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CHEMICAL CONTAMINANTS  
AND BIOLOGICAL ABNORMALITIES  
IN CENTRAL AND SOUTHERN PUGET SOUND

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## EXECUTIVE SUMMARY

Samples of sediments and bottom-dwelling fishes, crabs, shrimps, clams, and worms were collected at quarterly intervals in 1979 from four urban embayments in Puget Sound: Elliott Bay (Seattle), Commencement Bay (Tacoma), Sinclair Inlet (Bremerton), and Budd Inlet (Olympia). Similar sampling was done in two nonurban (reference) areas: Case Inlet and Port Madison.

Sediment samples were analyzed for petroleum hydrocarbons, PCB's, chlorinated pesticides and other chlorinated organic compounds, and metals. The community characteristics (i.e., abundance and species diversity) of the sediment-associated invertebrates and bottom fish were defined; and their tissues were analyzed for the above-mentioned organic compounds and metals.

The highest concentrations of PCB's, chlorinated pesticides, other chlorinated organic compounds, petroleum hydrocarbons, and some metals (e.g., arsenic and lead) in sediments were in samples from the waterways of Commencement Bay; the Duwamish Waterway, Seattle Waterfront, and West Point areas of Elliott Bay; and from Point Herron in Sinclair Inlet. Sediments from reference embayments, Case Inlet and Port Madison, also contained many of these chemicals, but most were present in lower concentrations. Highest concentrations of many of the chlorinated organic compounds, including hexachlorobutadiene which has been implicated as a carcinogen, were in sediment samples from Commencement Bay and its adjacent waterways.

In contrast to the above-mentioned organic compounds and metals, the concentrations of other toxic metals, such as nickel and chromium, were similar in sediment samples from both reference and urban areas.

Tissue samples generally had concentrations of organic contaminants which reflected the chemical composition of sediment in the subarea from which the organisms were obtained. Generally, chlorinated organic compounds were present in higher concentrations in fish and crustacean tissues than in associated sediments. The reverse relationship was generally true for petroleum hydrocarbons. Petroleum hydrocarbons, PCB's, chlorinated pesticides, hexachlorobenzene, and hexachlorobutadiene were detected in various concentrations in several types of organisms from both urban and nonurban sites. Typically, highest concentrations of these chemicals were found in animals from Elliott and Commencement Bays.

The findings indicate that although major differences exist between the concentrations of many contaminants in sediment and biota from nonurban and urban areas, embayments in Puget Sound considerably removed from industrial influences are not free of these contaminants.

In most cases, the same animals from which tissues were taken for chemical analyses were also examined for grossly-visible and microscopic lesions. In fish, the most commonly detected nonparasitic lesions were in the liver. The eight distinct types of liver lesions, of which two were types of tumors, resembled lesions previously reported in the scientific

literature which were induced in laboratory animals (rodents and fish) by controlled exposures to toxic chemicals. The incidence of liver lesions in English sole, rock sole, Pacific tomcod and staghorn sculpin was generally highest in fish from areas with the highest levels of sediment-associated contaminants within Commencement and Elliott Bays. Tumor-bearing sole were found only in the following areas of Commencement and Elliott Bays at the indicated average annual frequencies for each species: Elliott Bay's Duwamish Waterway [English sole, 2.4% (5 of 210); Pacific tomcod, 3.4% (2 of 59); and rock sole, 2.1% (3 of 142)] and Seattle Waterfront [rock sole, 1.4% (1 of 71)]; and Commencement Bay's Hylebos Waterway [English sole, 2.3% (3 of 129) and Pacific tomcod, 2.7% (3 of 111)] and other waterways (e.g., Sitcum and Blair) [English sole, 2.2% (3 of 138)], and the southwest portion of Commencement Bay [rock sole, 2.7% (2 of 79)].

Fish with the other types of liver lesions tended to be more widely distributed in Puget Sound. Focal hepatocellular hyperplasia (an abnormal increase in the number of normal liver cells), for example, was observed in rock sole from most of the above-mentioned areas, at average annual frequencies of 3 to 6%. They were also found in individuals of this species obtained from Port Madison (10.0%, 2 of 20), Case Inlet (4.3%, 1 of 23), Budd Inlet (3.2%, 2 of 62), and Sinclair Inlet (2.6%, 1 of 39).

Shrimps and crabs with six major types of lesions were distributed in Puget Sound in much the same pattern as diseased fish. The most commonly affected organs were the hepatopancreas (equivalent to the vertebrate liver and pancreas) and bladder. Shrimp with necrosis of the hepatopancreas were found in the Hylebos and other Waterways of Commencement Bay at average annual frequencies of 19% (11 of 59) and at lower frequencies in Budd (4%, 2 of 46), Case (7%, 3 of 44) and Sinclair (5%, 3 of 57) Inlets and along the Seattle Waterfront (7%, 5 of 65). Crabs with this condition were captured in the same waterways of Commencement Bay (27%, 8 of 30), the Duwamish Waterway (13%, 4 of 31), and Case Inlet (9%, 1 of 11). Necrosis was also observed in the bladders of crabs from the Duwamish Waterway (30%, 9 of 30), Seattle Waterfront (11%, 1 of 9), and the Commencement Bay Waterways (27%, 8 of 30).

Community characteristics of infaunal invertebrates (i.e., invertebrates living within the sediment) were measured in terms of numerical abundance, the Infaunal Trophic Index (a method based on feeding strategies of benthic invertebrates), and species richness (the number of species in a sediment sample). Of these three indices, species richness values were found to correlate best with concentrations of certain sediment-associated toxic chemicals. Consistently low species richness values were found in the Duwamish Waterway.

In summary, results have been presented of a study that constitutes a first step in better understanding the impact of human activities on Puget Sound. A major multidisciplinary scientific effort requiring several years will be needed to understand the nature and degree of the effects of toxic chemicals on fish and other biota in Puget Sound. Such an effort combined with rational regulation of discharges of chemicals should optimize chances for maintaining and improving the environmental quality of Puget Sound and the health of its inhabitants in the face of increasing urban pressures.

