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MONITORING NUTRIENTS AND PLANKTON IN THE VICINITY OF THE IONA ISLAND SEWAGE OUTFALL

By

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INTRODUCTION

Previous to 1963 there were no sewage treatment plants for the Vancouver area (Waldichuk 1983, 1984). As a result of this situation, sewage discharge was mostly in the raw state and via shallow outfalls. By the 1940's, the Vancouver and District Joint Sewerage and Drainage Board developed a new plan for sewage discharge in the Vancouver area. The first phase of this plan (called the Rawn Report; Rawn et al. 1953), called for the construction of a sewage treatment plant on Iona Island. This meant that the raw sewage outfalls into Burrard Inlet and the Fraser River could be eliminated with the hope of improving beaches in English Bay and improving shellfish harvesting in the Fraser River estuary.

Primary treated effluent from the Iona plant is presently discharged through an open excavated channel on Sturgeon Bank tidal flats (see Figure 1). For some time it has shown that the area near the effluent channel has shown a marked deterioration (Figure 1) due to the deposition of organic matter and the accumulation of high metal concentrations in the sediment (McGreer 1982). To correct this situation the greater Vancouver Regional District is considering the installation of a deep submarine outfall of Sturgeon Bank (S & S Consultants 1983). Therefore, the object of this report is to discuss monitoring of nutrients and plankton in the vicinity of the Iona Island sewage outfall, before and after construction of the deep submarine outfall.

1 OTHER MONITORING PROGRAMS

Several deep sea sewage outfalls are already in operation in the Pacific west coast. Four of these sites and the results from their monitoring programs are briefly reviewed here. Some of their recommendations are probably applicable to the proposed monitoring scheme for the deep submarine Iona Island sewage outfall.

1.1 French Creek

French Creek is located on the east coast of Vancouver Island and it is the site of a deep sea domestic sewage outfall. Effluent is discharged via a 2 km outfall and ends in a diffuser 61 m below low water. This new outfall was monitored for three years (Pomeroy 1982). Monitoring included salinity, temperature, dissolved oxygen, nutrients, sediment particle size, organic content of the sediment, heavy metal content of the sediment, and benthic fauna. A submersible was used to examine the diffuser, the sediments around the diffuser and the response of organisms to the presence of the discharge.

No marked changes were observed in the water column but changes in the benthic environment occurred. Organic content of the sediments increased and there were increases in metal concentrations (e.g. copper, manganese, iron, and nickel).

1.2 Macaulay Point

Macaulay Point is located near Victoria, B.C. Monitoring was conducted to assess the influence of discharge through a deep sea outfall to 60 m (Ellis et al. 1971). Monitoring included, temperature, salinity, water stability, dissolved oxygen, turbidity, nutrients, chlorophyll a and coliform bacteria.

Monitoring recommendations were that ammonium and nitrate concentrations are good indicators of sewage. Lower salinities, decreased dissolved oxygen, increased turbidity and coliform bacterial counts can be used to detect the presence of the discharge. Ellis et al. recommended that total nitrogen and phosphorus budgets be included. This would include all forms of dissolved inorganic and organic nitrogen, particulate nitrogen, and the nitrogen content of planktonic animals, and nitrogen measurements of the sediments and benthic organisms. Sampling should be less frequent during the winter because biological activity is low and mixing by high winds is extreme. It is important to record the phase of the tidal cycle and the direction and speed of tidal currents during sampling.

1.3 Los Angeles

Two large outfalls, Hyperion (Los Angeles city) and Whites Point (serving Los Angeles county) are deep sea outfalls. Monitoring studies by Thomas and Carsola (1980) indicate that the subsurface discharge (about 40 m) could be traced by its high ammonium concentration. The effluent leaving the diffuser contains 2200 μM of ammonium. Maximum ammonium concentrations of 155 μM at 27 m and 2 km from the diffuser were recorded.

Elevated surface concentrations (3 to 10 μM) were found over the outfalls. In stratified water, high values were found below 15 m, but in well-mixed water, high concenrations were detected at the surface. Subsurface high concentrations were associated with turbid layers, coliform bacteria and reduced oxygen levels. Since the distribution of ammonium correlated well with measured subsurface currents, Thomas and Carsola (1980) have suggested that ammonium may be a useful tracer of the discharge of sewage in seawater.

Since elevated ammonium concentrations occur in the surface water, phytoplankton uptake of nitrogen is less than the discharge rate. This reduction in uptake of ammonium appears to be due to inhibitory levels of heavy metals or organics (MacIsaac et al. 1979). Ammonium must exceed 100 μM before it will exert toxic effects on phytoplankton growth (Thomas et al. 1980). Thomas et al. (1974) have also shown that when nitrogen is present in excess, other nutrients such as phosphate or silicate may become limiting.

1.4 Kaneohe Bay, Hawaii

Primary treated and later, secondary treated domestic sewage was discharged into this shallow bay for several decades. The main effect of this discharge was a severe decline in the coral reef ecosystem and substantial phytoplankton eutrophication (Caperon et al. 1971; Laws and Redalje 1978, 1982).

A study of the phytoplankton community and water column chemistry in Kaneohe Bay, before and after the diversion of secondary teated sewage from the bay has shown that changes in total nutrient concentrations in the water column cannot be accurately predicted without taking into account water column-benthos interactions. During the first year after sewage diversion, the decompostion of about 400 tons of benthic organisms which were primarily filter feeders, resulted in water column dissolved organic nitrogen and phosphorus concentrations roughly an order of magnitude higher than those expected in the absence of such interactions. In a shallow water community, close coupling between the water column and benthos cannot be ignored in predicting and assessing the impact of ecological manipulations.

2 IONA ISLAND SEWAGE TREATMENT PLANT

A more comprehensive description of the sewage treatment plant can be found in the Rawn Report (Rawn et al. 1953) and more recently in the report by S & S Consultants (1983). The principle aspects are summarized here.

The plant was built on Iona Island in 1963 and has undergone three expansions. It receives both sanitary sewage and storm runoff from the city of Vancouver, and portions of Richmond and Burnaby. The flow varies from 3.8 to 17.7 m^3 s^{-1}. The plant provides primary treatment (i.e., screening, grit removal, scum and grease removal and sedimentation) and seasonal (May 1 to September 30) chlorination to reduce bacterial coliform counts during the summer.

The primary treated effluent is discharged into a 7.3 km long and 40 m wide outfall channel that runs across Sturgeon Bank. At low tide the effluent is confined to the channel but at high tide the channel is submerged and the effluent is diluted and flows over and onto the adjacent mudflats. The sand-filled rock jetty extends along the north side of the outfall channel for about 5.1 km to prevent the effluent from flowing around Point Grey and into nearby English Bay for at least two tidal cycles. This delay allows time for bacterial dilution and inactivation due to seawater exposure.

3 STURGEON BANK STUDY SITE AND SURROUNDING AREA

3.1 Physical Characteristics

The tides in the Strait of Georgia are the mixed semi-diurnal type with two high and two low tides each day. The tide heights are usually asymmetrical with highs ranging from 4 to 5 m.

Tidally induced surface currents result in flow north or south from the discharge pipe. It is common to have a large counter clockwise gyre in the middle of the strait and a smaller clockwise gyre immediately west of the Iona jetty, especially during times of high discharge from the Fraser River. Drogue studies have been conducted (Tabata et al. 1971; Crean and Ages 1972) and they demonstrate that freqently there is a northward flow from Iona Island into Burrard Inlet, especially when the discharge from the Fraser River is high (June-July) and the drogues are released at low tide (Figure 2). Current speeds are approximately 10 to 20 $cm.s^{-1}$.

Winter winds are predominantly from the east or south-east and the summer winds from the northwest. The Iona Island area is somewhat protected from the southeast winds by land. It is the northwest wind which causes the build-up of large waves in the area because they are the strongest and have the largest fetch.

The Iona study area is influenced by Fraser River runoff and consequently the brackish water upper layer (10 m) varies from 16% in the winter (low river discharge) to 5% in the summer (river discharge is 10 times winter discharge). Heating of surface waters in the summer, in combination with decreased salinities results in a very strong pycnocline at 10 m and a weaker one of about the same depth in winter.

Seasonal changes in irradiance and light penetration into the water (Secchi depth) are shown in Figure 3.

3.2 Chemical Characteristics

The chemical characteristics of the study area include measurements of dissolved oxygen, nitrogen and phophorus. Dissolved oxygen within the first 300 m of the outfall discharge are ` 2 $mg \cdot L^{-1}$ and these values are low enough to kill some species of fish and stress other aquatic organisms (Birtwell et al. 1983). Beyond about 1500 m, the oxygen concentration values return to saturation levels of about 9 $mg \cdot L^{-1}$.

Sewage contains high concentrations of nitrogen, phosphorus, urea, ammonium, nitrate and other dissolved organic nitrogen constituents. Total phosphorus levels in the effluent channel close to the outfall are approximately 0.5 $mg \cdot L^{-1}$ (16 μM) and ammonium is about 9 $mg \cdot L^{-1}$ (650 μM). These nutrients decrease substantially (by about two orders of magnitude) about 2 km west beyond the jetty (Table 1). Increases in phytoplankton have been reported near the jetty (Harrison 1981). If the increased phytoplankton biomass settles out onto the sediment (rather than being grazed or transported away), the decomposition of this material would aggrevate the low O_2 problem. Typical winter and summer values for O_2 and nutrients for a normal area well beyond the jetty are given in Table 1 and shown in Figure 3. There are no data sets which include nitrate, ammonium, urea, and dissolved organic nitrogen and phosphorus concentrations along a transect away from the jetty and over different seasons.

3.3 Biological Characteristics

3.3.1 Phytoplankton. There appear to be no data on phytoplankton biomass or species composition near the outfall. This is important information that should be obtained in the future. The phytoplankton well beyond the outfall (control station) in the Strait of Georgia is typical of cold, temperate coastal waters with some estuarine influence. Diatoms are the most abundant group (Legare, 1957; Stockner et al. 1979, Shim 1977a; 1977b; Harrison et al. 1983). The most common species (frequency and biomass) is *Skeletonema costatlum*, a chain-forming centric diatom. Other diatoms that are also abundant are *Thalassiosira* spp., *Chaetoceros* spp. (especially *Chaetoceros debilis*), *Leptocylindrus danicus*, *Nitzschia* spp. and a few very large diatoms such as *Coscinodiscus* spp., *Cerataulina* and

Eucampia. There is little indication that large salinity changes caused by the Fraser River discharge influences the compostion of the diatom community (Shim 1977b). Buchanan (1966) studied flagellates in Indian Arm and found that cryptomonads, especially Rhodomonas minuta were major primary producers. Some species such as the chrysomonad Heterosigma okashiwa (Olisthodiscus luteus) and the dinoflagellate Protogonyaulax tamarensis both prefer estuarine waters of less than 15 or 20‰ and form blooms primarily on the east side of the strait on either side of the Fraser River plume. Both of these species may form dense blooms which may discolor the water and hence, they are often referred to as "red-tide" species. They are both very common in English Bay in the summer. However, blooms of these species have been observed in areas where there is no influence of sewage and therefore their presence in English Bay cannot be attributed to sewage effects (Harrison et al. 1983).

The standing stock of phytoplankton is generally assessed in terms of chlorophyll a. These values for the strait range from 1 $mg \cdot m^{-3}$ in the winter to 15 $mg \cdot m^{-3}$ during spring or early summer blooms (Stockner et al. 1979; Parsons et al. 1981; Harrison et al. 1983; see Figure 3). There are no good estimates of phytoplankton standing stocks along a transect away from the jetty.

Primary productivity for the strait ranges from a maximum of 1.2 g $C \cdot m^{-2} \cdot d^{-1}$ in May to low summer values of 0.2 g $C \cdot m^{-2} d^{-1}$ (Figure 3) (Parsons et al. 1970; Parsons 1979). However recent estimates have been higher, up to 8 g $C \cdot m^{-2} \cdot d^{-1}$ (Stockner et al. 1979). The reasons for the differences between these estimates has been discussed by Harrison et al. (1983). Phytoplankton standing stock and primary productivity are depressed near the mouth of the Fraser River due to the turbidity of the river water and the increased extinction coefficient (Figure 4). The increased nitrogen input into the Fraser River is thought to have only a minor contribution to increased primary productivity. Estimates are that the diversion of sewage from Vancouver Harbour to the Fraser River has only increased the nutrient loading in the river from 5% in 1967 to 12% in 1977

(Clark and Drinnan 1980). In addition, the contribution of sewage to the total nitrogen concentration of the river is, to a minor extent, controlled by the discharge volume of the river for that particular year. Very high primary productivity has been observed in Burrard Inlet, especially at Port Moody Arm (532 g $C \cdot m^{-2} \cdot yr^{-1}$) (Stockner and Cliff 1979).

3.3.2 Zooplankton. The zooplankton community structure and changes in biomass for the central strait are shown in Figure 5. The winter community is composed chiefly of small copepods such as Pseudocalanus spp. Other less dominate species are Paracalanus parvus, Oithona helgolandica and Corycaeus sp. In the spring there is a massive recruitment of nauplii and copepodite stages of Neocalanus plumchrus from deep water to the surface and some migration of adult Calanus marshallae, C. pacificus and Metridia pacifica. Components of the estuarine plankton community include the genera Acartia, Pseudocalanus, Centropages and Epilabidocera. Decapod zoea and juveniles and barnacle nauplii form the bulk of the meroplankton. During extended periods of calm weather the larvacean Oikopleura may produce extensive blooms (Sibert et al. 1976). Zooplankton biomass and community structure has not been well studied in the vicinity of the outfall.

3.3.3 Bacteria. The distribution of fecal coliform bacteria in the outfall area has been frequently studied (Churchland 1979). Fecal coliform concentrations in the effluent are extremely high, particularly during the non-chlorination period from October to May (23 x 10^6 fecal coliforms/100 ml). Typical counts close to the outfall are 16 x 10^5 fecal coliforms/100 ml, with a decrease to 8 x 10^3/100 ml at 2 km from the outfall. Control samples from the north side of the jetty had counts of 2 x 10^3/100 ml, which is well above the standard of 200/100 ml used as a limit for recreational waters.

The distribution of bacteria in the Strait of Georgia is not well known. Recent investigations by Albright and co-workers have examined the influence of the Fraser River on bacterial distribution in the plume area (Valdes and Albright 1981; Albright 1983; Bell and Albright 1981). The freshwater bacteria are predominantly rod-shaped and larger in volume ($0.3 \mu m^3$) than their marine counterparts ($0.07 \mu m^3$) and are generally attached to particles, in contrast with the predominance of free-floating marine forms. Bacterial numbers in surface sediments were much greater (by several orders of magnitude) than in overlying waters. The Fraser River contains about 1.2×10^7) total bacteria per ml of river water, which is twice as high as the strait (Bell and Albright 1981; Albright 1983). Most of the Fraser River bacteria are killed when the salinity rises above 16 $^o/oo$, but a few appear to remain viable but not very active.

