observed in this study. Diatoms were dominant in all seasons. Occurrences of Chlorophytes and Cyanophytes in excess of 10% abundance were spotty. Hydrurus foetidus was found only in the May and June quantitative samples as described by Sheehan et al. (1980) but also appeared in two qualitative samples collected from the Akamina-Kishinena in August, 1978, and July, 1982.

3. Species Composition

a. Chlorophyta

Twelve species of green algae were collected during the study period (Table 7). The most common chlorophyte genus was Stigeoclonium. Ulothrix spp. were also frequently encountered. An unidentified unicellular green alga was the dominant chlorophyte in the April, 1979, Elder Creek samples, but this species was never encountered again.

In the mountains of New Hampshire, Ulothrix zonata was found in streams from logged watersheds but absent in streams from undisturbed watersheds (Pierce et al. 1972). This species is ubiquitous (Stein 1975) and not usually characteristic of disturbed ecosystems. In the current study U. zonata was present at all stations except Elder Creek and was also the most abundant chlorophyte in the western Flathead drainage (Sheehan et al. 1980). In the Flathead River Basin there is no relation between logging activity and the presence of U. zonata.

b. Cyanophyta

The most abundant blue-green algae were Oscillatoria spp. (Table 7). Five other cyanophyte species were collected, but only Gloeotrichia sp. and Nostoc verrucosum made up 10% or more of the algae on any rock.

Nostoc verrucosum was abundant in several streams of the western Flathead drainage (Sheehan et al. 1980). In the eastern region it was found only in Elder Creek, where it represented about 30% of the algal volume in November, 1979. Since several Nostoc species can fix atmospheric nitrogen (Fogg 1974), the presence of N. verrucosum in the low-nitrate waters of Elder Creek is not surprising.

c. Non-Diatom Chrysophytes

The only non-diatom chrysophytes encountered were Hydrurus foetidus and a species which remained unidentified. Sheehan et al. (1980) found H. foetidus in the Flathead River and all its tributaries except Sage Creek. In the current study, H. foetidus was present at all stations including Sage Creek (Table 7).

TABLE 7. Occurrence of non-diatom algal species. Open circles (o) denote species always contributing less than 10% to any rock's species composition. Solid circles (●) denote that a species made up greater than 10% of at least one rock's species composition. Q indicates that a species was found in qualitative samples only.

| Species | Akamina Creek | Kishinena Creek | Elder Creek | Sage Creek |
|---|---|---|---|---|
| Chrysophyta | | | | |
| Bacillariophyceae | | | | |
| Non-Diatom Chrysophytes | | | | |
| Hydrurus foetidus | ● | ● | ● | ● |
| Unidentified species | ● | | ● | o |
| Chlorophyta | | | | |
| Closterium sp. | | o | Q | o |
| Cosmarium sp. | | | | o |
| Microspora sp. | | | | Q |
| Mougeotia sp. | | o | | |
| Oedogonium sp. | | o | Q | ● |
| Spirogyra sp. | | o | o | ● |
| Stigeoclonium sp. | ● | ● | ● | ● |
| Ulothrix zonata | | o | | Q |
| Ulothrix sp. | | o | o | ● |
| Zygnema sp. | | | | Q |
| Unidentified filamentous | | Q | | |
| Unidentified unicellular | | | ● | |
| Cyanophyta | | | | |
| Gloeotrichia sp. | ● | | | |
| Lyngbya sp. | o | o | | |
| Merismopedia sp. | | o | | o |
| Oscillatoria sp. A | ● | ● | o | Q |
| Oscillatoria sp. B | ● | ● | ● | ● |
| Oscillatoria sp. | ● | ● | o | o |
| Nostoc verrucosum | | | ● | |
| Spirulina sp. | | o | | |

Temperature appears to be a major factor regulating the distribution of H. foetidus. This chrysophyte is found in cold, usually mountainous streams (McConnell and Sigler 1959, Parker et al. 1973, Stein 1975). A logging-induced temperature increase could reduce the abundance of H. foetidus. Unfortunately, the post-logging samples at Kishinena Creek were not taken during the season when Hydrurus is most likely to be found. Further, H. foetidus was never very abundant at the Kishinena station. Thus, from the data available it is impossible to infer a change in water temperature using Hydrurus as an indicator species.

4. Diatoms

Because diatoms were the most abundant algae present, they were analysed in more detail than the other algal groups. In the following sections, diatom cell numbers, number of species, Shannon-Wiener diversity indices and species composition will be discussed.

a. Diatom Cell Numbers

The density of diatom cells was, like chlorophyll a concentrations, highly variable among rocks (Figure 16). There were no significant differences in cell densities among sampling stations, but seasonal differences and the station-date interaction were statistically significant.

