DEPARTMENT OF ENVIRONMENT
ENVIRONMENTAL PROTECTION SERVICE
PACIFIC REGION

RECEIVING ENVIRONMENT CONDITIONS IN THE VICINITY OF FRENCH CREEK SEWAGE OUTFALL, Vancouver Island, B.C., (1977-1980)

Regional Program Report 82-12

by

W.M. Pomeroy

October, 1982

ABSTRACT

The impact of the French Creek sewage discharge on the receiving environment was monitored by the Envrionmental Protection Service from 1977 to 1980. Water quality characteristics of salinity, temperature, dissolved oxygen and nutrients, and benthic characteristics of sediment particle size, organic content, heavy metal concentration and benthic fauna were investigated. The Pisces IV submersible was used to examine physical features of the diffuser, immediate effects on the substrate and obvious responses of the organisms to the presence of the discharge.

Results to 1980 suggested some minor effects which could be attributed to the discharge of effluent from a biological secondary treatment plant. Water quality characteristics were typical of the Strait of Georgia showing normal seasonal variations. Distribution patterns of sediment particle size reflected a natural rather than an outfall induced situation. Sediment organic content measured in 1980 showed a significant increase over the 1977 pre-discharge levels, an obvious effluent effect. An overall increase in copper, manganese, iron and nickel in sediments at most stations was also suggestive of a discharge effect.

Polychaete worms were the most common form of infauna, being recorded in great abundunce over the entire study area in 1977. Species density was greatest east of the outfall. Evenness or the distribution of individuals amongst species was high (0.679 to 0.850) along with species diversity index. Pre-operational levels (1977) of heavy metals in the tissue of english sole varied from station to station with lead and cadmium below detection. A further sampling in 1980 indicated elevated levels of iron and zinc suggesting a possible discharge effect. Further sampling of more resident species is required to confirm this effect.

Observations from Pisces IV submersible dives indicate no major adverse physical effect on the substrate in the vicinity of the diffuser

Invertebrate colonization of the pipe and the presence of large numbers of rockfish were noted in a dive about 1½ years after outfall installation. Little non-biodegradable debris was present. One point to note was the undercutting occurring at some points along the outfall and diffuser pipe. Future examinations should be made to note any weakening.

RÉSUMÉ

De 1977 à 1980, le Service de la protection de l'environnement a étudié les effets de la décharge des eaux usées à French Creek sur le milieu récepteur. L'étude a porté sur les aspects suivants: qualité de l'eau, salinité et température, proportion d'oxygène dissous, éléments nutritifs, qualité des sédiments benthiques: granulométrie, teneur en matières organiques, taux de concentration en métaux lourds et faune benthique. On a procédé à des plongées à l'aide du Pisces IV afin d'examiner les caractéristiques physiques du diffuseur, ses effets directs sur le substrat et les réactions les plus caractérosées des organismes en présence de la décharge.

Les résultats obtenus jusqu'en 1980 révèlent certains effets mineurs que l'on peut attribuer au déversement des effluents prvenant de l'usine d'épuration biologique. La qualité de l'eau présentait les caractéristiques saisonnières typiques du détroit de Georgia. La répartition des sédiments selon la dimension des particules était un phénomène naturel plutôt que provoqué par la présence de la décharge. Le contenu organique des sédiments mesuré en 1980 était en proportion sensiblement accrue par rapport aux proportions relevées avant le déversement des effluents, en 1977, ce qui révèle le rôle joué par ces derniers. L'augmentation généralisée de la proportion du cuivre, manganèse, fer et nickel relevée dans les sédiments de la plupart des points choisis révèle également l'effet des effluents.

On a constaté que les polychètes constituaient l'espèce la plus communément recontrée, 1977, dans toute la zone étudiée. La densité de l'habitat était la plus forte à l'est de l'exutoire. On a relevé un indice élevé (de 0.679 à 0.85) dans la répartition des sujets par rapport aux espèses ainsi qu'un indice élevé de diversité des espèces. Avant le déversement des effluents (1977), les taux de concentration des métaux lourds dans les tissus de la sole anglaise variaient d'un point à un

autre, les taux de plomb et de cadmium étant même trop faibles pour pouvoir être mesurés. Un échantillon pris en 1980 a révélé une augmentation du taux de fer et de zinc, conséquence possible du déversement d'effluents. Il est bon d'examiner un plus grand nombre d'espèces autochtones afin de vérifier cette conclusion.

D'après les observations faites de Pisces IV on n'a relevé aucun effet physique négatif d'importance sur le substrat situé près de l'exutoire. Lors d'une plongée effectuée un an et demi après l'installation de l'exutoire, on a constaté la formation de colonies d'invertébrés dans la canalisation et relevé la présence d'un grand nombre d'achigans de mer. La quantité des débris non biodégradables était négligeable. Il est bon de signaler un certain affouillement à certains endroits situés le long de l'exutoire et de la canalisation de décharge. D'autres examens devraient être entrepris afin de déceler tout fléchissement des installations.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

SUMMARY

1) Studies were undertaken to assess the effect biological secondary treated domestic sewage effluent discharged through a deep marine outfall has on the receiving environments in the French Creek area. Parameters examined included water quality, physical-chemical-biological characteristics of the sediment, characteristics of benthic fauna and visual examination of the bottom using the Pisces IV submersible.

2) Water quality profiles of salinity, temperature, dissolved oxygen and dissolved nutrients did not demonstrate any effluent discharge effect. Temporal variations noted during the study were attributed to normal seasonal fluctuations.

3) Sediments in the most easterly portion of the study area had higher percent composition of the 62.5 μm fraction compared to other areas throughout the study. Also, a general trend to a decreased percent composition of the 250-62.5 μm fraction and a concomitant increase in other fractions was recorded. Alteration in sediment size fractions cannot be linked to an effluent discharge effect at this time.

4) Sediment organic content was highest in the easterly portion of the study area. At all stations, organic composition had increased by 50 to over 110% by the last survey in 1980. An effluent discharge effect was evident for this parameter.

5) A general increase in the concentration of certain heavy metals (Cu, Mn, Fe, Ni) in sediments throughout the study area were recorded over pre-operational levels. Stations farthest east of the outfall had higher background levels and the highest concentrations in subsequent years of plant operation. The overall increase in heavy metals suggests an effluent discharge effect.

6) The polychaete worms Prionospio steenstrupi and Aricidea neosuecica were the most common form of infauna, being recorded in great abundance over the entire study area in pre-operation grab sampling.

7) Statistical analyses of pre-operational invertebrate data indicated species density to be greatest east of the outfall ranging from 25 to 37 species. Evenness values ranged from 0.679 to 0.850 and diversity from 3.229 to 4.396. Diverse invertebrate communities are indicated with no significant dominants.

8) Pre-operational (1977) levels of certain heavy metals in Parophrys vetulus (english sole) tissue varied from station to station. Lead and cadmium were below detection.

9) An effluent discharge effect is suggested in comparing 1977 tissue metal levels in english sole with those from 1980. Copper and mercury decreased by one half while zinc and iron increased by at least a factor of two. Further collections and analyses of other fauna are required to confirm this effect.

10) Pisces IV submersible dives at the time of diffuser installation in 1978 indicated the presence of a clean sand-mud substrate. A 1980 dive showed changes in several areas:

    1) The pipe had been colonized by tunicates, urchins and serpulid worms.
    2) Rockfish were present in large numbers around the pipe.
    3) Undercutting has occurred with the pipe being completely suspended in same areas. However, the area in the vicinity of the pipe did not appear to be adversely affected by the discharge (ie. no buildup of non biodegradable debris or bacterial growths).

1 INTRODUCTION

French Creek, (49°20.12'N, 124°21.10'W) on the east coast of Vancouver Island approximately 4.6 km northwest of Parksville, is the site of a deep sea domestic sewage outfall servicing the northern portion of the Nanaimo Regional District (Fig. 1). The secondary treatment facility began operation in June, 1978 discharging chlorinated effluent through a 2,438 m outfall ending in a diffuser 61 m below low water. Chlorination was stopped in October 1979 when it was found to be unnecessary for the maintenance of shellfish growing water quality.

The planned capacities and discharge volumes for the sewage treatment plant are detailed in a report prepared by Dayton and Knight Ltd. (1977). Stage 1, now in operation, serves 12,000 people with an average flow of 1.2 MIGPD. This value is to be doubled in Stage 2 and again in Stage 3 as population increases warrant implementation.

The Environmental Protection Service has completed three surveys to date at French Creek. Background data were collected in 1977 prior to plant startup. The receiving environment was subsequently monitored for impacts in 1978 and again in 1980. The parameters of interest on each survey included physical oceanographic (temperature, salinity, dissolved oxygen and nutrients) and sediment characteristics (particle size, organic content, heavy metal content, and benthic fauna). Trawling was also conducted to determine species composition of the epibenthic and bathypelagic faunal community and to collect material for tissue heavy metal analysis. Dives were made using the Pisces IV submersible to visually inspect the physical condition of the diffuser and surrounding habitat.

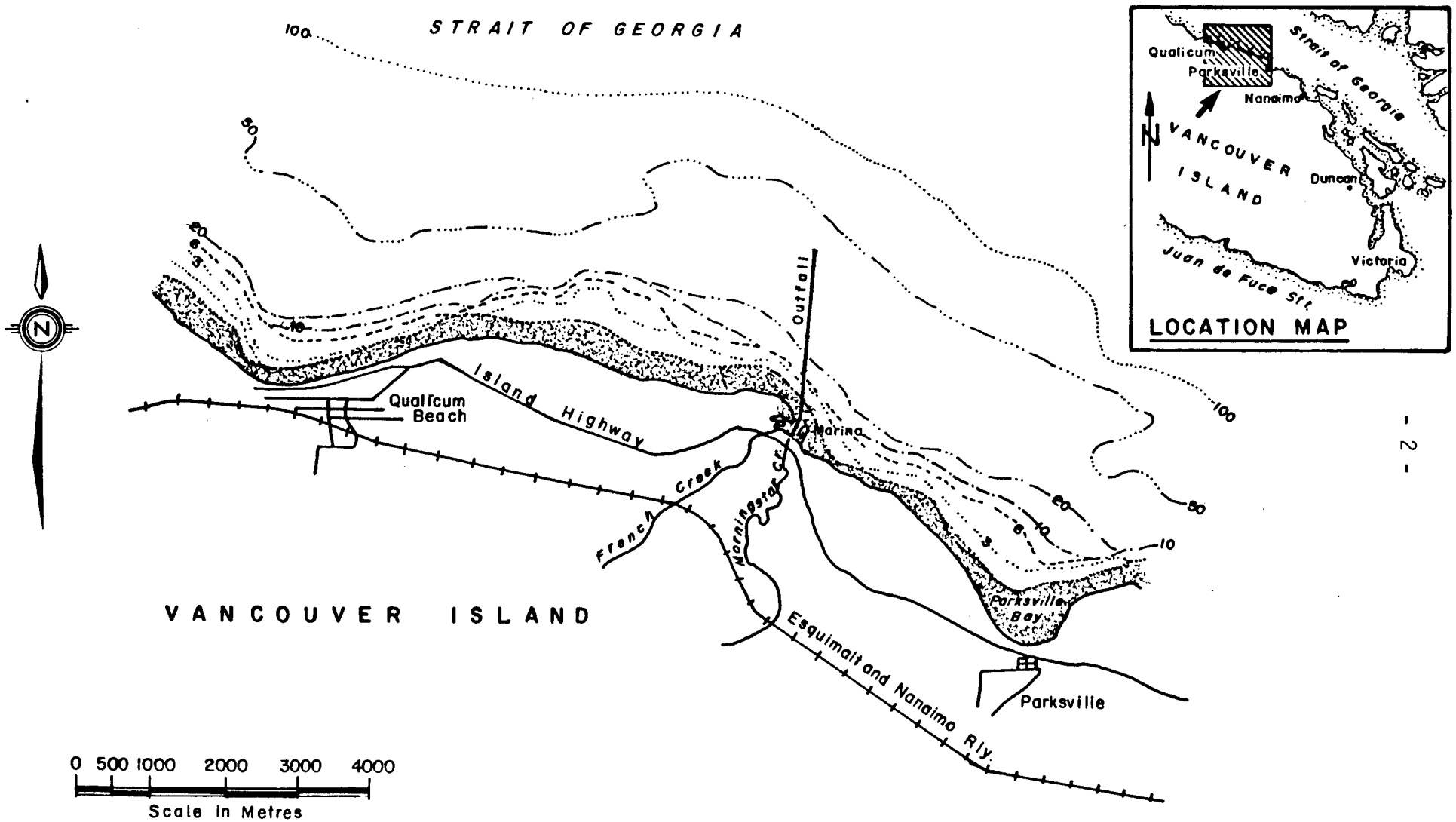

FIGURE 1 LOCATION MAP AND STUDY AREA

2 MATERIALS AND METHODS

Oceanographic and benthic sampling at French Creek were conducted August 23-24, 1977 and November 12, 1980 from the research vessel C.S.S. VECTOR. On April 27, 1978 the PANDORA II was used as a base for sampling. Also on this date, and March 17, 1980 dives were made with the Pisces IV submersible.