3.3.4 Benthic Algae. The benthic algae in the vicinity of the outfall have not been well studied. Reports of Ulva lactuca and Enteromorpha sp. abundance suggests that it has responded to increased nutrient concentrations (Hoos and Packman 1974). Benthic microalgae (primarily diatoms) on top of the sediment or in the first one centimeter suggests that benthic primarily productivity may be considerable based on estimates of chlorophyll a concentrations of 0.2 to 0.3 $g \cdot m^{-2}$ from July to October for the area north of the jetty (Harrison 1981).

3.3.5 Benthic Invertebrates and Fish. These two components of the food web have been studied the most extensively in the outfall area. Prawns, shrimp, and crabs of commercial importance inhabit Sturgeon Bank (Hoos and Packman 1974; Levins and Constalin 1975; Levings et al. 1983). Other abundant sediment-dwelling invertebrates include polychaetes (e.g. Lumbrineridae) and nematodes (Harrison 1981; Levings et al. 1983). Harpacticoid copepods are an important food source for bottom feeding fish such as flatfish and juvenile salmon (Harrison 1981; Levings et al. 1983). The harpacticoids in the area north of the jetty has been well studied (Harrison 1981). Mud communities were distinct from sand communities and both of these communities showed strong seasonal changes. Therefore, any comparisons of the outfall area with a control area must be careful to consider sediment type (spatial variability) and seasonal changes (temporal variability). The extent of this temporal and seasonal variability is shown for the area north of the jetty for 1978 (Figure 6). The clam, Macoma balthica has been extensively studied in the area receiving sewage effluent (McGreer 1979, 1982). He found that the distribution was seriously affected by the sewage effluent, probably due to a combination of factors such as, increased heavy metal content of the sediment, and lower O_2 concentrations in the sediment. Sublethal effects such as burrowing behaviour was also affected by the heavy metal contaminated sediments (McGreer 1979). Twenty-seven species of fish have been observed in the sewage outfall area and tumors in some fish have been reported (Birtwell et al. 1983).

3.3.6 Pelagic Food Webs. The pelagic food web in the outfall area is relatively unknown. The food webs for the main part of the Strait of Georgia changes with the seasons and these changes are summarized in Figure 7. The main food web is the diatoms/dinoflagellates — macrozooplankton — small fish, chaetognaths, ctenophores or hydromedusae.

4 MONITORING PLAN FOR PLANKTON

4.1 Physical and Chemical Indicies of Water Quality

Turbidity and water colour may be a useful indication of how much the sewage effluent is getting diluted by the surrounding water and the direction the sewage plume is moving. One quick way to measure turbidity and light extinction is with a secchi disc. The measurement is the depth at which a standard 30 cm white disc just disappears from view. When this measurement is used in conjunction with chlorophyll a measurements, it is possible to separate the extinction of light due to the presence of phytoplankton from that due to particles such as silt or debris. Turbidity and light extinction can also be measured with a submersible light meter or with a transmissometer which may even be towed under water.

Temperature and salinity are not indicators of pollution, but they should be measured because they are useful in assessing water movement, stability, and water density.

Large decreases in dissolved oxygen concentrations are generally a result of biological processes such as respiration. Decomposition of high concentrations of dissolved or particulate organic carbon by bacteria consumes oxygen and may result in very low oxygen concentrations (2 $mg \cdot L^{-1}$) either in the water just above the sediments or in the sediments themselves. This utilization of oxygen by these processes is generally referred to as biological oxygen demand (BOD). Low oxygen or anoxic conditions can greatly reduce benthic invertebrate or fish biomass in the area and alter the species diversity. Samples can be taken for oxygen and measured by Winkler titration or an oxygen electrode (Parsons et al. 1984). Oxygen value in the range of 6-9 $mg \cdot L^{-1}$ are normal, while values 2-5 $mg \cdot L^{-1}$ indicate oxygen depletion stress of the environment depending on the species and other physical and chemical characteristics of the water.

Water samples can be collected for nutrient analyses. Nitrate, nitrite, ammonium, urea, phosphate, dissolved organic phosphorus, and nitrogen should be measured. These methods of collection and analysis are described in Parsons et al. 1984. The normal range of concentrations found during winter and summer are given in Table 1. Increases in dissolved components above normal concentrations indicates potential eutrophication, provided light, temperature, and water stability are appropriate for phytoplankton growth. Of all the nutrients listed above, ammonium is the best one to monitor because normal concentrations are low and concentrations in sewage effluent are very high. In addition, since marine waters are generally nitrogen limited, nitrogen compounds are important to monitor.

4.2 Biological Indicies of Water Quality

4.2.1 Phytoplankton. The effects of sewage on indigenous aquatic organisms can be assessed at four different levels. These are: 1) abundance (numbers and biomass), 2) taxonomic composition (species diversity and composition), 3) growth (productivity, respiration, and metabolic rates) and, 4) bioaccumulation of toxic substances (Figure 8; Worf 1980). A list of parameters used to assess these four levels is given in Table 2.

The biomass of phytoplankton in the outfall area has not been carefully studied. Biomass estimates in terms of chlorophyll *a* or cell numbers are known for the area well beyond the outfall; they range from 1 to 10 mg chl $a \cdot m^{-3}$ and from 10^4 to 5×10^6 $cells \cdot L^{-1}$, respectively (Figure 3). Chlorophyll *a* measurements are the easiest way to monitor phytoplankton biomass and this can be done continuously by using *in vivo* fluorescence from a small boat using a battery operated fluorometer, strip chart recorder and pump. Using a grid cruise track, horizontal variations in biomass can be measured and the measurements can be used to construct a surface contour map. Similarily, vertical profiles of biomass can be obtained to determine if biomass is patchy with respect to depth. Determining biomass in terms of cell numbers is much more time consuming since this is usually done by counting a sample with a microscope, although estimates of particles (a chain of diatoms is counted as one particle) can be achieved by using a particle counter.

Taxonomic composition of phytoplankton in the sewage outfall area has not been specifically studied. Dominant species in the area well beyond the outfall has been discussed in Section 3.3.1. The only way to determine species composition is by using a microscope. Samples can be taken and preserved and counted with an inverted microscope some time later. Even though microscope counts are very time consuming they can be valuable since species composition does change with sewage stress and generally species diversity decreases with only a few tolerant species remaining under extreme conditions.

Metabolic rates are usually measured in terms of growth or photosynthetic rate. The uptake of ^{14}C-labelled bicarbonate is used to access short term photosynthetic rates (Strickland and Parsons 1972). There are no known measurements made in the outfall area. Values exceeding 5 mg C m^{-3} d^{-1} would indicate eutrophic conditions (Laws 1981).

Phytoplankton may accumulate high levels of metals if concentrations in the surrounding waters are high. Monitoring intracellular levels of copper and mercury, for example, would give some indication of the degree of metal stress in the area.

4.2.2 <u>Zooplankton</u>. The same four levels of assessment can be applied to zooplankton as well as phytoplankton. Zooplankton biomass must be assessed by sampling with nets. Two sizes of mesh are used, > 200 µm to > 330 µm for the macrozooplankton and > 60 to 200 µm for the microzooplankton. Vertical hauls are best for assessing the total biomass in the water column. Harpacticoid copepods and amphipods which lie in the water just above the sediment are more difficult to sample quantitatively.

Assessing taxonomic composition is very time consuming since a microscope must be used. Growth of zooplankton is difficult to assess and the easiest measurement of metabolic rate is respiration. This can be done using an O_2 electrode and rates would be expected to increase with pollution stress.

4.2.3 Bacteria. In addition to the standard coliform bacterial counts total bacterial numbers should be assessed using epifluoresence microscopy (Daley and Hobbie 1975). Total counts would aid in assessing the extent of the bacterial activity associated with organic matter breakdown and its relation to the dissolved oxygen concentration in the water.

Bacterial productivity can be assessed by the rate of uptake of a radioactively labelled organic compound such as glucose or by the incorporation of ^{3}H-labelled thymidine.

4.2.4 Benthic Organisms. Benthic organisms generally show a clearer response to a point source pollutant than planktonic organisms. Since benthic organisms are relatively fixed, spatially, sampling them at different distances from the outfall frequently reveals the gradient effect of the pollutant. Benthic diatoms and benthic macrophytes (seaweeds) should be assessed in terms of biomass, chemical composition and species composition along a transect away from the outfall.

Considerable attention has been give to benthic invertebrates in terms of species composition (Levings and Constalin 1975; Levings et al. 1983; S & S Consultants 1983) and in terms of bioaccumulation of metals (McGreer 1979, 1982). Bottom feeding fish have also been investigated and they are also good indicators of sewage stress (Birtwell et al. 1983; S & S Consultants 1983).

Other benthic characteristics that are useful to measure and that aid in the interpretation of the benthic organisms responses, are particle size, organic content and heavy metal concentrations in the sediment. The use of a submersible (e.g. Pisces IV) is recommended for direct observations on the benthic environment that might otherwise be missed or confused because of the selected sampling schemes (Pomeroy 1982).

4.2.5 Other Indices. In addition to the long term field monitoring approach described above, short term testing (bioassays) can be conducted. Different types of bioassays are summarized in Table 3.

There are two main types of bioassays. First, is the in situ tests which are conducted at the field test site with natural assemblages of organisms. In order to carry a time series of sampling on the same assemblage and avoid the movement of plankton oraganisms by advection, in situ enclosures are used (Schelske 1984; Shubert 1984). The second type of bioassay is conducted in the laboratory to assess plant effluents or water from the fold test site. Usually a "calibrated" bioassay organism is used, rather than a natural assemblage and its repsonse to different concentrations is determined. The parameters monitored during these bioassay tests may include bioaccumulation of metals or organics, acute toxicity (LC_{50}) or low level responses such as changes in behaviour or growth rates (Table 3).

4.3 Summary

A biological and water quality parameter list, sampling frequencies and priority for proposed biomonitoring programs in the USA are given in Table 4 (Worf 1980). This list can be simplified when it is applied to the Iona Island sewage outfall and limited to assessing water quality and plankton (Table 5). Counts of coliform bacteria must be made to assess water quality. Two key parameters for monitoring potential phytoplankton eutrophication in the lowest possible cost monitoring program are ammonium concentrations in the water and chlorophyll a concentration (as estimate of phytoplankton biomass). Because these parameters are good indicators of eutrophication they should be monitored bi-monthly from April to October (Table 1). Parameters of secondary importance are dissolved oxygen, other nutrients (especially the inorganic and organic nitrogen components), phytoplankton and zooplankton species composition and zooplankton biomass. All these parameters should be monitored along a transect away from the outfall and also in English Bay since there is considerable northward flow. Utilization of the high nutrient concentrations by phytoplankton may not take place until the water stratifies in more quiescent areas such as English Bay.

