AECL-6984

ATOMIC ENERGY OF CANADA LIMITED

L'ÉNERGIE ATOMIQUE DU CANADA LIMITÉE

SEASONAL EFFECTS OF LOW-GRADE HEAT ON A PHYTOPLANKTON COMMUNITY

Effets saisonniers d'effluents d'eau chaude sur une communauté de phytoplanctons

J.W. McMAHON and A.E. DOCHERTY

Chalk River Nuclear Laboratories Laboratoires nucléaires de Chalk River

Chalk River, Ontario

June 1980 juin

ATOMIC ENERGY OF CANADA LIMITED

SEASONAL EFFECTS OF LOW-GRADE HEAT ON A PHYTOPLANKTON COMMUNITY

J.W. McMahon and A.E. Docherty
Health Sciences Division
Environmental Research Branch

Chalk River Nuclear Laboratories
Chalk River, Ontario
1980 June

AECL-6984

L'ENERGIE ATOMIQUE DU CANADA, LIMITEE

Effets saisonniers d'effluents d'eau chaude sur une communauté de phytoplanctons

par

J.W. McMahon et A.E. Docherty

Résumé

Des études in situ ont été effectuées de mars à décembre 1976 pour déterminer les effets "de l'eau de refroidissement enrichie de chaleur" sur une communauté naturelle de phytoplanctons. La concentration des algues, leur composition, la succession des espèces et le taux de fixation du carbone ont été relevés deux fois par semaine dans deux enceintes en polyéthylène placées dans un lac nordique oligotrophe L'une de ces enceintes était chauffée tandis que l'autre, non chauffée, servait de témoin. Sur les 31 espèces quantitativement étudiées, onze espèces dominantes ont fait l'objet d'un examen détaillé. Le phytoplancton a réagi, au printemps, de façon marquée à l'eau enrichie de chaleur. Cette réaction a été attribuée à une seule espèce de bacillaire: *Synedra ulna*.

La composition des espèces et le type des successions saisonnières étaient semblables dans l'enceinte expérimentale, dans l'enceinte témoin et dans le lac. On commente dans le rapport la relation existant entre les quotients de production biomassique (P/B) et la température de l'eau dans le lac et dans l'enceinte expérimentale. L'enrichissement thermique pourrait être employé bénéfiquement dans les eaux froides pour stimuler la production biomassique des organismes aquatiques unicellulaires. L'accroissement des réserves nutritives résultant de l'augmentation de la température de l'eau, pourrait alors intensifier la productivité du zooplancton filtrant et d'autres herbivores.

Laboratoires nucléaires de Chalk River
Chalk River, Ontario

Juin 1980

AECL-6984

ATOMIC ENERGY OF CANADA LIMITED

SEASONAL EFFECTS OF LOW-GRADE HEAT ON A PHYTOPLANKTON COMMUNITY

J.W. McMahon and A.E. Docherty
Health Sciences Division
Environmental Research Branch

ABSTRACT

Field studies, carried out over the period 1976 March to December, examined the effects of "heat-enriched cooling waters" on a natural phytoplankton community. Algal concentrations, composition, species succession and carbon fixation rates were determined twice-weekly in heated and unheated (control) polyethylene enclosures located in a northern oligotrophic lake. Results were compared with data collected from the open lake. Of 31 species quantitatively studied, eleven dominant species were examined in detail. A marked response to heat enrichment by the phytoplankton occurred in the spring and was attributed to a single species of Bacillariophyceae - *Synedra ulna*.

Species composition and seasonal succession patterns were similar in the experimental column, the control column and the lake. The relationship between production biomass quotients (P/B) and water temperature in the lake and experimental enclosure is discussed. It is suggested that thermal enrichment might be used beneficially in cold waters for enhancing biomass production of unicellular aquatic organisms. This increased availability of food, in conjunction with increased water temperatures, might then accelerate productivity of filter-feeding zooplankton and other herbivores.

Chalk River Nuclear Laboratories
Chalk River, Ontario
1980 June

AECL-6984

ATOMIC ENERGY OF CANADA LIMITED

SEASONAL EFFECTS OF LOW-GRADE HEAT ON A PHYTOPLANKTON COMMUNITY

J.W. McMahon and A.E. Docherty
Health Sciences Division
Environmental Research Branch

INTRODUCTION

Seasonal effects of heated effluent on freshwater algae in northern temperate lakes are not well understood. Some field studies have been carried out at nuclear and coal-fired power stations in Canada ([1], [2], [3]) but the most complete study on northern waters has been reported by Poltaracka [4]. This involved a study of three Polish lakes of which one received warm water discharge from an operating power station. Poltaracka's study involved a seasonal comparison of species composition in these lakes. Using a controlled heat source and waters isolated from the lake by polyethylene cylinders McMahon and Docherty [5] adopted this format to examine the relationship among algal species composition, cell numbers and carbon fixation rates. Results from the heated column were compared to a non-heated control column and the open lake. Thermal enrichment enhanced the population density of certain species of phytoplankton. Since this study was limited to summer conditions it was decided to obtain additional data on the effects of heat enrichment with particular emphasis on phytoplankton in late winter-early spring and in late fall when the ice cover was forming.

This study, using a larger heat source and polyethylene enclosures, examines seasonal effects of low-grade heated water on an oligotrophic phytoplankton community over the period 1976, early March to December.

MATERIALS AND METHODS

Experiments were carried out in Maskinonge Lake, an oligotrophic lake located on the property of Atomic Energy of Canada Limited Research Company (AECL-RC) at Chalk River, Ontario. Samples were taken from a

column of lake water isolated from the lake by a large (5 m dia. x 8 m deep) polyethylene (6 μm) enclosure. Heated water, up to 12°C above ambient, was provided by circulating surface water from the enclosure through a controlled heating facility located on shore. Heated water was discharged back into the enclosure at a depth of 2 m through a horizontal pipe diffuser.

Water samples (10 L) were collected twice-weekly by raising and lowering a submersible pump through the desired sampling depths (surface to 2 m, and 2 m to 4 m). This represents the major regions of primary production in the open lake. Aliquots of water from these samples were used for determining carbon-14 primary productivity, phytoplankton densities, species diversity, pH, total organic and inorganic carbon concentrations. Temperature and dissolved oxygen concentration were monitored continuously at a depth of 1 m in the heated enclosure. Similar measurements were taken twice-weekly at 1-m intervals to a depth of 6.5 m.

