MICROBIAL BIOMASSES AND HETEROTROPHIC ACTIVITIES IN SURFACE SEDIMENTS AND OVERLYING WATERS OF SEVERAL COASTAL AREAS OF BRITISH COLUMBIA

by

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Microbial Biomasses and Heterotrophic Activities in Surface and Overlying Waters of Several Coastal Areas of British Columbia

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ABSTRACT

Several coastal waters and marine sediments off British Columbia were analyzed and compared for microbial biomasses (colony forming units, adenosine - 5' - triphosphate levels and numbers of active bacteria as indicated by microautoradiography), glucose and alanine heterotrophic activities and dissolved (DOC) and particulate organic carbon (POC). DOC sediment values were approximately ten fold greater than those of overlying water. Biomass, heterotrophic potential and turnover time values were always greater in the sediments, whereas $K_t + S_n$ (an estimate of transport constant plus the natural concentration of substrate) values were variable. Heterotrophic potentials per unit biomass were greater in the overlying waters than in sediments in most areas. Thus, per unit biomass the sediment heterotrophic bacteria are not as metabolically active as those in the overlying water.

TO MY DEAR WIFE AND

TO MY PEOPLE

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Microbial populations of marine sediments are important in decomposition of organic matter, in several geochemical transformations, in nutrient regeneration, and as food sources for benthic fauna (Johnson and Calder, 1973; Litchfield, 1973; Hodson et al., 1976). Of special importance is the boundary area between water and sediment since this region is a site of intensive microbial (including bacterial) activity (Harrison et al., 1971). A great variety of bacteria can be isolated in high concentrations (Zobell 1938, 1946; Zobell and Anderson, 1936; Zobell and Feltham, 1942; Harrison et al., 1971). However, there have been few attempts to determine the in situ bacterial activity of this particular environment (Meyer-Reil, 1978).

The important role of sediments in contributing nutrients to the water column has been stressed by various authors (Pomeroy et al., 1972; Bodungen et al., 1975; Smatacek et al., 1976). Previous investigators have concluded that one important function of sediment microrganisms is their role in mineralizing organic matter (Harrison et al., 1971)."Benthic conversions of bacteria may at times be the principal source of new organic material in a water column" (Seki, 1968; Seki et al., 1968). That production is represented by a reutilization of stored energy through heterotrophic and chemosynthetic processes (Seki et al., 1968). "In this sense it must be classed as secondary production, although the material produced serves as a primary food source , when considered from the point of view of trophic relations" (Seki et al., 1968).

Heterotrophic bacteria exhibit three functions in an aquatic ecosystem (Hoppe, 1976): 2.

"1. They are consumers of dissolved organic matter (DOM) in the environment, resulting in "self-purification" of photosynthetic and allochthonous compounds;

2. They contribute to the recycling of inorganic substrates for the primary producers;

3. They are also producers in that they are able to convert dissolved organic substrates into particulate matter, and thus make them utilizable for the primary links in the food chain."

The DOM represents an intermediate carbon pool between detritus and bacteria (Hall et al., 1972). Therefore, a measure of the dynamics of its utilization should give an indirect estimate of the microbial heterotrophic production as well as detrital decomposition (Jannasch, 1958; Hall et al., 1972). Since there are many complex organic molecules present at low concentration in waters and sediments, it is often very difficult to measure the growth and activity response of microorganisms to specific organic solutes. There is at present no assay to determine their net utilization rates. The best available technique to study solute utilization is the heterotrophic potential technique described originally by Parsons and Strickland (1962), where they studied the incorporation of ^{14}C-labelled substrates into marine planktonic organisms and discovered that their data followed Michaelis-Menten enzyme kinetics. This technique has been adopted by many investigators as a standard technique to assay the heterotrophic activity by microorganisms in the aquatic environment (Wright and Hobbie, 1965; Vaccaro and Jannasch, 1966; Wood, 1970; Harrison et al., 1971; Hall et al., 1972; Azam and

Holm-Hansen, 1973; Albright and Wentworth, 1973; Dietz et al., 1976; Meyer-Reil, 1978).

Much previous research has involved heterotrophic bacterial activity of waters rather than sediments. However, several workers (Wood, 1970; Harrison et al., 1971; Hall et al., 1972; Meyer-Reil, 1978) have used the heterotrophic potential technique to study microbial activity in sediments. Wood (1970) demonstrated that this technique functioned using estuarine sediments. Harrison et al (1971), described a method for measuring mineralization in sediment samples which were obtained from Upper Klamath Lake, Oregon. Hall et al. (1972), studied Marion Lake, British Columbia, to determine the importance of bacteria in the benthic community and factors which affect assimilation of organic solutes. Meyer-Riel (1978) measured uptake and respiration of bacteria in sediment cores taken from sandy, wavewashed beaches of the Baltic Sea.

The present work compares the heterotrophic activities of microbial populations in sediments and overlying water at several sites off the British Columbia coast. Comparisons were made on the basis of total glucose and alanine heterotrophic activity as well as activity per viable bacterium as indicated by colony forming units, by active bacterial numbers indicated by microautoradiography and by ATP concentration as an indication of biomass, to determine if bacterioplankton are as metabolically active as sediment bacteria.

MATERIAL AND METHODS

Sample Collection:

Samples of sediments from the intertidal region of Sturgeon Bank , at the West side of Iona Island which is located at $49^{o}13'30"N$, $123^{o}13'W$ (fig. 1), were collected using a sample collector situated permanently in that location. This sediment collector consisted of an iron bottom plate (o.50 x 40 x 60 cm) with six Petri plates (15 mm standard) secured to the base. Due to wave action sediments were continuously deposited within these plates. Samples of sediment from deeper waters at various depths in Georgia Strait and contiguous inlets (see locations in fig. 1) were obtained by using a Phleger corer. The upper 1 cm. of sediment was used for experimental purposes.

Water samples from the intertidal region at Iona Island were obtained by holding a sterile, stoppered 1 l flask about 10 cm from the sediment surface whereupon it was opened and allowed to fill. The stopper was then replaced and the flask was removed. Water samples from other locations were taken using a Van Dorn sampler. Temperatures and salinities were determined at the time of sampling using a field thermometer and a Y S I Model 33S-C-T Meter (Yellow Spring Instrument Co. Yellow Spring, Ohio), respectively. Water and sediment samples were processed within 30 min. of removal.

Determination of heterotrophic activities:

Heterotrophic activities for overlying waters were estimated using the technique developed by Dietz et al., (1976). Briefly this is: an aliquot of sample water was aspirated into a disposable plastic syringe (Plastipak, 10 ml). This was immediately followed

FIGURE I.

Chart of Southwestern British Columbia waters. Sampling stations are noted as:

1..... Iona Island;

2..... Port Moody;

3..... Indian Arm;

4, 5, 6, 7..... Georgia Strait;

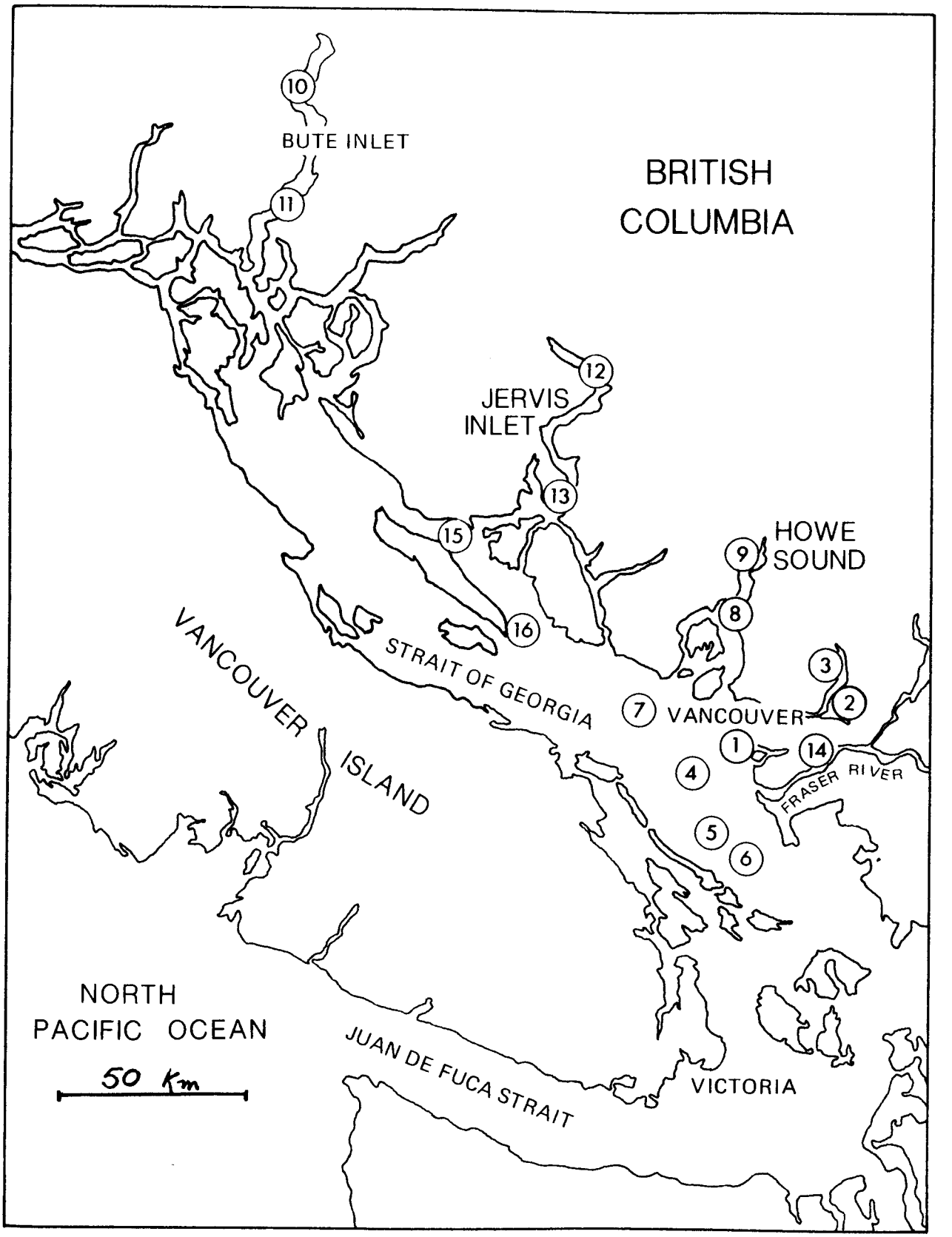
8, 9..... Howe Sound;

10, 11..... Bute Inlet;

14..... Fraser River

15..... Vicinity Montgomery Banks;

16..... Merry 2- Ballenas.


10
BUTE INLET
11
BRITISH
COLUMBIA
12
JERVIS
INLET
13
15
HOWE
SOUND
9
8
16
VANCOUVER
ISLAND
STRAIT OF GEORGIA
3
2
7
VANCOUVER
1
14
4
FRASER RIVER
5
6
NORTH
PACIFIC OCEAN
50 Km
JUAN DE FUCA STRAIT
VICTORIA

by the addition of a radioactively labelled substrate through the orifice of the syringe using a microlitre pipette.

Duplicate and control syringes were prepared for each experiment. Water samples were incubated at ambient water temperatures. After incubation, the samples were filtered through previously wetted Millipore filters (0.22 um. pore size, 47 mm. diameter) and rinsed with 20 ml. of isotonic solution cooled to $5^{o}C$. After filtration, the filters were placed in scintillation vials containing 15 ml. of Beckman Filter-Solv.(R) Once the filters were partially dissolved and clarified (app. 24 h) the radioactivities were determined using a Beckman LS-250 liquid scintillation spectrometer (Beckman Instruments Inc., Fullerton, California). Counts per minute (cpm) were corrected for quench by the external standard method, for machine efficiency and half life decay, and reported as desintegration per minute (dpm).

Sediments for heterotrophic activities were first diluted 10:1 with sterile artificial seawater (Rila Marine Products, Teaneck, N.J.), and then treated as described above. Incubated samples were filtered through wetted 0.4 um. pore size, 47 mm. diameter, Millipore filters (Type HA).

Tritiated glucose (D - 6 - ^{3}H glucose, specific activity 10 Ci/m Mole, Amersham/Searle Corp.) was used, as well as tritiated alanine (L- 2,3 - ^{3}H) specific activity 41 Ci/m Mole and 36 Ci/m Mole, Amersham/ Searle Corp.). The tritiated compounds were diluted in carbon free water, prepared by the method of Strickland and Parsons (1972).

Care was taken to ensure that metabolite utilization rates of

both sediments and waters were linear with time.

The uptake response that follows the Michaelis-Menten equation is transformed into a linear relationship by the application of a modified Lineweaver-Burke equation as derived by Wright and Hobbie (1965). This equation is

$$T/f = \frac{(K_t + S_n)}{V_{max}} + \frac{A}{V_{max}}$$

where T is incubation time (in hours), f is the fraction of available substrate utilized, K_t is an uptake constant, V_{max} is the maximal velocity of utilization, S_n is the natural substrate concentration and A is the concentration of added substrate. If uptake is measured at several concentrations of A, each of which generates a different T/f, and T/f is then plotted against A, a straigt line should result. The intercept of this curve with the abscissa yields a value of $-(K_t + S_n)$ whereas $1/V_{max}$ is its slope. Turnover time is calculated by $(K_t + S_n)/V_{max}$.

Net substrate uptake by bacteria of the sediments is rapid, therefore a very short time of incubation was chosen (1o min). The time of incubation for water samples was 60 min. The uptake curves obtained were in agreement with the requirements of measuring uptake using the heterotrophic potential technique:

a) linearity of response over time;

b) absence of substrate exhaustion;

c) minimal changes of substrate concentration over the incubation period (Meyer-Reil, 1978).

Determination of naturally occurring nutrients:

Dissolved organic carbon (DOC) was determined using a

Beckman IR analyzer (Beckman Instruments, Fullerton, California) according to the technique described by Strickland and Parsons (1972). Particulate organic carbon (POC) was assayed using a Beckman CHN analyzer (Beckman Instruments, Fullerton, California).

Determination of microbial populations:

Numbers of heterotrophic marine bacteria of both sediment and water were determined by spreading the samples on Marine Agar 2216 (DIFCO), and incubating them at 15^{o}C for 14d.

Adenodine 5' - triphosphate (ATP) from water was extracted and analyzed according to the technique described by Holm-Hansen and Booth (1966). The technique developed by Bancroft et al., (1976) was used for extracting and analyzing sediment ATP levels. The recovery of ATP, estimated by the internal standard method, fluctuated between 64.0 and 81.5%.

Numbers of actively metabolizing bacteria of both sediments and overlying waters were determined following the technique of Hoppe (1976): 1 ml of water or sediment (previously diluted 1:10 as described above) was aspirated into a 10 ml disposable plastic syringe. The material in one of these syringes was immediately fixed with 2% glutaraldehyde (control) to quantitatively determine non-specific sorption. This was followed by the addition of the selected radiotracer (D - 6 - ^{3}H glucose, specific activity 10 Ci/m Mole, Amersham/Searle Corporation) to yield a final concentration of 1.8 x 10^{-6} mg/l. After 3h incubation at the in situ temperature, the contents of the remaining syringes were fixed with 2% glutaraldehyde and the volume brought to 10 ml with sterile seawater containing 10^{-6} M glucose. (This reduces adsorption and improves distribution of the bacteria on the filter,

(Hoppe, 1976). The samples were filtered through wetted Nucleopore filters(R) (25 mm diameter, 0.2 um pore size), at vacuum head of 150 mm Hg. After air drying, the filters were fixed to gummed microscopic slides (Scotch(R) double sticky tape), and coated with KODAK NTB-2 emulsion. After drying, the slides were stored at 5°C for 10 d in black plastic boxes. The autoradiograms were developed for 5 min. in Kodak D-19 developer, and fixed with Kodak F-5 for 5 min. followed by a 30 min. rinse with tap water (Baserga and Malamud, 1969). Spots were counted using a Zeiss phase contrast microscope (Model Standard WL) at 1250 x magnification. The numbers of actively metabolizing bacteria (NAB per ml) were calculated following Hoppe (1976).

RESULTS AND DISCUSSION

Data for numbers of colony forming units (CFU) are presented in Table I. Figure 2 illustrates the ratio of CFU values of overlying water to sediment (P:B) versus sample index. The sample index refers to location and date of sampling as outlined in Table III. Bacterial populations at Iona Island, as indicated by CFU, were always greater in the sediment than in the water, in some cases by as much as three orders of magnitude. The population means between the overlying water and the benthos at Iona Island differed by two orders of magnitude. The highest value for CFU in overlying water was 1.1×10^6 and it was found in early April; the lowest value was 1.8×10^4 in late May, averaging 3.2×10^5 cells per ml during a year cycle. The highest CFU value in sediments was also found in early April and it was 1.4×10^9 cells per ml; the lowest CFU value was found in November with 2.9×10^6 cells per ml, averaging 2.2×10^8 cells per ml during a year's cycle. Numbers of CFU for other British Columbia coastal waters were also always greater in sediments than in water, in some cases by as much as three orders of magnitude (Table I, figure 2). The values in water ranged from 1.0×10^2 cells per ml (sample index 21) to 8.2×10^3 cells per ml (sample index 18), averaging 1.9×10^3 cells per ml. The values for sediments averaged 7.7×10^5 cells per ml (range 1.2×10^3 - 6.3×10^6).