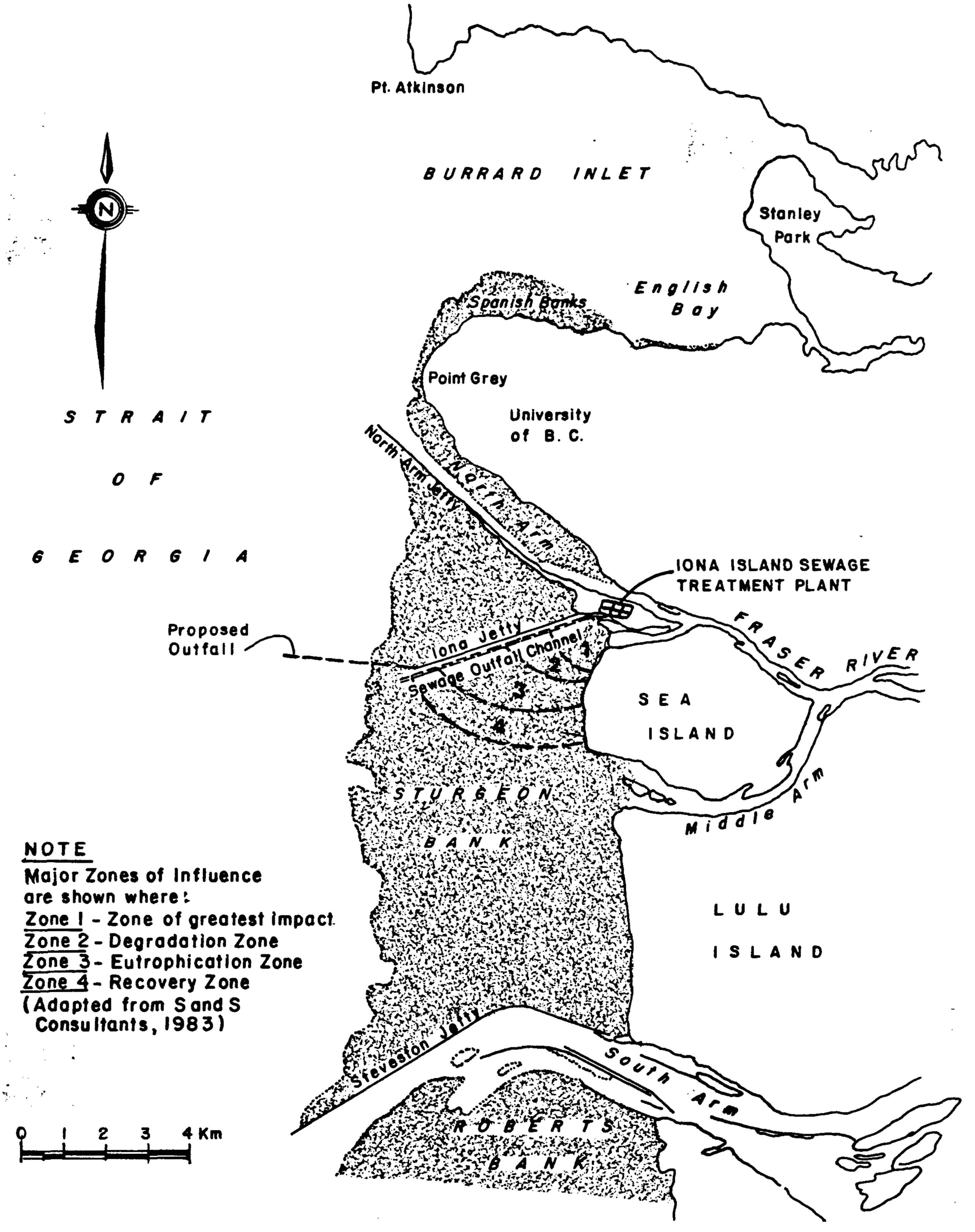

FIGURE 1 IONA ISLAND SEWAGE OUTFALL AND THE SURROUNDING AREA

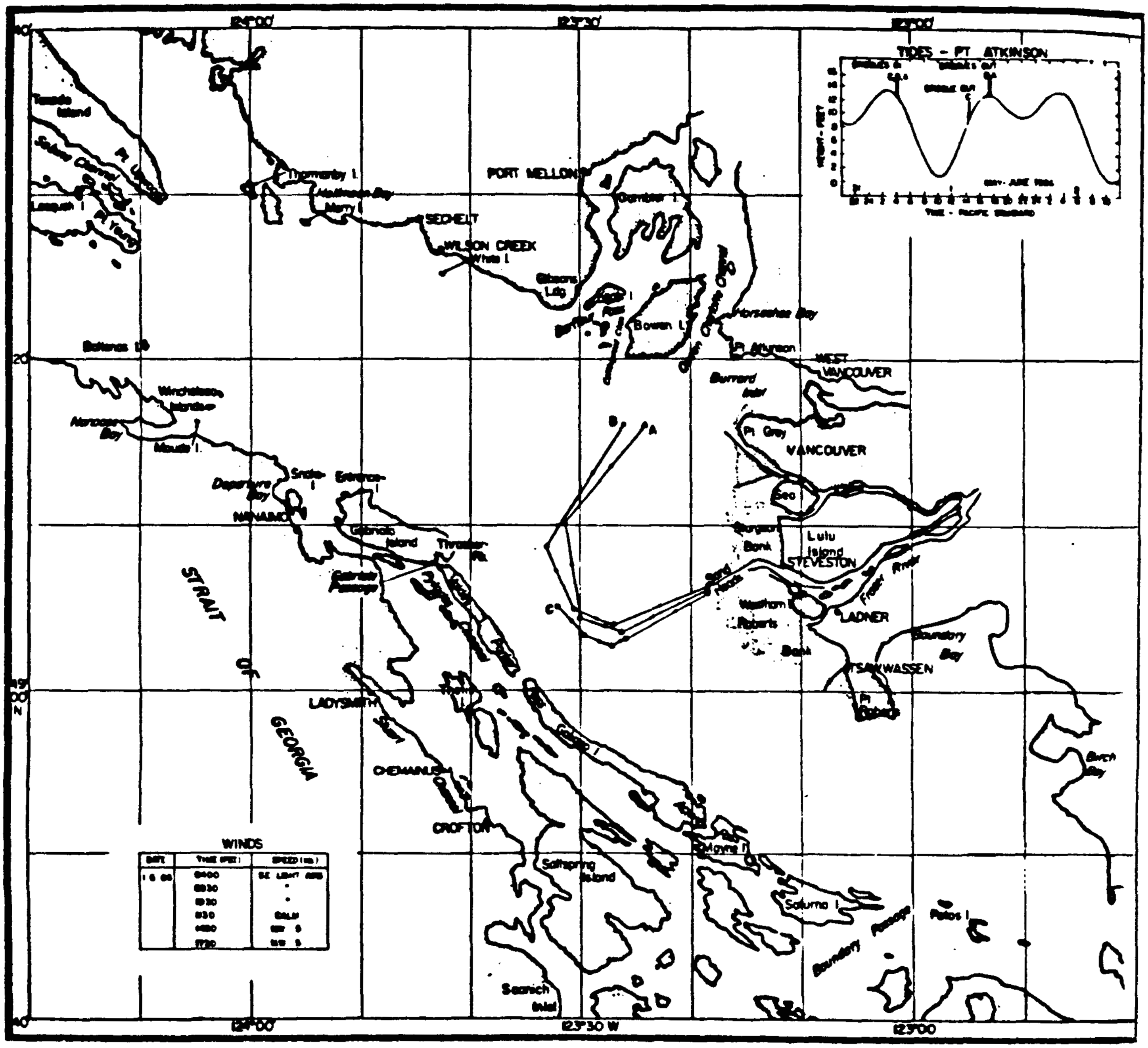

Fig. 2 Movement of surface drogues in the vicinity of Iona jetty during a tidal cycle (Crean and Ages 1972).

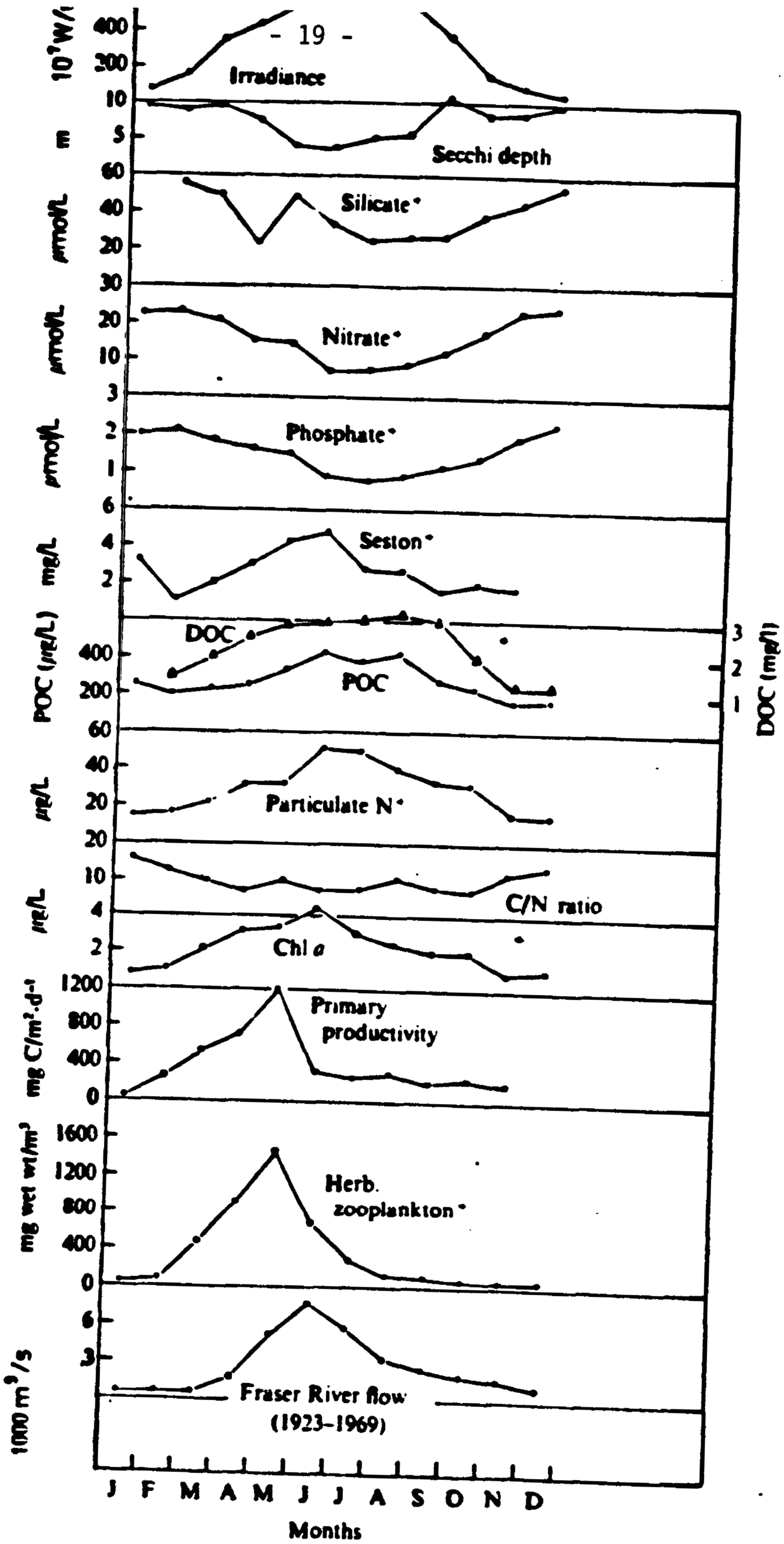

Fig. 3 Seasonal cycle in physical and chemical parameters, standing stock, and productivity expressed as monthly averages for the period 1965-68 for the Strait of Georgia (+ denotes average value for 0-20 m in the water column). DOC and POC represent dissolved and particulate organic carbon, respectively (from Parsons 1979). Recent studies (Stockner et al.1979) indicate that the values for primary productivity could be twice as high as represented in this figure.

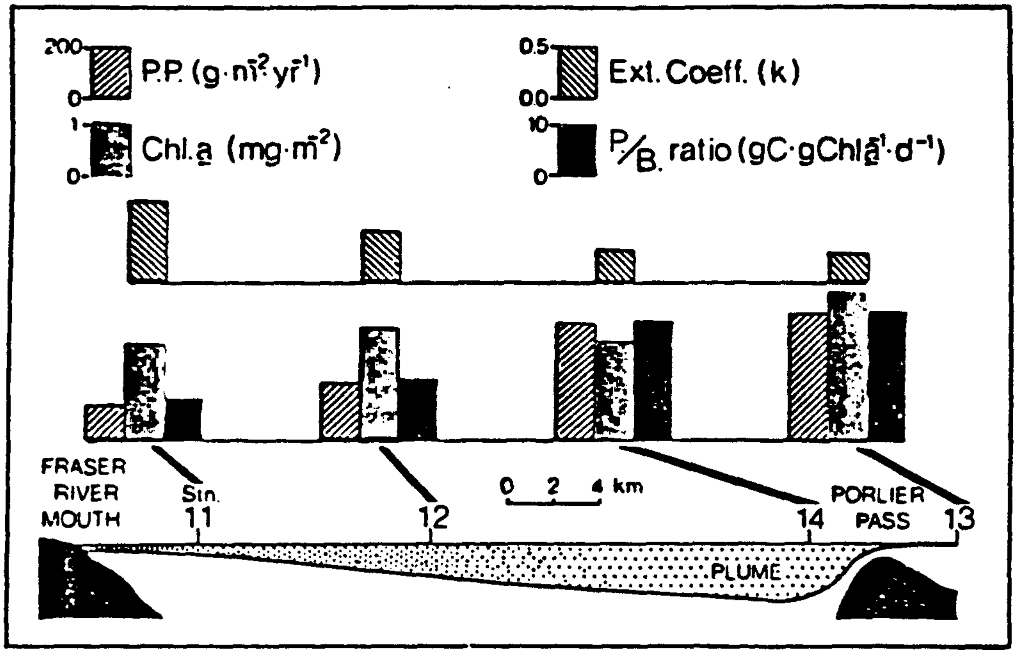

Fig.4 Schematic illustration of the impact of the Fraser River discharge on light attenuation and primary production. Histograms are mean 1976 values for stations on the east-west transect from the river mouth to inside Porlier Pass (from Stockner et al.1979).

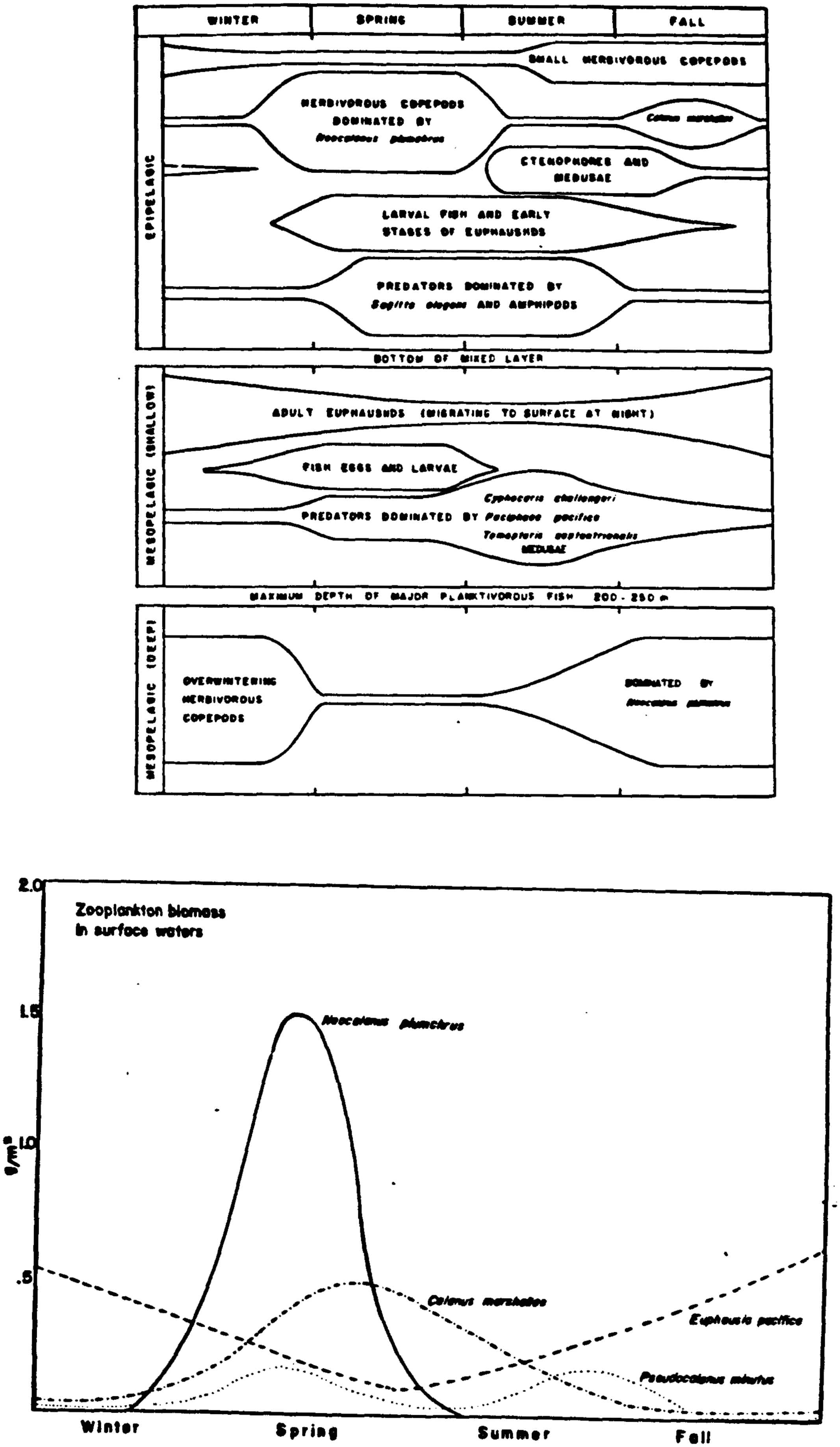

Fig.5 Generalized schematic representation of the zooplankton community structure for the strait. (A) Changes in relative abundance with seasons and depth. (B) Seasonal changes in biomass (g wet wt $\cdot$ m^{-3}) of dominant species inhabiting the upper 20-50 m of the water column (from Harrison et al 1983)

