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ABSTRACT

Primary productivity (using a radiocarbon 14 tracer technique), biomass and species composition of both phytoplankton and periphyton were determined at three stations in the Ottawa River, near Ottawa, at two week intervals during the ice-free season, 1971-72, and monthly at one station during the ice-covered season. Temperature, conductivity, pH, total alkalinity, free CO_2, water transparency (Secchi depth) and total incident radiant energy were recorded for each sampling date.

It was shown that seasonal patterns in phytoplankton productivity, biomass and species composition are related to the physical factors measured as well as river discharge. Temperature was found to be the most influential factor in determining seasonal variation in phytoplankton primary productivity and biomass. During the spring runoff period, discharge and water transparency were found to be important controlling factors in determining phytoplankton primary productivity and biomass.

Periphyton were found to have much lower levels of primary productivity per unit biomass than the phytoplankton. Postulated reasons for this difference are cell surface area to volume ratio which was higher for phytoplankton than periphyton and cell density which was lower for phytoplankton than periphyton. Seasonal patterns in productivity and biomass differed between the phytoplankton and

periphyton. Phytoplankton productivity peaked in early June and biomass during July and August. Periphyton productivity and biomass peaked during July and August. Both communities had increases in productivity and biomass in October, and very low levels during the winter. Species composition differed between the two communities. Almost 25% of the 111 diatom species observed occurred in samples from both communities.

Spatial variation in phytoplankton productivity, biomass and species composition was negligible, but periphyton differences were shown to exist between stations and with depth.

Periphyton from plexiglass slides were compared with that from naturally occurring substrates. Total community biomass was similar between the substrate types. Species composition differed to some extent between the substrate types but no distinct selectivity pattern for either substrate type was observed.

CHAPTER I

INTRODUCTION

Primary productivity of phytoplankton and periphyton has been little studied in temperate rivers. Information emphasizing algal abundance and species lists exists for phytoplankton in major rivers in the U.S. and Europe. Very little information on periphyton in large rivers is available. In addition, the relative importance of phytoplankton and periphyton to primary productivity has been rarely estimated for any freshwater habitat, including rivers.

Of the literature on algae in temperate rivers about 2% deals with Canadian environments (Hynes, 1970). Thus, little data is available on phytoplankton and periphyton in Canadian rivers, particularly in those with ice cover several months each year, such as the Ottawa River.

The literature on algae in rivers and streams has been summarized by Hynes (1970), Blum (1956) and Butcher (1932). Periphyton have been found to dominate small streams. In large rivers, though, the large water mass may allow a very important phytoplankton element to exist, possibly in excess of the periphyton.

Most of the phytoplankton studies on rivers have emphasized species lists, cell counts or chlorophyll concentrations. Primary productivity of phytoplankton has been measured infrequently in large rivers. It has been studied by the oxygen and dark-light bottle techniques in the Pyasina River in USSR (Ermolaev, 1973), and the Rivers Thames and Kennet in England (Kowalczewski and Lack, 1972).

These methods consist of measuring the change in dissolved oxygen over a period of time in clear and darkened sealed bottles filled with river water, in order to assess photosynthesis and respiration by the plankton community. In particular, the ^{14}C tracer technique has been used on phytoplankton in the Upper Ohio River (Woods, 1965; and Seilheimer, 1963) and in the Rhine River at Koblenz (Knopp, 1960). This method consists of adding a CO_2 tracer as $NaH^{14}CO_3$ to light and dark bottles filled with river water and measuring the $^{14}CO_2$ uptake by the algae over a set time period.

In a synoptic view of 125 American rivers, Williams (1972) related water quality to phytoplankton diatom species composition. There was a striking similarity in major diatom species between most of the rivers. Dominant phytoplankton species in temperate rivers are usually diatoms, namely: Asterionella formosa, Fragilaria crotonensis, Stephanodiscus hantzschii and Melosira spp. (Ermolaev, 1973; Cushing and Rancitelli, 1972; Juris, 1972; Lack, 1972). Phytoplankton numbers in temperate rivers peak usually in the spring and autumn (Lack, 1972; Thomann, 1972; Woods, 1965). A single peak in phytoplankton primary productivity was observed by Woods (1965), during the spring on the Upper Ohio River.

Early in this century, work began to investigate the physical and chemical factors affecting river phytoplankton. Phytoplankton levels in rivers were found to vary inversely with hydro-

graphic instability and stream discharge (Rice, 1938; Rheinhard, 1931; Galtsoff, 1924; Allen, 1920; Kofoid, 1903; and Schroder, 1899). Temperature was isolated as the major factor in determining phytoplankton seasonal distribution (Brinley and Katzin, 1942; Coffing, 1937; Roach, 1932; Allen, 1920; and Wundsch, 1920). More recently the inverse relationship between discharge and phytoplankton population size has been described by Lack (1972), Thomann (1972) and Greenberg (1964). On the Thames River in England, high turbidity was associated with high river discharge, and light was isolated as the controlling factor for phytoplankton productivity and pigment levels (Kowalczewski and Lack, 1972). Work is still needed to clarify what controlling factors come into play with respect to seasonal changes and their effect on phytoplankton productivity and biomass.

Periphyton in artificial lotic habitats has been studied by McIntire et al (1969, 1965, 1964), McIntire (1968, 1966), Zimmerman (1962), Whitford (1960) and others. Studies in natural lotic systems include Dickman (1973), Ertil et al (1973), Moore (1972), Welch et al (1972), Sherman and Phinney (1971), Gargas (1970), Moss (1969), Nelson et al (1969), Cushing (1967), Fraser (1966), Tamas (1966), Fjerdingstad (1964), Eichelberger (1963), Cabejszek and Stanislawska (1962), Rawstron (1961), Douglas (1958), Blum (1957) and Butcher (1940).

In the Ohio River at Louisville, Kentucky, maximum periphyton production was found at 0.1 m depth throughout the year (Eichelberger, 1963). Temperature, followed by river discharge and light, was found to have the greatest seasonal effects on periphyton productivity. Seasonal periphyton production was measured in the Columbia River by Cushing (1967). Here, maximum production was observed in August and April, but June and July were not sampled. Solar radiation, and chlorophyll a content correlated closely with production rate (biomass per day).

The development of periphyton methodology is still in its infancy. Methods of sampling periphyton were reviewed by Sladeckova (1962). This still remains the most complete work in this area. A few new methods have been described and some old ones improved since 1962 (Clasby et al, 1973; Schindler, 1973; Allen, 1971; Staley, 1971; Stockner and Armstrong, 1971; and Nelson et al, 1969) but no major break-through methods have appeared at this writing.

Periphyton primary productivity using the ^{14}C tracer technique has been measured more frequently on lakes (Schindler et al, 1973; Allen, 1971) than any other type of freshwater body. The use of this method on rivers has been minimal. The study on the Ohio River by Eichelberger (1963) is the sole citation by Wetzel in the IBP Handbook on Primary Productivity (Vollenweider, 1969). Kobayashi (1961) used the ^{14}C technique but broke up and suspended the periphyton as if it were plankton in the incubation bottles. The results

from using such a method are hard to interpret and difficult to compare with other studies.

The role that current plays on periphyton productivity was studied by McIntire (1966) who showed a direct relationship between current velocity and production as well as respiration. The need for inducing water movement in the closed bottle methods of assessing periphyton primary productivity has been stressed by Hynes (1970).

Accurate in situ estimates of periphyton primary productivity have never been made due to substrate and community heterogeneity and small sample size (Schindler et al, 1973). Much research is needed in this direction.

The relative contribution of periphyton and phytoplankton to a river's primary production has not been extensively studied. Periphyton comprise the main source of primary production in most small streams (Cushing, 1967). Large rivers like the Columbia contain a significant phytoplankton community derived from the periphyton and lentic habitats along the river's course (Moore, 1972; Cushing, 1967; Butcher, 1940). Periphytic and phytoplanktonic algal growth were compared in the Duwamish estuary (Washington) in relation to hydrographic factors (Welch et al, 1972). Maximum growth occurred at the same location in the estuary but at a different time of year for the periphyton than for the phytoplankton. The seasonal variation in periphytic growth was related mainly to incident light. Phytoplankton

growth was related mainly to hydrographic conditions such as tides and river discharge. This explained the temporal dissimilarities between the phytoplankton and periphyton. The spatial similarities were attributed to nutrient concentrations in the water.

It is correct to state that primary productivity data for phytoplankton and periphyton in temperate rivers is wanting. Although information exists in terms of algal abundance and species composition, productivity estimates have rarely been made. Periphyton has been studied even less than phytoplankton in large rivers. The methodology for study of periphyton is still in early stages of development, so research is needed in this direction.

Objectives of the Study

The major objective was to survey the seasonal trends in primary productivity and biomass of the phytoplankton and periphyton in a northern river. A secondary objective was to develop a method to assay periphyton productivity *in situ* using a ^{14}C tracer technique.

A final objective was to examine differences between phytoplankton and periphyton productivity and species composition in three situations differing in terms of water pollutants: (1) the impact zone below a sulphite paper mill, (2) in a partial recovery zone below a sulphite paper mill and (3) below a municipal sewage treatment plant.

CHAPTER II

DESCRIPTION OF THE SAMPLING AREA

Description of the Ottawa River

The Ottawa River is the largest all-Canadian watershed in Eastern Canada. The river runs 720 miles from its headwaters in Lake Capimitchigama to its confluence with the St. Lawrence River at Lac St. Louis, and (via the des Prairies River) at Repentigny, draining an area of 56,000 square miles of eastern Ontario and western Quebec. The River's mean annual flow is in excess of 70,000 cfs near the mouth (Beak Consultants, 1972).

The drainage area includes part of the Canadian Shield, which is primarily acidic rock originating in the Precambrian period as well as Paleozoic limestone of the St. Lawrence lowlands. The Lower Ottawa valley (encompassing the present study area) has a bedrock of flat-lying Ordovician limestones and shales. These are frequently covered by clays and sands dating back from the period of the Champlain Sea inundation some 11,000 B.P. (Rowe, 1972). Top soils are generally high in organic material and are composed of gray brown luvisols and melanic brunisols which have been developed with some humo-ferric podzols (Rowe, 1972).

The climatic region encompassing the present study area is described by Koppen as a "cold snow-forest climate, moist in all seasons and with warm summers" (Petterssen, 1958).

The dominant forest cover type in the Lower Ottawa valley is composed of sugar maple and beech. Associated with these are red

maple, yellow birch, basswood, white ash, largetooth aspen and red and bur oaks (Rowe, 1972).

The water of the Ottawa River is characteristically soft, low to intermediate in total alkalinity with pH just slightly basic (7.1-7.2) and brownish-yellow in colour because of humic acids. The river has been used extensively by man for industry, logging and municipal wastes (Beak Consultants, 1972).

Seven pulp and paper mills along the river contribute over 90% of the 500 tons of BOD discharged to the river daily (Ontario Water Resources Commission, Quebec Water Board, 1971). Of the 38 municipalities containing a total of 514,000 people, eight provide adequate treatment to reduce organic loads to acceptable levels, according to OWRC. No municipality provided tertiary treatment to remove inorganic nutrients prior to 1971. Municipal waste sources discharge 5,200 lbs/day of total phosphorus and 19,000 lbs/day of total nitrogen. About 43% of the municipal phosphorus load to the Ottawa River is contributed by the cities of Ottawa and Hull.

Although there are two pulp and paper mills upstream of the City of Ottawa (59 miles and 242 miles upstream, respectively), the OWRC-QWB survey (OWRC-QWB, 1971) indicated generally satisfactory water quality for most river uses, upstream of the city of Ottawa. The area downstream of the city revealed gross contamination originating primarily from the CIP Gatineau and E. B. Eddy pulp and

paper mills and the cities of Ottawa and Hull. Evidence for this included: extensive bottom sludge deposits; floating sludge mats; high concentration of suspended wood fiber; reduced water transparency; elevated levels of BOD, ammonia, and conductivity; excessive periphytic slime growths; odour; mercury contamination of sediments, plants, fish and water; coliform bacterial contamination and increased levels of inorganic nutrients.

Description of the Sampling Stations

The geographic coordinates of the centre of the study area are 45°27'30"N latitude and 75°37'50"W longitude. This location is near the City of Ottawa, 4 miles and 3 miles downstream of the mouths of the Rideau and Gatineau Rivers respectively.

The major criteria for choosing the three mid-channel stations were: 1) pollution sources; 2) the station's proximity and accessibility; 3) equipment security.

Figure 1 shows the location of the three stations. Station "A", named CIP channel, was located one mile downstream of the Canadian International Paper sulphite mill. Station "B", named Blair Road, was located seven miles downstream of the Hull-Ottawa E. B. Eddy sulphite paper mill. Station "C", named Lower Duck Island, was located 1.5 miles downstream of Blair Road station and 0.5 miles downstream of the City of Ottawa primary treatment sewage plant.

Station "D", named Lower Duck Island littoral station was located directly across the river from station C on the shore of Lower Duck Island. Station "X" was the location used by Warnock (1972) in describing the bathymetry of a cross-section of the river.

Figure 1

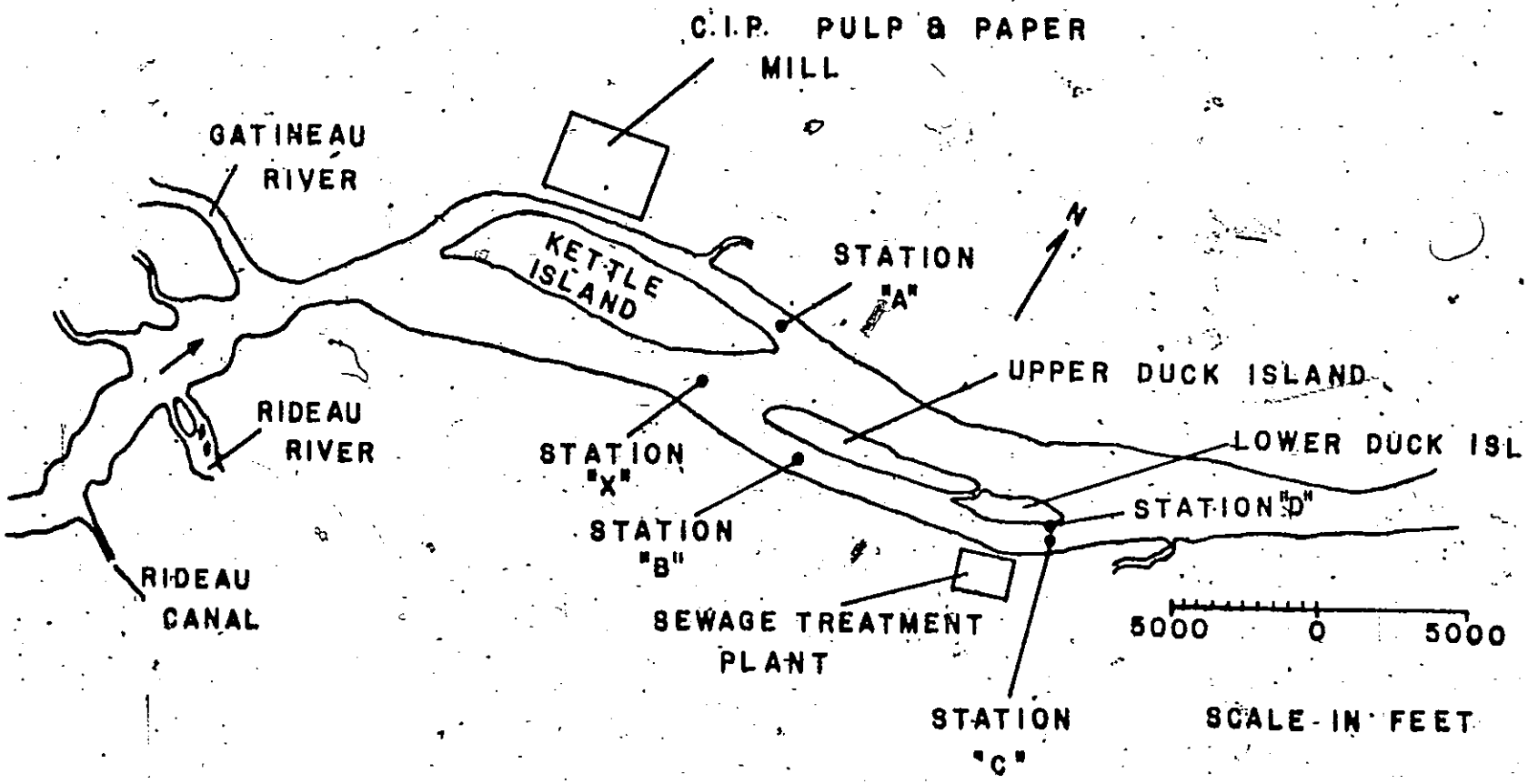
Diagram of sampling area on the Ottawa River including mid-channel sampling stations A - CIP channel

B - Blair Road

C - Lower Duck Island

littoral zone station D - Lower Duck Island

and station "x" locating the cross-section of river used for bathymetry analysis.


C.I.P. PULP & PAPER MILL
GATINEAU RIVER
KETTLE ISLAND
STATION "A"
N
UPPER DUCK ISLAND
LOWER DUCK ISLAND
RIDEAU RIVER
STATION "X"
STATION "B"
STATION "D"
RIDEAU CANAL
SEWAGE TREATMENT PLANT
5000 0 5000
STATION "C"
SCALE IN FEET

CHAPTER III

MATERIALS AND METHODS

Sampling Schedule

Physical, chemical and biological measurements were carried out from August 17, 1971 to August 31, 1972 on a biweekly basis at all three stations during the ice-free season and monthly at the Blair Road station during the ice-covered season. Diurnal phytoplankton studies were conducted at the Blair Road station on June 28, July 27 and August 31, 1972.

Phytoplankton sampling and measurements of productivity were carried out at CIP channel 18 times, at Blair Road 28 times (including winter and diurnal studies) and at Lower Duck Island 16 times.

The ice-covered season lasted 145 days (December 7, 1971 to April 19, 1972) and the ice-free season during the study year lasted 220 days (August 17 to December 6, 1971 and April 20 to August 16, 1972).

Physical and Chemical Measurements

Water samples for temperature and conductivity measurement were taken with a Meyer sampler at 0.5 m depth. Temperature was measured with a mercury thermometer to the nearest 0.1°C. Conductivity was measured on the same sample with a Lisle Co. meter (Model #MC59B) and results were converted to μmhos/cm^2 at 25°C (Golterman, 1969).

The pH, total alkalinity and free CO_2 were measured using a Hach Chemical Company Direct Reading Engineers Laboratory field kit.

Secchi depth was measured from the shaded side of a boat permitted to drift in the river current to eliminate horizontal movement of the disc. Two measurements were taken and the mean recorded.

Snow thicknesses were measured by driving a meter stick down to the ice surface. By hooking a modified meter stick under the ice cover, ice thicknesses were measured on the holes cut for taking water and plankton samples. Ice holes were cut by hand with an axe.

River stage height was provided by the Department of the Environment, Marine Science Directorate, from their gauge in Hull, Quebec (Dohler, pers. comm.).

Phytoplankton Primary Productivity Methods

The method used in the phytoplankton *in situ* experiments followed that of Goldman (1963). This method estimates in between net and gross primary productivity using a ^{14}C tracer. Some modifications and additions to the Goldman methods were necessary in light of new findings (McMahon, 1973; Nalewajko and Lean, 1972; Schindler et al, 1972; Williams et al, 1972; Wallen and Geen, 1968) and because lotic river systems provide different sampling difficulties.

These changes included: using a different incubation bottle-holder apparatus; employing water-rinsing of the Millipore^{R} filters to remove extraneous ^{14}C; ^{14}C-counting of wet filters, not dry; and the use of Aquasol^{R} scintillation fluor in ^{14}C-counting.

A floatable styrofoam, wood and rope apparatus (Figure 2.1) was constructed to hold the light and dark incubation bottles in the current at different depths. Each bottle was fastened by a metal clip to one of the parallel wooden bars so it could oscillate freely in the water current (Figure 2.3). Bottles were suspended at 0.1, 0.5, 1, 3 and 4 meters depth for a period of four hours at monthly intervals at each of the threo stations. Incubations at 0.5 m depth were carried out simultaneously at all three stations bi-weekly and the data from these were transformed to be representative of the water column (Rodhe et al, 1958). Three light bottle replicates were used in the former analyses and four in the latter. One dark bottle was used for each depth examined. Each bottle was innoculated by syringe with one ml of deionized water containing 4μCi of ^{14}C as $NaH^{14}CO_3$. This amounted to a negligible addition of bicarbonate to the incubation medium because it was deionized water.

The incubation period was from 10 a.m. to 2 p.m. (Goldman, 1963). After removal, the incubation bottles were transported to the laboratory in a light-tight box. The contents of each bottle (125 ml) was filtered through a 47 mm Millipore^{R} filter (0.45 μ pore size). Each filter was rinsed before and after filtration with approximately 30 ml of deionized water to reduce any retention of extraneous ^{14}C by the filter or filter residue (Nalewajko and Lean, 1972).