The number of bacteria (represented by CFU) in marine sediments is large in comparison with the number found in overlying water as well as in the water column. Drew (1912) reported 1.6×10^8 bacteria per ml in sediment and 1.6×10^2 per ml in water at

TABLE I.

MICROBIAL BIOMASSES AND GLUCOSE HETEROTROPHIC ACTIVITIES VALUES
FOR PLANKTON (P) AND SEDIMENT (B) AT VARIOUS LOCATIONS OF COASTAL BRITISH COLUMBIA

IONA ISLAND

Sampl Indx.	Sample Date		Temp. °C	$K_t + S_n$ mgl^{-1}	Vmax $mgl^{-1}h^{-1}$	Turnover Time, h	CFU/ml	ATP mg/l	NAB/ml	DOC mgl^{-1}	POC mgl^{-1}	Vmax/CFU mgh^{-1}
1	5.I.77	P	3	1.7	1.3×10^{-1}	12.2	5.8×10^{4}	1.6×10^{-5}	4.7×10^{6}	3.7	2.8	2.3×10^{-9}
		B	2.3	6.7	6.5	1.0	3.6×10^{8}	1.7×10^{-1}	2.0×10^{7}	25.5	2.1	1.8×10^{-11}
2	25.I.77	P	4.5	7.5	5.8×10^{-1}	12.8	6.8×10^{4}	4×10^{-5}	6.2×10^{6}	2.4	4.8	8.5×10^{-9}
		B	4.0	8.0	11.5	0.6	1.2×10^{7}	1.7×10^{-1}	1.2×10^{7}	36.0	3.85	9.0×10^{-10}
3	9.II.77	P	3.8	7.8	7.4×10^{-1}	10.5	1.0×10^{5}	1.65×10^{-5}	9.2×10^{6}	3.9	N.A.	7.0×10^{-9}
		B	3.4	11.5	11.9	0.9	6.4×10^{8}	4.4×10^{-1}	1.1×10^{8}	55.0	71.3	1.8×10^{-11}
4	9.III.77	P	4.5	3.0	3.3×10^{-1}	8.8	5.7×10^{5}	6.0×10^{-5}	4.6×10^{6}	2.9	1.8	5.9×10^{-10}
		B	3.8	4.5	3.1	1.4	5.0×10^{8}	1.1×10^{-1}	5.2×10^{8}	23.0	6.8	6.2×10^{-12}
5	5.IV.77	P	23	7.1	2.2×10^{-1}	32.0	1.0×10^{6}	3.9×10^{-5}	6.1×10^{6}	2.6	3.1	2.0×10^{-10}
		B	22	3.5	1.1	1.9	1.4×10^{9}	1.6×10^{-1}	5.3×10^{7}	25.0	15.9	1.2×0^{-12}
6	31.V.77	P	14	9×10^{-1}	1.5×10^{-2}	12.0	1.8×10^{4}	1.1×10^{-3}	1.7×10^{5}	4.0	3.1	4.1×10^{-9}
		B	13.5	6.5	36.1	0.1	5.0×10^{6}	4.1×10^{-1}	6.0×10^{7}	35.0	8.6	7.2×10^{-9}
7	22.VI.77	P	26.5	24.7	3.0×10^{-1}	80	1.6×10^{5}	3.9×10^{-3}	3.7×10^{6}	3.2	5.5	1.9×10^{-9}
		B	26.0	18	37.5	0.4	1.4×10^{7}	2.47	7.3×10^{8}	36.0	14.5	2.6×10^{-9}
8	14.VII.77	P	28	1.2	1.2×10^{-1}	10.0	39×10^{5}	9.2×10^{-4}	3.7×10^{6}	3.1	5.1	3.0×10^{-10}
		B	27	1.0	4.0	0.2	1.9×10^{7}	1.3×10^{-1}	5.2×10^{8}	62.1	8.4	2.1×10^{-11}
9	3.VIII.77	P	19.5	6.7	8.1×10^{-1}	8.2	6.4×10^{5}	9.0×10^{-4}	1.8×10^{6}	4.2	N.A.	1.2×10^{-9}
		B	19.5	2.3×10^{-1}	7.6×10^{-1}	0.3	1.2×10^{7}	3.1×10^{-2}	7.9×10^{7}	39	3.1	6.3×10^{-11}

TABLE I.. Cont'd. IONA ISLAND.

Smpl. Indx.	Sample Date		Temp. ^{o}C	$K_t + S_n$ mgl^{-1}	Vmax $mgl^{-1}h^{-1}$	Turnover Time h	CFU/ml	ATP mg/l	NAB/ml	DOC mgl^{-1}	POC mgl^{-1}	Vmax/CFU mgh^{-1}
10.	7.IX.77	P	14	1.0	1.2×10^{-2}	81	7.5×10^{4}	5.2×10^{-4}	8.9×10^{5}	3.4	0.4	1.6×10^{-10}
		B	14	8.0×10^{-1}	11	0.7	2.9×10^{6}	3.4×10^{-2}	6.8×10	51.5	8.1	3.9×10^{-10}
11.	5.X.77	P	9.5	11.0	2.4×10^{-1}	45	3.6×10^{5}	5.7×10^{-4}	9.6×10^{5}	3.2	4.1	6.7×10^{-10}
		B	9.8	1.4	2.8	0.5	2.9×10^{7}	6.0×10^{-2}	6.1×10^{7}	59	8.0	9.6×10^{-11}
12.	2.XI.77	P	7.0	1.6	2.6×10^{-2}	61.0	2.1×10^{5}	5.0×10^{-4}	2.5×10^{5}	3.1	2.6	1.2×10^{-10}
		B	7.5	8.5×10^{-1}	1.88	0.4	3.2×10^{7}	1.7×10^{-1}	8.5×10^{7}	29.0	6.14	5.8×10^{-11}
13.	7.XII.77	P	5.5	1.2	2.4×10^{-2}	50.0	4.8×10^{5}	1.2×10^{-4}	9.8×10^{4}	1.9	3.9	5.0×10^{-11}
		B	6.0	1.2	1.33	0.9	6.3×10^{7}	9.0×10^{-1}	5.0×10^{8}	22.0	6.25	2.1×10^{-11}
14.	8.II.78	P	6.0	7.1	1.1×10^{-1}	60.0	3.0×10^{5}	1.1×10^{-4}	5.7×10^{6}	NA	NA	3.9×10^{-10}
		B	6.1	9.1×10^{-1}	8.3×10^{-1}	1.1	1.2×10^{7}	5.6×10^{-1}	4.7×10^{8}	NA	NA	6.9×10^{-11}
	BURRARD INLET											
15.	27.IV.77	P	14	17.5	6.4×10^{-1}	27.2	2.8×10^{3}	2.5×10^{-4}	1.5×10^{3}	1.4	1.6	2.2×10^{-7}
		B	12	2.0	8.3	0.2	9.3×10^{5}	1.32	3.2×10^{5}	14.0	25.7	8.9×10^{-9}
16.	13.V.77	P	11	1.1	1.5×10^{-2}	70	5.6×10^{3}	2.2×10^{-5}	NA	2.8	5.3	2.8×10^{-9}
		B	12	3.8	5.4	0.7	6.3×10^{6}	5.0×10^{-1}	NA	28.0	32.0	8.6×10^{-10}
	STRAIT OF GEORGIA AND INLETS											
17.	3.VI.77	P	10.5	3.0	6×10^{-2}	50	5.4×10^{3}	5.2×10^{-4}	1.2×10^{6}	1.3	5.4	1.1×10^{-8}
		B	12.5	3.3	3.4	0.9	3.1×10^{6}	1.1×10^{-1}	2.9×10^{8}	80	6.3	1.1×10^{-9}
18.	10.VI.77	P	12.5	9.0	9.4×10^{-2}	95	8.2×10^{3}	7.7×10^{-3}	2.7×10^{5}	4.2	1.7	1.1×10^{-8}
		B	12.5	3.5	7.0	0.5	3.8×10^{4}	1.2×10^{-1}	3.8×10^{7}	64.0	11.8	1.8×10^{-7}

TABLE I ... Cont'd.

STRAIT OF GEORGIA AND INLETS

Smpl. Indx.	Sample Date		Temp. °C	$K_t + S_n$ mgl^{-1}	Vmax $mgl^{-1}h^{-1}$	Turnover Time, h	CFU/ml	ATP mg/l	NAB/ml	DOC mgl^{-1}	POC mgl^{-1}	Vmax/CFU mgh^{-1}
19	10.VI.77	P	9.0	1.8	2.2×10^{-2}	80	3.1×10^{3}	4.8×10^{-4}	1.5×10^{5}	1.0	2.1	1.9×10^{-9}
		B	12.5	6.3	8.1	0.1	5.0×10^{4}	1.6×10^{-1}	2.4×10^{7}	54.0	16.2	1.6×10^{-7}
20.	19.XII.77	P	6.5	10.9	1.2×10^{-1}	84	7×10^{2}	2.4×10^{-4}	6.0×10^{5}	3.4	0.4	1.8×10^{-4}
		B	3.5	5.5×10^{-1}	3.9×10^{-1}	1.4	6.5×10^{4}	2.8×10^{-3}	4.8×10^{6}	28.6	5.3	6.0×10^{-6}
21.	19.XII.77	P	9	1.5	3.0×10^{-2}	50	1×10^{2}	4.4×10^{-5}	8.9×10^{4}	3.5	3.7	5.0×10^{-5}
		B	4.1	6.5×10^{-1}	1.3	0.5	5.9×10^{4}	3.1×10^{-3}	5.3×10^{6}	29.1	1.9	2.2×10^{-5}
22.	20.XII.77	P	2°C	8.5×10^{-1}	2.5×10^{-3}	340	9.0×10^{2}	7.8×10^{-5}	1.2×10^{5}	5.78	0.3	2.7×10^{-6}
		B	2.1	1.5	4.6×10^{-1}	3.2	7.9×10^{5}	3.6×10^{-3}	8.7×10^{6}	35.1	3.6	5.9×10^{-7}
23.	20.XII.77	P	5	3.2	1.0×10^{2}	320	5.5×10^{2}	5.6×10^{-4}	6.9×10^{5}	2.1	0.5	1.8×10^{-5}
		B	5.1	4.8	6.6×10^{-1}	7.2	5.3×10^{4}	7.1×10^{-3}	8.8×10^{6}	29.5	4.6	1.2×10^{-5}
24.	20.XII.77	P	6.5	1.2	1.1×10^{-3}	1100	6.3×10^{2}	2.5×10^{-4}	5.6×10^{5}	6.2	1.4	1.7×10^{-6}
		B	6.1	6.0	2.5×10^{-1}	24	2.5×10^{5}	9.4×10^{-3}	1.6×10^{7}	42.6	0.2	1.0×10^{-6}
25.	21.XII.77	P	8°C	2.8	6.6×10^{-3}	420	4.5×10^{2}	2.5×10^{-6}	9.1×10^{4}	2.9	0.2	1.4×10^{-5}
		B	6.5	5.0×10^{-1}	1.78×10^{-1}	2.8	1.8×10^{4}	9.4×10^{-5}	3.9×10^{5}	35.5	0.1	9.8×10^{-6}
26.	21.XII.77	P	6°C	5.0×10^{-1}	2.7×10^{-3}	180	1.1×10^{3}	2.1×10^{-6}	9.9×10^{4}	2.8	3.1	2.5×10^{-6}
		B	5.0	5.5×10^{-1}	5.0×10^{-2}	11	5.9×10^{4}	1.4×10^{-4}	6.2×10^{5}	31.6	3.1	8.4×10^{-7}
27.	21.XII.77	P	9.0	3.5×10^{-1}	1.4×10^{-3}	250	8.4×10^{2}	8.8×10^{-6}	2.8×10^{4}	5.4	0.7	1.6×10^{-6}
		B	7.0	1.4	8.7×10^{-1}	1.6	4.9×10^{5}	1.2×10^{-3}	5.1×10^{6}	62.4	1.4	1.7×10^{-6}
28.	22.XII.77	P	8.5	1.4	5.2×10^{-3}	265	5.9×10^{2}	4.1×10^{-5}	1.5×10^{5}	2.3	1.1	8.9×10^{-6}
		B	6.5	1.5	1.5	1.0	8.4×10^{4}	2.1×10^{-4}	9.0×10^{5}	36.0	3.2	1.7×10^{-5}
29.	29.VI.77	P	9.0	5.9	1.9×10^{-2}	310	4.7×10^{2}	1.7×10^{-4}	1.2×10^{4}	3.8	1.2	4.0×10^{-8}
		B	9.0	2.1	3.5	0.6	4.5×10^{4}	8.8×10^{-2}	8.8×10^{7}	67.0	8.6	7.7×10^{-8}

TABLE I ...Cont'd. STRAIT OF GEORGIA AND INLETS

Smpl. Indx.	Sample Date		Temp. °C	$K_t + S_n$ mgl^{-1}	Vmax $mgl^{-1}h^{-1}$	Turnover Time,h	CFU/ml	ATP mg/l	NAB/ml	DOC_{-1} mgl^{-1}	POC_{-1} mgl^{-1}	$Vmax_{-1}/CFU$ mgh^{-1}
30.	29.VI.77	P	10.0	14.3	1.6×10^{-1}	85	1.6×10^{2}	3.5×10^{-5}	1.9×10^{4}	1.6	0.4	1.0×10^{-6}
		B	10.0	4.5×10^{-1}	5.2×10^{-1}	0.8	1.2×10^{3}	4.4×10^{-2}	6.5×10^{7}	88.0	11.8	4.4×10^{-7}

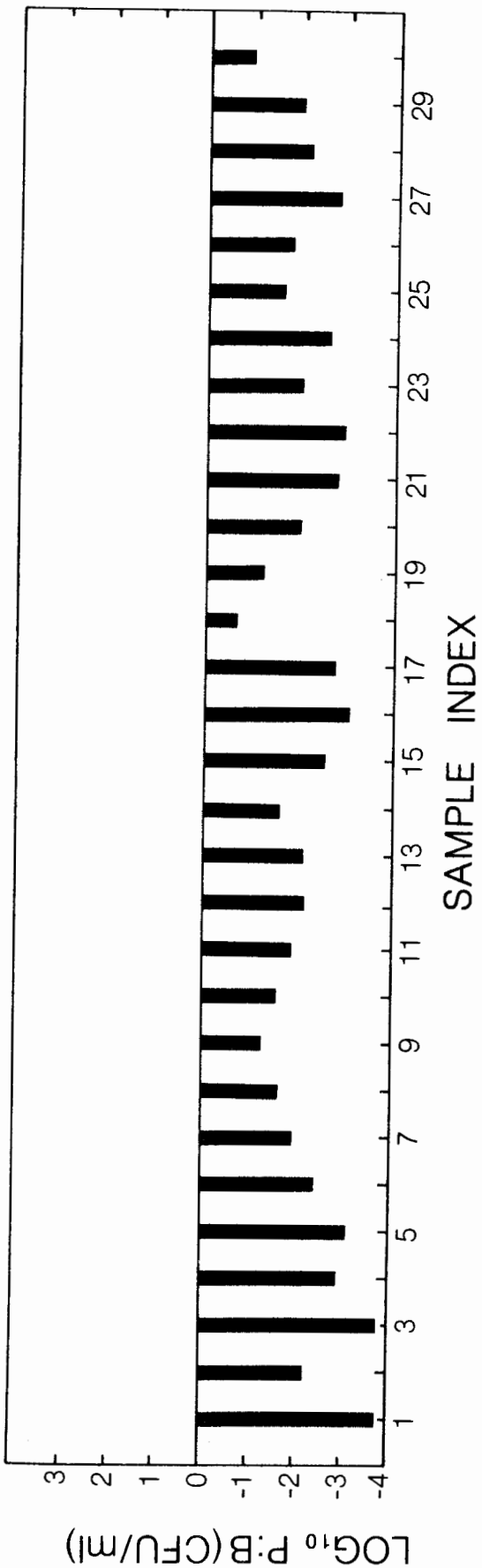
N.A. = Not Available

FIGURE 2.

P:B ratios for colony forming units (CFU) per ml of sample versus sample index. See Tables I and III for sample index. Downward spikes indicate greater values in sediment.

P= overlying water.

B= sediment.