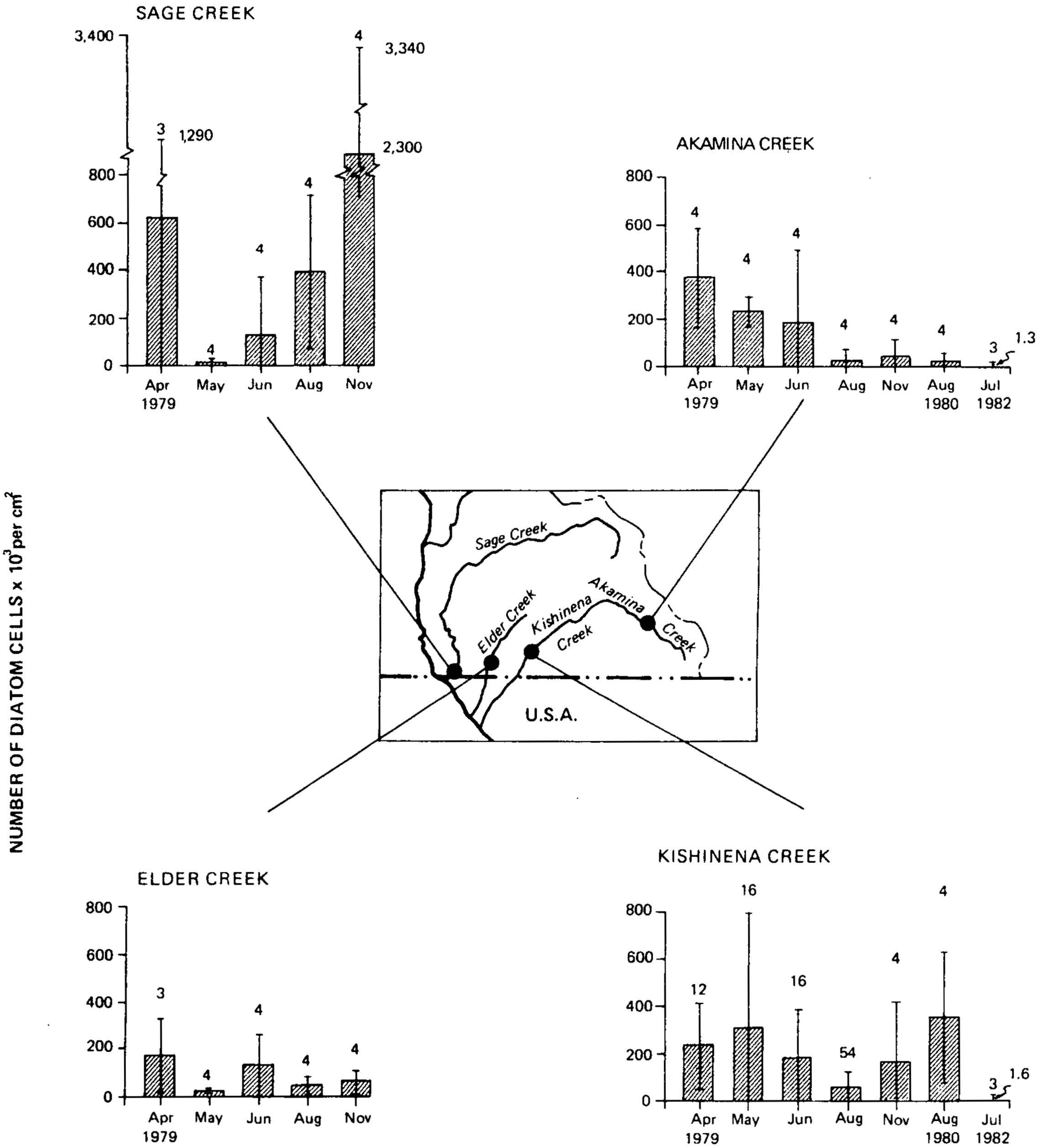


Fig. 16 Mean number of diatom cells attached to rocks in the eastern Flathead River Basin, April, 1979 - July, 1982. Vertical lines represent standard deviations. The number of rocks sampled is indicated above each bar.

Seasonal differences can only partially be explained. The cell counts at Sage Creek in November, 1979, were extremely high, as were the chlorophyll a values, but as previously discussed (Section VIII - F-1) the reason is not apparent. Cell counts at Elder and Sage Creeks were lowest in May. This minimum is probably due to loss of cells from scouring during freshet (Rounick and Gregory 1981).

Cell counts were much lower in July 1982, than on any other sampling date (Figure 16). This decline could not have been due to logging as it occurred at both Akamina and Kishinena Creeks. It appears to have been a natural fluctuation in the system. On the same date the concentrations of dissolved nitrates plus nitrites and (at Kishinena Creek) total nitrogen (Figures 8 and 9) were lower than they had been at any other sampling time.

b. Number of Species

The number of diatom species per rock was much less variable than cell density but followed similar patterns. There were no significant differences among sampling stations, but seasonal differences were significant ($P<0.01$). Although date by date comparisons are suspect due to heteroscedasticity, it appears from the graphs (Figure 17) that lowest numbers of species per rock were found during freshet (usually June). As mentioned for cell numbers, this minimum