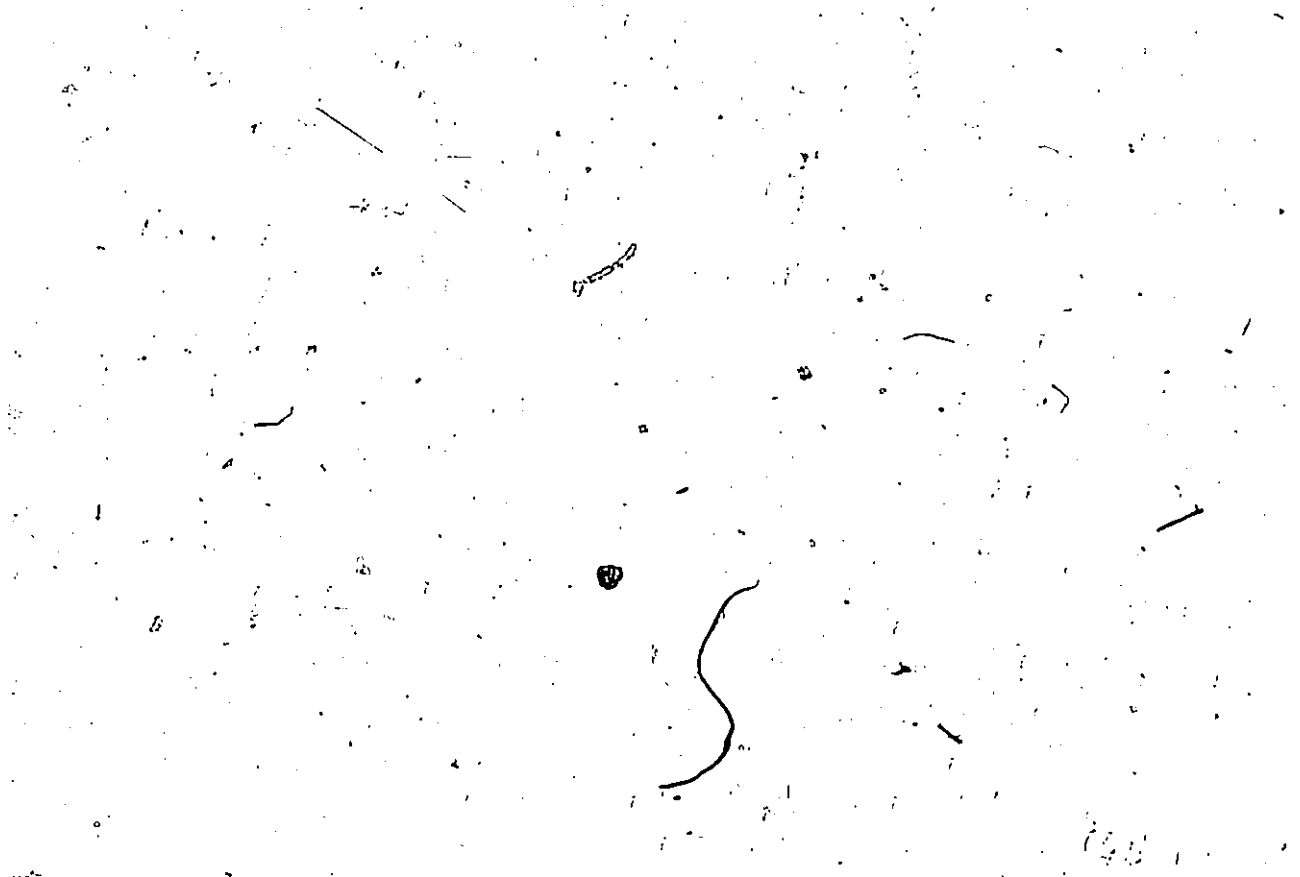
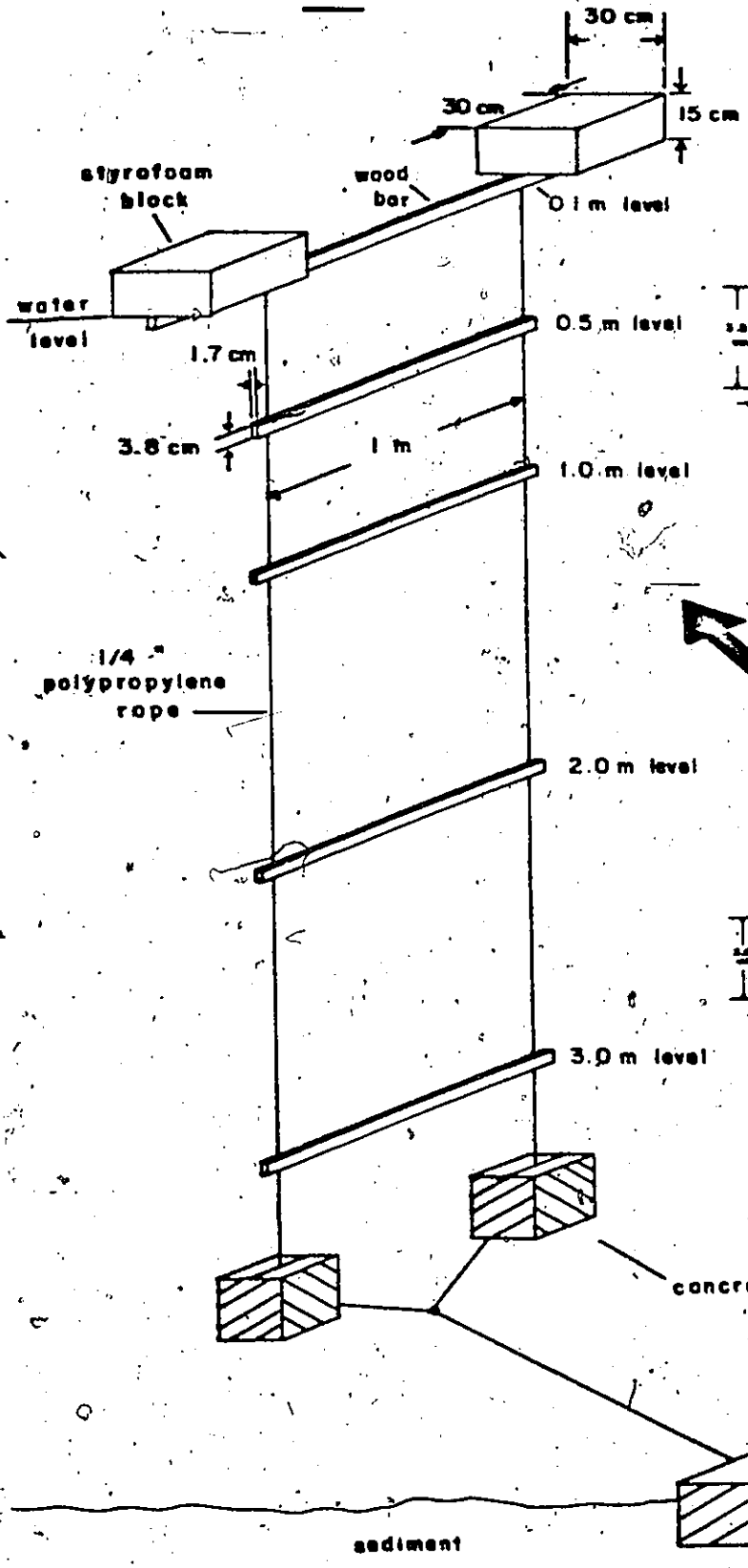


Fig. 2.1 Rope, wood and styrofoam apparatus

Fig. 2.2 The plexiglass slides held by the apparatus

Fig. 2.3 The 125 ml productivity bottles (for phytoplankton analyses) and those containing plexiglass slides (for periphyton analyses).

FIGURE
2-1



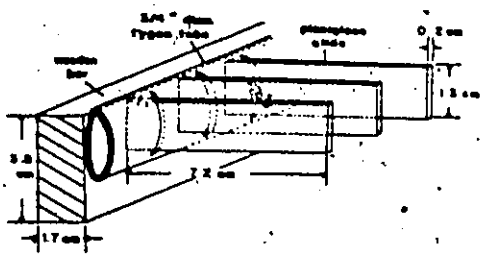
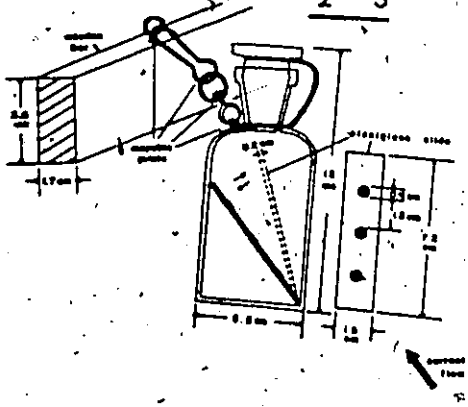


FIGURE
2-2

FIGURE
2-3



The wet filters (Wallen and Geen, 1968) were immediately submerged in 10 ml of a liquid scintillation cocktail, Aquasol^{R} (NEN Co.), in glass scintillation vials. The filters became optically clear in a few minutes and were counted the following day on a Beckman LS-233. In addition, a 0.5 ml aliquot of filtrate was removed from each incubation bottle using an Eppendorf^{R} pipette. This was counted in 10 ml of Aquasol^{R}. These samples were shaken in their counting vials immediately prior to counting to avoid lowered counts due to density phasing.

To correct for colour and chemical quench, an internal standard technique, using ^{14}C-toluene was employed as recommended by D. C. Mortimer (pers. comm.). Loss of sample radioactivity due to volatility upon removal of the spectravial^{R} top during the internal standard procedure was not observed.

Constancy of detection geometry was measured by repeatedly shaking the vial and then counting. No significant variation in counts occurred in this procedure, indicating detection geometry was not variable. No significant change was found in counts after sonification of the filter and subsequent suspension in the gel form of Aquasol^{R}.

Carbon-14 was estimated in terms of counts per minute. Counting runs were for two minutes giving a total count of about 30,000.

Primary productivity in terms of natural carbon (^{12}C) was calculated using the following formula:

$$P = \frac{L - D}{S} \times A \times \frac{x}{t}$$

where,

P = inorganic ^{12}C fixation expressed as mg C/m^3 hr

L = cpm ^{14}C in the filter residue (light bottle)

D = cpm ^{14}C in the filter residue (dark bottle)

S = cpm ^{14}C in the incubation bottle (125 ml).

A = total inorganic ^{12}C in the incubation bottle (mg C/125 ml)

x = 8×10^3 (transformation of 125 ml to 1 m^3)

t = 4 hr incubation period

Lack of evidence in the literature for a significant isotope effect on carbon fixation rates merited its exclusion as a correction factor. Total ^{12}C was calculated according to standard methods (APHA, 1971). A Beckman carbon analyser (furnace and infrared analyser Model 215-A) was employed frequently as a check (courtesy of the Department of Civil Engineering, University of Ottawa).

Phytoplankton productivity was expressed for each experiment on a unit of water surface area basis by plotting the values (mg C/m^3 hr) against depth and calculating the area under the curve. These data (mg C/m^2 hr) were converted to daily rates using the ratio

between incident radiant energy per hour during the incubation period and that over the whole day (Schindler and Holmgren, 1971). Incident radiant energy was measured on a continuous recording Kahlsico actinograph (Robitsch type). The yearly production was calculated from the area under the seasonal curve of daily rates.

Periphyton Primary Productivity Methods

Periphyton productivity was measured on plexiglass slides (7.2 cm x 1.3 cm x 0.2 cm) prepared to allow colonization only over a specific round area (0.04 π cm^2). Each slide was wrapped with black non-toxic PVC tape except for three holes (4 mm diam.), spaced 1.5 cm apart on one surface of the slide. Two of these slides were taped back to back, secured to tygon tubing, allowing the six holes in the tape to be exposed for colonization and set in the river at 0.5 m depth with their long axis parallel to flow (Figure 2.2).

After a one month colonization period, the productivity test was performed, the tape covers being carefully removed, leaving only the three small circular areas on each slide bearing periphyton, prior to transfer to bottles. Five light and five dark bottles (125 ml BOD) were used, each containing one slide. This comprised a total of 15 light and 15 dark replicates. Each bottle was filled with river water. Filtering of river water was not done because competition for $H^{14}CO_3^-$ by the phytoplankton was deemed negligible. Discarding the incubation water and rinsing the slide probably removed any

phytoplankton from the periphyton. Each bottle was innoculated with 4 μCi of $NaH^{14}CO_3$ and incubated for four hours at 0.5 m depth using the bottle holding apparatus (Figures 2.1, 2.3). Next, the bottles were removed from the water and returned in the dark to the laboratory. Each slide was rinsed thoroughly with deionized water. The slide was then broken into three roughly equal portions and each placed into a separate liquid scintillation vial with 10 ml of Aquasol^{R}. Each plexiglass portion rested horizontally on the base of the liquid scintillation vial with the colonized circular area facing up.

A control at time zero was also performed in the laboratory to check for adsorption of ^{14}C to the plexiglass and periphyton. Acid washing (0.01 N HCl) of the periphyton was tried occasionally and did not significantly reduce ^{14}C counts, indicating that precipitation of $^{14}CO_3^{=}$ did not occur on the cell walls, mucilage or the plexiglass.

The internal standard technique as previously explained was used to check for occurrence of colour and chemical quench in the scintillation fluor. Results from checks for quenching caused by plexiglass dissolution in the scintillation cocktail proved negative.

Separating the cells of the periphyton in the scintillation vial by vigorous shaking did not significantly change counts. This indicated that self-absorption among overlying cells and filaments was not significant.

As in the phytoplankton experiments, a 0.5 ml aliquot (Eppendorf^{R} pipette) of radioactive incubation water was counted for each bottle to estimate total available ^{14}C.

The following formula was used to calculate the periphyton productivity values:

$$P_p = \frac{L_p - D_p}{S_p} \times A_p \times \frac{1}{ta}$$

P_p = periphyton productivity ($\mu g\ C/mm^2 \cdot hr$)

L_p = cpm ^{14}C per $4\pi\ mm^2$ (light bottle)

D_p = cpm ^{14}C per $4\pi\ mm^2$ (dark bottle)

S_p = cpm ^{14}C in the incubation bottle (125 ml)

A_p = total inorganic ^{12}C in the incubation bottle ($\mu g\ C/125$ ml)

t = 4 hr (incubation period)

a = $4\pi\ mm^2$ (area of single sample)

These determinations were made biweekly between August 17 and December 5, 1971 at all three stations and monthly between June 26 and September 29, 1972 at Lower Duck Island mid-channel (Station C, Figure 1) and littoral zone (Station D, Figure 1). All sampling and incubations were done at 0.5 meter depth.

Between August 17, 1971 and December 5, 1971 no tape covers were used on the plexiglass slides and one subsample was taken from

each fully colonized slide. The known area of periphyton was scraped from each plexiglass slide. These subsamples were then filtered and rinsed on separate 47 mm Millipore® filters (0.45 μ pore) and counted as were the phytoplankton samples. Five replicates were used in the 1971 series.

Phytoplankton Biomass Methods

Biweekly sampling of phytoplankton at all three stations was carried out between August 17 and December 3, 1971 and between April 21 and August 31, 1972 and monthly at Blair Station between January 17 and March 28, 1972.

On each date, a three-liter sample of water was taken at 0.5 m depth using a Van-Dorn sampler and concentrated with a 20 μ-mesh conical-shaped net. The residue in the net was rinsed into a small vial and preserved with Lugol's iodine solution (Vollenweider, 1969).

Phytoplankton biomass was calculated (Vollenweider, 1969) using a Wild Co. M-40 inverted phase microscope and a ten milliliter Utermohl counting chamber. Cells were measured and their volumes calculated using formulae generated from similar geometric shapes (Kutkuhn, 1958). The specific gravity of the cells was assumed to be unity. Cell and colony counts were made in at least 20 fields at 150X magnification for each sample. Biomass for each taxonomic

category was expressed in terms of µg/l fresh weight.

Periphyton Biomass Methods

Biweekly sampling of periphyton grown on plexiglass slides at all three stations was carried out between August 17 and December 3, 1971 and between June 16 and August 31, 1972. Natural substrates were sampled using the Stockner and Armstrong (1971) sampler on July 20 and August 24, 1972.

Plexiglass substrate periphyton was grown and collected at five depths (0.1, 0.5, 1, 2 and 3 meters). Enough slides for three months of sampling were put on the holder apparatus (Figure 2). A minimum colonization period of one month before harvesting was allowed. Sampled slides were replaced with new slides. Each sampling consisted of removing five replicate slides from each depth level at all three stations.

The sampled periphyton was scraped completely from each slide and gently homogenized with 40 ml of water in a blender to separate the cells. A small aliquot was removed for species identification and appraisal of relative abundance and was preserved in Lugol's iodine solution. The rest of the homogenate was filtered through a tared GF/A glass filter (4.25 cm diameter) and allowed to air-dry at room temperature over dessicant for 72 hours. The dry weight was determined using a Mettler^{R} (resolution 10^{-5} gm). The filters were

then combusted in a furnace (500°C) for one hour and reweighed. A minor correction factor was employed for the small amount of volatile material in the glass filter lost at 500°C. Water of hydration was deemed a negligible factor. The ash-free dry weights were expressed in mg/cm^2. Confidence intervals (95% probability) were calculated for the five replicates per treatment.

Taxonomic Groupings

For the phytoplankton samples, algae were identified to genera and their biomass was estimated. Subsamples were taken for use in identifying diatom species. The diatoms were cleared with potassium hydroxide and mounted in Hyrax.

The relative abundance of periphyton in subsamples was estimated using the following scale: 1) trace (1-100 cells/cm^2); 2) sparse (100-500 cells/cm^2); 3) common (500-1000 cells/cm^2); 4) abundant (1000-5000 cells/cm^2); 5) dominant (5000 cells/cm^2). Subsamples were examined at 150X magnification in 20 microscope fields. Higher powers of magnification were used for identification and counting of smaller forms. For analysis of diatom species the subsamples were cleared with potassium hydroxide.

The following taxonomic works were used for identification: Patrick and Reimer, 1966; Prescott, 1962; Cleve-Euler, 1951; Huber-Pestalozzi, 1942; Hutstedt, 1927-30.

CHAPTER IV

PHYTOPLANKTON STUDIES

Seasonal Variation in Phytoplankton Productivity and Biomass

Phytoplankton productivity ranged from 0.596 mg C/m^2 day (February 6, 1972 under ice cover at Blair Road) to 405.9 mg C/m^2 day (June 6, 1972 at Blair Road). The grand mean for the whole year, which was derived by integrating the area under the seasonal productivity curves (Figure 3) for all stations was 57.2 mg C/m^2 day. One major peak in productivity occurred in June, 1972 (Figure 3). In addition, a smaller less distinct peak occurred in the fall of 1971.