## 1. INTRODUCTION

Puget Sound, a unique fjord-like estuary, has several cities located on its shores, including Seattle, Tacoma, Bremerton, and Olympia. Wastes from domestic and industrial sources are commonly released into marine waters near these cities. The Pacific Office of the Office of Marine Pollution Assessment (OMPA), a part of the National Oceanic and Atmospheric Administration (NOAA), was established to focus scientific research on environmental problems relating to Puget Sound. The objective of the project is to use an integrated program of multidisciplinary research to document the occurrence and fluxes of contaminants of special concern, the dynamic processes influencing their physical and chemical transport and fate, and their biological and ecological effects.

This is a report on the first year of an investigation of the distribution of chemical contaminants and biological abnormalities in the waters of Central and Southern Puget Sound. This study represents a cooperative effort between OMPA and the National Marine Fisheries Service (NMFS), also of NOAA. In addition to identifying and estimating the levels of major chemical contaminants in the bottom sediments and biota of the major urban-associated embayments, several aspects of the health status of bottom-dwelling animals were assessed. The urban-associated sampling areas were Seattle's Elliott Bay, Tacoma's Commencement Bay, Olympia's Budd Inlet, and Bremerton's Sinclair Inlet. The reference areas were Case Inlet in South Puget Sound and Port Madison in central Puget Sound. The animals examined included selected fish, crustacea (crabs and shrimp), and sediment-dwelling invertebrates (bivalves and polychaete worms).

The scientific disciplines represented by the researchers involved in this study included fish pathology; invertebrate pathology; fish ecology; invertebrate ecology; and analytical chemistry. Fish and invertebrate species were examined for gross and microscopic pathological conditions or ecological perturbations and were subjected to chemical analyses, as were the bottom sediments from each of the sampling stations where these animals were collected. The main purpose of chemical analyses was to document the identity, concentration, and geographical distribution of three major classes of environmental contaminants: halogenated hydrocarbons, polynuclear aromatic hydrocarbons, and metals.

This report describes analyses or examinations of samples collected in the winter, spring, summer, and fall of 1979 in each of the six sampling areas in Puget Sound. Emphasis will be given to descriptions of the most severe biological/ecological abnormalities and how they may relate to the presence of chemical contaminants in tissues and sediments.

## 2. METHODS AND MATERIALS

### 2.1 Sampling Areas and Sampling Stations

The location and types of sampling stations in the urban-associated areas, Elliott Bay, Commencement Bay, Budd Inlet, and Sinclair Inlet, are displayed in Figures 1 to 5. The same information for the reference areas, Case Inlet and Port Madison, is shown in Figures 5 and 6. Each area had two general types of sampling stations: (a) stations from which fish, invertebrates, and sediments were collected for pathological, biological (catch statistics, benthic community data, etc.), and chemical analyses (35 stations, referred to hereafter as complete sampling stations), and (b) stations from which only sediments were collected for chemical analyses (8 stations, referred to as sediment-only stations). Detailed descriptions of each sampling station are shown in Tables 1 to 3. Most stations in Elliott and Commencement Bays were grouped into subareas (Table 4).

The locations of the complete sampling stations in the urban areas were chosen, in part, on the basis of their proximity to point sources of pollutants, and from predictions of the distribution of biological anomalies. Chemical analyses of bottom sediments from these areas previously performed by the NOAA National Analytical Facility (see Appendix A) demonstrated the presence of certain pollutants in these areas. Also, previous reports of pathologic conditions of flatfish in Puget Sound identified some locations as having substantial numbers of abnormal animals (Pierce et al. 1978). Another major criterion for choosing the location of sampling stations was the type of sediment; most sampling stations were depositional (in Puget Sound such areas are characterized by a high mud to sand ratio). Depositional areas were selected because industrial chemicals readily adsorb to aquatic sediments (Wildish et al. 1980), and such areas should reflect man's activities.

Therefore, the majority of the sites were selected to reflect "worst-case" situations, and proportionally fewer sites in dilution zones and "reference" areas were selected. The data do not at all reflect general conditions in the central basin of Puget Sound or in the region as a whole.

### 2.2 Logistics and General Sampling Procedures

#### 2.2.1 Logistics

The dates during 1979 when samples were collected in all the sampling areas are given in Table 5. The sampling vessels were the R.V. Malka and the R.V. Harold W. Streeter.

#### 2.2.2 General Sampling Procedures

The R.V. Malka was used to collect demersal fish and epibenthic invertebrates with an otter trawl having the following characteristics: 7.5 m opening, 10.8 m total length, 3.8 cm mesh in the body of the net,

and 0.64 cm mesh liner in the cod end. Individual tows were made for five minutes and covered a distance of approximately 386 m or 0.2 nautical miles. The R.V. Streeter was operated as a floating laboratory by fish pathologists and for the collection of sediments using a modified Van Veen sediment grab. This grab is modified such that sediments can be sampled in a manner that does not disturb the bottom surface. Temperature, salinity, and dissolved oxygen measurements at or near the bottom at each sampling station were also taken from the R.V. Streeter.

During each sample collection, the first sample to be taken at each station was a sediment grab. The grab sample was examined for texture, and if sufficient mud (greater than about 20%) was present, the sediment was sampled. When sediment was taken for chemical analyses, a surface sample of the top 2 cm (about 500 g) was removed. The remaining sediment was used for collection of benthic invertebrates.

The same site from which the sediment was taken was then sampled by otter trawl. This general sampling routine was followed at each of the three depth contours sampled per station. At stations with uniform depths, such as the Duwamish River stations, three grabs from approximately the same depth were taken along the path of the otter trawl.

## 2.3 Specific Protocols

### 2.3.1 Analytical Chemistry

The analytical protocols are summarized below and given in detail in Appendix B.

Five sediment sample cores (5.5-cm diameter X 2-cm height) were collected from each of two grab samples at each sampling station. The ten cores of sediment were thoroughly mixed in a teflon beaker with a teflon stirring rod. Portions of the mixed sediment were placed in a glass bottle for organics analysis and in a plastic container for metals analysis. These samples were frozen in the field and kept frozen until they were thawed for analysis.

Biological samples for chemical analysis were placed in glass bottles, sealed with lids with teflon lining, frozen in the field, and kept frozen until they were thawed for analysis.

All samples were extracted with organic solvents. Column chromatography was used to isolate the compounds of interest. Analysis was accomplished using glass capillary gas chromatography with flame ionization, electron capture, and mass spectrometer detectors (Table 6).

Samples were digested with acid while heating, diluted to volume, and analyzed for metals by plasma emission spectrometry (Table 7). Samples were analyzed separately for mercury (cold vapor atomic absorption).

