Abundance and Activity of Heterotrophic Marine Bacteria in Selected Bays at Cape Hatt, N. W. T. 1980

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ABUNDANCE AND ACTIVITY OF HETEROTROPHIC MARINE BACTERIA IN SELECTED BAYS AT CAPE HATT, N.W.T. 1980

First report to the Baffin Island
Oil Spill (BIOS) project

by

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On the basis of bacterial abundance and activity, three bays (9, 10, 11) at Cape Hatt, N.W.T., have been judged to be similar and therefore suitable for comparative microbiological studies during and after experimental petroleum spills in 1981. Analyses of variance of total counts of viable heterotrophs (TVH) and concentrations of particulate and dissolved organic carbon in water columns of the three bays did not reveal any differences at the 1.0% level of significance. Maximum velocities (V_{max}) of glutamic acid uptake and total counts (TC) of bacterial cells did not show significant differences between bays 9 and 10 or 10 and 11, but a significant difference was found between bays 9 and 11. This has been attributed to the residence time of water in bay 11. Maximal velocities at the beginning of the open water season averaged 5.35 $\mu g\ L^{-1}d^{-1}$, similar to other areas in Baffin Bay, Lancaster Sound and Frobisher Bay.

Variations in values between the sediments of stations and bays for V_{max}, total count and total viable heterotrophs were attributed to changes in the areas of sediment sampling and methods of collection. Mean total counts of bacteria appeared to reach a peak early in the open water season and then slowly decline, whereas the means of V_{max} increased slowly across the sampling period to mid-September.

Mineralization of n-(1-^{14}C)hexadecane in the three bays was uniformly low, or not detectable by our analytical procedure. Few oleoclastic or petroleum-degrading cells were determined by a similar analysis.

The measurement of glutamic acid uptake in benthic *in situ* incubation systems (BISIS) corresponded closely to laboratory results. Glutamic acid uptake at the sediment-water interface was found to be different from uptake in the water immediately above the sediment. Experimental work with BISIS units is planned for 1981.

Key words: arctic, marine, bacteria, abundance, activity, heterotrophic, oleoclastic, carbon, petroleum

RESUME

Bunch, J. N., R. C. Harland and J. Laliberté. 1981. Abundance and activity of heterotrophic marine bacteria in selected bays at Cape Hatt, N.W.T. 1980. Can. MS Rep. Fish. Aquat. Sci. 1611: xiii + 68 p.

Basé sur l'abondance et l'activité bactérienne, trois baies (9, 10, 11) à Cape Hatt, T.N.O., ont été jugées semblables et par conséquent, propices à des études microbiologiques comparatives pendant et après des déversements expérimentaux de pétrole en 1981. Des analyses de variance du nombre total d'hétérotrophes viables (TVH), et des concentrations de carbone organique dissout et particulaire dans les colonnes d'eau des trois baies n'ont révélé aucune différence pour un niveau de probabilité de 1.0%. Les vitesses maximums (V_{max}) de l'incorporation de l'acide glutamique et les comptes totaux (TC) de cellules bactériennes n'ont montré aucune différence significative entre les baies 9 et 10 ou 10 et 11, alors qu'une différence significative a été observée entre les baies 9 et 11. Ceci a été attribué au temps de résidence de l'eau dans la baie 11. Les vitesses maximales au début de la saison des eaux libres avaient une moyenne de 5.35 µg $L^{-1}d^{-1}$, semblable à d'autres régions dans la baie de Baffin, le goulet de Lancaster et la baie de Frobisher.

Les variations entre les valeurs obtenues dans les sédiments des différentes stations et baies pour le V_{max}, le compte total et le nombre total d'hétérotrophes viables ont été attribuées à des changements dans les régions d'échantillonnage des sédiments de même qu'aux méthodes de collection. La moyenne des comptes totaux de bactéries a semblé atteindre un pic tôt dans la saison des eaux libres pour ensuite diminuer lentement, tandis que les moyennes de V_{max} ont augmenté progressivement tout au long de la période d'échantillonnage jusqu'à la mi-septembre.

La minéralisation de n-(1-^{14}C)hexadecane dans les troit baies était uniformément peu élevée, ou même non détectée par nos méthodes d'analyse. Des analyses similaires n'ont décelé que peu d'oléoclastes, ou cellules aptes à dégrader le pétrole.

La mesure de l'incorporation de l'acide glutamique à l'aide de systèmes d'incubation benthique <u>in situ</u> (BISIS) a montré une correspondance étroite avec les résultats obtenus en laboratoire. L'incorporation de l'acide glutamique à l'interface sédiment-eau a été différente de celle réalisée dans l'eau immédiatement au-dessus des sédiments. Du travail d'ordre expérimental avec les unités BISIS a été planifié pour 1981.

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1.0 INTRODUCTION

The Baffin Island Oil Spill (BIOS) project at Cape Hatt, N.W.T., is a four year study designed to evaluate the effects of chemical dispersants during and after experimental oil spills in 1981. Integrated physical, chemical and biological studies during 1980 yielded baseline data. The "core" biological studies include benthic and microbiological studies supported by environmental chemistry. Aspects of oil degradation by microorganisms are being studied during this project by a group of Norwegian microbiologists. Our laboratory is concerned with the seasonal abundance and activities of heterotrophic bacteria in water columns and sediments and the effect of petroleum and petroleum-dispersant mixtures on these activities, both experimentally and as a consequence of the spills. Limited studies on the bacterial degradation of a hydrocarbon fraction were also undertaken.

On the basis of gross biological and physical similarities, two bays were selected in June and a third bay in August to serve as sites for the experimental spilling of crude petroleum and crude petroleum mixed with dispersant. The third bay will serve as a control. Sampling was conducted through the ice in June and in open water in August and September.

The objectives for the first year of study (1980) were:

1. characterization of numbers and heterotrophic activities of bacteria in the water and sediment of selected bays at Cape Hatt;
2. assessment of the above measurements during all seasons in relation to other biological and chemical cycles.

Microorganisms, including bacteria, yeasts, other fungi and phytoplankton are vital components of the world's oceans. Carbon is fixed and utilized by phytoplankton, providing foragable biomass and dissolved organic nutrients for the marine food chain. As part of the carbon cycle, heterotrophic bacteria, through a process of oxidation, decompose complex organic molecules to smaller monomolecular units for incorporation into their protoplasm, thereby utilizing the greater part of the dissolved organic nutrients formed by phytoplankton. In so

doing, particulate bacterial biomass is made available for grazing by organisms at other trophic levels, and essential nutrients such as ammonia and phosphate are released by mineralization for re-entry into nutrient cycles. Bacterial floras have been estimated to comprise upwards of 50% of the biomass of the world's oceans (Morita, 1977) and therefore are important marine constituents in terms of both abundance and function.

When introduced into the marine ecosystem petroleum forms a highly complex part of the dissolved and particulate organic material in the water. Heterotrophic activity by bacteria and fungi comprises the sole route for degradation and mineralization of petroleum as part of the carbon cycle. This is an oxidative process which requires a source of nitrogen, phosphorus, oxygen and trace elements and is very dependent on temperature. The degradation and mineralization of petroleum hydrocarbons releases carbon and energy for the maintenance, growth and multiplication of some heterotrophic marine bacteria, defined here as oleoclasts.

The heterotrophic activity of bacteria in the marine environment is regulated by the availability of inorganic nutrients and organic substrates required for growth and multiplication. As previously indicated, the availability of substrates depends on the activities of other biological components of the system, especially the primary producers. Heterotrophic activity is, therefore, linked to the cycle of primary production. Oleoclastic bacteria, capable of deriving carbon and energy from hydrocarbon fractions in addition to naturally-occurring organic substrates, appear to form a proportion of the bacterial floras of most marine environments even when petroleum is not present. Oleoclasts demonstrate a cycle of abundance and activity in concert with other bacterial activities in northern ocean areas which are ice-covered much of the year. With declining biological activity during the period of ice formation and the paucity of organic substrates in the water, heterotrophic floras including oleoclasts decline.

Little is known about the effects of petroleum on bacteria other than effects on their capacity for biodegradation of petroleum fractions. The controlled influx of petroleum and dispersants into a measured environment provides an opportunity to observe possible changes in the cycles of bacterial abundance and activities. These changes may be a result of alterations in other biological cycles, or a consequence of direct effects on bacterial populations. In the first year of the BIOS project, various parameters have been quantitated and compared in three bays. A description of these baseline data forms the substance of this report.

2.0 STUDY AREA

As part of the BIOS project, located at Cape Hatt on northern Baffin Island (Fig. 1), eight stations were sampled for microbiological activity in 1980 (Fig. 2). The stations sampled during June in bays 9, 10 and 13, were on transects surveyed on the ice by Dr. J. M. Semples of Petro-Canada. These were located at water depths of 12 to 14 m along the two outer of three transect lines. The stations were moved slightly in August after ice break-up to coincide with the shore markers placed by Gary Sergy of the Environmental Protection Service (EPS), Department of the Environment. Temporary floats were used to mark the location of the stations and permanent markers will be deployed in 1981. From 19 August onwards, bay 11 was sampled in preference to bay 13. Stations in bay 11 were located at depths of 11 to 12 m.

In each of the bays chosen, two stations were sampled for water and sediments. The field season was divided into seven sampling cycles, two from 6 to 16 June under winter and early spring conditions and five cycles from 11 August to 16 September under summer and fall conditions. Cycles were defined as the time taken to sample all three bays once (Table 1).

3.0 METHODS AND MATERIALS

3.1 Sampling Procedures

3.1.1 Water Column

Water samples from depths of 1, 5, and 10 m were collected at all microbiology stations using a 5.0 L Niskin bottle and hand-line. The samples were transferred to 4.0 L bottles and transported in a sample box to the Cape Hatt laboratory where they were processed within several hours of collection.

3.1.2 Sediments

During the first three sampling cycles sediments were collected at all stations using a Petersen-type grab or a Phleger corer. Station 1A on 6 June was not sampled since the bottom was found to be rocky. Beginning with the fourth cycle of sampling that started on 19 August, divers from LGL Ltd. made collections at a depth of 7 m, slightly inshore from the station markers, by scraping a 2.0 cm layer of sediment into a wide mouth jar. From the original sample, two modified 50 mL disposable syringes were filled with surface sediment. One syringe was frozen and later transported to Ste-Anne-de-Bellevue for organic carbon and dry weight determinations. The other was refrigerated for microbiological processing the following day. From the refrigerated syringe, two 1.0 mL wet subsamples were measured with a modified 3 mL disposable syringe and were suspended in 2.0 L of filter-sterilized 10 m water collected from the same station. The 0.1% by volume sediment-water mixture was then manually agitated and the suspension maintained in a crushed ice bath on a magnetic stirrer during processing.

3.2 Chemical and Physical Oceanography

The values for chlorophyll _a_, reactive phosphate and nitrate used in this report originated from Green (1981). Collection of the material for these analyses was made at the same time as microbiological sampling.

3.3 Total Viable Count of Heterotrophs (TVH)

Petri dishes containing a modified formulation of the Lib X agar

medium of Griffiths, Hanus and Morita (1974) were prepared in Ste-Anne-de-Bellevue, shipped to Cape Hatt, and stored at 2.0°C until used. The medium consisted of 2.3 g trypticase (Baltimore Biological Laboratories), 1.2 g Bacto-yeast extract (Difco), 7.69 g tris buffer (Trizma-7.2; Sigma Chemical Co.), 0.3 g sodium citrate, 0.3 g L-glutamic acid, 0.05 g sodium nitrate, 0.001 g ferric chloride, and 12.0 g Bacto-agar (Difco). The ingredients were dissolved in 1.0 L of 34°/$_{oo}$ Instant Ocean (Aquarium Systems, Inc.). The medium was autoclaved, cooled and dispensed in 100 mm petri dishes. Final pH at 5.0°C was 7.8. Plate count agar was prepared in a similar fashion using Plate Count Broth (Difco) dissolved in distilled water and supplemented with Bacto-agar. A spin-plate technique was employed to dispense a 0.1 mL aliquot of the water sample on the surface of triplicate cold Lib X agar plates with a 0.2 mL sterile pipette. From the original 0.1% by volume (10^{-3}) sediment-suspension sample, two sequential 10 fold dilutions were prepared such that 10^{-4} and 10^{-5} dilutions of sediment in seawater were obtained. Triplicate petri dishes of Lib X and plate count agar were spun for each of the sediment dilutions. After incubation at 2.0°C for three weeks, the plates were examined and those with an uneven distribution of colonies were discarded. The colonies of a replicate set were enumerated and the mean value was expressed as the total number of viable heterotrophs (TVH) per litre of water sample or litre of 0.1% by volume sediment-water suspension.

3.4 Most Probable Number (MPN) of Oleoclasts

The abundance of oleoclastic or petroleum-degrading heterotrophs was determined by the most probable number (MPN) procedure (American Public Health Association, 1971). Ten mL samples of seawater or sediment-suspension, and 10 fold serial dilutions up to 10^{-9} in 9.0 mL of sterile Instant Ocean (34°/$_{oo}$) were prepared in triplicate using screw-cap test tubes. Each tube was supplemented with 0.2 mL of nitrate-phosphate nutrient solution, 10.0 µL of sterile 8.0% weathered Lago Medio crude petroleum, and 15.0 µL of n-(1-^{14}C)hexadecane (Amersham

Corp.). The nitrate-phosphate concentrate yielded a final concentration of 1.0 g NH_4NO_3 and 0.1 g K_2HPO_4 per litre of sample water. Final activity of hexadecane was 3.0 μCi L^{-1} of sample water. The tubes were incubated at 5.0°C for a 60 day period after which time they were acidified by addition of 0.2 mL of 5.0 N H_2SO_4 through the septum of the cap.

In the laboratory at Ste-Anne-de-Bellevue, the tubes were purged of CO_2 in a gas train. The CO_2 was collected in NaOH and precipitated as $BaCO_3$. The precipitates were filtered through two 24.0 mm Whatman GFC filters and the filters added to scintillation vials containing 7.0 mL of Aquasol (New England Nuclear Corp.). The vials were shaken on a vortex mixer to disperse the precipitate, and 3.0 mL of distilled water were added to gel the Aquasol and ensure that a uniform distribution of the precipitate was maintained in the vial. Vials were counted in a Nuclear-Chicago Isocap 300 scintillation counter and corrected for quenching by the channel ratios method. Sample counts of more than double the background value were considered positive. Vials were scored for the highest dilutions yielding positive results; these were used to obtain the MPN of oleoclasts by reference to a standard MPN statistical table.