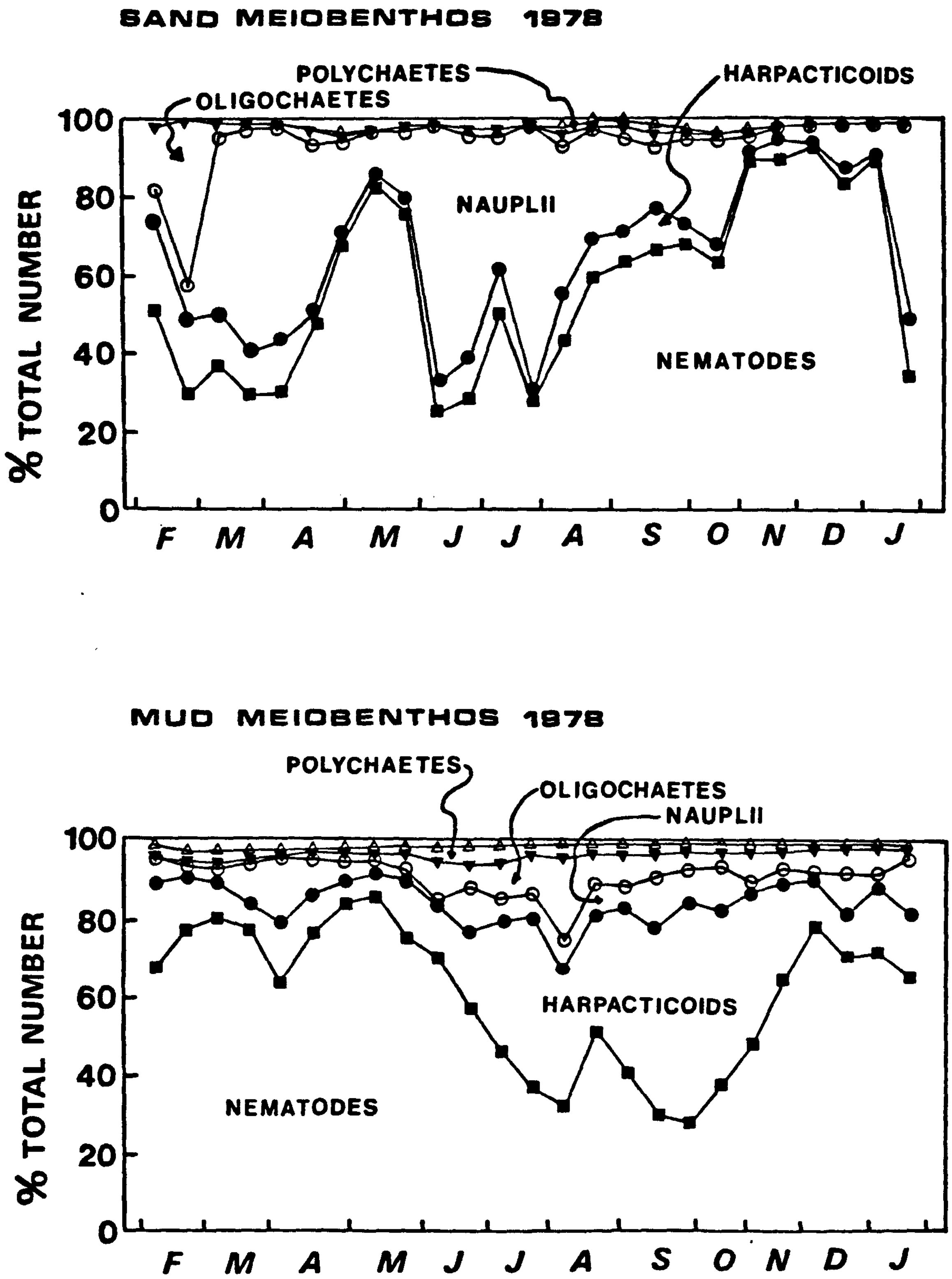

Figure 6 Seasonal variation in percentage contribution of most abundant taxa to the total number of meiobenthic organisms collected from each site through 1978 (from Harrison 1981).

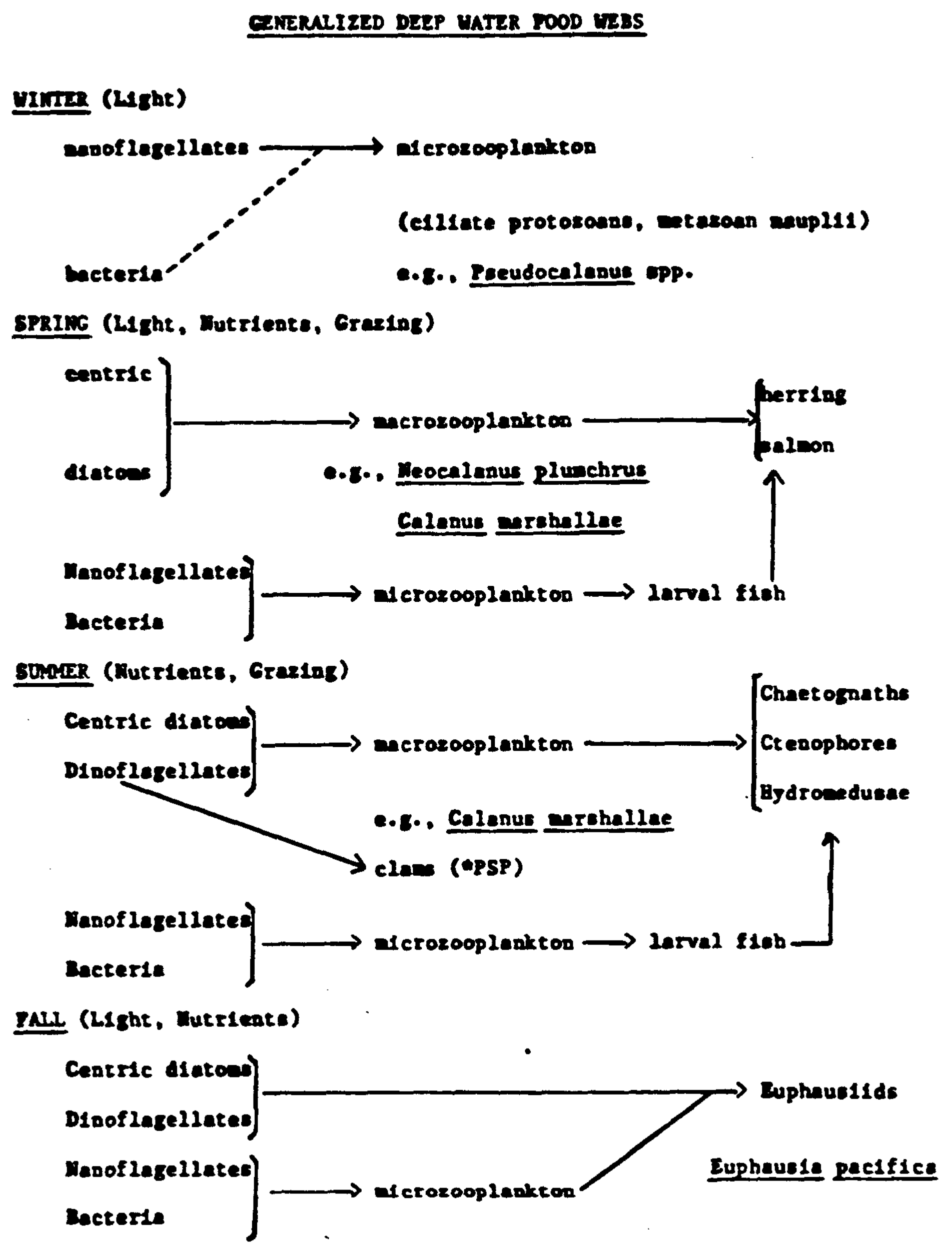

Fig. 7 Generalized schematic representation of food webs during different seasons in the Strait of Georgia. Important factors influencing primary productivity are shown in parentheses for each season. Broken lines indicate that the degree of interaction between the two trophic levels is unknown (*PSP = paralytic shellfish poisoning) (from Harrison etal.1983)

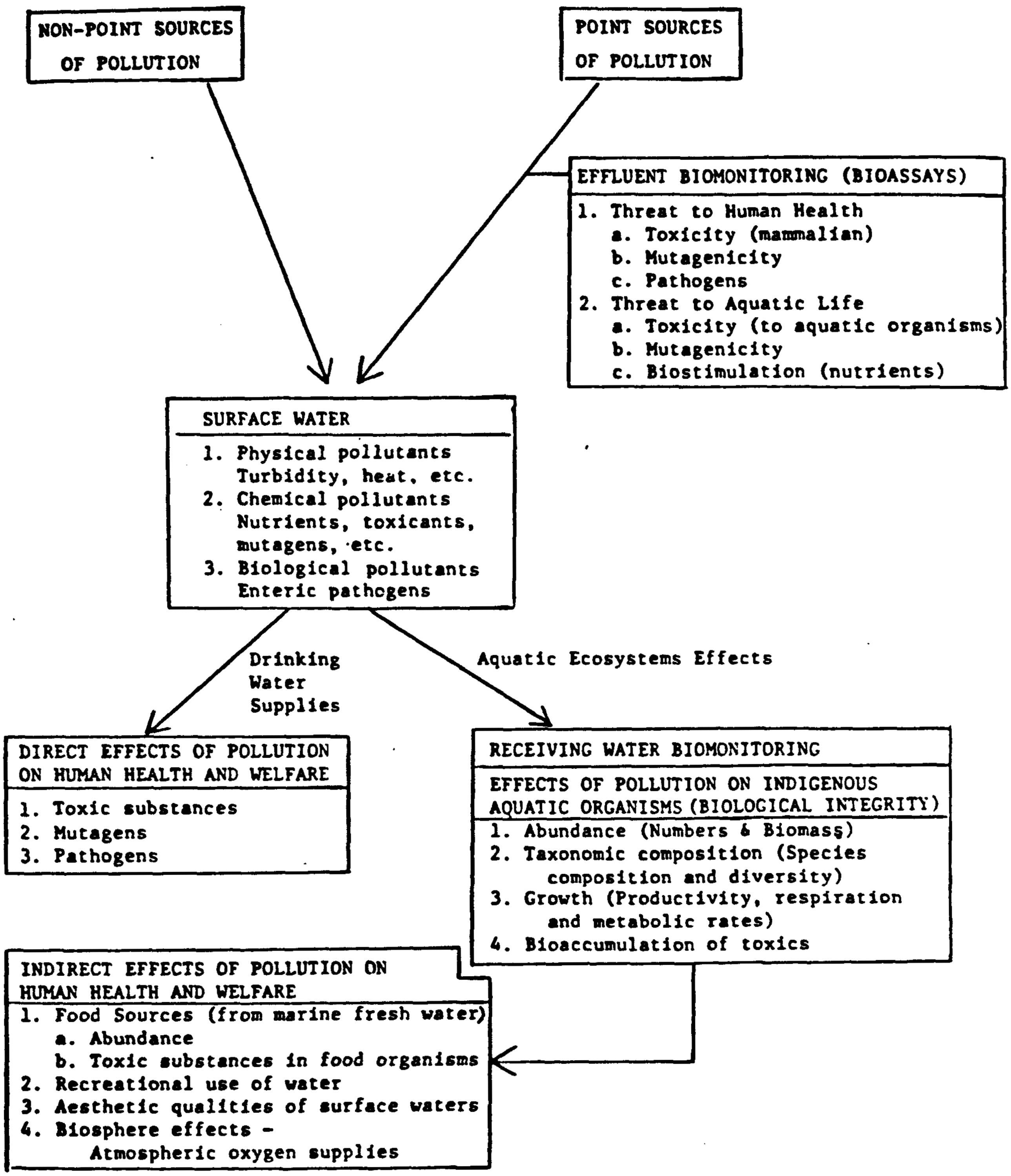

Figure 8 Biological Effects of Pollution on Human Health and Aquatic Life (After Worf 1980).

TABLE 1 Concentrations of dissolved oxygen and nutrients for central Strait of Georgia, near the outfall and at the mouth of the Fraser River. (DON = dissolved organic nitrogen)

SITE	Nutrient conc'n ($mg \cdot l^{-1}$)					
	NO_3	NH_4	Urea	DON	PO_4	O_2
Central Strait- Winter	0.4	0.03	0.04	0.05	0.06	9
Central Strait-Summer	0	0.01	0.01	0.01	0.01	9
Outfall	-	9.0	-	-	0.5	1.5
Fraser River-Winter	0.2	0.06	-	-	0.009	9
Fraser River-Summer	0.02	0.01	-	-	0.003	9

Table 2
Properties of Indigenous Communities of Aquatic Organisms Used in Determining the Biological Integrity of Surface Waters (from Worf 1980).

	Community					
Parameters	*Phyto plankton*	*Zoo-plankton*	*Peri-phyton*	*Macro-phyton*	*Macro-invert*	*Fish*
Standing Crop						
1. Count	X	X	X	X	X	X
2. Volume	X	X	X		X	
3. Wet weight	X	X	X	X	X	X
4. Dry weight	X	X	X	X	X	
5. Ashfree weight	X	X	X	X	X	
6. DNA content	X					
7. ATP content	X	X	X			
8. Chlorophyll *a* content	X		X	X		
Taxonomic Composition						
1. Species identification	X	X	X	X	X	X
Indicator species	X	X	X	X	X	X
Number of individual species	X	X	X	X	X	X
Total number of species	X	X	X	X	X	X
Diversity index	X	X	X	X	X	X
2. Pigment composition						
Biomass/Chlorophyl *a*	X		X			
Chlorophyl *a*/Chlorophyl *b*	X		X			
Chlorophyl *a*/Chlorophyl *c*	X		X			
Pheophytin content	X		X			
3. Nitrogen (N_2) fixation	X		X			
Metabolic Activity or Condition						
1. *Primary productivity*						
Carbon-14 uptake	X		X	X		
Oxygen evolution	X		X	X		
2. *Respiration rate*						
Plankton dark-bottle O_2 uptake	X					
Electron transport	X					
Benthic respirometer O_2 uptake			X	X	X	
3. *Nitrogen* (N_2) *fixation*	X		X			
4. *Chemical composition*				X		
Macronutrient content				X		
Enzyme content						
Acetyl choline esterase					X	X
Phosphatase	X			X		
Nitrate reductase	X					
Toxic organics and metals content	X	X	X	X	X	X
5. *Flesh tainting*					X	X
6. *Histopathology*					X	X
7. *Condition factor*						X

Table 3
Use of Captive Organisms in Biomonitoring and Toxicity Tests (from Worf 1980).

	Organism					
Type of Test	*Phyto-plankton*	*Zoo-plankton*	*Peri-phyton*	*Macro-phyton*	*Macro-invert*	*Fish*
In Situ Tests						
1. *Bioaccumulation*						
Toxic metals	X	X	X	X	X	X
Pesticides (organics)	X	X	X	X	X	X
Flesh tainting					X	X
2. *Toxicity tests*						
Acute toxicity					X	X
Histopathology					X	X
Histochemistry			X	X	X	X
Choline esterase						X
In-plant Tests (Effluents)						
1. *Bioaccumulation*						
Toxic metals			X	X	X	X
Pesticides (organics)			X	X	X	X
Flesh tainting					X	X
2. *Toxicity tests*						
Acute toxicity	X	X			X	X
Low-level responses						X
(behavioral responses)					X	X
Histopathology					X	X
3. *Biostimulatory tests*						
Algal growth response (AGP)	X		X			
Laboratory Tests						
1. *Bioaccumulation*						
Toxic metals	X	X	X	X	X	X
Pesticides (organics)	X	X	X	X	X	X
Flesh tainting					X	X
2. *Toxicity tests*						
Acute toxicity	X	X			X	X
Chronic toxicity	X	X	X	X	X	X
Histopathology					X	X
Low-level responses						X
(behavioral responses)					X	X
3. *Biostimulatory tests*						
Algal growth response (AGP)	X		X			

Biological Parameter List, Sampling Frequencies, and Priority for Proposed Biomonitoring Programs (from Worf 1980).