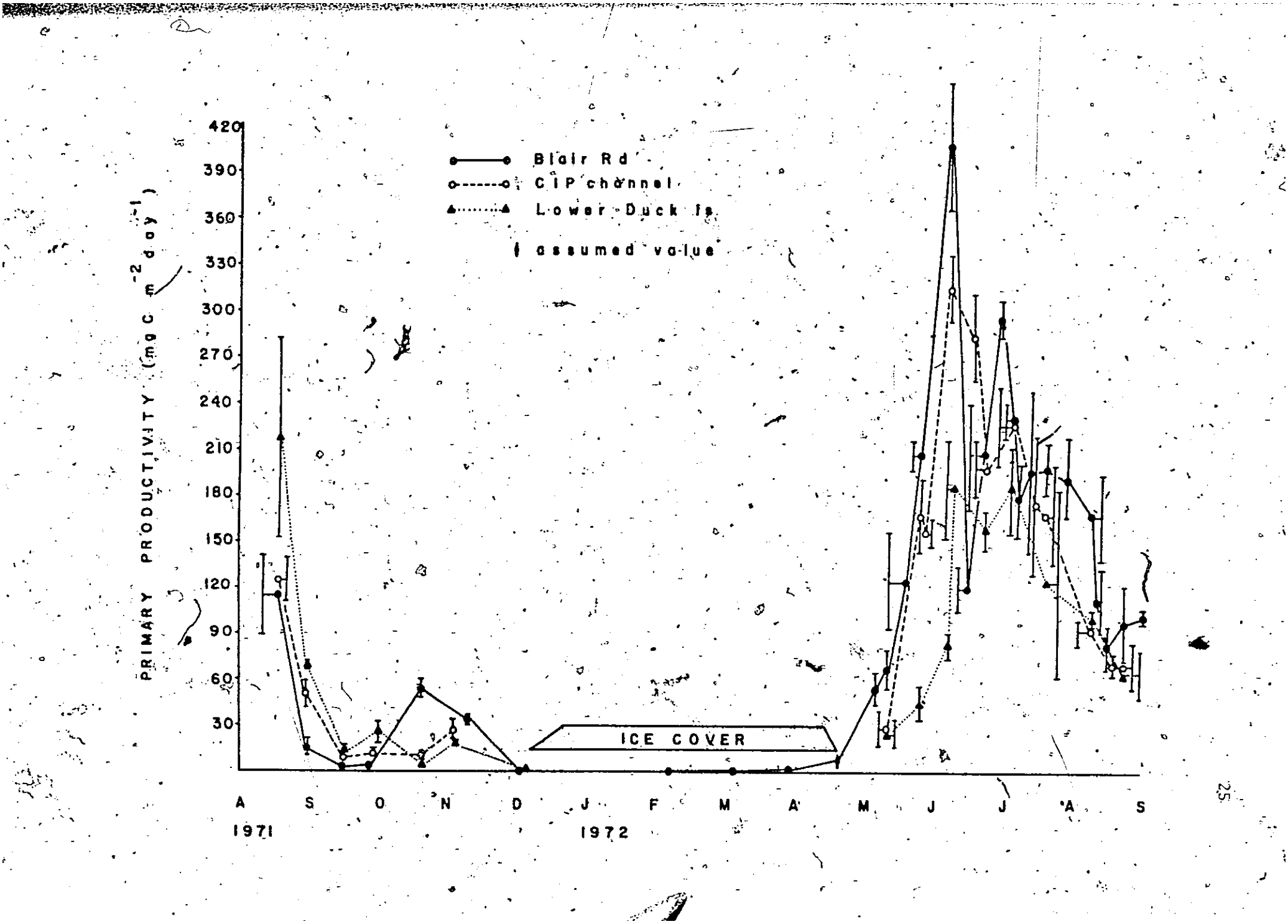
Freshweight biomass ranged from 0.5 µg/l (February, 1972 at Blair Road) to 51 µg/l (August, 1972 at Blair Road, Figure 4). The number of cells ranged from almost zero (March, 1972) to 90,000 per liter in late October, 1971 (Figure 5). Two major peaks in biomass and cell numbers occurred over the year in fall (October and November) and summer (July and August, Figures 4 and 5). The spring (June, 1971) peak in primary productivity did not occur during the period of maximum biomass July and August. As well, primary productivity increased only slightly during the October peak in cell numbers and biomass. Although biomass was about the same in October as during July and August, primary productivity was lower in October than it was either in July or August.

Diurnal Variation in Phytoplankton Productivity and Biomass

The three diurnal studies at Blair Road station included

Figure 3

Phytoplankton primary productivity at Blair Road, CIP Channel and Lower Duck Island from August, 1971 to September 1972. Vertical lines represent 95% confidence limits based on four replicates.


Blair Rd
CIP channel
Lower Duck Is.
assumed value
PRIMARY PRODUCTIVITY (mg C m-2 day-1)
420
390
360
330
300
270
240
210
180
150
120
90
60
30
ICE COVER
A
S
O
N
D
J
F
M
A
M
J
J
A
S
1971
1972

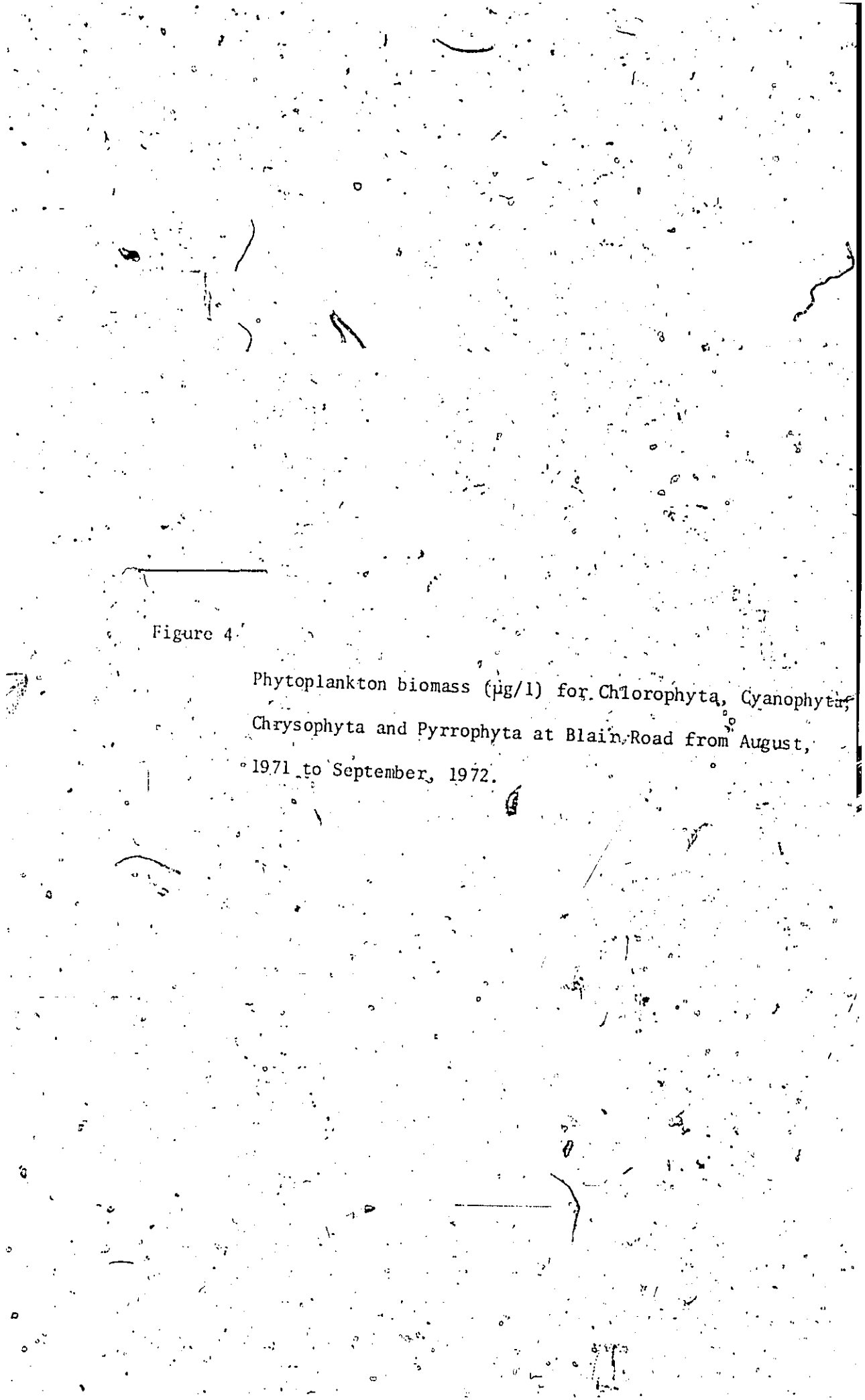


Figure 4. Phytoplankton biomass (µg/l) for Chlorophyta, Cyanophyta, Chrysophyta and Pyrrophyta at Blain Road from August, 1971 to September, 1972.

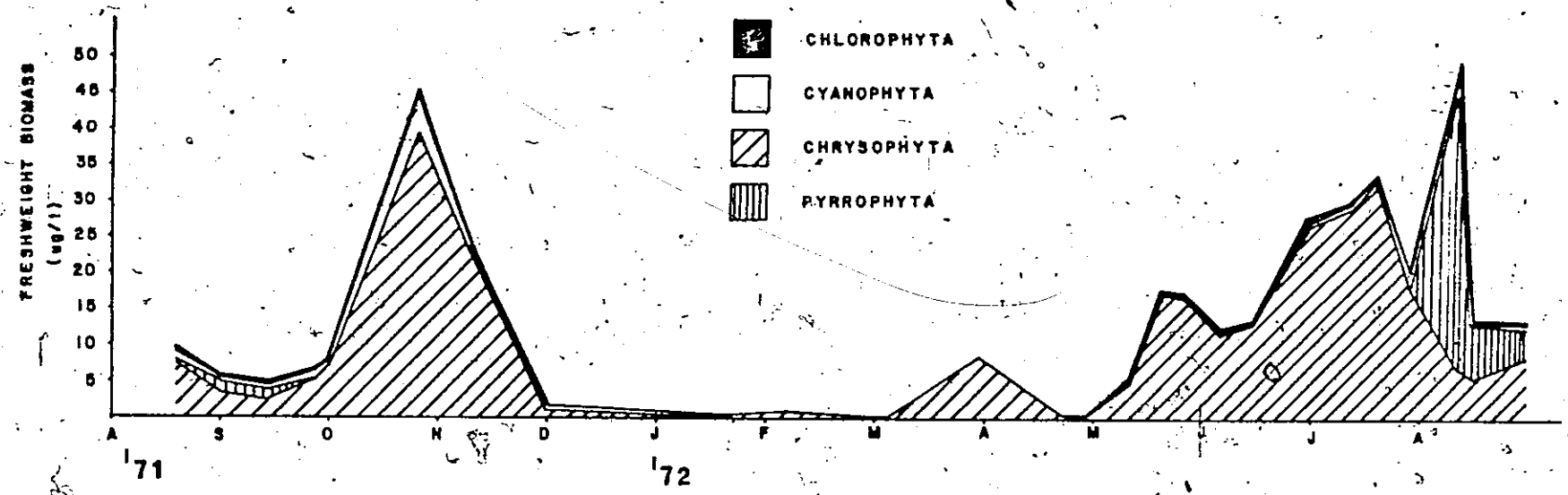
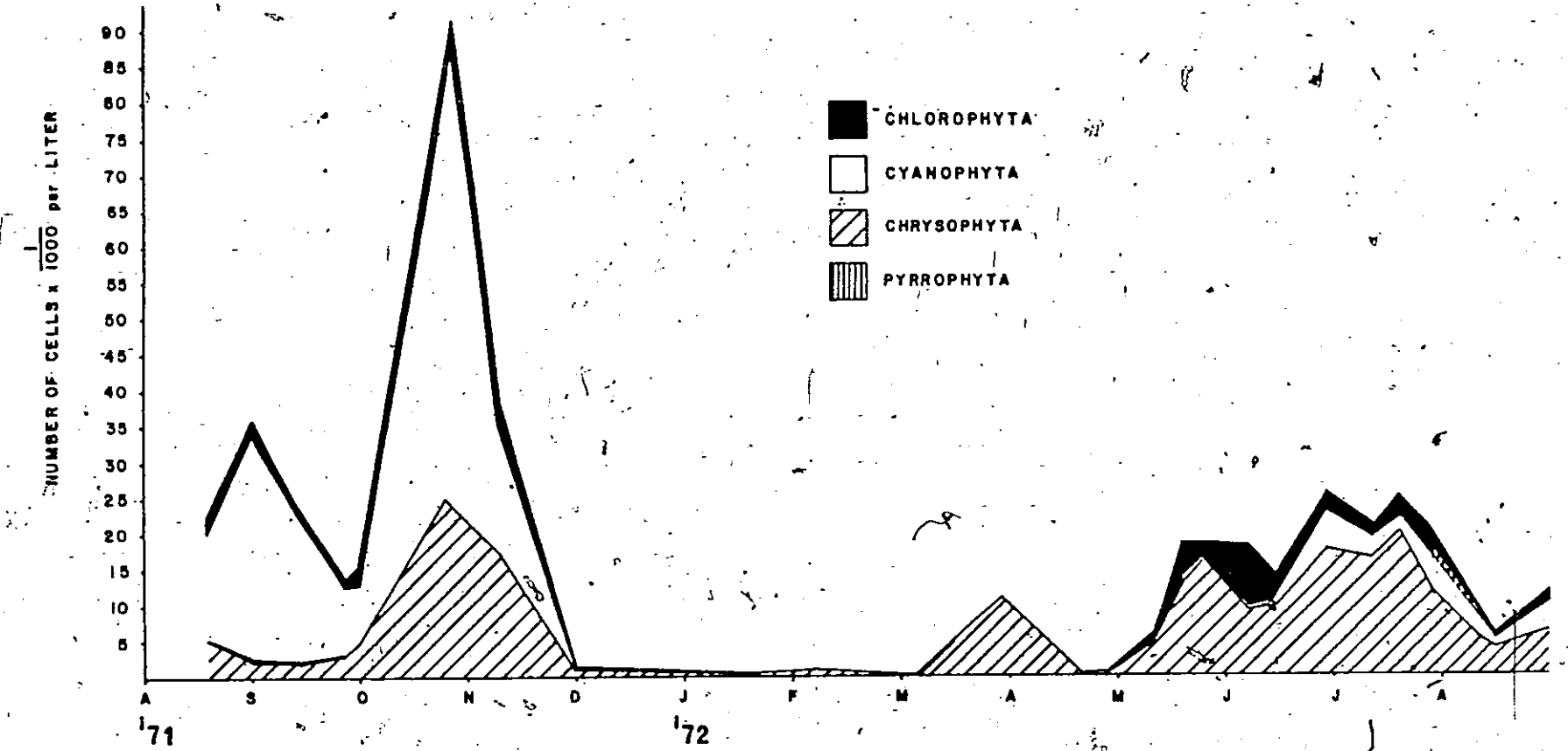

FRESHWEIGHT BIOMASS
(ug/l)
50
45
40
35
30
25
20
15
10
5
A
S
O
N
D
J
F
M
A
M
J
J
A
'71
'72
CHLOROPHYTA
CYANOPHYTA
CHRYSOPHYTA
PYRROPHYTA

Figure 5

Phytoplankton cell numbers per liter for Chlorophyta, Cyanophyta, Chrysophyta and Pyrrophyta at Blair Road Station from August, 1971 to September, 1972.


NUMBER OF CELLS x 1/1000 per LITER
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
CHLOROPHYTA
CYANOPHYTA
CHRYSOPHYTA
PYRROPHYTA
A
S
O
N
D
J
F
M
A
M
J
J
A
'71
'72

measurement of phytoplankton productivity at 0.5 m depth, incident radiant energy, Secchi depth and temperature. These studies were carried out on June 28, July 27 and August 31, 1972 (Figure 6). Phytoplankton samples were taken every four hours (i.e. for each productivity series) in each study.

Biomass did not vary diurnally but differed between the dates as follows: June 28, 27.8 µg/l; July 27, 21.1 µg/l; August 31, 13.3 µg/l. Microscopic examination of identically prepared samples of phytoplankton taken at four hour intervals on each date showed no differences in species composition and biomass between samples taken on the same date.

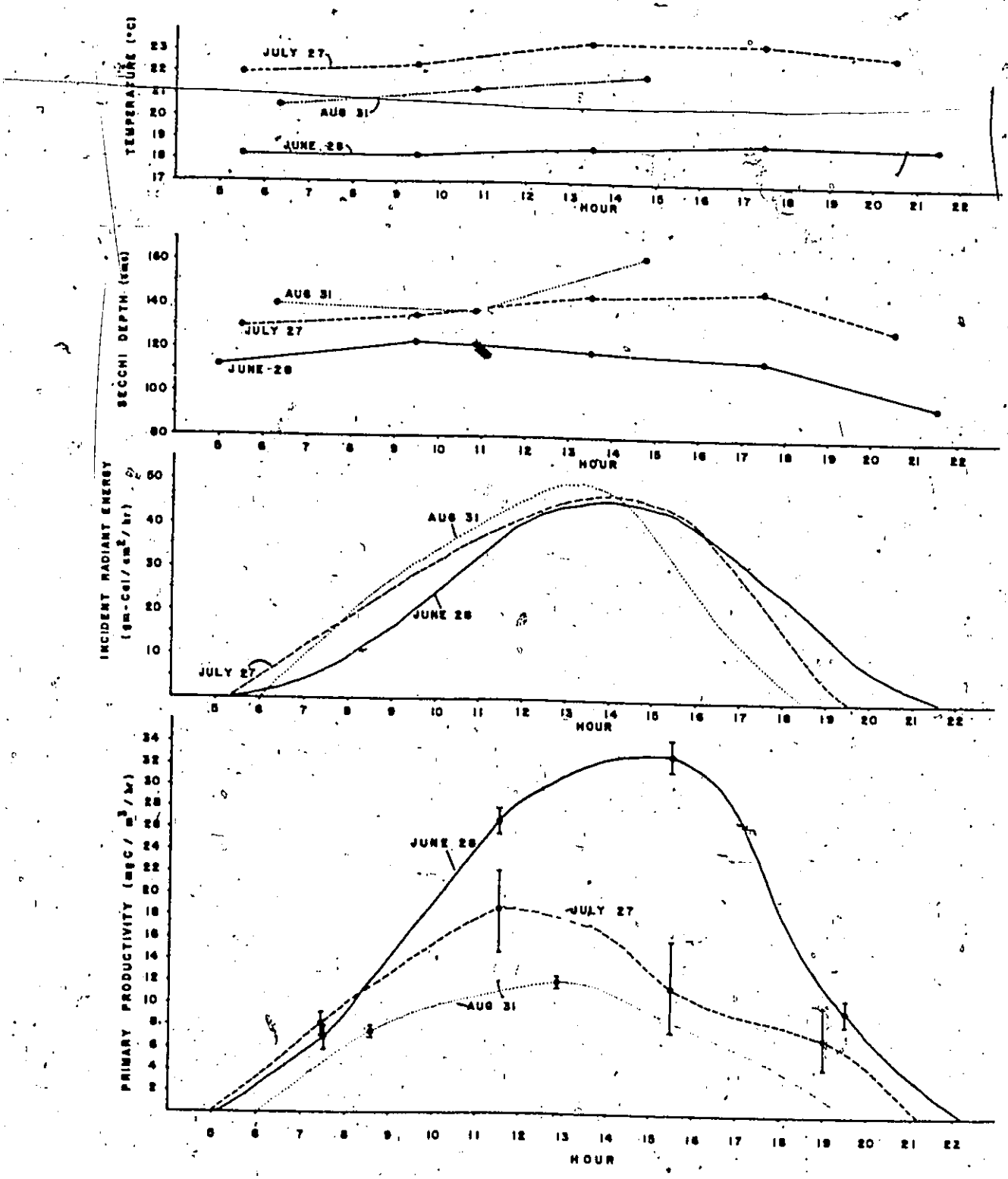
The sky was mainly clear on all three sampling dates. Productivity (0.5 m depth) peaked during the period of highest incident radiant energy for each date. Temperature rose later in the day by almost one centigrade degree about one hour after the peak in incident radiant energy. Secchi depth diurnal variation was not regular between dates probably due to changes in the angle of incidence of the sun between the dates and observer error.

For each of the three dates, productivity bottles were maintained at 0.5 m throughout the day by exchanging them for new ones every four hours. Interpolation between productivity data points (Figure 6) was therefore meaningful because each is a mean value for a four hour period of incubation. Productivity was assumed to be

Figure 6

Phytoplankton diurnal studies at Blair Road

Phytoplankton productivity (0.5 m depth), incident radiant energy, Secchi depth and temperature at Blair Road on June 28, July 27, and August 31, 1972. Vertical lines represent 95% confidence limits.


TEMPERATURE (°C)
JULY 27
AUG 31
JUNE 28
HOUR
SECCHI DEPTH (cm)
AUG 31
JULY 27
JUNE 28
HOUR
INCIDENT RADIANT ENERGY (gm-cal/cm²/hr)
AUG 31
JUNE 28
JULY 27
HOUR
PRIMARY PRODUCTIVITY (mgC/m³/hr)
JUNE 28
JULY 27
AUG 31
HOUR

negligible during the night, thus analyses were carried out from sunrise to sunset.