3.5 Total Counts

Total counts of bacteria in seawater were made using a procedure slightly modified from that described by Watson, Nowitsky, Quinby and Valois (1977). Polycarbonate membrane filters (Nucleopore Corp.) of pore size 0.2 μm and 25.0 mm diameter were prestained in a 0.2% solution of irgalan black in 2.0% by volume acetic acid. The filter was then rinsed in cell-free distilled water and placed on a 25.0 mm glass filter holder (Millipore Corp.). A seawater or sediment-suspension sample of 2.0 to 15.0 mL, fixed at the time of collection with 0.2% gluteraldehyde, was added to the filter funnel after shaking on a vortex mixer and sufficient acridine orange (80% dye content), at a concentration of 0.1% in 0.02 mol tris (pH 7.2), was added to the sample to yield a final stain

concentration of 0.02%. After two minutes, the sample was filtered and rinsed with 5.0 mL of cell free water. The membrane was then placed on a glass slide, wetted with a drop of Cargille Type A immersion oil, and covered with a cover glass. A Zeiss model WL microscope equipped with an epifluorescent condenser, a 50 watt mercury lamp, a BG 12 excitation filter, a No. 50 barrier filter, and a No. 500 beam splitter was used to view the fluorescing cells. For counting, a reticule with a 10 mm grid was used. A sufficient amount of seawater or sediment-suspension sample was filtered to yield about 100 cells per grid field. Ten randomly selected grid fields of each sample membrane were counted and the mean value expressed as the number of cells per litre of seawater or sediment-suspension sample.

3.6 Bacterial Heterotrophic Potential

An extensive modification of the procedure described by Harrison, Wright and Morita (1971) was employed throughout this study. Water samples and sediments were collected, as previously described, and processed immediately. To measure substrate assimilated and retained by bacteria, 10.0 mL of water sample or sediment-suspension were added to 14 chilled and sterile 55 mL screw-cap bottles containing varying amounts of glutamic acid substrate. Seven varying ratios of labelled to unlabelled glutamic acid were used in these supplements, yielding duplicate vessels containing total glutamic acid concentrations of 1.0 to 60.0 $\mu g\ L^{-1}$ of sample water, and activity of 2.0 or 20.0 $\mu Ci\ L^{-1}$. The specific activity of the L-[^{14}C(U)] glutamic acid (New England Nuclear Corp.) was 292.0 $mCi\ mmol^{-1}$. A fifteenth vessel containing 1.0 $\mu g\ L^{-1}$ of glutamic acid with 2.0 $\mu Ci\ L^{-1}$ of radioactivity served as a background control for the seven concentrations. Upon addition of the seawater or sediment-suspension aliquot, the reaction volume of the control vessel was immediately filtered through a 25.0 mm membrane filter (Millipore Corp.) with a pore size of 0.45 μm, and rinsed twice with 15.0 mL portions of cold, filtered seawater. The fourteen vessels were incubated at 2.0°C for 9.0 or 18.0 hours.

Suspended sediment samples were incubated at 2.0°C for 5.0 or 9.0 hours. Incubation times were varied in view of the expected bacterial activity at the time of sampling. Incubation was stopped by simultaneous filtration of the 14 vessels followed by cold rinsing. Rinsed membranes were transferred to scintillation vials containing 8.0 mL of Aquafluor (New England Nuclear Corp.), a dioxane-based fluor, as suggested by Thompson and Hamilton (1974).

To measure substrate respired by bacteria, fifteen 50 mL serum bottles were prepared with substrate and sample water or sediment-suspension as above. Upon addition of the sample to the control vessel, 0.2 mL of 5.0 N H_2SO_4 was immediately added to reduce the pH of the sample to below 2.0. Bottles were stoppered with serum caps fitted with plastic reaction wells (Kontes Glass Co.). The wells, suspended above the reaction volume, contained a fluted wick of two glass filters (Whatman GFA-24 mm). After incubation as above, the reaction in the serum vessels was stopped by the addition of 5.0 N H_2SO_4 through the rubber serum caps by means of a syringe. At the same time, 0.2 mL of β-phenethylamine (New England Nuclear Corp.) was added through the cap into the plastic well where it was completely absorbed by the wick. The bottles were then further incubated for 12 h at 40.0°C, during which time $^{14}CO_2$ was evolved from the seawater and absorbed by the phenethylamine-soaked wicks. The bottles were then opened and wicks were transferred to scintillation vials containing 8.0 mL of Aquasol. Scintillation vials were transported to Ste-Anne-de-Bellevue for counting. Results of membrane and wick counts were combined to yield total uptake of the glutamic acid substrate. Uptake kinetics were generated using computer programs (Section 3.10).

3.6.1 Theory

Kinetic parameters from the uptake of the glutamic acid substrate were calculated from a modified Michaelis-Menten equation (Dowd and Riggs, 1965):

$$\frac{D\mu t}{d} = \frac{(K+S)}{V_{max}} + \frac{A}{V_{max}}$$

where $D\mu$ = radioactivity added, d = radioactivity taken up, t = incubation

time in hours, K = an uptake constant, S = concentration of the natural substrate, V_{max} = the maximum velocity of uptake and A = concentration of the substrate added. Plotting $\frac{(D\mu t)}{d}$ against A yields a straight line where the reciprocal of the slope = V_{max}, Y intercept = turnover time in hours (T), and X intercept = (K+S).

The maximum velocity (V_{max}), or potential of heterotrophic activity, is the velocity of uptake at which the substrate saturates the uptake system such that the velocity can no longer increase. V_{max} indicates the physiological state of the bacterial flora by demonstrating the potential ability of the flora to use a particular substrate; i.e. its degree of adaptedness to that substrate.

3.7 Determination of Mineralization of Hexadecane

To assess the amount of mineralization of n-(1-^{14}C)hexadecane in water samples from a depth of 5 m or sediment-suspension samples, 30.0 mL aliquots of the samples were added to fifteen 50.0 mL serum bottles and supplemented with 0.6 mL of a sterile tris buffer solution, 30 µL of sterile 8.0% weathered Lago Medio crude and 30 µL of hexadecane containing n-(1-^{14}C)hexadecane to yield a final concentration of 2.0 µCi L^{-1} of sample. To account for the possibility of nutrient limitation, a second set of bottles was also prepared and supplemented with 0.6 mL of a sterile nitrate-phosphate concentrated solution with a final concentration of 1.0 g NH_4NO_3 and 0.1 g K_2HPO_4 per litre of sample. To measure the effect of dispersant on hexadecane mineralization, two additional sets of bottles were prepared as above and supplemented with 30 µL of 10% by volume Corexit 9527 (Exxon Chemical Co.) in water solution. The final ratio of Corexit to oil was 1:10. In each of the four sets, the 15th bottle was immediately acidified to pH 2.0 with 0.6 mL of 5.0 N H_2SO_4 and served as a background control. All vessels were incubated at 5.0°C and, at five or ten day intervals up to fifty days, two bottles from each set were acidified. Evolved $^{14}CO_2$ was quantitated as in the MPN procedure. Maximum DPM was generally obtained after the 50 day incubation.

3.8 Organic Carbon Determinations

Water samples were analysed for carbon by a procedure which modified and combined those of Menzel and Vaccaro (1964) and Stainton (1973). Freshly collected 100.0 mL water samples were filtered through previously ashed Whatman GFC-24 mm glass filters. Filters and filtrates were immediately frozen for subsequent analysis.

Dissolved organic carbon (DOC) was determined from the thawed filtrate by wet oxidation with potassium persulphate in a sealed ampule after removal of inorganic carbonate. Particulate organic carbon (POC) was determined from the thawed glass filters in a similar fashion. In both cases, evolved CO_2 was reduced to methane on a nickel catalyst in a continuous stream of hydrogen. Production of methane was determined by flame ionization using a Hewlett-Packard 5700A gas chromatograph and recorded and quantitated by a Hewlett-Packard 3380 recorder-integrator. Procedures for organic carbon determinations in the sediments will be reported at a later date.

3.9 In Situ Sediment Incubation

The presence of divers at the BIOS project site permitted the development and use of a benthic in situ incubation system (BISIS) (Fig. 3). The BISIS was designed to study and compare the in situ uptake of radio-labelled substrates by bacteria at the water-sediment interface and the water immediately above the sediment.

As illustrated in Figure 3, the BISIS consists of a cylinder divided in two compartments by a centre plate. The open bottom of the BISIS is forced into, and closed off by, the sediment. Rubber springs between the top end plate, centre support collar, centre plate, and bottom support collar maintain openings A, B, and C, thereby allowing a free flow of water through the compartments until the unit is closed. When closed by tightening the clamp handle, the two compartments each contain approximately 1 L of water. The bottom support collar acts as a flange to control the depth to which the BISIS unit can be placed into the sediment, thereby defining the water volume of the lower compartment. Incubation proceeds with the injection of radio-labelled

substrate into each compartment from the previously-loaded substrate syringes. After incubation, a 60.0 mL volume of sample water is withdrawn from the bottom compartment *in situ* using the attached 50 mL sampling syringe. Upon retrieval of the BISIS from the sediment, 60.0 mL of water from the top compartment is sampled at the surface by attaching another 50 mL sampling syringe to the top compartment sampling port.

BISIS units were deployed by divers on three occasions at Cape Hatt:

13 August, Station 4
6 September, Station 2
15 September, Station 2

Sufficient L-[^{14}C(U)] glutamic acid was injected into top and bottom compartments to yield a final concentration of 10.0 μg L^{-1} with 20.0 μCi L^{-1} activity. After incubations of approximately 9 h, water samples were withdrawn from top and bottom compartments. In two instances, surface sediment was collected from the area under the units. In each instance, water was collected outside and immediately adjacent to the units for comparative *in vitro* studies. All samples were maintained on crushed ice and, when returned to the laboratory, immediately processed.

To measure the amount of substrate retained by bacteria, incubation was stopped in the laboratory by simultaneous filtration of three 10.0 mL aliquots of sample water through a 25.0 mm membrane filter with a pore size of 0.45 μm and two subsequent rinsings with 15.0 mL portions of cold, filtered seawater. Rinsed filters were transferred to scintillation vials containing 8.0 mL of Aquafluor. To measure the amount of substrate respired, three 10.0 mL aliquots of sample water were transferred to 50 mL serum bottles and stoppered with serum caps fitted with a plastic reaction well. Samples were then treated as described in section 3.6.

Assuming a linear relationship between uptake and incubation time for each BISIS, a correction factor was introduced to standardize results to a 9 h incubation period. A linear correction was also

introduced when sample volumes were less than 10.0 mL due to collection problems with some sampling syringes.

The surface sediment sample collected by the diver from under the BISIS, was subsampled in the laboratory with a modified 3 mL syringe. A 1.0 mL aliquot of this wet sediment was diluted to 10^{-3} with sterile filtered seawater. Three 10.0 mL aliquots of this suspension were filtered in the same fashion as the water samples to quantitate the retention of radio-labelled substrate by bacteria in the sediment.

Finally a kinetic uptake experiment, as described in section 3.6, was made using water from outside the BISIS unit.

3.10 Statistics

Kinetic parameters of glutamic acid uptake and their correlation coefficients were generated using computer programs developed by D. Burrage (Department of Computer Sciences, McGill University) and J. N. Bunch. Multi-way analysis of variance (ANOVA) was determined at the 1.0% level of significance. This statistical procedure is part of the Statistical Analysis System (SAS Institute Inc., Cary, N.C., USA) available through the McGill University Computing Centre.

4.0 RESULTS

4.1 Water Columns

Statistical analysis of the results indicated that no significant differences existed between depths at the same station, or stations in the same bay. For the purposes of this report, values from the three depths sampled at both stations in a bay have been averaged and are presented in Figures 4 to 8. Data for all stations and depths are presented in Tables 7 and 8. Since bay 13 was found to be unsuitable for these studies, data obtained at stations 1A and 2A have been reported (Tables 7 and 8) but are not included in figures and other tables, nor in discussions and comparisons.

4.1.1 Total Count of Bacterial Cells

The total count of bacterial cells found in the June sampling period (cycles 1 and 2) ranged from 5.2×10^7 to 8.3×10^7 cells per litre (Fig. 4). When collections resumed in August (cycle 3), values had increased to 3.4×10^8 and 3.3×10^8 cells per litre for bays 10 and 9 respectively. The number of cells continued to increase in all bays, with the greatest population size occurring in late August. The largest population, 9.6×10^8 L^{-1} was found in bay 11 on 28 August. Water samples taken during the last cycle indicated a decline in total cell numbers in all bays, with population size in bays 9 and 10 returning to that found during cycle three.

4.1.2 Total Viable Heterotrophs

In all bays, the total number of viable heterotrophs, as determined by the number of colony-forming units, was less than 4.0×10^5 L^{-1} on plates inoculated with water samples collected up to 21 August (Fig. 5). Most results are missing for 13 and 15 August because plated samples froze in a faulty incubator. Heterotrophic numbers increased rapidly after 21 August, the maximum heterotrophic population size occurring in Cape Hatt waters in late August and early September. There was only a slight decline in numbers from early September until the last collection on 16 September.

4.1.3 Dissolved and Particulate Organic Carbon

Dissolved organic carbon (DOC) remained stable in June at an average of 1.5 mg L^{-1}. Early August results were up slightly to 1.9 mg L^{-1} and 2.0 mg L^{-1} for bays 10 and 9 respectively and increased to a maximum between 28 August and 1 September (Fig. 6). The highest concentration (3.4 mg L^{-1}) was found in bay 10 on 30 August. During the last sampling cycles, values in all bays had decreased and were similar to June values.

Particulate organic carbon (POC) concentrations were low in June samples, ranging from 35 µg L^{-1} to 60 µg L^{-1}. As illustrated in Figure 7, August and September values were similar in all bays, and roughly three times greater than June values, ranging from a low of 130 µg L^{-1} (bay 11 on 28 August) to a high of 188 µg L^{-1} (bay 9 on 15 August). A trend towards lower values appeared to be forming as the field season ended.

4.1.4 ^{14}C-Glutamic Acid Uptake

The maximum velocity (V_{max}) at which bacteria can potentially utilize glutamic acid is one of the kinetic parameters used to indicate the physiological state of bacterial floras.

During the June sampling period, activity was minimal and increased slightly from 0.23 µg $L^{-1}d^{-1}$ to 0.57 µg $L^{-1}d^{-1}$. When sampling was resumed in August, V_{max} in bay 10 had already reached an observed maximum of 5.49 µg $L^{-1}d^{-1}$. In bays 9 and 11, similar maximum values were obtained in the fourth cycle. As indicated in Figure 8, mid-August was the period of greatest potential activity after which time values decreased steadily for the balance of the field season. Values obtained in mid-September were roughly half those in mid-August.

4.1.5 Most Probable Number of Oleoclastic Cells

The numbers of oleoclastic cells in water samples from 5 m determined by the most probable number procedure (MPN) using 8% weathered Lago Medio crude as a carrier for n-(1-^{14}C)hexadecane are presented in Table 2. Counts of between 40 and 90 L^{-1} were observed

on some occasions, but generally the numbers of oleoclastic cells appeared to be too low to be detected.