Station positions as located by radar are given in Appendix I.

2.1 Oceanographic Sampling

Oceanographic sampling was done at stations indicated on Figure 2. Water samples were obtained from selected depths using N.I.O. bottles with paired, protected reversing thermometers. Temperatures were recorded within five minutes of recovery and calculated to the temperature at depths using the equation of Sverdup et al (1946). Salinity values were determined at the laboratory on a Guildline salinometer (Autosal Model 8400). Dissolved oxygen was measured on board ship using the azide modification of the Winkler method (Swingle and Davidson, 1979). Percent saturation of oxygen was calculated using the equation of Gameson and Robertson (1955).

Water samples collected for nutrient analysis were stored frozen (Strickland and Parsons, 1971). Nitrate, nitrite, ammonia, total phosphate (1978, 1980) and ortho-phosphate (1977, 1980) concentrations were determined at the EPS chemistry laboratory as described by Swingle and Davidson (1979).

2.2 Benthic Sampling

Stations occupied for benthic grab sampling are shown on Figure 3.

Surface sediments were sampled using a Smith-MacIntyre grab sampler. After noting visual characteristics, material in the grab was mixed until homogeneous and sub-samples taken for particle size, organic

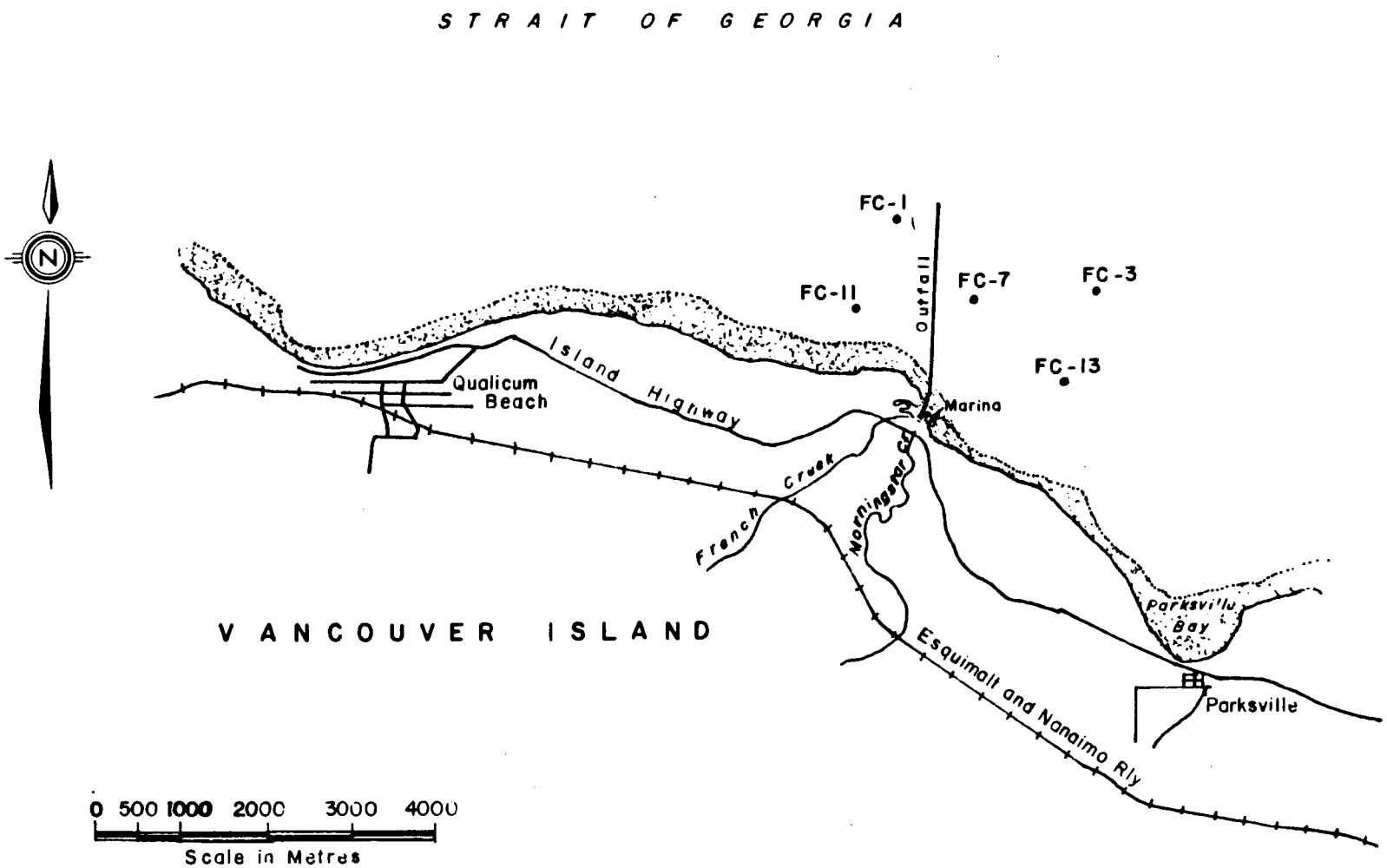

FIGURE 2 OCEANOGRAPHIC SAMPLING STATIONS

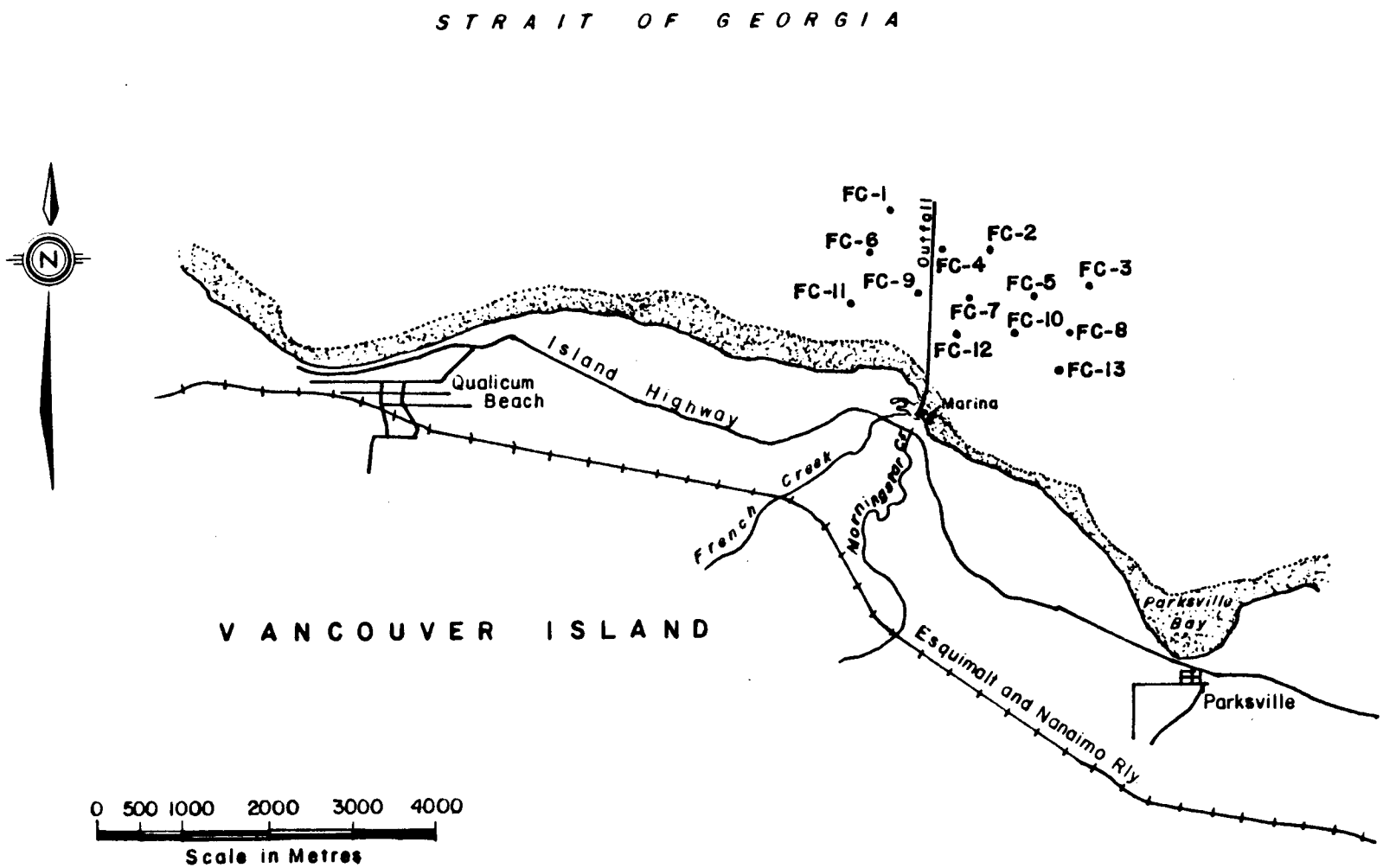

FIGURE 3 BENTHIC SAMPLING STATIONS

carbon content and heavy metal analysis. These were placed in "whirl-pak" bags and stored frozen.

In 1977, sediments to be analyzed for heavy metals were thawed, air dried, disaggregated and passed through an 80 mesh (2.5 phi) nylon sieve. Portions of the less than 80 mesh fraction were sent to Dr. W.K. Fletcher (U.B.C., Geology Department) for analysis. Samples were also digested in a 4:1 nitric-perchloric acid mixture, evaporated to dryness over an air bath, taken up in 1.5 ml HCl and analyzed for cobalt (Co), copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), lead (Pb) and zinc (Zn) on a Perkin Elmer 303 Atomic Absorption Spectrophotometer.

Sediment heavy metals and mercury (Hg) analysis in 1978 and 1980 were done by the EPS chemistry laboratory as described by Swingle and Davidson (1979). Heavy metal methods were similiar to those used in 1977.

Sediment particle size distribution was determined by wet sieving through three sizes of screens (500 μm, 250 μm and 62.5 μm). The fraction retained on each screen was weighed and expressed as a percentage of the total sample weight.

Organic content of sediment samples was determined using an acid digestion technique (Swingle and Davidson, 1979). Results are expressed as percent organic.

Benthic invertebrates (infauna and epifauna) were collected, identified and enumerated in 1977. Three litres of the original grab sample were removed and sieved through a 500 μm screen. Organisms retained were fixed in 10% formalin and preserved in 70% isopropyl alcohol after three days, for longer storage.

2.3 Otter Trawls

Otter trawls were done over a distance of 0.5 nautical miles in 1977 at the locations shown on Figure 4. Due to time constraints, only stations FCT-3, FCT-4 and FCT-5 were sampled in 1980. Samples of english sole (*Parophrys vetulus*) and rockfish (*Sebastes* sp.) were frozen for tissue heavy metal analysis.