(*a*) Model State Water Monitoring Program

Community	*Parameter*	*Priority*[a]	*Collection and Analysis Mathematics*[b]	*Sampling Frequency*[c]
Plankton	Counts and identification	1	Grab samples	Once each—in spring, summer, and fall
	Chlorophyll *a*	2		
	Biomass as ashfree weight			
Periphyton	Counts and identification	1	Artificial substrates	Minimally once annually during periods of peak periphyton population
	Chlorophyll *a*	2		
	Biomass as ashfree weight	2		
Macrophyton	Areal coverage	2	As circumstances prescribe	Minimally once annually during period of peak macrophyton population density and/or diversity
	Identification	2		
	Biomass as ashfree weight	2		
Macroinvertebrate	Counts and identification	1	Artificial and natural substrates	Once annually during periods of peak macroinvertebrate population density and/or diversity
	Biomass as ashfree weight	2		
	Flesh tainting	2		
	Toxic substances in tissue[d]	2		
Fish	Toxic substances in tissue[d]	1	Electrofishing or netting	Once annually during spawning runs or other times of peak fish population density and/or diversity
	Counts and identification	2		
	Biomass as wet weight	2		
	Condition factor	2		
	Flesh tainting	2		
	Age and growth	2		

(*b*) Basic Water Monitoring Program

	Community of Aquatic Organisms			
	Plankton	*Periphyton*	*Macroinvertebrates*	*Fish/Shellfish*
Parameters				
Counts			X	
Species identification			X	X
Biomass (ashfree weight)		X		
Chlorophyll *a*	X	X		
Toxic substances				X[e]
Habitat Types				
Rivers		X	X	X
Lakes	X	X	X	X
Estuaries	X			X

Table 4 continued

	Community of Aquatic Organisms			
	Plankton	*Periphyton*	*Macroinvertebrates*	*Fish/Shellfish*
Sampling Methods				
Sampling season	6/15-9/15	6/15-9/15	6/15-9/15	6/15-9/15
Sampling frequency	Monthly grab	Once annually	Once annually	Once annually
Sampling method		Glass slides Floating Sampler	Hester-Dandy Multiplace	
Number of replicate samples	3	3	3	

[a]Priority: 1—minimum program; 2—Add as soon as capability can be developed.

[b]See EPA biological methods mannual.

[c]Keyed to dynamics of community.

[d]See *Analysis of Pesticide Residues in Human and Environmental Samples*, CSEPA, Perrine Primate Research Laboratories, Perrine, Fla., 1970, and *Pesticide Analytical Manual* (Washington: Department of Health, Education, and Welfare).

[e]Fish tissue analysis is a specific requirement of the basic ambient monitoring program.

Table 4
Biological Parameter Units

Community	*Parameter*	*Units*
Plankton	Counts	Numbers/ml by genus and/or species
	Chlorophyll *a*	mg/m^3
	Biomass (ashfree dry weight)	mg/m^3
Periphyton	Counts	$Numbers/mm^2$
	Chlorophyll *a*	mg/m^2
	Biomass (ashfree weight)	mg/m^2
	Autotrophic index	$\frac{\text{Ashfree weight } (mg/m^2)}{\text{Chlorophyll } a\ (mg/m^2)}$
Macrophyton	Areal coverage	Maps by species and species associations
	Biomass (ashfree weight)	g/m^2
Macroinvertebrate	Counts	Grab—number/m^2 Substrate—number/sampler
	Biomass	g/m^2
	Toxic substances	mg/kg
Fish	Toxic substances	mg/kg
	Counts	Number/unit of effort, expressed as per shocker hour or per 100 ft of a 24-hour net set
	Biomass (wet weight)	Same as counts
	Condition	$K(TL) = \frac{10^5 \times \text{weight in grams}}{L^3 \text{ (length in mm)}}$

Source: *Model State Water Monitoring Program* (Washington: Environmental Protection Agency 1975).

TABLE 5 PHYSICAL (I), CHEMICAL (II), AND BIOLOGICAL (III) PARAMETERS THAT CAN BE MEASURED IN ORDER TO MONITOR THE EFFECTS OF SEWAGE EFFLUENT DISCHARGE. The methods are listed and the ease of measurement rated as + = easy, ++ = moderate, and +++ = difficult or time consuming.

	PARAMETER	METHOD	EASE OF MEASUREMENT	FREQUENCY OF MEASUREMENT
I	Light extinction (turbidity)	Secchi disc or transmissometer	+	bimonthly
	Temperature and salinity	temperature and salinity probe	+	"
II	Dissolved O_2	Winkler titration	++	bimonthly
	Inorganic nutrients (NO_3, NH_4, urea, PO_4, SiO_4)	Autoanalyzer	++	"
	Dissolved organic N and P	Digestion and autoanalyzer	++	monthly
	Particulate N and P	Digestion and autoanalyzer	++	"
III	Chlorophyll a - phytoplankton	in vivo fluorescence	+	monthly
	Cell counts - coliform bacteria	microscope	+++	"
	- phytoplankton	particle counter & microscope	++	"
	Species composition - phytoplankton, zooplankton, & bacteria	microscope	+++	"
	Metabolic rates - phytoplankton	^{14}C uptake	+++	"
	Bioaccumulation - phytoplankton & bacteria (e.g. metals)	atomic absorption spectometry	+++	"
	Zooplankton biomass	net hauls	++	"

Bibliography I - Fraser River Estuary

1. Albright, L.J. 1977. Heterotrophic bacterial dynamics in the lower Fraser River, its estuary and Georgia Strait, B.C., Canada. Mar. Biol. 39: 203-211.

   bacteria, heterotrophic production, Fraser River, Fraser River estuary, nutrients, salinity

2. Albright, L.J. 1980. Photosynthetic activities of phytoneuston and phytoplankton. Can. J. Microbiol. 26: 380-392.

   photosynthesis, phytoplankton, bacteria, Fraser River estuary, heterotrophic production, carbon

3. Albright, L.J. 1982. Heterotrophic bacterial biomasses, activities and productivities within the Fraser River plume. Can. J. Fish. Aquat. Sci. 40(Suppl.1): 216-220.

   bacteria, heterotrophic production, biomass, Fraser River plume, salinity, chlorophyll, nutrients, primary production

4. Albright, L.J. 1983. The influence of river-ocean plumes upon bacterioplankton production of the Strait of Georgia, British Columbia. Mar. Ecol. Prog. Ser. 12: 107-113.

   bacteria, Fraser River plume, heterotrophic production, salinity

5. Anon. 1982. A living river by the door: a proposed management program for the Fraser River estuary. Fraser River Estuary Study - Phase II. Government of Canada and Province of British Columbia, Vancouver, B.C. 64 p.p

   Fraser River estuary, pollution

6. Bawden, C.A., W.A. Heath and A.B. Norton. 1973. A preliminary baseline study of Roberts and Sturgeon Banks. Tech. Rep. Westwater Res. Cent. 1: 54 p.

   survey, Roberts Bank, Sturgeon Bank, invertebrates, intertidal, mudflats, sediments

7. Becker, R.E. 1971. An ecological perspective of the Fraser River delta foreshores. M.Sc. thesis University of British Columbia, Vancouver, B.C. 49 p.

   Fraser River estuary, mudflats, ecology, survey, invertebrates

2.

8. Bell, C.R. and L.J. Albright. 1981. Attached and free-floating bacteria in the Fraser River estuary, British Columbia, Canada. Mar. Ecol. Prog. Ser. 6: 317-327.

bacteria, Fraser River estuary, salinity, nutrients, heterotrophic production, biomass, carbon

9. Bell, C.R. and L.J. Albright. 1982. Bacteriological investigations of the neuston and plankton in the Fraser River estuary, British Columbia, Canada. Estuarine Coastal Shelf Sci. 15: 385-394.

Fraser River estuary, bacteria, plankton, heterotrophic production

10. Benedict, A.H., K.J. Hall and F.A. Koch. 1973. A preliminary water quality survey of the lower Fraser River system. Tech. Rep. Westwater Res. Cent. 2: 50 p.

survey, Fraser River, Fraser River estuary, water chemistry, faunistic survey, subtidal zone, dredge, community

11. Birtwell, I.K., J.C. Davis, M. Hobbs, M.D. Nassichuk, M. Waldichuk, and J.A. Servizi. 1981. Brief presented to the British Columbia Pollution Control Board Inquiry pertaining the the Annacis Island Sewage Treatment Plant and municipal waste discharges into the Lower Fraser River. Can. Ind. Rep. Fish. Aquat. Sci. 126: xi + 40 p.

Fraser River estuary, sewage, nutrients, toxicity, oxygen, fish

12. Birtwell, I.K., G.L. Greer, M.D. Nassichuk, and I.H. Rogers. 1983. Studies on the impact of municipal sewage discharged onto an intertidal area within the Fraser River estuary, British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. No. 1170: 55 p.

Fraser River estuary, sewage, nutrients, toxicity, fish, Iona Island

13. Boulton, M., W. Rapatz and S. Huggett. 1983. Current atlas. Juan de Fuca Strait to Strait of Georgia. Can. Hydrographic Service, Ottawa 209 p.

physical oceanography, currents

14. Bradfield, G.E. and G.L. Porter. 1982. Vegetation structure and diversity components of a Fraser estuary tidal marsh, British Columbia, Canada. Can. J. Bot. 60: 440-451.

<u>Carex</u>, <u>Festuca</u>, <u>Menyanthes</u>, community, Fraser River estuary, Canoe Pass, statistics

15. B.C. Research. 1973. Water quality studies in the lower Fraser River: annual report - Project No. 1462. B.C. Research, Vancouver, B.C.

water chemistry, Fraser River, survey, toxicity

3.

16. B.C. Research. 1973. Environmental studies at Iona Island. [Unpubl. Rep.] Greater Vancouver Sewerage and Drainage District, Vancouver, B.C. 100 p.

pollution, sewage, Iona Island

17. Brown, D.A., C.A. Bawden, K.W. Chatel and T.R. Parsons. 1977. The wildlife community of Iona Island jetty and heavy metal pollution. Environ. Conserv. 4: 213-216.

Fraser River estuary, heavy metals, pollution, food chains, mudflats, toxicity, Mollusca

18. Cain, R.T., M.J.R. Clark and N.R. Zorkin. 1979. Fraser River Estuary Study. Water quality, trace organic constituents in discharges. Ministry of the Environment, Victoria, B.C. 56 p.

Fraser River estuary, water chemistry, organic compounds, toxicity

19. Cain, R.T. and L.G. Swain. 1980. Fraser River Estuary Study. Water quality, municipal effluents. Ministry of the Environment, Victoria, B.C. 101 p.

Fraser River estuary, water chemistry, organic compounds, toxicity, sewage, survey

20. Carefoot, T. 1977. Pacific seashores. J.J. Douglas Ltd., Vancouver, B.C. 208 p.

intertidal, life history, ecology, community, macroalgae, bivalves, benthic invertebrates

21. Chang, B.D. 1975. Some factors affecting distribution and productivity in the estuarine amphipod Anisogammarus pugettensis. M.Sc. thesis University of British Columbia, Vancouver, B.C. 128 p.

distribution, Fraser River estuary, secondary production, amphipods, Anisogammarus, ecology, water properties, life history, intertidal, feeding, Boundary Bay

22. Chocair, J.A. and L.J. Albright. 1981. Heterotrophic activities of bacterioplankton and bacteriobenthos. Can. J. Microbiol. 27: 259-266.

heterotrophic production, bacteria, biomass, distribution

23. Churchland, L.M. 1979. Fraser River Estuary Study. Water quality, microbial water quality 1970-1977. Ministry of the Environment, Victoria, B.C. 142 p.

Fraser River estuary, water chemistry, organic compounds, nutrients, bacteria, survey

4.

24. Clark, J.R. and R.W. Drinnan. 1980. Is the Strait of Georgia becoming more eutrophic? Comment. Can. J. Fish. Aquat. Sci. 37: 1047-1048.

sewage, organic nitrogen, nitrogen, nutrients, primary production

25. Clemens, W.A. 1935. Red water bloom in British Columbia waters. Nature 152: 473.

red water bloom, phytoplankton, water properties

26. Cordes, R.E., S. Pond, B.R. deLange Boom and P.H. LeBlond. 1980. Estimates of entrainment in the Fraser River plume, British Columbia. Atmosphere-Ocean 18: 15-26.

Fraser River plume, vertical mixing, salinity

27. Crean, P.B. and A.B. Ages. 1971. Oceanographic records from 12 cruises in the Strait of Georgia and Juan de Fuca Strait 1968. Department of Energy, Mines, Resources, Marine Science Branch, Victoria, B.C. 5v.

subtidal zone, temperature, salinity, oxygen, seasonal effects

28. Davidson, L.W. 1979. On the physical oceanography of Burrard Inlet and Indian Arm, British Columbia. M.Sc. thesis University of British Columbia, Vancouver, B.C. 221 p.

physical oceanography, Burrard Inlet, Indian Arm

29. deLange Boom, B.R. 1976. Mathematical modelling of the chlorophyll distribution in the Fraser River plume, British Columbia. M.Sc. thesis University of British Columbia, Vancouver, B.C. 140 p.

mathematical models, chlorophyll, distribution, Fraser River plume, fluourescence, salinity

30. Dorcey, A.J.H. (ed.). 1976. The uncertain future of the lower Fraser. Westwater Research Centre, University of British Columbia, Vancouver, B.C. 202 p.

review, economics, Fraser River estuary, shrimps, fishery, mariculture

31. Drinnan, R.W. and M.J.R. Clark. 1980. Fraser River Estuary Study. Water quality, water chemistry, 1970-1978. Ministry of the Environment, Victoria, B.C. 150 p.

water chemistry, Fraser River estuary, survey

32. Dunford, W.E. 1975. Space and food utilization by salmonids in marsh habitats of the Fraser River estuary. M.Sc. thesis University of British Columbia, Vancouver, B.C. 81 p.

Fraser River estuary, Woodward Island, juveniles, Oncorhynchus, food habits, marshes, intertidal

33. Ferguson, K.D. and K.J. Hall. 1979. Fraser River Estuary Study. Water quality, storm water discharges. Ministry of the Environment, Victoria, B.C. 197 p.