4.1.6 Hexadecane Mineralization

Hexadecane mineralization in a 30.0 mL water sample, using 8% weathered Lago Medio crude as a carrier for ^{14}C-hexadecane are presented in Table 2. A long lag period was observed and activity was shown only after incubation for 40 or 50 days. Although overall response was low, the most active samples were those supplemented with nutrients. Hexadecane mineralization was negligible in the presence of Corexit 9527 and was not enhanced by nutrient supplementation. A comparison of the use of 8% weathered Lago Medio crude and well-weathered Norman Wells crude as carriers for n-(1-^{14}C)hexadecane did not show any significant difference in hexadecane mineralization even with nutrient supplementation.

The two highest results obtained after 50 days of incubation were at station 6 on 16 September and station 1 on 5 September, with values of 19 825 disintegrations per minute (dpm) and 14 902 dpm respectively.

4.2 Sediments

One sediment sample was collected from each station during each of the seven collection cycles for determining the V_{max} of glutamic acid uptake, total counts of bacteria and total numbers of viable heterotrophs. The data are reported in Table 9. The lack of homogeneity in the few sediment samples, together with the use of several techniques for sediment collection, yielded varying results. Figure 9 and Table 3 show the means of six sediment collections from three bays during sampling cycles. Sediment studies were performed with 0.1% by volume sediment-water suspensions and the results for total count, total viable heterotrophs and V_{max} are expressed per litre of suspension.

4.2.1 Total Counts of Bacterial Cells

The means of total counts for the June sampling cycles were 2.9×10^8 and 1.9×10^8 L^{-1} of sediment suspension (Table 3, Fig. 9). A mean count

of 5.8 X 10^8 L^{-1} was obtained from the bays during 13-15 August and a maximum mean count of 7.5 X 10^8 L^{-1} was obtained in the following cycle of collection (19-23 August). Counts declined slowly in the sediments of the three bays in subsequent collections to the end of the sampling season.

4.2.2 Total Viable Heterotrophs

The means of counts of total viable heterotrophs (TVH) from sediments (Table 3, Fig. 9) refer to counts of colonies which developed on a marine plating medium (Lib X) at 2.0°C. Some data in August (Table 9) are missing because plates froze in a faulty incubator and were therefore discarded. Mean counts from sediment samples taken during the June sampling cycles were 5.7 X 10^5 and 3.3 X 10^5 L^{-1}. The fluctuation in mean counts during the first two cycles in August can be regarded as spurious since only one sediment sample was counted for the sampling cycle of 13-15 August. Mean counts of 11.9 X 10^5 to 15.5 X 10^5 L^{-1} were observed for the balance of the season, values that were approximately three times higher than during June.

No colony formation was observed on plate count agar, a terrestrial plating medium prepared with fresh water, after inoculation with sediment suspensions.

4.2.3 ^{14}C-Glutamic Acid Uptake Kinetics

The maximum velocity (V_{max}) of glutamic acid by bacterial floras in sediments showed large fluctuations, probably as a result of variation in sediment samples and methods of collection. In addition, the uptake activity in the sediments was higher than any observations previously made in other areas by our laboratory (unpublished data). The bacterial flora was rapidly saturated by all but the lowest concentrations of glutamic acid and the kinetic parameters were difficult to estimate. The means of V_{max} determined from the two cycles of collection in June were 10.8 and 13.4 $\mu g\ L^{-1}d^{-1}$ (Table 3, Fig. 9). A similar mean was determined from the first sampling cycle in open water (13-15 August). The means of uptake activity were observed to increase approximately

2.5 fold across the balance of the sampling season to a mean of 34.0 $\mu g\ L^{-1}d^{-1}$ in the sediments of the three bays during 12-16 September.

4.2.4 Most Probable Number of Oleoclasts

With two exceptions, the mineralization of n-(1-^{14}C)hexadecane by sediment samples could not be detected by our procedure. Most probable numbers, therefore, could not be calculated. The two exceptions were cell counts of 1.9 X 10^2 L^{-1} from sediment at station 6 and 2.9 X 10^3 L^{-1} from sediment at station 4 on 10 June and 13 August respectively.

4.2.5 Amounts of Hexadecane Mineralization

With one exception, no determinations of amounts of hexadecane mineralization were made for the reason given above (4.2.4). Had incubation intervals extended beyond fifty days, a possible lag might have been overcome and positive results obtained. The only exception was a single result of 1432 dpm obtained from evolved $^{14}CO_2$ after 50 days incubation of sediment collected at station 4 on 15 September.

4.3 *In Situ* Sediment Incubations

On 13 August, three benthic *in situ* incubation systems (BISIS) were installed at station 4. For comparative purposes, all results were equalized in terms of a 9.0 hour incubation time and 10.0 mL of water or sediment-suspension sample.

The three upper compartments yielded reproducible results both in uptake (filter membranes) and respiration (wicks) (Table 4). These results also related very closely to those obtained by means of the *in vitro* incubation carried on simultaneously in the laboratory (Table 4). A respiration percentage of 43 was obtained in the top chamber in the BISIS whereas 44% respiration was recorded by the *in vitro* uptake experiment using 10 m water from station 4.

Greater fluctuation was recorded in the results of the lower compartments, both for uptake and respiration. The lower compartment of one unit was not sampled because of a valve malfunction. The average

uptake value in lower compartments was five times lower than in the outside water, while the average percent respiration was twice as high as in the surrounding water. No sediment samples were collected from under the compartment following incubation.

On 6 September, three BISIS units were placed at station 2. The results obtained from the upper compartments were similar in uptake and respiration (Table 4). They also compared favourably with the results obtained *in vitro*. Uptake values increased from approximately 33 000 dpm on 13 August to nearly 40 000 dpm on 6 September, whereas respiration values and percent respiration decreased. The respiration values obtained from all three bottom compartments showed little variation and were similar to the respiration values observed in the surrounding water. However, uptake results, with a mean value almost 20% higher than the control, showed considerable fluctuation. An uptake value of about 105 000 dpm was obtained for a 10 mL sediment-suspension sample.

In situ incubations on 16 September at station 2 yielded reproducible results in top compartments both for uptake and respiration (Table 4). Respiration was similar to the *in vitro* control value but uptake showed a 1.5 fold increase with respect to the surrounding water at 10 m. When these results were compared to those obtained on 13 August, a decrease of 20% for uptake and of more than 50% for respiration was noted. The lower compartments showed moderate fluctuations in both uptake and respiration, the average uptake values being slightly lower and the average respiration value being more than three times higher than the *in vitro* control. A sediment uptake value of 216 623 dpm showed a two fold increase over 6 September.

5.0 DISCUSSION

5.1 Water Columns

Analysis of variance (Section 3.10) of the data for V_{max}, total count, DOC and POC did not demonstrate any significant difference between the three depths of a station or between the two stations within a bay during August and September. For this reason, the data are presented as six replicate samples of a given bay on a particular sampling date. The uniformly low values for the same parameters in the June period did not lend themselves to inclusion in the statistical analyses, nor was it deemed necessary. The data from bay 13 were not included in statistical analyses. Although the three bays (9, 10, and 11) were occupied across a four day sampling period (Table 1), simultaneous sampling was assumed in the summary of data presented in Figure 10 and Table 5, where the results of three bays are given as a cycle mean.

No significant difference between the three bays was evident in the concentrations of POC or DOC during the August-September period. Concentrations of DOC in the three bays did show a significant difference with time. The average concentration of DOC increased two fold across the sampling periods and returned to a concentration of 1.49 mg L^{-1} by mid-September (Fig. 10A). This is probably the concentration which persists in the water during the winter months. The seasonal increase can be attributed largely to extruded or degraded products of phytoplankton blooms and the decline corresponded to the increase in bacterial numbers. Bada and Lee (1977) suggested that bacterial floras utilize the readily oxidizable products of primary production. The remainder, which in part forms a baseline level of DOC, is refractory to bacterial utilization or is only slowly oxidized and incorporated into bacterial biomass.

The concentrations of POC in water columns of the three bays did not show significant differences with time although the mean cycle value had decreased from 185 to 149 µg L^{-1} from early August to mid-September (Fig. 10C). High levels of POC are a consequence of phytoplankton blooms and the biomass of phytoplankton forms a part of measured POC. It is probable that much of an earlier bloom of phytoplankton settled

out of the near-shore environment at Cape Hatt. Sediment traps placed at a depth of 10 m in Frobisher Bay, N.W.T. during 1980 demonstrated that a large amount of detrital material settled out in a two day period within a few weeks of maximum bloom conditions (J. W. Wacasey, personal communication). Had POC measurements been made closer to the time of ice breakup at Cape Hatt (27 July), values higher than those of 11-13 August would probably have been obtained. POC concentrations in excess of 1000 $\mu g\ L^{-1}$ have been measured at Frobisher Bay after a week of the maximum bloom of phytoplankton (unpublished data). Data from Cape Hatt in September were similar to those from Frobisher Bay during the same period and a slow decline across the winter to June levels or lower seems evident.

The abundance of bacterial cells in the water columns of the bays increased across the open water season. The number of viable heterotrophic cells (TVH) determined by colony formation on marine plating medium increased approximately 10 fold to $1.4 \times 10^6\ L^{-1}$ (Fig. 10B) and remained at that level to the end of the sampling season. This increase was in response to primary production and paralleled the increase in DOC. Seasonal 10 fold increases in TVH occur yearly at Frobisher Bay, and the bays at Cape Hatt appear to be following previously observed trends in arctic marine waters. There was no significant difference between the three bays in TVH determinations.

A similar increase was observed in the total counts of bacterial cells as determined by fluorescent microscopy (Fig. 10B). The maximum number of cells, expressed as a cycle average, occurred during the 28 August to 1 September cycle when counts averaging $6.8 \times 10^8\ L^{-1}$ were obtained. Predictably, this value was two orders of magnitude higher than that of TVH, and is a more realistic estimate of bacterial numbers. As previously noted, total counts of bacterial cells paralleled the increase and subsequent decrease in the concentrations of DOC. There was a significantly higher count of bacteria in bay 11 than in bay 9. This may be attributable to the longer residence time of water in bay 11.

The highest values for maximal velocity (V_{max}) of glutamic acid

uptake occurred at the beginning of the summer sampling period in the bays and these rates persisted into the next cycle of sampling. The cycle means during this period were approximately 5.5 μg $L^{-1}d^{-1}$ (Fig. 10A). Similar rates have been obtained at Frobisher Bay (unpublished data) approximately two weeks following ice breakup, and larger rates are seldom observed in this area. At Cape Hatt, sampling began during the time when V_{max} was probably greatest in the bays. The subsequent decrease in V_{max} in the bays to the end of the sampling season corresponded to decreases in DOC and total counts of bacteria, and appears to reflect declining activities and numbers of bacteria under conditions of diminishing organic substrate.

A significant difference was found between bays 9 and 11 with respect to V_{max} of glutamate uptake (Fig. 8). This may be attributable to the four day time difference between the sampling of bay 11 and bay 9 (Table 1). Values of V_{max} tend to peak rapidly and this rapidity may be reflected in the differences observed. Alternatively, the larger V_{max} values in bay 11 can be construed to be a result of the activity of the larger number of bacterial cells observed in bay 11 over those in bay 9 (Fig. 4).

Analyses of sample waters for reactive nitrate and phosphate and chlorophyll a were performed by Seakem Oceanography Ltd. and reported by Green (1981). The data summarized in Figure 10 and Table 5 are from that source.

Reactive nitrate and phosphate levels were high in water columns during the June sampling period and uniformly low throughout the open water sampling period. Phosphate values were not significantly different between bays but were significantly different across the open water season, increasing slightly during the last sampling cycle in September. This has been attributed to a storm surge which occurred at that time. Low levels of phosphate and nitrate from early August on can be attributed to depletion of these nutrients by an earlier bloom of phytoplankton.

The bloom of phytoplankton which occurred prior to the commencement of sample collection in August was not reflected in the concentrations of

chlorophyll a obtained during the sampling cycle of 13-15 August. Chlorophyll a levels had presumably decreased rapidly in the near-shore waters with nutrient depletion and the cessation of the bloom. The slight increase in chlorophyll a levels in September was attributed to the storm surge replenishing nutrients, which could enhance phytoplankton production (i.e. increased chlorophyll a). Alternatively, higher levels of chlorophyll were present in deep offshore water which may have been brought near-shore by the storm surge. As an adjunct to the chlorophyll measurements, water samples were collected for enumeration of phytoplankton cells. These data will be reported at a later date.

Determinations of V_{max} of glutamic acid uptake from other regions near Cape Hatt and at Frobisher Bay are presented in Table 6 as a comparison to determinations from bay 11 at Cape Hatt. Measured concentrations of chlorophyll a, reactive nitrate and particulate organic carbon are also included. These stations (unpublished data) were chosen for comparison because of their spatial and temporal proximity to Cape Hatt. In the case of Frobisher Bay, the given rates of V_{max} were observed at an interval after ice breakup similar to the time after breakup at Cape Hatt. Station 4A was occupied near the mouth of Navy Board Inlet and station 16A near the mouth of Pond Inlet. Data from station 4A suggest that the station was occupied during the commencement of a bloom of phytoplankton. The V_{max} in the top 5 m of the water column indicated a high level of bacterial activity in response to primary production. A V_{max} of 1.69 $\mu g\ L^{-1}d^{-1}$ at 20 m, together with a chlorophyll a value of 0.7 $\mu g\ L^{-1}$ and POC of 40.0 $\mu g\ L^{-1}$ indicated that phytoplankton and bloom products had not yet descended into the water column. Reactive nitrate was not yet depleted at this depth.

In water samples taken from 1 m and 5 m at station 16A, levels of bacterial activity, together with concentrations of POC and reactive nitrate, suggested post-bloom conditions whereas at 20 m, a high V_{max}, and high levels of chlorophyll a and POC verified that the water column was in an advanced state of bloom. At Frobisher Bay, intensive site-specific work across the seasons in 1979 allowed us to follow the course of phytoplankton and bacterial activity very closely. The largest

values of chlorophyll a occurred approximately 2.5 weeks after ice breakup and during this time, reactive nitrate was exhausted in the water column and POC in excess of 600 μg L^{-1} was noted. V_{max} values were uniformly high in the 20 m water column.

When these data are compared to those obtained in bay 11 at Cape Hatt 19 August, it would appear that the sampled waters were in a post-bloom condition, and the V_{max} of glutamate uptake remained high. Reactive nitrate was essentially depleted and concentrations of chlorophyll a and POC were probably decreasing. To ensure that the development of the bloom is observed in 1981, sample collections should commence prior to ice breakup.