The same monitoring-sampling program was carried out in an identical, non-heated control enclosure and at an open lake station. The control enclosure was monitored for possible temperature-independent changes in species composition or algal densities. Comparison of cell numbers and primary productivity in the lake and control enclosure (Figs. 3 and 6) indicates no apparent differences between the open and entrapped waters. To simplify the presentation herein only the lake data are compared with results obtained from the heated enclosure.

Six consecutive studies, each of approximately 25 days duration, covered the following time intervals: March 04 to 29; April 26 to May 25; June 10 to July 05; July 16 to August 12; September 27 to October 22, and December 02 to 11, 1976.

Primary production rates were determined "*in situ*" by the ^{14}C method [6]. Duplicate 100 mL samples were taken for ^{14}C assay from both light and dark bottles which had been incubated at 1.5 and 3.0 m depths at the three sampling stations over a four-hour period (1:00 a.m. to 2:00 p.m.) twice-weekly. The filtration procedure outlined by McMahon [7] was used to minimize ^{14}C counting errors. The ^{14}C was assayed out by liquid scintillation counting ([8], [9]). The dioxane base fluor (3 L) consisted of 150 mg of dimethyl POPOP, 12 g of PPO and 360 g of napthalene. One-half millilitre of CO_2 absorbent-phenethylamine was added to 10 mL volume of fluor. Cab-O-Sil, a thixotropic gel, was used to keep the ^{14}C-labelled cells evenly dispersed throughout the counting vial.

Phytoplankton biomass, based on adenosine triphosphate determinations, is presented as organic carbon wet weight — using a conversion factor of 250 [10]. Adenosine triphosphate (ATP) was determined by the "luciferin luciferase" technique of Rudd and Hamilton [11].

Cell densities of net phytoplankton, retained on #25-Nitex filter cloth, were determined visually on fresh 1-L samples which were concentrated to 10 mL and immediately counted in a Sedgwick-Rafter counting chamber. The taxonomic works of Prescott [12] and Huber-Pestalozzi ([13], [14], [15], [16]) were used for identifying phytoplankton.

RESULTS

Seasonal variability in water temperature of the lake and heated enclosure at a depth of 1 m is shown in Figure 1a. Minimum lake temperatures ($\leq 4^{o}C$) were recorded under ice cover in March and December while a maximum value of 24°C occurred in early July. Temperatures in the heated enclosure ranged from 16°C in March to a maximum of 28°C in June. The sudden decrease in temperature in the heated enclosure during the September-October study was due to an electrical failure.

Figure 1b compared dissolved O_2 content of the lake and heated waters at 1 m. Highest O_2 values (11.0 $mg \cdot L^{-1}$) were recorded in the lake in early May and October following vernal and autumnal circulation within the lake. As expected, O_2 values were generally slightly lower in the heated enclosure (8 to 10 $mg \cdot L^{-1}$).

In this study heat enrichment was confined to the top 2 m of water in the column. Preliminary studies on primary productivity indicated that carbon assimilation was carried out mainly in the top 4 m (Fig. 2). A maximum carbon fixation rate of 5.2 mg $C \cdot m^{-3} \cdot h^{-1}$ occurred in the top 3 m of the lake in August.

A minimum value of $\leq$ 0.5 mg $C \cdot m^{-3} \cdot h^{-1}$ was recorded during the winter months. For a more accurate assessment of seasonal effects of thermal enrichment on the algal community, with particular reference to carbon production, results are given as mean values of data obtained at increasing depths between the lake surface and 4 m.

Phytoplankton Seasonal Abundance

Seasonal changes in cell concentration of the net phytoplankton are shown in Figure 3 for the lake, control and heated enclosures. Numbers of algae in the lake ranged from lowest values in March and December (0.6 and 9.0 x 10^6 cells$\cdot m^{-3}$, respectively) to a maximum in June of 50 x 10^6 cells$\cdot m^{-3}$. Seasonal variations and cell densities were similar in the non-heated control enclosure. In contrast, phytoplankton numbers in March for the heated enclosure averaged 18 x 10^6 cells$\cdot m^{-3}$ with a maximum of 51 x 10^6 cells$\cdot m^{-3}$. The highest algal concentration obtained in the heated enclosure was 119 x 10^6 cells$\cdot m^{-3}$ in May as compared to 30 x 10^6 cells$\cdot m^{-3}$ in the lake for the same period. Algal numbers were

consistently greater in the heated enclosure throughout the study except in December when the community and seasonal dynamics were similar for both the lake, control and heated enclosures.

Phytoplankton Group Composition

A comparison of the phytoplankton groups in the lake and heated enclosure is shown in Figure 4. Succession patterns for each taxon of algae are similar for both sampling sites. The largest algal group, the Bacillariophyceae, was dominant in both the lake and heated enclosure throughout the study. The highest concentration of diatoms (10.4×10^7 cells$\cdot m^{-3}$) occurred in the heated enclosure in mid-May. The next largest group, the Chrysophyceae, dominated the phytoplankton community in early June. Maximum cell numbers recorded for the lake and heated enclosure were 44×10^6 and 53×10^6 cells$\cdot m^{-3}$, respectively. The blue-green algae (Myxophyceae) became dominant in late July at both locations. Maximum concentrations, recorded on August 03, were 33×10^6 and 45×10^6 cells$\cdot m^{-3}$ for the lake and heated enclosure, respectively. Blue-greens were essentially absent from the plankton in March and were minimal and similar at both locations over the periods April to July and October to December.

The Chlorophyceae and Dinophyceae contributed very little in terms of numbers of cells to the plankton biomass in both the lake and heated enclosure. A maximum concentration of Chlorophyceae (5.4×10^6 cells$\cdot m^{-3}$ out of a total population of 49×10^6 cells$\cdot m^{-3}$) was recorded for the heated enclosure in early August. This peak mainly represented one species of *Ulothrix*. The Dinophyceae represented less than 2% of the phytoplankton at both stations throughout the study.