Phytoplankton Species Composition - Seasonal Variation

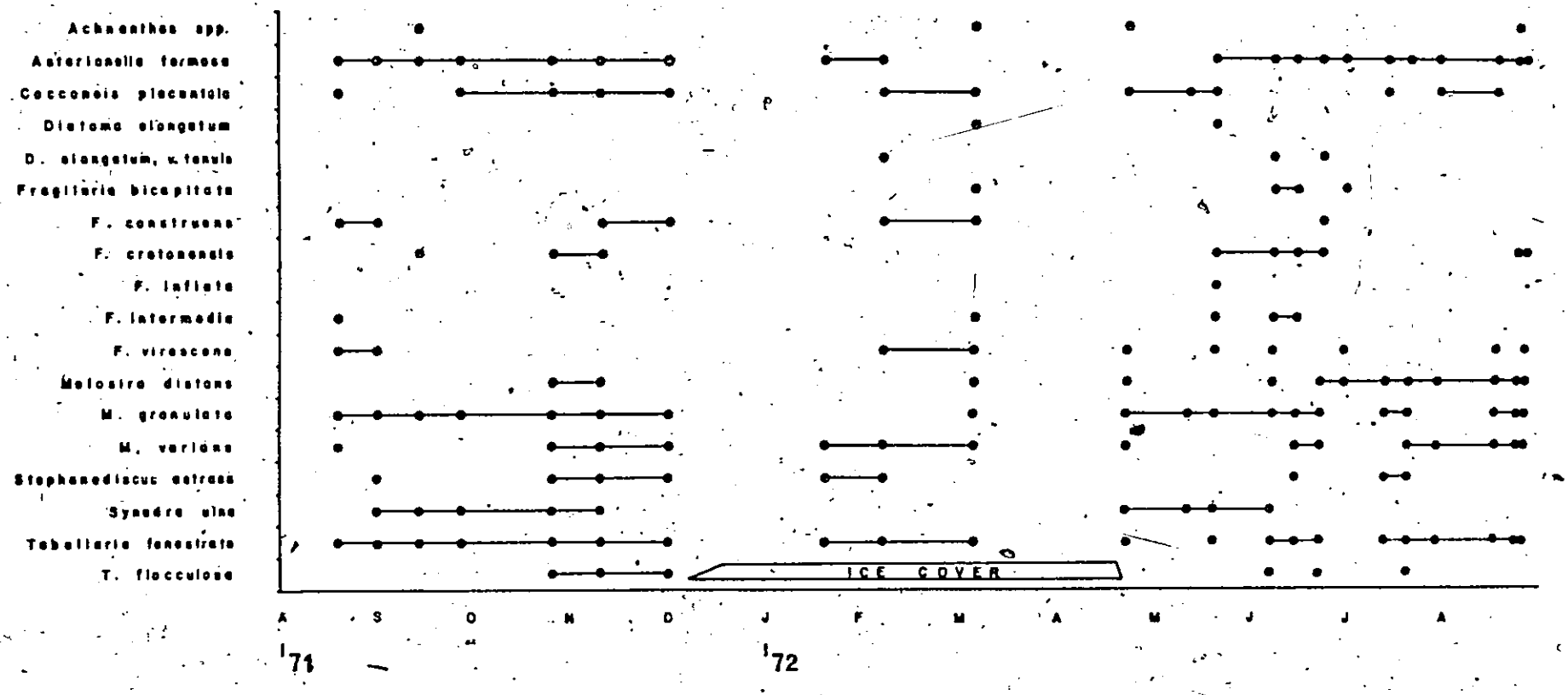
The chrysophytes, mostly diatoms, were always present throughout the study year. They contributed the greatest percentage to the total phytoplankton biomass and were practically the only algae found under the ice cover. Diatom percent composition varied seasonally. Three major decreases in percent composition occurred: a) in September, 1971 when Cyanophyta were abundant (Microcystis mostly), b) in the first week in June, 1972 when Chlorophyta was abundant and c) in August when Pyrrophyta was dominant.

Diatom species occurrence was evaluated on a seasonal basis (Figure 7). The occurrence of each species was followed from one sampling day to the next. Certain species occurred on a continual basis for different lengths of time during the year. Asterionella formosa, Melosira granulata and Tabellaria fenestrata occurred continuously from the commencement of the study (August 17, 1971) to December, 1971. Asterionella formosa persisted again from mid-May, 1972 to the end of the sampling year in August, 1972.

Chlorophyta were detected from August to December, 1971 and May to August, 1972 at relatively constant biomass between 0.5 and 1.5 ug/l (Figure 4). Chlorophyta varied more in terms of cell numbers

Figure 7

Seasonal variation in diatom species occurrence in phytoplankton samples at Blair Road from August 1971 to September 1972. Occurrence on consecutive sampling dates is indicated by a line joining the dots.


Achnanthes spp.
Asterionella formosa
Cocconeis placentula
Diatoma elongatum
D. elongatum, v. tenuis
Fragilaria bicapitata
F. construens
F. crotonensis
F. inflata
F. intermedia
F. virescens
Melosira distans
M. granulata
M. varians
Stephanodiscus astraea
Synedra ulna
Tabellaria fenestrata
T. flocculosa
ICE COVER
A S O N D J F M A M J J A
'71
'72

than in biomass. Cell numbers peaked in June staying relatively constant during the rest of the above stated periods (Figure 5). Chlorophyta occurred in very low numbers between December, 1971 and May, 1972.

The Cyanophyta had a much more variable seasonal distribution than Chlorophyta. Cyanophyta peaked in cell numbers during October-November (63,000 cells per liter, Figure 5). This group was not present between December, 1971 and May, 1972. It then increased to a summer high of about 5,000 cells per liter after the Chlorophyta summer peak of 8,000 cells per liter in June, 1972. Cyanophyta and Chlorophyta did not greatly contribute to the total phytoplankton biomass however, as their combined average percent composition was only about 10%.

Spatial Variation in Phytoplankton Productivity, Biomass and Species Composition

On an annual basis, phytoplankton productivity was significantly* lower at the Lower Duck Island station than at the Blair Road station. That at the CIP channel station was not significantly different from the Blair Road and Lower Duck Island stations. Annual production at each station including the 95% confidence interval was:

Blair Road	25,100 ± 3800 mg $C/m^2 \cdot$ year
CIP channel	20,000 ± 3000 mg $C/m^2 \cdot$ year
Lower Duck Island	17,500 ± 2600 mg $C/m^2 \cdot$ year

* t -test, 95% probability

Phytoplankton biomass in the mid-channel did not vary spatially. Samples taken every four hours at 0.5 m depth during the three diurnal studies at Blair Road station were not different from each other, for each study. This is in fact a spatial analysis because the river flows approximately eight miles every four hours. Samples taken at 0.1, 0.5, 1, 2 and 3 meters at all three stations in August, 1971 when prepared identically and compared microscopically for phytoplankton, were not different from each other.

In a comparison of the frequency of occurrence of diatom species at the three stations, only Tabellaria fenestrata differed greatly between Blair Road and the other two stations (Table 1).

Winter Phytoplankton

During winter, biomass and primary productivity were extremely low at the single station sampled. The low for phytoplankton productivity was 0.59 mg C/m^2·day in February, 1972 under the ice at Blair Road (Figure 3). Biomass at that time was about 1 µg/l (freshweight) and was solely made up of diatoms. Primary productivity was not detected at depths greater than one meter below the ice. With the formation of melt water over the ice cover in March, a significant increase in phytoplankton biomass was detected (8 µg/l, Figure 4). The ice at that time was covered by a 10 cm layer of water which was at the base of a 40 cm layer of snow (Table

	C.I.P. channel	Lower Duck Island	Blair Road
Asterionella formosa	5/7	4/6	5/6
Cocconeis placentula	3/7	2/6	2/6
Diatoma elongatum	0/7	0/7	1/6
" " " v. tenuis	0/7	0/7	1/6
Fragilaria bicapitata	1/7	1/6	1/6
F. construens	2/7	1/6	1/6
F. crotonensis	2/7	4/6	3/6
F. inflata	0/7	0/7	1/6
F. intermedia	1/7	0/7	2/6
F. virescens	2/7	1/6	3/6
Melosira distans	4/7	4/6	5/6
M. granulata	6/7	5/6	6/6
M. varians	4/7	2/6	4/6
Stephanodiscus astraea	3/7	2/6	1/6
Synedra ulna	2/7	1/6	3/6
Tabellaria fenestrata	4/7	6/6	6/6
T. flocculosa	0/7	0/7	3/6

Table 1: Frequency of diatom species for comparable phytoplankton samples at Blair Road, CIP channel and Lower Duck Island in the Ottawa River. Data are expressed in terms of ratios (e.g. 5/7 or 5 of 7 samples contained species x).

DATE	ICE THICKNESS (metres)	SNOW COVER THICKNESS (metres)
December 7, 1971	beginning of ice formation	negligible
January 18, 1972	0.43	0.10
February 6	0.40	0.18
March 4	0.40	0.40
March 26	0.35	0.43 (including 10 cms H_2O)
March 28	0.35	0.43 "
April 19	ice break-up	no data

Table 2: Ice and snow cover thicknesses at Blair Road station (300 ft. from the Ontario shoreline).

2). Although biomass was 8 times higher in March than in February, primary productivity increased only about 2 fold (0.59 mg $C/m^2 \cdot day$ in February to 1.30 mg $C/m^2 \cdot day$ in March).

Phytoplankton Primary Productivity and Related Environmental Factors

In this study, phytoplankton productivity was correlated with incident radiant energy, water transparency, water temperature and river discharge.

Water transparency and incident radiant energy (Figure 8) were plotted for the station and date upon which primary productivity tests were performed. Water temperature and stage (river height), which is a measure of river discharge were the same for each station and are plotted in Figure 9. Seasonal variation in these measurements are clearly evident and are related to primary productivity and biomass variation in the following discussion.

Primary productivity (z) was correlated against incident radiant energy (x) for the ice-free season ($r = 0.47$; regression equation $z = 36.3 + 0.30\ x$; analysis of variance F ratio 5.89, 95% probability critical F level of 4.32). Repeating this comparison but using only data when temperature was relatively constant (between 19°C and 22°C) yielded a correlation coefficient of 0.78 ($z = -12.28 + 0.46\ x$; F ratio 14.13, 95% probability critical F level of 5.12).

Figure 8

Secchi disc readings and incident radiant energy for the three stations Blair Road, CIP Channel and Lower Duck Island on the days that primary productivity was measured.

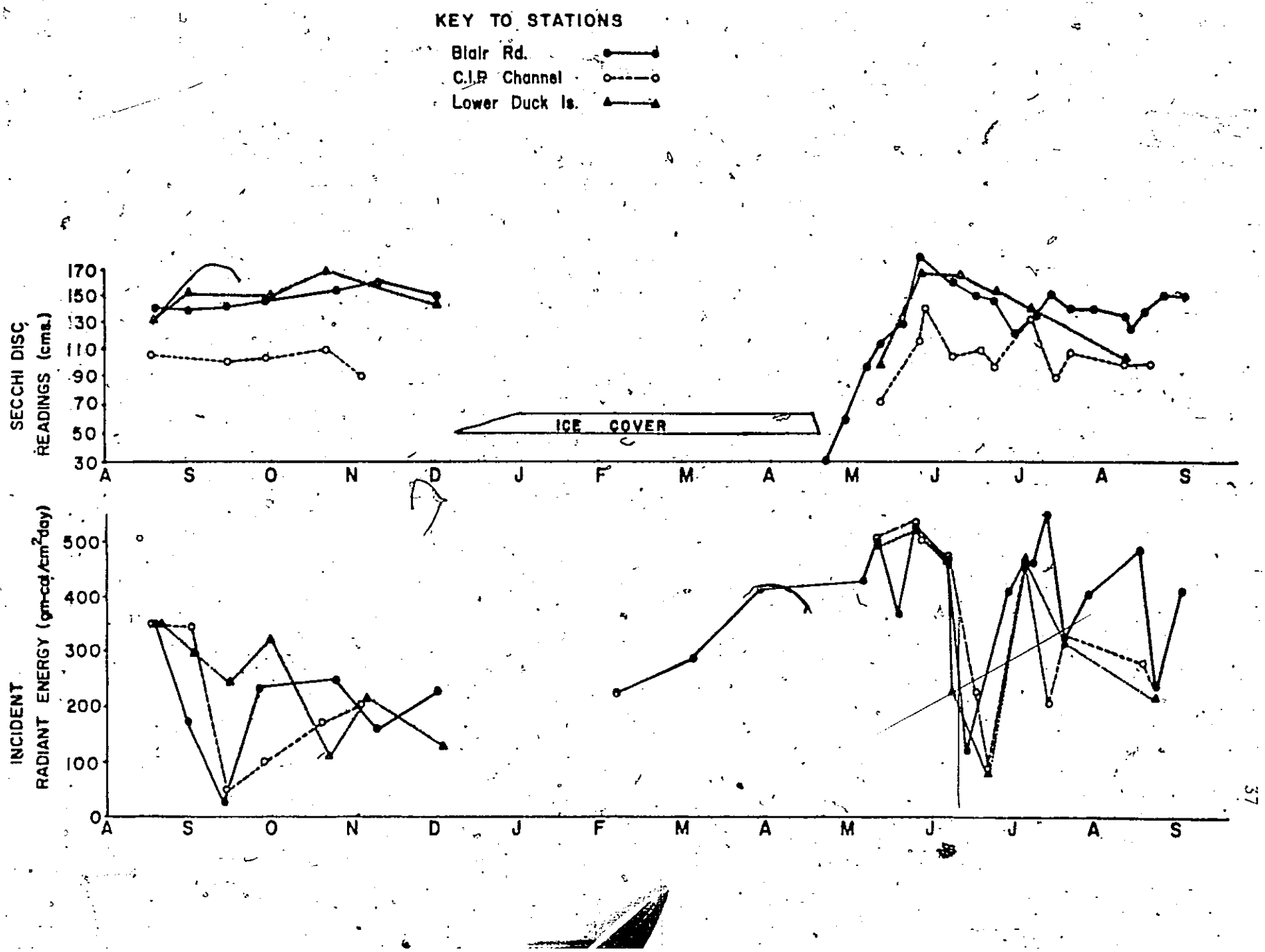
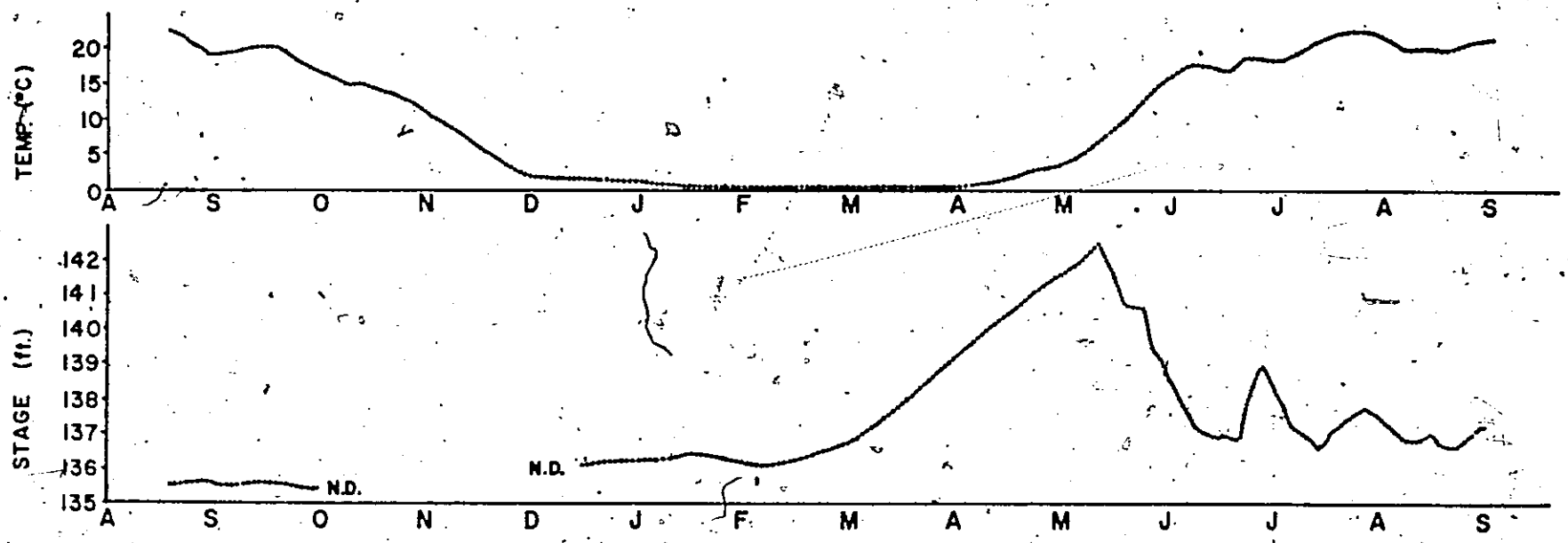

KEY TO STATIONS
Blair Rd.
C.I.P. Channel
Lower Duck Is.
SECCHI DISC READINGS (cms.)
170
150
130
110
90
70
50
30
ICE COVER
A S O N D J F M A M J J A S
INCIDENT RADIANT ENERGY (gm-cal/cm²day)
500
400
300
200
100
0
A S O N D J F M A M J J A S

Figure 9

Seasonal variation in temperature and stage height in the study area from August, 1971 to September, 1972.


TEMP. (°C)
20
15
10
5
0
A S O N D J F M A M J J A S
STAGE (ft.)
142
141
140
139
138
137
136
135
N.D.
N.D.
A S O N D J F M A M J J A S

The results from these two correlations indicate that a) the relationships between primary productivity and environmental factors are not singular but involve factor interaction and b) temperature plays an important role in determining the relationship between incident radiant energy and primary productivity. Further to this, primary productivity (z) was correlated against both temperature (y) and incident radiant energy (x) over the ice-free season, with a multiple linear correlation. The resultant multiple correlation coefficient (R), was 0.69; $z = -86.35 + 4.59\ y + 0.41\ x$ (F ratio 8.89, 99% probability critical F level of 3.49). Thus the square of R, $(0.69)^2$ or 0.47 represents the fraction of the variation in primary productivity attributable to temperature and incident radiant energy (Snedecor and Cochran, 1972, p. 402).

To further describe the relative importance of the temperature and incident radiant energy factors, a correlation was performed between primary productivity and temperature, keeping incident radiant energy "relatively constant" (between 250 and 500 $gmcal/cm^2.day$). This yielded a statistically significant correlation of 0.52 ($z = 32.6 + 7.7\ y$; F ratio 5.30, 95% probability critical F value of 4.60). The conclusion is that temperature appears to be more important than incident radiant energy with respect to effect on primary productivity.

Considering biomass as a further independent variable,

possibly affecting primary productivity, the following correlations were performed. Biomass (w) was correlated against primary productivity (z) keeping incident radiant energy "relatively constant" as before. This yielded a correlation coefficient of 0.39, which was not statistically significant. Repeating this correlation, but using the data over which temperature and incident radiant energy were "relatively constant" yielded a statistically significant correlation coefficient of 0.72 ($z = 65.5 + 5.07\ w$; F ratio 6.35, 95% probability critical F value of 5.99). Employing a multiple linear correlation between primary productivity and biomass (w) and incident radiant energy (x) for data over the ice-free season yielded a multiple correlation coefficient of 0.57; $z = -10.65 + 2.33\ w + 0.31\ x$ (F ratio 4.59, 99% probability critical F value 3.47). Thus $(.57)^2$ or 33% of the variation in primary productivity was associated with the variables biomass and incident radiant energy. Lastly, substituting water temperature for incident radiant energy in the multiple correlation yielded a multiple correlation coefficient of 0.56; $z = 2.79 + 1.63\ w + 5.79\ y$, (F ratio 5.15, 99% probability critical F value of 3.42). Thus $(0.56)^2$ or 31% of the variation in primary productivity was attributable to biomass and temperature. This value is very close to the 33% attributed to biomass and incident radiant energy. Thus the relative importances of temperature and incident radiant energy from this statistical approach appear to be almost equal.

The correlations of variables up to now have included data from the whole study year. Examination of data from the spring season, yields a relationship between stage height and primary productivity during this high run-off period. After ice-out in April, 1972, the stage height increased and peaked at the beginning of May, approximately 6.5 feet above the lowest water level September, 1971. Stage height then decreased rapidly during May as the period of high run-off ended (Figure 9). During this period of decrease in stage(s), phytoplankton productivity (z) increased. The correlation coefficient between these two variables was -0.98 ($z = 11{,}273 - 78.9\ s$; F ratio 88.5, 95% probability critical F value of 10.13). This inverse relationship was not found when all the data over the study year were compared.

Associated with high stage height during the spring run-off period was low water transparency (Figures 8, 9). As stage decreased, transparency increased, along with primary productivity and biomass. Thus during this dynamic period of change in May, temperature was increasing from 3°C to 18°C, Secchi disc from 30 cms to 170 cms (Blair Road), incident radiant energy was high (between 350 and 550 gmcal/cm^2·day) and stage height was decreasing 142 feet to 137 feet. These all coincided with a distinct increase in primary productivity (from 60 to 406 mg C/m^2·day) and biomass (1 µg/l to 20 µg/l), with a peak in Chlorophyta (8,000 cells/liter). A period of change to this degree is not found during the rest of the year.

By evaluating the data obtained over the ice-free season as a whole, the relationships between the factors during the spring lose their distinction to some degree. Seasonal variation in factor interaction appears to be important.

Seasonal variation in the relationships of these physical factors to primary productivity and biomass was evident. The following examples explain this further. Productivity and biomass increased as previously stated while water temperature increased in the spring. The peak in productivity occurred when temperature was 18°C. Further increase in temperature to 22°C in July was not accompanied by an increase in primary productivity (Figures 3, 9). Biomass of phytoplankton did increase during this period however and peaked at the same time with temperature (Figures 5, 9).

Low water temperatures (0.1°C) prior to ice formation coincided with very low primary productivity and algal biomass values (Figures 3, 9). Light and Secchi transparency remained relatively high at this time (Figure 8). The positive relationship between light and primary productivity seen in the summer was not significant here probably because the temperature was so low. With the formation of ice cover, light penetration was decreased, temperature remained 0.1°C and productivity and biomass fell to their lowest levels of the year.