5.2 Sediments

The fluctuations observed in sediment data are possibly due to the small one mL wet samples used. When values from six stations in each sampling cycle (Fig. 9) are averaged, the mean V_{max} slowly increased during August and September, giving an almost straight line response. This gradual increase in heterotrophic potential suggests that seasonal changes in the sediment occur much more slowly than in the water which had already peaked between June and August, and was showing a gradual decrease in values during the same period when sediment activity was increasing. Since sampling was terminated before a maximum V_{max} could be observed, it would be difficult to estimate when or at what value this peak might occur.

Averaging of total counts or total viable heterotrophs indicated no significant change during the August and September sampling cycles. The total count values for the June sampling cycles were slightly lower than in August-September. The large seasonal fluctuations found in the water column were not apparent in the sediment. This will be investigated more thoroughly in the coming season with changes in sediment sampling procedures, which should reduce the fluctuation between individual samples.

5.3 In Situ Sediment Incubations

Since one of the three in situ experiments was carried out in a different bay, only comparisons between the two chambers of a sampler and between each sampler and the control water was attempted. The possible influence of bivalves filtering out radio-labelled substrate and bacteria in the bottom chambers rendered the interpretation of the activity displayed by each group of organisms difficult.

Throughout the experiments, water from the top chamber yielded uptake and respiration results similar to those obtained from water surrounding the BISIS. The uptake and respiration values observed in the bottom chambers were different from those in the surrounding water or in the top chambers. Generally lower uptake values in water from bottom chambers can be explained by the removal of bacteria with incorporated radio-labelled substrate by filter-feeding organisms. In addition, sediment bacteria would utilize a fraction of the labelled substrate and consequently reduce the quantity of available radio-labelled glutamic acid for bacteria in the overlying water. Carbon dioxide produced by the sediment bacteria would escape to the overlying water and add to the $^{14}CO_2$ generated by water bacteria, thus increasing respiration values to the high levels observed in the bottom chamber. Utilization of radio-labelled bacteria and substrate by filter-feeders would also contribute to evolved $^{14}CO_2$ in the lower compartments.

The implication of sediment bacteria in the production of $^{14}CO_2$ was reflected by sediment samples taken from under the BISIS units after incubation. Those sediments yielding very high uptake results indicated that bacteria within the surface sediment layer were assimilating and presumably respiring ^{14}C-glutamic acid present in the overlying water. No attempt was made to evaluate respiration in the sediment on the assumption that most of the $^{14}CO_2$ had been liberated into the water.

First experiments with the BISIS units have provided in situ data of bacterial activity at the sediment-water interface. In addition, in situ data have compared favourably with laboratory results. Some

modifications are to be made to the units for the 1981 season. Experiments will be performed to assess the influence of filter-feeding invertebrates in the bottom compartment, enumerate bacteria inside the compartments before and after incubations, and measure the effects of petroleum and dispersants on glutamate uptake. Mineralization of hexadecane at the sediment-water interface will also be evaluated.

5.4 Hexadecane Mineralization

Mineralization of n-(1-^{14}C)hexadecane was used to estimate the numbers of oleoclastic bacteria in water and sediment samples and their rates of activity. With maximum recorded observations of 90 oleoclastic bacteria per litre of water at Cape Hatt (Table 2), the three 10.0 mL undiluted sample tubes used in the most probable number determinations contained a maximum of 2.7 oleoclastic bacteria. One or two or even three of the tubes would therefore probably have no oleoclastic bacteria. This was the limit of detection using a 10.0 mL sample. The carrier for labelled hexadecane was 8% weathered Lago Medio crude (D. Mackay, personal communication) and was a subsample of the large volume of weathered Lago Medio crude presently on-site at Cape Hatt. The results could have been confounded by the small sample volume or the use of slightly weathered Lago Medio crude. If various indigenous populations of oleoclasts were present and preferred a fraction or component of the Lago Medio crude other than hexadecane, this would not be obvious by measuring n-(1-^{14}C)hexadecane mineralization. This possibility, however, has been ruled out since visual inspection of MPN tubes for turbidity (i.e. growth and multiplication at the expense of the crude) yielded the same results as the measurement of hexadecane mineralization. Alternatively, the presence of the Lago Medio crude inhibited growth and hexadecane mineralization due to toxic fractions remaining in the crude after 8% weathering. This possibility was also ruled out in view of the limited results obtained in three trials at Cape Hatt with highly weathered Norman Wells crude, a sample of which has been used routinely for several years by our laboratory with favourable results in several geographic locations in the Arctic and on the Grand Banks of Newfoundland.

Where determinations of rates of n-(1-^{14}C)hexadecane mineralization were attempted, a 30.0 mL subsample of seawater was incubated in a serum bottle as opposed to the 10.0 mL subsample contained in screw-cap test tubes for the MPN procedure. Evidence of hexadecane mineralization was obtained three times as often with the 30.0 mL sample volume as with the 10.0 mL volume. This again suggests that the indigenous population capable of mineralizing hexadecane was sparse and not always available in 10.0 mL aliquots. This possibility will be tested in the coming year with the use of larger sample volumes.

In attempting to measure rates of hexadecane mineralization, replicates were removed at intervals up to 50 days. In most cases, the lag before detectable activity extended beyond the 40 day interval and some positive results were obtained only at the 50 day and final interval. A lag period of more than 50 days, therefore, would not yield a positive result. Supplementation of nitrate and phosphate in the incubation vessels reduced the lag sufficiently to almost double the number of positive observations at 50 days.

The addition of Corexit 9527, with and without nutrient supplementation, increased the lag to the extent that there was no activity recorded after 50 days of incubation. The Corexit either suppressed hexadecane mineralization or provided a substrate preferred by oleoclasts over the hexadecane; evidence from experiments at Frobisher Bay suggest the latter. In the presence of nitrate and phosphate, hexadecane mineralization proceeded at a rapid rate after a long lag, during which time it seems probable that one or more fractions of Corexit were utilized by oleoclasts. In view of the marginal oleoclastic activity detected at Cape Hatt, the maximum incubation times for hexadecane mineralization experiments may be increased to 60 days for the 1981 season. With increased sample volume as well, the sensitivity of this procedure should increase significantly.

Only meagre evidence of hexadecane mineralization was observed in the sediments, either from our rate experiments or the most probable number determinations. It can only be concluded that oleoclastic bacteria, capable of hexadecane mineralization, were inactive or not present in the sediment in detectable numbers. In future studies, the

sample size will be increased by using smaller sediment dilutions for hexadecane mineralization studies.

Oleoclastic activity in the water was not observed until the last three sampling cycles. It is reasonable to assume that since seasonal trends occur more slowly in the sediment, oleoclastic activity in the sediment might have been observed later in September had sampling continued for a longer period.

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7.0 Figures

Figures 1-10

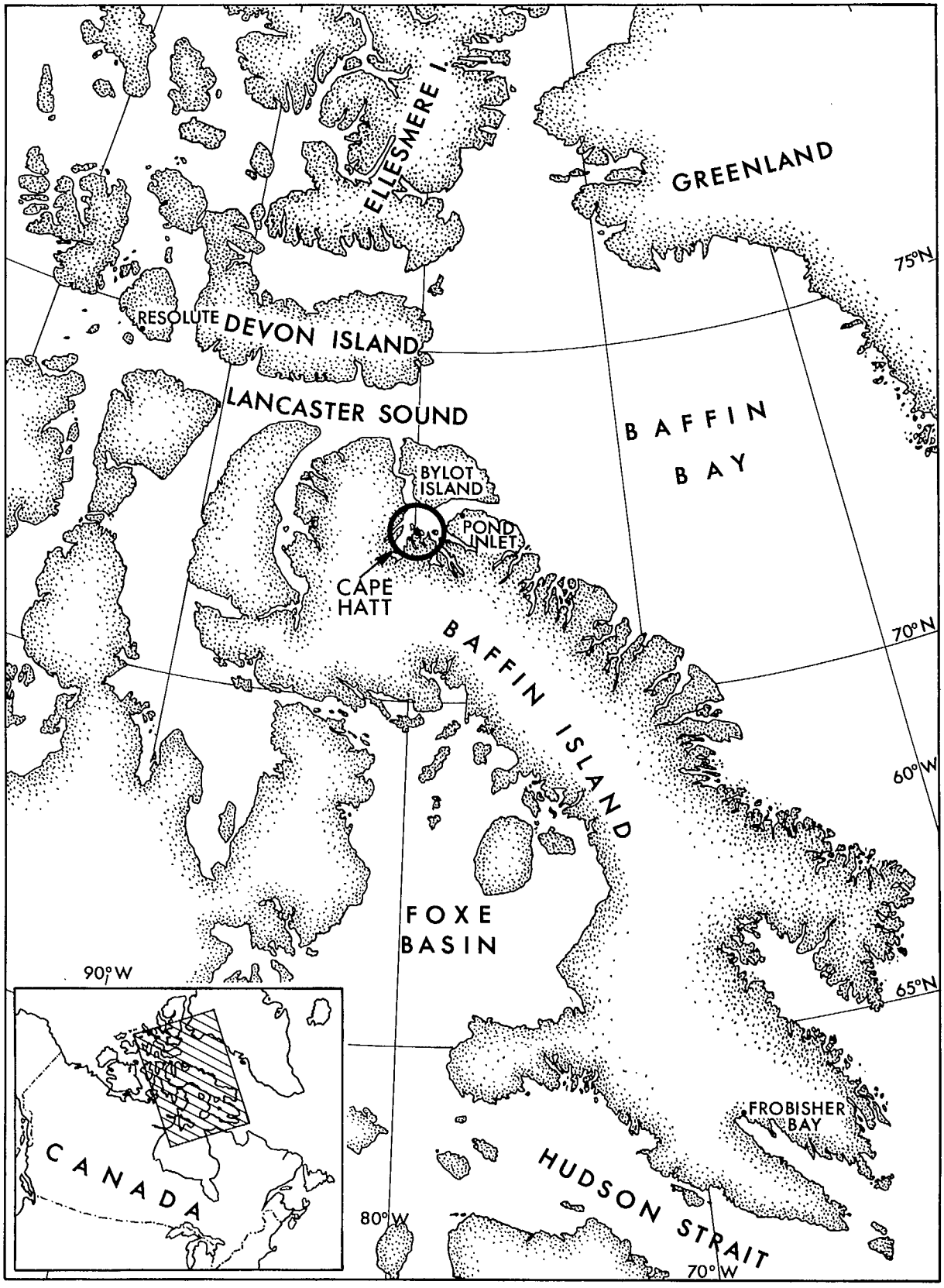


Figure 1. Location of the BIOS project, Cape Hatt, N.W.T.

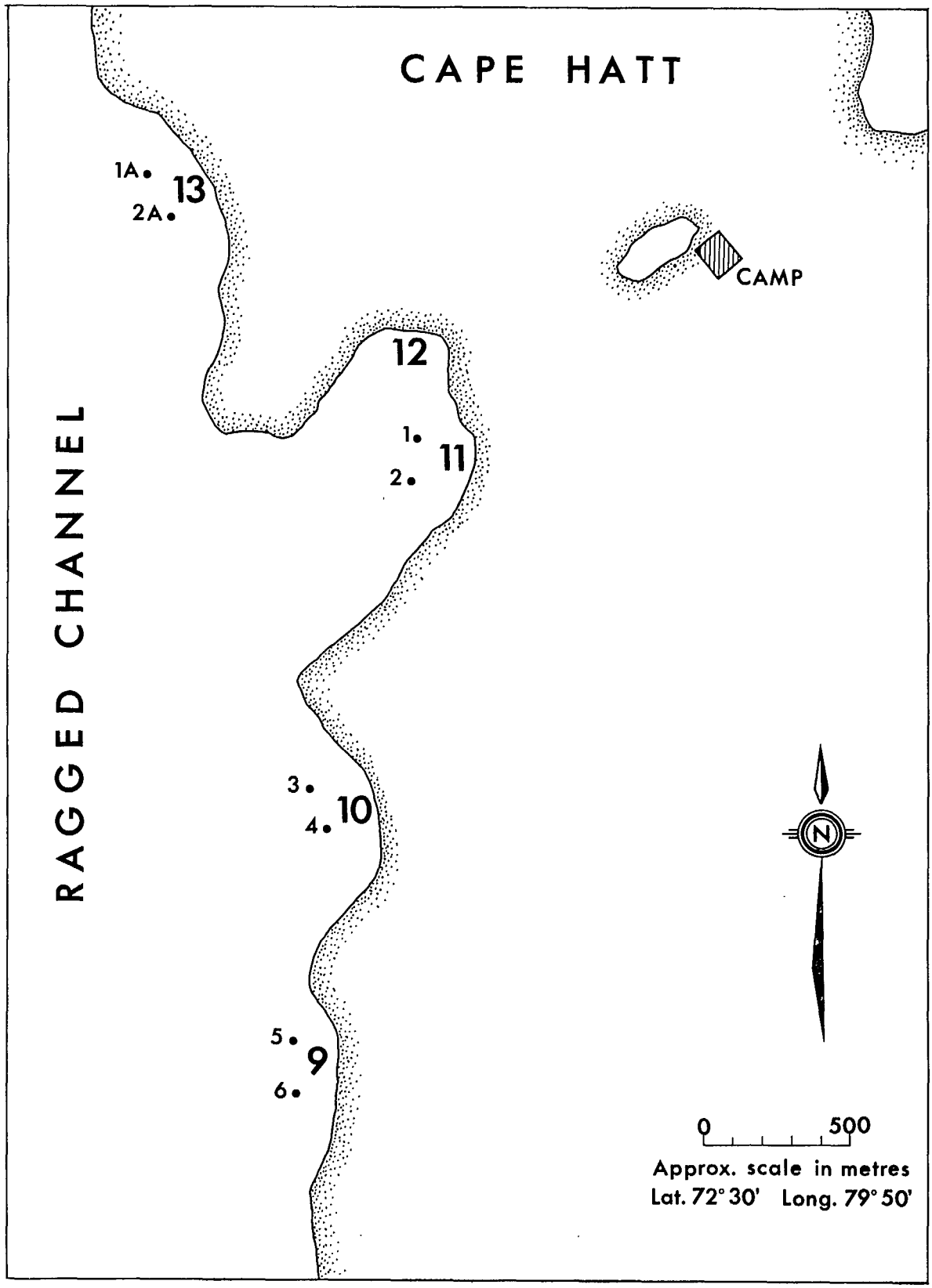
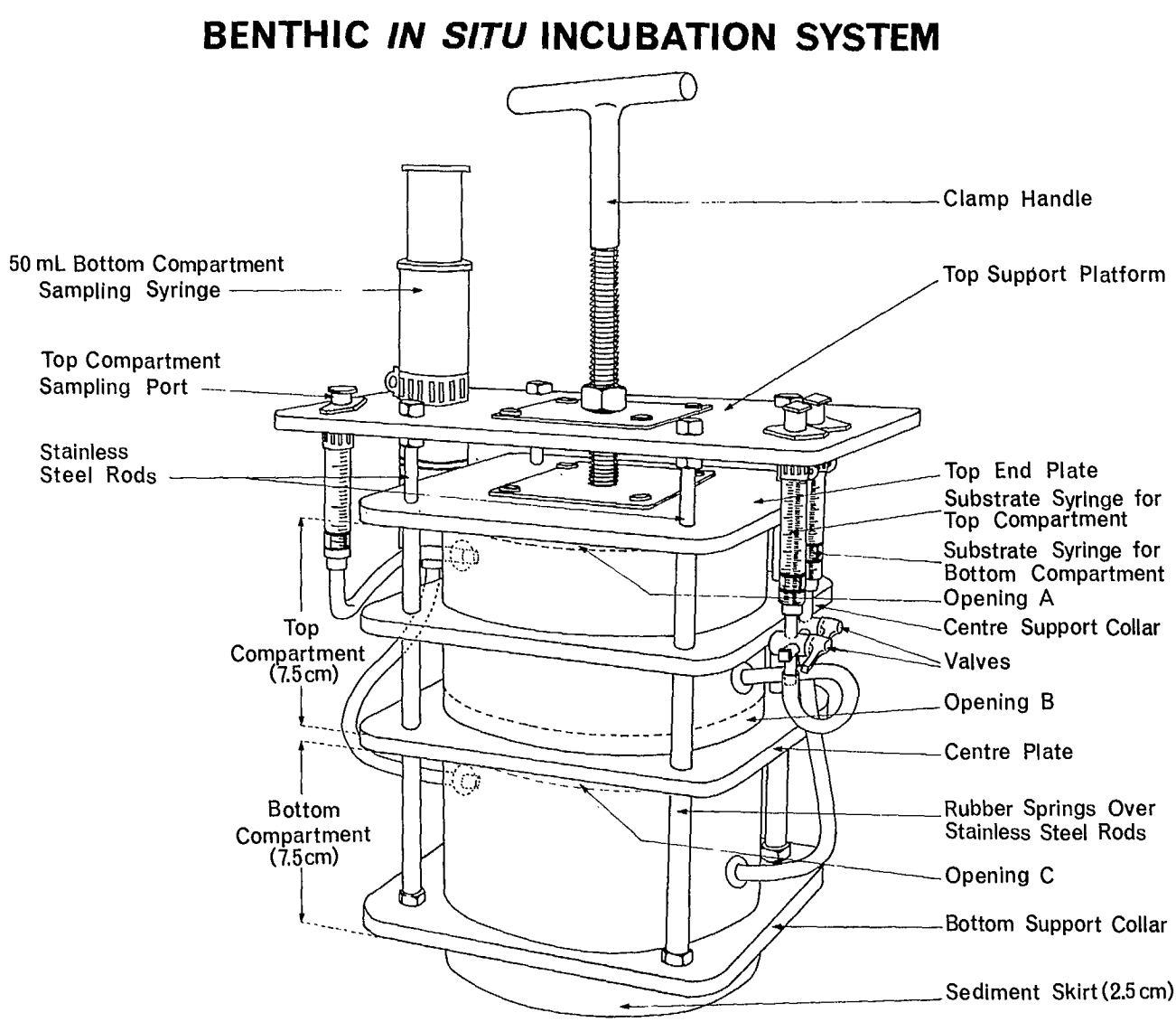