Seasonal Species Succession

Species succession and numbers of algal species present in the samples were similar for both stations. The smallest number of species (seven) were observed in early spring. Only four of these contributed more than 3% each to the total community. Of 14 species present in mid-summer, six accounted for more than 3% each of the total count. The seasonal dominance and succession of the most prominent organisms (i.e., those comprising more than 3% of total count) are shown in Figure 5. Solid histograms represent a numerical dominance of a particular species in the heated enclosure above that found in the lake. Hatched histograms represent a higher number present in the lake. The three groups represented are the Bacillariophyceae (four species); the Chrysophyceae (four species); and the Myxophyceae (three species).

The diatom *Synedra ulna* was the most numerous organism in both the lake and heated enclosure throughout the study. In May *S. ulna* in the heated enclosure showed an increase in cell numbers above the lake value of 39 x 10^6 cells·m^{-3} and represented over 85% of the phytoplankton population. During this same period *Synedra* accounted for 60% of total lake plankton. *Fragilaria zasuminensis* was consistently higher in numbers in the heated enclosure with maximum numbers being recorded in June and September. Of the two remaining diatoms *Nitzschia holzatica* was greater in the heated enclosure from March to July than in the lake and then was essentially absent in both the lake and heated enclosure through to December. *Asterionella formosa* was more abundant in the heated enclosure in June-July. By September this species was more numerous in the lake.

Of the Chrysophyceae, *Dinobryon divergens* occurred in greater numbers in the heated enclosure from March to May and then in the lake from June through to December. *Dinobryon bavaricum* followed a similar pattern but showed a maximum difference in cell numbers between the lake and heated enclosure in the June-July period. Cell numbers of *Synura uvella* were greater in the heated enclosure than in the lake in September and October while *Mallomonas caudata* was more numerous in the lake throughout the study period, exhibiting a maximum difference of 0.7 x 10^6 cells·m^{-3} in September above the density found in the heated enclosure.

Of the Myxophyceae two algae, *Chroococcus dispersus* and *Coelosphaerium kuetzingianum*, were more numerous in the heated enclosure in July and August. *Chroococcus limneticus* was dominant in the heated enclosure in September-October. Both *C. dispersus* and *C. limneticus* were more numerous in the lake than in the heated enclosure in early summer.

Primary Productivity

Primary production rates, measured twice-weekly at the lake station, control and heated enclosures, are presented in Figure 6. The minimum hourly photosynthetic rates in the lake (surface to 4 m) were recorded in March. These rates, measured over mid-day, ranged from 0.01 to 1.1 mg C·m^{-3}·h^{-1}. Highest values were measured in late April through August with peaks of 6.9 and 7.9 mg C·m^{-3}·h^{-1} in April and June. During early winter, carbon fixation was again low (1.5 mg C·m^{-3}·h^{-1} in December) and values were similar to those obtained in March. Carbon-14 primary productivity values in the control enclosure were similar to those obtained in the lake.

Higher photosynthetic rates were observed in the heated enclosure throughout the entire study. In early spring the maximum primary production rate was 9.6 mg C·m^{-3}·h^{-1}. This increased to a recorded high of 20 mg C·m^{-3}·h^{-1} in May. These latter values are four to five times larger

than for the lake during this period. The maximum primary productivity rate in September-October of 6.9 mg $C \cdot m^{-3} \cdot h^{-1}$ was approximately twice the value for the lake during the same period. By December production rates in the heated enclosure had decreased to 3.7 mg $C \cdot m^{-3} \cdot h^{-1}$.

Biomass

Phytoplankton biomass was based on ATP determinations and is converted to organic carbon wet weight using a factor of 250 as recommended by Holm-Hansen [10]. The seasonal variations of biomass (mean values-surface to 4 m) at the lake station and heated enclosure are shown in Figure 7. Total organic carbon (biomass) in the lake, in early spring, averaged 121.75 mg C(wet wt.)$\cdot m^{-3}$. Highest values (344 and 391 mg $C \cdot m^{-3}$) occurred in April-May and the lowest in late July (15 mg $C \cdot m^{-3}$). Total organic carbon increased again during September-October to a maximum of 249 mg $C \cdot m^{-3}$.

In contrast lower biomass values (50 to 100 mg $C \cdot m^{-3}$) were measured in the heated enclosure during March and again in September-October. The highest values in May and June-July were 416 and 528 mg $C \cdot m^{-3}$, respectively. The highest recorded value of 1211 mg $C \cdot m^{-3}$, obtained in August, is probably due mainly to filamentous epiphytic algae scoured from the walls of the polyethylene enclosure. This resulted in termination of that particular experiment.

Production/Biomass (P/B) Quotients

Relative photosynthesis, the relation between primary production and the phytoplankton standing crop, was estimated on a seasonal basis by dividing hourly photosynthetic rates per m^3 by total organic carbon per m^3 considering a water column of 4 m (euphotic zone). To obtain a "specific growth rate" (P/B quotient), essentially independent of light intensity, photosynthetic rates were taken at mid-day. Specific growth rate may vary from zero (completely inactive population) to an upper limit determined by environmental regulatory factors such as temperature or nutrient availability [17].

Production/biomass quotients in the lake varied from 0.004 in March to a maximum of 0.12 mg $C \cdot h^{-1}$ in July-August. The relationship between these values and temperature (average values-surface to 4 m) is shown in Figure 8. In the lake specific growth rate increased as lake temperature increased from 5°C in March to 22°C during the July-August study. As the lake cooled to 12°C in September-October the quotient decreased to 0.02 mg $C \cdot h^{-1}$.

The relationship between P/B quotients and temperature in the heated enclosure was somewhat different. Specific growth rate varied from a high of 0.11 mg $C \cdot h^{-1}$ in March to a minimum of 0.03 mg $C \cdot h^{-1}$ in June. The quotient increased to 0.073 in September-October. In the heated enclosure, maximum quotients occurred at minimum temperatures while the lowest specific growth rate was related to the highest summer temperature (28°C).

DISCUSSION

Our studies show marked differences in phytoplankton densities and primary production rates between the lake and heat-enriched waters isolated from the lake in a polyethylene enclosure. These differences were shown to be due primarily to increased numbers of one particular alga — *Synedra ulna* — in heated water.