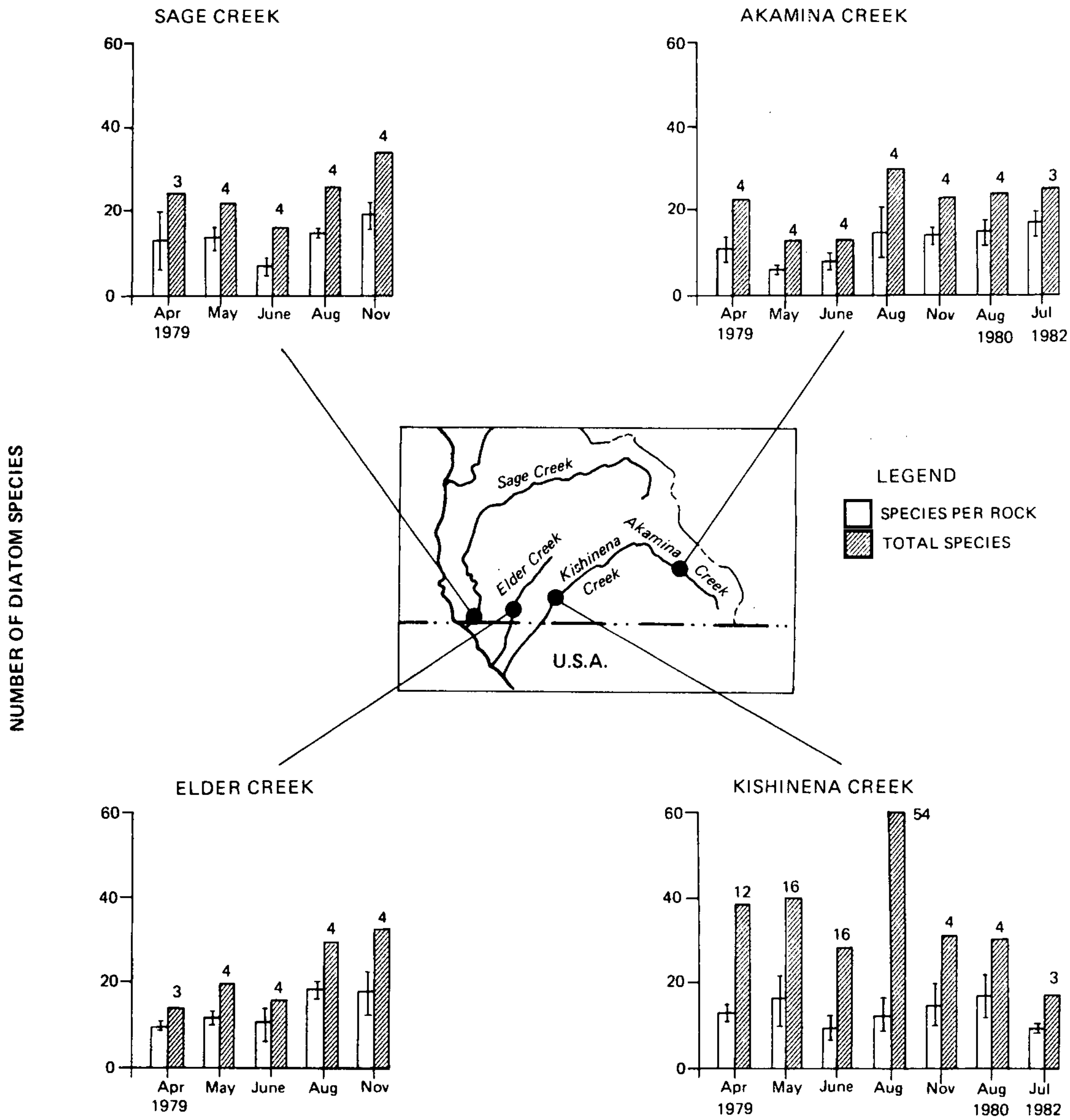


Fig. 17 Mean number of diatom species per rock and the total number of diatom species collected from all sample rocks from the eastern Flathead River Basin.

probably resulted from scouring which can detach filamentous forms, leaving low-growing species (Rounick and Gregory 1981).

No changes in average numbers of diatom species were observed in Kishinena Creek after logging had begun (1980 and 1982, Figure 17).

The total number of species collected at a sampling station followed the same pattern as the mean number of species per rock, but magnitude was related to the number of rocks sampled (note Kishinena Creek in Figure 17). The explanation for the seasonal pattern has been discussed (Section VIII - F-4a). The relationship between sample size and number of species collected is expected, since rare species are more likely to be encountered as sampling intensity increases.

c. Species Diversity

The Shannon-Wiener diversity index (H') measures two aspects of community structure, the total number of species and their proportional abundances. The diversity index rises as the number of species increases and as the relative abundances of species become more equal. Thus, it is not surprising that species diversity followed the same seasonal pattern as did number of species.

The variation in diversity among stations was statistically significant ($P<0.01$). Diversity at Elder Creek appeared higher than at the other stations, especially in August and November, 1979 (Figure 18) largely because of reduced dominance by a few species (see also Figures 19 and 20).

Mean diversity per rock appears to be a good estimator of the total diversity at a station (Figure 18). Composite diversities usually fell within one standard deviation and always, except for Elder Creek in November, within two standard deviations of the mean diversity. Composite diversities were sometimes lower than mean diversities. In many types of communities adding rare species has less effect on the diversity index than does decreasing the dominance of a few species (Gray 1981). The diatom assemblage of the eastern Flathead Basin appears to be one of these communities. The additional rare species added by increasing the number of rocks sampled usually resulted in only small increases in H', and in some instances H' actually decreased because greater proportions of the dominant species were collected.

Diversity indices have frequently been used to indicate water pollution. Species sensitive to pollution disappear while tolerant species increase greatly in abundance due to reduced competition. The result is both fewer species and