Figure 2. Microbiological stations occupied at Cape Hatt during 1980.

Figure 3.


BENTHIC *IN SITU* INCUBATION SYSTEM
Clamp Handle
50 mL Bottom Compartment Sampling Syringe
Top Support Platform
Top Compartment Sampling Port
Stainless Steel Rods
Top End Plate
Substrate Syringe for Top Compartment
Substrate Syringe for Bottom Compartment
Opening A
Centre Support Collar
Valves
Top Compartment (7.5cm)
Opening B
Centre Plate
Rubber Springs Over Stainless Steel Rods
Bottom Compartment (7.5cm)
Opening C
Bottom Support Collar
Sediment Skirt (2.5 cm)

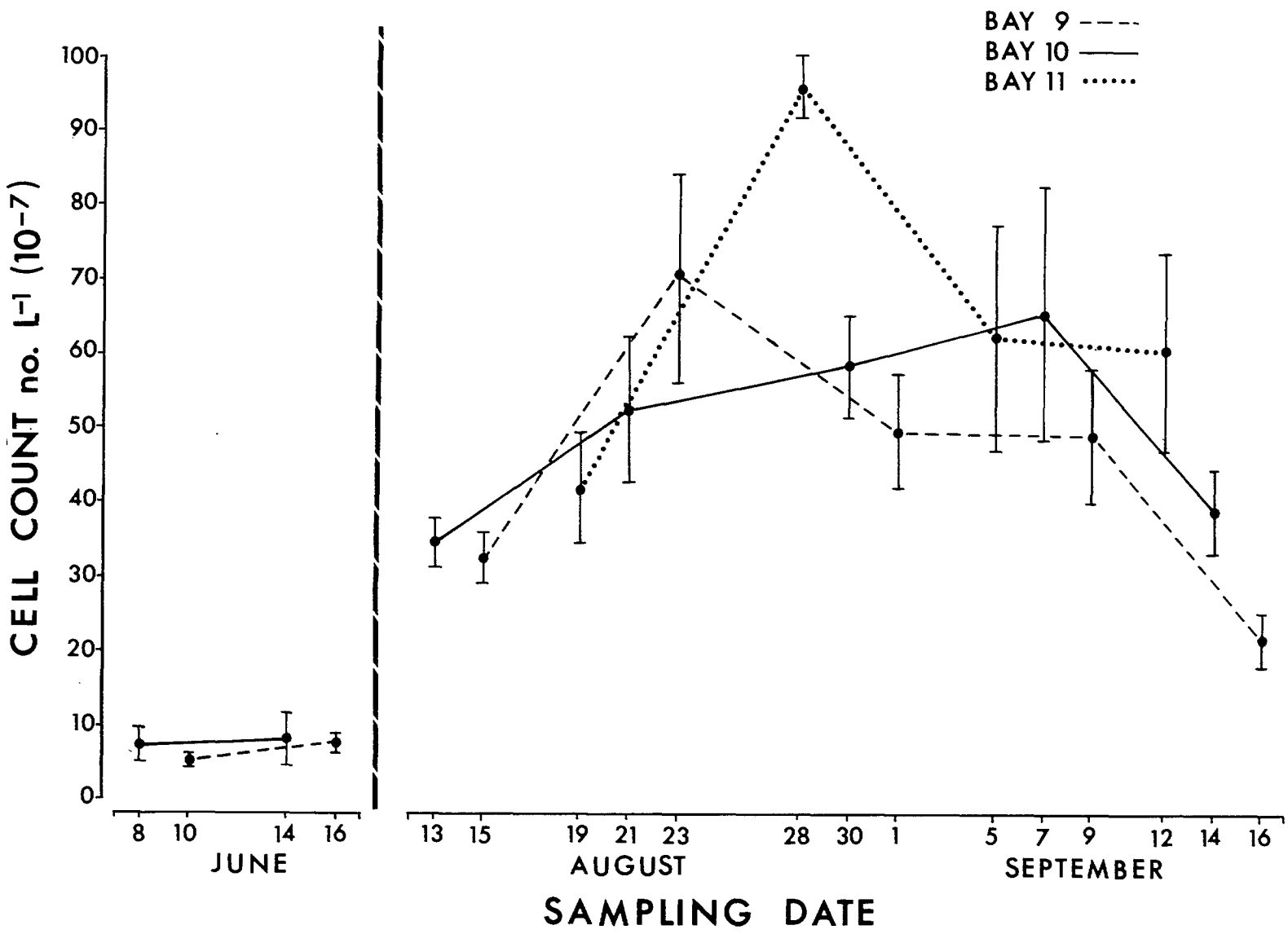


Figure 4. Total count (TC) of bacterial cells in water samples collected at Cape Hatt, 1980. Results are presented as means and standard deviations of six values from three depths at two stations in each bay.

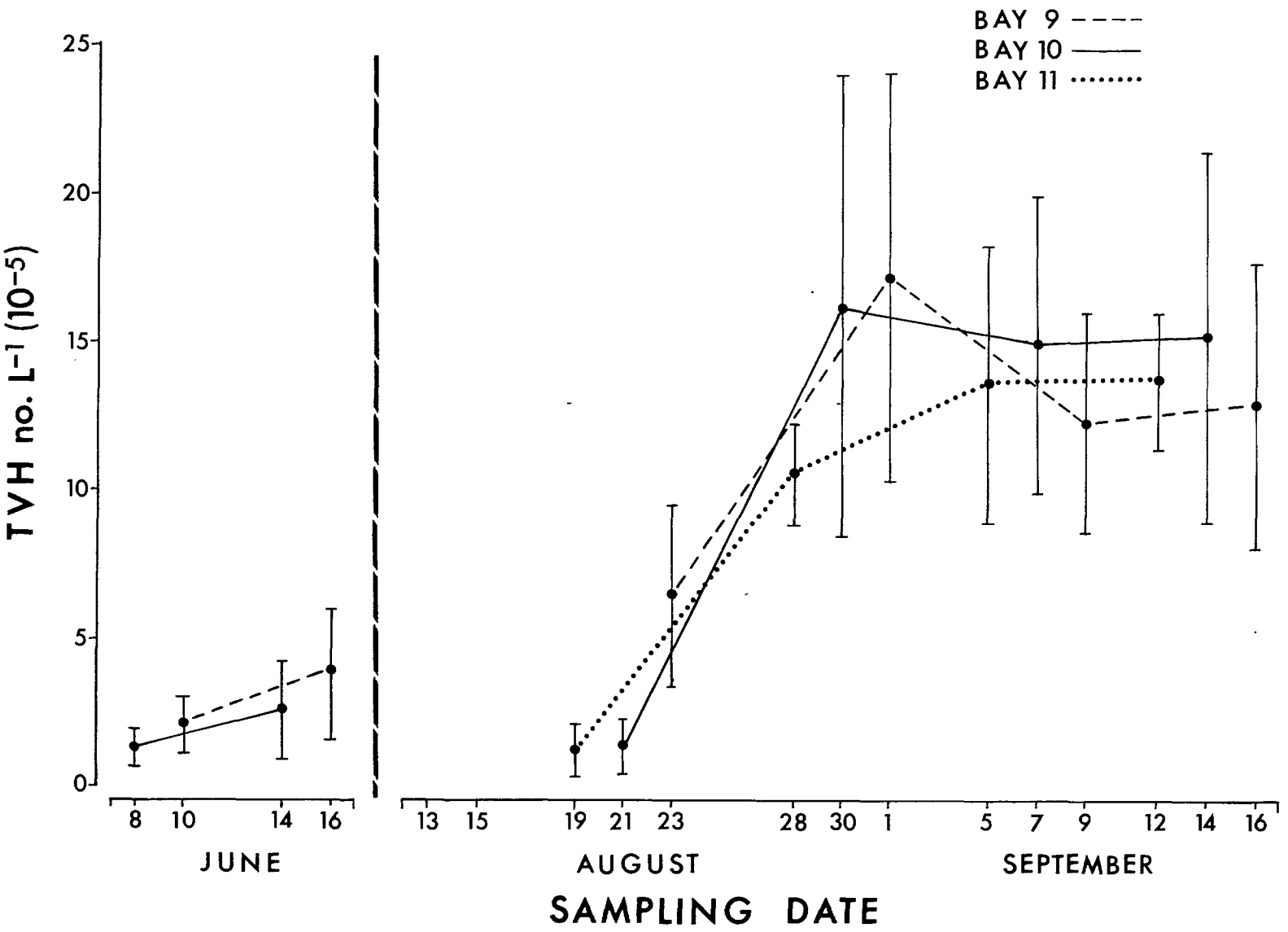


Figure 5. Total viable heterotrophs (TVH) determined by counts of colonies developed on a marine medium inoculated with water samples collected at Cape Hatt, 1980. Results are presented as means and standard deviations of six values from three depths at two stations in each bay.

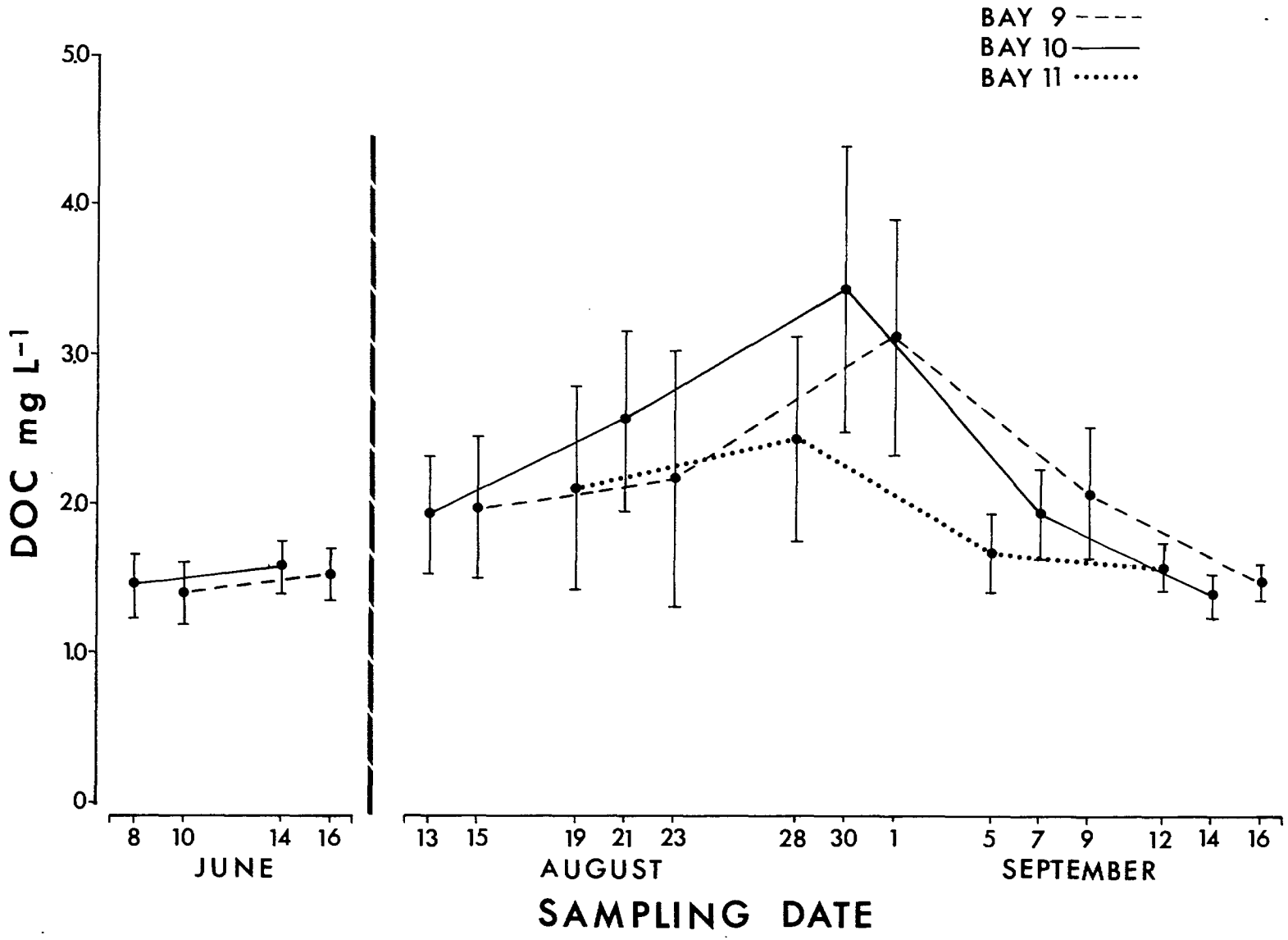


Figure 6. Concentrations of particulate organic carbon (DOC) in water samples collected at Cape Hatt, 1980. Results are presented as means and standard deviations of six values from three depths at two stations in each bay.