Species composition and seasonal succession patterns in both Maskinonge Lake and the heated enclosure were similar and not unlike those found in other oligotrophic lakes within the Laurentian Shield ([18], [19], [20], [21]). Major growth pulses in the lake phytoplankton community occurred in June and August, while the most noticeable changes in cell numbers and primary production in the heated enclosure were recorded in the spring (March to May).

Heat enrichment enhanced growth of the diatom *Synedra* but inhibited the development of several species of Chrysophyceae. This was particularly noticeable for two species of *Dinobryon* during June, July and August. This influence of temperature on *Dinobryon* has been noted in previous studies ([5], [22], [23]). The limitation of available phosphorus is another factor influencing maximum development of *Dinobryon* [24].

Another species of Chrysophyceae — *Mallomonas caudata* — showed a 15% increase in numbers in the lake in March but it was absent in the heated enclosure. Growth of this alga is also probably influenced by temperature. The average temperature of 17°C in the heated enclosure in March is similar to the upper temperature limit reported for two other *Mallomonas sp.* from the Great Lakes [19].

A positive response to thermal enrichment was observed for one species of Chlorophyceae — *Ulothrix sp.* — in July and August when a temperature maximum of 27°C occurred in the heated enclosure. Stoermer and Ladewski [19] noted maximum population densities of *Ulothrix monoliformis* in the Great Lakes were always associated with relatively high temperatures.

An obvious discrepancy occurs when cell concentrations and primary production rates are compared with organic carbon values calculated from ATP determinations on samples taken in March and September-October. During these periods numbers of organisms and primary productivity rates were higher in the heated enclosure than in the lake. In contrast, organic carbon values were lower in the heated enclosure than in the lake. This phenomenon has been noted elsewhere [25]. In a study in Lake Kinneret, Cavari [25] observed a rapid increase in numbers of *Peridinium* during February-March that was not accompanied by a proportionate increase in the carbon content, as measured by ATP, of the plankton. He suggested that either *Peridinium* contained less ATP than other algae, or that ATP synthesis was limited by a nutrient deficiency in the lake. Laboratory studies, using phosphorus-rich and phosphorus-depleted culture media, showed a ten-fold increase in ATP concentrations in *Peridinium* using the phosphorus-rich medium. He concluded that low concentrations of ATP in *Peridinium* did not affect the division rate of the cells. It might also be argued that low ATP concentrations observed herein in the heated enclosure in March and September-October did not appear to affect the division rate of *Synedra ulna*, since that diatom dominated the phytoplankton during these periods.

The production/biomass quotients (specific growth rates) are perhaps the best indicators of the influence of temperature on the phytoplankton community. There is a definite relationship between temperature and P/B quotients in the open lake. Low specific growth rates in the spring and fall relate to low water temperature while the highest rates reflect maximum solar input to the lake during the summer. Stadelmann, Moore and Pickett [26] observed a similar pattern in Lake Ontario. In their studies, P/B ratios were based on another biomass parameter — chlorophyll a. The seasonal relationship between P/B quotients and thermal enrichment is somewhat different to that observed in the lake. It is suggested that the high specific growth rates in the heated enclosure in the spring and fall indicate a beneficial effect of temperature on the phytoplankton. This thermal enhancement of carbon assimilation at the primary level might also stimulate secondary productivity among algae-consuming organisms.

Thermal enrichment in mid-summer, in contrast, results in lower P/B quotients. This decrease in specific growth rate suggests an inhibitory effect on phytoplankton productivity of increased water temperature at that time of year, possibly in association with other environmental factors. It is worth noting, however, that the minimum specific growth rate in heat-enriched waters is still higher than rates obtained in the open lake during spring and autumn periods. This increased production, as noted earlier, is due mainly to one or two species of algae which might be regarded as food sources for zooplankton.

The specific growth rates obtained in heat-enriched Maskinonge Lake water in a polyethylene enclosure are also probably higher than would be expected from an area of thermal discharge in the Great Lakes. Rapid

dilution of the heated discharge, evaporation and mixing result in a maximum increase in surface water temperature of 6°C within 1300 m of the discharge canal [1]. The thermal effects observed in our experiments might also be minimized through the use of a deep intake - surface discharge arrangement for the cooling water [22].

REFERENCES

[1] EFFER, W.R. and J.B. BRUCE. 1975. Thermal discharge studies on the Great Lakes: The Canadian experience, pp. 371-388 in *Environmental Effects of Cooling Systems at Nuclear Power Plants*. IAEA, Vienna.

[2] NURSALL, J.R. and D.N. GALLUP. 1971. The responses of the biota of Lake Wabamun, Alberta to thermal effluent, pp. 295-304 in *Proc. Int. Symp. on Identification and Measurement of Environmental Pollutants*. NRC, Ottawa.

[3] HICKMAN, M. 1974. Effects of the discharge of thermal effluent from a power station on Lake Wabamun, Alberta, Canada - The epipelic and epipsamnic algal communities. *Hydrobiologia* 45: 199-217.

[4] POLTARACKA, J. 1968. Specific composition of phytoplankton in a lake warmed up by waste water from a thermal power station and in lakes with normal temperatures. *Acta Soc. Bot. Pol.* 37: 297-325.

[5] McMAHON, J.W. and A.E. DOCHERTY. 1975. Effects of heat enrichment on species succession and primary production on freshwater plankton, pp. 529-546 in *Environmental Effects of Cooling Systems at Nuclear Power Plants*. IAEA, Vienna.

[6] STEEMANN-NIELSEN, E. 1952. The use of radioactive carbon (C^{14}) for measuring organic production in the sea. *J. Conseil Expl. Mer.* 18: 117-140.

[7] McMAHON, J.W. 1973. Membrane filter retention - A source of errors in the ^{14}C method of measuring primary production. *Limnol. Oceanogr.* 18: 319-324.

[8] WOLFE, D.A. and C.L. SCHELSKE. 1967. Liquid scintillation and Geiger counting efficiencies for carbon-14 incorporated by marine phytoplankton in productivity measurements. *J. Conseil Expl. Mer.* 31: 31-37.

[9] WALLEN, D.G. and G.H. GEEN. 1968. Loss of radioactivity during storage of ^{14}C-labelled phytoplankton on membrane filters. *J. Fish. Res. Bd. Canada* 25: 2219-2224.