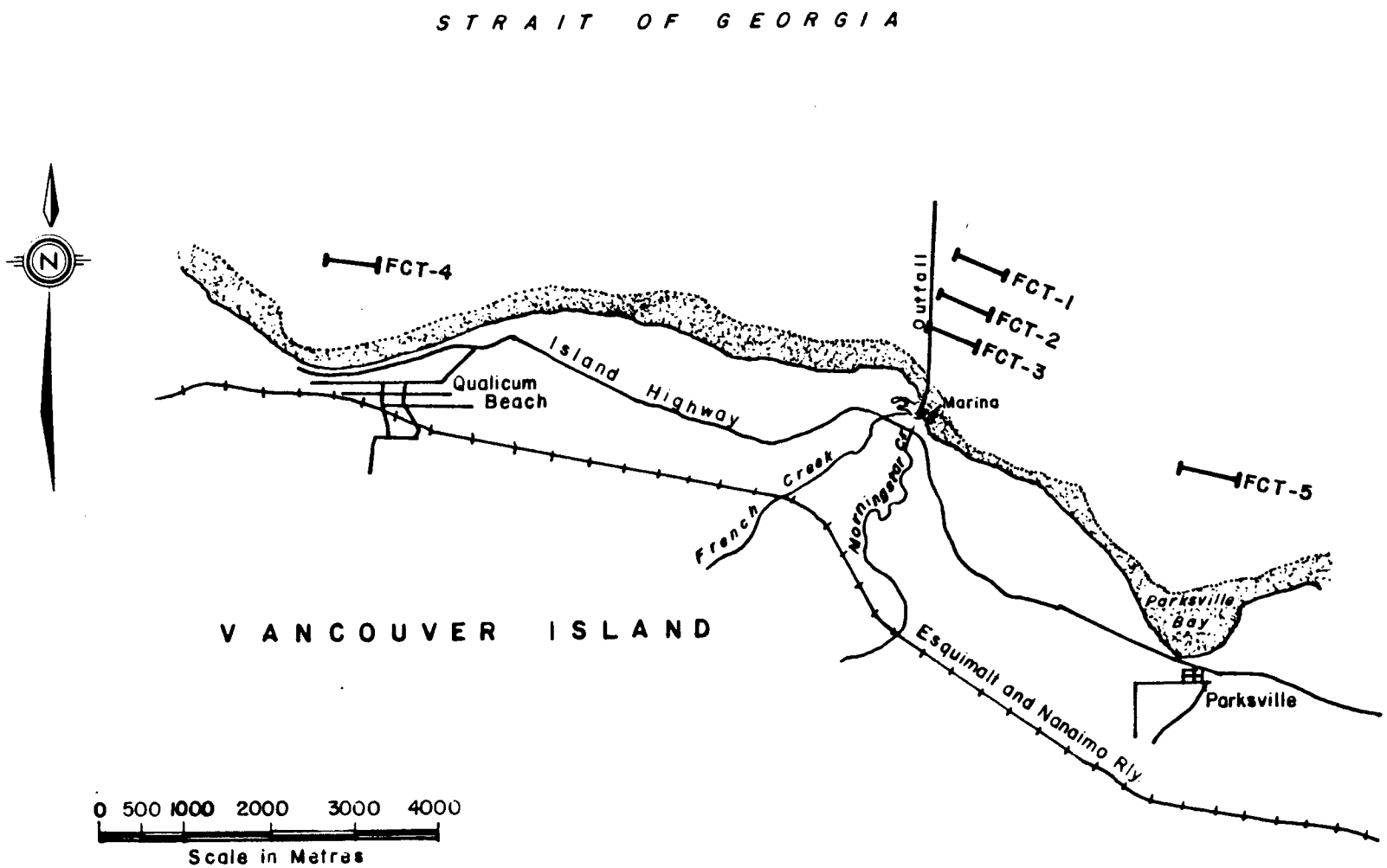

FIGURE 4 OTTER TRAWL STATIONS

2.4 Pisces IV Submersible Dives

Dives were conducted around the diffuser in 1978, 1980 and 1981 to visually assess water turbidity, the physical condition of the substrate, organic-inorganic accumulation and the composition of adjacent benthic communities. Photographs were taken with a Bolex 16 mm movie camera (Tungsten Ecktachrome EP 7242, ASA 125 film) and a Hassalblad 70 mm still camera (Kodak Aerocolor Negative 2445 film).

3 RESULTS AND DISCUSSION

3.1 Physical Oceanography

Salinity, temperature and dissolved oxygen data appear in Appendix II, and are summarized in Table 1 and Figures 5, 6 and 7.

There has been no obvious effluent discharge effect, spatial or temporal, in the physical oceanographic data collected as of the 1980 survey. Seasonal variations in pre-startup and operational studies were generally similar to those recorded in the Strait of Georgia.

In the pre-startup August 1977 survey, the water column was somewhat stratified with mean temperatures ranging from 11.79°C at the surface to 9.54°C at 50 m (Table 1). The effect of warming by surface insolation was evident. Salinity increased only slightly with depth (Fig. 5). Mean dissolved oxygen values decreased from 8.1 mg/L at the surface to 6.0 mg/L at 50 m.

The first operation survey in April, 1978 indicated very weak stratification of the water column typical of spring conditions (Fig. 6). Surface waters had not yet been warmed by solar heating, being only 0.72°C higher than those at 50 m (Table 1). The greatest change with depth over the water column was noted for oxygen which decreased from surface levels of 10.1 mg/L to 7.4 mg/L at 50 m. The average concentration of dissolved oxygen in the top 10 m was an increase of ca. 2.0 mg/L over summer and winter levels (Table 1) and likely represented a spring phytoplankton bloom.

Typical of winter conditions, little water column stratification was evident with respect to temperature and dissolved oxygen during the November 1980 survey (Fig. 7). Concentrations of dissolved oxygen were very similar to those recorded during August, 1977, ranging from a mean of 8.0°C at the surface to 6.6 at 50 m (Table 1). Salinity data were not obtained on this survey due to equipment failure.

TABLE 1 MEAN TEMPERATURE, SALINITY AND DISSOLVED OXYGEN MEASURED AT THE SURFACE AND 50 m DEPTH, AROUND THE FRENCH CREEK OUTFALL

	MEAN TEMPERATURE (°C)	MEAN SALINITY (o/oo)	MEAN DISSOLVED OXYGEN (mg/l)
August 24, 1977			
0 m	11.79	28.56	8.1
50 m	9.54	29.23	6.0
April 27, 1978			
0 m	8.83	28.49	10.1
50 m	8.11	29.17	7.4
November 12, 1980			
0 m	9.50	NS	8.0
50 m	9.61	NS	6.6