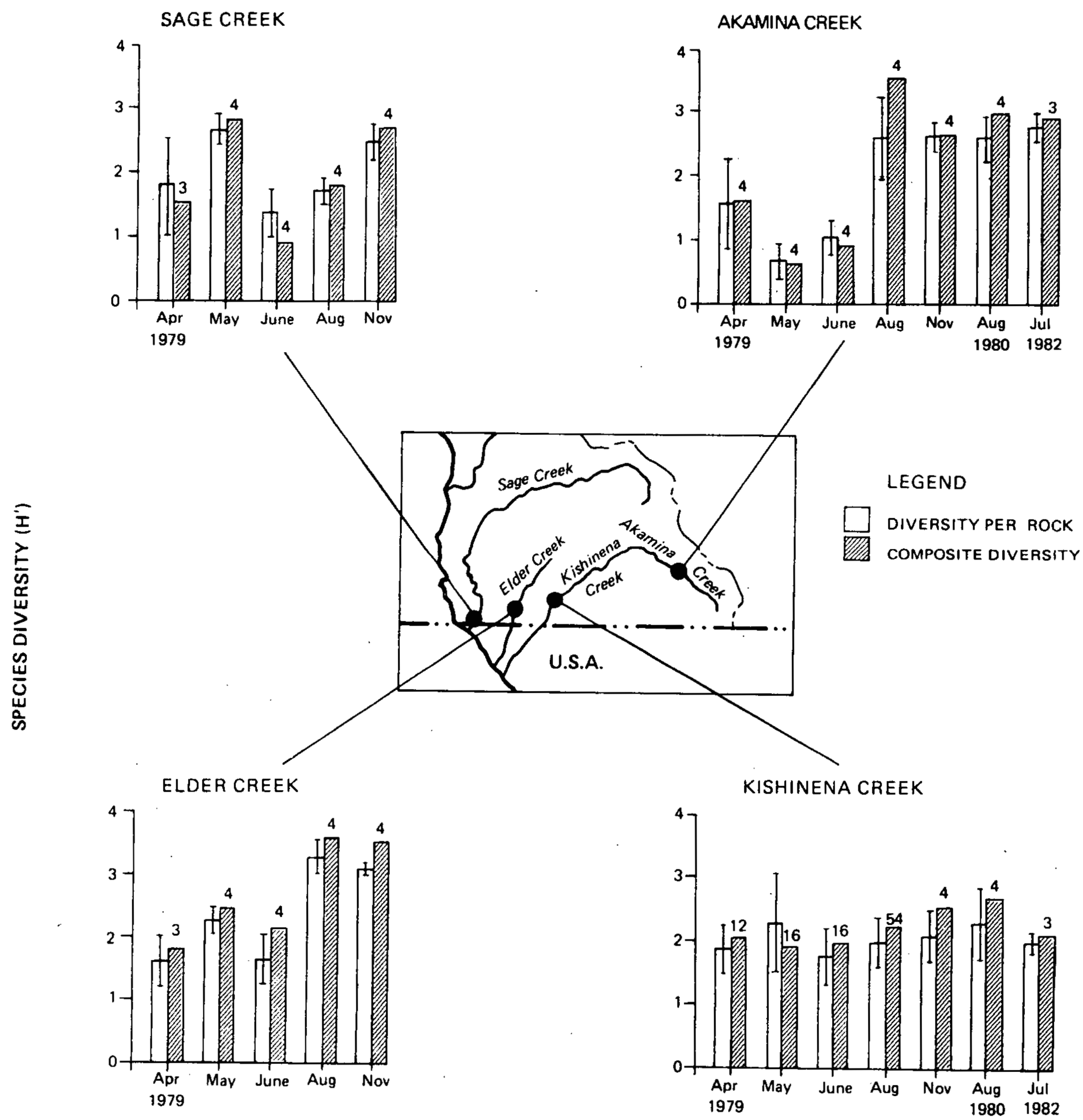


Fig. 18 Mean diversity per rock and composite diversity (based on all rocks sampled) of periphytic diatoms from the eastern Flathead River Basin, April, 1979 - July, 1982. Vertical lines represent standard deviations. Numbers above the bars indicate the number of rocks sampled.

greater dominance, thus a lower diversity index (Cairns 1977). Wilhm and Dorris (1968) have used benthic macroinvertebrate diversities to assess water quality. They associate diversities (H') >3.0 with unpolluted water and values <1.0 with heavily polluted waters. Patrick (1977) states that water quality analyses based on the Shannon-Wiener index could be applied to diatoms. However, there are limitations to this use of diversity indices. For example, Archibald (1972) found that while diversity of diatoms in heavily polluted water was low, communities of low diversity were also fairly common in clean waters. Further, mild organic pollution caused an increase in nitrogen heterotrophic species without a substantial reduction in other species, resulting in high diversity. He concluded that diversity alone was not a reliable indicator of water quality, and that understanding the requirements of the dominant species was far more useful. Most authors now recommend the use of diversity indices only in conjunction with other types of evidence for assessing biological integrity (eg. Cairns 1977).

Shannon-Wiener diversities of the diatoms of the Akamina-Kishinena and adjacent drainages were usually >3.0. The diversity at Akamina Creek fell below 1.0 in May and June, 1979. These values are lower than diatom diversities in the western Flathead Basin (Sheehan et al. 1980) and fall below the range indicative of "clean water" (Wilhm and Dorris 1968).

The Akamina-Kishinena Valley is a remote area, and prior to the logging (ie. before the 1980 samples) this watershed was generally undisturbed by human activity. Water chemistry measurements gave no indication of pollution. Therefore, the diversity indices do not appear to reflect pollution, but indicate that the diatom assemblages are "clean water low diversity" communities (<u>sensu</u> Archibald 1972).

The eastern Flathead Basin is characterized by lower nutrient waters and diatom communities that are heavily dominated by one or two species (See Figures 19 and 20 and discussion in Section VIII - F-4d). Any disturbance to the watershed which produces higher nutrient levels could cause diatom diversities to increase. Similarily, any change in water quality which adversely affected the dominant species might produce higher diversity values. The 1980 and 1982 diversity indices at Kishinena Creek neither increased nor decreased.

d. <u>Species Composition</u>

Eighty-three diatom species and varieties were identified among the four stations (Table 8), but most samples were highly dominated by one or two species. The most abundant