Sediments were analyzed for total organic carbon and grain size distribution. Sediment grain size was measured by screening samples of

sediment through a series of standard sieves according to methods reported by Krumbein and Pettijohn (1938). Total organic carbon was measured using a LICO induction furnace. Biological samples were analyzed for lipid content.

### 2.3.2 Fish Pathology

The investigators in each of the biological disciplines were concerned primarily with selected target species. Target species were defined by one or more of the following criteria: (1) wide distribution throughout Puget Sound, (2) life history stages directly or indirectly associated with sediments, and (3) previously observed abnormalities.

Target Fish Species. Fish species routinely examined for biological characteristics (e.g., weight and length) and gross and microscopic lesions were as follows:

English sole (Parophrys vetulus)  
Rock sole (Lepidopsetta bilineata)  
Pacific staghorn sculpin (Leptocottus armatus)  
Pacific tomcod (Microgadus proximus)  
Quillback rockfish (Sebastes maliger)(alternate species)

Necropsy Procedures. Most abnormal animals and up to ten normal appearing animals from each of the five fish species at each sampling station were necropsied; fish with previously well-characterized lesions were not always necropsied. In general, since three tows were usually made at each complete sampling station, the fish used for necropsies were taken from the total catch of all three collections. The necropsy procedure for each fish included measurement of total length and weight, determination of sex, collection of otoliths for age determination, description of the appearance of the animal, collection of blood for hematological tests, and excision and preservation of tissue from lesions and normal-appearing major organs. Blood for hematological and blood chemistry tests was collected by cardiac puncture or from caudal vessels with a syringe, or by excising the caudal fin. Aliquots of whole blood were used immediately after collection to determine hemoglobin concentrations and to make blood smears for differential white blood cell counts. The remaining blood was allowed to clot, and the serum was returned to the laboratory and frozen. An aliquot of the serum was sent to a commercial laboratory for chemical analyses (see Hematology and Blood Chemistry), and the remainder was retained for analyses of albumin and total protein in our laboratory.

The necropsy procedures varied with the size of the fish. With fish less than 15 cm in total length, the entire fish or the anterior portion (including all visceral organs) was preserved. After first opening the abdominal cavity and the head (the head was opened when the otoliths were removed), the specimens were placed in processing cassettes which were inserted into a labeled cloth bag and immediately placed in a 5-gallon container of Dietrich's fixative (see Appendix C). For fish over 15 cm, pieces of major tissues and organs (liver, spleen, gastrointestinal tract, gall bladder, gill, kidney, heart, gonad, skin, and fin) were excised and fixed in the same manner. When a lesion was observed in any tissue, a

portion of that tissue (as well as surrounding normal-appearing tissue) was excised and preserved along with the other major tissues described above. The gross appearance of all lesions was recorded. In some cases, tissue samples of the lesions were taken and fixed for electron microscopy using procedures described by Hawkes (1974).

Histological Procedures. For light microscopic examination, all preserved tissues were embedded in paraffin and sectioned at 5  $\mu$ m in the laboratory (Preece 1972). When necessary, tissues such as gills and bones were decalcified using a commercial decalcification solution (Scientific Products, Redmond, WA<sup>1</sup>) prior to processing. Paraffin sections were routinely stained with Mayer's hematoxylin and eosin-phloxine (Luna 1968). As stained tissues from each fish were examined microscopically, the presence of parasites and descriptions of all observed lesions were recorded. For further characterization of the components of specific lesions, additional sections were stained, as appropriate, with May-Grünwald Giemsa for RNA and DNA; Masson's trichrome for collagen; Periodic acid-Schiff for glycogen, mucin and basement membrane; Brown and Brenn's Gram stain for bacteria; Congo red for amyloid; Laqueur's method for alcoholic hyalin; Ziehl-Neelsen method for acid-fast bacteria and other acid-fast components; Gomori's iron reaction for iron pigments; or the Armed Forces Institute of Pathology (AFIP) method for lipofuscin and ceroid (Thompson 1966, Luna 1968, Preece 1972).

Tissues fixed for electron microscopy were embedded in plastic, sectioned and stained as described previously (Hawkes 1974) and examined by light microscopy or transmission electron microscopy.

Histopathological Procedures. - All slides of stained tissues were examined using a "blind" system. Each fish was assigned a field number when necropsied, then prior to microscopic examination the fish was assigned an identification number derived from a random number table. Histopathologists examining tissue sections had information on the species, length, weight, sex, and the presence of grossly visible lesions, but no knowledge of the area from which the fish was collected. All slides from an individual specimen were first screened for abnormal tissues; those sections with lesions were segregated for further examination. Periodically the types of observed abnormalities were summarized and each type of condition was classified using standardized nomenclature. Drs. Ellis Giddens (Veterinary Pathologist) and Marsha Landolt (Fish Pathologist) both of the University of Washington, were consulted for additional expertise in lesion classification.

Hematology and Blood Chemistry. Blood samples were taken from most fish subjected to routine necropsies and histopathological examination. Hematological tests initiated in the field and completed in the laboratory included hemoglobin analyses and blood smears. The latter were stained with Giemsa (Hepler 1973) for differential counts of white blood cells by microscopic examination. The remaining blood sample was maintained at 0°C

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<sup>1</sup>Mention of commercial products is for information only and does not constitute endorsement by the U.S. Department of Commerce.

until the serum was drawn off and frozen at -20°C, usually a period of no longer than 12 hours. Quantitative chemical analyses on serum were performed by a commercial laboratory (Biomedicals Laboratory, Seattle) for the following chemicals or enzymes: calcium, phosphorous, urea, nitrogen, glucose, cholesterol, total protein, albumin, alkaline phosphatase, lactic dehydrogenase, bilirubin, and transaminase. Analyses for albumin and total protein were also made by members of our staff using a commercially available kit (SST Total Protein/Albumin Rapid Stat Kit, Pierce Chemical Co.).

Statistical Analysis. The G-statistic or log-likelihood ratio was used to test the null hypothesis that the fish lesion frequency at a sampling station was the same as the average lesion frequency for all the central Puget Sound sampling stations. Since the data consisted of two categories (fish with lesions and normal fish), the Yates correction for continuity (Sokal and Rohlf, 1969) was applied. This method takes into account both the number of fish examined and the number of lesions observed.