NS = samples not obtained

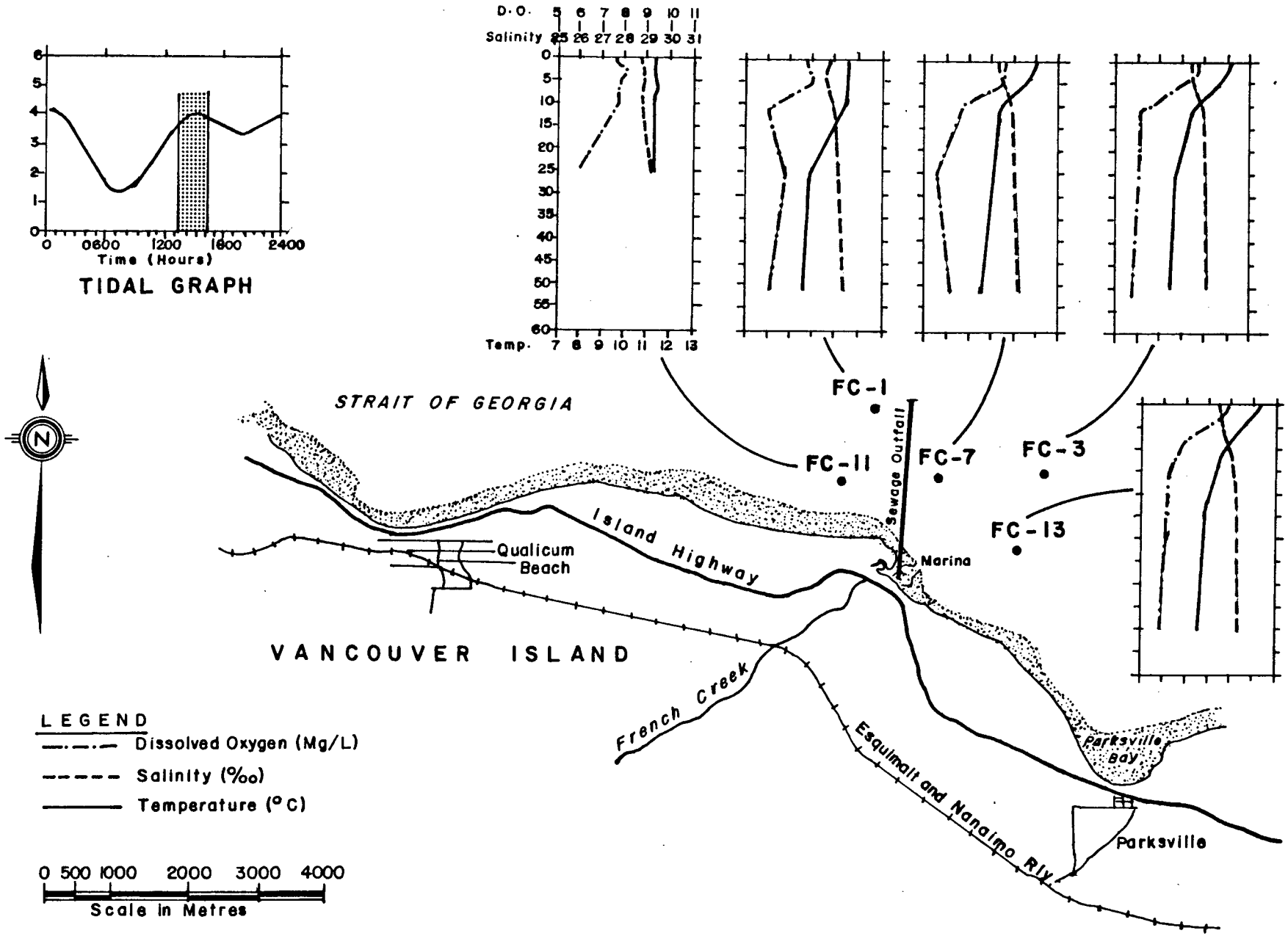

FIGURE 5 WATER QUALITY PROFILES, August 24, 1977

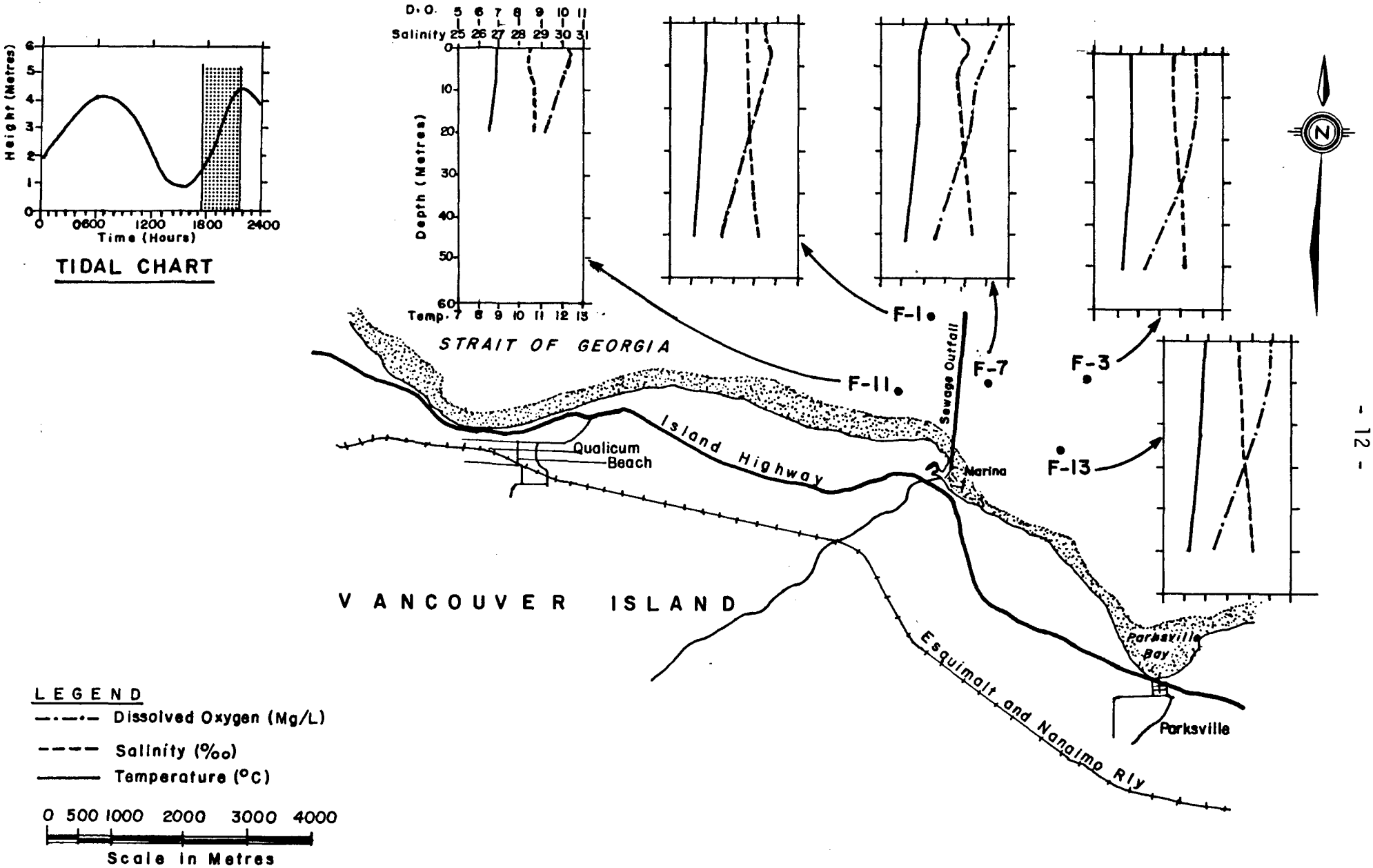

FIGURE 6 WATER QUALITY PROFILES - April 27, 1978

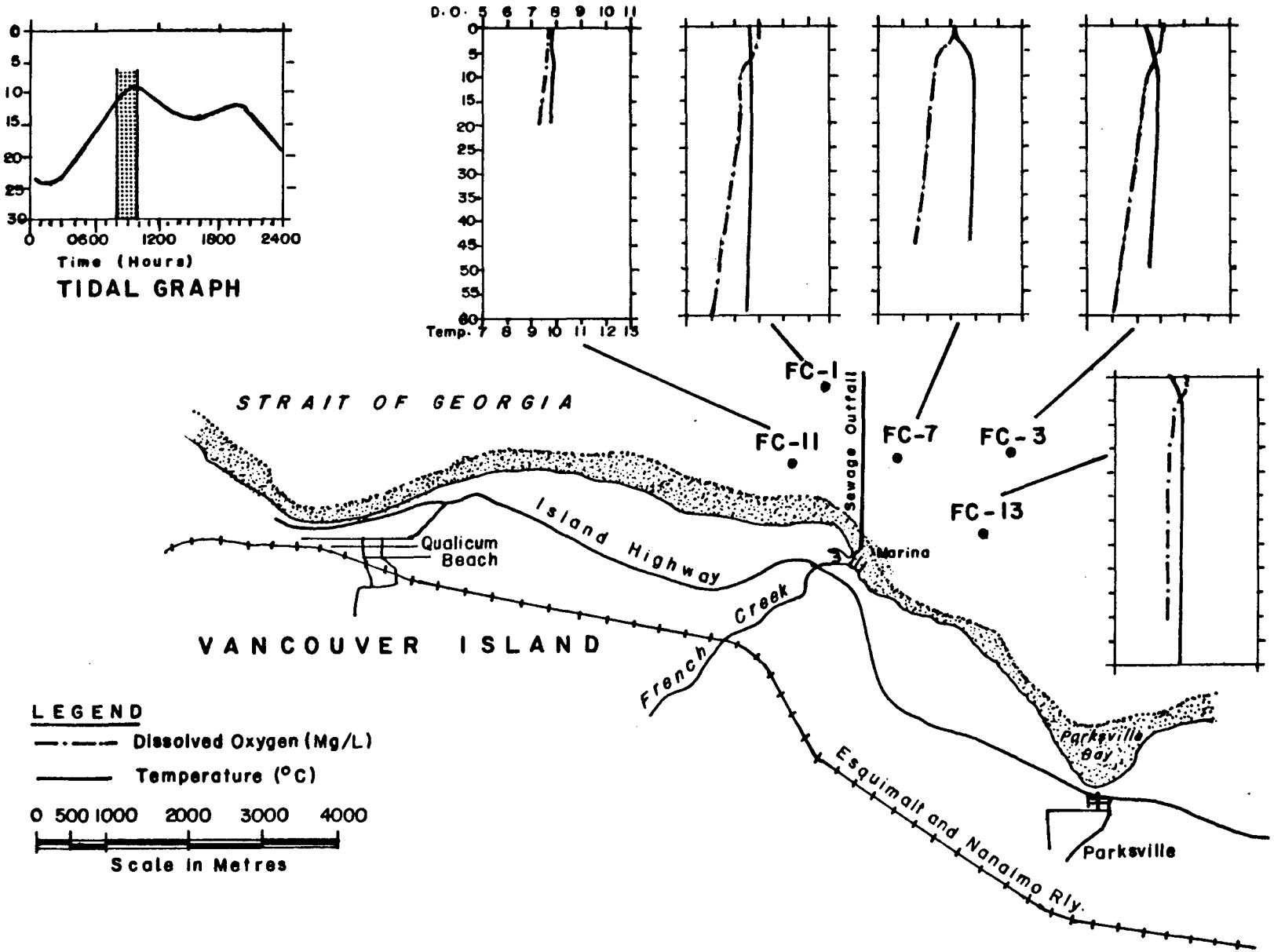

FIGURE 7 WATER QUALITY PROFILES, November 12, 1980

3.1.1 Dissolved Nutrients. Dissolved nutrient data are presented in Appendix III and summarized in Table 2.

Nutrient data collected 1977-1980 represent normal seasonal variations rather than changes attributable to effluent discharge (Table 2). Low surface nitrate in August 1977 likely resulted from active summer phytoplankton production (nutrient uptake). Increased surface nitrate concentrations in April 1978 followed a period of winter nutrient regeneration with reduced ammonia levels likely corresponding to the onset of spring phytoplankton bloom (ammonia taken up preferentially to other nitrogen sources). Well mixed, nutrient regenerated winter conditions were prevalent in the November 1980 survey.

3.2 Benthic Characteristics

3.2.1 Sediment Size Distribution. Little temporal change in the visual appearance of sediment grab samples taken from individual stations was noted during the study (Appendix IV). Samples were primarily fine sand with no evidence of reducing activity.

Detailed laboratory analysis of surface sediments from the grabs before plant startup (background state) indicated considerable station to station variation in percent composition of selected size fractions (Table 3). This variability continued into 1980 with individual stations showing increases or decreases. In all three surveys, stations FC-3, 5, 8, 10 and 13 farthest east of the outfall pipe had higher percent composition of fine (L62.5 μm) sediments compared to other stations. This is significant in terms of organic and heavy metal content as will be discussed in the following sections. Sediment input from French and Morningstar Creeks may be responsible for the localized pattern.

In spite of the expected yearly variation due to the problems of station repositioning in an area of non-homogenous substrate, a general pattern of changing particle size was evident from 1977 to 1980. Decreases in percent composition of the 250-62.5 μm fraction and

TABLE 2 MEAN NUTRIENT CONCENTRATIONS AT SURFACE AND 50 m DEPTH AROUND THE OUTFALL

	TOTAL PHOSPHATE (mg/L)	ORTHO-PHOSPHATE (mg/L)	NITRATE (mg/L)	NITRITE (mg/L)	AMMONIA (mg/L)
August 24, 1977					
0 m	NS*	0.046	0.176	0.006	0.013
50 m	NS	0.072	0.376	0.006	0.010
April 27, 1978					
0 m	0.071	NS	0.238	L0.005	0.008
50 m	0.081	NS	0.362	L0.005	L0.005
November 12, 1980					
0 m	0.054	0.062	0.271	L0.005	0.024
50 m	0.059	0.069	0.298	L0.005	0.019

NS* = samples not obtained
L = less than

TABLE 3 PERCENT COMPOSITION OF SELECTED SIZE FRACTIONS IN SURFACE SEDIMENTS
(August 24, 1977; April 27, 1978 and November 12, 1980)

STATION	SEDIMENT SIZE (% Composition)											
	G500 µm			500-250 µm			250-62.5 µm			L62.5 µm		
	1977	1978	1980	1977	1978	1980	1977	1978	1980	1977	1978	1980
FC-1	0.6	2.0	1.2	3.0	5.0	4.9	90.3	91.0	70.4	6.1	2.0	23.5
FC-2	0.9	1.0	20.9	3.8	2.0	12.7	88.8	89.0	60.6	6.5	8.0	5.8
FC-3	0.4	19.0	1.9	1.4	9.0	3.1	81.6	56.0	69.5	16.6	16.0	25.5
FC-4	0.4	1.0	5.8	2.8	3.0	4.6	90.9	88.0	82.7	5.9	8.0	12.1
FC-5	0.3	1.0	1.5	0.4	1.0	1.2	84.4	77.0	66.9	14.9	21.0	30.3
FC-6	0.7	2.0	0.8	4.4	6.0	4.6	87.8	85.0	76.6	7.1	7.0	18.0
FC-7	0.7	1.0	1.3	3.0	5.0	12.1	90.6	84.0	82.0	5.7	10.0	4.6
FC-8	0.7	1.0	1.4	3.0	3.0	3.0	81.2	74.0	69.2	15.1	22.0	26.5
FC-9	0.7	1.0	0.3	4.4	5.0	5.0	89.6	86.0	81.7	5.3	8.0	13.0
FC-10	0.6	2.0	0.8	0.8	2.0	2.7	83.4	80.0	82.6	15.2	16.0	13.9
FC-11	2.3	2.0	0.9	20.3	12.0	5.7	72.0	82.0	92.6	5.4	4.0	0.9
FC-12	0.3	2.0	1.0	1.6	3.0	13.3	90.9	84.0	76.8	7.2	11.0	8.8
FC-13	0.7	1.0	9.7	2.7	2.0	2.6	84.4	80.0	71.4	12.2	17.0	16.3
Mean Percentage	0.71	2.76	3.65	3.96	4.46	5.80	85.83	81.23	75.63	9.47	11.53	15.31

G = greater than

increases for the others (Table 3). This recurrent trend suggest either a naturally occurring shift or a possible effluent discharge effect. Further sampling is required.

3.2.2 Organic Content. A discharge effect is suggested based on rising particulate organic content of surface sediments at all stations between 1977 and 1980 (Table 4). Levels for 1977 pre-operational background sampling averaged L0.3%. By 1978 this average had risen to 0.44% (0.24 to 0.60%) and to 0.57% (0.40 to 0.95%) in the 1980 survey. Thus, in a period of three years mean organic content almost doubled.

In all three survey years, higher levels of sediment organics were present at stations farthest east of the outfall pipe (FC-3, 5, 8, 10 and 13) compared to stations adjacent to and on the west side (Fig. 3, Table 4). This distribution pattern is reasonable and corresponds well with the presence of a higher proportion of fine material (L62.5 um) at the eastern stations and the principle that finer sediments contain and retain more organic matter. The high pre-operational organic levels and somewhat finer sediment for the above noted stations may be a reflection of the input from French and Morningstar Creeks (Fig. 3). The substantial organic increases in 1977 and 1980 are considered to be attributable to the dishcarge with greater particulate settlement and microbiotic activity. Prevailing currents may be a factor in this area of higher organics.

3.2.3 Heavy Metals. Surface sediment heavy metal data appear in Appendix V with mean values for the study area summarized in Table 5.

Available data from 1980 indicate an outfall effect with substantial increases for some metals (Cu, Mn, Ni and Fe) over pre-operational background levels (Table 5). The greatest elevations were noted for manganese (Mn) with a study area mean of 99.619 ppm in 1977 increasing to 197.615 ppm in 1980 and for iron (Fe) which increased from an average of 9000 ppm to 14800 ppm over the same time period.

TABLE 4 PERCENT ORGANIC CONTENT OF SURFACE SEDIMENTS

STATION	ORGANIC CONTENT (%) August 24, 1977	April 27, 1978	November 12, 1980
FC-1	L0.3	0.31	0.45
FC-2	L0.3	0.40	0.45
FC-3	0.4	0.60	0.95
FC-4	L0.3	0.31	0.55
FC-5	0.4	0.51	0.60
FC-6	L0.3	0.27	0.40
FC-7	L0.3	0.28	No data
FC-8	0.4	0.44	0.75
FC-9	L0.3	0.34	0.40
FC-10	L0.3	0.48	0.75
FC-11	L0.3	0.24	0.40
FC-12	L0.3	0.39	0.55
FC-13	0.3	0.56	0.60
Mean	~ L0.3	0.44	0.57
Range	L0.3 to 0.4	0.24 to 0.60	0.40 to 0.95

L = less than

TABLE 5 MEAN HEAVY METAL CONCENTRATIONS IN SURFACE SEDIMENTS

DATE	MEAN HEAVY METAL CONCENTRATION								
	Cd (ppm)	Co (ppm)	Cu (ppm)	Mn (ppm)	Ni (ppm)	Pb (ppm)	Zn (ppm)	Fe (ppm)	Hg (ppm)
August 24 1977	NA	5.171	9.102	99.619	8.413	NA	24.707	9665	0.032
April 27 1978	NA	4.524	8.685	95.298	7.192	NA	23.572	7392	0.023
November 12 1980	LO.56	NS	10.269	197.615	10.569	23.86	23.238	14823	NS

NA = not analysed
NS = not sampled

As was the case with organic content, spatial variations were noted for heavy metal concentrations in the sediments (Appendix V). In pre-operational and subsequent surveys, stations farthest east of the outfall pipe having the highest organic content also tended to have the highest levels of heavy metals. French and Morningstar Creeks may have contributed to the higher background levels at Station FC3, 5, 8, 10 and 13 with the sewage outfall suggested as a source of the substantial increases recorded at these and other stations in 1980.

The recurrent pattern of higher heavy metal levels at stations farthest east of the outfall is, as was suggested for organic content, a function of sediment particle size. Turekian (1965) connected an increase in the concentration of absorbing heavy metals (Pb, Ni, Mn, Cu) with sediment of smaller particle size. This relationship of sediments size and metal concentration is apparent at the French Creek outfall (Table 3, Appendix V).