Clearly light, temperature and river discharge are all

involved in determining both the biomass, species composition and primary productivity of the algae. The controlling effect of each factor varies seasonally making it extremely difficult to sort out which is the principle factor at any one instant in time.

Comparison of Phytoplankton Primary Productivity Values from Similar Studies

The best approximation of an annual mean level employs a seasonal curve under which the area is measured. The area is divided by the number of days or light-hours in the year to obtain this mean value. This is rarely done in the literature as such. Usually arithmetic means as averages of a list of data comprise the bulk of the literature. This is a less accurate method, especially for data from temperate zones where seasonal fluctuation is large. Thus comparability of studies is hindered by this.

Two studies on the Upper Ohio River by Seilheimer (1963) and Woods (1965) revealed annual mean values of 35.6 and 35 mg $C/m^2 \cdot hr$, respectively. The means quoted from the Upper Ohio River studies reflect only the summer growth period and are comparable with the summer mean of the present study of 16 mg $C/m^2 \cdot hr$.

In the Rhine River, near Koblenz, the maximum phytoplankton productivity was 60 mg $C/m^2 \cdot hr$ (Knopp, 1960). Maximum phytoplankton primary productivity in the Pyasina River in the USSR was 32 mg $C/m^2 \cdot hr$

(Ermolaev, 1973), close to the maximum of 30 mg $C/m^2 \cdot hr$ from the present study.

Rodhe (1967) calculates the annual and summer means for a large number of lakes. It is interesting that an annual mean of 6 mg $C/m^2 \cdot day$ (from the present study) is equivalent to that found in an oligotrophic lake.

Phytoplankton Species Composition

As reported by Hynes (1970), the following true planktonic algal genera are found most frequently in flowing water: Asterionella, Tabellaria, Fragilaria, Melosira, Cyclotella, Coscinodiscus, Stephanodiscus, Scenedesmus, Ankistrodesmus, Pediastrum, Cryptomonas, Mallomonas, Chlamydomonas, Trachelomonas, Euglena, Synura, Ceratium, Gomphosphaeria, Aphanizomenon, Anacystis, Anabaena and Lyngbya. All of these genera except for one of the flagellates, Mallomonas, occurred in Ottawa River samples.

In addition to these planktonic genera, there were forms that probably developed as periphyton and were removed from their substrate into the water column (tychoplankton). These were essentially diatoms: Achnanthes, Cocconeis, Diatoma, Synedra and Navicula. In terms of both cell numbers and biomass, diatoms were the dominant group of algae found in the phytoplankton samples from the Ottawa River. Their importance in river flora has been widely documented (Hynes, 1970; Blum, 1956; Butcher, 1932).

CHAPTER V

PERIPHYTON STUDIES

Seasonal Variation in Primary Productivity of Periphyton from Plexiglass Slides

The productivity of periphyton grown on plexiglass slides at 0.5 m depth was measured at all stations from August to December, 1971 and at Lower Duck Island station from June to September, 1972 (Figure 10). At Lower Duck Island, a comparison of shore and mid-channel periphyton productivity was performed on three dates: June 26, July 25 and August 29, 1972 (Tables 4 and 5).

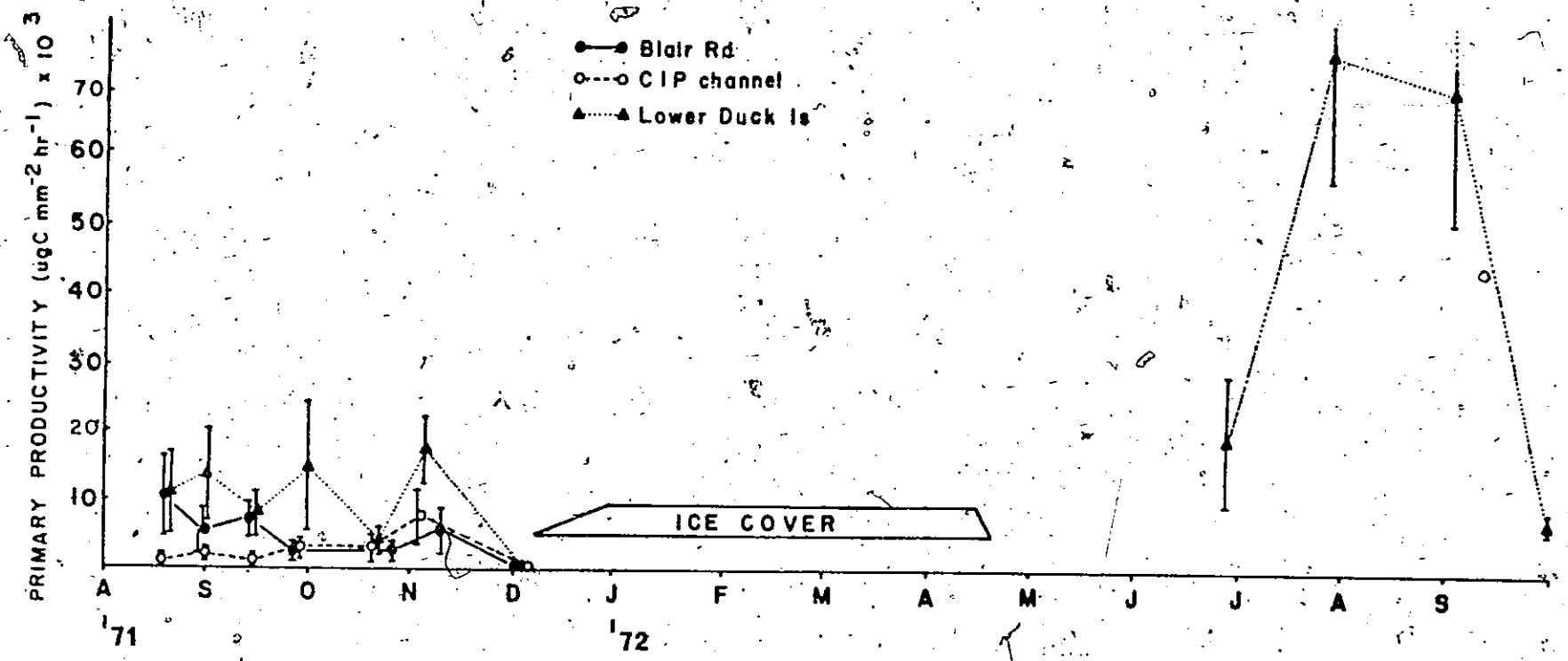
Periphyton productivity at the three stations ranged from 0.001 μg C/mm^2·hr in December just before ice formation to 0.075 μg C/mm^2·hr in July. This is the same as 10 mg C/m^2·day and 750 mg C/m^2·day by using conversion factors of 10 day-light hours in a day and 1 μg C/mm^2 equals 1000 mg C/m^2.

The productivity at the three stations rose in November, 1971. The maximum at this time was 0.0175 μg C/mm^2·hr at Lower Duck Island station. The major annual maximum was during July and August (0.075 μg C/mm^2·hr). Negligible colonization of plexiglass slides occurred during the winter under the ice. The primary productivity was then so low that it was not detectable with the technique used in this study.

Five replicates were used in the 1971 series and 15 in the 1972 series. The 95% confidence intervals were approximately the same for both series (Figure 10), indicating the smaller number of replicates was an adequate sample.

Figure 10

Seasonal variation in periphyton primary productivity at Blair Road, CIP channel and Lower Duck Island stations at 0.5 m. 95% confidence intervals are indicated by vertical lines.


PRIMARY PRODUCTIVITY (ugC mm^{-2} hr^{-1}) x 10^3
70
60
50
40
30
20
10
Blair Rd
CIP channel
Lower Duck Is
ICE COVER
A
S
O
N
D
J
F
M
A
M
J
J
A
S
'71
'72

Spatial and Temporal Variation in Periphyton Biomass from Plexiglass Substrates

Periphyton biomass as ash-free dry weight was plotted for five depths (0.1, 0.5, 1.0, 2.0 and 3 meters) and three stations from August, 1971 to August, 1972 (Figures 11.1, 11.2 and 11.3).

Two seasonal peaks in periphyton biomass were observed during the study year, one in October, 1971 and one in July-August, 1972 (Figures 11.1, 11.2, 11.3). This was true for all three stations and for each depth sampled. The maximum biomass on most occasions, was at 0.1 m. Over the depths sampled, 0.1 m always had the highest biomass during the two seasonal peaks. This was attributed to the intense growth of filamentous greens (Stigeoclonium and Cladophora) at this depth. At 0.5 m depth biomass usually decreased and remained relatively constant down to 3 m depth. Below 3 m depth, little algal growth was detected.

The overall range in biomass values was from 0.015 mg/cm^2 (at 3 m in July, 1972, Blair Road) to 4.95 mg/cm^2 (at 0.1 m in August, 1972, Lower Duck Island). The range at Blair Road was 0.015 mg/cm^2 (3 m, July, 1972) to 2.369 mg/cm^2 (0.1 m, July, 1972). The range at CIP channel was 0.039 mg/cm^2 (3.0 m, June 16) to 4.430 mg/cm^2 (0.1 m, August, 1972). The range at Lower Duck Island was 0.086 mg/cm^2 (3.0 m, August, 1972) to 4.95 mg/cm^2 (0.1 m, August, 1972). The

Figures 11.1, 11.2, 11.3

Seasonal and spatial variation in ash-free dry weight of periphyton grown on plexiglass slides at Blair Road, CIP channel and Lower Duck Island stations: 95% confidence intervals are indicated by vertical lines.

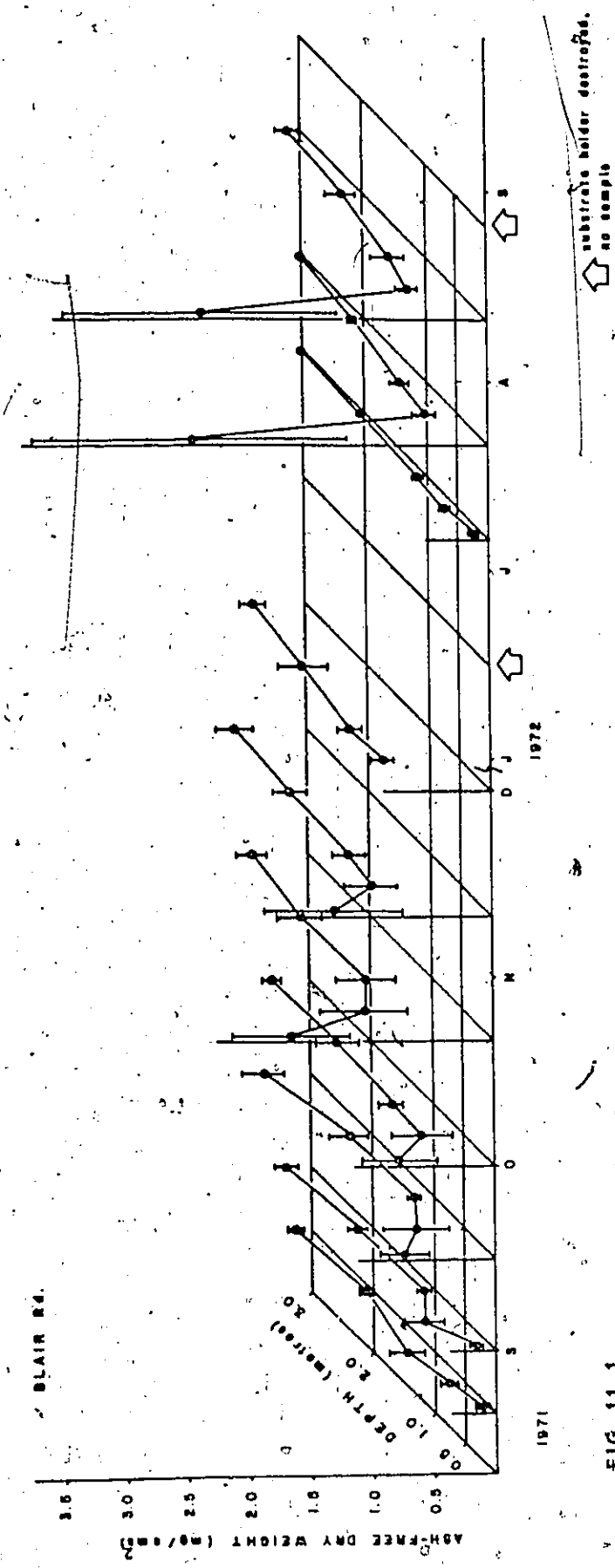

substrate holder destroyed, no sample
BLAIR R4.
ASH-FREE DRY WEIGHT (mg/cm²)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
DEPTH (metres)
0.0
1.0
2.0
3.0
1971
S
O
N
D
J
1972
A
S

FIG 11.1

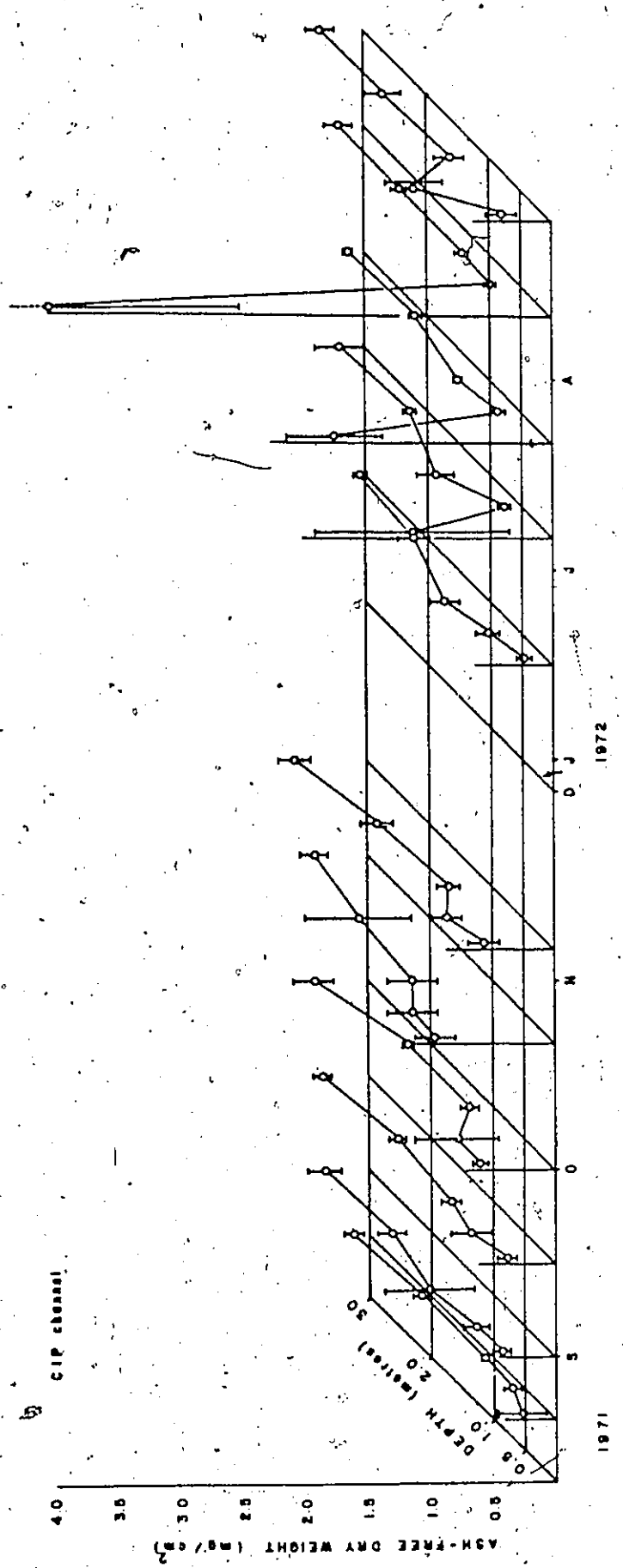

CIP channel
DEPTH (metres)
0.0
1.0
2.0
30
ASH-FREE DRY WEIGHT (mg/cm²)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
1971
S
O
N
D
J
1972
J
A

FIG 11.2

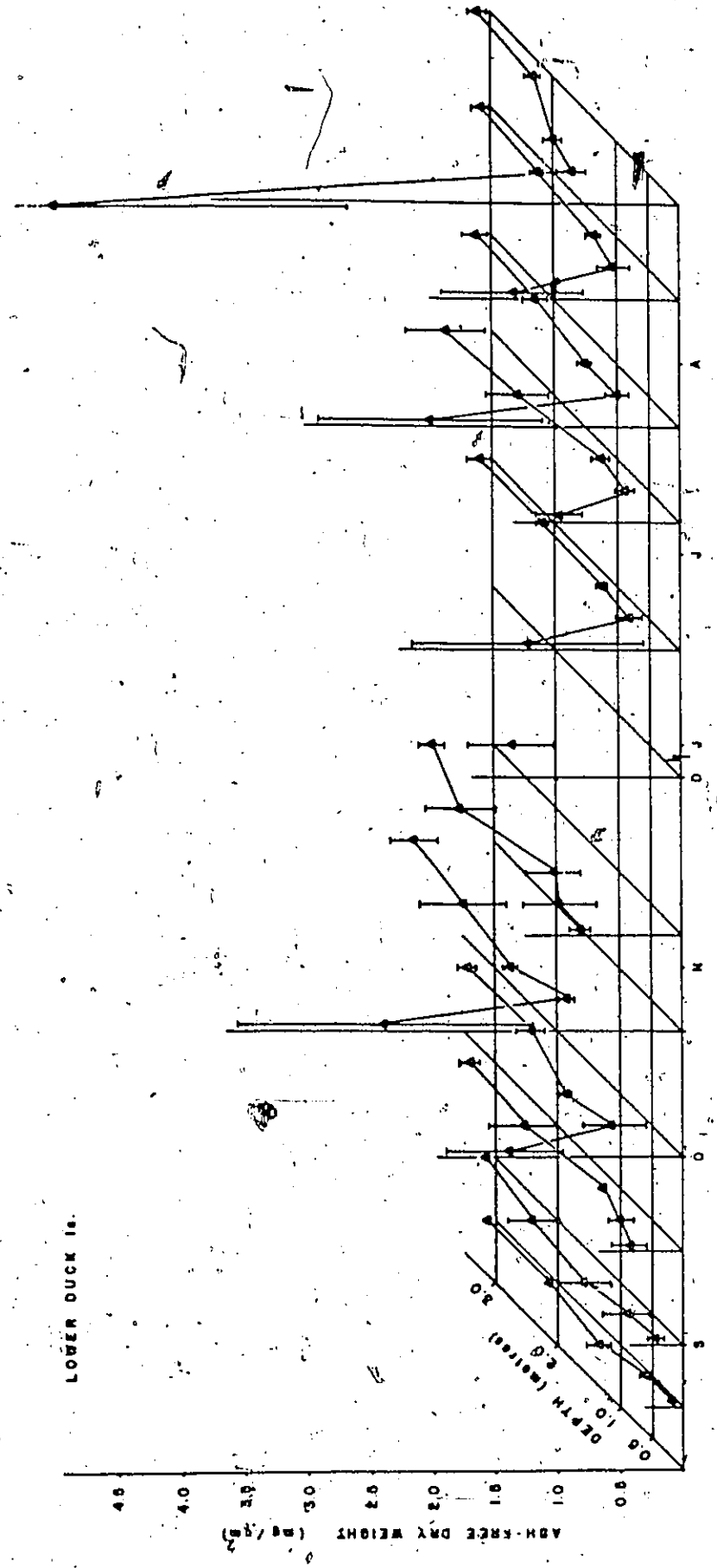

LOWER DUCK Is.
ASH-FREE DRY WEIGHT (mg/gm)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
DEPTH (meters) e.g.
0.0
1.0
2.0
3.0
1971
S
O
N
D
J
F
M
A
1972

FIG 11.3

periphyton biomass gradient with depth is steepest during the summer than at any other time of year. Associated with this steeper summer gradient are consistently high levels of phytoplankton biomass (Figure 4) which may be, along with other particulate matter reducing water transparency (Figure 8). This reduction in water transparency would allow less periphytic algal growth at further depths, thus creating this steeper gradient. At 0.1 m depth, where light is probably not limiting at this time, growth during the summer months yields the annual peak levels of biomass.

The water transparency, periphyton-biomass-gradient relationship as stated is not that simple though. Secchi depth data for CIP channel is consistently lower than at the other two stations (Figure 8). The gradient in biomass though, between 0.1 m and 3 m depth is not greater at CIP channel than at the other two stations. This is because much of the biomass at CIP channel station was non-algal, usually filamentous bacteria (Figure 12). These bacteria grow at all depths and are unaffected by light because they are not photosynthetic. Since the method to determine periphyton ash-free dry weight did not segregate for algae, relatively high biomass values were found at lower depths at CIP station.