LOG10 P:B (CFU/ml)
3
2
1
0
-1
-2
-3
-4
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
SAMPLE INDEX

366 m off Andros Island, West Indies. Wood (1970) reported a high value of 1.2×10^7 bacteria per g of sediment in October and a low value of 3.0×10^5 cells per gr in February. Dietz et al., (1976) reported values for CFU in water at a depth of 1.0 to 1.5 m, which fluctuated from 1.8×10^2 to 2.1×10^4 bacteria per ml in the Strait of Georgia. Rittenberg (1940), found viable bacteria at sediment depths between 342-355 cm, however, the greatest concentration has been found at the sediment - water boundary (Lloyd, 1931; Reuszer, 1933; Zobell and Anderson, 1936; Rittenberg, 1940; Zobell and Feltham, 1942). Rittenberg (1940) also reported that the number of aerobes in the topmost layer is high ranging between 1.0×10^6 and 8.0×10^6 per g wet weight. The higher number of bacteria in sediments were expected, since these numbers are related to the concentration of organic matter (Reuszer, 1933; Jannasch, 1969; Wood, 1970).

One approach to the measurement of productivity of microbial communities would be to count the cell number and estimate the seasonal fluctuations that occurs (Hall et al., 1972). However, this has not generally been a successful approach since it is very difficult to differentiate sediment microbes from detritus. Furthermore, plate counting greatly underestimates bacterial numbers since only a small fraction of total viable cells will grow on any single nutrient medium incubated at one atmosphere pressure (Hodson et al., 1976; Bancroft, 1976). Extinction dilution which is also commonly used to quantitatively enumerate marine bacteria is also selective because of the chemical composition of the media and because of inherent physical parameters such as temperature and pressure. In addition,

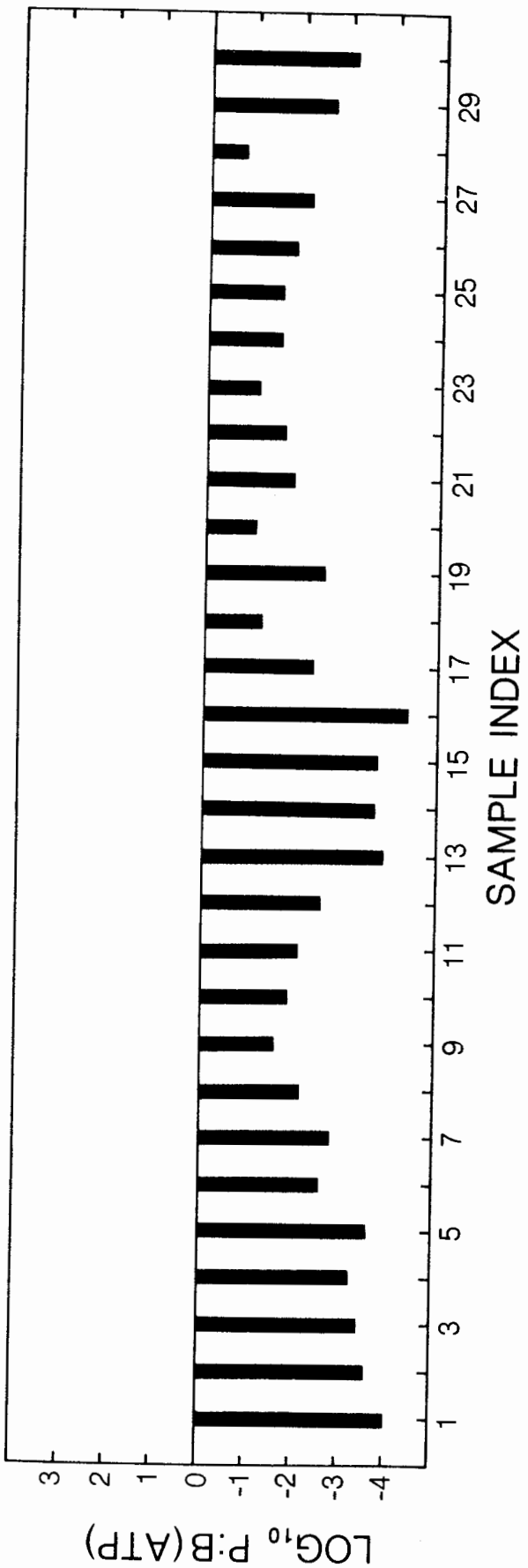
extinction dilution may be biologically selective in that one form may easily overgrow another (Hamilton and Holm-Hansen, 1967).

Data on biomasses as indicated by ATP levels are presented in Table I. Figure 3 illustrates the water to sediment ratios of ATP levels. Extractable ATP concentrations of the sediments at Iona Island were as much as four orders of magnitude greater than those of the water. Thus the microbial biomass of the sediments is greater than that of the total microbial biomass in an equal volume of overlying water. The mean ATP concentration of Iona Island sediment was 4.1×10^{-1} mgl^{-1} (range $2.4 - 3.1 \times 10^{-2}$), and the average of ATP in overlying water was $6.3 \times 1o^{-4}$ mgl^{-1} (range $3.9 \times 10^{-3} - 1.6 \times 10^{-5}$). As illustrated in figure 3, the ATP ratio for other British Columbia coastal waters was also always greater in the sediments than in the water, in one case by as much as four orders of magnitude. The concentration of ATP in the sediments ranged from 9.4×10^{-5} mgl^{-1} (sample index 25) to 1.3 mgl^{-1} (sample index 15). The values of ATP for overlying water ranged from $2.1 \times 10^{-6} mgl^{-1}$ (sample index 26) to 7.7×10^{-3} (sample index 18). The variations in these ranges could be due to the wide variety of sampling situations (different latitudes, time of the year, temperature, depth).

Karl et al., (1976) recorded values for ATP concentration at the Mid-Atlantic Ridge station at different depths, to 4100 m. the ATP concentrations rapidly decreased from a near surface maximum of 400 ngl^{-1}, to a value of 3 ngl^{-1} at about 280m. Below 300m, the ATP concentration increased to a maximum of 225 ng ATP l^{-1} at 650 m. Below this, the ATP concentration gradually decreased to a value of $8.0 \times 10^{-1} ngl^{-1}$ at 2000 m. Between 3 and

FIGURE 3.

P:B ratios of ATP concentration per ml of sample versus sample index. See Tables I and III for sample index.


LOG10 P:B(ATP)
3
2
1
0
-1
-2
-3
-4
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
SAMPLE INDEX

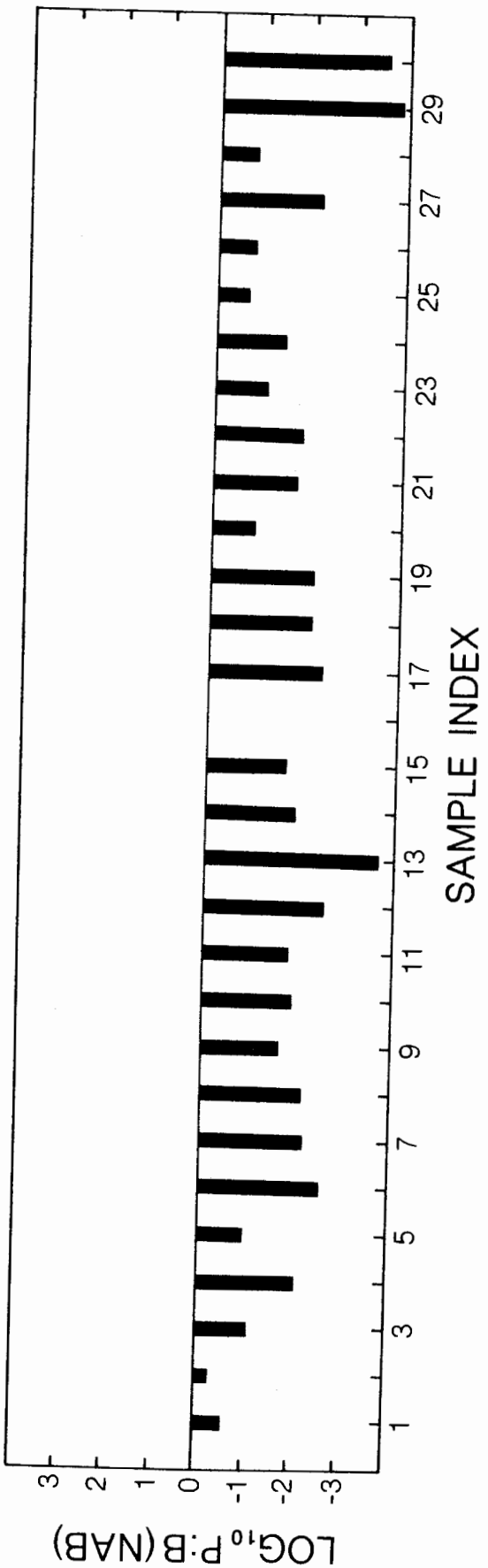
5 m above the bottom, the ATP concentration was 3.2 ngl^{-1}. At the Abyssal Plain Station they found a similar pattern. They also noted that the ATP concentration in the topmost sediment layer (0 to 2 cm) was three orders of magnitude greater than in overlying water. Dietz et al., (1976) give data for ATP concentration in different B. C. coastal waters of between 1 to 1.5 m of depth which fluctuate from 3.0×10^{-6} mgl^{-1} to 6.9×10^{-4} mgl^{-1}. Hodson et al., (1976) made determinations of ATP at depths of 1000 and 200m in the upper 6 cm of sediments in the Atlantic Ocean off Northwest Africa. They found that the average concentration in the shallower sediment was 545 ng ATP ml^{-1} wet sediment, as compared to 195 ng ATP ml^{-1} wet sediment at the deeper station.

ATP is characteristic of living cells and leaches from dead or damaged cells (Lee et al., 1971; Hamilton and Holm-Hansen, 1967; Holm-Hansen and Booth, 1966). Although the process of filtration to concentrate the bacterial cells prior to extraction submits these microbes to stress that in some instances result in damage to or death cells, the method is useful for extracting ATP from water samples (Griffiths et al., 1973; Dietz et al., 1976; Bancroft et al., 1976). However, several ATP extraction procedures have been described for sediment samples (Lee et al., 1971a,'b; Ernst and Goerke, 1974; Karl and LaRock, 1975; Hodson et al., 1976; Bancroft et al., 1976), with extraction efficiencies varying greatly from method to method. Therefore, it is very difficult to compare the values obtained by different workers.

Data for numbers of active bacteria are presented in Table I. Figure 4 illustrates the ratio of water to sediment (P:B) of NAB values versus the sample index. Bacterial populations as

FIGURE 4.

P:B ratios of numbers of actively metabolizing bacteria (NAB) per ml of sample versus sample index. See Tables I and III for sample index.


LOG10 P:B(NAB)
3
2
1
0
-1
-2
-3
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
SAMPLE INDEX

indicated by NAB values at Iona Island as well as at the other coastal areas of British Columbia, were always greater in the sediments. The population mean for NAB values in the sediments of Iona Island was 68 - fold greater than in the water, which represents an average of 2.3×10^8 cells ml^{-1} in the sediments (range 1.2×10^7 - 7.3×10^8) and 3.4×10^6 cells ml^{-1} in the overlying water (range 9.8×10^4 - 9.2×10^6). In other coastal areas of British Columbia, the bacterial population, as NAB values, fluctuated between 3.2×10^5 - 2.9×10^8 in the sediments and between 7.5×10^3 - 1.2×10^6 cells ml^{-1} in the overlying water.

Hoppe (1976) found in Inner Kiel Bay at 1 m depth values that fluctuated from 1.7×10^5 active cells ml^{-1} in January 1975 to 1.9×10^6 active cells ml^{-1} in July 1974. CFU values for the same samples were 1.0×10^4 and 2.3×10^4 ml^{-1} respectively. Values for the middle of the Kiel Bight at 1m depth were 1.2×10^6 active cells per ml in July 1974 and 5.7×10^4 active cells per ml in January 1975. For the same samples, CFU values were 1.5×10^2 and 3.3×10^2 respectively. The results of Peroni and Lavarello (1975) present a comparable ratio between CFU and NAB values in water of generally 1:1000; however, that data is from an open sea area.

There are few data available of numbers of actively metabolizing heterotrophic bacteria in sediments, probably because autoradiography has only been recently used as a tool to investigate the in situ activities of those types of cells.

Ocurrence of nutrients

Data for DOC and POC are presented in Table I. Figures 5 and 6 illustrate overlying water to sediment ratio for DOC and POC respectively. DOC values were always reater in the sediments at all stations sampled. The mean DOC value at Iona Island was 11 - fold greater in the sediment, averaging 38.3 mgl^{-1} (range 22 - 62.1) in the sediment and 3.2 mgl^{-1} in the overlying water (range 1.9 - 4.2 mgl^{-1}). The DOC value for other coastal waters tested fluctuated from 14 mgl^{-1} (sample index 15) to 88 mgl^{-1} (sample index 30) in the sediments and from 1.0 mgl^{-1} (sample index 19) to 6.2 mgl^{-1} (sample index 24) in water.

The POC mean value in Iona Island sediment was 8.1 mgl^{-1} (range 2.1 - 15.9 mgl^{-1}) and the mean for overlying water was 3.4 mgl^{-1} (range 4.5 x 10^{-1} - 5.5 mgl^{-1}). Values for other coastal areas of British Columbia fluctuated from 2.8 x 10^{-1} mgl^{-1} (sample index 24) to 32 mgl^{-1} (sample index 16) in sediments and from 2.1 x 10^{-1} mgl^{-1} (sample index 25) to 5.4 mgl^{-1} (sample index 17) in overlying water.

There have been many investigations of organic matter concentration in the oceanic habitat (Stephens et al., 1967; Vaccaro et al., 1968; Seki et al., 1968; Holm - Hansen, 1972; Holm-Hansen and Pearl, 1972; Albright and Wentworth, 1973). The concentration and distribution of these values has in many cases been related to factors such as depth, time of the year and type of water. For example, Holm-Hansen (1972) found that in coastal water off San Diego, the maximum POC value was in the euphotic zone with a sharp decrease below. Dietz et al., (1976) found in

FIGURE 5.

P:B ratios of DOC concentration per ml of sample versus sample index. See Tables I and III for sample index.

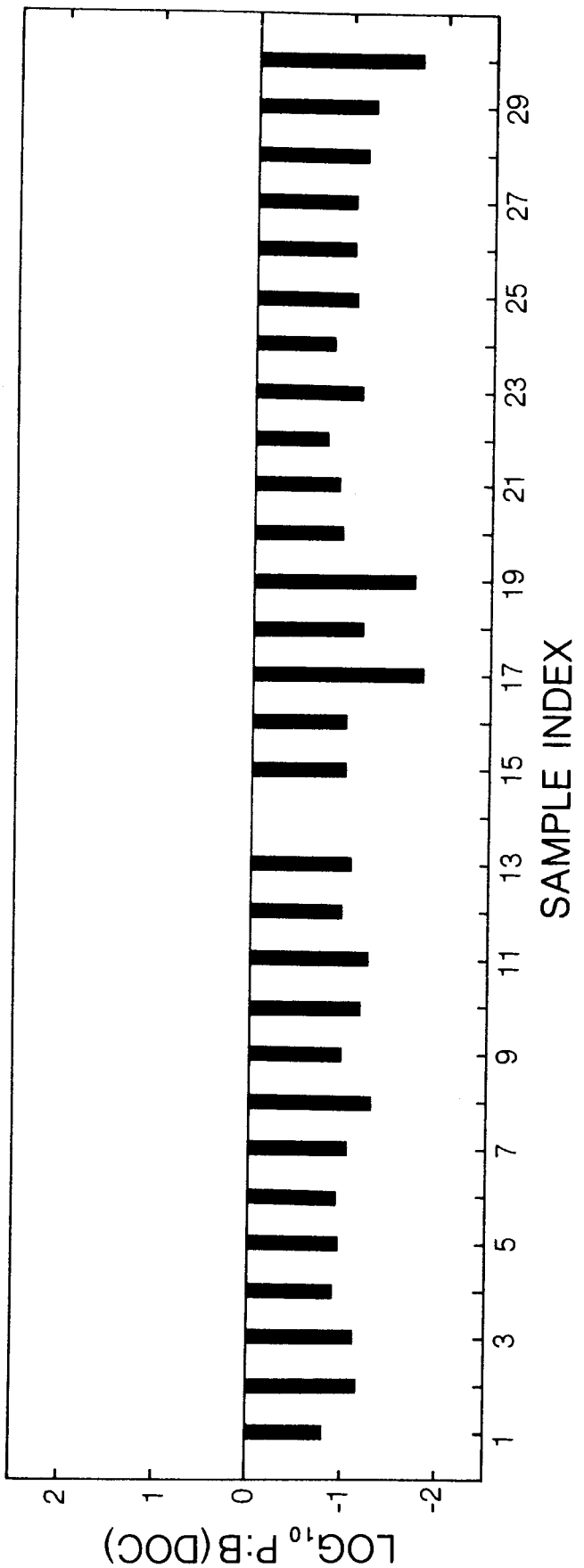
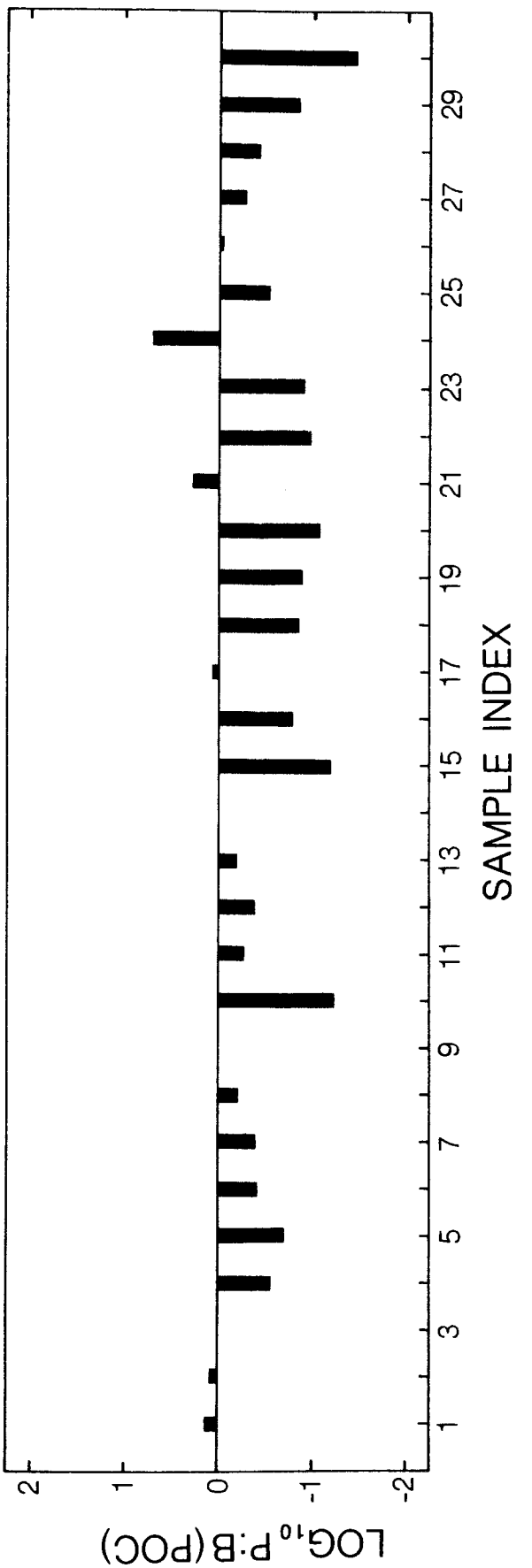