3.3 Benthic Community

3.3.1 Benthic Infauna. Benthic invertebrates identified in 1977 pre-operation grab sampling were heavily dominated by polychaete worms at all stations (Appendix VI). *Prionospio steenstrupe* and *Aricidea neosuecica* proved most abundant. Amphipods were next in abundance, followed by bivalves.

Species density, a simple measure of diversity, ranged from 25 at FC-1 furthest seaward to 37 at FC-12 nearest shore (Table 6). Density was generally greater at those stations east of the outfall pipe compared to those to the west.

A somewhat similiar pattern was evident for total number of organisms (Table 6), with greater abundance east of the outfall. This area had sediments of smaller particle size and higher organic content, factors more favorable to invertebrate (infaunal) colonization.

TABLE 6 SPECIES DENSITY AND TOTAL NUMBER OF INVERTEBRATES COLLECTED FROM BENTHIC GRAB SAMPLES (August 24, 1977)

STATION	SPECIES DENSITY (S)[a]	TOTAL NUMBER OF ORGANISMS[b]
FC-1	25	168
FC-2	30	172
FC-3	36	152
FC-4	30	101
FC-5	27	134
FC-6	29	130
FC-7	26	118
FC-8	31	159
FC-9	30	118
FC-10	35	196
FC-11	30	87
FC-12	37	239
FC-13	30	133

[a]S = number of species per sample

[b] organisms in three litres of sediment

Evenness, a measure of inequality among the abundances of different species, ranged from 0.679 (FC-5) to 0.850 (FC-3) (Table 7). Lower values indicate less even species distribution at a station.

Species diversity (Shannon-Weaver) correlated well with evenness, being high at FC-3 (4.396) and low at FC-5 (3.229) (Table 7, Figure 8) reflecting diverse communities lacking highly dominant species.

3.4 Heavy Metal Concentrations in Tissues

Pre-operation levels of heavy metals in fish (english sole and rockfish) collected in otter trawls around the outfall pipe are given in Appendix VII and summarized in Table 8.

Only english sole (*Parophrys vetulus*) were present in sufficient numbers to provide good comparisons. In these, metal levels varied considerably within the different size categories (small, medium and large). For example, wet weight copper values of 1.5 and 3.3 ppm and zinc of 5.4 and 8.6 ppm were recorded from small sole at FCT-1. Comparable ranges were noted in other size categories and at other stations.

Some spatial variation was evident for metals tested, other than lead and cadmium which were consistently below the level of detection (Appendix VII). In english sole, mean wet weight values of zinc ranged from 5.3 to 9.9 ppm, mercury from 0.03 to 0.06 ppm, iron 3.3 to 5.2% and copper 2.4 to 2.9 ppm (Table 8).

Trawl FCT-3 was repeated in 1980 and *P. vetulus* collected at that time indicated temporal charges in levels of heavy metals (Table 8). Copper and mercury concentrations had decreased by approximately one half and iron and zinc had more than doubled. An effluent discharge effect is suggested.

TABLE 7 SPECIES DIVERSITY AND EVENNESS VALUES FOR INVERTEBRATES COLLECTED FROM BENTHIC GRABS (August 24, 1977)

STATION	DEPTH (m)	DIVERSITY[a] INDEX	EVENNESS
FC-1	73	3.470	0.747
FC-2	66	3.832	0.781
FC-3	80	4.396	0.850
FC-4	44	3.715	0.757
FC-5	76	3.229	0.679
FC-6	38	3.570	0.735
FC-7	49	3.581	0.762
FC-8	62	3.959	0.799
FC-9	20	3.799	0.774
FC-10	70	4.081	0.796
FC-11	20	4.026	0.820
FC-12	46	3.888	0.746
FC-13	60	3.838	0.782

[a]Shannon-Weaver ($\log_2$)

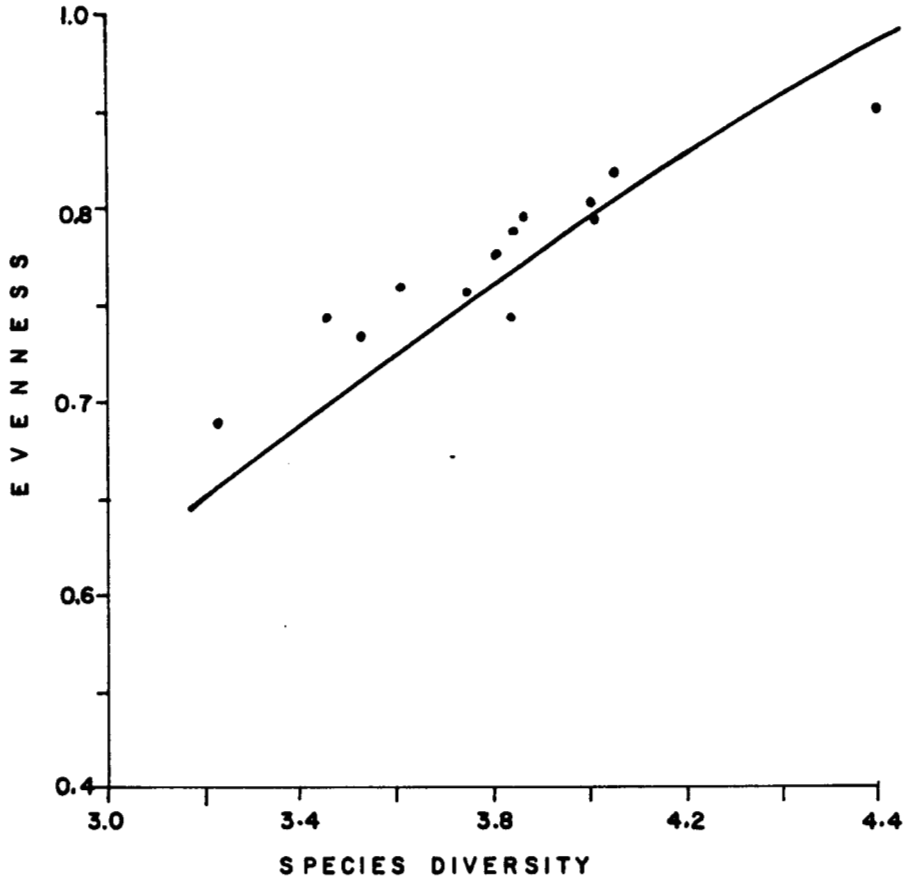

FIGURE 8 INVERTEBRATE SPECIES DIVERSITY VERSUS EVENNESS

TABLE 8 MEAN HEAVY METAL CONCENTRATIONS IN ENGLISH SOLE (*Parophyrs vetulus*) TISSUE

Levels Expressed in Wet and Dry Weight

TRAWL	Cu		Fe		Zn		Hg	
	dry	wet	dry	wet	dry	wet	dry	wet
	(ppm)		(ppm)		(ppm)		(ppm)	
1977								
FCT-1	11.3	2.4	16.4	3.4	33.8	7.1	0.19	0.04
FCT-2	11.5	2.5	13.3	2.9	25.3	5.5	0.18	0.04
FCT-3	11.7	2.6	15.3	3.3	24.7	5.3	0.27	0.06
FCT-4	13.2	2.9	12.4	3.4	26.0	5.5	0.13	0.03
FCT-5	10.3	2.4	22.7	5.2	42.5	9.9	0.13	0.03
1980								
FCT-3	6.0	1.3	39.5	8.2	65.3	13.9	0.12	0.02

3.5 Pisces IV Dive Observations

The first dive was done April 1978 following outfall-pipe installation but prior to plant startup. At this time, the pipe had minimal settlement of debris and no evident growth (Plate 1). The substrate was clean with some algae carried against the pipe by current action. No undercutting of the pipe or concrete supports was noted during the dive.

The second dive in March 1980 indicated that conditions had changed considerably (Plates 3, 4 and 5). Sediment and fine organic debris were present on the pipe along with calcareous-tube dwelling polychaete worms (Serpulids), tunicates, anemones and sea urchins. Numerous rockfish (*Sebastes* sp.) were around the outfall pipe and diffuser and in the depression that had formed under the pipe since installation. In some areas, the pipe was completely suspended off the bottom with the concrete collars also being undercut (Plate 3).

Sediment around the diffuser ports was minimally impacted by effluent discharge with little evidence of non-biodegradable debris (Plates 2 and 4).

The conditions described above are very similiar to those reported for the Five Fingers outfall near Nanaimo, (Pomeroy, 1981).

Still (70 mm) and 16 mm movie films of both dives are on file with EPS.

Plate 1. Section of diffuser and surrounding substrate April 1978, prior to sewage plant start-up.

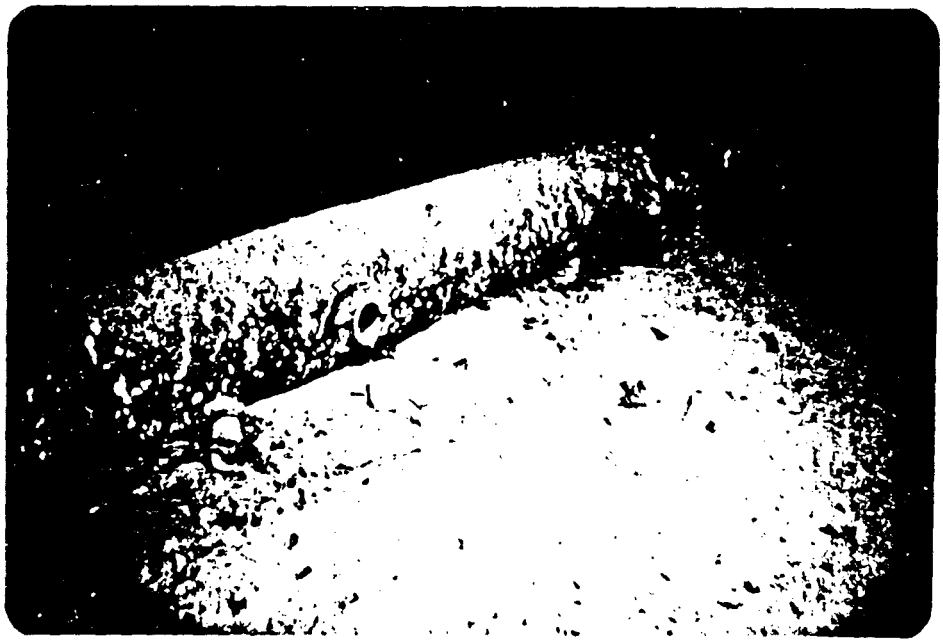

Plate 2. Diffuser port and surrounding substrate March, 1980. Note presence of sea urchins, tunicates and serpulid worms on pipe.

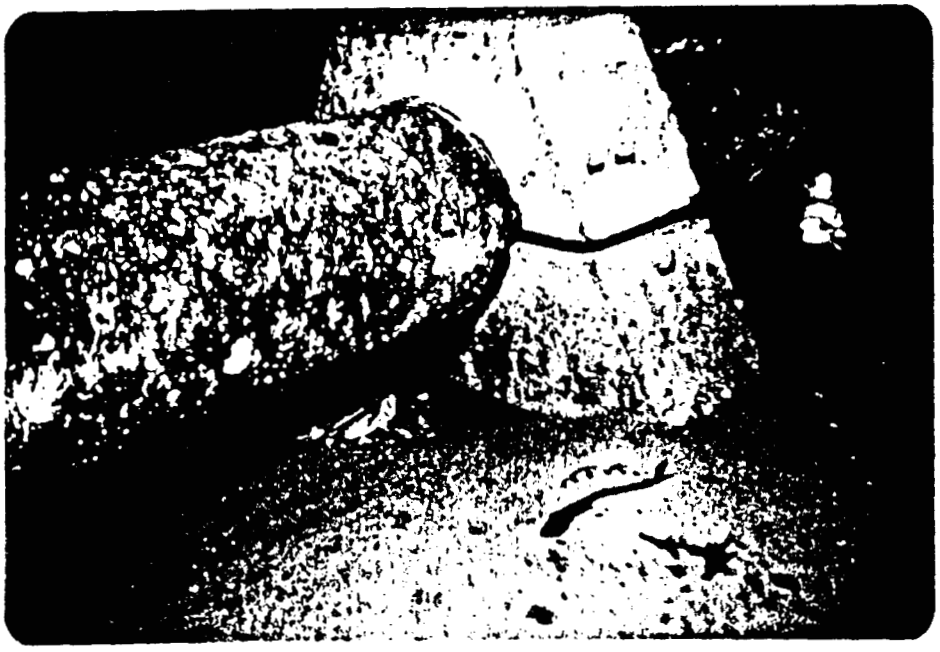

Plate 3. Outfall pipe and concrete collar. Rockfish, anemones, tunicates and serpulid worms present on pipe. Note under cutting.