Significant differences between stations (judged by 95% confidence intervals not overlapping) were observed five times over

the year at 0.1 m depth in which Lower Duck Island values were greater than those in the CIP channel (Figures 11.2, 11.3). Lower Duck Island and Blair Road values were not found to be significantly different using the method of overlap of confidence intervals (Figures 11.1, 11.3). Blair Road values were significantly higher than those at CIP channel on three occasions at 0.1 m depth (Figures 11.1, 11.2).

Taxa from Periphyton Grown on Plexiglass Substrates

Filamentous green algae, filamentous bacteria and diatoms comprised the majority of the biomass over the year of sampling (Figure 12). Chlorophyta was represented by 15 genera of which the following were most abundant: Cladophora, Closterium, Cosmarium, Spirogyra and Stigeoclonium. At 0.1 m depth Stigeoclonium occurred the most frequently of all the chlorophytes (70% of the samples). At 1 m depth Closterium became dominant (38% frequency). At 3 m the only chlorophyte genus observed was Echinosphaerella which occurred only once, at the CIP station.

Cyanophyta was represented by 5 genera of which Oscillatoria was the most abundant (Figure 12). This genus occurred in about 70% of the samples at 0.1 m, 55% at 1 m and 20% at 3 m (Figures 12 and 13).

Chrysophyta was represented by 81 diatom species, 31 of

Figure 12

Occurrence as percentage of samples containing selected periphyton Taxa at Blair Road, CIP channel and Lower Duck Island stations and depths of 0.1, 1 and 3 meters.

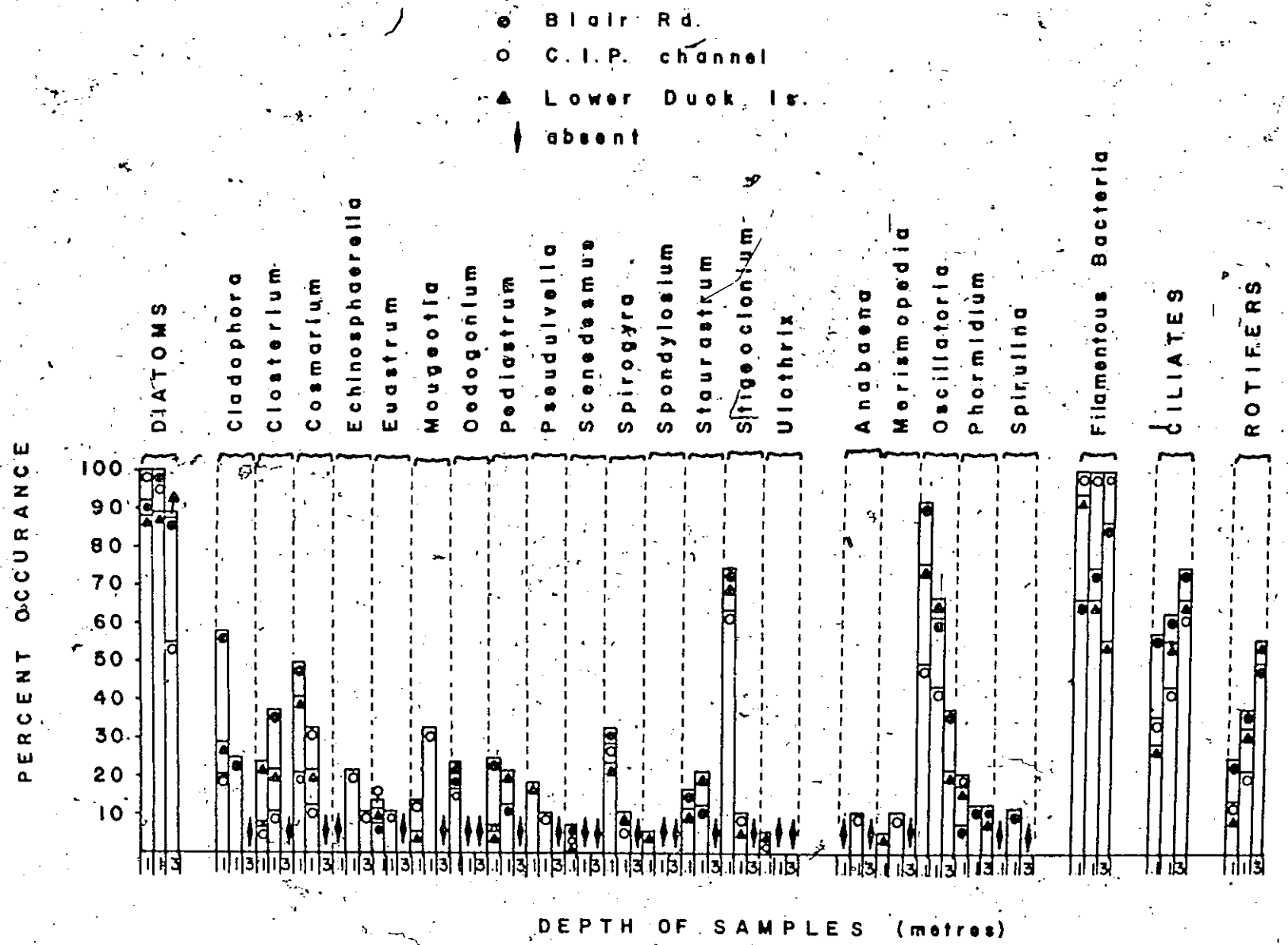
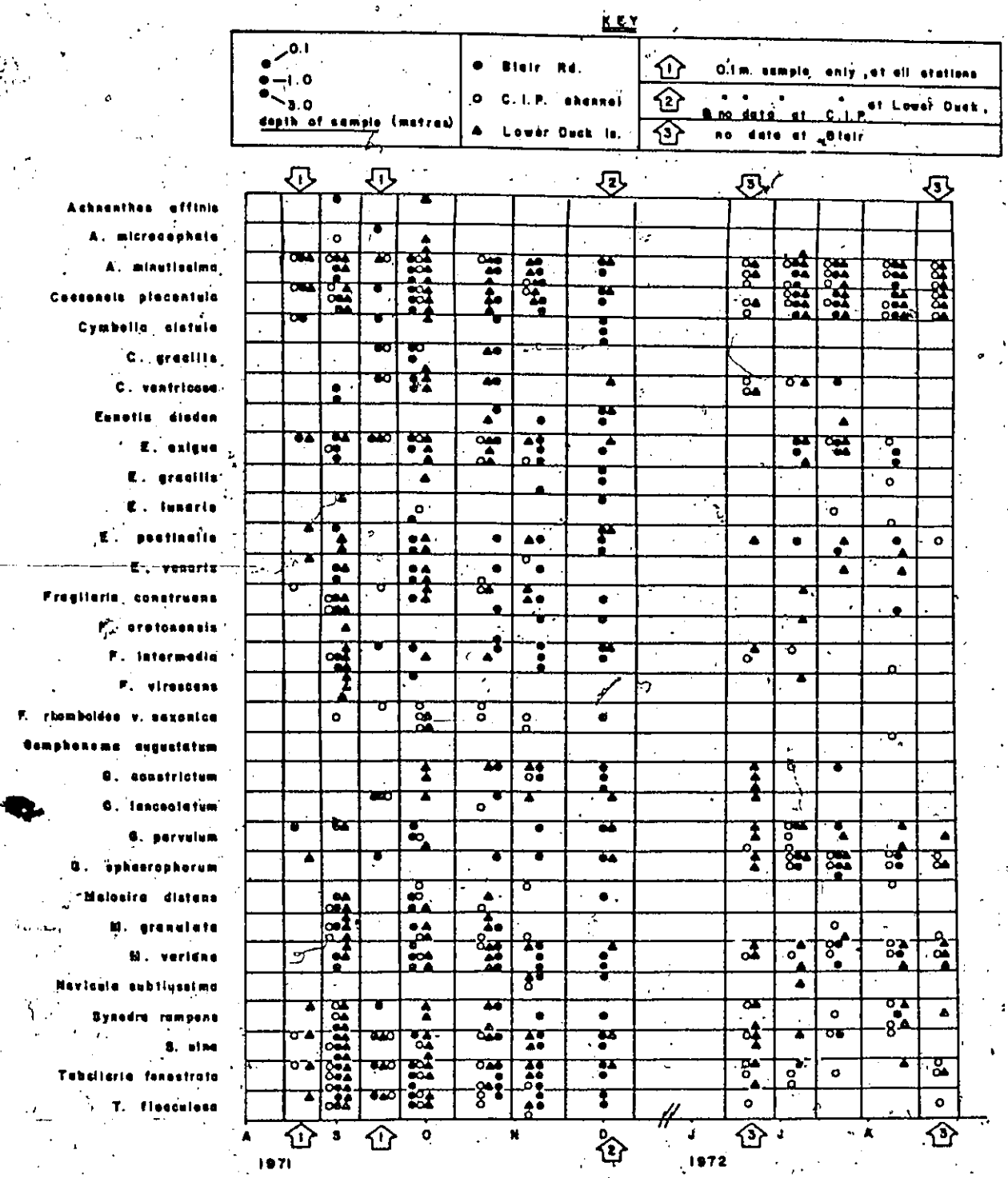

Blair Rd.
C.I.P. channel
Lower Duck Is.
absent
DIATOMS
Cladophora
Closterium
Cosmarium
Echinosphaerella
Euastrum
Mougeotia
Oedogonium
Pediastrum
Pseudulvella
Scenedesmus
Spirogyra
Spondylosium
Staurastrum
Stigeoclonium
Ulothrix
Anabaena
Merismopedia
Oscillatoria
Phormidium
Spirulina
Filamentous Bacteria
CILIATES
ROTIFERS
PERCENT OCCURANCE
100
90
80
70
60
50
40
30
20
10
1
3
DEPTH OF SAMPLES (metres)

Figure 13

Seasonal occurrence of selected Taxa for periphyton on plexiglass slides at Blair Road, CIP channel and Lower Duck Island at 0.1, 1 and 3 meters depth.


KEY
0.1
1.0
3.0
depth of sample (metres)
Blair Rd.
C.I.P. channel
Lower Duck Is.
1 0.1m. sample only, at all stations
2 " " " " at Lower Duck, & no data at C.I.P.
3 no data at Blair
Achnanthes affinis
A. microcephala
A. minutissima
Cocconeis placentula
Cymbella cistula
C. gracilis
C. ventricosa
Eunotia diodon
E. exigua
E. gracilis
E. lunaris
E. pectinalis
E. veneris
Fragilaria construens
F. crotonensis
F. intermedia
F. virescens
F. rhomboidea v. saxonica
Gomphonema augustatum
G. constrictum
G. lanceolatum
G. parvulum
G. sphaerophorum
Melosira distans
M. granulata
M. varians
Navicula subtilissima
Synedra rumpens
S. ulna
Tabellaria fenestrata
T. flocculosa
A
S
O
N
D
J
J
A
1971
1972

which occurred in at least 5% of all samples taken (Figure 14). The diatoms showing the highest frequency of occurrence and persistence throughout the year were Achnanthes minutissima, Cocconeis placentula, Eunotia exigua, Gomphonema sphaerophorum, Melosira varians, Synedra ulna and Tabellaria fenestrata (Figure 15). Twenty-five of these 31 dominant species occurred at all sample depths. Only six did not occur at the 3 m depth.

The Blair Road and Lower Duck Island stations were quite similar in species composition and biomass. The CIP station was different in species composition. The dominant biomass at CIP at all depths was filamentous bacteria, largely Sphaerotilus natans. Cladophora and Stigeoclonium which made up the dominant biomass at 0.1 and 0.5 meter depths at Blair Road and Lower Duck Island, were found in very low abundance at CIP. Lower abundance levels of the following genera were found at CIP as well: Closterium, Cosmarium, Oedogonium, Pediastrum and Oscillatoria. The following genera were found in higher abundance at CIP than at Blair Road and Lower Duck Island: Mougeotia, Merismopedia, and Euastrum. Echinosphaerella and Anabaena were observed only at the CIP station, but at very low levels of abundance. Staurastrum and Spondylosium were observed at Blair Road and Lower Duck Island but not at CIP.

The consistently low diatom cell density at the CIP station at 0.1 m depth comprised the most striking difference between stations (Figure 16). No large differences in diatom cell densities

Figure 14

Occurrence as percentage of samples containing diatom species for periphyton grown on plexiglass slides at Blair Road, CIP channel and Lower Duck Island stations at 0.1, 1 and 3 meter depths.

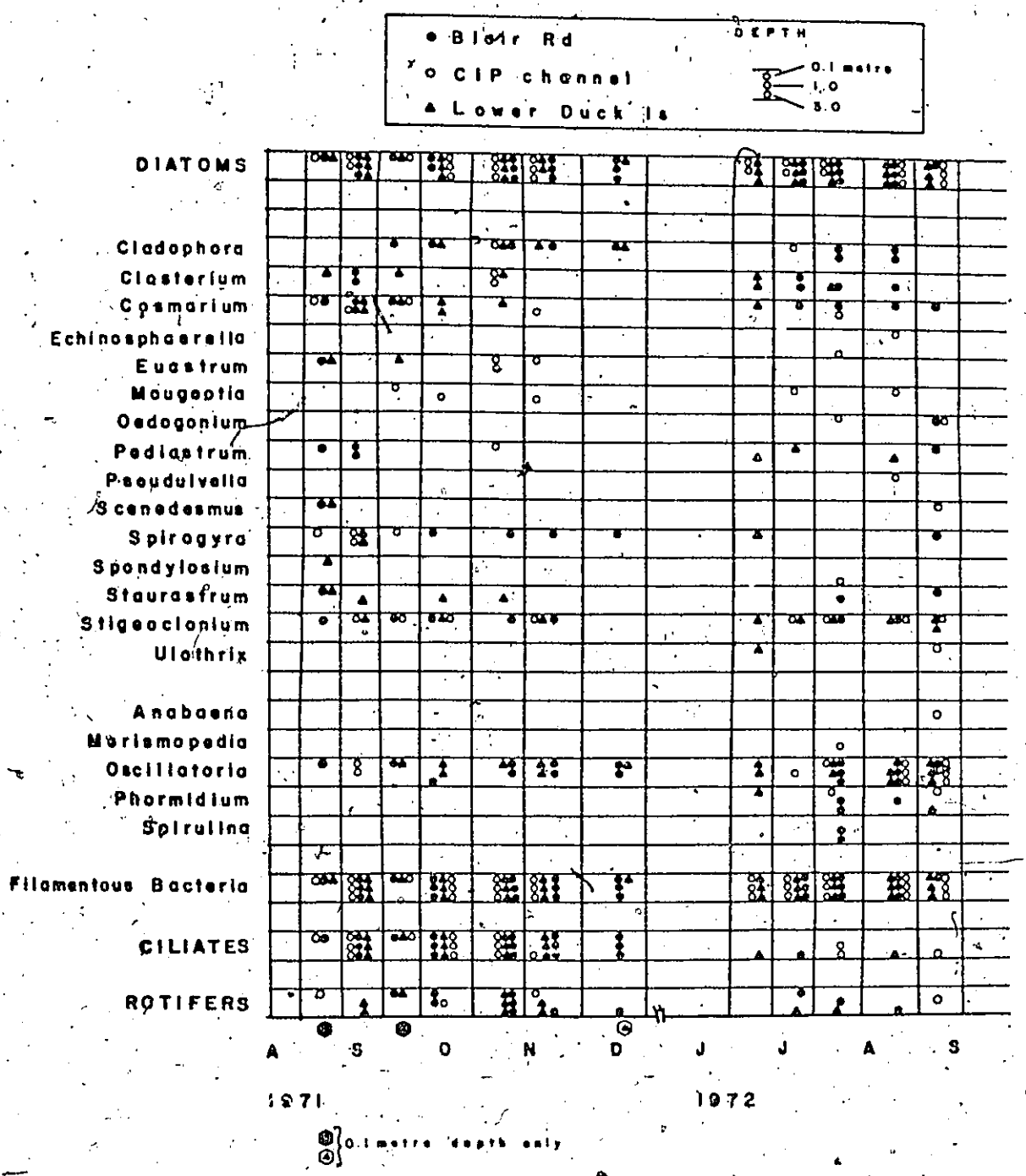
Figure 14

Occurrence as percentage of samples containing diatom species for periphyton grown on plexiglass slides at Blair Road, CIP channel and Lower Duck Island stations at 0.1, 1 and 3 meter depths.

Achnanthes affinis
A. microcephala
A. minutissima
Cocconeis placentula
Cymbella cistula
C. gracilis
C. ventricosa
Eunotia diodon
E. exigua
E. gracilis
E. lunaris
E. pectinalis
E. veneris
Fragilaria construens
F. crotonensis
F. intermedia
F. virescens
F. rhomboides v. saxonica
Gomphonema augustatum
G. constrictum
G. lanceolatum
G. parvulum
G. sphaerophorum
Melosira distans
M. granulata
M. varians
Navicula subtilissima
Synedra rampens
S. ulna
Tabellaria fenestrata
T. flocculosa
100 90 80 70 60 50 40 30 20 10
PERCENT OCCURANCE
DEPTH OF SAMPLE
ABSENT
0.1 1.0 3.0
metres

Figure 15

Seasonal occurrence of diatom species for periphyton on plexiglass slides at Blair Road, CIP channel and Lower Duck Island stations at 0.1, 1 and 3 meter depths.


• Blair Rd
○ CIP channel
▲ Lower Duck Is
DEPTH
0.1 metre
1.0
5.0
DIATOMS
Cladophora
Closterium
Cosmarium
Echinosphaerella
Eucstrum
Mougeotia
Oedogonium
Pediastrum
Pseudulvella
Scenedesmus
Spirogyra
Spondylosium
Staurastrum
Stigeoclonium
Ulothrix
Anabaena
Merismopedia
Oscillatoria
Phormidium
Spirulina
Filamentous Bacteria
CILIATES
ROTIFERS
A S O N D J J A S
1971
1972
0.1 metre depth only

occurred between stations when 1 and 3 m depths were compared. Two major peaks at Blair Road station, one in November and one at the end of July, at 0.1 m, were not observed at the other two stations. The peaks at Lower Duck Island station were about half the corresponding Blair Road values in October and July. Almost no diatoms were found on substrates placed at 0.1 m and 1 m below the ice cover during the winter. No other algal forms were found on these winter substrates.

Water quality measurements showed dissolved inorganic carbon to be similar at all three stations (Table 6). However, conductivity was substantially higher and pH lower at CIP than at the other two stations (Table 3). Conductivity and pH were not different between Blair Road and Lower Duck Island.

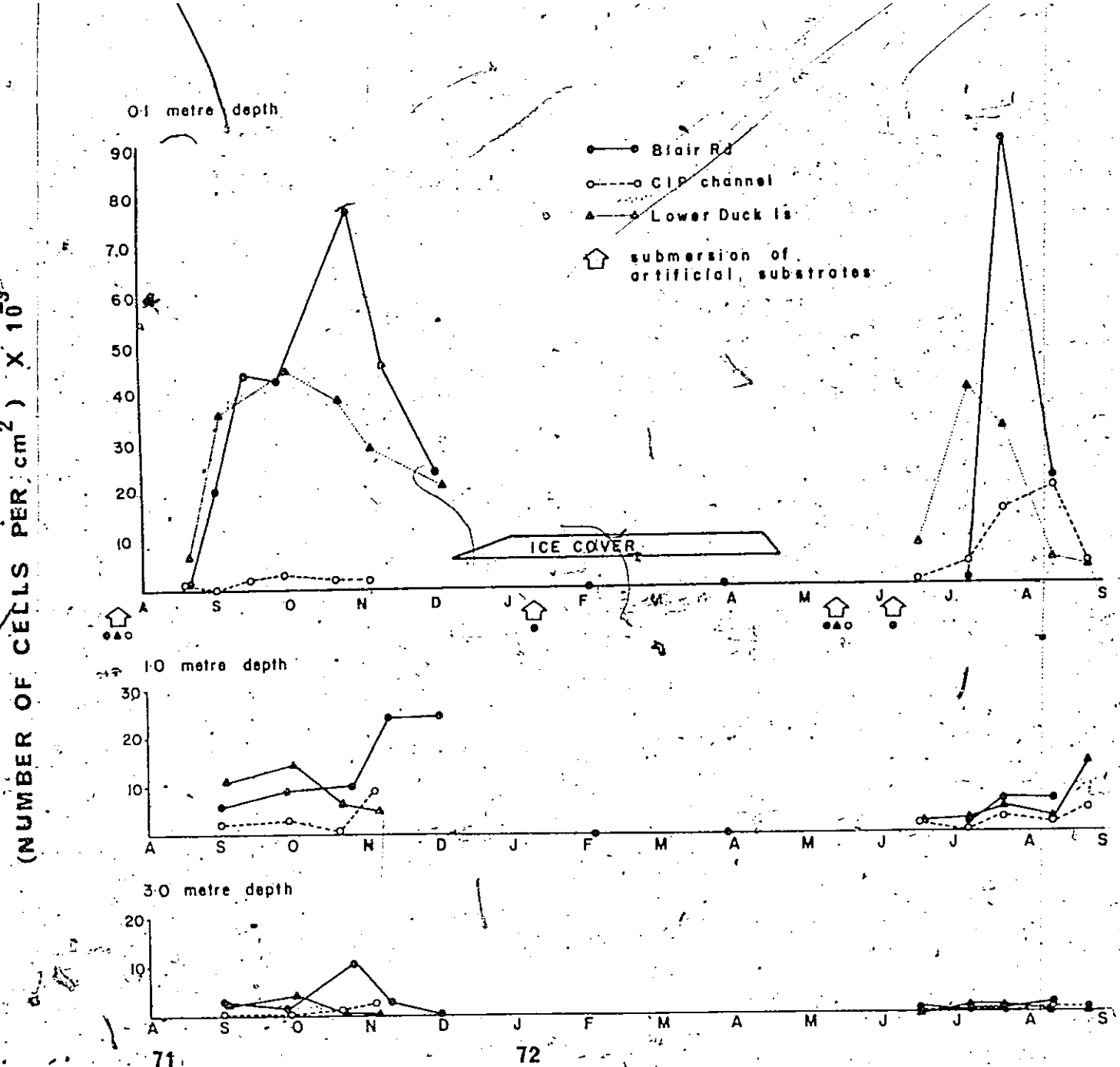
Water quality appears to be different at the GIP channel station than at the other stations and this may explain the differences in species composition. Additionally, Secchi depth was consistently lower at the CIP station than at the other two stations over the year (Figure 8).