LOG10 P:B(DOC)
2
1
0
-1
-2
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
SAMPLE INDEX

FIGURE 6.

P:B ratios of POC concentration per ml of sample versus sample index. See Tables I and III for sample index.


LOG10 P:B(POC)
2
1
0
-1
-2
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
SAMPLE INDEX

the Strait of Georgia (at 100m depth) POC values ranging from 1.7×10^{-1} to 4.6×10^{-1}, whereas values of from 4.0 to 8.6 mgl^{-1} were reported for DOC.

Many investigators have found that the number of microbial cells in water and sediments are related to the amount of organic matter (Reuszer, 1933, Zhukova and Fedosov, 1963; Jannasch, 1958; Wood, 1970); which is in general agreement with the results of this study (figures 2 - 6). Seki et al., (1968) showed that a relative increase in bacterial biomass followed addition of glucose to sediment, however the percentage of sediment organic carbon attributable to viable cells is small, since the relationship 1.0×10^{7} bacteria per ml is equivalent to $1.0 \times 10^{-3} mgl^{-1}$ of organic matter (Zobell, 1946). In shallow coastal waters, the retention time of organic matter in the water column is short, and this may imply that sediments under shollow waters will have a higher input of organic material (Hartwig, 1976). In most sediments transport, therefore, represents the major input of organic carbon, although there is also production within the sediments, which represents another source of organic carbon, which may include both photo and chemo-autotrophic production, although this happens only in a very limited portion of the total sediment area available in the ocean (Hartwig, 1976). Other sources of carbon inflow include larger material that sinks to the sediment surface and material that is transported horizontally by water currents.

HETEROTROPHY

Data for heterotrophic activity are presented in Tables I and II. The heterotrophic potential (V_{max}) values were calculated for two different tritiated substrates, glucose and alanine.

Uptake of glucose.

The turnover times of glucose in sediments and in overlying water are illustrated in figures 7 and 12. The turnover times of glucose in the sediments of Iona Island were lowest in winter (average 1.0 h) and the greatest in summer (average 0.4 h). The mean value was 0.7 h (range 0.1 - 1.9 h). In other coastal areas of British Columbia, the turnover of glucose was always faster in sediments (range 0.2 - 24h) than in overlying water (range 27.2-1.1 x 10^3h). Wood (1970) reported the average for turnover time in sediment of 6 x 10^{-2}h, with the slowest in winter, in agreement with the finding reported here, and with a more rapid turnover in spring and the fall. Hall et al., (1972) also found much faster turnover times for glucose in sediments than those reported for the water column by various authors (Hobbie and Wright, 1965; Dietz et al., 1976; Burnison and Morita, 1974). These findings have been reported for freshwaters as well as marine waters.

The transport constant plus substrate concentration ($K_t' + S_n$) valuefor a year cycle at Iona Island is illustrated in figure 8 and the overlying water to sediment ratio (P:B) for a variety of sampling sites is presented in figure 9. The $K_t + S_n$ values were greatest in Spring for both water and sediment (averaging 10.9 and 9.3 mgl^{-1} respectively), quite variable during the rest of the year, but were generally lowest in summer (2.9 mgl^{-1} in overlying water and 6.7 x 10^{-1} mgl^{-1} in sediment). The P:B ratio were very

TABLE II

ALANINE HETEROTROPHIC ACTIVITY VALUES FOR PLANKTON (P) AND SEDIMENT (B) AT VARIOUS LOCATIONS OF COASTAL BRITISH COLUMBIA. ---- IONA ISLAND ----

Smpl. Indx.	Sample Date		Temp. oC	$K_t + S_n$ mgl^{-1}	$Vmax_1$ $mgl^{-1}h^{-1}$	Turnover Time, h	Vmax/CFU mgh^{-1}
1.	5.I.77	P	3	1.1	2.0×10^{-1}	5.5	3.4×10^{-9}
		B	2.3	8.0×10^{-1}	1.1	0.6	3.2×10^{-12}
2.	25.I.77	P	4.5	8.0×10^{-1}	7.1×10^{-2}	11.2	1.0×10^{9}
		B	4.0	6.4×10^{-1}	5.3×10^{-1}	1.2	4.4×10^{-11}
3.	9.II.77	P	3.8	1.5	4.2×10^{-1}	3.5	4.0×10^{-9}
		B	3.4	2.4×10^{-1}	2.0×10^{-1}	1.2	3.1×10^{-13}
4.	9.III.77	P	4.5	8.0×10^{-1}	1.8×10^{-1}	4.3	3.2×10^{-10}
		B	3.8	7.0×10^{-2}	4.1×10^{-2}	1.7	8.2×10^{-11}
5.	5.IV.77	P	23.0	4.5×10^{-1}	2.2×10^{-2}	20	2.0×10^{-11}
		B	22.0	1.5×10^{-1}	5.5×10^{-2}	2.7	3.8×10^{-14}
6.	31.V.77	P	14.0	4.0×10^{-1}	7.8×10^{-3}	57	4.3×10^{-10}
		B	13.5	3.8×10^{-1}	2.6	0.1	5.2×10^{-10}
7.	22.VI.77	P	26.5	14.7	4.5	3.2	2.8×10^{-8}
		B	26.0	9.0×10^{-1}	3.3	0.2	2.3×10^{-10}
8.	14.VII.77	P	28.0	2.9×10^{-1}	9.6×10^{-1}	3.2	2.4×10^{-9}
		B	27.0	1.9×10^{-1}	3.4×10^{-1}	0.5	1.8×10^{-11}
9.	3.VIII.77	P	19.5	6.8×10^{-1}	1.7×10^{-1}	4.0	2.6×10^{-10}
		B	19.5	2.2×10^{-1}	4.3×10^{-2}	5.2	3.5×10^{-12}
10.	7.IX.77	P	14.0	5.1×10^{-1}	3.3×10^{-2}	15.2	4.4×10^{-7}
		B	14.0	8.3×10^{-1}	4.8×10^{-1}	1.7	1.6×10^{-7}
11.	5.X.77	P	9.5	6.5×10^{-1}	1.3×10^{-2}	46.7	3.8×10^{-8}
		B	9.8	7.7×10^{-1}	7.6×10^{-1}	1.0	2.6×10^{-8}
12.	2.XI.77	P	7.0	9.3×10^{-1}	3.2×10^{-2}	29.0	1.5×10^{-7}
		B	7.5	3.7×10^{-2}	1.1×10^{-2}	3.1	3.7×10^{-10}
13.	7.XII.77	P	5.5	9.8×10^{-1}	2.9×10^{-2}	33.0	6.1×10^{-8}
		B	6.0	1.0	5.47×10^{-1}	1.9	8.6×10^{-9}

TABLE II

Cont'd.

Smpl. Indx.	Sample Date		Temp. oC	$K_t + S_n$ mgl^{-1}	Vmax $mgl^{-1}h^{-1}$	Turnover Time, h	Vmax/CFU mgh
14.	8.II.78	P	6.0	1.0	1.0×10^{-1}	10.5	3.3×10^{-7}
		B	6.1	9.0×10^{-1}	5.0×10^{-1}	1.8	4.1×10^{-8}
	BURRARD INLET						
15.	27.IV.77	P	14.0	7.8×10^{-1}	8.0×10^{-3}	97	2.8×10^{-9}
		B	12.0	7.7×10^{-1}	5.9×10^{-1}	09	6.3×10^{-10}
16.	13.V.77	P	11.0	1.5×10^{-1}	7.1×10^{-4}	210	1.2×10^{-10}
		B	12.0	7.0×10^{-1}	3.5×10^{-1}	2.0	5.5×10^{-11}
	STRAIT OF GEORGIA						
17.	3.VI.77	P	105	5.5×10^{-1}	3.1×10^{-3}	175	5.8×10^{-10}
		B	12.5	4.0×10^{-1}	5.7×10^{-1}	0.6	1.8×10^{-10}
18.	10.VI.77	P	12.5	1.9×10^{-1}	1.0×10^{-3}	190	1.2×10^{-10}
		B	12.5	1.5×10^{-1}	2.1×10^{-1}	0.7	5.6×10^{-9}
19.	10.VI.77	P	9.0	3.8×10^{-2}	2.5×10^{-4}	150	8.1×10^{-11}
		B	12.5	5.0×10^{-1}	3.5×10^{-1}	1.4	7.0×10^{-9}
29.	29.VI.77	P	9.0	1.3×10^{-1}	4.5×10^{-4}	290	9.5×10^{-10}
		B	9.0	5.0×10^{-1}	5.2×10^{-1}	0.9	1.1×10^{-8}
30.	29.VI.77	P	10.0	1.0×10^{-1}	4.7×10^{-4}	220	2.9×10^{-9}
		B	10.0	3.0×10^{-1}	1.3×10^{-1}	2.3	1.1×10^{-7}

TABLE III

SAMPLE INDEX NUMBER AND LOCATION
OF EACH STATION SAMPLED.

Sample Index	Depth (m)	Location	Longitude	Latitude
1 - 14		Iona Island	123° 13' W	49° 13' 30"N
15		Port Moody	122° 55' 53"W	49° 17' 42"N
16		Indian Arm	122° 54' N	49° 20' 30"
17		Georgia Strait	123° 18' W	49° 12' 30"N
18	20m	Georgia Strait	123° 18' 54"W	49° 12' 42"N
19	250m	Georgia Strait	123° 30' 54"W	49° 14' N
20	400m	Georgia Strait	123° 41' W	49° 16' 25"N
21	270m	Georgia Strait	125° 05 W	49° 58' 3" N
22	90m	Bute	124° 50' 04"W	50° 49' 7" N
23	696	Bute	124° 58' W	50° 33' 04"N
24	170	Vicinity Montgomery Bnk.	124° 55' 4" W	49° 51' 5" W
25	234	Jervis	123° 57' 9" W	50° 11'
26	700	Jervis	123° 55' 8" W	49° 54' 4" N
27	350	Merry 2-Ballenas	124° 02' W	49° 23' 2" N.
28	180	Fraser River Plume	123° 20' 6" W	49° 04' 7" N
29	120	Howe Sound	123° 17' 46"W	49° 26' 23"N
30	45	Howe Sound	123° 15' 42"W	49° 33' 54"N

FIGURE 7.

Seasonal variation of glucose (open circles) and alanine (closed circles) turnover times in intertidal waters at Iona Island.

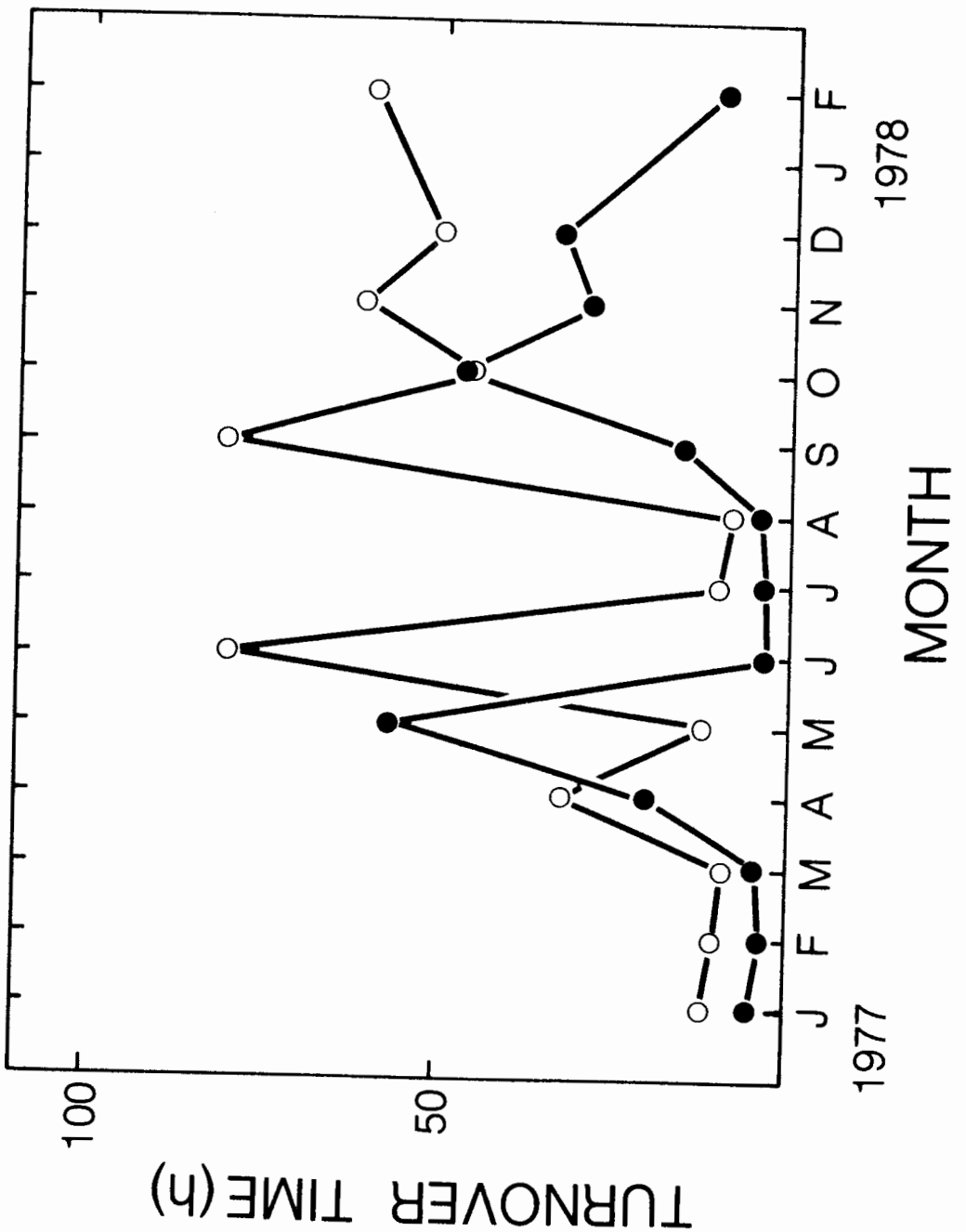

TURNOVER TIME (h)
100
50
J F M A M J J A S O N D J F
1977
1978
MONTH

FIGURE 8

Seasonal variation in glucose $K_t + S_n$ values at Iona Island in sediment (closed circles) and in overlying water (open circles).