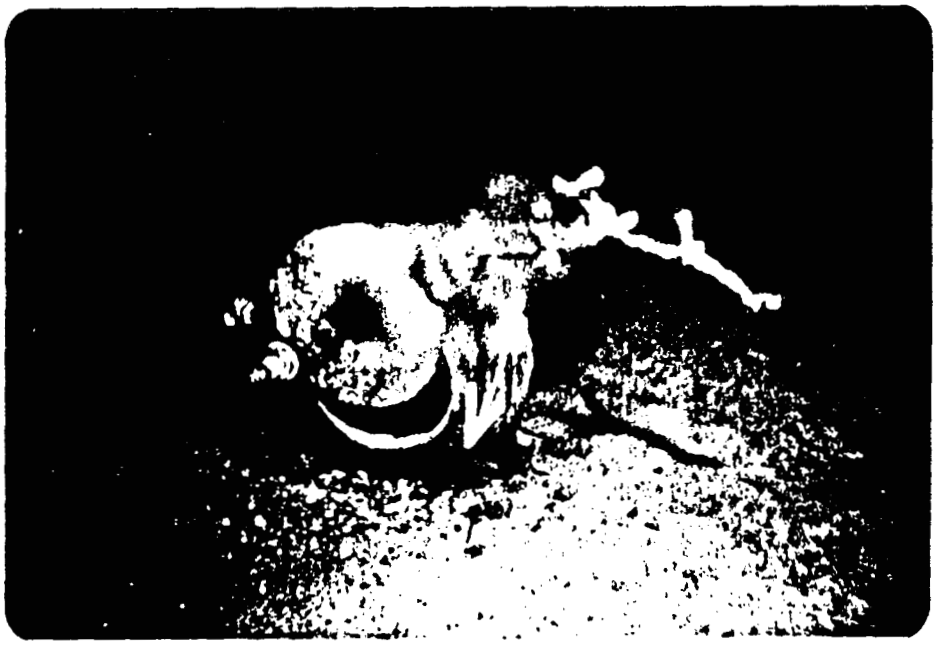

Plate 4. End of diffuser showing effluent discharge. Note absence of non-biodegradable debris.

REFERENCES

1. Gameson, A.L.H. and K.J. Robertson. The Solubility of Oxygen in Pure Water and Seawater. J. Appl. Chem. 5:502 (1955).

2. Pomeroy, W.M., and G.A. Packman. Environmental Effects of a Deep Marine Sewage Outfall at Five Fingers Island, Nanaimo, British Columbia, 1977-1980. EPS Regional Program Report: 81-4 (1981).

3. Strickland, J.D.H. and T.R. Parsons. A Practical Handbook of Seawater Analysis. Bull. Fish. Res. Board Can. 167:311 p. (1971).

4. Svedrup, J.V., M.W. Johnson and R.H. Fleming. The Oceans: Their Physics, Chemistry and General Biology. Prentice-Hall, New York. 1087 p (1946).

5. Swingle, R.B. and J.W. Davidson. Environmental Laboratory Manual. Department of Enviornment, Environmental Protection Service, 1979.

6. Turekian, K.K., Some Aspects of the Geoghemistry of Marine Sediments, In: J.P. Riley and G. Skirrow (Eds.)., Chemical Oceanography, Academic Press, London, Vol. 2 Chap. 16 (1965).

ACKNOWLEDGEMENTS

The author would like to thank N. Holman for his aid in field sampling and for providing his photographic expertise during Pisces IV dives. The assistance of D. Brothers, D. Sullivan and G. Packman in field operations is also acknowledged with thanks.

The assistance and cooperation of the officers and crew of the CSS VECTOR, PANDORA II and PISCES IV were invaluable in completing field surveys.

APPENDIX I

POSITIONS OF SAMPLING STATIONS

APPENDIX I POSITIONS OF SAMPLING STATIONS

STATION	LATITUDE	LONGTITUDE
1	49° 22.2' N	124° 21.6' W
2	49° 22.1' N	124° 20.9' W
3	49° 21.8' N	124° 19.8' W
4	49° 22.0' N	124° 21.5' W
5	49° 21.7' N	124° 21.1' W
6	49° 22.1' N	124° 22.2' W
7	49° 21.7' N	124° 21.1' W
8	49° 21.4' N	124° 20.1' W
9	49° 21.7' N	124° 21.7' W
10	49° 21.5' N	124° 20.6' W
11	49° 21.8' N	124° 22.2' W
12	49° 21.5' N	124° 21.3' W
13	49° 21.2' N	124° 20.2' W

Otter Trawls - 0.5 nautical miles long, starting at:

1	49° 22.0' N	124° 20.8' W
2	49° 21.7' N	124° 20.9' W
3	49° 21.5' N	124° 21.0' W
4	49° 22.0' N	124° 26.8' W
5	49° 20.7' N	124° 18.5' W

APPENDIX II

PHYSICAL OCEANOGRAPHIC DATA

a) August 24, 1977
b) April 27, 1978
c) November 12, 1980

APPENDIX II PHYSICAL OCEANOGRAPHIC DATA
a) August 23, 1977

STATION	DEPTH (m)	TEMPERATURE (°C)	SALINITY (o/oo)	DISSOLVED OXYGEN (mg/l)	% SATURATION
FC-1	0	11.49	28.64	7.7	86.79
	2	11.49	28.63	7.8	87.92
	5	11.49	28.64	8.0	90.18
	10	11.51	28.86	6.1	68.90
	25	9.84	29.12	6.8	74.08
	50	9.53	29.32	6.1	66.07
	Bottom = 73	9.18	29.53	5.5	59.17
FC-3	0	12.09	28.49	8.5	97.01
	2	12.09	28.47	8.7	99.27
	5	11.73	28.52	8.0	90.60
	10	10.50	28.83	6.2	68.44
	25	9.86	29.04	6.1	66.45
	50	9.53	29.12	5.7	61.65
	Bottom = 80	9.05	29.62	5.6	60.10
FC-7	0	11.91	28.50	8.3	94.34
	2	11.91	28.56	8.5	96.67
	5	11.81	28.58	8.5	96.47
	10	10.52	28.86	6.8	75.11
	25	10.06	29.14	5.6	61.33
	50	9.59	29.28	6.2	67.19
	Bottom = ??				
FC-11	0	11.24	28.71	7.3	81.87
	2	11.23	28.74	8.0	89.72
	5	11.23	28.71	7.7	86.34
	10	11.10	28.75	7.2	80.51
	25	11.03	29.07	5.9	66.01
	Bottom = ??				
FC-13	0	12.23	28.46	8.9	101.86
	2	12.14	28.48	8.7	99.39
	5	11.59	28.49	7.8	88.03
	10	10.77	28.84	6.6	73.30
	25	9.76	29.13	6.2	67.42
	50	9.52	29.23	5.9	63.85
	Bottom = 60				

APPENDIX II PHYSICAL OCEANOGRAPHIC DATA
b) April 27, 1978

STATION	DEPTH (m)	TEMPERATURE (°C)	SALINITY (o/oo)	DISSOLVED OXYGEN (mg/l)	% SATURATION
FC-1	0	8.68	28.60	9.48	100.16
	2	8.64	28.60	9.50	100.28
	5	8.64	28.59	9.62	101.55
	10	8.67	28.61	9.55	100.89
	25	8.49	28.77	8.98	94.56
	50	8.12	29.17	7.51	78.60
	65	8.09	29.31	6.78	70.97
	Bottom = 66				
FC-3	0	8.77	28.61	9.72	102.92
	2	8.75	28.61	9.71	102.77
	5	8.73	28.61	9.70	102.62
	10	8.74	28.61	9.73	102.96
	25	8.62	28.70	9.30	98.20
	50	8.09	29.17	7.38	77.18
	80	8.13	29.47	6.32	66.29
	Bottom = 100				
FC-7	0	8.93	28.31	10.70	113.50
	2	8.82	28.55	10.80	114.46
	5	8.79	29.06	10.35	109.97
	10	8.73	28.60	9.82	103.89
	25	8.66	28.67	9.35	98.79
	50	8.11	29.16	7.48	78.25
	Bottom = 54				
FC-11	0	8.87	28.41	10.35	109.72
	2	8.87	28.41	10.38	110.02
	5	8.84	28.46	10.20	108.08
	10	8.80	28.54	9.81	103.91
	20	8.42	28.66	9.38	98.53
	Bottom = 27				
FC-13	0	8.88	28.54	9.98	105.90
	2	8.82	28.54	9.98	105.75
	5	8.78	28.53	9.90	104.81
	10	8.76	28.56	9.90	104.77
	25	8.58	28.71	9.15	96.52
	50	8.11	29.18	7.30	76.39
	Bottom = ??				

APPENDIX II PHYSICAL OCEANOGRAPHIC DATA
c) November 12, 1980

STATION	DEPTH (m)	TEMPERATURE (°C)	SALINITY (o/oo)	DISSOLVED OXYGEN (mg/l)	% SATURATION
FC-1	0	9.67	SL	8.0	82.88
	2	9.68	SL	8.0	84.51
	5	9.80	SL	7.9	82.08
	10	9.87	SL	7.3	79.52
	25	9.78	SL	7.1	77.70
	50	9.58	SL	6.3	68.63
	60	9.46	SL	5.9	62.01
	Bottom = 70				
FC-3	0	9.53	SL	8.1	85.27
	2	9.64	SL	8.1	87.17
	5	9.79	SL	7.9	84.77
	10	9.96	SL	7.4	80.78
	25	9.85	SL	7.1	76.79
	50	9.58	SL	6.3	67.28
	65	NS	SL	6.0	--
	Bottom = 69				
FC-7	0	9.23	SL	8.2	87.42
	2	9.29	SL	8.2	87.55
	5	9.87	SL	7.6	82.23
	10	9.89	SL	7.3	79.03
	25	9.90	SL	7.0	74.81
	45	9.65	SL	6.5	69.98
	Bottom = 51				
FC-11	0	9.69	SL	7.8	82.95
	2	9.79	SL	7.6	83.20
	5	9.91	SL	7.6	82.32
	10	9.89	SL	7.5	82.27
	20	9.89	SL	7.2	77.95
	Bottom = 22				
FC-13	0	9.38	SL	8.1	86.66
	2	9.44	SL	8.2	86.15
	5	9.76	SL	7.7	81.50
	10	9.91	SL	7.4	78.58
	25	9.87	SL	7.1	77.34
	50	9.65	SL	7.2	75.52
	60	9.66	SL	NS	76.39
	Bottom = 69				

*NS = not sampled SL = sample lost

APPENDIX III

DISSOLVED NUTRIENT DATA

a) August 24, 1977
b) April 27, 1978
c) November 12, 1980

APPENDIX III DISSOLVED NUTRIENT DATA (mg/l)
a) August 24, 1977

STATION	DEPTH	ORTHO-PHOSPHATE	NITRATE	NITRITE	AMMONIA
FC-1	0	0.052	0.210	0.006	0.014
	2	0.050	0.200	0.006	0.014
	5	0.050	0.210	0.006	0.012
	10	0.065	0.315	0.006	L0.010
	25	0.066	0.330	0.005	0.013
	50	0.071	0.370	0.006	L0.010
	65	0.075	0.400	0.006	L0.010
FC-3	0	0.043	0.158	0.006	0.012
	2	0.044	0.162	0.006	0.011
	5	0.048	0.192	0.006	0.011
	10	0.062	0.294	0.006	0.013
	25	0.078	0.300	0.006	0.010
	50	0.071	0.370	0.006	L0.010
	80	0.080	0.410	0.006	L0.010
FC-7	0	0.043	0.158	0.006	0.010
	2	0.042	0.158	0.006	0.011
	5	0.043	0.152	0.006	0.010
	10	0.064	0.272	0.006	0.020
	25	0.068	0.335	0.006	L0.010
	50	0.072	0.375	0.006	L0.010
FC-11	0	0.054	0.232	0.006	ND*
	2	0.051	0.230	0.006	ND
	5	0.054	0.230	0.006	ND
	10	0.057	0.242	0.006	ND
	25	0.070	0.350	0.006	ND
FC-13	0	0.037	0.122	0.006	0.014
	2	0.039	0.132	0.006	0.013
	5	0.050	0.194	0.006	0.015
	10	0.069	0.282	0.006	L0.010
	25	0.061	0.310	0.006	L0.010
	50	0.073	0.390	0.006	L0.010