Fraser River estuary, water chemistry, pollution, trace metals

34. Finnigan, R.P. 1969. Sewage and pesticides in the marine environment. Wildl. Manage. Rep. B.C. Fish Wildl. Branch 10: 4 p.

sewage, pollution, organic compounds

35. Fjarlie, R.L.I. 1950. The oceanographic phase of the Vancouver sewage problem. Pacific Oceanographic Group, Nanaimo, B.C. 21 p.

sewage, pollution, Vancouver

36. Foreman, R.E. and J. Root. 1975. Macrophyte studies in the Strait of Georgia: a review of the current status of macrophyte knowledge and research. BERP Rep. Univ. B.C. Dep. Botany 75-2: 52 p.

macroalgae, review, distribution, bibliography

37. Fraser River Estuary Study, Water Quality Work Group. 1979. Water quality: summary report of the Water Quality Work Group. Ministry of the Environment, Victoria, B.C. 176 p.

Fraser River estuary, water chemistry, pollution, trace metals, organic compounds, survey

38. Fulton, J.D., O.D. Kennedy, J. Skelding and K. Stephens. 1969. Physical, chemical and biological data, Strait of Georgia, 1968. (Data record). Manuscr. Rep. Fish. Res. Board Can. 1049: 34 p.

zooplankton, physical oceanography, meroplankton, water chemistry

39. Fulton, J.D., O.D. Kennedy, K. Stephens and J. Skelding. 1967. Physical, chemical and biological data, Strait of Georgia, 1966. (Data record). Manuscr. Rep. Fish Res. Board Can. 915: 145 p.

physical oceanography, water chemistry, plankton

40. Fulton, J.D., O.D. Kennedy, K. Stephens and J. Skelding. 1968. Physical, chemical and biological data, Strait of Georgia, 1967. (Data record). Manuscr. Rep. Fish. Res. Board Can. 968: 197 p.

physical oceanography, water chemistry, phytoplankton

6.

41. Gardner, G.A. 1977. Analysis of zooplankton population fluctuations in the Strait of Georgia, British Columbia. J. Fish. Res. Board Can. 34: 1196-1206.

zooplankton, population ecology, Neocalanus, Calanus, statistics, temperature, salinity, distribution

42. Gardner, G.A. and I. Szabo. 1982. British Columbia pelagic marine Copepoda: an identification manual and annotated bibliography. Can. Spec. Publ. Fish. Aquat. Sci. 62: 536 p..

taxonomy, copepods, keys, bibliography

43. Garrett, C.L. 1980. Fraser River Estuary Study. Water quality, toxic organic contaminants. Ministry of the the Environment, Victoria, B.C. 125 p.

Fraser River estuary, toxicity, organic compounds, pollution

44. Gibson, V.R. and G.D. Grice. 1977. Response of macro-zooplankton populations to copper: controlled ecosystem pollution experiment. Bull. Mar. Sci. 27: 85-91.

CEPEX, zooplankton, copper, toxicity, growth

45. Gilmartin, M. 1962. Annual cyclic changes in the physical oceanography of a British Columbia fjord. J. Fish. Res. Board. Can. 19: 921-974.

physical oceanography, seasonal effects, fjord, Indian Arm

46. Gilmartin, M. 1964. The primary production of a British Columbia fjord. J. Fish. Res. Board Can. 21: 505-538.

primary production, fjord, Indian Arm, phytoplankton, nutrients, temperature, salinity, oxygen

47. Giovando, L.F. 1973. The effluent outfall proposed for the Five Finger Island area, Nanaimo, B.C.: oceanographic and related considerations. Pac. Mar. Sci. Rep. 73-12: 130 p.

Nanaimo River estuary, sewage, physical oceanography

48. Giovando, L.F. and S. Tabata. 1970. Measurements of surface flow in the Strait of Georgia by means of free-floating current followers. Fish. Res. Board Can. Tech. Rep. 163: 69 p.

currents, physical oceanography

7.

49. Greater Vancouver Sewerage and Drainage District. 1983. Iona Island sewage treatment plant source control study. (Unpubl. Rep.)

Iona Island, sewage, nutrients

50. Greer, G.L., C.D. Levings, R. Harbo, B. Hillaby, T. Brown and J. Sibert. 1980. Distribution of fish species on Roberts and Sturgeon Bank recorded in seine and trawl surveys. Can. Manuscr. Rep. Fish. Aquat. Sci. 1596: 51 p.

Fraser River estuary, Sturgeon Bank, Roberts Bank, intertidal, fish, Oncorhynchus, juveniles, distribution, survey

51. Hall, K.J., F.A. Koch and I. Yesaki. 1974. Further investigations into water quality conditions in the lower Fraser River system. Tech. Rep. Westwater Res. Cent. 4: 104 p.

Fraser River estuary, water chemistry, trace metals, nutrients

52. Hall, K.J., I. Yesaki and J. Chan. 1976. Trace metals and chlorinated hydrocarbons in the sediments of a metropolitan watershed. Tech. Rep. Westwater Res. Cent. 10: 73 p.

trace metals, organic compounds, toxicity, pollution, sediments, Fraser River estuary

53. Harrison, B.J. 1981. The biological determinants of the structure of harpacticoid copepod communities on an estuarine intertidal flat (Fraser River delta, B.C.). Ph.D. thesis University of British Columbia, B.C. 350 p.

Fraser River estuary, Sturgeon Bank, intertidal, harpacticoids, copepods, sediments, community

54. Harrison, P.G. 1977. Decomposition of macrophyte detritus in seawater: effects of grazing by amphipods. Oikos 28: 165-169.

decomposition, eelgrass, macroalgae, amphipods, grazing, bacteria

55. Harrison, P.G. 1979. Reproductive strategies in intertidal populations of two co-occurring seagrasses (Zostera spp.). Can. J. Bot. 57: 2635-2638.

intertidal, population ecology, eelgrass, Zostera, growth

56. Harrison, P.G. 1982. Spatial and temporal patterns in abundance of two intertidal seagrasses, Zostera americana den Hartog and Zostera marina L. Aquat. Bot. 12: 305-320.

Boundary Bay, intertidal, sediments, population ecology, Zostera, eelgrass

8.

57. Harrison, P.G. 1982. Seasonal and year to year variations in mixed intertidal populations of Zostera japonica Aschers. & Graebn. and Ruppia maritima L.S.L. Aquat. Bot. 14: 357-371.

eelgrass, Zostera, growth, population ecology, intertidal, Boundary Bay, seasonal effects

58. Harrison, P.J., J.D. Fulton, F.J.R. Taylor and T.R. Parsons. 1983. Review of biological oceanography of the Strait of Georgia: pelagic environment. Can. J. Fish. Aquat. Sci. 40: 1064-1094.

review, phytoplankton, zooplankton, bacteria, food chains, primary production, ecology, nutrients, chlorophyll, secondary production, grazing, irradiance, heterotrophic production

59. Higgs, T.W. 1977. A study of municipal wastewater toxicity, Iona Island sewage treatment plant, August 1976. Manuscr. Rep. Environ. Prot. Serv. Pac. Reg. 77-11: 54 p.

sewage, Iona Island, toxicity, pollution, nutrients

60. Holman, N., M. Pomeroy and G. Packman. 1981. Baseline environmental data collected at Cape Lazo, Vancouver Island prior to installation of a domestic sewage outfall. (Data Record). Environ. Prot. Serv. Reg. Program Rep. 81-1: 44 p.

sewage, pollution, nutrients, water chemistry

61. Hoos, L.M. and G.A. Packman. 1974. The Fraser River estuary: status of environmental knowledge to 1974. Report of Estuary Working Group, Department of the Environment, Regional Board, Pacific Region. Spec. Estuary Ser. 1: 518 p.

review, bibliography, Fraser River estuary

62. Hoos, R.A.W. 1977. Environmental assessment of an ocean dumpsite in the Strait of Georgia, British Columbia. Environ. Prot. Serv. Surveillance Rep. EPS 5-PR-77-2: 31 p.

Point Grey, solid wastes, sediments, pollution, subtidal zone, invertebrates

63. Hutchinson, A.H. 1928. A biohydrographical investigation of the sea adjacent to the Fraser River mouth: Paper II. Factors affecting the distribution of phytoplankton. Trans. R. Soc. Can. III 22(5): 293-310.

Fraser River, physical oceanography, distribution, phytoplankton, water properties, diatoms

9.

64. Hutchinson, A.H. and C.C. Lucas. 1930. Effect of the Fraser River on the waters and phytoplankton of the Strait of Georgia. Proc. 4th Pac. Sci. Cong. 3: 443-448.

Fraser River, physical oceanography, distribution, phytoplankton, water properties, diatoms

65. Hutchinson, A.H. and C.C. Lucas. 1931. The epithalassa of the Strait of Georgia. Can. J. Res. 5: 231-284.

seasonal effects, water chemistry, physical oceanography, distribution, phytoplankton, diatoms

66. Hutchinson, A.H., C.C. Lucas and M. McPhail. 1929. Seasonal variations in the chemical and physical properties of the waters of the Strait of Georgia in relation to phytoplankton. Trans. R. Soc. Can. III 23: 177-183.

seasonal effects, water chemistry, physical oceanography, distribution, phytoplankton, diatoms

67. Hutchinson, I. 1982. Vegetation-environment relations in a brackish marsh, Lulu Island, Richmond, British Columbia, Canada. Can. J. Bot. 60: 452-462.

Scirpus, Carex, Trichlochia, Agrostis, Potentilla, Distichlis, Typha, Fraser River estuary, intertidal, sediments

68. Joy, C.S. 1975. Water quality models of the lower Fraser River. Tech. Rep. Westwater Res. Cent. 6: 52 p.

mathematical models, water chemistry, Fraser River

69.. Kistritz, R.U. 1978. An ecological evaluation of Fraser estuary tidal marshes: the role of detritus and the cycling of elements. Tech. Rep. Westwater Res. Cent. 15: 59 p.

Fraser River estuary, tidal flat, marshes, detritus, decomposition, bacteria

70. Kistritz, R.U. and I. Yesaki. 1979. Primary production, detritus flux, and nutrient cycling in a sedge marsh, Fraser River estuary. Tech. Rep. Westwater Res. Cent. 17: 53 p.

primary production, detritus, decomposition, marshes, Fraser River estuary

71. Koch, F.A., K.J. Hall and I. Yesaki. 1977. Toxic substances in the wastewaters from a metropolitan area. Tech. Rep. Westwater Res. Cont. 12: 107 p.

Fraser River estuary, toxicity, heavy metals, pollution

10.

72. LeBlond, P.H. 1983. The Strait of Georgia: functional anatomy of a coastal sea. Can. J. Fish. Aquat. Sci. 40: 1033-1063.

physical oceanography, Fraser River estuary, currents

73. LeBrasseur, R.J., W.E. Barraclough, O.D. Kennedy and T.R. Parsons. 1969. Production studies in the Strait of Georgia: Part III. Observations on the food of larval and juvenile fish in the Fraser River plume, February to May 1967. J. Exp. Mar. Biol. Ecol. 3: 51-61.

larvae, fish, juveniles, feeding, secondary production

74. Légaré, J.E.H. 1957. The qualitative and quantitative distribution of plankton in the Strait of Georgia in relation to certain oceanographic factors. J. Fish. Res. Board Can. 14: 521-552.

zooplankton, biomass, distribution, temperature, salinity

75. Levings, C.D. 1980. Vertical distribution and abundance of epibenthos and macrozooplankton in the lower Fraser River estuary. Can. Data Rep. Fish. Aquat. Sci. 241: 59 p.

Fraser River estuary, Fraser River, Roberts Bank, epibenthos, zooplankton, temperature, salinity

76. Levings, C.D., R. Armour and N.G. McDaniel. 1978. A trench through mudflat communities of macro-invertebrates on Roberts Bank, Fraser River delta, B.C. Fish. Mar. Serv. Manuscr. Rep. 1501: 51 p.

macro-invertebrates, sediments, Roberts Bank, Fraser River estuary

77. Levings, C.D. and J.B. Constalin. 1975. Zonation of intertidal biomass and related benthic data from Sturgeon and Roberts Banks, Fraser River estuary, British Columbia. Fish. Mar. Serv. Tech. Rep. 408: 139 p.

Fraser River estuary, Sturgeon Bank, Roberts Bank, macro-invertebrates, intertidal, transect

78. Levings, C.D., R.E. Foreman and V.J. Tunnicliffe. 1983. Review of the benthos of the Strait of Georgia and contiguous fjords. Can. J. Fish. Aquat. Sci. 40: 1120-1141.

review, macroalgae, benthic invertebrates, food chains, primary production, zonation, pelagic-benthic transfer

79. Levy, D.A. and T.G. Northcote. 1981. Juvenile salmon residency in a marsh area of the Fraser River estuary. Can. J. Fish. Aquat. Sci. 39: 270-276.

Oncorhynchus, juveniles, Fraser River estuary, Woodward Island, growth, intertidal, marshes

80. Levy, D.A. and T.G. Northcote. 1981. The distribution and abundance of juvenile salmon in marsh habitats of the Fraser River estuary. Tech. Rep. Westwater Res. Cent. 25: 117 p.

juveniles, Oncorhynchus, marshes, Fraser River estuary, distribution, population ecology

81. Levy, D.A., T.G. Northcote and G.J. Birch. 1979. Juvenile salmon utilization of tidal channels in the Fraser River estuary, British Columbia. Tech. Rep. Westwater Res. Cent. 23: 70 p.

Oncorhynchus, juveniles, fish, Fraser River estuary, Woodward Island, growth, intertidal, marshes

82. Mackas, D.L., G.C. Louttit and M.J. Austin. 1980. Spatial distribution of zooplankton and phytoplankton in British Columbian coastal waters. Can. J. Fish. Aquat. Sci. 37: 1476-1487.

distribution, nutrients, microdistribution, fronts, phytoplankton, chlorophyll

83. Mackie, G.O. and C.E. Mills. 1982. Use of the PISCES IV submersible for zooplankton studies in coastal waters of British Columbia. Can. J. Fish. Aquat. Sci. 40: 763-776.

submersible, plankton

84. McDaniel, N.G., R.D. MacDonald, J.J. Dobrocky and C.D. Levings. 1976. Biological surveys using in-water photography at three ocean disposal sites in the Strait of Georgia, British Columbia. Fish. Mar. Serv. Tech. Rep. 713: 41 p.

solid wastes, Thornborough Channel, Point Grey, Burrard Inlet, sediments, macro-invertebrates, subtidal zone

85. McGreer, E.R. 1979. Studies of the bivalve Macoma balthica on a mudflat receiving sewage effluent and on an unpolluted mudflat, Fraser River estuary, British Columbia. M.Sc. thesis University of British Columbia, Vancouver, B.C. 99 p.

Macoma, mudflats, sewage, Fraser River estuary, population ecology, Roberts Bank, Sturgeon Bank, intertidal, growth, sediments

86. McGreer, E.R. 1979. Sublethal effects of heavy metal contaminated sediments on the bivalve Macoma balthica L. Mar. Pollut. Bull. 10: 259-262.

heavy metals, sediments, bivalves, Macoma, distribution, pollution

12.