### 2.3.3 Invertebrate Pathology

Target Invertebrate Species. Invertebrate species examined for gross and microscopic lesions were:

Crabs - Cancer magister, C. gracilis, and C. productus  
Shrimp - Pandalus danae, P. jordani and Crangon alaskensis  
Clams - Macoma carlottensis, M. nasuta, and Acila castrensis  
Marine worms - Glycera capitata, Capitella capitata, Prionospio pinnata

Necropsy Procedures. Crab and shrimp species were captured along with fish species in epibenthic trawls. These target species were separated from the total catch, placed in holding tanks, and the total number and weight of each target species was recorded. In instances of large catches, only a total count of each species was made. When the sample contained more than ten animals of a given species, a subsample of ten animals was sexed, measured, and examined for visible abnormalities. The length of the carapace from the eye socket to the dorsal medial edge of the posterior end was measured on shrimp. Crabs were measured across the widest points of the dorsal carapace.

Shrimp were serially cut into 6 mm thick cross sections through the entire length of the cephalothorax and the anterior two segments of the abdomen. These cross sections were immediately fixed in Davidson's fixative and later transferred to 50% ethanol (EtOH), then 70% EtOH.

Crabs were necropsied by excision of the following organs: eye, brain, thoracic ganglion, cardiac stomach, pyloric stomach, midgut, anterior caecum, posterior caecum, heart, hemopoetic tissue, bladder, epidermis, mandibular organ, ovary, testis, and gill. These organ samples were preserved in Helly's fixative and later transferred to 50% EtOH and 70% EtOH.

Bivalves and polychaetes were sorted from sediment grab samples. Bivalves were opened and polychaetes removed from their tubes and fixed in Davidson's fixative. All specimens were transferred to 50% EtOH, then to 70% EtOH. Polychaetes were later identified and sorted.

Histologic Procedures. Tissues were processed for histology by standard techniques in a Tissue Tek II automatic tissue processor. All specimens were vacuum infiltrated with Paraplast for fifteen minutes, then embedded in Paraplast blocks. Sections, 5  $\mu$ m to 7  $\mu$ m thick, were cut with a microtome and placed on glass microscope slides. Hematoxylin and eosin (H&E) were used to stain all sections for routine examination. In some cases, where bacteria or certain protozoan parasites were suspected, Giemsa stain was employed. Fungal infections were demonstrated with the use of Grocott's Methenamine-Silver (GMS) stain.

Histopathological Procedures. Specimens from the winter and summer sample collections were examined for the presence of parasites, secondary fungal and bacterial infections, and for lesions, without knowledge by the examiner of the area from which the animal came. Benthic invertebrates from spring quarter sampling were not available for histopathologic examination due to the small sample sizes and the higher priority of processing for analytical chemistry. The numbers of benthic invertebrates in fall quarter samples were very small, and were not examined.

#### 2.3.4 Fish Ecology

At each sampling station, the catch was sorted into target species and additional species. After sorting, ten specimens (when available) of each target fish species were transferred to holding tanks for subsequent pathological analysis aboard the R.V. Streeter. If any additional individuals of fish target species remained, 10 each of age 1+ specimens were individually weighed, measured, and the otoliths removed for age determination. All, or a representative subsample, of any remaining target species were individually weighed and measured. All nontarget fish species were counted and the total weight of the species recorded. During sorting, each individual fish was scanned visually for external pathological abnormalities. Any abnormal individual was held alive for transfer to the R.V. Streeter.

Catch per unit of effort (CPUE) was calculated using a 5-minute tow as a single unit of effort. The CPUE for a given station or area was calculated by summing the catch over the location involved and dividing by the number of tows made. Whenever possible, the data for fishes captured at different depths at the same station were maintained separately. Species richness was determined by counting the number of species occurring at a station or area. The diversity of species ( $H'$ ) was determined by using the Shannon-Weaver diversity index (Zar, 1974):

$$H' = \frac{n \ln n - \sum_{i=1}^k f_i \ln f_i}{n},$$

where  $n$  is the sample size,  $f_i$  is the number of fish in species  $i$ , and  $k$  is the number of species.

### 2.3.5 Invertebrate Ecology

Benthic grab samples were taken using a modified Van Veen grab (Word 1976). Two core samples each with a surface area of 100 cm<sup>2</sup> and usually with a depth of 10 cm were taken from each grab for analysis of infaunal organisms. If a grab sample with at least 10 cm of undisturbed sediment could not be obtained in three attempts, the grab sample containing the most sediment was used and the depth of the sediment collected was recorded.

Sediment from the 1,000 cm<sup>3</sup> core samples was wet sieved through 1 mm mesh stainless steel sieves and all the material remaining in the sieves was placed in a labeled glass jar. The samples were then preserved using 10% formalin buffered with sodium borate. All samples were later transferred to a solution containing 70% EtOH and rose bengal and sorted into major taxonomic groups by one of seven sorters. Among worms, whole animals and worm fragments, those with the head attached were counted. Empty mollusk shells were discarded. Oligochaetes and Archannelids were not counted after the first quarter because it was found that these organisms could not be reliably identified by all sorters.

Mollusks were identified by one of two invertebrate biologists using the taxonomic keys of Kozloff (1974), and of Keen and Coan (1974). When there was a disagreement over the name given to a particular mollusc the terminology used in Abbott (1954) was followed. Polychaetes were identified by a single invertebrate biologist using the keys of Fauchald (1977) and of Banse and Hobson (1974). Selected polychaete and mollusc specimens were also identified by personnel at Western Washington University. Amphipods collected during summer and fall quarters were identified by a specialist. Other invertebrates were identified using the keys of Kozloff (1974). Representative specimens of each species or higher taxon were placed in a reference collection.

Water quality data were taken using a Hydrolab Model 6 instrument (Hydrolab Corporation) equipped with a probe which measures dissolved oxygen, conductivity, and temperature. Some of the dissolved oxygen data for the winter quarter was obtained using samples collected with a 4 liter Van Dorn bottle, and a modified Winkler method was used to analyze dissolved oxygen in these samples. All water quality data were collected one meter above bottom unless the depth exceeded 100 ft; then water quality data were taken at the 100-foot level (maximum cable length).