*ND = not done
L = less than

APPENDIX III DISSOLVED NUTRIENT DATA (mg/l)
b) April 27, 1978

STATION	DEPTH (m)	NITRATE	NITRITE	AMMONIA	TOTAL PHOSPHATE
FC-1	0	0.299	L0.0050	0.0055	0.0710
	2	0.302	L0.0050	0.0050	0.0857
	5	0.306	L0.0050	0.0070	0.0688
	10	0.301	L0.0050	0.0080	0.0698
	25	0.315	L0.0050	0.0140	0.0735
	50	0.360	L0.0050	L0.0050	0.0775
	65	0.390	L0.0050	L0.0050	0.0825
FC-3	0	0.276	L0.0050	0.0110	0.0608
	2	0.280	L0.0050	0.0110	0.0675
	5	0.257	L0.0050	0.0090	0.0638
	10	0.277	L0.0050	0.0100	0.0673
	25	0.315	L0.0050	0.0110	0.0715
	50	0.375	L0.0050	L0.0050	0.0809
	80	0.390	L0.0050	L0.0050	0.0845
FC-7	0	0.189	L0.0050	0.0100	0.0852
	2	0.191	L0.0050	0.0100	0.0650
	5	0.228	L0.0050	0.0100	0.0675
	10	0.276	L0.0050	0.0100	0.0705
	25	0.285	L0.0050	0.0100	0.0705
	50	0.380	L0.0050	L0.0050	0.0785
FC-11	0	0.211	L0.0050	0.0065	0.0675
	2	0.221	L0.0050	0.0080	0.0660
	5	0.239	L0.0050	0.0090	0.0655
	10	0.259	L0.0050	0.0120	0.0685
	20	0.300	L0.0050	0.0110	0.0709
FC-13	0	0.217	L0.0050	0.0080	0.0678
	2	0.240	L0.0050	0.0105	0.0698
	5	0.241	L0.0050	0.0100	0.0690
	10	0.261	L0.0050	0.0110	0.0675
	25	0.305	L0.0050	0.0080	0.0724
	50	0.375	L0.0050	L0.0050	0.0821

L = less than

APPENDIX III DISSOLVED NUTRIENT DATA (mg/l)
c) November 12, 1980

STATION	DEPTH (m)	NITRATE	NITRITE	AMMONIA	TOTAL PHOSPHATE	ORTHO-PHOSPHATE	SILICA
FC-1	0	0.288	L0.0050	0.0599	0.0360	0.0661	1.08
	2	0.263	L0.0050	0.0367	0.0552	0.0629	0.73
	5	0.257	L0.0050	L0.0050	0.0536	0.0587	0.74
	10	0.270	L0.0050	0.0350	0.0514	0.0627	0.76
	25	0.314	L0.0050	0.0112	0.0638	0.0726	0.90
	50	0.311	L0.0050	L0.0050	0.0702	0.0720	0.88
	60	0.285	L0.0050	0.0108	0.0536	0.0630	0.77
FC-3	0	0.271	0.0062	0.0389	0.0524	0.0633	0.84
	2	0.277	0.0055	L0.0050	0.0533	0.0642	0.86
	5	0.268	L0.0050	0.0114	0.0471	0.0526	0.77
	10	0.293	L0.0050	0.0081	0.0551	0.0662	0.88
	25	0.284	L0.0050	0.0075	0.0615	0.0674	0.86
	50	0.293	L0.0050	0.0403	0.0564	0.0699	0.82
	60	0.281	L0.0050	0.0086	0.0539	0.0679	0.77
FC-7	0	0.245	L0.0050	0.0338	0.0439	0.0550	0.72
	2	0.292	L0.0050	0.0085	0.0560	0.0653	0.84
	5	0.265	L0.0050	0.0353	0.0496	0.0545	0.75
	10	0.285	L0.0050	0.0091	0.0567	0.0659	0.76
	25	0.295	L0.0050	0.0189	0.0551	0.0649	0.76
	45	0.308	L0.0050	0.0068	0.0696	0.0718	0.84
FC-11	0	0.248	L0.0050	L0.0050	0.0517	0.0564	0.70
	2	0.259	L0.0050	0.0063	0.0599	0.0583	0.72
	5	0.312	L0.0050	0.0057	0.0593	0.0697	0.94
	10	0.309	L0.0050	0.0065	0.0633	0.0687	0.84
	25	0.282	L0.0050	L0.0050	0.0562	0.0660	0.77
FC-13	0	0.305	0.0062	0.0052	0.0598	0.0680	0.92
	2	0.268	0.0080	0.0406	0.0501	0.0505	0.87
	5	0.272	0.0055	0.0082	0.0488	0.0624	0.81
	10	0.228	L0.0050	0.0095	0.0568	0.0631	0.82
	25	0.266	L0.0050	0.0185	0.0534	0.0624	0.79
	50	0.289	L0.0050	0.0129	0.0511	0.0671	0.82
	60	0.310	L0.0050	L0.0050	0.0261	0.0717	0.89

L = less than

APPENDIX IV

VISUAL CHARACTERISTICS OF SEDIMENT GRAB SAMPLES

a) August 24, 1977

b) April 27, 1978

c) November 12, 1980

APPENDIX IV VISUAL CHARACTERISTICS OF SEDIMENT GRAB SAMPLES
a) August 24, 1977

STATION	DEPTH (m)	CHARACTERISTICS
FC-1	73	Fine grey sand/silt, homogeneous in appearance.
FC-2	66	Fine grey sand/silt, homogeneous in appearance.
FC-3	80	Fine grey sand.
FC-4	44	Sand.
FC-5	76	Fine grey sand, homogeneous in appearance.
FC-6	38	Sand.
FC-7	49	Mud, course sand and rocks.
FC-8	62	Fine grey sand.
FC-9	20	Sand.
FC-10	70	Fine sand.
FC-11	20	Course brown sand.
FC-12	46	Sand.
FC-13	60	Fine sand.

APPENDIX IV VISUAL CHARACTERISTICS OF SEDIMENT GRAB SAMPLES
b) April 27, 1978

STATION	DEPTH (m)	CHARACTERISTICS
FC-1	66	Fine sand, grey color.
FC-2	70	Fine sand, grey color.
FC-3	100	Fine grey sand, some gravel.
FC-4	58	Sand.
FC-5	73	Fine sand.
FC-6	54	Sand.
FC-7	54	Sand and rocks.
FC-8	73	Fine grey sand.
FC-9	36	Sand.
FC-10	47	Fine sand.
FC-11	27	Course sand.
FC-12	35	Sand.
FC-13	--	--

APPENDIX IV VISUAL CHARACTERISTICS OF SEDIMENT GRAB SAMPLES
c) November 12, 1980

STATION	DEPTH (m)	CHARACTERISTICS
FC-1	74	Fine sand, grey-brown in color.
FC-2	64	Fine sand, grey-brown in color.
FC-3	70	Fine grey sand.
FC-4	60	Sand, course and fine mix.
FC-5	74	Fine sand, grey in color.
FC-6	55	Sand and rock.
FC-7	52	Sand, mud and rocks.
FC-8	76	Fine sand, grey in color.
FC-9	42	Course and fine sand mix.
FC-10	60	Fine sand.
FC-11	22	Course brown sand.
FC-12	34	Sand, grey-brown.
FC-13	69	Fine sand.

APPENDIX V

SEDIMENT HEAVY METAL DATA

a) August 24, 1977
b) April 27, 1978
c) November 12, 1980

APPENDIX V SEDIMENT HEAVY METAL DATA

a) August 24, 1978

STATION	Cd (ppm)	Co (ppm)	Cu (ppm)	Mn (ppm)	Ni (ppm)	Pb (ppm)	Zn (ppm)	Fe (ppm)	Hg (ppm)
FC-1	NA*	4.264	8.637	92.504	7.539	NA	23.738	8370	0.026
FC-2	NA	4.129	8.637	100.392	8.692	NA	25.946	9910	0.026
FC-3	NA	7.648	11.660	116.527	11.762	NA	32.202	12410	0.041
FC-4	NA	5.077	7.341	90.353	7.564	NA	22.358	8600	0.020
FC-5	NA	5.552	10.364	112.941	10.099	NA	28.062	11020	0.038
FC-6	NA	4.941	8.205	92.504	7.588	NA	22.542	8140	0.032
FC-7	NA	4.354	8.205	95.014	6.855	NA	23.738	9300	0.026
FC-8	NA	5.462	10.364	107.563	8.275	NA	25.486	10930	0.047
FC-9	NA	5.009	7.341	87.843	7.246	NA	22.542	8600	0.032
FC-10	NA	7.031	10.796	109.356	10.049	NA	26.682	11020	0.041
FC-11	NA	4.016	6.910	88.560	6.051	NA	18.677	8050	0.026
FC-12	NA	4.467	9.933	97.524	8.447	NA	24.842	9070	0.032
FC-13	NA	5.280	9.933	103.978	9.210	NA	24.382	10230	0.038
Mean	--	5.171	9.102	99.619	8.413	--	24.707	9665	0.032

NA* = not analysed.

APPENDIX V SEDIMENT HEAVY METAL DATA

b) April 27, 1978

STATION	Co (ppm)	Cu (ppm)	Mn (ppm)	Ni (ppm)	Pb (ppm)	Zn (ppm)	Fe (ppm)	Hg (ppm)
FC-1	4.585	7.976	115.981	6.803	0.0	25.553	8210	0.020
FC-2	5.146	7.324	93.154	6.396	0.0	22.767	8240	0.020
FC-3	6.071	13.919	126.736	9.922	0.0	32.409	11630	0.027
FC-4	3.827	7.976	88.632	7.721	0.0	22.392	7950	0.021
FC-5	6.333	10.596	99.235	9.261	0.0	26.134	9450	0.021
FC-6	3.787	7.174	84.466	6.193	0.0	23.788	7060	0.021
FC-7	3.986	7.976	87.293	5.889	0.0	21.743	7830	0.022
FC-8	5.126	9.729	99.316	7.394	0.0	23.315	8980	0.021
FC-9	3.929	7.558	88.224	6.376	0.0	21.029	7320	0.025
FC-10	4.365	9.002	91.075	7.598	0.0	22.569	7840	0.028
FC-11	3.926	6.342	79.915	5.019	0.0	18.822	6640	0.021
FC-12	4.086	8.111	86.938	7.272	0.0	23.722	7320	0.021
FC-13	5.146	9.255	97.889	7.660	0.0	22.203	8780	0.031
Mean	4.524	8.685	95.298	7.192	0.0	23.572	7392	0.023

APPENDIX V SEDIMENT HEAVY METAL DATA
c) November 12, 1980

STATION	Cd (ppm)	Co (ppm)	Cu (ppm)	Mn (ppm)	Ni (ppm)	Pb (ppm)	Zn (ppm)	Fe (ppm)	Hg (ppm)
FC-1	L0.56	NA*	9.9	180.0	10.1	23.7	22.7	14200	NA*
FC-2	L0.56	NA	10.3	180.0	10.0	21.9	20.9	14900	NA
FC-3	L0.55	NA	13.9	226.0	13.2	28.8	27.9	18400	NA
FC-4	L0.56	NA	9.6	179.0	10.0	22.9	22.0	13800	NA
FC-5	0.65	NA	10.8	197.0	10.6	23.7	26.5	15300	NA
FC-6	0.67	NA	8.9	219.0	9.8	21.8	21.5	15100	NA
FC-7	L0.56	NA	9.1	185.0	10.3	21.9	21.3	14100	NA
FC-8	0.78	NA	11.8	211.0	11.8	27.2	27.4	15900	NA
FC-9	L0.56	NA	8.2	180.0	9.8	21.7	18.5	13200	NA
FC-10	0.72	NA	10.9	205.0	11.0	24.4	26.3	15100	NA
FC-11	0.78	NA	8.7	197.0	9.9	22.7	19.7	13200	NA
FC-12	L0.56	NA	9.9	200.0	10.1	24.1	23.0	14300	NA
FC-13	L0.56	NA	11.5	210.0	10.8	25.4	24.4	15200	NA
Mean		--	10.3	197.6	10.6	23.9	23.2	148	--

NA* = not analysed
L = less than

APPENDIX VI

IDENTIFICATION OF BENTHIC INFAUNA FROM GRAB SAMPLES

Taken August 24, 1977

APPENDIX VI FRENCH CREEK BENTHIC SAMPLES
August 24, 1977

PHYLUM CLASS	FAMILY GENUS SPECIES	NUMBER OF INVERTEBRATES/STATION Station # (FC-)												
		1	2	3	4	5	6	7	8	9	10	11	12	13
NEMERTEA	Unidentified	1				1	1		1	1	4	1	1	1
ANNELIDA	Polyodontidae													
Polychaeta	Peisidice aspera											5		
	Phyllodocidae													
	Eteone pacifica			2			2		4	1			4	1
	Phyllodoce sp.											2		
	Phyllodoce groenlandica	2	1	1	1		1						2	1
	Phylladoce williamsi			1			1					2		
	Hesionidae													
	Gyptis brevipalpa		1										1	
	Sigalionidae													
	Thalenessa spinosa											1		
	Syllidae													
	Exogone lourei	1	9	2				2		2				
	Syllis sp.										1			
	Syllis heterochaeta		5		1		4	2	2	4		1	1	1
	Nereidae													
	Nereis procera									1				
	Nephtyidae													
	Nephtys sp.	5	5	3	13	5	9		6	9	7	9	16	5
	Glyceridae													
	Glycera capitata	1	1	1		1			1	1	1		1	
	Glycera convoluta		2	2	1	1	1	2						1
	Onuphidae													
	Onuphis iridescens			1	1	1							1	
	Diopatra ornata											1		
	Lumbrineridae													
	Lumbrineris latrelli	2			1	2	2		1	3			1	
	Lumbrineris luti		2	6	1	7			8	1	12		1	2
	Ninoe gemmea			1		3			4		1		1	3
	Arabellidae													
	Unidentified			1		1								1