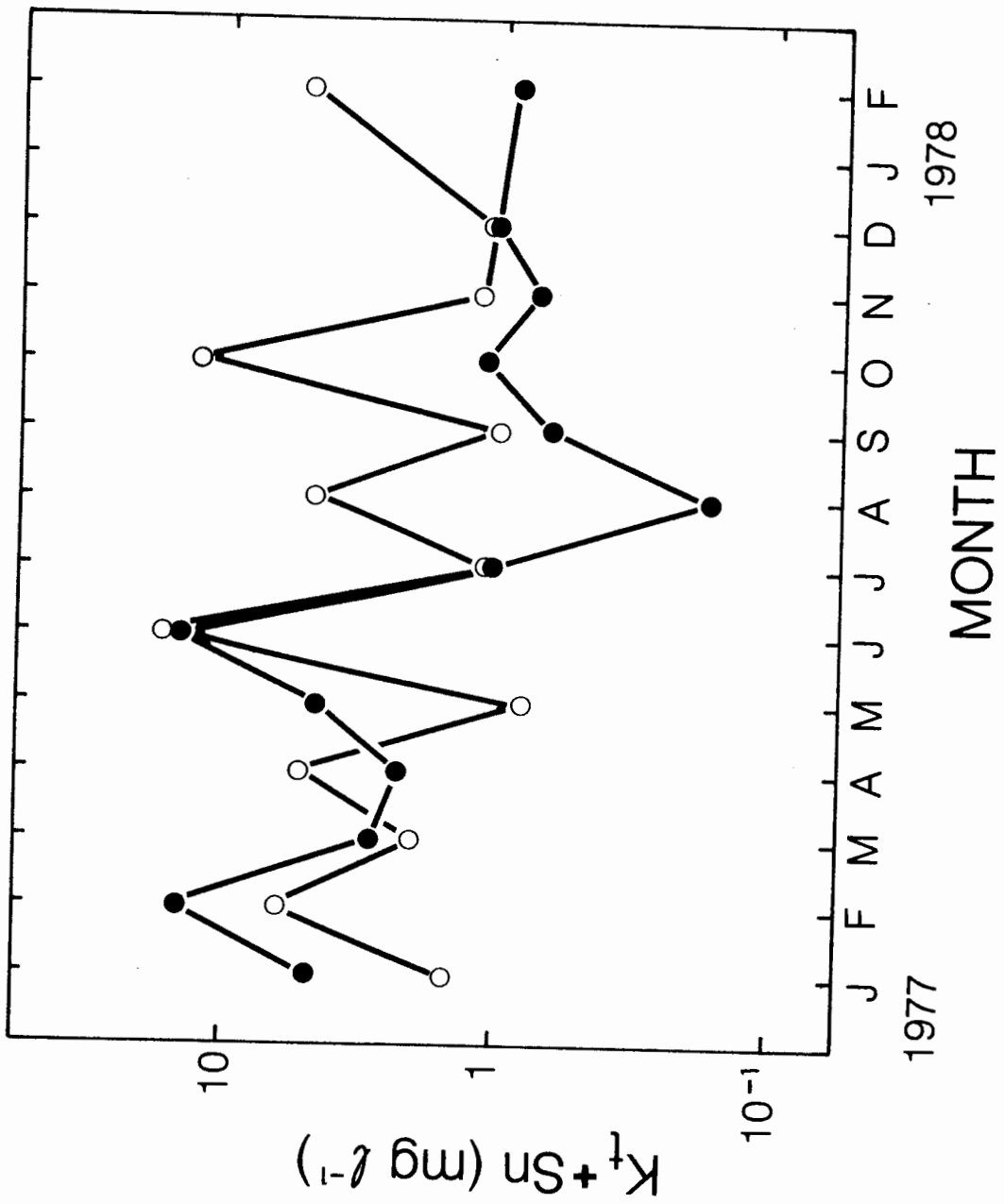
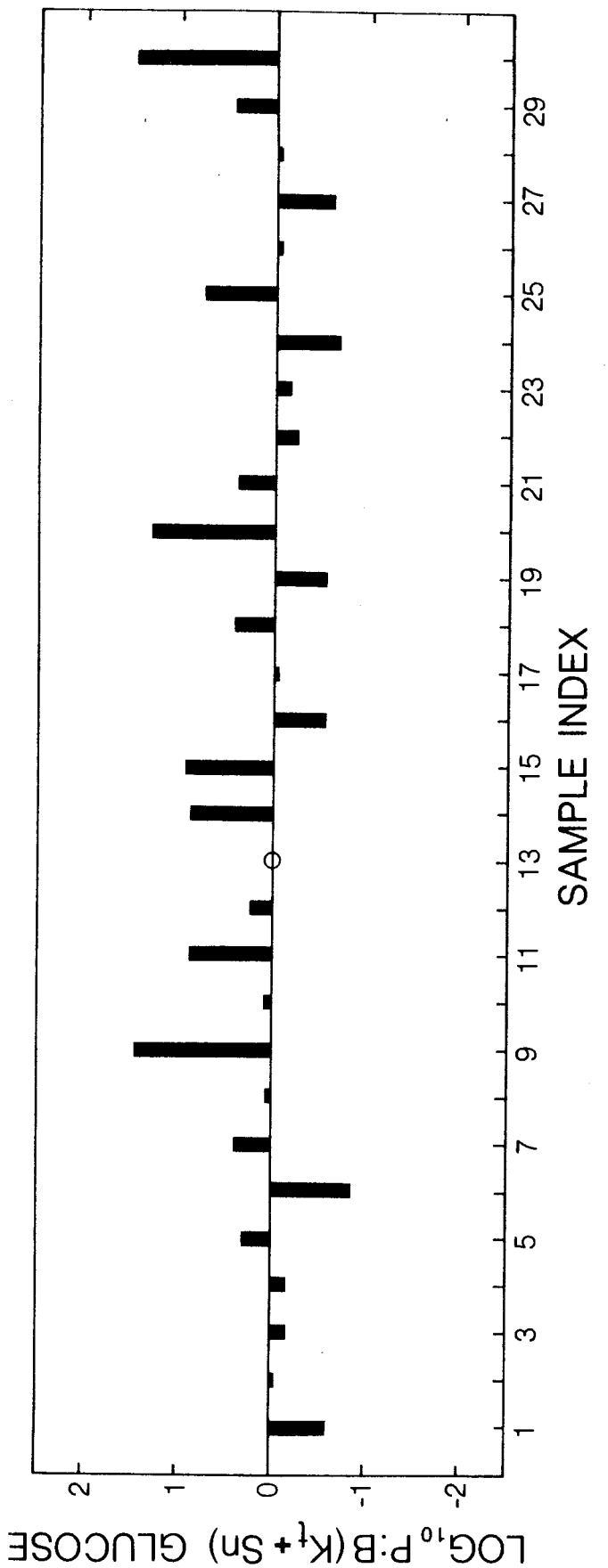

K_t+Sn (mg ℓ^{-1})
10
1
10^{-1}
J F M A M J J A S O N D J F
1977
1978
MONTH

FIGURE 9

P:B ratios of glucose $K_t + S_n$ values versus sample index. Downward spikes indicate greater values in sediment.


LOG10 P:B(Kt+ Sn) GLUCOSE
2
1
0
-1
-2
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
SAMPLE INDEX

variable for the other coastal areas sampled. The average $K_t + S_n$ value for the overlying water at Iona Island was 5.8 mgl^{-1} (range 9×10^{-1} - 24 mgl^{-1}). The average for sediment at the same location was4.6 mgl^{-1} (range 2.3×10^{-1} - 18 mgl^{-1}). For the other coastal areas sampled the $K_t + S_n$ values fluctuated between 3.5×10^{-1}-17.5 mgl^{-1} in overlying water and between 4.5×10^{-1} - 6.3 mgl^{-1} in sediments (Table IV). Wood (1970) working with glucose in sediments, found a marked increase in the $K_t + S_n$ value in the Spring, but variable values during the rest of the year. Hall et al., (1972) and Dietz et al., (1976) have found variable $K_t + S_n$ values for sediments and water respectively.

The average V_{max} values in overlying waters and sediments were $2.6 \times 10^{-1} mgl^{-1}h^{-1}$ (range 1.2×10^{-2} - 8.1×10^{-1} $mgl^{-1}h^{-1}$) and 8.6 $mgl^{-1}h^{-1}$ (range 7.6×10^{-1} - 37.5 $mgl^{-1}h^{-1}$) respectively. The V_{max} values for overlying water and sediments in other coastal ares of British Columbia are shown in Table IV. As illustrated in figure 11, the P:B ratio for the V_{max} values were always greater in sediments than in overlying waters in all the areas sampled. This was expected since the numbers of bacteria are greater in the sediments.

The greatest V_{max} value for glucose in Iona Island sediment was found in late spring and the least in summer and fall. The high value of the glucose V_{max} in spring may be related to phytoplankton decay and bacterial activity in the bottom (Wood, 1970).

Seki (1968) noted a relationship between production and mineralization in the water column, whereas mineralization was dominant in sediments. The V_{max} sediment values reported by Meyer-Reil (1978) are variable, averaging 1.7×10^{-1} mg glucose $g^{-1}h^{-1}$. Hall et al., (1972) found rates of between $5.0 \times 10^{-2}$and 3.1×10^{-1}

FIGURE 10.

Seasonal variation in glucose heterotrophic potential values in intertidal sediment (closed circles) and in overlying water (open circles) at Iona Island.

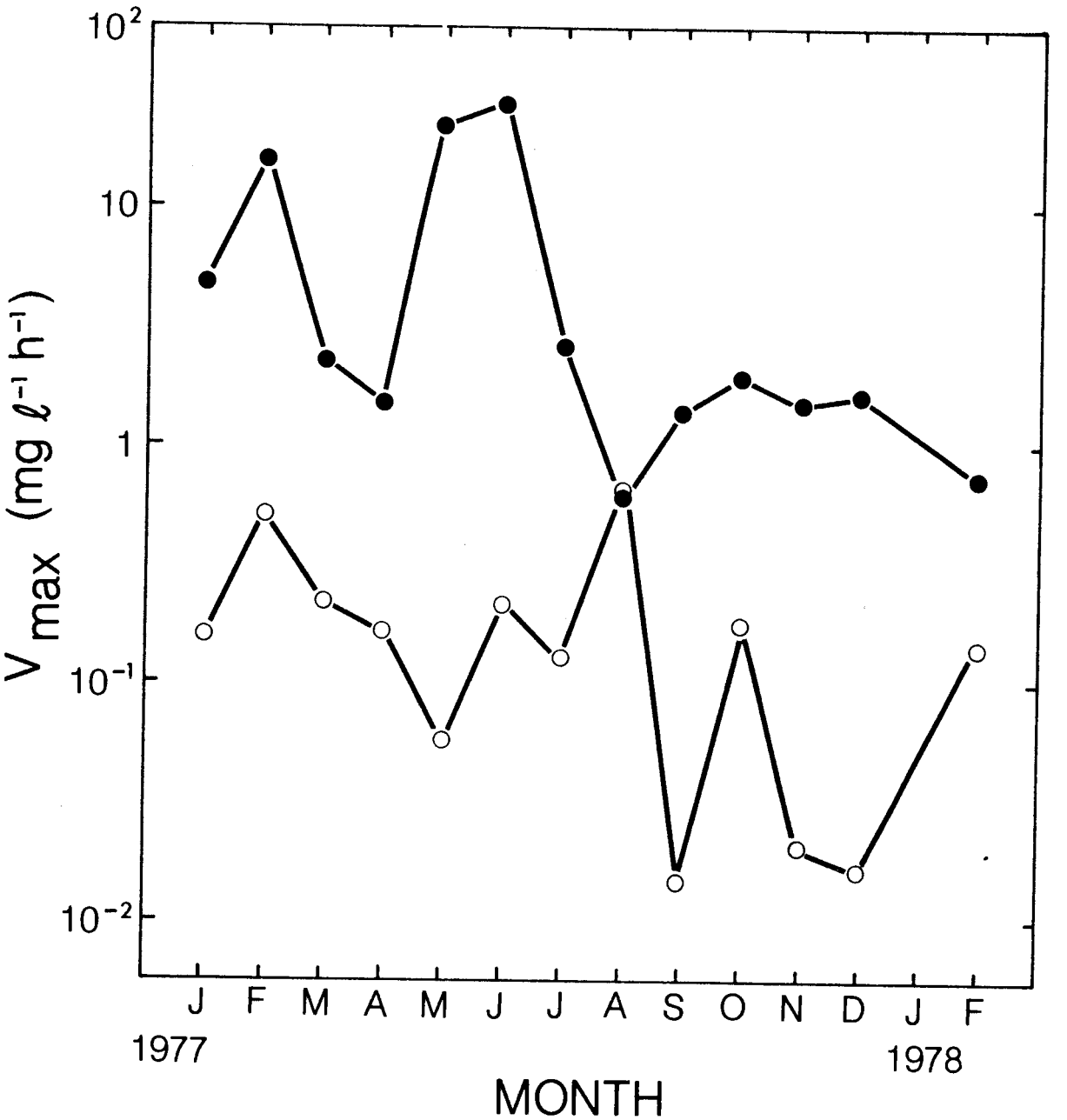
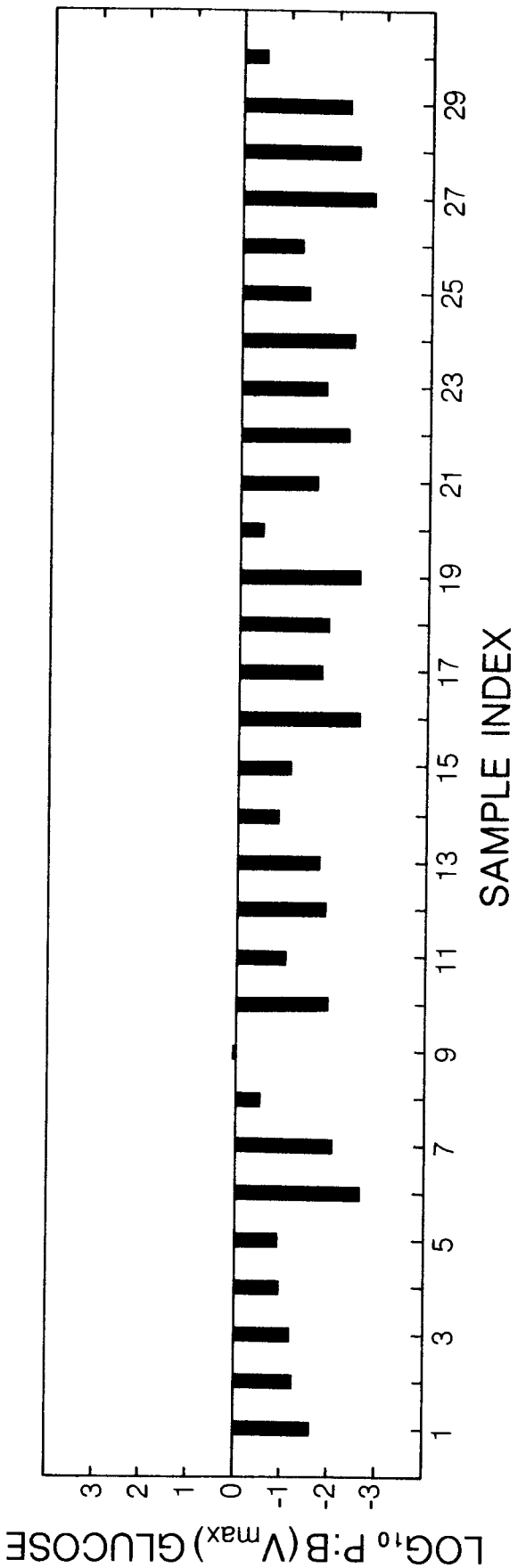

10^2
10
1
10^{-1}
10^{-2}
V_{max} (mg ℓ^{-1} h^{-1})
J F M A M J J A S O N D J F
1977
1978
MONTH

FIGURE 11.

P:B ratios of glucose Vmax values per ml of sample versus sample index. See Tables I and III for sample index.


LOG10 P:B (Vmax) GLUCOSE
3
2
1
0
-1
-2
-3
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
SAMPLE INDEX

ug ^{14}C- glucose g^{-1} h^{-1} in a lake sediment; Harrison et al.,(1971) obtained a V_{max} value of 2.4 ug g^{-1} h^{-1} and Wood (1970) working with suspended sediments obtained an average V_{max} of 3.0×10^2 ug g^{-1} h^{-1}.

The uptake kinetic values of alanine by sediment bacterial communities in Iona Island showed short turnover times, relatively high velocities and variable transport constants (Table IV). Turnover times of alanine at Iona Island are illustrated in figures 7 and 12. The V_{max} and $K_t + S_n$ values of alanine by sediment and overlying water bacterial communities at Iona Island are illustrated in figures 13 and 14 respectively. Values of the kinetic parameters are shown in Table IV. Figures 15 and 16 show the overlying water to sediment ratio (P:B) for the different kinetic parameters.