[10] HOLM-HANSEN, O. 1973. The use of ATP determinations in ecological studies. *Bull. Ecol. Res. Commun. (Stockholm)* 17: 215-222.

[11] RUDD, J.W.M. and R.D. HAMILTON. 1973. Measurement of adenosine triphosphate (ATP) in two Precambrian Shield Lakes of northwestern Ontario. *J. Fish. Res. Bd. Canada* 30: 1537-1546.

[12] PRESCOTT, G.W. 1951. Algae of the western Great Lakes area. Bull. 31. Cranbrook Inst. Sci., Bloomfield Hills, Michigan.

[13] HUBER-PESTALOZZI, G. 1938. Das phytoplankton des Susswassers, Teil 1, Blaualgen, Bacterien, Pilze, in *Thienemann, A. (Ed.), Die Binnengewasser, Band 16*. 342 pp.

[14] _____ 1941. Das phytoplankton des Susswassers, Teil 2, 1 Halfte. Chrysophyceen, Farblose Flagellaten, Heterokonten, in *Thienemann, A. (Ed.), Die Binnengewasser, Band 16*, pp. 1-365.

[15] _____ 1942. Das phytoplankton des Susswassers, Teil 2, 2 Halfte. Diatomeen, in *Thienemann, A. (Ed.), Die Binnengewasser, Band 16*, pp. 366-549.

[16] _____ 1950. Das phytoplankton des Susswassers, Teil 3, Crytophyceen, Chloromonadinen, Peridineen, in *Thienemann, A. (Ed.), Die Binnengewasser, Band 16*, pp. 1-310.

[17] TALLING, J.F. 1969. Relations between primary production and population density, in *A Manual on Methods for Measuring Primary Production in Aquatic Environments (R.A. Vollenweider, Ed.)*. IBP Handbook #12. Blackwell Scientific Publ., Oxford.

[18] SCHINDLER, D.W. and S.K. HOLMGREN. 1971. Primary production and phytoplankton in the Experimental Lakes Area, north-western Ontario and other Low Carbonate Waters, and a liquid scintillation method for determining ^{14}C activity in photosynthesis. *J. Fish. Res. Bd. Can.* 28(2): 189-201.

[19] STOERMER, E.F. and T.B. LADEWSKI. 1976. Apparent optimal temperatures for the occurrence of some common phytoplankton species in southern Lake Michigan. Great Lakes Institute, University of Toronto, Toronto, Ontario. Publ. #18. 49 pp.

[20] NALEWAJKO, C. 1966. Composition of phytoplankton in surface waters of Lake Ontario. *J. Fish. Res. Bd. Can.* 23: 1715-1725.

[21] VOLLENWEIDER, R.A., M. MUNWAR and P. STADELMANN. 1974. A comparative review of phytoplankton and primary production in the Laurentian Great Lakes. *J. Fish. Res. Bd. Can.* 31: 739-762.

[22] McMAHON, J.W. and A.E. DOCHERTY. 1978. Phytoplankton and cooling systems: Temperature effects using different intake and discharge depths. *Water Res.* 12(11): 925-929.

[23] LEHMAN, J.T. 1976. Ecological and nutritional studies o' *Dinobryon* Ehrenb: Seasonal periodicity and the phosphate toxicity problem. *Limnol. Oceanogr.* 21: 646-658.

[24] RODHE, W. 1948. Environmental requirements of fresh water plankton algae. *Symb. Bot. Upsal.* 10: 1-149.

[25] CAVARI, B. 1976. ATP in Lake Kinneret: Indicator of microbial biomass or of phosphorus deficiency? *Limnol. Oceanogr.* 21(2): 231-236.

[26] STADELMANN, P., J.E. MOORE and E. PICKETT. 1974. Primary production in relation to temperature structure, biomass concentration and light conditions at an inshore and offshore station in Lake Ontario. *J. Fish. Res. Bd. Can.* 31: 1215-1232.

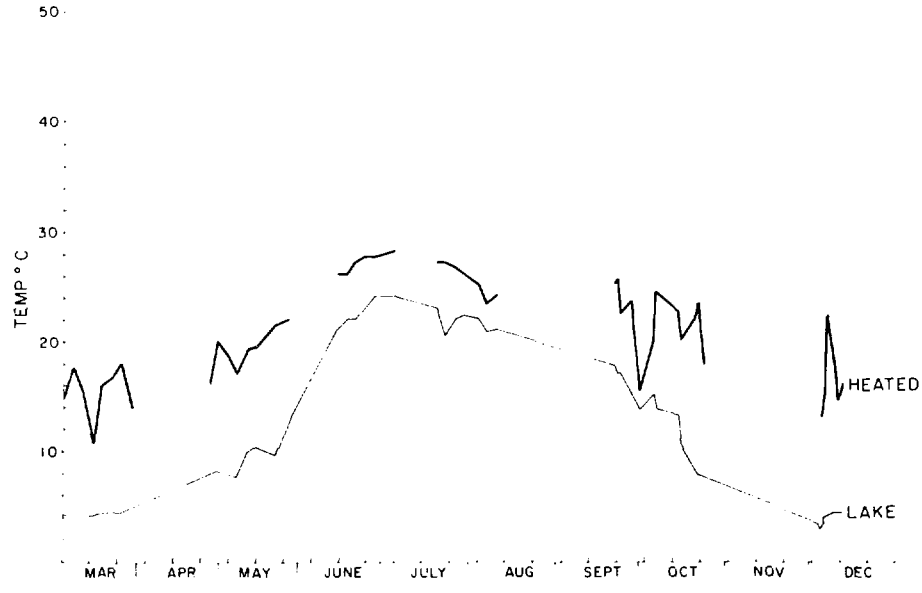

Figure 1a. Comparison of water temperatures (1 m) in the lake and heated enclosure.