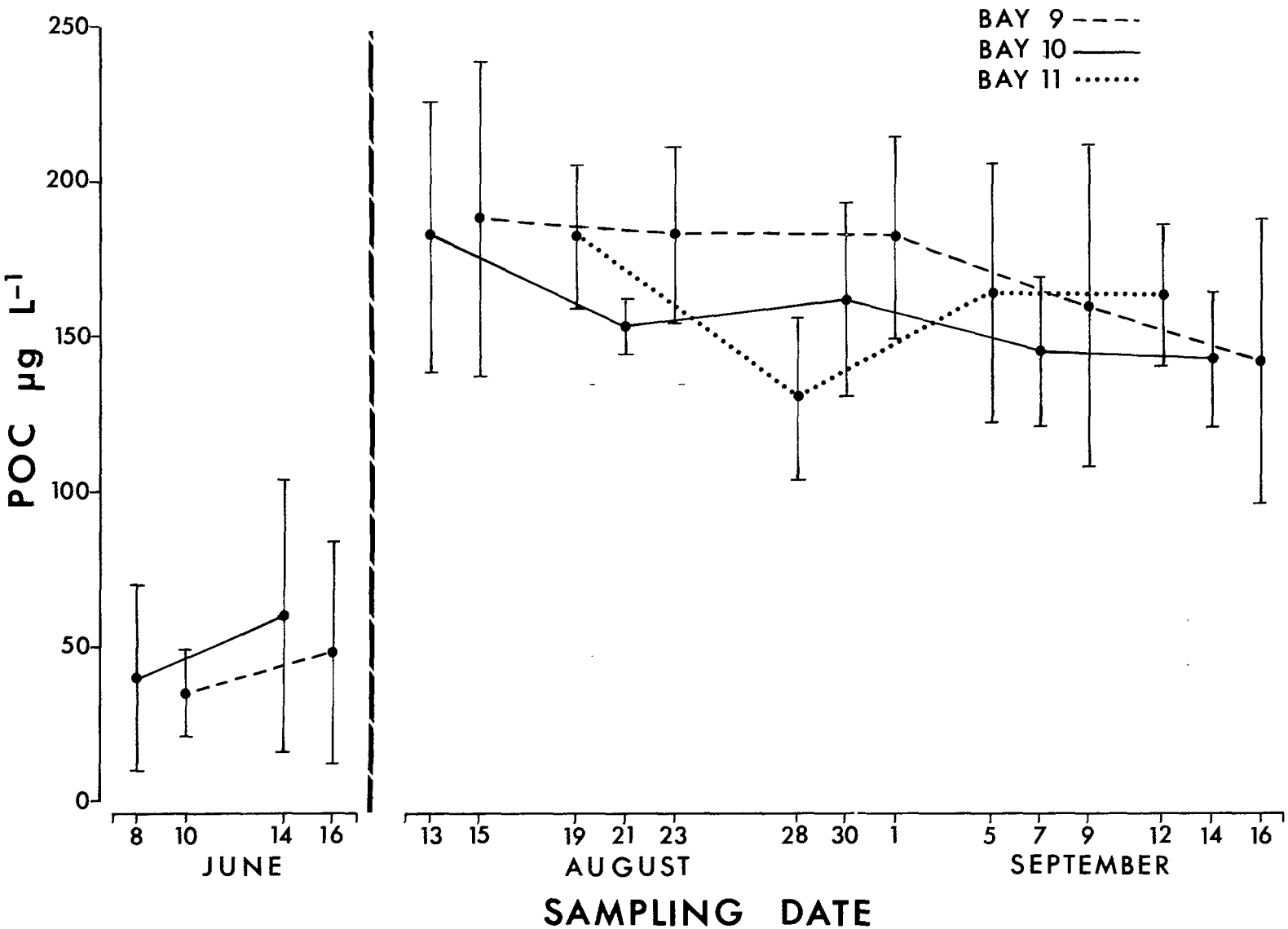


Figure 7. Concentrations of particulate organic carbon (POC) in water samples collected at Cape Hatt, 1980. Results are presented as means and standard deviations of six values from three depths at two stations in each bay.

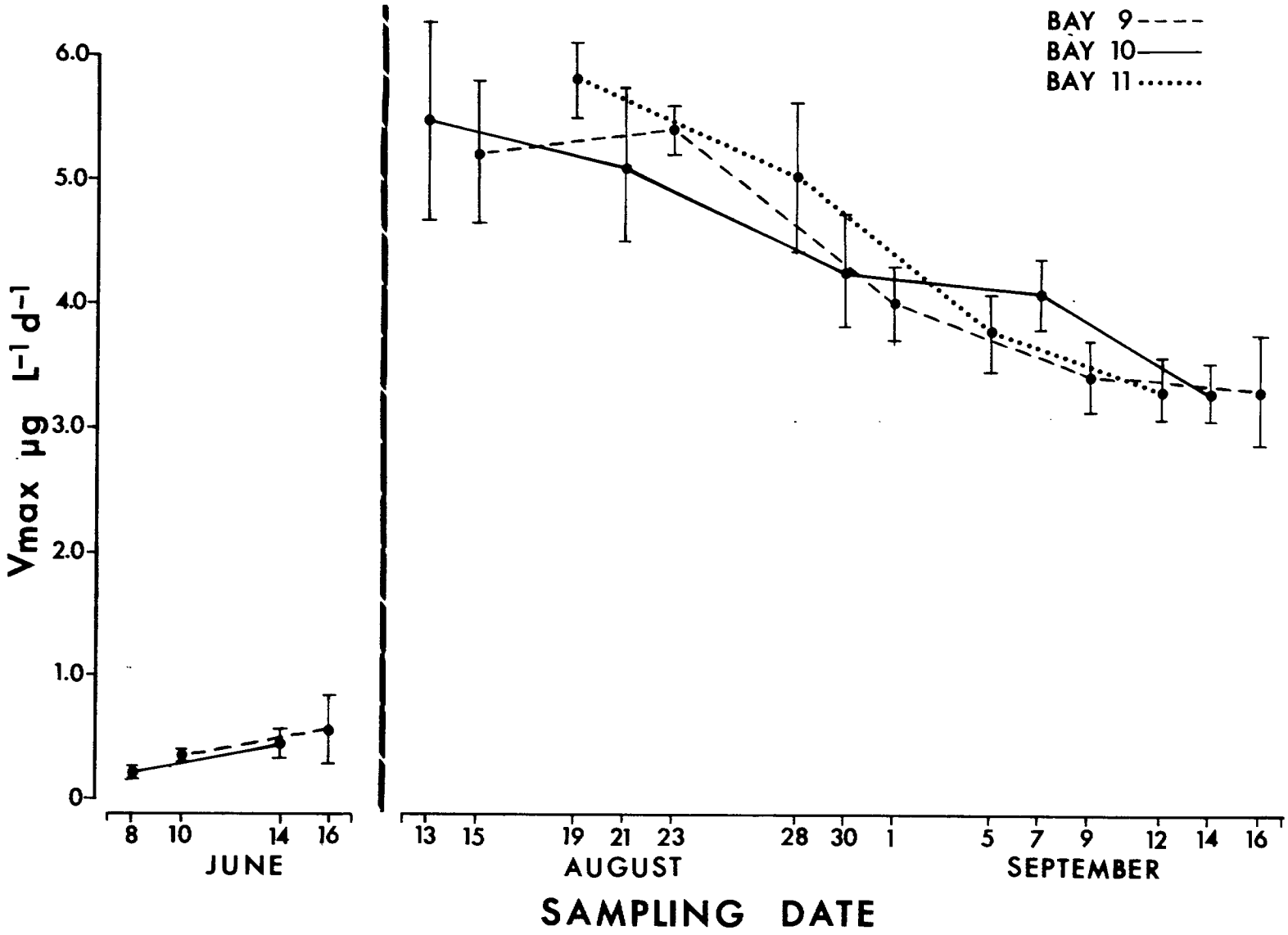


Figure 8. Maximum velocity (V_{max}) of glutamic acid uptake determined in water samples collected at Cape Hatt, 1980. Results are presented as means and standard deviations of six values from three depths at two stations in each bay.

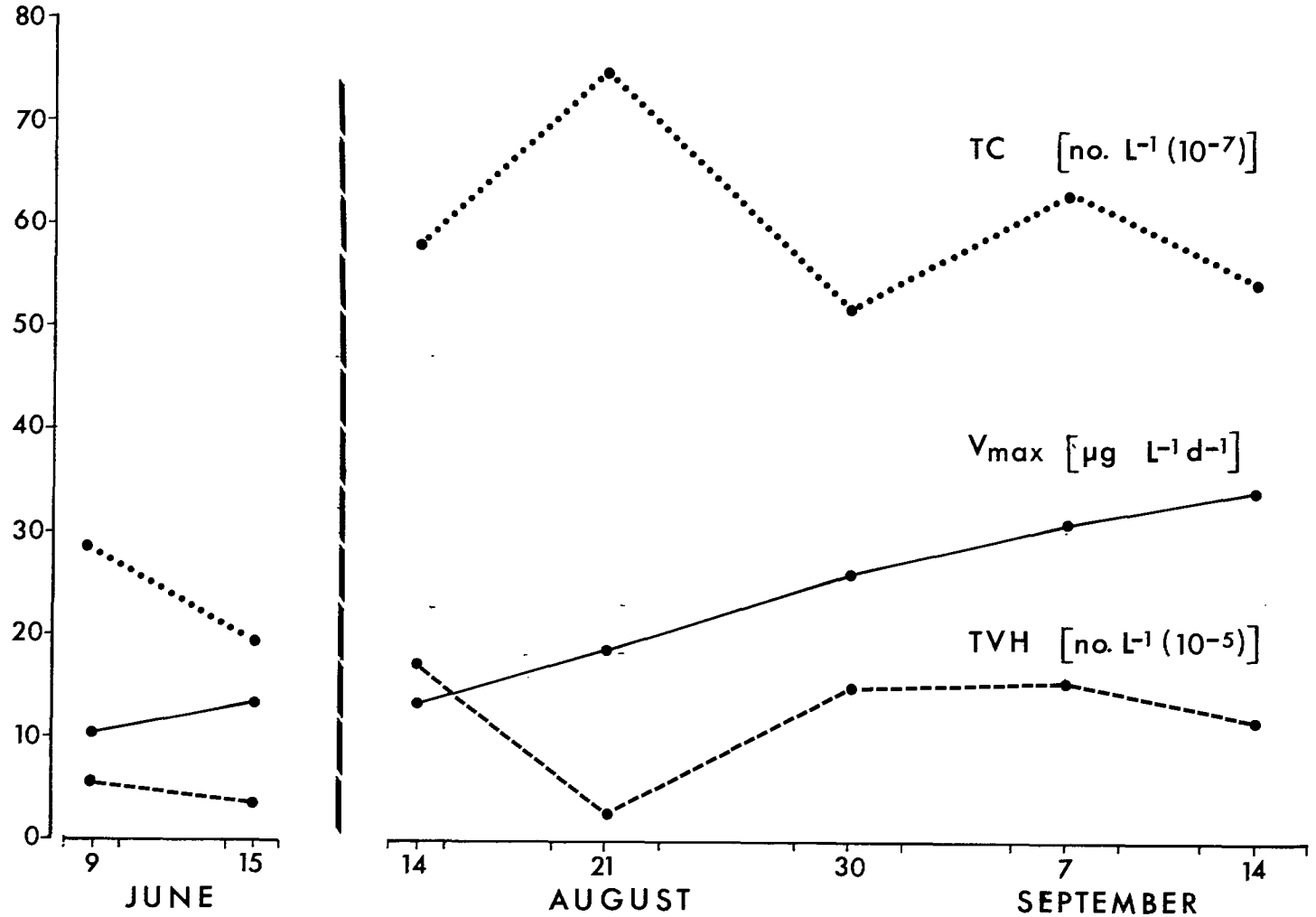


Figure 9. Means of values determined for total count (TC) of bacteria, maximum velocity (V_{max}) of glutamic acid uptake and total viable heterotrophs (TVH) in sediment samples. These means are of two stations for each of two or three bays that represented one sampling cycle (see Table 3). Units of volume (L) refer to a 0.1% by volume sediment-water suspension.