Wet weight biomass of mollusks, crustaceans, annelids including annelid fragments, and ophiuroids was measured for winter quarter samples. Dry weight conversion factors reported by Lie (1968) were then used to estimate dry weight biomass values. The conversion factors used were: mollusks (0.055), crustaceans (0.150), annelids (0.133), and ophiuroids (0.122). The wet weight of a specimen was measured by placing the organisms which had been identified and cleaned of sediment and tubes into a plastic cylinder with an 0.25 mm Nytex mesh bottom, allowing it to drain on dry paper towels for three minutes before weighing.

The Infaunal Trophic Index (ITI) has been proposed as a community index indicative of pollution effects on benthic marine environments (Word 1978,

Thom et al. 1979). It has two advantages over indices such as species diversity ( $H'$ , the Shannon-Weaver Index), which have also been used in studies of pollution effects. The first is the ITI uses more biological information than indices based solely on taxonomy, since it also incorporates feeding strategy. The second is that ITI uses an abbreviated taxonomic list (Table 8) which speeds processing of benthic samples.

For computation of the ITI, benthic marine invertebrate taxa are divided into four groups on the basis of feeding strategy (Thom et al. 1979):

- Group 1. Suspension feeders that actively or passively reconcentrate organic matter for food. Species frequently collected and relatively abundant in samples from reference areas are also included in this category;
- Group 2. Suspension feeders and surface detritus feeders that become abundant at the fringe of areas influenced by deposition of particulate organic material;
- Group 3. Surface detritus feeders that are often found in sediments with increased levels of organic enrichment;
- Group 4. Sub-surface detritus feeders that thrive in areas of high organic enrichment and are rarely encountered in reference areas.

The taxa used in the present study (Table 8) are those recommended by Thom et al. (1979).

Infaunal index values can range from 0 to 100. Word (1978) has shown the interval over which each feeding type group is numerically dominant in Southern California coastal areas. Group 1 organisms dominate when index values are between 78 and 100, Group 2 dominates when values range from 58 to 77, Group 3 ranges from 25 to 57 and Group 4 ranges from 0 to 24.

Other investigations have frequently focussed on total abundance (TA, the number of individual organisms in a sample), species richness (S, the number of species in a sample), species diversity ( $H'$ , the Shannon-Weaver diversity index), or species evenness (J, the ratio between the observed diversity in a sample and the maximum diversity value possible given the number of species present). In this study, analogous measures based on the taxa used in computing the Infaunal Trophic Index (Table 8) will be reported. These indices include taxon richness (the number of taxa in a sample), taxon diversity, and taxon evenness. Computational formulae for all indices (including the ITI) are given in Table 9.

Taxon richness and taxon diversity values cannot overestimate the values for species richness or species diversity; taxon evenness cannot underestimate species evenness. When each taxon in a sample is represented by a single species, as is often the case when few individuals are present, index values calculated on the basis of higher taxa are identical to those calculated on the basis of species.

The behavior of several community indices is illustrated in Table 10 using hypothetical data. It is obvious from these examples that the computation of ITI is not correlated with TA, S, H', or J.

During the fall quarter sampling period Commencement Bay station 6 was abandoned in favor of sampling station 22 on the basis of spring quarter chemical analysis data. Because of this change, average seasonal values of taxon richness, abundance and the infaunal index do not include these two stations.

Statistical Methods. The primary statistical methods used in the infaunal benthic community study were the computation of simple correlation coefficients ( $r$ ), coefficients of determination ( $r^2$ ), multiple correlation coefficients, and multiple coefficients of determination (Kleinbaum and Kupper, 1978). These methods were chosen because all variables were continuous or approximately continuous and because it was desirable to take variability into account. Results of bivariate and multivariate statistical tests were not considered significant if  $\alpha$  was greater than 0.05.

Multiple regression analysis was performed using backward stepwise selection to remove variables which did not contribute significantly to the regression equation when entered after all other variables. Once the variables had been selected in this way, forward stepwise selection was used to produce the overall regression equation.

All correlation and multiple regression analyses were performed using the computer programs of Nie et al. (1975). Data management used the programs of Robinson et al. (1979).

### 3. RESULTS

The results from the five scientific disciplines will be presented essentially independent of each other, with consideration of interrelationships between these data to be given in the Discussion Section.

#### 3.1 Analytical Chemistry

The concentration of selected chemicals in sediment and biota are reported in Appendix D. Minimum detectable concentrations are noted by a less than sign (<) and used in each case where a component was not detected. The minimum detectable concentration is the value a component could have been measured in that particular sample. The (<) value has no relevance to the absolute presence or absence of a chemical(s) in a sample. A (N) was used to designate that a measurement could not be made.

The results for metals in sediments are summarized in Figure 7. The results for organic chemicals are summarized in Tables 11-20 and are reported by subarea. In summarizing the data only the measurable concentrations were averaged where a subarea had one or more samples with (<) values, these (<) values were not included in calculating the average. Where this occurred it

is noted by a ratio of the number of samples containing measurable quantities to the total number of samples for that particular subarea. The (<) values that are reported in the summary tables are not averages. In such cases the highest (<) value for that particular subarea was reported.

### 3.1.1 Sediment

Analyses for Metals. Concentrations of some of the most toxicologically important metals found (silver, arsenic, cadmium, chromium, copper, mercury, manganese, nickel, lead, and selenium) are shown in Figure 7.

Within Elliott Bay, the sampling stations located in the Duwamish Waterway subarea had the highest concentrations of most metals. A concentration gradient of metals was evident in this waterway, with the highest levels occurring at the stations nearest the mouth of the river. Stations near Alki Point, West Point, Pier 42, and Magnolia Bluff had the lowest metal concentrations.

In Commencement Bay, most of the sampling stations located in the industrial waterways had substantial metal concentrations, but no definite pattern emerged. The station in the Sitcum Waterway had the highest levels of most metals (for example copper and arsenic concentrations of 1600 ug/g and 470 ug/g, respectively).

The stations in the Elliott Bay and Commencement Bay waterways had concentrations of lead in the sediment as many as ten times higher than those found in the sediment from Case Inlet, Port Madison, and Budd Inlet.

Metal concentrations in samples from the three westerly stations of Sinclair Inlet were similar to each other. The concentrations of all metals were lower in the sediment sample from the mouth of the Inlet. The levels of mercury in sediment samples from Sinclair Inlet were higher than those found in sediments from most stations in Elliott and Commencement Bays.