STATION	pH	conductivity (μmhos/cm at 25°C)	inorganic carbon (elemental C in mg/l)
Blair Road	7.07 (7.0-7.2)	70 (69-74)	5.1 (4.1-7.3)
Lower Duck Island	7.01 (6.9-7.2)	73 (70-78)	5.2 (4.6-7.8)
CIP	6.74 (6.7-6.8)	90 (85-99)	5.0 (3.8-7.0)

TABLE 3 Annual means and ranges (in brackets) of pH, conductivity, and inorganic carbon concentration from data taken over August, 1971 to August, 1972.

Figure 16

Seasonal variation in numbers of cells of diatoms from periphyton grown on plexiglass slides at Blair Road, CIP channel and Lower Duck Island stations from depths of 0.1, 1.0 and 3.0 meters.


0·1 metre depth
1·0 metre depth
3·0 metre depth
(NUMBER OF CELLS PER cm^2) X 10^{-3}
Blair Rd
CIP channel
Lower Duck Is
submersion of artificial substrates
ICE COVER
A S O N D J F M A M J J A S
71
72

It is interesting that at CIP channel, phytoplankton productivity and species composition over the year, did not differ from the Blair Road station, although periphyton did differ. The ability for periphyton to integrate over time the effect of the water quality at the colonization site (Dickman, 1973), and the inability of the phytoplankton to do this, might explain this apparent conflicting result.

Non-Algal Biota from Plexiglass Substrates

Filamentous bacteria were found in all samples at all depths at the CIP station. The filamentous sewage bacterium Sphaerotilus natans dominated the CIP station community. Filamentous bacteria were found in about 80% of the samples at the other stations as well (Figure 12).

Ciliates and rotifers were found in increasing frequency with increasing depth (Figure 12). At 3 m depth, ciliates were found in about 70% of the samples and rotifers in 60%. At 0.1 m depth, ciliates were in 40% of the samples and rotifers 15%. Ciliates were most abundant between August, 1971 and December, 1971 (Figure 13).

Shore to Mid-Channel Comparison of Periphyton Primary Productivity, Biomass and Species Composition

The periphyton growth on plexiglass slides in the mid-channel

at Lower Duck Island station were compared with that on similar slides in the littoral zone of the island (Station D, Figure 1) directly across from the mid-channel station. Periphyton primary productivity, biomass (ash-free dry weight) and species composition were compared on June 26, July 25 and August 29 (Tables 4 and 5).

Although primary productivity was not found to be significantly* different between the two stations on June 26 and July 25, the shoreline was significantly lower than the mid-channel on August 29.

Ash-free dry weight followed the same pattern as primary productivity in the above comparison between stations. The ash-free weight at mid-channel and shore station was 0.896 mg/cm^2 and 0.276 mg/cm^2 respectively on August 29 (Table 4). Those on the previous two dates were not different.

Diatoms were more numerous in the mid-channel than on the shore on two of the three dates (14,771 and 4,558 respectively on July 25 and 23,575 and 5,483 respectively on August 29, Table 5). Diatoms were also represented by a greater number of species in the mid-channel than on the shore (10 and 3 respectively on July 25 and 12 and 6 respectively on August 29).

The dominant chlorophytes and cyanophytes found on the shoreline samples were always represented in the mid-channel samples. Stigeoclonium and Oscillatoria were the dominant non-diatom algal

* analysis of variance, 95% probability

	Channel June 26	Shore June 26	Channel July 25	Shore July 25	Channel Aug. 29	Shore Aug. 29
Ash-free dry weight (mg/cm^2)	0.061	0.086	0.315	0.285	0.896	0.276
Primary productivity ($\mu g/mm^2 \cdot hr$)	0.0191	0.0127	0.0753	0.0649	0.0697	0.0331
(±95% conf. int.)	±0.0095	±0.0029	±0.018	±0.0129	±0.0188	±0.0179
	NS difference		NS difference		**S difference	

Table 4: Periphyton biomass (ash-free dry weight) and primary productivity at Lower Duck Island mid-channel and littoral stations, June 26, July 25 and August 29, 1972.

Diatom species (no. cells/cm^2)	Channel June 26	Shore June 26	Channel July 25	Shore July 25	Channel Aug. 29	Shore Aug. 29
Achnanthes minutissima	665	3815	4267	3808	2760	1560
Cocconeis placentula	578	35	5960	-	13225	2135
Eunotia dioden	-	-	-	-	115	-
E. exigua	-	347	547	635	-	115
E. pectinalis	-	-	-	-	115	-
Fragilaria intermedia	-	-	-	-	690	-
Gomphonema lanceolatum	-	-	55	-	115	-
G. parvuium	-	-	438	-	-	-
G. sphaerophorum	260	-	711	-	345	115
Melosira grandulata	-	-	385	-	2070	-
M. varians	-	58	2080	115	2415	1327
Synedra rampens	-	-	219	-	345	-
S. ulna	-	-	-	-	115	-
Tabellaria fenestrata	-	-	109	-	1265	231
Total Diatoms	1503	4255	14771	4558	23575	5483
Genus (Present X) (Absent 0)						
Bulbochaete	0	0	0	0	0	X
Cosmarium	0	0	0	0	0	X
Merismopedia	0	0	0	0	0	X
Oedogonium	0	X	X	X	X	X
Oscillatoria	0	0	X	X	X	X
Pseudulvella	0	X	0	X	0	X
Spirogyra	0	0	X	0	0	0
Stigeoclonium	0	0	X	X	X	X
Filamentous bact.	X	X	X	X	X	X

Table 5: Taxonomical comparison between Lower Duck Island mid-channel and littoral stations, from samples taken June 26, July 25 and Aug. 29, 1972.

genera in both the channel and shore samples. Diatoms as already stated were not found to occur equally. The following diatom species found in the mid-channel samples were not found in the shore samples: Fragilaria intermedia, Melosira granulata and Synedra spp.

The Use of Plexiglass Slides to Sample Periphyton

Plexiglass substrates were preferred to glass because the latter are selective for some diatoms and against some filamentous forms (Albin, 1965). Filamentous greens were certainly not selected against using plexiglass in the present study because Cladophora and Stigeoclonium made up the dominant biomass at 0.1 and 0.5 m depths for most of the ice-free season.

Adequate quantitative data on natural substrates for comparison between natural and artificial substrates are difficult to obtain. This is obvious, because the rationale for using artificial substrates in the first place is that natural substrates are so difficult to evaluate quantitatively (Sladeckova, 1962).

Sampling of naturally occurring substrates was limited to two dates during the height of the growing season: July 20 and August 24, 1972. Ash-free dry weight and qualitative relative abundance of taxa were compared to that from plexiglass slides for the same dates (Tables 6 and 7).

Many differences in taxonomical relative abundance were

observed between the two types of substrate. Stigeoclonium occurred in all the samples but differed in relative abundance at Lower Duck Island on August 24 and CIP channel on July 20 (Table 6). Diatoms occurred in all samples except for the one from the natural substrate on July 20 at Lower Duck Island. Diatoms were not found in equal relative abundance between the two substrates on all occasions except for one on August 24 at CIP channel.

Filamentous blue greens (Cyanophyta) occurred in all samples but in differing abundance between the two substrate types on three dates: July 20 and August 24 at Lower Duck Island and July 20 at CIP channel. Filamentous bacteria occurred in all samples but only similar in relative abundance between the two substrates on one occasion: August 24 at CIP channel. The two substrates in four of the five comparisons were found to contain some taxa with the same degree of relative abundance. On one occasion, July 20 at CIP channel, all the taxa occurred at differing levels of relative abundance between the two substrates.

Ash-free dry weights were found to be similar between substrate types in all comparisons except for the August 24 CIP channel comparison in which the plexiglass values were lower. The low biomass on these plexiglass slides was attributed to high waves, which probably removed the attached community prior to sampling.

The primary productivity method developed in this study for

Table 6: Comparison of natural and artificial substrates.

Qualitative relative abundance of taxa from plexiglass substrates and dead-head log substrates (natural) from 0.1 meter depth at Lower Duck Island, Blair Road and CIP channel stations during the height of the growing season (July 20, 1972 and August 24, 1972).

LOWER DUCK ISLAND

Plexiglass substrate	Dead-head log substrate
July 20, 1972 - Stigeoclonium (dominant) - filamentous Cyanophyta (sparse) - filamentous bacteria (sparse) - diatoms (sparse)	July 20, 1972 - Stigeoclonium (dominant) - Cladophora (trace) - filamentous bacteria (abundant) - filamentous Cyanophyta (sparse) - Rotifers (present)
August 24, 1972 - Stigeoclonium (dominant) - filamentous Cyanophyta and bacteria (trace) - diatoms (sparse)	August 24, 1972 - Stigeoclonium (abundant) - Mougeotia, Oedogonium, Spirogyra (trace) - filamentous Cyanophyta (dominant) - filamentous bacteria (present) - diatoms (abundant)

BLAIR ROAD

Plexiglass substrate	Dead-head log substrate
July 20, 1972 - Stigeoclonium (dominant) - Cladophora (dominant) - Oscillatoria (present) - fil. bacteria (present) - diatoms (abundant)	July 20, 1972 - Stigeoclonium (dominant) - Cladophora (dominant) - fil. Cyanophyta (present) - fil. bacteria (abundant) - diatoms (trace)

C.I.P.

Plexiglass substrate	Dead-head log substrate
July 20, 1972 - Stigeoclonium (present) - Oedogonium - filamentous Cyanophyta (abundant) - filamentous bacteria (abundant) - diatoms (present)	July 20, 1972 - Stigeoclonium (dominant) - Cladophora (present) - Spirogyra (trace) - Oedogonium (trace) - fil. Cyanophyta (present) - fil. bacteria (present) - diatoms (dominant)
August 24, 1972 - Stigeoclonium (abundant) - Ulothrix (present) - Scenedesmus (trace) - Oscillatoria (abundant) - other fil. Cyanophyta (present) - fil. bacteria (abundant) - diatoms (present) - Nematode (trace)	August 24, 1972 - Stigeoclonium (abundant) - fil. Cyanophyta (present) - fil. bacteria (abundant) - diatoms (present)

Table 7: Ash-free dry weight of periphyton from artificial and natural substrates at Blair Road, Lower Duck Island and CIP channel stations from 0.1 meter depth during the height of the growing season, July 20, 1972 and August 24, 1972.

DATE	LOCATION	SUBSTRATE TYPE	ASH-FREE DRY WEIGHT (mg/cm^2) (95% conf. interval)	NUMBER OF SAMPLES
1972				
July 20	Blair	dead-head log (a)*	1.06	1
"	"	dead-head log (b)	2.24	1
"	"	plexiglass	2.369 ± 1.262	5
"	Lower Duck	dead-head log (c)	3.20	1
"	"	plexiglass	1.95 ± .896	5
"	CIP	buoy	1.12	1
"	"	dead-head log (d)	3.48	1
"	"	plexiglass	1.739 ± 0.38	5
August 24	Blair	log (a)*	3.29	1
"	"	log (b)	7.54	1
"	"	plexiglass	slides destroyed	5
"	Lower Duck	log (c)	3.60	1
"	"	"	3.63	1
"	"	plexiglass	4.95 ± 2.34	5
"	CIP	buoy	1.29	1
"	"	log (d)	1.37	1
"	"	plexiglass	0.339 ± 0.15	5

* bracketed letters indicate the same substrate was sampled on July 20 and August 24.

the plexiglass-grown periphyton was sufficient for defining the seasonal variation and differences between stations. A number of features of this method made in situ work on the river relatively easy and simplified sample preparation for liquid scintillation counting. The tape cover method allowed a standard area for colonization, increased the number of replicates, and reduced the time for sampling and laboratory sub-sampling. The shaking bottle held by clips in the river (Figure 2.3) induced water movement over the moving slide in the closed bottle. This was adequate water movement because additional shaking by hand over the 4 hour incubation period in an experiment at Lower Duck Island shore including 21 replicates for each treatment (September 29, 1972), did not increase primary productivity. As previously explained the liquid scintillation counting method gave reproducable results and was very much simplified by using the plexiglass.

CHAPTER VI

COMPARISON OF PHYTOPLANKTON AND PERIPHYTON

Primary Productivity and Biomass

To make absolute comparisons between planktonic and attached algae, the data must have a common base. Chlorophyll a concentration per unit substrate area for periphyton was compared with chlorophyll a concentration per unit water volume for phytoplankton by Welch et al (1972). Similarly, cell numbers and chlorophyll a per unit area for epipelic algae and per unit volume for phytoplankton were used by Moss (1969). The above area to volume comparisons are not equivalent in my opinion, and therefore may not constitute a legitimate comparison. Employing the concept of the water column allows phytoplankton data to be expressed in terms of water surface areal units (Schindler and Holmgren, 1971), thus giving a direct measure of all the phytoplankton in a defined column of water. The depth of water column used depends on the depth of periphyton to which it is being compared. The latter of course can only be expressed on an areal basis.

Primary productivity maxima differed between the two communities with periphyton highest during July and August and phytoplankton highest in June. Both communities showed slight increases in November and lowest levels in the winter.

Productivity of phytoplankton varied from 0.6 mg $C/m^2 \cdot day$ to 406 mg $C/m^2 \cdot day$. Periphyton productivity at 0.5 m which is an accurate measure of all depths combined (Appendix VI), ranged from 1 mg $C/m^2 \cdot day$

to 750 mg C/m^2·day. The ratios between the maxima and minima for the phytoplankton and periphyton are 670 fold and 750 fold, respectively.

Phytoplankton freshweight biomass ranged from 0.5 µg/l to 51 µg/l or when converted to an equivalent of a three meter water column with 1 m^2 surface area, 1.5 mg/m^2 to 153 mg/m^2. The equivalent values in ash-free dry weight are 0.12 mg/m^2 and 12.24 mg/m^2. This ratio between maximum and minimum phytoplankton biomass is about 100 fold, compared with that of the phytoplankton productivity which was 670 fold.

Periphyton ash-free dry weight ranged from approximately 500 mg/m^2 to 50,000 mg/m^2 at 0.1 m depth, and from approximately 500 to 10,000 mg/m^2 at 0.5 m depth. The maximum phytoplankton biomass for a 0.1 m, 0.5 m or even 3 m water column is at least three orders of magnitude less than the maximum periphyton biomass values (12 mg/m^2 vs 10,000 to 50,000 mg/m^2). On the other hand, the phytoplankton and periphyton productivity maxima were of the same order of magnitude (406 and 750 mg C/m^2·day, respectively). This very high biomass and relatively low productivity of the periphyton when compared to the phytoplankton must be examined more closely as follows.

The phytoplankton and periphyton productivity analyses were very similar in methodology and the results obtained can be compared satisfactorily. However, the respective biomass methods

differed. The phytoplankton biomass data was generated from microscopic estimation of algal volumes and cell densities. The periphyton ash-free dry weight method did not segregate for the algae. The total periphyton community was assessed - invertebrates, bacteria, fungi, algae and debris. The high biomass and low productivity associated with the periphyton would be explained if the majority of biomass was non-algal. However, about 80% of the periphyton biomass was algal (estimated from relative abundance data). Thus the phenomenon of low productivity per unit of biomass of periphyton and high productivity per unit biomass of phytoplankton appears to be real.

Periphyton productivity data from my study were of the same order of magnitude as in other similar studies. In Borax Lake, California for instance, Wetzel (1963) observed a summer mean value of 730 mg C/m^2 day for glass-slide-grown periphyton. In Lawrence Lake in New Hampshire, Allen (1971) observed a summer mean value of 300 mg C/m^2 day for plexiglass-grown periphyton. The summer mean observed in the Ottawa River in 1972 was 350 mg C/m^2 day. The conclusion from this is that the periphyton productivity data are realistic along with the biomass estimates and the ratios examined above can be assumed to be accurate.

Thus it appears that the periphyton productivity per unit biomass is substantially lower than that of the phytoplankton. This

has been indirectly observed by Findenegg (1965) in a study comparing standing crop of phytoplankton and its primary productivity. He concluded the biomass-productivity relationship varies from water body to water body but a) the small algae (nannoplankton) are more active in relative assimilation than larger species and b) increasing population density diminished relative assimilation rates. The higher metabolic rate of smaller cells can be attributed to their greater surface area to volume ratio, which facilitates gaseous and nutrient exchange. On the whole, periphyton are made up of medium to large sized cells (Ottawa River mean cell volume 1000 μ^3) and phytoplankton small to medium (mean cell volume 400 μ^3). This could partially explain the higher productivity to biomass ratio found in phytoplankton. With regard to density, periphyton are much more crowded than the phytoplankton. Competition between algae is likely to be much more intense on these substrates, than if they were suspended in the water column. The relative amount of senescent, dead or non-photosynthesizing cells in successionally mature periphyton communities may be higher than that for the phytoplankton. These so-called "dead" cells would not be included in the productivity estimates and not corrected for in the biomass estimates. This could be a further contributing factor to the observed result.

Species Composition of the Periphyton and Phytoplankton

One hundred and eleven species of diatoms occurred in all

the periphyton and phytoplankton samples examined (Appendix V). The species of diatoms shared by the two communities totalled 39 but only eleven were found in any abundance (at least five in a subsample): Cocconeis placentula, Fragilaria construens, F. crotonensis, F. intermedia, F. virescens, Melosira distans, M. granulata, M. varians, Synedra ulna, Tabellaria fenestrata and T. flocculosa.

Filamentous green algae were never observed in the phytoplankton samples although they dominated the periphyton surface samples. This is probably because the phytoplankton samples were taken in the mid-channel, far from the shorelines where these algae were concentrated. Upon attrition from their substrate branched filamentous forms tend to be clumped (from laboratory observation) and would not be mixed into the mid-channel by the relatively weak shoreline current as would smaller, less dense forms.

The filamentous blue-greens Anabaena, Oscillatoria and Phormidium were shared by the two communities. These are not branched filaments and thus unlike the green algae Cladophora and Stigeoclonium, did not form clumps and could be swept into the mid-channel to be sampled as phytoplankton. Additionally, the blue-greens have much shorter filaments than the greens reducing filament weight and possible clumping. Colonial blue-greens like Microcystis were found mostly in the phytoplankton samples. Merismopedia was found in a few periphyton samples. Colonial greens were found almost exclusively in the phytoplankton samples. The pyrrophyte Ceratium

was found only in the phytoplankton samples.

Relative Contribution by the Phytoplankton and Periphyton to the Algal Primary Productivity and Biomass of a One-Meter-Wide Cross-Section of the Ottawa River

During the peak of the growing season, July 1972, productivity values for periphyton (0.5 m depth) and phytoplankton (3 m water column) were 750 and 220 mg C/m^2 · day, respectively. Similarly biomass values were 10,000 and 12 mg/m^2, respectively. By knowing the bathymetry of a cross-section of river (Station X, Figure 1) the contribution to primary productivity and biomass for periphyton and phytoplankton may be calculated. The area of river bottom available for periphyton colonization is determined by the 3 meter water depth level, the base of the euphotic zone. This value is 100 m^2 for a 1 meter wide strip across the river from Warnock's (1972) drawing of the cross-section through Station X (Figure 1). The area of river surface encompassing a three meter euphotic zone of actively photosynthesizing phytoplankton is 740 m^2 for this same strip. The resultant standing crop in this cross-section for periphyton is 1,000 gm and for phytoplankton 8.9 gm. The corresponding periphyton primary productivity is 75 gm C/day and for that of the phytoplankton is 162.8 gm C/day. This illustrates the phenomenon of high productivity per unit biomass for phytoplankton relative to periphyton.