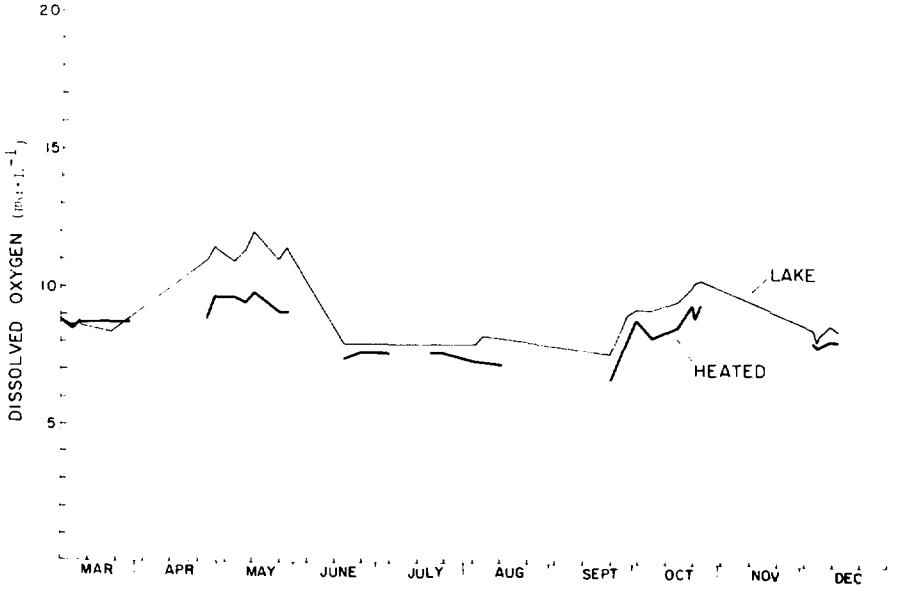

Figure 1b. Dissolved oxygen content ($mg \cdot L^{-1}$) in the lake and heated enclosure.

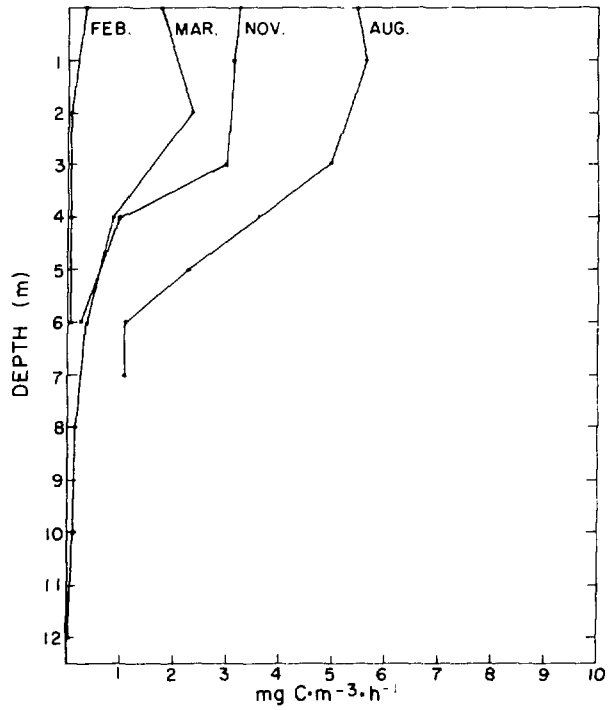

Figure 2. Carbon production rates (mg $C \cdot m^{-3} \cdot h^{-1}$) at increasing depths in Maskinonge Lake from February to November.

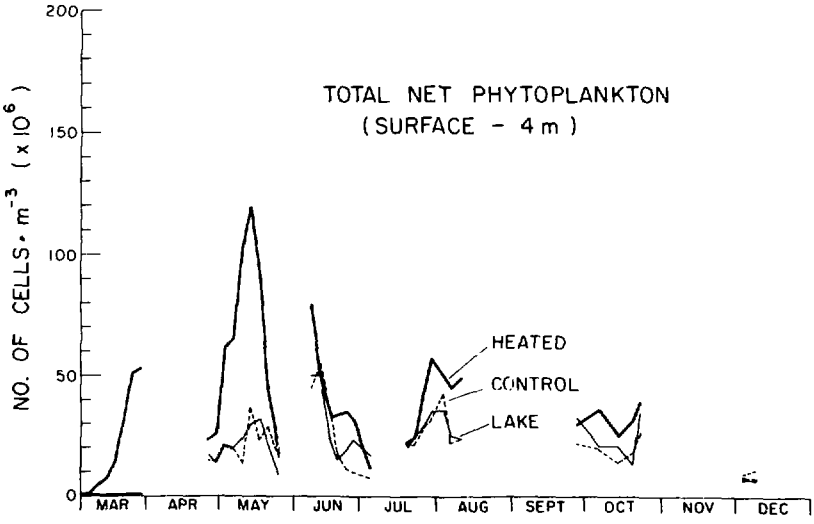

Figure 3. Comparison of phytoplankton concentrations (numbers of cells·m^{-3}) in the surface to 4 m regions of the lake, control and heated enclosures.