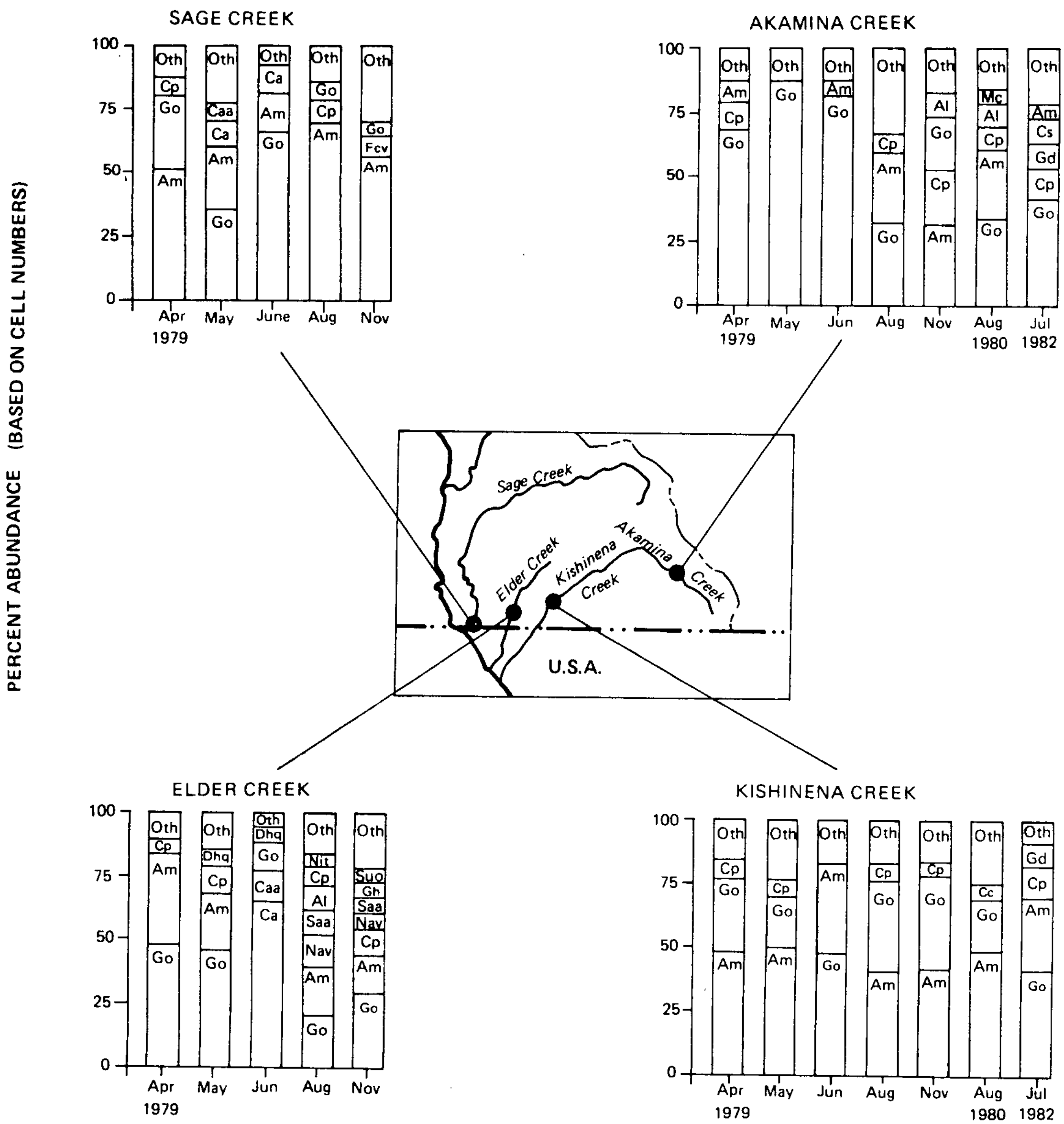


Fig. 19 Average percent abundance per rock (based on cell numbers) of common diatom species (≥ 5 percent of the total number) collected in the eastern Flathead River Basin, April, 1979 - July, 1982.

The diatom species are: Al, *Achnanthes lanceolata;* Am, *Achnanthes minutissima;* Ca, *Ceratoneis arcus;* Caa, *Ceratoneis arcus* var. *amphioxys;* Cc, *Cymbella caespitosa;* Cp, *Cocconeis placentula;* Cs, *Cymbella sinuata;* Dhq, *Diatoma hiemale* var. *quadratum;* Fcv, *Fragilaria construens* var. *venter;* Gd, *Gomphonema olivaceoides* var. *densestriata;* Gh, *Gomphonema herculeanum;* Go, *Gomphonema olivaceum;* Mc, *Meridion circulare;* Nav, *Navicula* sp.; Nit, *Nitzschia palea;* Oth, All other species; Saa, *Synedra acus* var. *angustissima;* Suo, *Synedra ulna* var. *oxyrhynchus.*