The concentrations of most of the metals noted above were considerably lower in sediments from Case Inlet and Port Madison compared to those measured in sediments from the waterways of Elliott Bay, Commencement Bay and Sinclair Inlet, while Budd Inlet had intermediate concentrations. The concentrations of several metals with known toxic effects (e.g., chromium, manganese, and nickel) were similar in all embayments.

Analyses for Polynuclear Aromatic Hydrocarbons (PAH's). Polynuclear aromatic hydrocarbons are a very large group of compounds and presently available analytical schemes do not allow for isolating and measuring the concentrations of each of them. Thus, 25 compounds were selected for identification and quantitation (Table 6). The sums of the concentrations of the quantitated PAH's containing 1- or 2-aromatic rings are given in Table 11. The sums of the concentrations of the quantitated PAH's containing 3- to 5-ring aromatics are given in Table 12. In general, the summed values of the PAH's were indicative of the relative concentrations of the individual PAH's. For example, the sediment samples with the highest concentrations of the carcinogens, phenanthrene (PHN), benz[a]anthracene

(BaA), and benzo[a]pyrene (BaP), generally had the highest values for the concentration of 3- to 5-ring aromatic hydrocarbons (Tables 12, 13, 14, and 15).

The concentrations of PAH's in sediments varied considerably within a subarea. For example, most sediments from the Seattle Waterfront subarea of Elliott Bay had high concentrations of PAH's. However, sediment from the station near Pier 42 had very low concentrations of PAH's (Appendix D), probably because this area had recently received fill materials. Average PAH concentrations (the sum of the average values of the 1- and 2-ring and the 3- to 5-ring aromatic hydrocarbons, Tables 11, 12) were generally high in sediments from the subareas of Elliott Bay [Duwamish Waterway (12  $\mu\text{g/g}$ ), Seattle Waterfront (12  $\mu\text{g/g}$ ), and West Point (45  $\mu\text{g/g}$ )], subareas of Commencement Bay [Hylebos Waterway (16  $\mu\text{g/g}$ ), Commencement Waterways (13  $\mu\text{g/g}$ ), and SW Commencement Bay (6  $\mu\text{g/g}$ )] and one station in Sinclair Inlet (Pt. Herron station, 18  $\mu\text{g/g}$ ). Sediments from the remaining subareas, generally had concentrations of measured PAH's totaling less than 4  $\mu\text{g/g}$ .

Phenanthrene (PHN) was found in all sediment samples (Table 13). Sediments from Case Inlet, Port Madison, Budd Inlet, and Brown's Point subareas contained concentrations below 0.10  $\mu\text{g/g}$ . Higher levels were found in the Outer Elliott Bay (average 0.17  $\mu\text{g/g}$ ), Sinclair Inlet (average 0.48  $\mu\text{g/g}$ ), and Southwest Commencement Bay (average 0.67  $\mu\text{g/g}$ ) subareas. The highest levels of PHN were found in the Duwamish Waterway (average 1.0  $\mu\text{g/g}$ ), Commencement Bay Waterways (average 1.2  $\mu\text{g/g}$ ), Seattle Waterfront (average 1.3  $\mu\text{g/g}$ ), Hylebos Waterway (average 1.9  $\mu\text{g/g}$ ), and West Point (4.2  $\mu\text{g/g}$ ) subareas. It is worth noting that the West Point sample, though having a higher concentration than the average for any other subarea, did not have the highest levels of PHN for any single sample. Samples from stations in the Seattle Waterfront, Hylebos Waterway and Commencement Bay Waterways subareas contained higher levels.

Benz[a]anthracene and BaP were found in all sediment samples, at concentrations ranging from .003  $\mu\text{g/g}$  to 6.8  $\mu\text{g/g}$  for BaA and from .002  $\mu\text{g/g}$  to 2.6  $\mu\text{g/g}$  for BaP (Tables 14 and 15). The average concentration of BaA was 0.080  $\mu\text{g/g}$  or less in sediments from Case Inlet, Port Madison, and Budd Inlet. The average concentration of BaA in sediments from Sinclair Inlet was 0.72  $\mu\text{g/g}$ . In Elliott Bay subareas the average concentrations ranged from 0.13  $\mu\text{g/g}$  to 4.8  $\mu\text{g/g}$ , and in the subareas of Commencement Bay from 0.040  $\mu\text{g/g}$  to 1.2  $\mu\text{g/g}$  (Table 14). The average concentrations of BaP in sediment were .027  $\mu\text{g/g}$  or less in Case Inlet, Port Madison, and Budd Inlet, and 0.30  $\mu\text{g/g}$  in Sinclair Inlet. Average concentrations of BaP in sediments from Elliott Bay subareas ranged from 0.077  $\mu\text{g/g}$  to 4.0  $\mu\text{g/g}$ , and in Commencement Bay subareas, from 0.010  $\mu\text{g/g}$  to 0.58  $\mu\text{g/g}$  (Table 15).

Analyses for Polychlorinated Biphenyls (PCB's). There are over 200 isomers of PCB's including chlorobiphenyls through decachlorobiphenyl. The concentration of each class of isomers of PCB's (dichloro- through nonachlorobiphenyls) in sediment samples are presented in Appendix Tables D-3 to D-5 and are described in this section as the sum of the concentrations of the detected isomers (Table 16).

Fourteen of 17 sediment samples from Elliott Bay contained measurable concentrations of PCB's, as did 12 of 14 from Commencement Bay, and all at the remaining sediment samples (Table 16).

The concentrations of PCB's varied greatly among the sediment samples, following much the same pattern of distribution as the PAH's. However, the total concentrations of PCB's in sediments were at least an order of magnitude lower than the concentrations of PAH's (Tables 11, 12, and 16). The highest concentration of PCB's measured in sediment was 1.2  $\mu\text{g/g}$ , which was found in sediment from the Hylebos Waterway. The PCB concentrations were lowest in Port Madison and Case Inlet ( $< 0.01 \mu\text{g/g}$ ). The concentrations of PCB's in sediment from Sinclair Inlet ranged from 0.028  $\mu\text{g/g}$  to 0.22  $\mu\text{g/g}$ . The highest levels in Elliott Bay occurred in the Duwamish Waterway (range 0.099  $\mu\text{g/g}$  to 0.67  $\mu\text{g/g}$ ).