The $K_t + S_n$ value have been found very variable for different environments using different substrates which could be caused by a high diversity of microorganisms with different transport constants or localized concentration of fresh decomposing detritus releasing solutes into the intertitial water (Hall et al., 1972).

Although total heterotrophic activities of sediments were usually greater than those of overlying waters at the sites sampled (figures 11 and 16), heterotrophic activities per unit of biomass (CFU, NAB and ATP basis) were frequently greater in overlying water when both glucose and alanine were used as substrates (figures 17 to 22). The reasons for the exceptions to this trend are not known.

Iona Island sediment microflora had approximately 10% the glucose heterotrophic potential of the water per CFU; 43% on an

FIGURE 12.

Seasonal variation in glucose (open circles) and alanine (closed circles) turnover times in sediments at Iona Island.

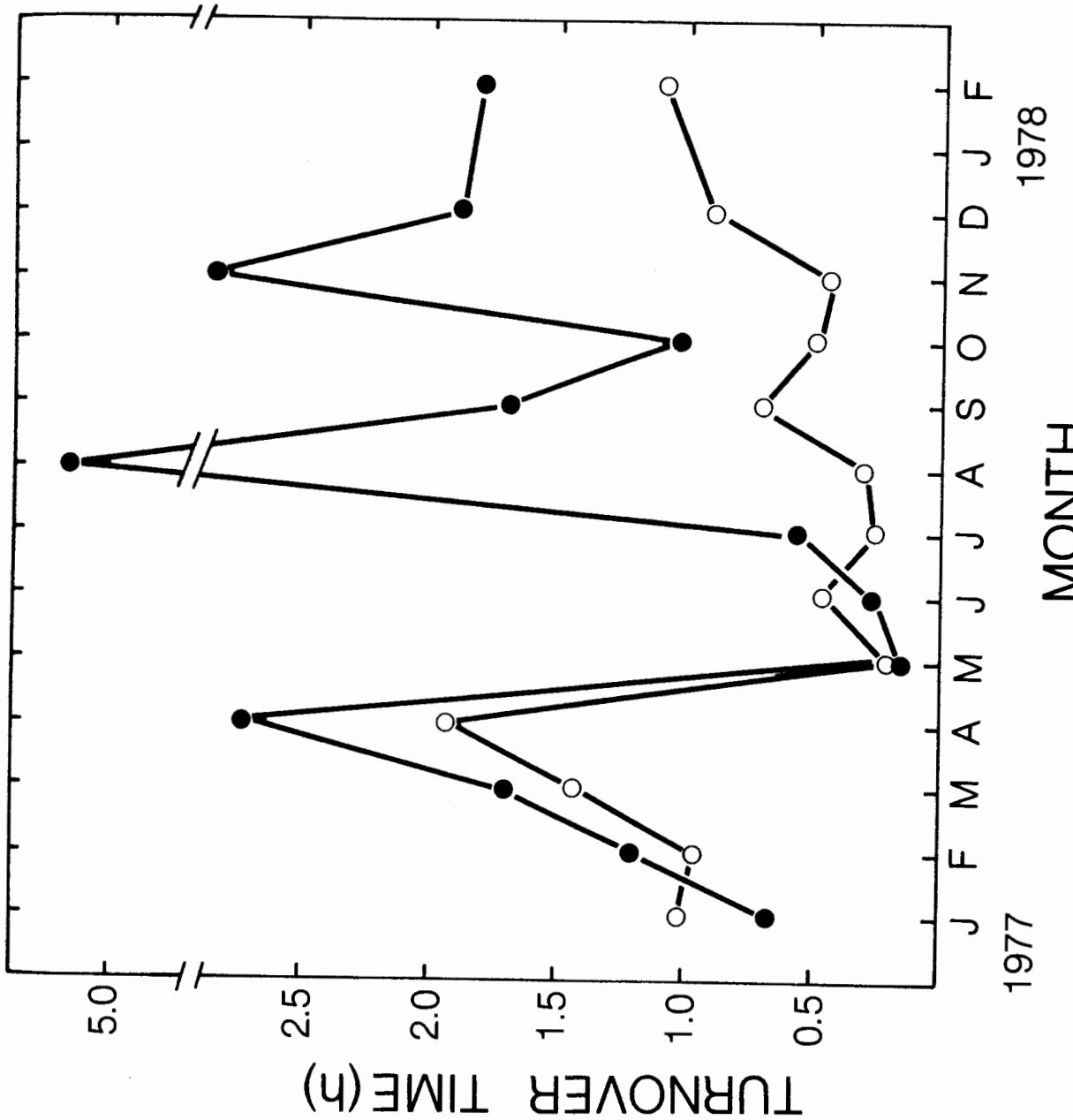

TURNOVER TIME (h)
5.0
2.5
2.0
1.5
1.0
0.5
J F M A M J J A S O N D J F
1977
1978
MONTH

FIGURE 13.

Seasonal variation in alanine $K_t + S_n$ values at Iona Island in intertidal sediment (closed circles) and overlying water (open circles).

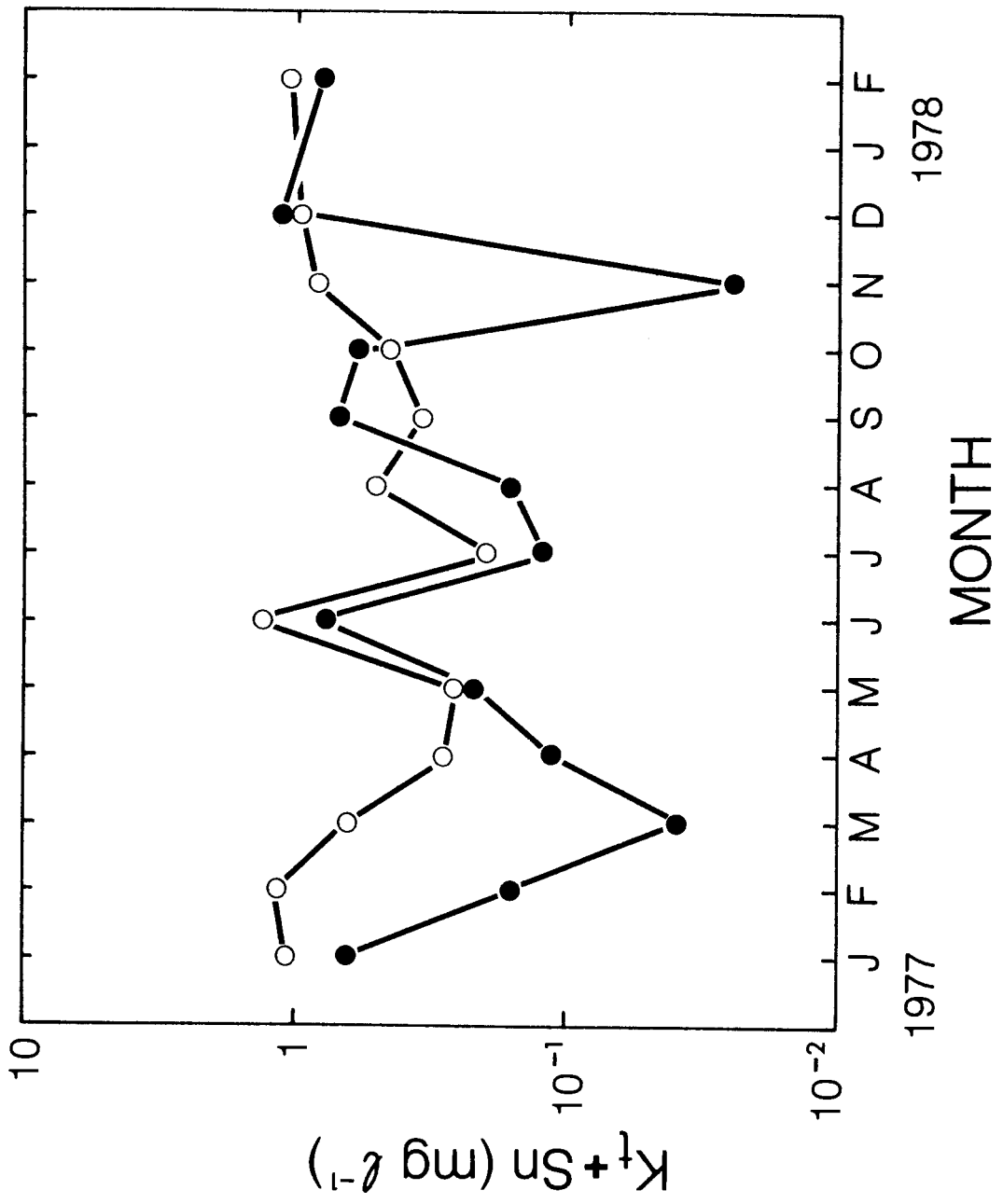

10
1
10^{-1}
10^{-2}
K_t+Sn (mg ℓ^{-1})
J F M A M J J A S O N D J F
1977
1978
MONTH

FIGURE 14.

Seasonal variation in alanine Vmax value in intertidal sediment (closed circles) and in overlying water (open circles) at Iona Island.

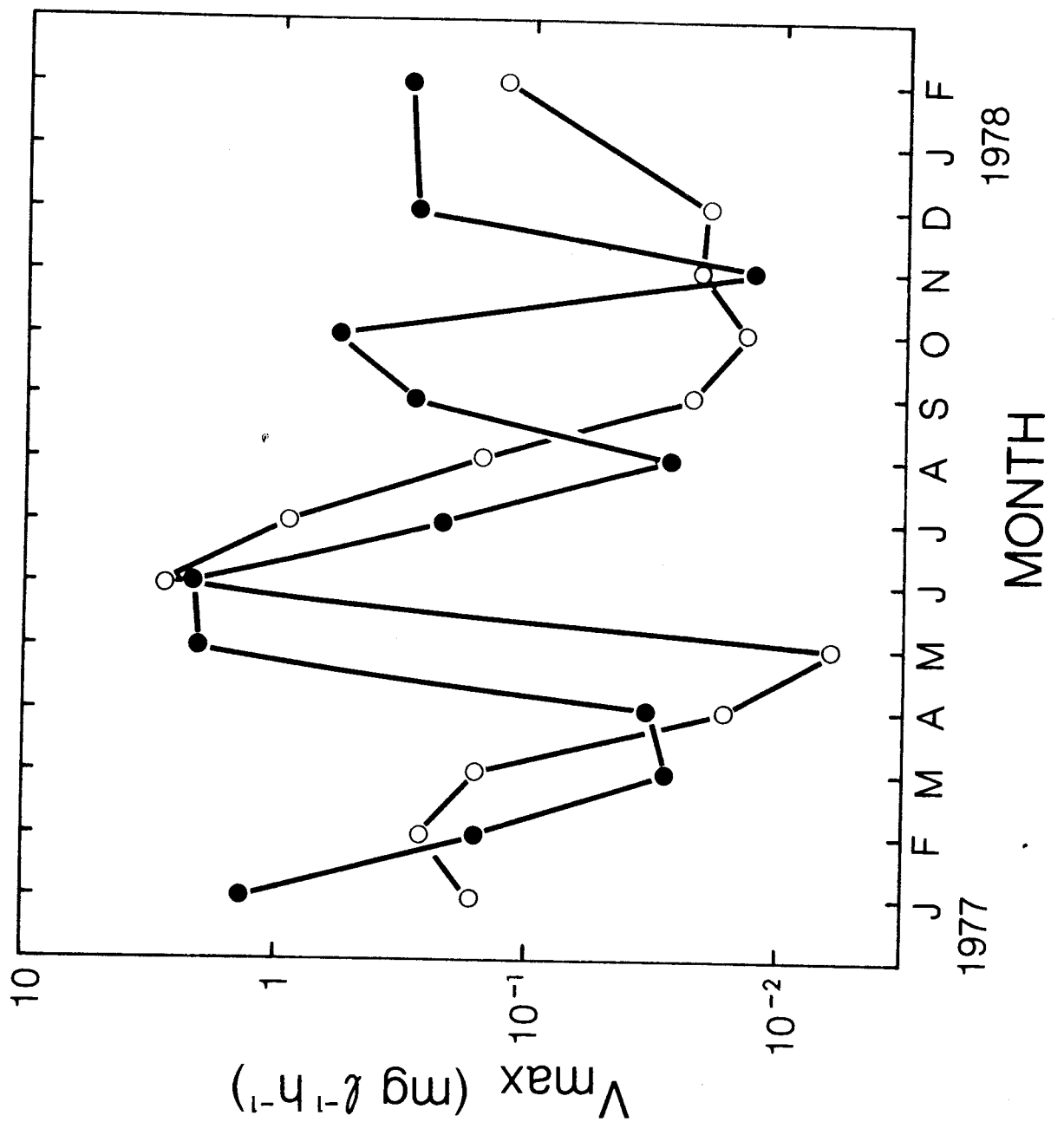

10
1
10^{-1}
10^{-2}
V_{max} (mg ℓ^{-1} h^{-1})
J F M A M J J A S O N D J F
1977
1978
MONTH

FIGURE 15.

P:B ratios of alanine $K_t + S_n$ values per ml of sample versus sample index. See Tables II and III for sample index. Downward spikes indicate greater values in sediment.

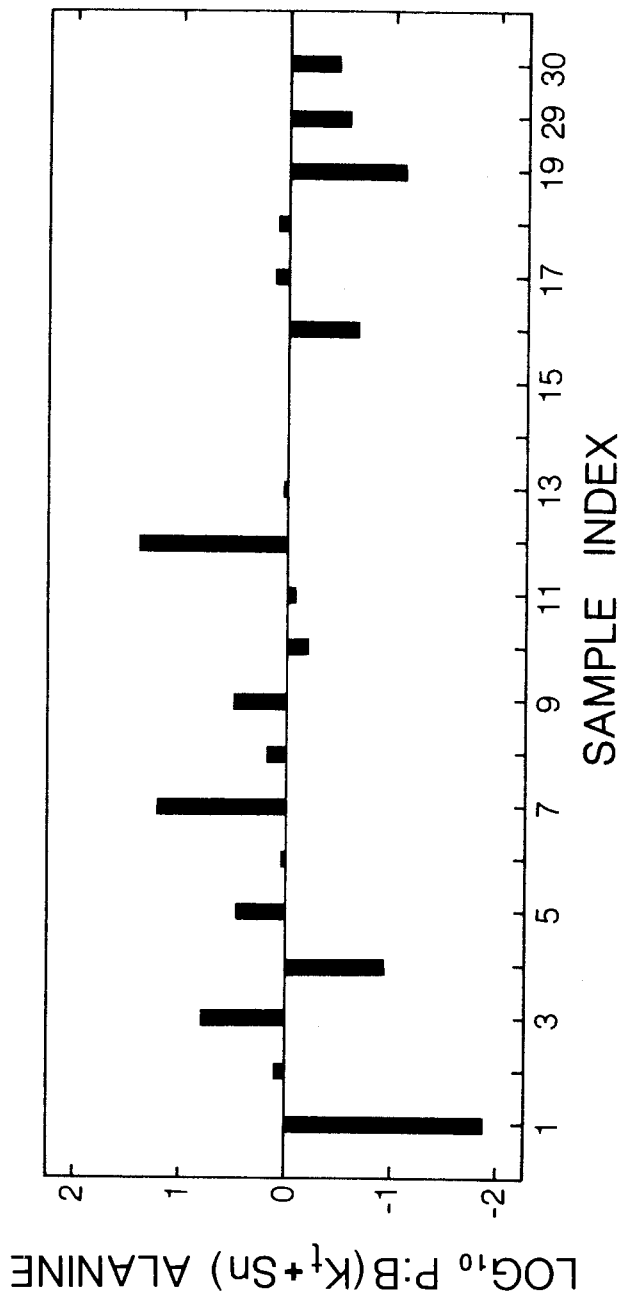

LOG10 P:B(Kt+Sn) ALANINE
2
1
0
-1
-2
1
3
5
7
9
11
13
15
17
19
29
30
SAMPLE INDEX

FIGURE 16

P:B ratios of alanine V_{max} value per ml of sample versus sample index. See Tables II and IV for sample index. Downward spikes indicate greater values in sediment.