87. McGreer, E.R. 1982. Factors affecting the distribution of Macoma balthica (L.) on a mudflat receiving sewage effluent. Mar. Environ. Res. 7: 131-149.

sewage, mudflat, Macoma, bivalve, distribution

88. Mayer, J.A. and F.J.R. Taylor. 1979. A virus which lyses the marine nanoflagellate Micromonas pusilla. Nature 281: 299-301.

virus, nanoflagellates, Micromonas, population ecology, phytoplankton

89. Northcote, T.G. 1974. Biology of the lower Fraser River: a review. Tech. Rep. Westwater Res. Cent. 3: 94 p.

Fraser River estuary, Fraser River, review, phytoplankton, plankton, nutrients, salinity, food chains, ecology

90. Northcote, T.G., N.T. Johnston and K. Tsumura. 1976. Trace metal concentrations in lower Fraser River fishes. Tech. Rep. Westwater Res. Cent. 7: 41 p.

Fraser River estuary, trace metals, fish, chemical composition

91. Northcote, T.G., N.T. Johnston and K. Tsumura. 1976. Benthic, epibenthic and drift fauna of the lower Fraser River. Tech. Rep. Westwater Res. Cent. 11: 227 p.

benthic invertebrates, Fraser River, Fraser River estuary, epibenthos, survey

92. Northcote, T.G., N.T. Johnston and K. Tsumura. 1978. A regional comparison of species distribution, abundance, size and other characteristics of lower Fraser River fishes. Tech. Rep. Westwater Res. Cent. 14: 38 p.

Fraser River, fish, standing stock, distribution, species lists

93. Northcote, T.G., N.T. Johnston and K. Tsumura. 1979. Feeding relationships and food web structure of lower Fraser River fishes. Tech. Rep. Westwater Res. Cent. 16: 73 p.

Fraser River, fish, standing stock, distribution, food chains, feeding

94. Otte, G. and C.D. Levings. 1975. Distribution of macroinvertebrate communities on a mud flat influenced by sewage, Fraser River estuary, British Columbia. Fish. Mar. Serv. Tech. Rep. 476: 63 p.

macro-invertebrates, sewage, pollution, oxygen, intertidal, Fraser River estuary, Sturgeon Bank, mudflats, distribution, community

95. Pacific Oceanographic Group. 1950. Data record - Fraser River estuary project, 1950. Manuscr. Rep. Biol. Stn. Fish. Res. Board Can. 459: 489 pp.

Fraser River estuary, physical oceanography, water chemistry, survey

96. Pacific Oceanographic Group. 1954. Physical and chemical data record, Strait of Georgia, 1949-1953, with Appendix I - current measurements, March 1953. Pacific Oceanographic Group, Nanaimo, B.C. 437 p.

Fraser River estuary, physical oceanography, currents, survey

97. Packman, G. 1980. An environmental assessment of the Point Grey ocean disposal area in the Strait of Georgia, British Columbia. Environ. Prot. Serv. Reg. Program Rep. 80-3: 128 p.

solid wastes, pollution, sediments, macro-invertebrates, subtidal zone, Point Grey, environmental impact

98. Parsons, C.O. 1975. Vegetation pattern in a salt marsh at Boundary Bay, British Columbia. Lambda 1: 45-52.

marshes, Boundary Bay, tidal flat, vegetation, distribution

99. Parsons, T.R. 1979. The Strait of Georgia program, p. 133-149. In: Marine production mechanisms. M.J. Dunbar (ed.). Cambridge University Press, Cambridge, Mass.

plankton, ecology, larvae, fish, food chains, review, primary production

100. Parsons, T.R., L.J. Albright and J. Parslow. 1980. Is the Strait of Georgia becoming more eutrophic? Can. J. Fish. Aquat. Sci. 37: 1043-1047.

phytoplankton, nitrogen, sewage, organic nitrogen, nitrate, ammonium, primary production, pollution, Fraser River estuary

101. Parsons, T.R., L.J. Albright, F. Whitney, C.S. Wong and P.J. leB. Williams. 1980. The effects of glucose on the productivity of seawater: an experimental approach using controlled aquatic ecosystems. Mar. Environ. Res. 4: 229-242.

CEPEX, phytoplankton, bacteria, heterotrophic production, organic compounds

102. Parsons, T.R., C.A. Bawden and W.A. Heath. 1973. Preliminary survey of mercury and other metals contained in animals from the Fraser River mudflats. J. Fish. Res. Board Can. 30: 1014-1016.

Fraser River estuary, Iona Island, heavy metals, benthic invertebrates, toxicity, mudflats

103. Parsons, T.R., R.J. LeBrasseur and W.E. Barraclough. 1970. Levels of production in the pelagic environment of the Strait of Georgia, British Columbia: a review. J. Fish. Res. Board Can. 27: 1251- 1264.

plankton, ecology, larvae, fish, food chains, review, primary production, nutrients, phytoplankton, zooplankton, spring bloom

14.

104. Parsons, T.R., R.J. LeBrasseur, J.D. Fulton and O.D. Kennedy. 1969. Production studies in the Strait of Georgia: Part II. Secondary production under the Fraser River plume, February to May 1967. J. Exp. Mar. Biol. Ecol. 3: 39-50.

secondary production, larvae, fish, juveniles, rations, spring bloom, Fraser River plume, phytoplankton, primary production, zooplankton, grazing, distribution, food chains

105. Parsons, T.R., W.K.M. Li and R. Waters. 1976. Some preliminary observations of the enhancement of phytoplankton growth by low levels of mineral hydrocarbons. Hydrobiologia 51: 85-89.

CEPEX, phytoplankton, growth, pollution, hydrocarbons

106. Parsons, T.R., K. Stephens and R.J. LeBrasseur. 1969. Production studies in the Strait of Georgia: Part I. Primary production under the Fraser River plume, February to May 1967. J. Exp. Mar. Biol. Ecol. 3: 27-38.

primary production, spring bloom, phytoplankton, nutrients, irradiance, chlorophyll, photosynthesis, Fraser River plume, salinity, stability

107. Parsons, T.R., J. Stronach, G.A. Borstad, G. Louttit and R.I. Perry. 1981. Biological fronts in the Strait of Georgia, British Columbia, and their relation to recent measurements of primary production. Mar. Ecol. Prog. Ser. 6: 237-242.

fronts, primary production, stability, chlorophyll, fluorescence, remote sensing, phytoplankton, nutrients, vertical mixing

108. Parsons, T.R., W.H. Thomas, D. Seibert, J.R. Beers, P. Gillespie and C. Bawden. 1977. The effect of nutrient enrichment on the plankton community in enclosed water columns. Int. Rev. Ges. Hydrobiol. 62: 565-572.

CEPEX, phytoplankton, growth, nutrients, diatoms, nanoflagellates

109. Parsons, T.R., K. von Bröckel, P. Koeller, M. Takahashi, M.R. Reeve and O. Holm-Hansen. 1977. The distribution of organic carbon in a marine planktonic food web following nutrient enrichment. J. Exp. Mar. Biol. Ecol. 27: 235-247.

CEPEX, phytoplankton, growth, nutrients, diatoms, nanoflagellates, carbon, food chains

110. Pickard, G.L. 1956. Surface and bottom currents in the Strait of Georgia. J. Fish. Res. Board Can. 13: 581-590.

physical oceanography, currents

111. Pomeroy, W.M. 1982. Receiving environment conditions in the vicinity of French Creek sewage outfall, Vancouver Island, B.C. (1977-1980). Environ. Prot. Serv. Reg. Program Rep. 82-12: 58 p.

sewage, pollution, water chemistry

112. Pomeroy, W.M. and C.D. Levings. 1980. Association and feeding relationships between Eogammarus confervicolus (Amphipoda, Gammarida) and benthic algae on Sturgeon and Roberts Bank, Fraser River estuary. Can. J. Fish. Aquat. Sci. 37: 1-10.

Fraser River estuary, Sturgeon Bank, Roberts Bank, microbenthic algae, feeding, growth, Eogammarus, intertidal, community

113. Pomeroy, W.M and G.A. Packman. 1981. Environmental effects of a deep marine sewage outfall at Five Finger Island, Nanaimo, British Columbia, 1977-1980. Environ. Prot. Serv. Reg. Program Rep. 81-4: 66 p.

pollution, toxicity, organic compounds, benthic invertebrates, sewage, Nanaimo River estuary

114. Prakash, A. and F.J.R. Taylor. 1966. A "red water" bloom of Gonyaulax acatenella in the Strait of Georgia and its relation to paralytic shellfish toxicity. J. Fish. Res. Board Can. 23: 1265-1270.

red water bloom, Gonyaulax, shellfish, toxicity

115. Royer, L. 1983. Variations of the Fraser River plume: observations and computer simulations. Ph.D. thesis University of British Columbia, Vancouver, B.C. 134 p.

Fraser River plume, mathematical models, currents, physical oceanography

116. S & S Consultants. 1983. Iona deep sea outfall feasibility study. Vol. I and II. Greater Vancouver Sewerage and Drainage District. 159 p.

Iona Island, sewage, nutrients, pollution, toxicity

117. Samuels, G. 1979. A mixing budget for the Strait of Georgia, British Columbia. M.Sc. thesis University of British Columbia, Vancouver, B.C. 261 p.

Fraser River estuary, vertical mixing, nutrients, salinity, physical oceanography

118. Servizi, J.A. and R.A. Burkholder. 1970. Selected measurements of water quality and bottom-dwelling organisms of the Fraser River system, 1963 to 1968. International Pacific Salmon Fisheries Commission, New Westminster, B.C. 70 p.

water chemistry, benthic invertebrates, Fraser River estuary

16.

119. Rawn, A.M., C.G. Hyde and J. Oliver. 1953. Sewerage and drainage of the Greater Vancouver area, British Columbia, Vancouver and Districts Sewerage and Drainage Board.

Iona Island, sewage, nutrients, currents

120. Shim, J.H. 1976. Distribution and taxonomy of planktonic marine diatoms in the Strait of Georgia, B.C. Ph.D. thesis University of British Columbia, Vancouver, B.C. 272 p.

taxonomy, distribution, diatoms, phytoplankton, survey, species lists, nutrients, salinity

121. Shim, J.H. 1977. Distributional ecology of planktonic diatoms in the Strait of Georgia, B.C. J. Oceanogr. Soc. Kor. 12: 13-32.

distribution, phytoplankton, survey, nutrients, salinity, diatoms

122. Shim, J.H. 1977. Relative importance of environmental parameters in predicting the distribution of planktonic marine diatoms. Proc. Coll. Nat. Sci. (Seoul) 2(1): 169-187.

distribution, phytoplankton, survey, nutrients, salinity, diatoms

123. Shim, J.H. 1977. A taxonomic study of marine planktonic diatoms of Vancouver Island coastal waters. Proc. Coll. Nat. Sci. (Seoul) 2(2): 79-184.

taxonomy, phytoplankton, diatoms, species lists

124. Sibert, J.R. and T.J. Brown. 1975. Characteristics and potential significance of heterotrophic activity in a polluted fjord estuary. J. Exp. Mar. Biol. Ecol. 19: 97-104.

heterotrophic production, pollution, fjord, estuary, Nanaimo River estuary

125. Singleton, H.J. 1980. Fraser River Estuary Study. Water quality, acute toxicity of effluents. Ministry of the Environment, Victoria B.C. 91 p.

Fraser River estuary, toxicity, heavy metals, organic compounds, pollution

126. Spies, A., E.D. Nutbrown and T.R. Parsons. 1983. An experimental approach to estuarine microplankton ecology. Estuarine Coastal Shelf Sci. 17: 97-105.

phytoplankton, diatoms, bacteria, nutrients, salinity, growth, Fraser River

17.
127. Stancil, D.E. 1980. Fraser River Estuary Study. Water quality, aquatic biota and sediments. Ministry of the Environment, Victoria, B.C. 187 p.

Fraser River estuary, water chemistry, sediments, plankton, nutrients, survey

128. Stephens, K., J.D. Fulton and O.D. Kennedy. 1969. Summary of biological oceanographic observations in the Strait of Georgia, 1965-1968. Fish. Res. Board Can. Tech. Rep. 110: 93 p.

primary production, biomass, distribution, nutrients, phytoplankton, zooplankton, seasonal effects

129. Stockner, J.G. and D.D. Cliff. 1979. Phytoplankton ecology of Vancouver Harbour. J. Fish. Res. Board Can. 36: 1-10.

phytoplankton, primary production, nutrients, irrandiance, Vancouver Harbour

130. Stockner, J.G., D.D. Cliff and K.R.S. Shortreed. 1979. Phytoplankton ecology of the Strait of Georgia, British Columbia. J. Fish. Res. Board Can. 36: 657-666.

primary production, phytoplankton, nutrients, irradiance, chlorophyll, biomass, salinity, turbidity, grazing, diatoms, dinoflagellate

131. Stockner, J.G., K.S. Shortreed and E.A. MacIsaac. 1980. The benevolent strait: reply. Can. J. Fish. Aquat. Sci. 37: 1048-1055.

primary production, phytoplankton, nutrients, irradiance, chlorophyll, biomass, salinity, turbidity, grazing, diatoms, dinoflagellate

132. Stronach, J.A. 1977. Observational and modelling studies of the Fraser River plume. Ph.D. thesis University of British Columbia, Vancouver, B.C. 244 p.

mathematical models, Fraser River plume, vertical mixing, salinity

133. Stronach, J.A. 1981. The Fraser River plume, Strait of Georgia. Ocean Manage. 6: 201-221.

mathematical models, Fraser River plume, vertical mixing, salinity

134. Swain, L.G. 1980. Fraser River Estuary Study. Water quality, industrial effluents. Ministry of the Environment, Victoria, B.C. 195 p.

Fraser River estuary, water chemistry, organic compounds, pollution

18.

135. Swain, L.G. and L.J. Alexander. 1980. Fraser River Estuary Study. Water quality, Boundary Bay. Ministry of the Environment, Victoria, B.C. 55 p.