Analyses for Chlorinated Butadienes (CBD's). Chlorinated butadienes include several possible isomers from chlorobutadienes through hexachlorobutadiene. The concentrations of the tri-, tetra-, penta-, and hexachlorobutadienes are reported in Appendix Tables D-3 to D-5 and are described in this section as the sum of the concentrations of the detected isomers (Table 17).

Chlorinated butadienes were found in all 14 sediment samples from Commencement Bay; the concentrations ranged from 0.005  $\mu\text{g/g}$  to 9.0  $\mu\text{g/g}$ . The highest levels of CBD's were found at stations near Old Tacoma, the southside of Brown's Point, and in the Hylebos turning basin. Great variability was found in levels of CBD's in sediment, even within small areas (Table 17). These compounds were found in Sinclair Inlet sediments in concentrations ranging from 0.019  $\mu\text{g/g}$  to 0.090  $\mu\text{g/g}$  (Table 17). Very low concentrations of CBD's ( $< 0.008 \mu\text{g/g}$ ) were found in sediments from Port Madison, Budd Inlet, and Case Inlet. They were present in 13 of 17 samples from Elliott Bay, but at concentrations of less than 0.06  $\mu\text{g/g}$ . They were not found in the two sediment samples from near Pier 42 or from the Duwamish Waterway samples taken south of Harbor Island (Appendix Table D-3).

Analyses for Hexachlorobenzene (HCB). Hexachlorobenzene was present in 40 of the 42 sediment samples at concentrations from 0.00001  $\mu\text{g/g}$  to 0.25  $\mu\text{g/g}$  (Table 18). It was not found in the two sediments taken near Pier 42. HCB was not detected at levels above 0.001  $\mu\text{g/g}$  outside of Commencement Bay. Within Commencement Bay, HCB levels were high in the Southwest Commencement Bay and Hylebos Waterway subareas. The high mean level recorded for Southwest Commencement Bay reflects a single very high concentration found at the Old Tacoma sampling station (0.25  $\mu\text{g/g}$ ). The remaining two stations in this subarea showed relatively low concentrations (0.0001  $\mu\text{g/g}$  and 0.0002  $\mu\text{g/g}$ ) (Appendix Table D-4).

Analyses for Chlorinated Pesticides. The concentration of chlorinated pesticides in each sample is described as the sum of the concentrations of the individual pesticides, lindane, aldrin, heptachlor, -chlordane, nonachlor, and the DDT family of compounds.

Chlorinated pesticides were found in Commencement Bay sediment samples from the Hylebos Waterway, the Commencement Waterways, and the Southwest Commencement Bay subareas (average concentrations ranged from 0.03 µg/g to 0.07 µg/g) (Table 19). The pesticide concentrations in sediment from the remaining subareas generally averaged less than or equal to 0.01 µg/g. The exception was the Duwamish Waterway subarea in Elliott Bay which had an average of 0.03 µg/g.

Analyses for Other Organics. Selected sediment samples were analyzed for as many compounds as could be identified by GC-MS. For most of these samples, the compounds identified, in addition to the standard list, were alkyl substituted aromatic hydrocarbons. In some cases, there were hundreds of these compounds. More than one hundred chlorinated compounds were present in some of the sediment samples. Many of the chlorinated compounds appeared to be highly chlorinated aliphatic hydrocarbons, as well as polychlorinated phenanthrenes, pyrenes, and styrenes. A list of halogenated compounds that have been identified in these analyses is included in Appendix Table D-6. Standards and reference spectra are not available for these compounds, however, efforts will continue to identify as many of these compounds as possible by interpreting their mass spectra.

Physicochemical Characterization. Sediment samples were characterized by grain size and total organic carbon content. The results of these analyses are given in Appendix Table D-7.

Cluster and Principal Components Analyses of Sediment Data. Chemical variables of interest were selected from the sediment data for each sampling station and the stations were grouped using principal components and cluster analyses (Wishart 1975). The results of these analyses are given in Appendix E.

### 3.1.2 Biota

Livers from English and rock sole, Pacific staghorn sculpins, quillback rockfish, and Pacific tomcod were analyzed. Because English and rock sole were found at most stations and had the highest prevalence of abnormalities (Section 3.2), the analytical results for the livers of these two species of fish and other biota are given below. The results for all species are given in Appendix D.

Analyses for Metals. The results of analyses of tissue samples for metals are given in Appendix Table D-8.

Analyses for Polynuclear Aromatic Hydrocarbons (PAH's). The concentrations of individual aromatic compounds in most samples of fish liver were below or close to detectable limits. However, livers from fish captured in Elliott Bay and Commencement Bay generally had higher values for PAH concentrations than did fish livers from the other embayments (Tables 11 and 12). The compounds most commonly detected in liver were benzothiophene, dibenzothiophene, pyrene, and chrysene (Appendix D).

Concentrations of PAH's in worms, clams, shrimp, and crab hepatopancreas, though present at levels higher than in fish livers, were lower than the concentrations of PAH's in associated sediments (Tables 11 and 12). With the exception of shrimp, the highest concentrations of PAH's were found in animals from the Duwamish Waterway, Commencement Bay and Hylebos Waterway subareas. Composite worm samples from the Outer Elliott Bay subarea, Sinclair Inlet, and Port Madison had values of 0.6  $\mu\text{g/g}$  (average of 2 samples), 0.5  $\mu\text{g/g}$ , and 0.2  $\mu\text{g/g}$ , respectively for 3- to 5-ring aromatics. The values for composite samples of clam tissue were much higher in samples from the Commencement Waterways (4.6  $\mu\text{g/g}$ ), Hylebos Waterways (1.0  $\mu\text{g/g}$ ), Seattle Waterfront (1.6  $\mu\text{g/g}$ ), the Duwamish Waterway (5.1  $\mu\text{g/g}$ ), and Sinclair Inlet (1.8  $\mu\text{g/g}$ ) (Table 12). Composite samples of crab hepatopancreas from the Duwamish, Commencement, and Hylebos Waterways had similar concentrations of 3- to 5-ring aromatic hydrocarbon (1.2  $\mu\text{g/g}$ , 0.6  $\mu\text{g/g}$ , and 1.2  $\mu\text{g/g}$ , respectively). In contrast, crab hepatopancreas samples from Budd, Case, and Sinclair Inlets had values of 0.2  $\mu\text{g/g}$  or less.