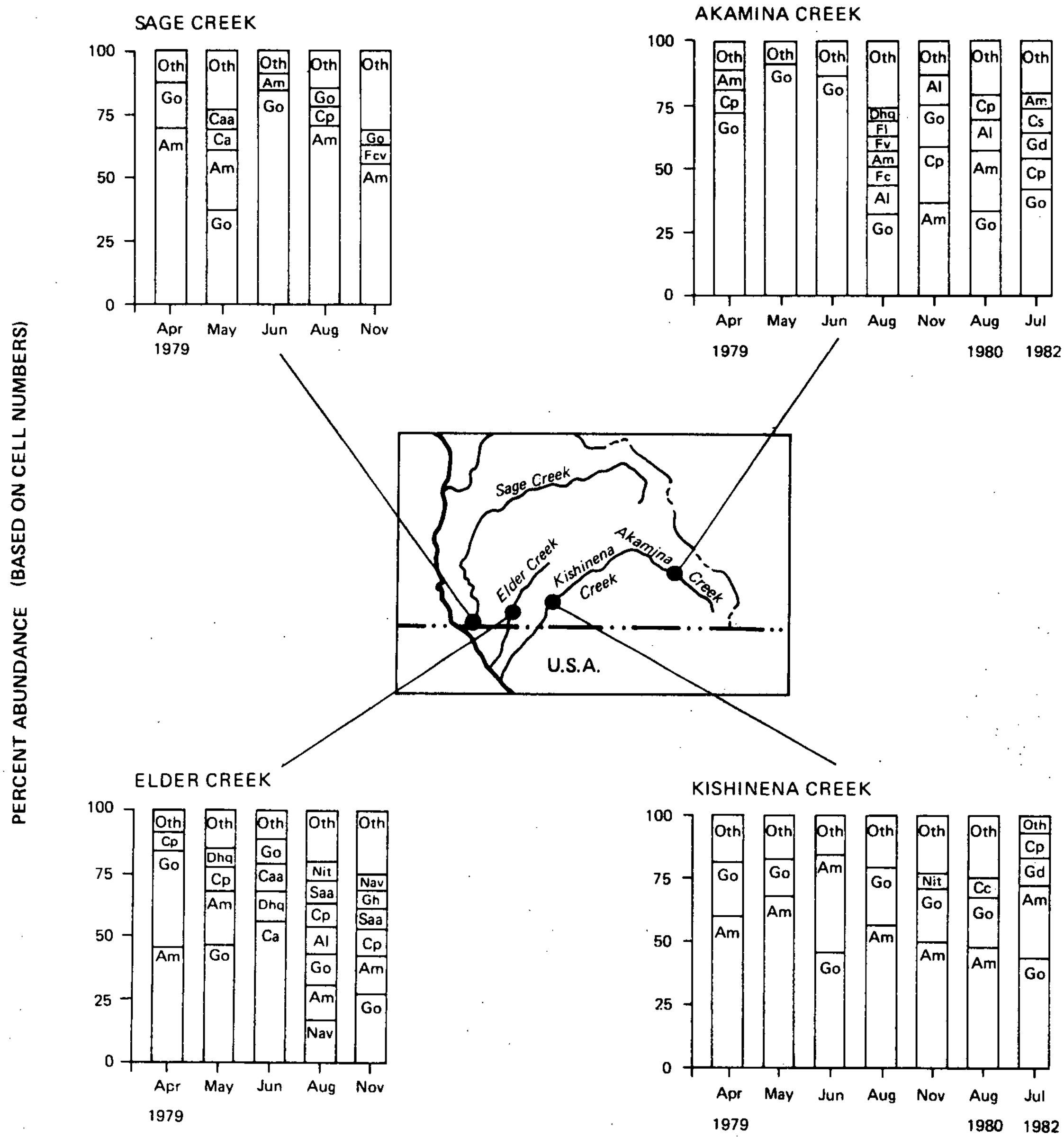


Fig. 20 Percent abundance (based on total cell counts from all rocks) of common diatom species (≥ 5 percent of the total number) collected in the eastern Flathead River Basin, April, 1979 - July, 1982.

The species are: Al, *Achnanthes lanceolata;* Am, *Achnanthes minutissima;* Ca, *Ceratoneis arcus;* Caa, *Ceratoneis arcus* var. *amphioxys;* Cc, *Cymbella caespitosa;* Cp, *Cocconeis placentula;* Cs, *Cymbella sinuata;* Dhq, *Diatoma hiemale* var. *quadratum;* Fc, *Fragilaria construens;* Fcv, *Fragilaria construens* var. *venter;* Fl, *Fragilaria leptosauron;* Fv, *Fragilaria vaucheriae;* Gd, *Gomphonema olivaceoides* var. *densestriata;* Gh, *Gomphonema herculeanum;* Go, *Gomphonema olivaceum* ; Nav, *Navicula* sp.; Nit, *Nitzschia palea;* Oth, All other species; Saa, *Synedra acus* var. *angustissima.*

TABLE 8. Occurrence of periphytic diatoms in the eastern Flathead River Basin. + denotes a species which always made up less than 5% of any rock's diatom composition. ++ denotes a species which made up 5-20% of at least one rock's diatom composition. +++ denotes a species which made up more than 20% of at least one rock's diatom composition. Q indicates that a species was found in qualitative samples only.

| Species | Akamina Creek | Kishinena Creek | Elder Creek | Sage Creek |
|---|---|---|---|---|
| Coscinodiscales | | | | |
| *Cyclotella glomerata* | | + | | + |
| *Cyclotella ocellata* | | + | + | |
| *Melosira granulata* | | + | | |
| *Melosira varians* | | + | | |
| Fragilariales | | | | |
| *Ceratoneis arcus* | +++ | ++ | +++ | ++ |
| *Ceratoneis arcus* var. *amphioxys* | ++ | ++ | +++ | ++ |
| *Diatoma elongatum* | + | + | | + |
| *Diatoma hiemale* | + | + | + | + |
| *Diatoma hiemale* var. *quadratum* | ++ | + | ++ | ++ |
| *Diatoma vulgare* | + | + | | + |
| *Fragilaria capucina* | + | + | | + |
| *Fragilaria construens* | ++ | + | ++ | ++ |
| *Fragilaria construens* var. *binodis* | + | + | | ++ |
| *Fragilaria construens* var. *venter* | ++ | ++ | + | ++ |
| *Fragilaria crotonensis* | | + | + | + |
| *Fragilaria leptostauron* | ++ | + | + | + |
| *Fragilaria vaucheriae* | ++ | ++ | + | ++ |
| *Meridion circulare* | ++ | ++ | + | + |
| *Meridion circulare* var. *constrictum* | Q | | | |
| *Synedra acus* var. *radians* | Q | + | | |
| *Synedra acus* var. *angustissima* | | + | ++ | + |
| *Synedra rumpens* var. *fragilarioides* | + | | | |
| *Synedra ulna* | + | + | ++ | + |
| *Synedra ulna* var. *oxyrhynchus* | | + | ++ | Q |
| *Tabellaria fenestrata* | | + | | |
| *Tabellaria flocculosa* | + | | | |
| Achnanthales | | | | |
| *Achnanthes flexella* | | + | + | + |
| *Achnanthes lanceolata* | ++ | + | ++ | + |
| *Achnanthes microcephala* | | ++ | | ++ |
| *Achnanthes minutissima* | +++ | +++ | +++ | +++ |
| *Achnanthes* sp. | + | + | + | ++ |
| *Cocconeis placentula* | +++ | +++ | +++ | +++ |
| *Rhoicosphenia curvata* | | | + | + |
| Naviculales | | | | |
| *Amphipleura pellucida* | | + | + | + |
| *Amphora coffeaeformis* | + | + | + | + |