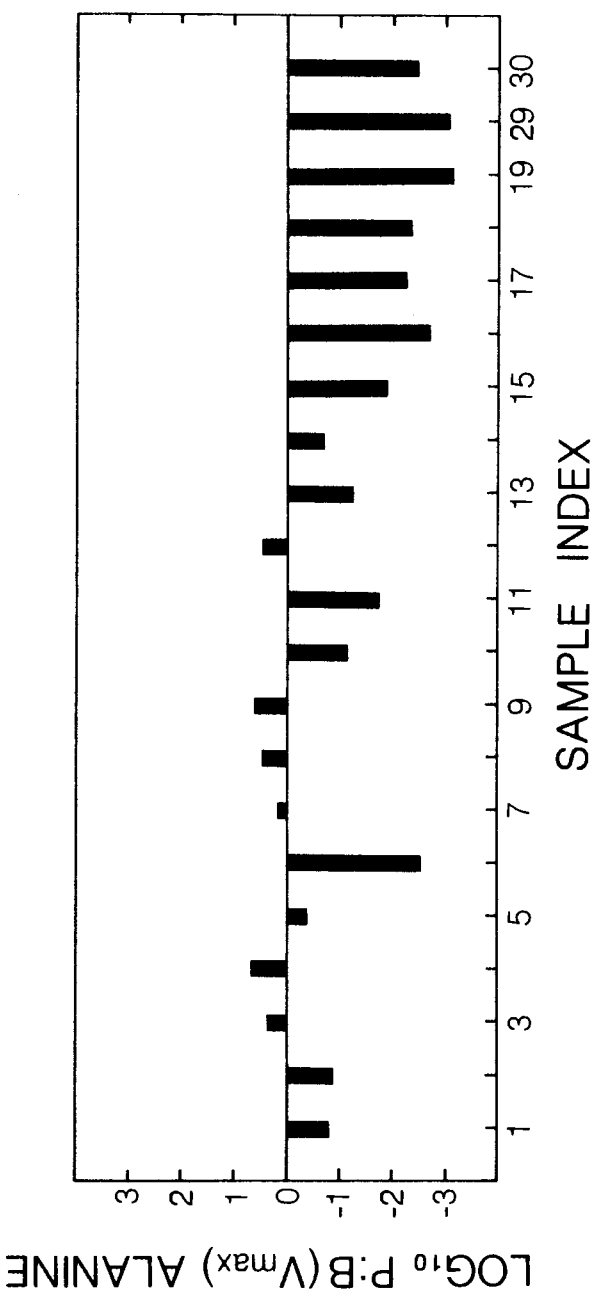

LOG10 P:B(Vmax) ALANINE
3
2
1
0
-1
-2
-3
1
3
5
7
9
11
13
15
17
19
29
30
SAMPLE INDEX

TABLE IV

VALUES OF MEANS AND RANGES FOR GLUCOSE AND ALANINE HETEROTROPHIC ACTIVITIES OF WATERS AND SEDIMENTS FROM (1) OFF IONA ISLAND AND (2) OTHER COASTAL AREAS OF BRITISH COLUMBIA.

	KINETIC PARAMETERS	IONA ISLAND (1)				OTHER COASTAL AREAS (2)	
		GLUCOSE		ALANINE		GLUCOSE	ALANINE
		Average	Range	Average	Range	Range	Range
SEDIMENT WATER	Vmax ($mgl^{-1}h^{-1}$)	$2.6x10^{-1}$	$1.2x10^{-2}$-$1.8x10^{-1}$	$4.8x10^{-1}$	$7.8x10^{-3}$-4.5	$1.1x10^{-3}$-$6.4x10^{-1}$	$2.5x10^{-4}$-$8.0x10^{-3}$
	$K_t + S_n$ (mgl^{-1})	5.8	$9x10^{-1}$-24	1.7	$2.9x10^{-1}$-14.7	$3.5x10^{-1}$-17.5	$3.8x10^{-2}$-$7.8x10^{-1}$
	T_t (h)	34.5	8.2-81	17.5	3.2-57	27.2 - 1100	97 - 290
	Vmax (mgl^{-1} h^{-1})	8.6	$7.6x10^{-1}$-37.5	$7.6x10^{-1}$	$1.1x10^{-2}$-3.3	$5.0x10^{-2}$-8.3	$1.3x10^{-1}$-$5.9x10^{-1}$
	$K_t + S_n$ (mgl^{-1})	4.6	$2.3x10^{-1}$-18	$5.1x10^{-1}$	$3.7x10^{-2}$-1.0	$4.5x10^{-1}$-6.3	$1.5x10^{-1}$-$7.7x10^{-1}$
	T_t (h)	0.7	0.1-1.9	1.6	$1.4x10^{-1}$-5.2	0.2 - 24	0.6 - 2.3

Vmax = Maximum Velocity of uptake

K_t+S_n = Transport Constant plus Natural Substrate Concentration

T_t = Turnover Time.

FIGURE 17

P:B ratios of glucose Vmax/CFU values versus sample index. See Tables I and III for sample index. Upward spikes indicate greater values in overlying water.

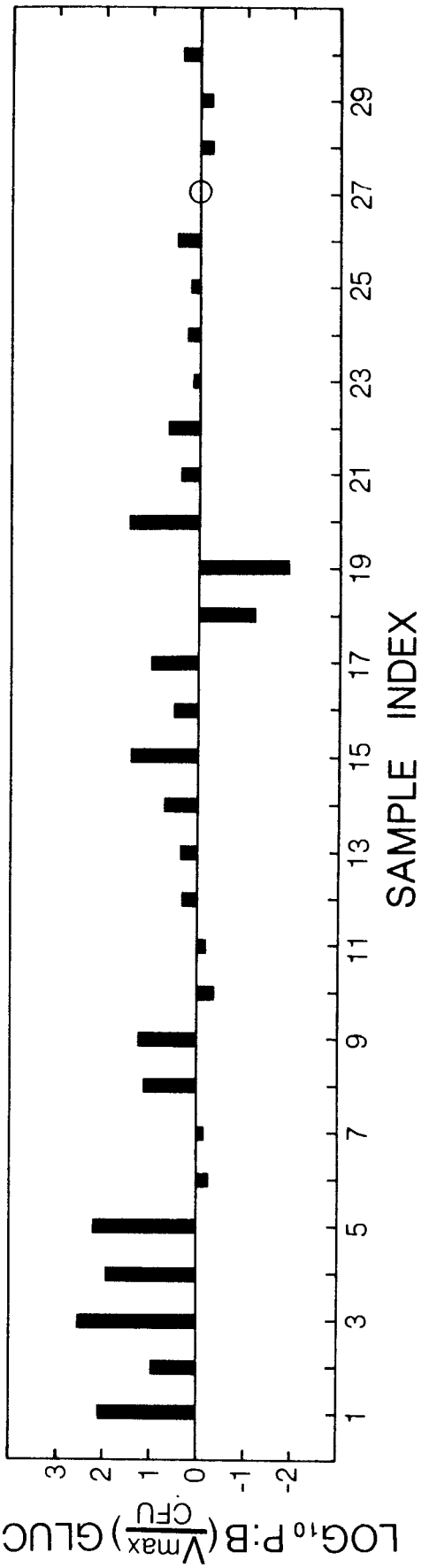

LOG10 P:B (Vmax/CFU) GLUCOSE
3
2
1
0
-1
-2
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
SAMPLE INDEX

FIGURE 18.

P:B ratios of glucose Vmax/ATP values versus sample index. See Tables I and III for sample index. Upward spikes indicate greater values in overlying water.

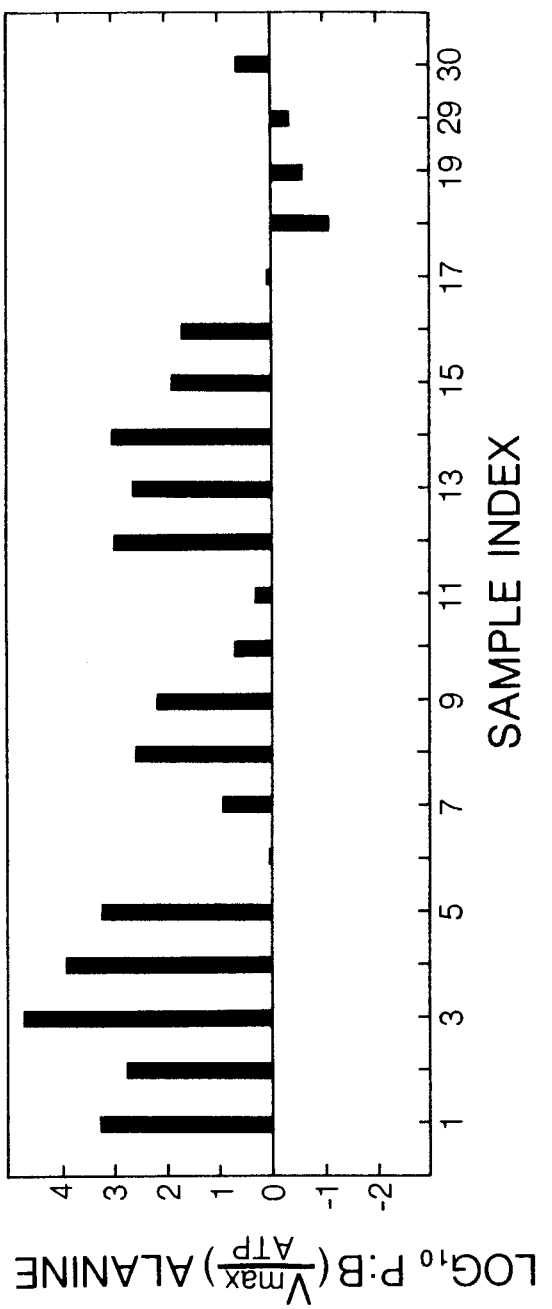

LOG10 P:B ($\frac{V_{max}}{ATP}$) ALANINE
4
3
2
1
0
-1
-2
1
3
5
7
9
11
13
15
17
19
29
30
SAMPLE INDEX

FIGURE 19.

P:B ratios of glucose Vmax/NAB values versus samples index. See Tables I and III for sample index. Upward spikes indicate greater values in overlying water.

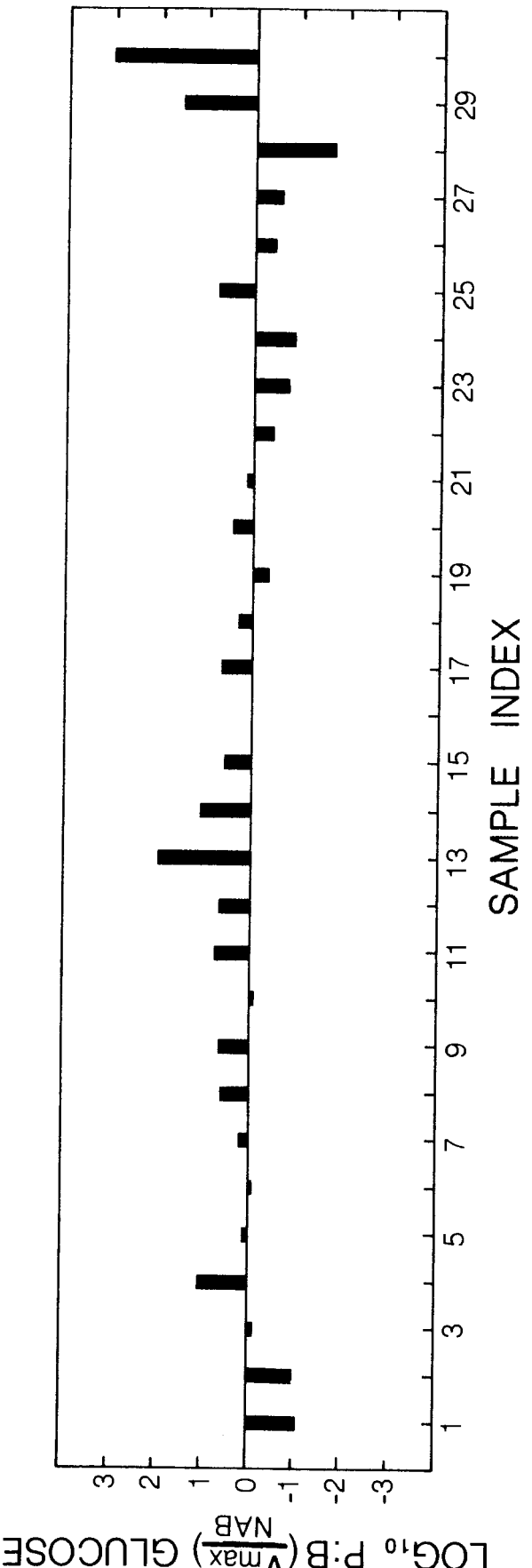

LOG10 P:B (Vmax/NAB) GLUCOSE
3
2
1
0
-1
-2
-3
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
SAMPLE INDEX

FIGURE 20.

P:B ratios of alanine Vmax/CFU values versus sample index. See Tables II and III for sample index. Upward spikes indicate greater values in overlying water.

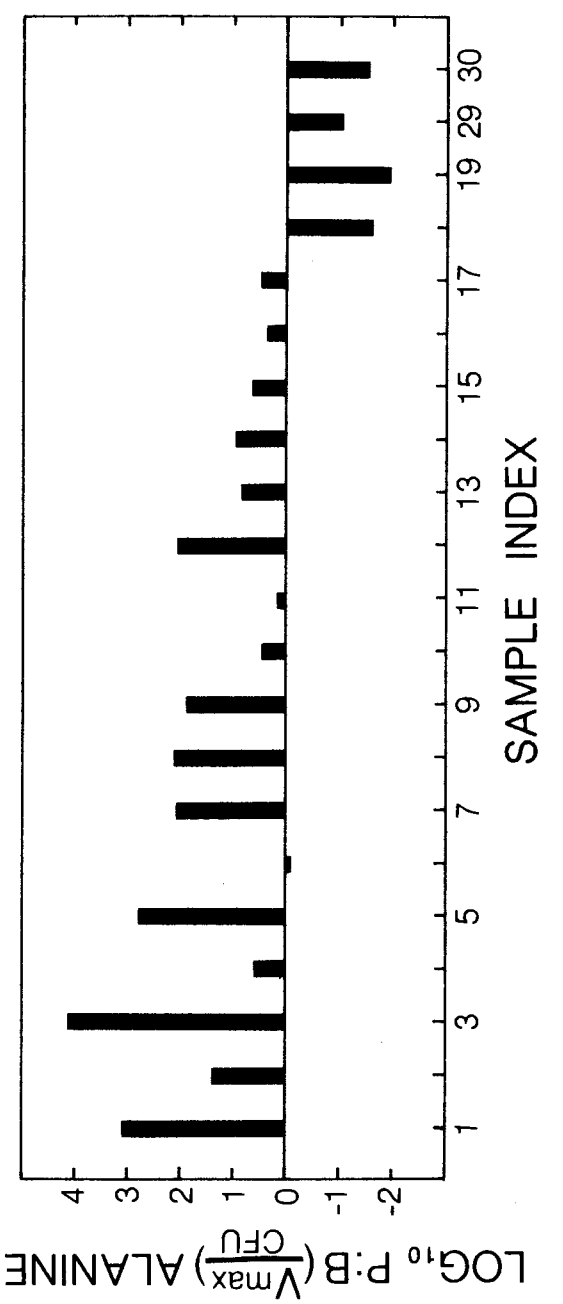

LOG10 P:B (Vmax/CFU) ALANINE
4
3
2
1
0
-1
-2
1
3
5
7
9
11
13
15
17
19
29
30
SAMPLE INDEX

FIGURE 21.

P:B ratios of alanine Vmax/ATP values versus sample index. See Tables II and III for sample index. Upward spikes indicate greater values in overlying water.