APPENDIX VI FRENCH CREEK BENTHIC SAMPLES
August 24, 1977

(Continued)

PHYLUM CLASS	FAMILY GENUS SPECIES	NUMBER OF INVERTEBRATES/STATION Station # (FC-)												
		1	2	3	4	5	6	7	8	9	10	11	12	13
ANNELIDA	Orbiniidae													
Polychaeta	Scoloplos armiger											3		
	Scoloplos panamensis	2												
	Scoloplos pugettensis	4		3	4	3	4	1	2	2	1		5	2
	Paraonidae													
	Aricidea lopezi	2		2	1				1		1	1	1	1
	Aricidea neosuecica	20	47	8	6	15	5	19	15	13	21		14	15
	Aricidea quadrilobata			4	1		1	5		3	1		2	1
	Aricidea ramosa		3	4	2		1	1	1	3	11		7	5
	Paronis gracilis	14	8	13	3	1	1	5	9	4	26		18	4
	Spionidae													
	Laonice cirrata			1										
	Polydora sp.					1								
	Polydora giardi											1		
	Polydora socialis												1	
	Prionospio steenstrupi	42	29	28	32	60	48	40	44	38	41	12	63	33
	Magelonidae													
	Megalomma splendida								1					
	Cirratulidae													
	Tharyx sp.			2										
	Tharyx parvus							7						
	Cossuridae													
	Cossura sp.			3							2			
	Scalibregmidae													
	Scalibregma inflatum		1	2		1	3		2	1	2		2	1
	Capitellidae													
	Unidentified	1		1									1	
	Decamastus gracilis	7	7	10	1	8	1	4	13		7		2	8
	Mediomastus sp.	1	1	7				3			5		5	
	Notomastus sp.	3		2	1		1	1	1		1		6	3
	Notomastus lineatus								8					

PPENDIX VI FRENCH CREEK BENTHIC SAMPLES
August 1977

Continued)

HYLUM CLASS	FAMILY GENUS SPECIES	NUMBER OF INVERTEBRATES/STATION Station # (FC-)												
		1	2	3	4	5	6	7	8	9	10	11	12	13
NNELIDA Polychaeta	Opheliidae													
	Ammotrypane aulogaster		1		1					2		1		
	Travisia brevis	1		3	1	3	2	2	1	3	2		2	1
	Oweniidae													
	Myriochele aculata		7	1			5		8		9	3	33	22
	Owenia fusiformis		2				8	3			1	2	5	
	Pectinariidae													
	Pectinaria californiensis												2	
	Pectinaria hyperborea											1		
	Ampharetidae													
	Unidentified								1		1	1		
	Ampharete acutifrons	1		2		1	1	1			1		1	
	Amage anops		1							1			1	1
	Lysippe lobiata	4	3	1	2	1			3	1	6		1	2
	Melinna cristata								1					
	Melinna elisabethoe										3			2
	Terebellidae													
	Polycirrus sp.							1						
	Tricobranchidae													
	Terebellides stroemi									1				1
	Sabellidae													
	Chone infundibuliformis										1			
	Demonax medias									1				
	Potamilla neglecta									1				
	Pseudopotamilla reniformis									2				
ARTHROPODA	Amphipoda (unidentified)	22	11	5	13	4	17	7	4	10	10	22	25	8
	Brachyura (unidentified)							1		1	1			

PENDIX VI FRENCH CREEK BENTHIC SAMPLES
August 1977

Continued)

HYLUM CLASS	FAMILY GENUS SPECIES	NUMBER OF INVERTEBRATES/STATION Station # (FC-)												
		1	2	3	4	5	6	7	8	9	10	11	12	13
SIPUNCULA	Unidentified			3					1		1			
ECHIURA	Echiura sp.							1						
PHORONIDA	Unidentified													1
ECHINODERMATA														
Ophuroidea	Unidentified	1	4	6	1	1	2	2	5		9	1		4
Holothuroidea	Cucumaria sp.					1		1			1			1
	Molpadia sp.			1										
	Sphaerothura sp.				1			2					2	
MOLLUSCA														
Amphineura	Chetoderma sp.			2		1			1		1			
Gastropoda	Amauropsis sp.						1							
	Balcis sp.		1											
	Bittium sp.				1		2					1	2	
	Calliotropis sp.						1					1		
	Cylichna sp.								1					
	Epitonium sp.											2		
	Mitrella sp.		2											
	Natica sp.											1		
	Olivella sp.												1	
	Polinices sp.	1	1			1						1		
	Rissoella sp.											1		
	Solariella sp.				1									
	Turritella sp.											2		
	Unidentified	1												

APPENDIX VI FRENCH CREEK BENTHIC SAMPLES
August 1977

(Continued)

PHYLUM CLASS	FAMILY GENUS SPECIES	NUMBER OF INVERTEBRATES/STATION Station # (FC-)												
		1	2	3	4	5	6	7	8	9	10	11	12	13
Bivalvia	Axinopsida serricata	28	8	20		7		2	8		2			
	Axinulus ferruginosus	1												
	Cardiomya sp.					2								
	Clinocardium sp.				1					1				
	Compsomyax subdiaphana				3						1	1	3	5
	Crenella columbiana												1	
	Lasaea rubra		1											
	Lyansia californica			1										
	Macoma sp.		1				1						1	
	Mysella sp.							1				1		2
	Nucula tenuis					1								
	Nuculana minuta				2									
	Psephidia lordi		2		2		3	2	1	5		3		
	Yoldia sp.				1									
	Unidentified		5				1			1			1	

APPENDIX VII

HEAVY METAL CONCENTRATIONS IN FAUNAL TISSUES

a) August 24, 1977

b) November 12, 1980

APPENDIX VII HEAVY METAL CONCENTRATIONS FOR FISH CAUGHT IN TRAWLS

a) August 24, 1977

TRAWL	SPECIES	Cu (ppm)		Fe (%)		Zn (ppm)		Pb (ppm)		Cd (ppm)		Hg (ppm)	
		wet	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry
FCT-1	Parophrys vetulus												
	large	6.5	1.3	9.0	1.9	22.0	4.6	L1.0	L0.2	L0.5	L0.1	0.21	0.04
	large	17.0	4.2	15.0	3.6	24.0	5.8	L1.0	L0.2	L0.5	L0.1	0.09	0.02
	medium	9.2	1.9	19.0	4.1	51.0	11.0	L1.0	L0.2	L0.5	L0.1	0.22	0.05
	small	7.9	1.5	25.0	4.7	46.0	8.6	L1.0	L0.2	L0.5	L0.1	0.17	0.03
	small	16.0	3.3	14.0	2.8	26.0	5.4	L1.0	L0.2	L0.5	L0.1	0.26	0.05
	$\bar{x}$	11.3	2.4	16.4	3.4	33.8	7.1	L1.0	L0.2	L0.5	L0.1	0.19	0.04
FCT-2	Parophrys vetulus												
	medium	13.0	2.7	11.0	2.4	23.0	5.0	L1.0	L0.2	L0.5	L0.1	0.12	0.03
	medium	15.0	3.5	13.0	3.2	25.0	5.9	L1.0	L0.2	L0.5	L0.1	0.12	0.03
	medium	6.4	1.3	16.0	3.2	28.0	5.7	L1.0	L0.2	L0.5	L0.1	0.31	0.06
	$\bar{x}$	11.5	2.5	13.3	2.9	25.3	5.5	L1.0	L0.2	L0.5	L0.1	0.18	0.04
	Sebastes sp.	6.6	1.5	19.0	4.2	24.0	5.3	L1.0	L0.2	L0.5	L0.1	0.33	0.07
FCT-3	Parophrys vetulus												
	medium	13.0	2.8	15.0	3.3	24.0	5.4	L1.0	L0.2	L0.5	L0.1	0.33	0.07
	medium	10.0	2.0	17.0	3.2	25.0	4.8	L1.0	L0.2	L0.5	L0.1	0.21	0.04
	small	12.0	2.9	14.0	3.4	25.0	5.6	L1.0	L0.2	L0.5	L0.1	L0.07	L0.02
	$\bar{x}$	11.7	2.6	15.3	3.3	24.7	5.3	L1.0	L0.2	L0.5	L0.1	0.27	0.06
	Sebastes sp.	23.0	5.5	75.0	18.0	34.0	7.9	L1.0	L0.2	L0.5	L0.1	0.20	0.05
		14.0	3.1	23.0	5.2	36.0	8.3	L1.0	L0.2	L0.5	L0.1	0.14	0.03
	Ophiodon elongatus	9.0	1.9	20.0	4.3	38.0	8.3	L1.0	L0.2	L0.5	L0.1	0.07	0.02
		8.7	1.8	21.0	4.5	47.0	9.9	L1.0	L0.2	L0.5	L0.1	L0.07	L0.01

APPENDIX VII HEAVY METAL CONCENTRATIONS FOR FISH CAUGHT IN TRAWLS
a) November 12, 1980

(Continued)

TRAWL	SPECIES	Cu (ppm)		Fe (%)		Zn (ppm)		Pb (ppm)		Cd (ppm)		Hg (ppm)	
		wet	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry
FCT-4	*Parophrys vetulus*												
	medium	26.0	5.8	14.0	3.0	22.0	4.9	L1.0	L0.2	L0.5	L0.1	0.16	0.03
	small	9.3	1.9	16.0	3.2	21.0	4.2	L1.0	L0.2	L0.5	L0.1	0.16	0.03
	small	11.0	2.3	10.0	2.2	42.0	8.7	L1.0	L0.2	L0.5	L0.1	0.10	0.02
	small	6.6	1.4	9.4	2.1	19.0	4.1	L1.0	L0.2	L0.5	L0.1	0.10	0.02
	$\bar{x}$	13.2	2.9	12.4	3.4	26.0	5.5	L1.0	L0.2	L0.5	L0.1	0.13	0.03
	Sebastes sp.	15.0	3.4	17.0	3.9	17.0	3.7	L1.0	L0.2	L0.5	L0.1	0.28	0.06
		7.8	1.9	18.0	4.2	21.0	5.1	L1.0	L0.2	L0.5	L0.1	0.27	0.06
FCT-5	*Parophrys vetulus*												
	large	8.5	1.9	28.0	6.2	45.0	9.9	L1.0	L0.2	L0.5	L0.1	0.15	0.03
	large	12.0	2.4	20.0	4.2	51.0	10.0	L1.0	L0.2	L0.5	L0.1	0.18	0.04
	medium	7.7	2.0	9.9	2.8	35.0	9.9	L1.0	L0.2	L0.5	L0.1	L0.07	L0.02
	medium	11.0	3.1	15.0	4.2	37.0	10.0	L1.0	L0.2	L0.5	L0.1	L0.07	L0.02
	small	8.3	1.9	25.0	5.5	45.0	10.0	L1.0	L0.2	L0.5	L0.1	0.09	0.02
	small	14.0	3.1	38.0	8.4	42.0	9.3	L1.0	L0.2	L0.5	L0.1	0.08	0.02
	$\bar{x}$	10.3	2.4	22.7	5.2	42.5	9.9	L1.0	L0.2	L0.5	L0.1	0.13	0.03
	Sebastes sp.	6.0	1.5	24.0	6.2	30.0	7.6	L1.0	L0.2	L0.5	L0.1	0.26	0.07
	Ophiodon elongatus	6.8	1.5	13.0	2.8	35.0	7.7	L1.0	L0.2	L0.5	L0.1	0.16	0.03

L = less than

APPENDIX VII HEAVY METAL CONCENTRATIONS FOR FISH CAUGHT IN TRAWLS

b) November 12, 1980

TRAWL	SPECIES	Cu (ppm)		Fe (%)		Zn (ppm)		Pb (ppm)		Cd (ppm)		Hg (ppm)	
		wet	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry
FCT-3	*Parophrys vetulus*												
	medium	6.1	1.3	38.0	8.2	64.3	13.9	L3.7	L0.8	L0.5	L0.1	0.10	0.02
	medium	5.9	1.3	41.0	8.3	66.3	13.8	L3.7	L0.8	L0.5	L0.1	0.15	0.02

L = less than