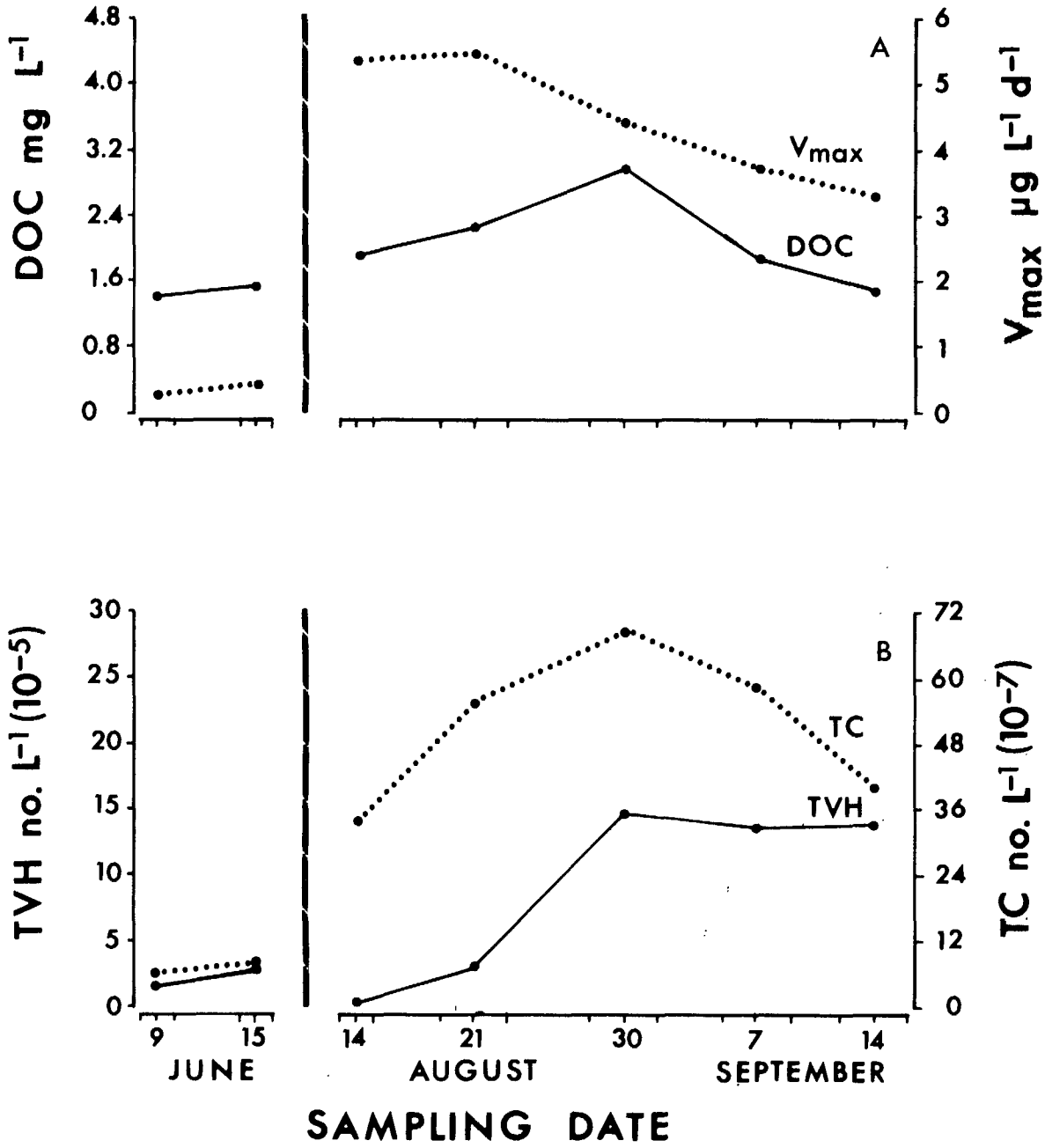


Figure 10 (A-D). Summary graphs of data obtained from three bays (9, 10 and 11) during each sampling cycle. Data are expressed as the mean of three depths from each of two stations in the three bays for a total of eighteen samples (see Table 5). Data for chlorophyll a, reactive nitrate and phosphate were obtained from Green (1981).

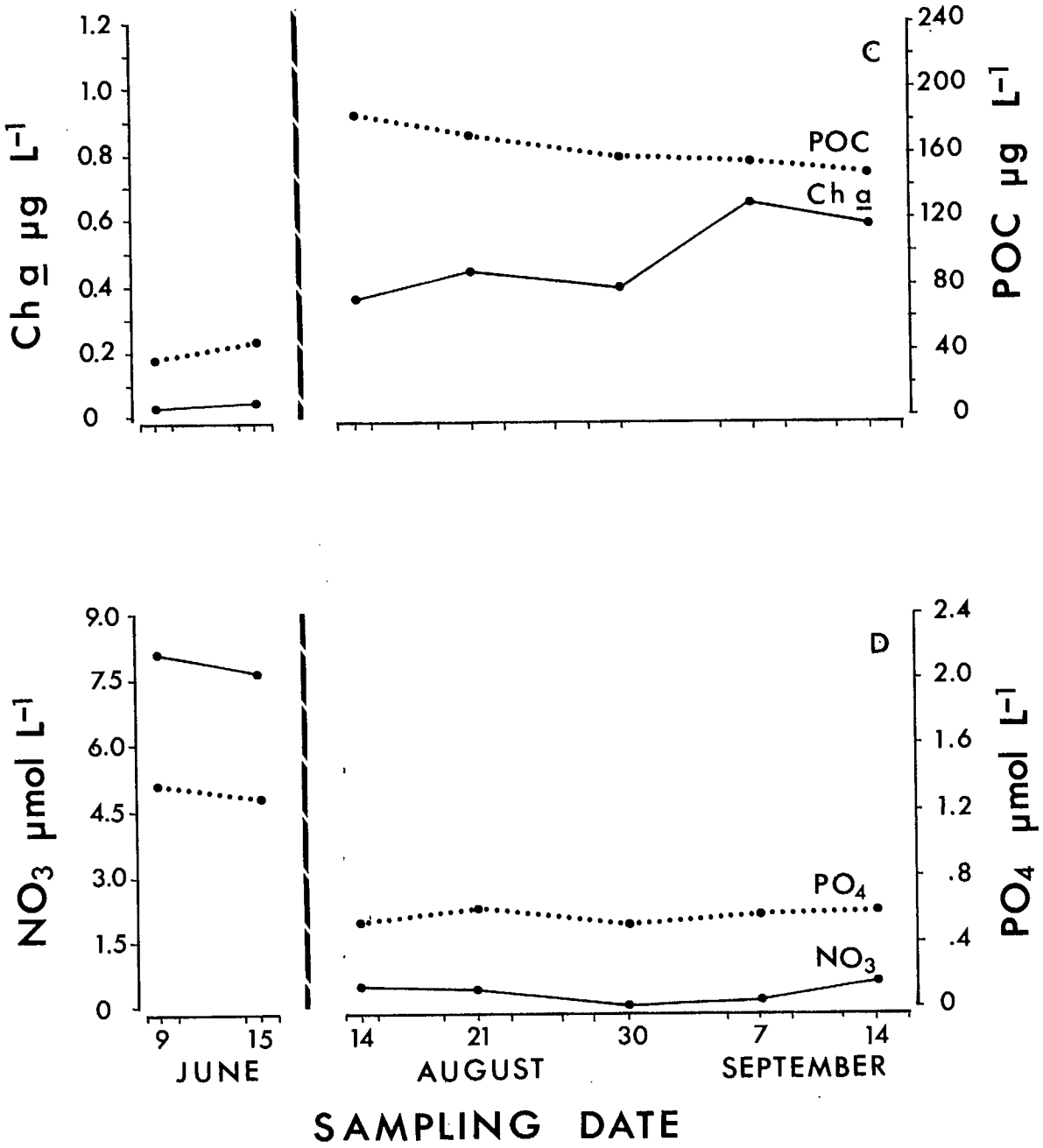


Figure 10 (Cont'd.)

8.0 Tables

Tables 1-9

Table 1. Station occupations at Cape Hatt 1980.

Date	Cycle	Bay	Stations	
6 June		13	1A	2A
8 June	1	10	3	4
10 June		9	5	6
12 June		13	1A	2A
14 June	2	10	3	4
16 June		9	5	6
11 Aug		13	1A	2A
13 Aug	3	10	3	4
15 Aug		9	5	6
19 Aug		11	1	2
21 Aug	4	10	3	4
23 Aug		9	5	6
28 Aug		11	1	2
30 Aug	5	10	3	4
1 Sept		9	5	6
5 Sept		11	1	2
7 Sept	6	10	3	4
9 Sept		9	5	6
12 Sept		11	1	2
14 Sept	7	10	3	4
16 Sept		9	5	6

Note: in other BIOS reports these station numbers may be prefixed by H (Hatt).

Table 2. Most probable number (MPN) determinations of oleoclastic cells and maximum disintegrations per minute (dpm) obtained from samples collected from 5 m at Cape Hatt during 1980 and incubated for 50 days with radiolabelled hexadecane and Lago Medio (L.M.) crude. Identical samples were incubated with or without nutrient supplementation. Some samples were also incubated with Norman Wells (N.W.) crude.

	Date	Stn. no.	L.M. crude hexadecane	L.M. crude hexadecane nutrients	N.W. crude hexadecane nutrients	Oleoclasts
			dpm	dpm	dpm	no. L^{-1}
Bay 9	06 10	5	0	0	--	0
		6	0	0	--	40
	06 16	5	0	0	--	0
		6	0	0	--	0
	08 15	5	0	0	--	0
		6	0	0	--	0
	08 23	5	0	0	--	0
		6	0	0	--	0
	09 01	5	320	6 349*	6 291	0
		6	301	0	--	0
	09 09	5	0	0	0	0
		6	0	401	--	0
	09 16	5	0	512	0	0
		6	7 152	19 825	--	0
Bay 10	06 08	3	0	0	--	0
		4	0	0	--	0
	06 14	3	0	0	--	0
		4	0	0	--	0
	08 13	3	0	163*	--	90
		4	0	0	--	40
	08 21	3	0	0	--	0
		4	0	0	--	0

Table 2. (cont'd)

	Date	Stn. no.	L.M. crude hexadecane	L.M. crude hexadecane nutrients	N.W. crude hexadecane nutrients	Oleoclasts
			dpm	dpm	dpm	no. L^{-1}
Bay 10	08 30	3	0	5 700	0	0
		4	0	1 108	--	0
	09 07	3	0	0	0	0
		4	0	0	--	0
	09 14	3	1 416	276	698	40
		4	1 809	1 394	--	0
Bay 11	08 19	1	0	0	--	0
		2	0	0	--	0
	08 28	1	0	0	12 590	0
		2	0	0	--	0
	09 05	1	0	14 902	5 602	0
		2	3 572	6 721	--	0
	09 12	1	0	0	0	40
		2	0	0	--	0

* Forty day incubation.

Table 3. Means of values determined for total count (TC) of bacteria, total viable heterotrophs (TVH), and maximum velocity (V_{max}) of glutamic acid uptake in sediment samples collected at Cape Hatt during 1980. Data are expressed as mean ± standard deviation of three depths from each of two stations in the three bays for a total of eighteen samples unless otherwise stated. Units of volume (L) refer to a 0.1% by volume sediment-water suspension.

Cycle	Date	TC	(n)*	TVH	(n)*	V_{max}	(n)*
		no. L^{-1} (10^{-7})		no. L^{-1} (10^{-5})		µg L^{-1} d^{-1}	
1	8-10 June	28.88±10.14	4	5.70± 2.17	4	10.79± 7.50	4
2	14-16 June	19.48±13.32	4	3.28± 2.72	4	13.44± 0.49	2
3	13-15 Aug	57.99±16.38	4	17.10± 0.0	1	13.35± 7.02	4
4	19-23 Aug	74.79±24.90	6	2.60± 2.91	5	18.70±15.11	6
5	28 Aug-1 Sept	52.06±11.75	6	15.18±10.12	6	26.85±16.17	6
6	5- 9 Sept	63.28±14.83	6	15.50± 9.54	6	30.80±10.82	6
7	12-16 Sept	54.78±18.94	6	11.90± 3.09	6	34.08± 9.77	6

* Number of samples.

Table 4. Disintegration per minute (dpm) obtained from wicks and filter membranes (FM) after *in situ* incubations in top and bottom compartments of BISIS units at Cape Hatt during 1980. Water collected at the same depth and treated in a similar fashion *in vitro* provided results for comparison only with top compartments. Sediment was collected from under the bottom compartments after incubation *in situ* to determine glutamic acid uptake by sediment bacteria (FM values). Results are expressed as means ± standard deviations of determinations from three units.

In situ uptake		13 August		6 September		16 September	
Compartment		Top	Bottom	Top	Bottom	Top	Bottom
Wick	(dpm)	25 362±1 289	35 721±3 476	18 921± 265	26 120± 3 899	9 759±371	27 212±2 767
FM	(dpm)	33 028± 447	5 516±3 051	39 976±1 604	46 111±27 088	25 657±192	14 167±4 801
W+FM	(dpm)	58 390±1 718	41 236±6 526	58 896±1 622	72 231±30 934	35 416±443	41 379±4 822
Respiration (%)*		43	87	32	36	28	66

In vitro uptake		13 August	6 September	16 September
Wick	(dpm)	24 491± 53	21 714± 774	8 262± 592
FM	(dpm)	31 394±201	36 776± 247	18 072±1 365
W+FM	(dpm)	55 885±254	58 490±1 021	26 334±1 956
Respiration (%)*		44	37	31

Sediment collection from under bottom compartment		13 August	6 September	16 September
FM	(dpm)	--	105 010±4 942	216 623±137 623

* % respiration = $\frac{\text{Wick}}{\text{W+FM}}$ X 100

Table 5. Summary table of data obtained in water samples from three bays (9, 10 and 11) during each sampling cycle. Data are expressed as the mean ± standard deviation of three depths from each of two stations in the three bays for a total of eighteen samples.

Cycle	Date	TVH	TC	V_{max}	NO_3^{-1} *	PO_4^{-3} *	DOC	POC	Ch a *
		no. L^{-1} (10^{-5})	no. L^{-1} (10^{-7})	µg L^{-1} d^{-1}	µmol L^{-1}	µmol L^{-1}	mg L^{-1}	µg L^{-1}	µg L^{-1}
1 †	8-10 June	1.73±0.92	6.32± 2.07	0.30±0.08	8.13±0.42	1.36±0.12	1.43±0.20	37.50±23.50	0.03±0.02
2 †	14-16 June	3.21±2.02	8.00± 2.64	0.50±0.22	7.65±0.44	1.28±0.05	1.55±0.17	54.17±40.71	0.05±0.03
3 †	13-15 Aug	0.43±0.19	33.48± 3.32	5.35±0.71	0.47±0.30	0.51±0.15	1.94±0.43	185.00±47.70	0.36±0.12
4	19-23 Aug	3.01±3.08	55.00±15.80	5.45±0.50	0.43±1.06	0.59±0.13	2.27±0.75	172.78±25.78	0.44±0.17
5	28 Aug-1 Sept	14.64±6.72	68.18±21.13	4.43±0.63	0.08±0.13	0.50±0.12	2.99±0.92	157.78±36.90	0.39±0.13
6	5- 9 Sept	13.57±4.63	59.05±15.87	3.76±0.40	0.36±0.68	0.59±0.15	1.89±0.37	155.88±41.59	0.65±0.57
7	12-16 Sept	13.88±4.85	40.37±18.05	3.30±0.32	0.59±0.68	0.61±0.03	1.49±0.16	148.89±33.65	0.58±0.09

† Bays 9 and 10 (12 samples)

* Data obtained from Green (1981)

Table 6. Comparison of measurements of V_{max} of glutamic acid uptake, chlorophyll a, reactive nitrate and particulate organic carbon (POC) from several arctic regions.