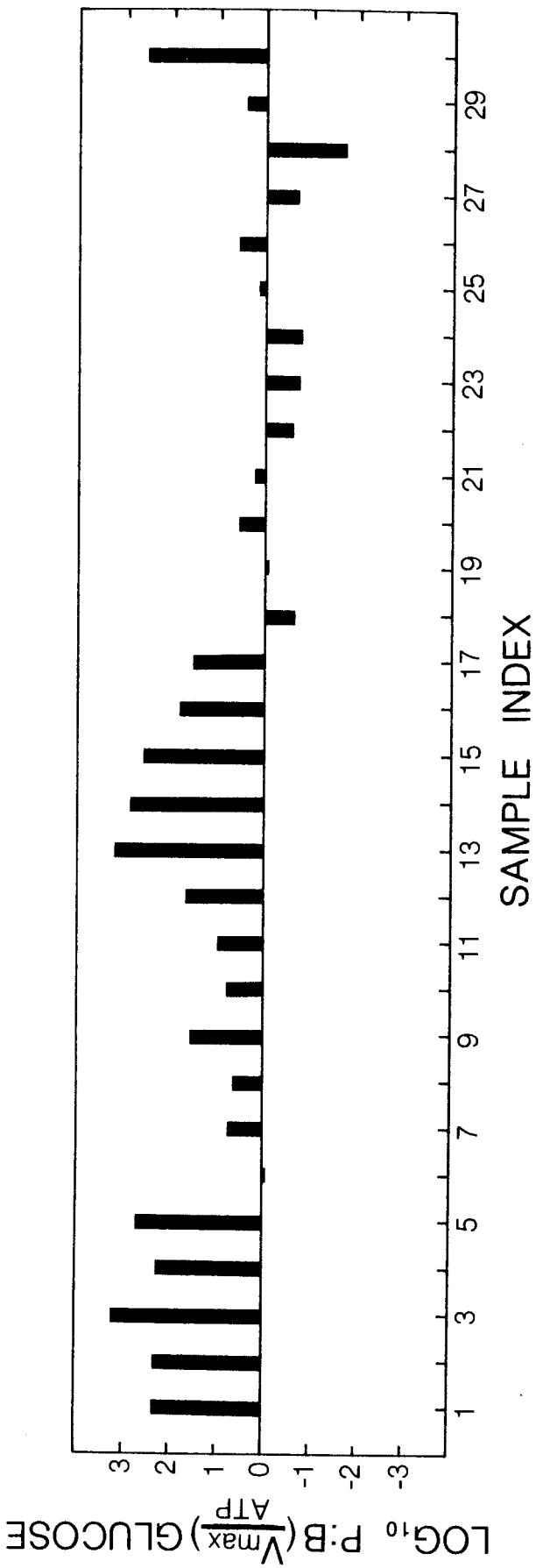
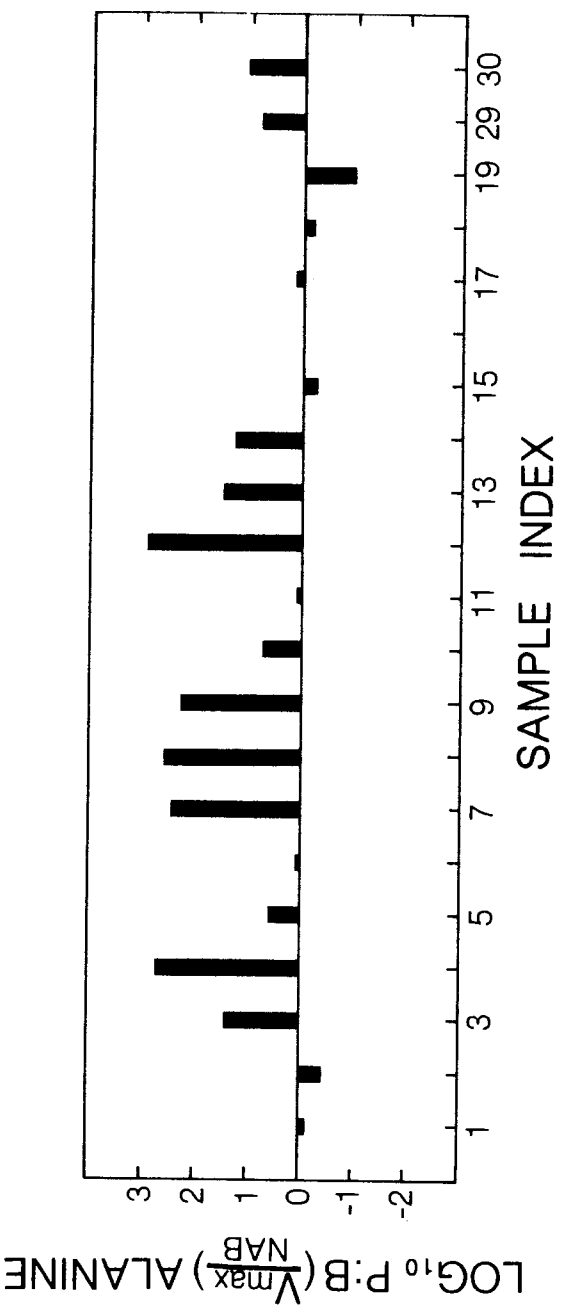

LOG10 P:B ($\frac{V_{max}}{ATP}$) GLUCOSE
3
2
1
0
-1
-2
-3
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
SAMPLE INDEX

FIGURE 22.

P:B ratios of alanine Vmax/NAB values versus sample index. See Tables II and III for sample index. Upward spikes indicate greater values in overlying water.


LOG10 P:B (Vmax/NAB) ALANINE
3
2
1
0
-1
-2
1
3
5
7
9
11
13
15
17
19
29
30
SAMPLE INDEX

NAB basis and 5% on an ATP basis; whereas the value for alanine were 23% of the heterotrophic potential of the water per CFU, 8% on an NAB basis and about 1% on an ATP basis. Although in the other coastal areas the values obtained were more variable, generally heterotrophic activity per functioning unit is higher in overlying water.

The fact that the activity per functioning unit is higher in water, indicates that each viable sediment cell is not as active metabolically as its planktonic counterpart. Since bacteria are adapted to utilization of substrates at low concentrations, and have specific transport mechanisms for substrates such as glucose, Hobbie (1966) has suggested that bacterial activity could exert some control over the concentration of DOC in the water column. Wood (1970) hypothesized that in shallow, well mixed systems, the activities of sediment bacteria control the amount of DOM of the water column. The reduction of activity in sediments could also be due to various environmental factors. The topmost sediment cells, especially in shallow, well mixed systems, as at Iona Island are under heavy stress since this is an intertidal region, which may influence the metabolic state of those populations. A major difference between shallow and deep waters is the greater environmental stability of the latter. The environmental changes in the sediment of shallow marine waters may be drastic with regard to factors such as light, temperature and salinity, which would influence the metabolic state of the microbes. An additional factor affecting the uptake could be oxygen concentration. However, Hall *et al.*, (1972) measured the uptake of glucose at two concentrations (72 and 288 ug/l) under aerobic (11.4 mg O_2/l) and anoxic (0.38 mg O_2/l) conditions and they found that

uptake and mineralization were almost identical under those conditions, indicating that oxygen did not immediately affect the uptake of solutes. However, prolonged anoxic conditions would probably influence heterotrophic activities.

The observation that sediment bacteria have lower glucose and alanine heterotrophic activities per cell than overlying water bacteria may be partially explained by the physical nature of the menstrum. Diffusion rates of metabolites to and waste products away from cells in sediments would probably be less than for cells in overlying water.

Both glucose and alanine $K_t + S_n$ values are similar in water and sediment, but DOC values in sediments are approximately one order of magnitude greater in sediment than in water. If these two compounds are representative of the relative amounts of non-refractile organic matter in both environments then total sediment DOC may be more resistant to assimilation or metabolization by the microorganisms in sediments. Dietz et al., (1976) found that heterotrophic activity per CFU was also greater in the plankton, when this comparison is done with the neuston, because the near surface area is recognized as a somewhat hostile environment for bacteria due to such factors as intense solar radiation, high redox potential, and high surface tension.

"The uptake of solutes by mixed sediment systems provides useful comparative information on how various parameters affect uptake and the relative variations in seasonal fluctuation, but the physical structure of the sediment is destroyed and the values cannot be directly applied to the intact benthic community" (Hall et al., 1972)

Correlation coefficient (r) were computed for all the variables assayed when glucose was used as the substrate for heterotrophic potential assay (Table V). In most instances, correlations were low, although significant correlations existed in some cases. In overlying waters the number of active bacteria correlated to a significant extent with V_{max}, whereas this correlation was not observed using sediment (r=.31). Several other weak correlations were noted as follows (1) overlying water: V_{max} - $K_t + S_n$ (r=.50), (2) sediments: $V_{max} - K_t + S_n$ (r=.55); ATP - $K_t + S_n$ (r=.62).

The sediment and overlying water sample parameters which were compared in Table V come from a variety of coastal sites off British Columbia (figure 1). However, there may have been an inherent sample variability which may have influenced the extents of correlations. To check this possibility, correlation coeffi - ients were determined for the fourteen samples which were assayed at one site, Iona Island (Table VI). Generally, these correlations were more numerous and greater. The r value between glucose V_{max} and $K_t + S_n$ for sediment at Iona Island become .74 as compared for .55 for all sample sites. Other significant correlations which became apparent were (1) overlying water: ATP - $K_t + S_n$, r=.70; POC - $K_t + S_n$, r=.56 and POC - CFU, r=.63, and (2) sediment: ATP - V_{max}, r=.63; CFU - T_t, r=.81; NAB - ATP, r=.67 and ^{o}C - DOC, r=.53.

The general pattern which averages from these comparisons is that the number of bacteria which actively metabolize glucose (NAB) tended to be proportional to V_{max} and $K_t + S_n$ in overlying waters whereas only glucose heterotrophic activities and glucose

concentration were significantly correlated in sediments.

Meyer-Reil (1978) also studied fluctuations and interactions of several microbiological parameters in sediments and overlying waters at three locations in the Baltic Sea. He found that significant relationships existed between the bacterial cell number and glucose concentrations and uptake rates in overlying waters as well as sediments.

TABLE V

CORRELATION COEFFICIENTS

FOR RELATIONSHIPS BETWEEN THE OVERLYING WATER AND SEDIMENT VARIABLES WHEN GLUCOSE WAS USED AS A SUBSTRATE FOR HETEROTROPHIC ACTIVITIES.

(See text for definitions of abbreviated symbols)

* significant at 0.05 level

** significant at 0.01 level

Overlying water

	$K_t + S_n$	V_{max}	T_t	CFU	ATP	NAB	DOC	POC	^oC
$K_t + S_n$	1.0	.50	-.21	.11	.37	-.43	-.19	-.11	.37
V_{max}		1.0	-.38	.33	-.17	.67**	-.07	.45	.19
T_t			1.0	-.31	-.10	-.34	.49	-.22	.25
CFU				1.0	-.14	.39	-.07	.28	.32
ATP					1.0	-.27	.14	.11	.36
NAB						1.0	.06	.45	-.11
DOC							1.0	-.26	-.09
POC								1.0	.42
^oC									1.0

Sediment (Student distribution)

	$K_t + S_n$	V_{max}	T_t	CFU	ATP	NAB	DOC	POC	^oC
$K_t + S_n$	1.0	.55*	.01	.20	.62*	.33	-.33	.42	.17
V_{max}		1.0	-.19	.13	.13	.31	-.18	.24	.38
T_t			1.0	-.19	.19	-.18	-.10	.04	-.22
CFU				1.0	-.03	.04	-.21	.37	.15
ATP					1.0	.06	.51*	.29	.41
NAB						1.0	.01	.07	.42
DOC							1.0	.09	.23
POC								1.0	.07
^oC									1.0

TABLE VI

CORRELATION COEFFICIENTS FOR RELATIONSHIPS BETWEEN THE OVERLYING WATER AND SEDIMENT VARIABLES FOR THE IONA ISLAND SITE WHEN GLUCOSE WAS USED AS A SUBSTRATE FOR HETEROTROPHIC ACTIVITIES. (See text for definitions and abbreviated symbols)

* significant at 0.05 level

** significant at 0.01 level

Overlying water

	$K_t + S_n$	V_{max}	T_t	CFU	ATP	NAB	DOC	POC	^oC
$K_t + S_n$	1.0	.35	.35	.12	.70**	.25	-.13	.56*	.35
V_{max}		1.0	-.48	.12	-.01	.52*	.30	.42	.25
T_t			1.0	.12	.39	-.35	-.25	.18	.47
CFU				1.0	.39	.05	.08	.63*	.64*
ATP					1.0	-.22	.02	.24	-.23
NAB						1.0	.15	.33	.38
DOC							1.0	.33	.37
POC								1.0	.25
^oC									1.0

Sediment

	$K_t + S_n$	V_{max}	T_t	CFU	ATP	NAB	DOC	POC	^oC
$K_t + S_n$	1.0	.74**	.10	.17	.70**	.24	.03	.44	.20
V_{max}		1.0	.43	-.22	.63*	-.33	.04	.11	.34
T_t			1.0	.81**	.27	.01	.03	-.12	-.26
CFU				1.0	-.10	-.25	.42	.39	.03
ATP					1.0	.67*	-.15	.12	.30
NAB						1.0	-.10	-.06	.36
DOC							1.0	.36	.53*
POC								1.0	.23
^oC									1.0

CONCLUSION

This study has shown that bacterial biomasses and glucose and alanine heterotrophic potentials of sediments are greater than that of overlying waters. However, when activities per cell are compared; bacteria in the overlying waters are on a per cell basis more active than those in surface sediments. This may be a function of the physical structure as well as the amount of available nutrients in the two environments.

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CURRICULUM VITAE

JORGE A. CHOCAIR
Simon Fraser University
Department of Biological Sciences
Burnaby, British Columbia.

Date and Place of Birth: June 7th, 1943, Santiago, Chile.

Marital Status: Married.

University Education:

Pedagogy in Biology: 1963-1967. University of Chile. Faculty of Philosophy and Education.
Thesis: "Factors de crecimiento en vegetales" (Growing factors in plants").
Supervisor: Dr. Juan Ibanez.

Marine Biology: 1963-1968 - University of Chile.
Thesis: "El Genero Genypterus en Aguas de Chile." (Study of Genus Genypterus in Chilean Seawaters).
Supervisor: Dr. Alberto Nani.

M.Sc. Graduate Student: 1975-1978 - Simon Fraser University, Department of Biological Sciences.

Scholarships and Awards:

1977: Simon Fraser University Presidency Scholarship.

PROFESSIONAL AND TEACHING EXPERIENCE.

1975-1978: Teaching Assistant, Department of Biological Sciences, Simon Fraser University.

Sept. 1973- May, 1974: Marine Biologist at Benmar Co., Ltd. (Private oyster hatchery) in Chile.

Jan. 1971- Sept. 1973: Director of the Fish and Game Division of the Ministry of Agriculture, Chile.

The position involved the planning, controlling and developing of different projects in relation to fisheries. Some of the projects under this Direction were: Salmon and Trout propagation and Acclimatization Program with the Japanese Government; Production of oysters seeds in the Division's Hatcheries for the private industry. Trout Propagation through the Chilean freshwaters; Control of the exploitation of the Marine species; Control of the endangered aquatic species, etc.

Other activities of the Director included:

1. To act as Vice-President of the Fisheries Development Institute Board;
2. Vice-President of the Marine and Freshwater Development Commission;
3. To attend the National and International meeting where its presence was required.
4. To assist the Foreign Ministry in relation to the Law of the Sea Conference, as well as in any international event involving fisheries.

April, 1969 - Dec. 1970: Lecturer at the University of the North Antofagasta - Chile.

Head of the Marine Biology Laboratory, Department of Fisheries, University of the North Antofagasta, Chile.

1967 - 1969: Part-time Jobs:

1. Teacher of Biology and Sciences at High school in Vina Del Mar, Chile.
2. Research Assistant in Plant Physiology at the University of Chile, Valparaiso, Chile, working for Dr. Juan Ibanez. The job involved lab work in relation to the study of growth of different natives

species using hormones.

3. Research Assistant at the Ichthyology Lab., at the Marine Biological Station, University of Chile, Valparaiso, Chile, working for Dr. Alberto Nani. The job involved field and lab work in relation to Taxonomical studies with different families of fish.

PAPERS:

1972: Chocair, J. and J. Hurtubia, "Principal Human Environmental Problems in Chile. (In relationship with the use and management of natural resources) presented to the Symposium "United Nations for Biosurvival", organized by the National Wildlife Federation (Washington, D.C.) in Stockholm, Sweden.

1970: Chocair, J. Echinoidea of the Antofagasta Bay. In : Informe de Ciencia y Tecnologia Pesquera #2, Univ. del Norte, Antofagasta, Chile.

1970: Asteroidea of Antofagasta Bay. In: Informe de Ciencia y Tecnologia Pesquera # 1, pp. 21- 32. Universidad del Norte, Antofagasta, Chile.

1970: Benthic Exploration of the Arica Bay. In : Informe de Ciencia y Tecnologia Pesquera # 3, Univ. del Norte, Antofagasta, Chile.

Report to the Dept. de Accion Social de la - Universidad de Chile, About the Fisheries Marine Resources of Calbuco (South of Chile, 1969).

Different Communications and reports about the Marine and Freshwater fishing resources stating the state of exploitation possibilties, etc.

OTHER PROFESSIONAL ACTIVITIES:

Member Fishery Chilean Commission to Europe, 1972, visiting Sweden, Denmark, France, Spain.

Chilean delegate to the Technical Conference on"Fishery Management and Development" in Vancouver, Canada, February, 1973.

Participant in the Symposium "United Nations for Biosurvival", organized by the National Wildlife Federation of Washington, D.C. in Sweden, 1972.

Chilean delegate to the U.N. Conference "Human Environment, Sweden, 1972.

Member of the Industrial Fishery Development Commission. - 1971 - 1973, Chile.

Attendance to the third Latin American Congress of Zoology, Santiago, Chile, 1965.

Courtesy visit to Japan, invited by the Japanese Government in relation with the Salmon projects, June, 1973.

Lecturer of Marine and Freshwater Resources in Summer Courses at Technical University of Chile, 1973.

Membership in Scientific organizations: Canadian Society of Microbiologists.

EXTRACURRICULAR ACTIVITIES AND INTERESTS:

Teacher of Spanish for Adults. Centenial School, Coquitlam, B.C.

Photography, soccer, guitar.