TABLE 8. Continued

| Species | Akamina Creek | Kishinena Creek | Elder Creek | Sage Creek |
|---|---|---|---|---|
| Amphora ovalis | + | + | | + |
| Amphora sp. | | + | | + |
| Anomoeneis exilis | | ++ | | |
| Cymbella affinis | Q | + | + | + |
| Cymbella caespitosa | + | ++ | + | + |
| Cymbella cistula | + | + | + | + |
| Cymbella mexicana | | | | + |
| Cymbella prostrata | | + | | |
| Cymbella sinuata | ++ | +++ | + | ++ |
| Cymbella turgida | + | + | | |
| Cymbella ventricosa | ++ | + | + | + |
| Cymbella sp. | | + | | |
| Diploneis decipiens | + | + | + | |
| Frustulia rhomboides | | + | + | |
| Gomphonema geminatum | | + | | |
| Gomphonema herculeanum | + | + | ++ | + |
| Gomphonema intricatum | + | + | | + |
| Gomphonema lanceolatum | | + | | + |
| Gomphonema olivaceoides var. densestriata | ++ | ++ | | |
| Gomphonema olivaceum | +++ | +++ | +++ | +++ |
| Gomphonema parvulum | ++ | + | | |
| Gomphonema sp. | + | + | | |
| Gyrosigma sciotense | | + | | |
| Navicula arvensis | | + | | |
| Navicula bicephala | | + | + | |
| Navicula pelliculosa | + | + | + | + |
| Navicula radiosa | | + | + | + |
| Navicula salinarum var. intermedia | + | + | | |
| Navicula scutelloides | + | + | + | |
| Navicula tripunctata | + | + | + | + |
| Navicula viridula | + | + | | |
| Navicula sp. B | | + | + | |
| Navicula sp. | + | ++ | +++ | + |
| Neidium sp. | + | + | + | |
| Pinnularia sp. | | + | | |
| Stauroneis anceps | | + | | |
| Stauroneis sp. | + | + | | |
| Surirellinees | | | | |
| Denticula elegans | + | | | |
| Epithemia sorex | | + | | |
| Epithemia turgida | + | + | + | |
| Nitzschia acicularis | | + | + | + |
| Nitzschia dissipata | + | + | + | + |
| Nitzschia frustulum | + | + | + | + |
| Nitzschia hantzschiana | + | + | + | + |
| Nitzschia linearis | + | + | + | |
| Nitzschia palea | + | ++ | ++ | ++ |
| Nitzschia sp. | | + | + | |
| Surirella angustata | | | | + |

diatoms were Achnanthes minutissima and Gomphonema olivaceum, which together usually made up more than 50% and sometimes more than 80% of the total cells in any sample (Figures 19 and 20). Cocconeis placentula was also abundant. All these species were among the dominants in the western Flathead Basin (Sheehan et al. 1980), but the characteristic species of that watershed, Ceratoneis (= Hannaea) arcus was only a minor component of the Akamina-Kishinena system, and was dominant only in the June 1979, Elder Creek samples.

Achnanthes minutissima is one of the most abundant and widely distributed diatom species known. It has been reported as a dominant in two Canadian subarctic rivers (Ennis and Albright 1982), oligotrophic waters on Vancouver Island (Stockner and Shortreed 1976), "hyperoligotrophic" waters in Belgium (Leclercq and Fabri 1982), highly calcareous streams in England (Butcher 1946), and a nutrient-poor Mississippi stream (O'Quinn and Sullivan 1983). A. minutissima was also dominant in the South African low-diversity, clean water community studied by Archibald (1972).

Gomphonema olivaceum and Cocconeis placentula are also widely distributed. Both were abundant in the calcareous streams studied by Butcher (1946) and in the Uintah Basin of

Utah (Evenson et al. 1981, Rushforth et al. 1981). G. olivaceum was dominant in the periphyton of two shallow, eutrophic Nebraska reservoirs (Hoagland et al. 1982). C. placentula was dominant in the "relatively eutrophic, warm" waters of Elk Lake, British Columbia, where it appeared to be in competition with A. minutissima (Brown and Austin 1973).

Several authors have attempted to use A. minutissima as an indicator of water quality conditions, but results of different studies have been variable and often opposite. This species is frequently considered an indicator of oxygen-rich waters of low organic content (Archibald 1971, Schoeman 1972, Evenson et al. 1981), but it was dominant in the eutrophic waters of Elk and Kootenay Lakes, B.C. (Brown and Austin 1973, Ennis 1975). Other authors have considered A. minutissima an indicator of low metal levels (Rushforth et al. 1981, Lampkin and Sommerfeld 1982), but Say and Whitton (1981) include it with species resistent to zinc. Patrick (1977) states that A. minutissima prefers a considerable amount of calcium, while Evenson et al. (1981) consider it a weak indicator of low calcium levels.

Gomphonema olivaceum and Cocconeis placentula have occasionally been used to indicate particular water quality conditions. G. olivaceum occurs in waters that are high in calcium (Patrick 1977, Evenson et al. 1981). C. placentula has been associated with high levels of heavy metals other than zinc (Rushforth et al. 1981). It was the dominant species in an English stream below a sewage outfall supplying elevated levels of nitrate and phosphorus (Jones 1978).

Because published reports of species tolerances are variable or in conflict with observed distributions in the Akamina-Kishinena region it appears that the dominant species identified in this study are of little value as indicators of any particular water quality conditions. However, A. minutissima, G. olivaceum, and C. placentula are characteristic of both the eastern (this study) and western (Sheehan et al. 1980) Flathead River Basin. Any major shift away from dominance by these species (plus Ceratoneis arcus) could indicate a change in water quality conditions. Such a change would have to be confirmed by measurements of other parameters.

No major change in species composition was observed at Kishinena Creek following logging. A species which had not been identified previously, Gomphonema olivaceoides var. densestriata made up about 10% of the cells in the July, 1982 samples. Since this species was equally abundant at the Akamina station, its appearance must reflect a natural change in the community rather than a response to logging.