Location	Station	Date	Depth	V_{max}	Ch a	POC	Nitrate
			m	µg L^{-1} d^{-1}	µg L^{-1}	µg L^{-1}	µmol L^{-1}
Cape Hatt 72°30'N 79°50'W	Average of Stations 1 and 2 (Bay 11)	80 8 19	1	5.96	0.59*	160	0.50*
			5	5.81	0.73*	200	0.0 *
			10	5.66	0.42*	185	0.15*
			20	--	--	--	--
Lancaster Sound 73°49'N 80°11'W	4A	79 8 25	1	6.05	1.44	210	1.10
			5	5.24	1.60	250	1.10
			10	--	--	--	--
			20	1.69	0.70	40	5.80
Baffin Bay 72°37'N 74°56'W	16A	79 8 27	1	3.51	0.87	120	1.10
			5	4.56	1.38	260	0.20
			10	--	--	--	--
			20	10.45	4.73	320	0.30
Frobisher Bay 63°43'N 68°31'W	1	79 7 10	1	6.42	0.79	240	0.30
			5	5.16	6.37	640	0.0
			10	5.53	10.20	620	0.0
			20	4.59	10.77	330	1.73

* Data obtained from Green (1981)

Table 7. Determinations of total viable heterothrophs (TVH), total count (TC) of bacteria, maximum velocity (V_{max}) of glutamic acid uptake, dissolved organic carbon (DOC) and particulate organic carbon (POC) from water samples collected at Cape Hatt during June 1980.

Date	Bay	Station	Depth	TVH	TC	V_{max}	DOC	POC
			m	no. L^{-1} (10^{-5})	no. L^{-1} (10^{-7})	$\mu g\ L^{-1}\ d^{-1}$	mg L^{-1}	$\mu g\ L^{-1}$
06.06	13	1A	1	9.80	8.08	0.13	1.10	20.0
		1A	5	2.00	5.64	0.23	1.30	20.0
		1A	10	1.20	6.70	0.21	1.50	10.0
06.06	13	2A	1	0.90	7.83	0.23	2.20	10.0
		2A	5	1.00	6.01	0.21	1.60	10.0
		2A	10	0.90	9.82	0.22	1.60	20.0
06.08	10	3	1	2.40	4.99	0.19	1.80	80.0
		3	5	1.00	10.84	0.22	1.40	40.0
		3	10	1.00	10.38	0.18	1.50	80.0
06.08	10	4	1	0.70	6.29	0.27	1.50	20.0
		4	5	0.90	6.35	0.24	1.40	10.0
		4	10	2.00	5.63	0.27	1.10	10.0

Table 7 (Continued)

Date	Bay	Station	Depth	TVH	TC	V_{max}	DOC	POC
			m	no. L^{-1} (10^{-5})	no. L^{-1} (10^{-7})	$\mu g\ L^{-1}\ d^{-1}$	mg L^{-1}	$\mu g\ L^{-1}$
06.10	9	5	1	1.70	3.61	0.39	1.70	50.0
		5	5	1.30	5.28	0.32	1.30	10.0
		5	10	2.30	5.46	0.35	1.60	50.0
06.10	9	6	1	1.80	4.58	0.42	1.30	30.0
		6	5	1.40	6.28	0.37	1.10	40.0
		6	10	4.20	6.15	0.33	1.40	30.0
06.12	13	1A	1	11.70	8.62	0.29	1.70	60.0
		1A	5	0.80	6.50	0.28	1.80	30.0
		1A	10	1.50	9.95	0.27	1.50	30.0
06.12	13	2A	1	2.00	7.07	0.28	1.40	10.0
		2A	5	1.40	6.68	0.25	1.50	30.0
		2A	10	4.40	6.74	0.30	1.30	10.0
06.14	10	3	1	4.40	11.96	0.53	1.80	130.0
		3	5	1.10	9.73	0.37	1.50	50.0
		3	10	5.30	10.51	0.35	1.60	30.0
06.14	10	4	1	2.10	1.06	0.66	1.80	110.0
		4	5	1.00	8.26	0.36	1.40	20.0
		4	10	1.80	7.99	0.35	1.40	20.0

Table 7 (Continued)

Date	Bay	Station	Depth	TVH	TC	V_{max}	DOC	POC
			m	no. L^{-1} (10^{-5})	no. L^{-1} (10^{-7})	$\mu g\ L^{-1}\ d^{-1}$	mg L^{-1}	$\mu g\ L^{-1}$
06.16	9	5	1	7.60	9.42	0.86	1.60	100.0
		5	5	1.20	7.23	0.42	1.30	10.0
		5	10	4.60	8.47	0.39	1.60	20.0
06.16	9	6	1	2.90	8.87	1.04	1.80	70.0
		6	5	1.60	6.93	0.37	1.40	10.0
		6	10	4.90	5.61	0.35	1.40	80.0

Table 8. Determinations of total viable heterotrophs (TVH), total count (TC) of bacteria, maximum velocity (V_{max}) of glutamic acid uptake, dissolved organic carbon (DOC) and particulate organic carbon (POC) from water samples collected at Cape Hatt during August-September 1980.

Date	Bay	Station	Depth	TVH	TC	V_{max}	DOC	POC
			m	no. L^{-1} (10^{-5})	no. L^{-1} (10^{-7})	$\mu g\ L^{-1}\ d^{-1}$	mg L^{-1}	$\mu g\ L^{-1}$
08.11	13	1A	1	--	35.83	4.63	2.70	150.0
		1A	5	--	35.33	2.61	2.10	110.0
		1A	10	--	47.29	3.33	3.50	210.0
08.11	13	2A	1	9.00	44.17	5.17	2.90	100.0
		2A	5	3.00	25.78	3.68	1.80	130.0
		2A	10	5.40	31.61	5.20	1.90	240.0
08.13	10	3	1	--	34.22	6.16	2.00	140.0
		3	5	--	37.24	5.63	2.60	150.0
		3	10	--	39.04	4.62	1.90	260.0
08.13	10	4	1	--	30.40	6.75	1.70	190.0
		4	5	0.70	34.02	5.22	1.30	140.0
		4	10	--	31.91	4.53	2.00	210.0

Table 8 (Continued)

Date	Bay	Station	Depth	TVH	TC	V_{max}	DOC	POC
			m	no. L^{-1} (10^{-5})	no. L^{-1} (10^{-7})	µg L^{-1} d^{-1}	mg L^{-1}	µg L^{-1}
08.15	9	5	1	--	30.30	4.63	1.70	130.0
		5	5	0.30	32.31	5.44	1.90	190.0
		5	10	0.30	33.01	5.28	2.50	210.0
08.15	9	6	1	--	27.39	5.58	1.50	280.0
		6	5	--	33.42	6.01	1.50	130.0
		6	10	--	38.54	4.33	2.70	190.0
08.19	11	1	1	--	42.76	5.68	1.80	150.0
		1	5	1.00	44.37	5.51	1.70	190.0
		1	10	2.70	35.33	5.94	3.60	160.0
08.19	11	2	1	0.90	45.48	6.24	1.70	170.0
		2	5	0.30	30.70	6.10	2.00	210.0
		2	10	--	53.62	5.37	1.80	210.0
08.21	10	3	1	0.30	33.01	5.83	2.50	150.0
		3	5	0.90	63.37	5.48	1.60	160.0
		3	10	2.80	57.64	4.70	3.40	170.0
08.21	10	4	1	2.10	48.39	5.75	2.10	150.0
		4	5	0.30	54.72	4.85	2.60	150.0
		4	10	1.80	58.54	4.11	3.10	140.0

Table 8 (Continued)

Date	Bay	Station	Depth	TVH	TC	V_{max}	DOC	POC
			m	no. L^{-1} (10^{-5})	no. L^{-1} (10^{-7})	$\mu g\ L^{-1}\ d^{-1}$	mg L^{-1}	$\mu g\ L^{-1}$
08.23	9	5	1	2.80	54.42	5.70	1.70	170.0
		5	5	11.20	55.43	5.61	1.60	160.0
		5	10	4.20	81.76	5.48	1.90	150.0
08.23	9	6	1	8.60	72.71	5.13	4.00	180.0
		6	5	5.30	65.27	5.20	1.50	230.0
		6	10	--	92.51	5.33	2.30	210.0
08.28	11	1	1	12.70	88.19	4.56	3.30	140.0
		1	5	9.90	95.02	4.62	1.80	110.0
		1	10	10.70	96.88	4.48	2.30	100.0
08.28	11	2	1	8.60	96.78	6.18	2.40	130.0
		2	5	8.50	97.69	5.41	1.50	180.0
		2	10	12.80	102.71	4.90	3.30	120.0
08.30	10	3	1	30.20	65.22	3.62	4.50	190.0
		3	5	16.60	59.19	4.15	3.80	210.0
		3	10	13.90	52.66	4.37	2.20	170.0
08.30	10	4	1	4.90	66.83	5.08	3.40	140.0
		4	5	19.70	59.90	4.29	2.20	140.0
		4	10	12.00	47.64	4.08	4.50	120.0

Table 8 (Continued)

Date	Bay	Station	Depth	TVH	TC	V_{max}	DOC	POC
			m	no. L^{-1} (10^{-5})	no. L^{-1} (10^{-7})	$\mu g\ L^{-1}\ d^{-1}$	mg L^{-1}	$\mu g\ L^{-1}$
09.01	9	5	1	31.00	48.34	3.93	3.20	160.0
		5	5	16.10	42.01	4.29	2.40	240.0
		5	10	17.90	43.72	3.57	2.90	160.0
09.01	9	6	1	8.80	65.83	4.30	4.20	140.0
		6	5	13.20	49.25	4.27	4.00	190.0
		6	10	16.10	49.45	3.66	2.00	200.0
09.05	11	1	1	20.30	62.01	3.81	1.70	150.0
		1	5	12.40	50.75	3.48	1.40	170.0
		1	10	11.10	48.74	3.72	1.50	170.0
09.05	11	2	1	13.30	46.83	4.32	2.00	--
		2	5	18.10	82.91	3.90	2.00	100.0
		2	10	6.10	82.41	3.36	1.40	230.0
09.07	10	3	1	15.20	82.21	3.78	1.80	140.0
		3	5	20.10	84.92	3.88	1.60	120.0
		3	10	22.50	80.50	4.13	2.40	160.0
09.07	10	4	1	9.70	51.66	3.83	2.10	120.0
		4	5	8.70	50.65	4.25	1.70	140.0
		4	10	13.10	44.52	4.60	2.10	190.0

Table 8 (Continued)

Date	Bay	Station	Depth	TVH	TC	V_{max}	DOC	POC
			m	no. L^{-1} (10^{-5})	no. L^{-1} (10^{-7})	$\mu g\ L^{-1}\ d^{-1}$	$mg\ L^{-1}$	$\mu g\ L^{-1}$
09.09	9	5	1	12.30	47.94	3.53	1.80	120.0
		5	5	14.90	38.69	3.60	1.50	140.0
		5	10	9.60	39.14	3.78	2.50	210.0
09.09	9	6	1	16.80	60.15	2.95	1.90	130.0
		6	5	14.40	61.66	3.14	2.80	110.0
		6	10	5.70	47.18	3.54	1.90	250.0
09.12	11	1	1	13.80	56.53	3.58	1.50	150.0
		1	5	9.40	43.67	2.97	1.60	170.0
		1	10	14.90	66.78	3.34	1.60	200.0
09.12	11	2	1	12.10	83.26	3.61	1.90	130.0
		2	5	16.30	65.68	3.03	1.40	180.0
		2	10	15.30	46.18	3.36	1.50	150.0
09.14	10	3	1	23.80	41.56	3.55	1.20	120.0
		3	5	13.80	41.76	2.94	1.60	130.0
		3	10	19.90	42.36	3.24	1.30	140.0
09.14	10	4	1	5.60	42.56	3.20	1.40	160.0
		4	5	9.40	26.28	3.63	1.40	120.0
		4	10	18.60	39.85	3.20	1.50	180.0

Table 8 (Continued)

Date	Bay	Station	Depth	TVH	TC	V_{max}	DOC	POC
			m	no. L^{-1} (10^{-5})	no. L^{-1} (10^{-7})	$\mu g\ L^{-1}\ d^{-1}$	$mg\ L^{-1}$	$\mu g\ L^{-1}$
09.16	9	5	1	13.40	26.68	3.30	1.50	120.0
		5	5	14.40	19.04	2.82	1.70	80.0
		5	10	19.70	22.16	2.81	1.50	160.0
09.16	9	6	1	4.40	16.26	4.12	1.50	100.0
		6	5	9.50	25.80	3.30	1.30	210.0
		6	10	15.60	20.28	3.42	1.40	180.0

Table 9. Determinations of maximum velocity (V_{max}) of glutamic acid uptake, total count (TC) of bacteria, and total viable heterotrophs (TVH) from sediment samples collected at Cape Hatt during 1980.

Date	Station	V_{max}	TC	TVH
		$\mu g\ L^{-1}\ d^{-1}$	no. L^{-1} (10^{-7})	no. L^{-1} (10^{-5})
06 08	3	3.57	24.49	2.10
06 08	4	23.21	46.36	5.90
06 10	5	6.62	21.80	7.60
06 10	6	9.74	22.88	7.20
06 14	3	--	4.87	0.10
06 14	4	13.93	31.37	5.50
06 16	5	12.95	34.09	6.40
06 16	6	--	7.60	1.10
08 13	3	22.24	60.20	--
08 13	4	14.08	58.49	--
08 15	5	14.51	79.70	17.10
08 15	6	2.58	33.57	--
08 19	1	18.32	47.74	1.00
08 19	2	16.82	66.13	--
08 21	3	20.75	74.87	1.50
08 21	4	48.91	125.73	8.40
08 23	5	4.10	77.18	1.30
08 23	6	3.32	57.08	0.80
08 28	1	11.24	70.05	9.50
08 28	2	17.31	48.34	5.70
08 30	3	55.75	63.62	29.30
08 30	4	37.08	42.61	8.80
09 01	5	9.97	35.68	8.30
09 01	6	29.76	52.06	29.50

Table 9. (cont'd)

Date	Station	V_{max}	TC	TVH
		$\mu g\ L^{-1}\ d^{-1}$	no. L^{-1} (10^{-7})	no. L^{-1} (10^{-5})
09 05	1	35.76	74.37	9.40
09 05	2	52.13	51.76	2.10
09 07	3	18.87	57.69	23.40
09 07	4	24.58	42.01	7.30
09 09	5	28.90	87.13	26.70
09 09	6	24.58	66.73	24.10
09 12	1	24.43	67.03	9.60
09 12	2	26.47	63.37	7.30
09 14	3	33.72	65.58	15.80
09 14	4	44.09	75.53	15.50
09 16	5	25.78	26.54	12.70
09 16	6	49.97	30.60	10.50