On an annual basis the phytoplankton would appear even more

dominant as primary producers because the spring peak in their productivity was not included in the above calculation.

The obvious reason for the greater primary productivity by phytoplankton is its greater habitat size (volume of water) than that for the periphyton (shoreline surface area). Added to this as already stated, the cell size and density differences between the communities must influence the result.

CHAPTER VII

SUMMARY

The major objective of this study was to survey the seasonal variation in primary productivity and biomass of phytoplankton and periphyton at three stations in a short section of the Ottawa River. A secondary objective was to develop a method to assay periphyton productivity *in situ* using a ^{14}C tracer technique. A final objective was to examine differences between phytoplankton and periphyton productivity and species composition, in three situations differing in terms of water pollutants: (1) the impact zone below a sulphite paper mill (CIP channel station), (2) in a partial recovery zone below a sulphite paper mill (Blair Road station) and (3) below a municipal sewage treatment plant (Lower Duck Island station).

Phytoplankton primary productivity at Blair Road station was found to have one major annual peak in June, 1972 (406 mg $C/m^2 \cdot day$) and a lesser peak in October, 1971 (54 mg $C/m^2 \cdot day$). Phytoplankton biomass at Blair Road station was found to have two major annual peaks in October, 1971 (45 µg/l) and during July-August, 1972 (49 µg/l).

On an annual basis phytoplankton productivity was lower at Lower Duck Island than at Blair Road. The postulated reason for this is the presence of a chemical factor derived from the sewage treatment plant, affecting Lower Duck Island station. Primary productivity was not found to be different between Blair Road and CIP channel and between Lower Duck Island and the CIP channel.

Phytoplankton biomass was not found to be different between stations and between the depths sampled (0.1, 0.5, 1, 2 and 3 meters). The conclusion from this is the mid-channel water is well-mixed in this section of the river and differences in biomass between stations are not detectable.

Diatoms were the dominant algae found in the phytoplankton samples. Asterionella formosa, Melosira granulata and Tabellaria fenestrata were the diatoms that occurred most consistently throughout the study year. Chlorophyta and Cyanophyta together made up about 10% of the phytoplankton biomass over the study year but in terms of cell numbers, they were relatively more abundant. Cyanophyta made up about 70% of the phytoplankton cell numbers in October, 1971. Chlorophyta made up about 45% of the cell numbers in June, 1972. This latter value was the annual peak in Chlorophyta cell numbers and coincided with annual peak in phytoplankton productivity.

During the study year, temperature was found to be the most influential factor in determining seasonal variation in phytoplankton primary productivity and biomass. In the main, high temperatures were associated with high productivity and biomass levels. During the spring, river discharge may have been the major negative controlling factor in determining phytoplankton primary productivity and biomass levels ($r = -0.98$). Water transparency measured, as Secchi depth, varied inversely with the discharge and directly with

productivity. The operating mechanism here was cited as the high runoff and flow conditions which produced high turbidity by stirring up the sediments, thus reducing the water transparency. Phytoplankton productivity and biomass could therefore be decreased because of lower water transparency and hydrologically unstable conditions.

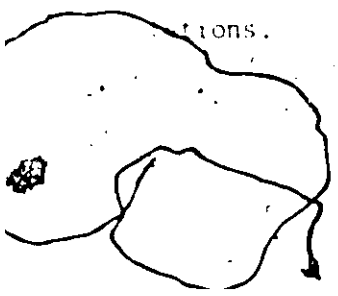
Periphyton primary productivity peaked once in the study year during July and August, 1972 (.075 ug C/mm^2 hr). Periphyton biomass peaked twice in the study year in October, 1971 (2,367 mg/cm^2 at 0.1 m depth) and during July and August, 1972 (4.430 mg/cm^2 at 0.1 m depth). Negligible colonization of plexiglass slides occurred during the winter under the ice. The primary productivity was then so low that it was not detectable with the technique used in this study.

Significant differences between stations in periphyton biomass were observed five times during the study year at 0.1 m depth, in which Lower Duck Island values were greater than those in the CIP channel. Lower Duck Island and Blair Road values were not found to be significantly different using the method of overlap of confidence intervals. Blair Road values were significantly higher than those at CIP channel on three occasions at 0.1 m depth.

Periphyton biomass was usually highest at the 0.1 m depth and decreased steadily towards the bottom depth that was sampled (3.0 m). This gradient with depth in biomass values, was steepest

throughout the summer months of the study year. The postulated reason for this was higher turbidity and lower water transparency during the summer, thus reducing algal growth at further depths. During the autumn, the water transparency was found to be higher and this gradient with depth in periphyton biomass was less than during the summer.

Filamentous green algae, filamentous bacteria and diatoms comprised the majority of the periphyton biomass over the year of sampling. The Blair Road and Lower Duck Island stations were quite similar in species composition and biomass. The CIP channel station was different in species composition. Biomass at this latter station was dominated by filamentous bacteria, largely Sphaerotilus natans. Cladophora and Stigeoclonium which made up the dominant biomass at 0.1 and 0.5 m depths at Blair Road and Lower Duck Island, were found in very low abundance at CIP channel. The consistently low diatom cell density at the CIP station at 0.1 m depth comprised the most striking difference between stations. No large differences in diatom cell densities were observed between stations when 1 and 3 m depths were compared. Water quality measurements (conductivity and pH) over the study year revealed that CIP channel station was consistently different from the other two stations. This may partially explain the differences in species composition between the CIP channel and the other two stations.



Periphyton were compared with phytoplankton in terms of primary productivity, biomass and species composition. The primary productivity seasonal maximum for periphyton occurred during July and August and that of the phytoplankton occurred in June. Both communities showed slight increases in November and lowest levels in the winter. The productivity to biomass ratio was considerably higher for phytoplankton than periphyton (i.e. P/B = 220 mg C/m^2 · day / 12 mg/m^2 for phytoplankton and P/B = 750 mg C/m^2 · day / 10,000 mg/m^2 for periphyton). The postulated reasons for this were 1) the smaller algae which make up much of the phytoplankton and little of the periphyton, are more active metabolically than the larger species because of their higher specific surface area and 2) the cell density which was lower for phytoplankton than periphyton, thus reducing competition and increasing relative assimilation.

Species composition differed considerably between the phytoplankton and periphyton. Of the 111 diatom species observed in the study, 39 were shared by the two communities, eleven of which occurred in any abundance (at least 5 cells in a subsample). It is interesting that at CIP channel, phytoplankton productivity and species composition over the study year, did not differ from the Blair Road and Lower Duck Island stations, although periphyton did differ. The ability for periphyton to integrate over time the effect of the water quality at the colonization site, and the in-

ability of the phytoplankton to do this, because of their short residence period, might explain this apparent conflicting result.

The relative contribution by phytoplankton and periphyton to the algal primary productivity and biomass of a meter-wide cross-section of the Ottawa River was calculated. The periphyton are restricted to the littoral zones (to a depth of 3 meters). The phytoplankton preside throughout the water mass and photosynthesis occurs in the top 3 meters across the river. This large water mass allows the phytoplankton to make up over 2/3 of the algal primary production in the river but less than 1/100 of the standing crop at the same time. This illustrates the phenomenon of high productivity per unit biomass for the phytoplankton relative to the periphyton.

Periphyton from plexiglass slides were compared with that from naturally occurring substrates. Total community biomass was similar between the two substrate types. Species composition differed to some degree between the substrate types but no distinct selectivity pattern for either substrate type was observed.

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APPENDIX I

Phytoplankton Primary Productivity from August 17, 1971 to August 31, 1972 at CIP channel, Blair Road and Lower Duck Island Stations. The data represent means from four replicates.

Date	CIP Channel (mg C/m^2. day)	Blair Road (mg C/m^2. day)	Lower Duck Island (mg C/m^2. day)
1971			
August 17, 18, 19	125.0	114.9	217.2
31, 30 Sept. 2	51.7	16.6	69.9
Sept. 14, 13. 15	10.6	2.9	11.4
Sept. 28, 26, 30	12.9	5.4	25.1
Oct. 19, 24, 21	11.2	54.3	4.2
Nov. 5, 9, 4	28.4	33.2	19.1
Dec. 1, 3		0.6	1.3
1972			
Feb. 6		0.6	
March 4		0.8	
March 28		1.3	
May 5		54.8	
May 10	28.4	67.1	26.5
May 18		124.8	
May 24	166.6	205.8	44.7
June 6	314.4	405.9	81.8
June 8			183.9
June 14		119.0	
June 16	282.1		
June 21	196.9	204.8	156.9
June 28		294.2	-
July 4	224.9	227.7	182.8
July 6		177.1	
July 11		194.9	
July 13	173.1		
July 18	166.9	196.7	121.9
July 27		190.9	
Aug. 8	90.6	165.5	99.5
Aug. 10		110.8	
Aug. 15		79.8	
Aug. 17	69.4	-	
Aug. 22	68.9	96.9	64.0
Aug. 31		101.3	
Annual production (mg C/m^2.yr)	20,034	25,165	13,469

APPENDIX II

Phytoplankton Freshweight Biomass and Cell Numbers from August 18, 1971 to August 31, 1972 at Blair Road.

The data represent single determinations.

Date	Biomass (µg/l)	Cells per liter
1971		
Aug. 18	9.42	22,496
Aug. 30	6.33	36,064
Sept. 13	5.04	23,883
Sept. 26	6.68	14,137
Sept. 30	8.00	15,873
Oct. 24	45.38	91,582
Nov. 9	24.15	38,249
Dec. 1	1.94	1,616
1972		
Jan. 18	0.57	519
Feb. 6	1.20	1,247
March 4	0.07	116
March 28	8.84	10,956
April 21	0.01	12
April 28	0.35	925
May 10	5.57	5,711
May 18	17.98	18,387
May 24	17.27	18,456
June 6	12.36	18,264
June 14	13.69	14,245
June 28	27.80	25,613
July 11	30.06	21,055
July 18	33.98	24,975
July 27	21.10	20,757
Aug. 10	49.39	8,796
Aug. 15	13.80	5,577
Aug. 31	13.32	11,454

APPENDIX III

Periphyton Primary Productivity from August 17 to December 3, 1971 at CIP channel, Blair Road and Lower Duck Island Stations and from June 26 to September 29, 1972 at Lower Duck Island channel and shore stations.

($\mu g\ C/mm^2 \cdot hr \times 10^3$)

Date	CIP Channel	Blair Road	Lower Duck Island (Channel)
1971			
Aug. 17, 18, 19	1.16	10.49	11.03
Aug. 31, 30 Sept. 2	1.94	5.34	13.70
Sept. 14, 13, 15	1.15	7.10	8.01
Sept. 28, 26, 30	2.75	2.38	14.86
Oct. 19, 24, 21	2.90	2.64	2.34
Nov. 3, 9, 4	7.70	5.42	17.50
Dec. 1, 3	-	0.10	0.21

Date	Lower Duck Island Shore	Lower Duck Island Channel
1972		
June 26	12.7	19.1
July 28	64.9	75.3
Aug. 29	33.1	69.7
Sept. 29	6.7	6.4

APPENDIX IV

Periphyton Biomass (ash-free dry weight) from August 17, 1971 to August 24, 1972 at CIP channel, Blair Road and Lower Duck Island Stations at all depths of 0.1, 0.5, 1.0, 2.0 and 3.0 meters.

Date	Depth (meters)	CIP Channel mg/cm^2	Blair Road mg/cm^2	Lower Duck Island mg/cm^2
1971				
August 17, 18, 19	0.1	0.225	0.065	0.035
	0.5	0.103	0.127	0.057
	1.0	0.087	0.157	0.174
	2.0	0.103	0.065	0.078
	3.0	0.136	0.143	0.075
August 31, 30	0.1	0.394	0.115	0.186
Sept. 2	0.5	0.396	0.345	0.217
	1.0	0.532	0.108	0.294
	2.0	0.321	0.142	0.229
	3.0	0.357	0.209	0.088
Sept. 14, 13, 15	0.1	0.364	0.714	0.370
	0.5	0.440	0.414	0.251
	1.0	0.356	0.167	0.151
	2.0	0.270	0.190	0.288
	3.0	0.371	0.374	0.204
Sept. 28, 26, 30	0.1	0.571	0.760	1.357
	0.5	0.555	0.368	0.325
	1.0	0.200	0.364	0.440
	2.0	0.181	0.282	0.219
	3.0	0.435	0.313	0.221
Oct. 19, 24, 21	0.1	0.931	1.640	2.367
	0.5	0.908	0.820	0.668
	1.0	0.650	0.540	0.884
	2.0	0.579	0.570	0.764
	3.0	0.430	0.460	0.648
Nov. 3, 9, 4	0.1	0.524	1.253	0.786
	0.5	0.628	0.745	0.731
	1.0	0.363	0.672	0.539
	2.0	0.431	0.642	0.776
	3.0	0.570	0.575	0.502

Date	Depth (meters)	CIP Channel	Blair Road	Lower Duck Island
Dec. 1, 3	0.1	-	-	-
	0.5	-	0.651	1.112
	1.0	-	0.671	-
	2.0	-	0.531	-
	3.0	-	0.437	-
1972				
June 16	0.1	0.199	-	1.175
	0.5	0.279	-	0.158
	1.0	0.377	-	0.127
	2.0	0.126	-	0.093
	3.0	0.039	-	0.110
July 6	0.1	1.103	0.071	0.931
	0.5	0.161	0.115	0.197
	1.0	0.438	0.093	0.126
	2.0	0.160	0.045	0.324
	3.0	0.204	0.015	0.376
July 20	0.1	1.739	2.369	1.954
	0.5	0.199	0.289	0.250
	1.0	0.279	0.257	0.261
	2.0	0.109	0.119	0.152
	3.0	0.121	0.040	0.135
August 10	0.1	4.430	2.280	1.288
	0.5	0.235	0.411	0.281
	1.0	0.221	0.309	0.189
	2.0	0.225	0.198	0.132
	3.0	0.229	0.109	0.086
August 24	0.1	0.333	-	4.953
	0.5	0.850	-	0.582
	1.0	0.320	-	0.504
	2.0	0.347	-	0.164
	3.0	0.332	-	0.103

APPENDIX V

List of Diatom Species and Other Algal Genera found in the Phytoplankton and Periphyton Samples between August 1971 and August 1972. Occurrence is indicated by an "X", absence by a "O" (Identification of diatoms by Dr. Krelina)

APPENDIX V

Species List

	Phytoplankton	Periphyton
Chrysophyta		
Achnanthes spp.	X	X
A. affinis Gruh.	O	X
A. microcephala (Kz.) Grun.	O	X
A. minutissima Kz.	O	X
A. lanceolata (Breb.) Grun.	O	X
Amphora sp.	X	X
A. ovalis Kz.	X	O
Asterionella formosa Hassal:	X	X
Caloneis sp.	O	X
Ceratoneis arcus (E.) Kz.	X	X
Cocconeis placentula E.	X	X
Cyclotella operculata (Ag.) Kz.	X	O
C. striata (Kz.) Grun.	X	O
Cymatopleura sp.	X	O
C. solea (Breb.) W.Sm.	X	X
Cymbella sp.	X	O
C. affinis Kz.	O	X
C. amphicephala Naeg.	X	O
C. capitata Brun.	O	X
C. cistula Hempr.	X	X
C. cymbiformis (Ag.) Kz.	X	O
C. gracilis (Rabh.) Cl.	O	X
C. heteropleura E.	O	X
C. lanceolata (E.) Vitt.	O	X
C. tumida (Breb.) V.A.	O	X
C. turgidula Grun.	O	X
C. ventricosa Kz.	X	X
Denticula sp.	X	O
Diatoma elongatum (Lyngb.) Ag.	X	X
D. hiemale (Lyngb.) Heib.	O	X
D. vulgare Bory	X	O

	Phytoplankton	Periphyton
Diploneis subovalis Cl.	X	0
Epithemia sp.	X	0
E. turgida (E.) Kz.	X	0
Eunotia sp.	X	0
E. arcus E.	0	X
E. diodon E.	0	X
E. exigua (Breb.) Rabh.	X	X
E. fallax A.Cl.	X	0
E. formica E.	0	X
E. gracilis (E.) Rabh.	0	X
E. lunaris (E.) Grun.	0	X
E. pectinalis (Kz.) Rabh.	X	X
E. praerupta (E.)	X	0
E. valida Hust.	0	X
E. veneris (Kz.) O.Mull.	0	X
Fragilara sp.	X	X
F. bicapitata A.Mull.	X	X
F. bidens Heib.	0	X
F. capucina Desnaz.	X	X
F. construens (E.) Grun.	X	X
F. crotonensis Kitt.	X	X
F. inflata (Heib.) Hust.	X	0
F. intermedia Grun.	X	X
F. pinnata E.	X	X
F. virescens Ralfa.	X	X
Frustulia rhomboides (E.) D.T.	X	X
F. rhomboides, v. saxonica (Rabh.) D.T.	0	X
Gomphonema sp.	X	0
G. acuminatum E.	0	X
G. angustatum (Kz.) Rabh.	0	X
G. augur E.	0	X
G. consecton H. H.	0	X
G. constrictum E.	X	X
G. gracile E.	0	X
G. lanceolatum E.	X	X
G. parvium Kz.	X	X
G. sphaerophorum E.	0	X
Gyrosigma acuminatum (Kz.) Cl.	X	X
Melosira sp.	0	X
M. distans (E.) Kz.	X	X
M. granulata (E.) Ralfs.	X	X

	Phytoplankton	Periphyton
M. islandica O.Mull.	X	O
M. varians Ag.	X	X
Meridion circulare (Greg.) Ag.	X	O
Navicula sp.	X	X
N. bicephala Hust.		X
N. capitata E.	X	O
N. cryptocephala (Kz.) Grun.	X	O
N. gottlandica Grun.	O	X
N. gregaria Donk.	O	X
N. pupula Kz.	O	X
N. radiosa Kz.	X	X
N. rhyncocephala Kz.	X	X
N. salinarum Grun.	X	X
N. subtilissima Cl.	O	X
N. viridula (Kz.) Kz.	X	O
Nitzschia sp.	X	X
N. amphibia Grun.	X	X
N. baccata Hust.	X	O
N. dissipata (Kz.) Grun.	X	O
N. palea (Kz.) W.Sm.	X	O
N. sigmoidea (E.) W.Sm.	X	O
Pinnularia sp.	X	X
Stauroneis anceps E., *v. linearis* (E.) Rabh.		X
S. phoenicentron (Nitzsch.) E.	X	O
S. tenera Hust.	X	O
Stephanodiscus astraea (E.) Grun.	X	X
St. dubius (Fr.) Hust.	X	O
St. hentzschii Grun.	X	O
Surirella sp.	X	O
S. angusta Kz.	O	X
S. linearis W.Sm.	O	X
S. robusta	X	O
S. ovata Kz.	O	X
Synedra sp.	X	X
S. rumpens Kz.	X	X
S. ulna (Nitzsch.) E.	X	X
Tabellaria fenestrata (Lyngb.) Kz.	X	X
T. flocculosa (Rabh.) Kz.	X	X

	Phytoplankton	Periphyton
Dinobryon	X	0
Synura	X	0
Chlorophyta		
Chroomonas	X	0
Cladophora	0	X
Closterium	X	X
Cosmarium	X	X
Echinosphaerella	0	X
Euastrum	X	X
Eudorina	X	0
Mougeotia	0	X
Oedogonium	0	X
Pediastrum	X	X
Pseudulvella	0	X
Scendesmus	X	X
Spirogyra	0	X
Spondylosium	0	X
Staurastrum	X	X
Stigeoclonium	0	X
Ulothrix	0	X
Cyanophyta		
Anabaena	X	X
Microcystis	X	X
Marismopedia	0	X
Oscillatoria	X	X
Phormidium	X	X
Spirulina	X	X
Pyrrophyta		
Ceratium	X	0
Gymnodinium	X	0

APPENDIX VI

The Use of 0.5 m Periphyton Primary Productivity Data as representative of all the depths combined (the euphotic zone).

Data for the euphotic zone were generated by plotting the primary productivity results from depths of 0.1, 0.5, 1, 2 and 3 meters against depth and finding the area under the curve. This was performed three times yielding the following results.

Periphyton Primary Productivity ($\mu g\ C/mm^2 \cdot hr \times 10^{-3}$)

Date	Station	Euphotic Zone	0.5 m depth
1971			
Sept. 15	Lower Duck Island	9.5	8
Sept. 14	CIP	1.3	1.15
Sept. 26	Blair Road	2.9	2.38