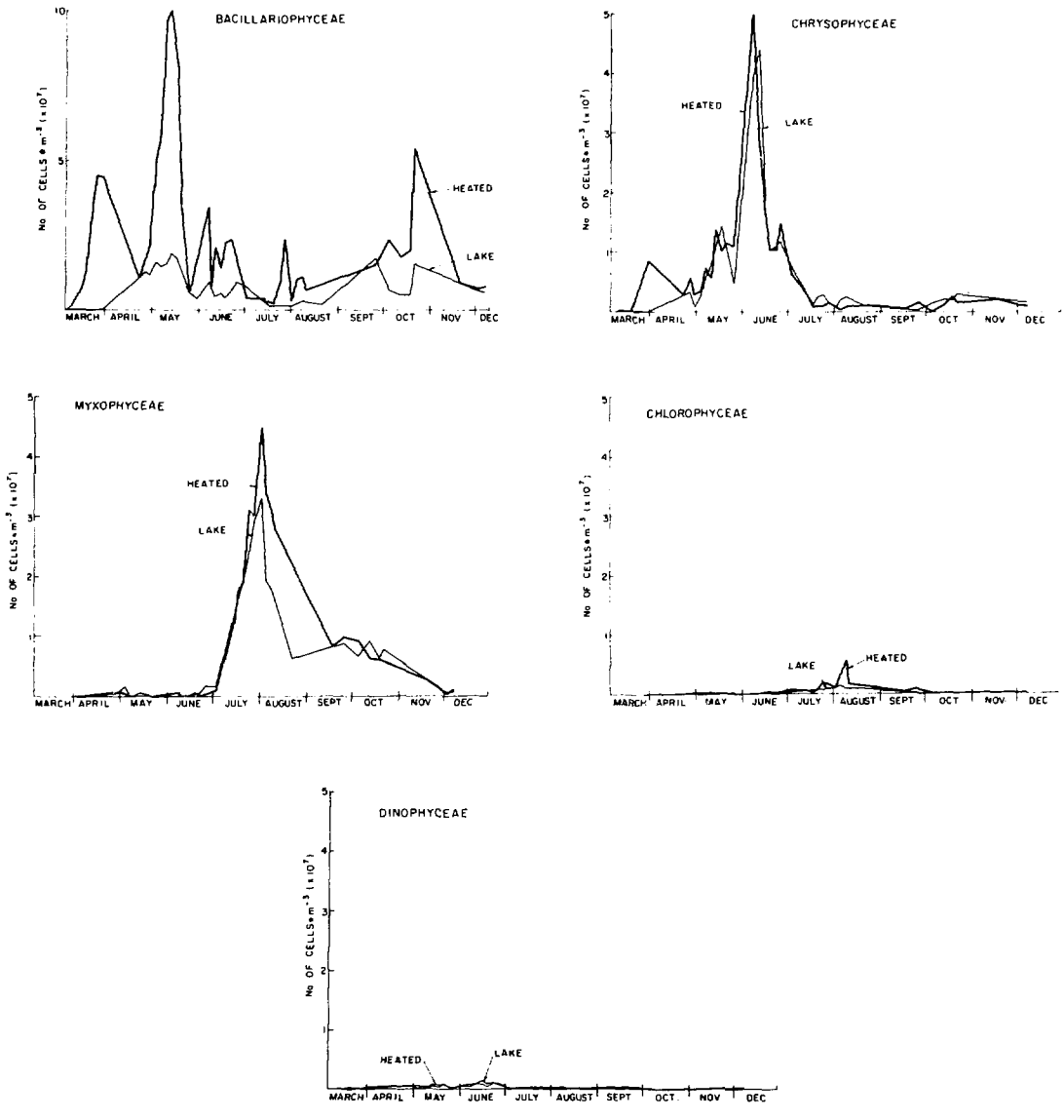

Figure 4. Algal group composition and seasonal succession patterns at the lake station and the heated enclosure over the period 1976 March to December.

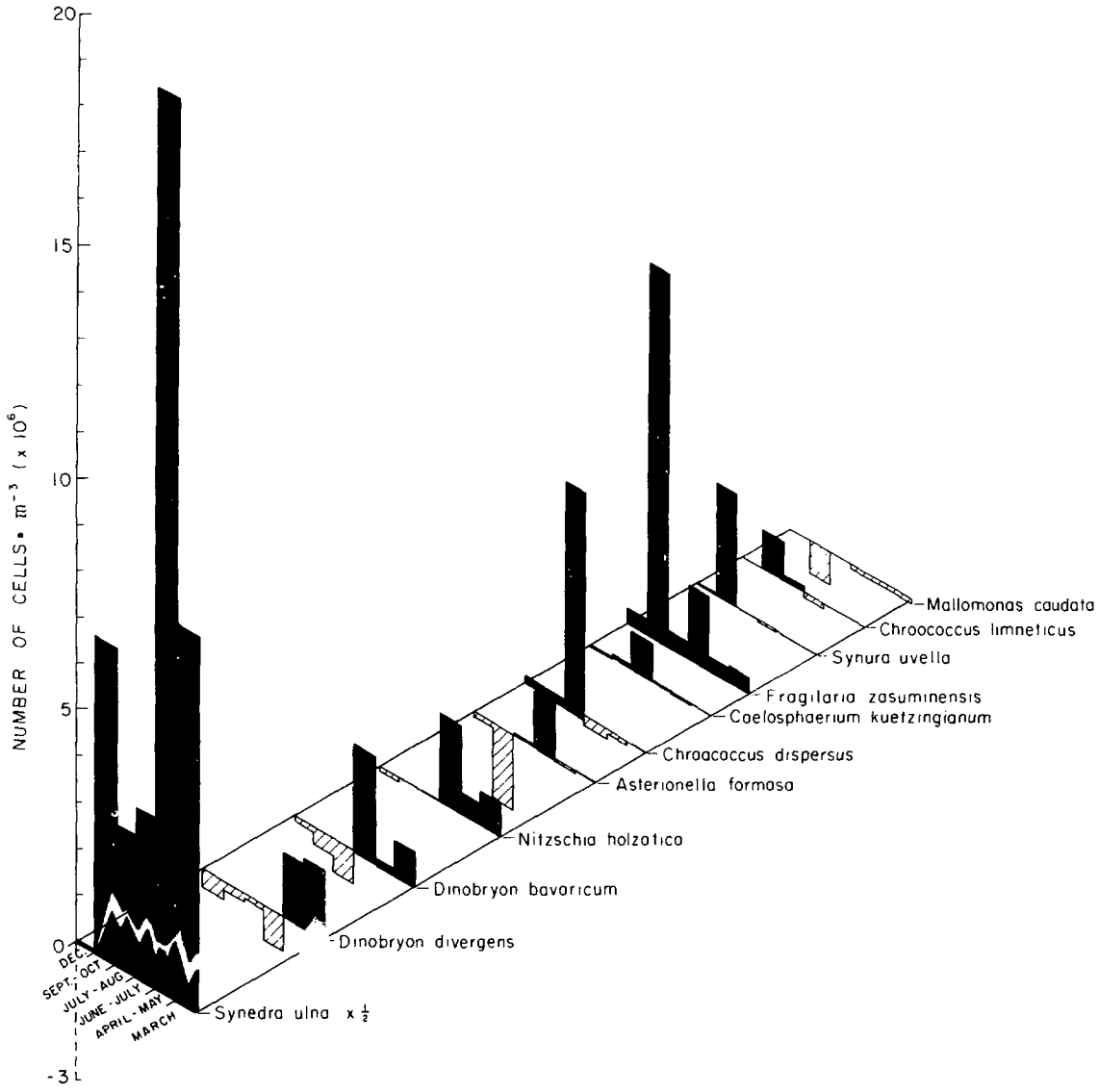

Figure 5. Species succession and abundance (numbers of cells·m^{-3}) of the dominant phytoplankton. Solid histograms indicate increased cell numbers in the heated enclosure above those found in the lake. Hatched histograms indicate a dominance in the lake for that particular species over concentrations obtained in the heated enclosure.