Fraser River estuary, water chemistry, Boundary Bay

136. Swinbanks, D.D. 1979. Environmental factors controlling floral zonation and distribution of burrowing and tube-dwelling organisms on Fraser delta tidal flats, British Columbia. Ph.D. thesis University of British Columbia, Vancouver, B.C. 274 p.

intertidal, macro-invertebrates, vegetation, Upogebia, Callianassa, Boundary Bay, Fraser River estuary, Roberts Bank, salinity, sediments

137. Tabata, S. 1970. Current velocity measurements in the Strait of Georgia 1969. Fish. Res. Board Can. Tech. Rep. 191: 72 p.

physical oceanography, temperature, salinity, Burrard Inlet, Indian Arm

138. Tabata, S. 1972. A brief oceanographic description of the waters of Burrard Inlet and Indian Arm. Appendix E. In: Environmental impact study, third crossing of Burrard Inlet, Vancouver, B.C. Report prepared by Environmental Impact Study Team. Environment Canada, Lands Directorate, Vancouver, B.C. 48 p.

physical oceanography, temperature, salinity, Burrard Inlet, Indian Arm

139. Tabata, S. 1972. The movement of Fraser River influenced surface water in the Strait of Georgia as deduced from a series of aerial photographs. Pac. Mar. Sci. Rep. 72-6: 69 p.

physical oceanography, currents, Fraser River, Fraser River plume, remote sensing

140. Tabata, S., L.F. Giovando and D. Devlin. 1971. Current velocities in the vicinity of the Greater Vancouver sewerage and drainage district's Iona Island Outfall - 1968. Fish. Res. Board Can. Tech. Rep. 263: 110 p.

physical oceanography, currents, Iona Island

141. Tabata, S., L.F. Giovando, J.A. Strickland and J. Wong. 1970. Current velocity measurements in the Strait of Georgia, 1968. Fish. Res. Board Can. Tech. Rep. 178: 112 p.

physical oceanography, currents

142. Takahashi, M., F. Fujii and T.R. Parsons. 1973. Simulation study of phytoplankton photosynthesis and growth in the Fraser River estuary. Mar. Biol. 19: 102-116.

phytoplankton, photosynthesis, chlorophyll, irradiance, nutrients, vertical mixing, mathematical models, growth, grazing, Fraser River estuary, light limitation

19.

143. Takahashi, M. and A.B. Norton. 1977. Seasonal changes in microbial biomass in the Fraser River estuary, B.C. Arch. Hydrobiol. 79: 133-143.

seasonal effects, bacteria, biomass, Fraser River estuary

144. Talbot, B.F., S. A. Vernon, D.A. Gillis, T.A. Noon, J.Q. Meeks, and F. Flintoff. 1983. Iona Island sewage treatment plant study of upgrading alternatives. Greater Vancouver Sewerage and Drainage District. (Unpubl. Rep.)

Iona Island, sewage, nutrients

145. Thomas, W.H., J.T. Hollibaugh and D.L.R. Seibert. 1980. Effects of heavy metals on the morphology of some marine phytoplankton. Phycologia 19: 202-209.

CEPEX, phytoplankton, heavy metals, toxicity, growth

146. Thomas, W.H. and D.L.R. Seibert. 1977. Effects of copper on the dominance and the diversity of algae: controlled ecosystem pollution experiment. Bull. Mar. Sci. 27: 23-33.

CEPEX, phytoplankton, copper, trace metals, toxicity, species diversity, biomass

147. Thomas, W.H., D.L.R. Seibert, J.T. Hollibaugh and G.T. Wallace. 1980. Toxicity of a mixture of ten metals to phytoplankton. Mar. Ecol. Prog. Ser. 2: 213-220.

CEPEX, phytoplankton, heavy metals, toxicity, growth

148. Thomas, W.H., D.L.R. Seibert and M. Takahashi. 1977. Controlled ecosystem pollution experiment: effect of mercury on enclosed water columns: III. Phytoplankton population dynmaics and production. Mar. Sci. Comm. 3: 331-354.

CEPEX, phytoplankton, copper, trace metals, toxicity, primary production, biomass

149. Thomson, R.E. 1981. Oceanography of the British Columbia coast. Can. Spec. Publ. Fish. Aquat. Sci. 56: 291 p.

physical oceanography, review, fjord, estuary, currents, wave action, temperature, salinity, pycnocline, vertical mixing, tides, halocline

150. Tully, J.P. and A.J. Dodimead. 1957. Properties of the water in the Strait of Georgia, British Columbia and influencing factors. J. Fish. Res. Board Can. 14: 241-319.

water properties, physical oceanography, temperature, salinity, halocline

151. Tully, J.P. and M. Waldichuk. 1953. The oceanographic phase of the Nanaimo sewage problem. Manuscr. Rep. Fish. Res. Board Can. 547: 80 p.

sewage, Nanaimo River estuary, pollution, physical oceanography

152. Vaccaro, R., F. Azam and R. Hodson. 1977. Response of natural marine bacterial populations to copper: controlled ecosystem pollution experiment. Bull. Mar. Sci. 27: 17-22.

CEPEX, bacteria, copper, trace metals, toxicity, growth

153. Valdés, M. and L.J. Albright. 1981. Survival and heterotrophic activities of Fraser River and Strait of Georgia bacterioplankton within the Fraser River plume. Mar. Biol. 64: 231-241.

heterotrophic production, Fraser River, Fraser River plume, bacteria, survival, biomass, salinity

154. Valiela, D. and R.U. Kistritz. 1979. Dependence of salmon on Fraser estuarine marsh ecosystems: a simulation analysis. Tech. Rep. Westwater Res. Cent. 18: 51 p.

Oncorynchus, Fraser River estuary, marshes, mathematical models

155. Waldichuk, M. 1957. Physical oceanography of the Strait of Georgia, British Columbia. J. Fish. Res. Board Can. 14: 321-486.

physical oceanography, currents, temperature, salinity

156. Waldichuk, M. 1958. Drift bottle observations in the Strait of Georgia. J. Fish. Res. Board Can. 15: 1065-1102.

physical oceanography, currents, temperature

157. Waldichuk, M. 1968. Waste disposal in relation to the physical environment: oceanographic aspects. Syesis 1: 4-27.

pollution, toxicity, currents, temperature, salinity

158. Waldichuk, M. 1983. Pollution in the Strait of Georgia: a review. Can. J. Fish. Aquat. Sci. 40: 1142-1167.

review, pollution, toxicity, organic compounds, sewage, pulp mills, heavy metals

159. Waldichuk, M. 1984. Sewage pollution in British Columbia in perspective. (Unpubl. Rep.) Workshop on Municipal Marine Discharge, Vancouver, B.C. 50 p.

Iona Island, sewage, nutrients, heavy metals, pollution

160. Waldichuk, M., J.R. Markert and J.H. Meikle. 1968. Fraser River estuary, Burrard Inlet, Howe Sound and Malaspina Strait: physical and chemical oceanographic data, 1957-1966. Manuscr. Rep. Fish. Res. Board Can. 939: 541 p.

Fraser River estuary, Burrard Inlet, Howe Sound, physical oceanography, water chemistry, survey

161. Weigand, R.C. and S. Pond. 1979. Fluctuations of chlorophyll and related physical parameters in British Columbia coastal waters. J. Fish. Res. Board Can. 36: 113-121.

chlorophyll, distribution, phytoplankton, physical oceanography, Fraser River plume

162. Whitfield, P.H. and H. Schreier. 1981. Hysteresis in relationships between discharge and water chemistry in the Fraser River basin, British Columbia. Limnol. Oceanogr. 26: 1179-1182.

water chemistry, Fraser River estuary, salinity

163. Yamada, S.B. 1977. Geographic range limitation of the intertidal gastropods *Littorina sitkana* and *L. planaxis*. Mar. Biol. 39: 61-65.

temperature, salinity, currents, reproduction, distribution, *Littorina*, intertidal

Bibliography II - Other Areas

1. Bishop, P.L., Marine pollution and its control. McGraw Hill Book Co. Toronto, 357 p.

2. Caperon, J., A. Cattell and G. Krasnick. 1971. Phytoplankton kinetics in a subtropical estuary: eutrophication. Limnol. Oceanogr. 16:599-607.

3. Chan, K., P.K. Wong and S.L. Ng. 1982. Growth of Enteromorpha linza in sewage effluent and sewage effluent-seawater mixtures. Hydrobiologia 97:9-13.

4. Davies, A.G. 1983. The effects of heavy metals upon natural marine phytoplankton populations. Prog. Phycol. Res. 2:113-145.

5. Dillon, P.F. and F.H. Rigler. 1975. A simple method for predicting the capacity of a lake for development based on lake trophic status. J. Fish Res. Board Can. 32:1519-1531.

6. Doig, III, M.T. and D.F. Martin. 1974. The response of Gymnodinium breve to municipal waste materials. Mar. Biol. 24:223-228.

7. Dorsey, J.H. 1982. Intertidal community offshore from the Werribee sewage-treatment farm: an opportunistic infaunal assemblage. Aust. J. Mar. Freshwater Res. 33:45-54.

8. Duedall, I.W., B.H. Ketchum, P.K. Park and D.R. Kester. 1982. Wastes in the Ocean. Vol I. Industrial and sewage wastes in the ocean. John Wiley & Sons, New York. 443 p.

9. Fonselius, S.H. 1978. The eutrophicating effects of organic matter and nutrient elements on natural waters. pp. 93-100. In: 5th FAO/SIDA Workshop on Aquatic Pollution in Relation to Protection of Living Resources. FAO, Rome.

10. Gerlach, S.A. 1982. Marine pollution: diagnosis and therapy. Springer-Verlag, New York. 218 p.

11. Goldman, J.C., K.R. Tenore and H.,I. Stanley. 1973. Inorgainc nitrogen removal from wastewater: Effect on phytoplankton growth in coastal marine waters. Science 180:955-956.

12. Haddrill, M.V., R. Keffer, G.C. Olivetti, G.B. Polleri and F. Giovanandi. 1983. Eutrophication problems in Emilia Romagna, Italy. Monitoring the nutrient load discharged to the littoral zone of the Adriatic Sea. Water Res. 17:483-495.

13. Heinonen, P. and S. Herve. 1984. A rapid biological method for the monitoring of eutrophication. Arch. Hydrobiol. 101:135-142.

14. Hershelman, G.P., H.A. Schafer, T.K. Jan and D.R. Young. 1981. Metals in marine sediments near a large California municipal outfall. Mar. Pollut. Bull. 12:131-134.

15. Humphries, R.B., G.M. Hornberger, R.C. Spear and A.J. McComb. 1984. Eutrophication in Peel Inlet. III. A model for the nitrogen scenario and a retrospective look at the preliminary analysis. Water Res. 18:389-395.

16. Karydis, M., L. Ignatiades and N. Moschopoulou. 1983. An index associated with nutrient eutrophication in the marine environment. Est. Coastal Shelf Sci. 16:339-344.

17. Kindig, A.C. and M.M. Littler. 1980. Growth and primary productivity of marine macrophytes exposed to domestic sewage effluents. Mar. Environ. Res. 3:81-100.

18. Laws, E.A. 1981. Aquatic pollution. John Wiley & Sons, New York. 482 p..

19. Laws, E.A. and D.G. Redalje. 1979. Effect of sewage enrichment on the phytoplankton population of a subtropical esturary. Pacific Sci. 33:129-144.

20. Laws, E.A. and D.G. Redalje. 1982. Sewage diversion effects on the water column of a subtropical estuary. Mar. Environ. Res. 6:265-279.

21. Laws, E.A. and K.L. Terry. 1983. The impact of sewage discharges at ocean outfalls on phytoplankton populations at waters surrounding the Hawaiian Islands. Mar. Environ. Res. 8:101-107.

22. Likens, G.E. (ed.) 1972. Nutrients and eutrophication: The limiting nutrient controversy. Spec. Symp. Vol. I. Limnol. Oceanogr. Soc. 328 p.

23. MacIsaac, J.J., R.C. Dugdale, S.A. Huntsman and H.L. Conway. 1979. The effect of sewage on uptake of inorganic nitrogen and carbon by natural populations of marine phytoplankton. J. Mar. Res. 37:51-66.

24. Maestrini, S.Y. D.J. Bonin and M.R. Droop. 1984. Phytoplankton as indicators of sea water quality: bioassay approach and protocols, pp. 71-132. In: Algae as Ecological Indicators, L.E. Shubert (ed.). Academic Press, New York.

25. Maestrini, S.Y., D.J. Bonin and M.R. Droop. 1984. Test algae as indicators of sea water quality: prospects, pp. 133-188. In: Algae as Ecological Indicators, L.E. Shubert (ed.) Academic Press, New York.

24.

26. Nixon, S.W., M.E.Q. Pilson, C.A. Oviatt, P. Donaghay, B. Sullivan, S. Seitzinger, D. Rudnick and J. Frithsen. 1983. Eutrophication of a coastal marine ecosystem - an experimental study using the MERL microcosms, pp. 105-129. In: Flows of Energy and Materials in Marine Ecosystems: Theory and Practice IV:13. M.J.R. Fasham (ed.) Plenum Press, New York.

27. Rastetter, E.B. and W.J. Cooke. 1979. Responses of marine fouling communities to sewage abatement in Kaneohe Bay, Oahu, Hawaii. Mar. Biol. 53:271-280.

28. Reise, K. 1983. Sewage, green algal mats anchored by lugworms and the effects on Turbellaria and small Polychaeta. Helgolander wiss Meeresunters. 36:151-162.

29. Reish, D.J. 1984. Domestic wastes, pp. 1711-1766. In: Marine Ecology, Vol. V, Part 4, O. Kinne (ed.). John Wiley & Sons Ltd., New York.

30. Sanders, J.G. and E.J. Kuenzler. 1979. Phytoplankton population dynamics and productivity in a sewage-enriched tidal creek in North Carolina. Estuaries 2:87-96.

31. Shubert, L.E. (ed.) 1984. Algae as ecological indicators. Academic Press, New York. 448 p.

32. Schelske, C.L. 1984. In situ and natural phytoplankton assemblage bioassays, pp.15-47. In: Algae as Ecological Indicators, L.E. Shubert (ed.). Academic Press, New York.

33. Stevens, R.J. and R.V. Smith. 1978. A comparison of discrete and intensive sampling for measuring the loads of nitrogen and phosphorus in the River Main, County Antrim. Water Res. 12: 823-830.

34. Thirkell, D. and R. Keatch. 1984. A model for the movement of sewage effluent, according to sea state, in a bay situation. Water Res. 18:917-920.

35. Thomas, W.H., D.L.R. Siebert and A.N. Dodson. 1974. Phytoplankton enrichment experiments and bioassays in natural coastal sea water and in sewage outfall receiving waters off Southern California. Est. Coastal Mar. Sci. 2:191-206.

36. Thomas, W.H. and A.J. Carsola. 1980. Ammonium input to the sea via large sewage outfalls - Part 1: Tracing sewage in southern California waters. Mar. Environ. Res. 3:277-289.

37. Thomas, W.H., J. Hastings and M. Fujita. 1980. Ammonium input to the sea via large sewage outfalls - Part 2: Effects of ammonium on growth and photosynthesis of southern California phytoplankton cultures. Mar. Environ. Res. 3:289-296.

25.

38. Thompson, G.B. and J. Ho. 1981. Some effects of sewage discharge upon phytoplankton in Hong Kong. Mar. Pollut. Bull. 12:168-173.

39. Thompson, G.B. 1983. Sewage pollution and the informal benthos of Victoria Harbour, Hong Kong. J. Exp. Mar. Biol. Ecol. 67:279-299.

40. Wharfe, J.R., K.S. Taylor and H.A.C. Montgomery. 1984. The growth of Cladophera glomerata in a river receiving sewage effluent. Water Res. 18:971-979.

41. Worf, D.L. 1980. Biological Monitoring for Environmental Effects. Lexington Books, Lexington. 227 pp.

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