# IX. CONCLUSIONS

## A. Hydrology, Suspended Sediments, Water Chemistry and Algae

The four creeks studied may be divided into two groups based on watershed areas and discharge. The watershed areas and flow rates of Akamina and Elder Creeks are similar as are those of Kishinena and Sage Creeks. At all four stations freshet appeared to occur between May and June in 1979.

Total suspended sediment levels were low ($\leq$10 mg/L) on all occasions at all stations.

Water chemistry and periphyton in Akamina, Kishinena, Elder and Sage Creeks were similar to water chemistry and periphyton reported from the mainstem and western tributaries of the Flathead River (Sheehan et al. 1980). Metal levels were low. Major ion levels were low and dominated by calcium.

Nutrient levels and periphyton biomass were typical of oligotrophic waters. Dominant algal species, such as the diatoms *Achnanthes minutissima* and *Gomphonema olivaceum* were also dominant in the mainstem and western tributaries of the Flathead River, but *Ceratoneis* (= *Hannaea*) *arcus* was less important in the eastern tributaries.

## B. Effects of Logging

### 1. Observed Effects

The sampling scheme was designed to detect only major changes, which might require further study or remedial action. Since the post-logging samples were taken in summer, changes best observed during freshet, such as increases in concentrations of suspended sediments, may have been missed.

No major changes in the water quality of Kishinena Creek were observed. Measured values of water chemistry parameters and suspended sediments were within the ranges of pre-logging data. Temporary changes in water chemistry (for example, flushing of nutrients immediately after timber harvesting), which most likely would have been missed with annual water sampling, might still have been reflected in changes in the algae. However, no changes which could be related to logging were detected in biomass, abundance, or species composition of the periphyton.

The lack of major deterioration in water quality is probably due to the logging practices employed. Buffer strips along stream banks, reseeding and water-barring of roads and skid trails, and the use of light flotation vehicles appear to have maintained the integrity of Kishinena Creek.

2. Potential for Future Effects

It is possible that in the future there will be some deterioration in the water quality of the Akamina-Kishinena system. Beschta (1978) has reported that in Oregon increased sediment loads from erosion of logging roads did not appear until as much as seven years after road construction. While it is hoped that the conservation measures described above will prevent delayed erosion, the possibility remains. Erosion problems may also develop as the steeper slopes characteristic of the Akamina watershed are logged. Further, changes in logging practices which began in 1983, including clearcutting in some blocks and leaving patchy rather than continuous buffer strips, may have some impact.

## X. SUGGESTIONS FOR FUTURE MONITORING

Because of the potential for delayed erosion in areas already logged and the possibility of impacts from altered logging practices, continued monitoring in the Akamina-Kishinena region is suggested.

At a minimum, monitoring should be conducted at the Kishinena Creek station at freshet and low flow (preferably August). This site is selected for the following reasons: 1) it is accessible by road; 2) logging activities continue in the watershed; and 3) pre-logging data are available.

Monitoring is not suggested at Akamina, Elder, and Sage Creeks for several reasons. These stations are not easily accessible. Akamina Creek can no longer function as a control station because logging has been extended into the watershed (see Figure 2). Sage Creek is already being monitoried approximately 8 km upstream from the site used for the present study (NAQUADAT No. 00BC08NP0006).

The parameters to be measured are those which, according to published literature, are most likely to change following logging. Levels of these parameters are given as guidelines to suggest a need for more detailed study. The guidelines are based on data collected from Akamina, Kishinena, Elder, and Sage Creeks and published levels recommended for protection of aquatic life. Parameters to be measured and guideline levels are as follows:

- Suspended sediments. If concentrations exceed 25 mg/L during freshet or 10 mg/L during low flow, more intensive sampling should be undertaken.

- Nutrients. If total phosphorus concentrations exceed 0.010 mg/L* during freshet or 0.005 mg/L* during low flow, further investigations, which may include algal abundance and species composition, are warranted. Nitrate plus nitrite levels exceeding 0.15 mg/L at freshet or 0.05 mg/L at low flow, and total nitrogen (total dissolved nitrogen plus particulate nitrogen) concentrations greater than 0.25 mg/L at freshet or 0.10 mg/L at low flow require further investigation as described above.

- Flow measurements should be taken when sediment and chemistry samples are collected.

Caution in the interpretation of any monitoring results is advised. Many factors besides logging can affect the water quality of these streams. Instances of natural erosion of stream banks in unlogged areas, avalanche damage on steep slopes, and blow-down of beetle-killed trees have been observed during aerial reconnaissance. All these factors may affect streams in ways similar to logging.

* These values do not apply if slush-ice conditions are present. (See Sheehan et al. 1980).

## ACKNOWLEDGEMENTS

We are pleased to acknowledge the encouragement and support of Dr. W.E. Erlebach, Chief of the Water Quality Branch, Pacific and Yukon Region throughout all phases of this study.

The discussions held with personnel from the B.C. Ministry of Forests were very productive and informative. In particular, we thank Don Embury of the Cranbrook Forestry Office and Gary Murdock of the Fernie Forestry Office for providing timely information. We are also grateful to Mr. F. Hegyi and Rich Baker of the B.C. Forest Inventory Branch, Victoria for supporting a low-level photography project in the Akamina-Kishinena watershed.

We thank personnel from Water Resources Branch of Canada, particularly John Gilbert who provided hydrometric measurements and Carol Penner of the New Westminster Sediment Laboratory who analyzed water samples for suspended sediment. We are grateful to F.T.S. Mah and personnel of the Analytical Services Division, Water Quality Branch, Pacific and Yukon Region for precise and timely data. We are also grateful to Stewart Yee and Mary Bolin for algal identifications. We express our thanks to Mary Lou Haines for typing the endless drafts of the report.

The constructive comments provided by the reviewers particularly Don Embury, Dr. R.E. Kwiatkowski, and Dr. L.M. Churchland, were appreciated.

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