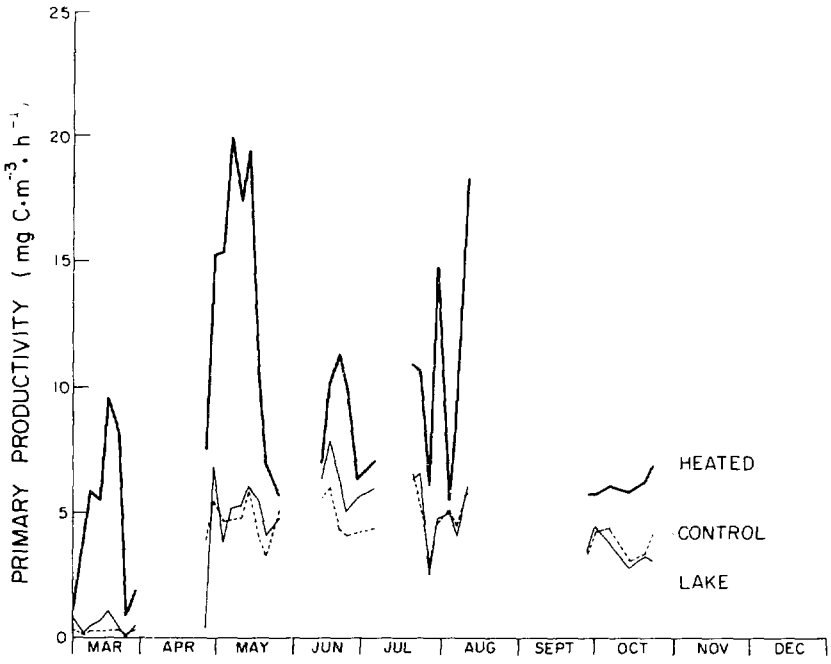

Figure 6. Primary production rates (mg $C \cdot m^{-3} \cdot h^{-1}$) in the lake, control and heated enclosures, over the period 1976 March to December.

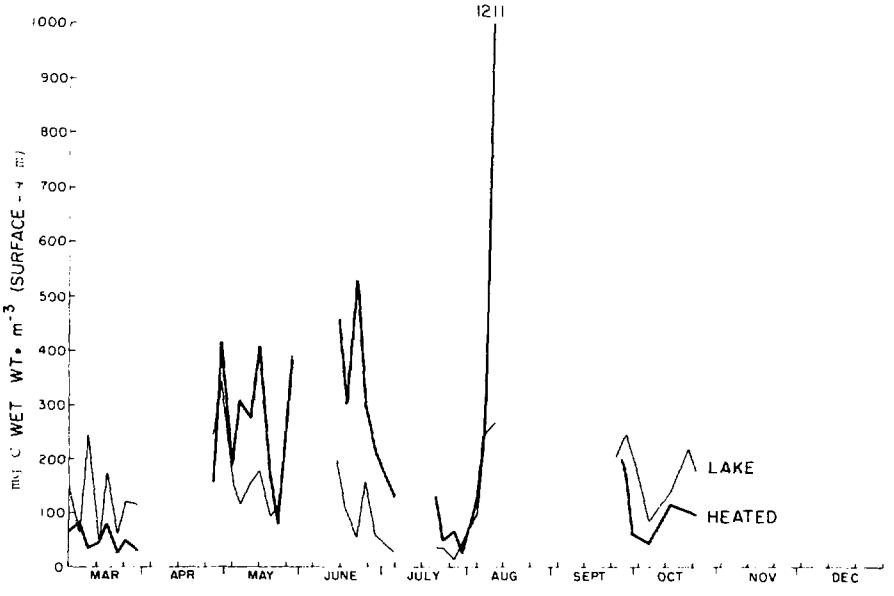

Figure 7. A comparison of total organic carbon content (mg C wet wt.$\cdot m^{-3}$) of phytoplankton in the lake and heated enclosure.

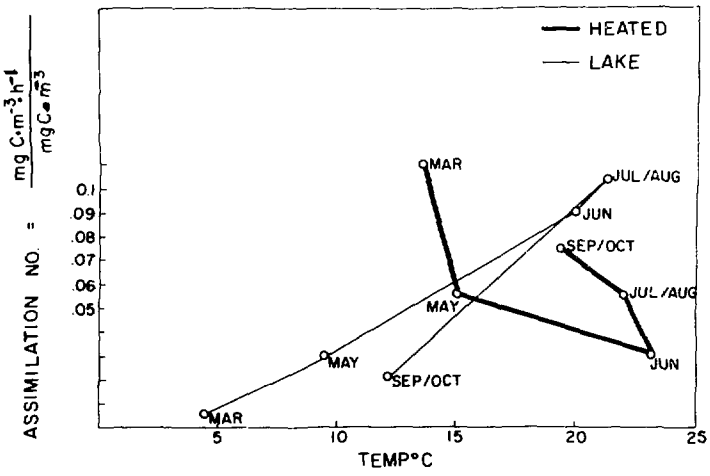

Figure 8. Relation between temperature and specific growth rate (mg $C \cdot m^{-3} \cdot h^{-1}$/mg total organic carbon$\cdot m^{-3}$), at light saturation, for the lake station and the heated enclosure.

ISSN 0067 - 0367

To identify individual documents in the series we have assigned an AECL- number to each.

Please refer to the AECL- number when requesting additional copies of this document

from

Scientific Document Distribution Office
Atomic Energy of Canada Limited
Chalk River, Ontario, Canada
K0J 1J0

Price $2.00 per copy

ISSN 0067 - 0367

Pour identifier les rapports individuels faisant partie de cette série nous avons assigné un numéro AECL- à chacun.

Veuillez faire mention du numéro AECL- si vous demandez d'autres exemplaires de ce rapport

au

Service de Distribution des Documents Officiels
L'Energie Atomique du Canada Limitée
Chalk River, Ontario, Canada
K0J 1J0

Prix $2.00 par exemplaire