One of the highest values for 3- to 5-ring aromatics was found in shrimp from Case Inlet (1.4  $\mu\text{g/g}$ ). Shrimp captured in the Hylebos and Duwamish Waterways had values of 1.2  $\mu\text{g/g}$  and 0.5  $\mu\text{g/g}$ , respectively (Table 12). Similar levels of PAH's were found in Sinclair and Budd Inlets. The lowest level was found in shrimp from Port Madison (0.1  $\mu\text{g/g}$ ). Tables 11 and 12 show that concentrations of 3- to 5-ring aromatics predominated over the 1- and 2-ring compounds in samples of clams, worms, and shrimp. Among the fish livers the 3- to 5-ring compounds predominated except in the Seattle Waterfront and Duwamish Waterway subareas where the 1- and 2-ring aromatics appeared to be favored. No such pattern was evident among the crab samples.

Phenanthrene was found in only two fish liver samples at concentrations of 0.08  $\mu\text{g/g}$  and 0.16  $\mu\text{g/g}$  (Table 13). It was found in 4 of 6 crab hepatopancreas samples at concentrations ranging from 0.020 to 0.50  $\mu\text{g/g}$ ; in 3 of 6 worm samples at concentrations ranging from 0.15 to 0.51  $\mu\text{g/g}$ ; in 2 of 8 shrimp samples at 0.12  $\mu\text{g/g}$  and 0.17  $\mu\text{g/g}$ ; and in 1 of 7 clam samples at 0.41  $\mu\text{g/g}$  (Table 13).

Benz[a]anthracene was found in 5 of 39 flatfish liver samples, with the highest concentrations being measured in samples from the Hylebos Waterway subarea (0.22  $\mu\text{g/g}$  and 0.060  $\mu\text{g/g}$ ; Table 14). Measurable levels of B[a]A were found in 3 of 6 samples of crab hepatopancreas at concentrations from 0.060  $\mu\text{g/g}$  to 0.090  $\mu\text{g/g}$ ; in 5 of 7 clam samples at levels ranging from 0.14  $\mu\text{g/g}$  to 1.0  $\mu\text{g/g}$ ; and in 8 of 8 shrimp samples at levels ranging from 0.010  $\mu\text{g/g}$  to 0.16  $\mu\text{g/g}$ , with the highest concentration being found in the sample from Case Inlet. All 8 worm samples contained measurable amounts of BaA with values ranging from 0.020  $\mu\text{g/g}$  to 3.0  $\mu\text{g/g}$ .

Benzo[a]pyrene was found in two liver samples, one crab hepatopancreas, three polychaete worm, four shrimp, and four clam samples (Table 15). Both of the fish liver samples were from Commencement Bay, and contained concentrations of 0.37  $\mu\text{g/g}$  (Hylebos Waterway) and 0.21  $\mu\text{g/g}$  (Brown's Point). The crab hepatopancreas sample with detectable concentrations of BaP (0.020  $\mu\text{g/g}$ ) came from the Duwamish subarea. Of the three worm samples with detectable amounts of BaP, two were from Commencement Bay (Hylebos Waterway, 0.73  $\mu\text{g/g}$  and Commencement Waterways, 0.25  $\mu\text{g/g}$ ), and one from

the Duwamish Waterway (0.35 µg/g). The highest concentration of BaP measured in shrimp was in the sample from Case Inlet (0.090 µg/g). The other shrimp samples with detectable concentrations came from the Sinclair Inlet (0.070 µg/g), Hylebos Waterway (0.050 µg/g), and Budd Inlet (0.030 µg/g) subareas. In clams, BaP was detected in samples from the Commencement Waterways (0.25 µg/g), Duwamish Waterway (0.23 µg/g), Sinclair Inlet (0.12 µg/g), and Seattle Waterfront (0.10 µg/g) subareas (Table 15).

Analyses for Polychlorinated Biphenyls (PCB's). PCB's were found in every tissue sample analyzed at levels ranging from 0.02 µg/g (in clams from Case Inlet) to 35 µg/g (in a fish liver sample from the Duwamish Waterway; Table 16). Fish livers from Elliott Bay, Commencement Bay and Sinclair Inlet had the highest levels of PCB's. The range in Elliott Bay was 1.8 µg/g to 35 µg/g. The Duwamish Waterway subarea in Elliott Bay had fish livers with the highest average level of PCB's (17 µg/g). The concentrations of PCB's in samples of fish livers from the Seattle Waterfront and West Point subareas were 6.3 µg/g and 3.9 µg/g, respectively. Fish liver samples from the Outer Elliott Bay subarea contained levels of PCB's averaging 2.5 µg/g. Samples from the Hylebos Waterway subarea had the highest average level of PCB's within Commencement Bay (11 µg/g). Average values from Brown's Point and Southwest Commencement Bay subareas were 9.4 µg/g and 4.7 µg/g, respectively. Samples from Sinclair Inlet had similar levels (average 6.3 µg/g). The levels of PCB's in flatfish liver samples from Case Inlet, Budd Inlet and Port Madison were similar to those found in the least contaminated of these species from Elliott and Commencement Bays (0.55 µg/g to 3.0 µg/g).

As with the fish livers, the concentrations of PCB's in composite samples of crab hepatopancreas were highest in the Duwamish Waterway (32 µg/g), Hylebos Waterway (28 µg/g), and Commencement Waterways (10 µg/g) subareas (Table 16). Lower average levels of PCB's were found in Sinclair Inlet (4.2 µg/g), Budd Inlet (1.4 µg/g), and Case Inlet (0.5 µg/g).

The highest levels of PCB's in shrimp composites were found in samples from the Hylebos Waterway (3.0 µg/g) and Duwamish Waterway (2.1 µg/g) subareas. Concentrations in shrimp composites from the Outer Elliott, Brown's Point, Port Madison, Case Inlet, Budd Inlet, and Sinclair Inlet subareas ranged from 0.1 µg/g to 0.7 µg/g (Table 16).

The highest levels of PCB's in worms were found in samples from the Duwamish Waterway (1.8 µg/g). The lowest concentrations of PCB's in worm samples was from Port Madison (0.2 µg/g, Table 16).

The small number of composite samples of whole clams analyzed for PCB's prevented a detailed comparison of these data. The levels of PCB's ranged from 0.02 µg/g (Case Inlet) to 1.3 µg/g (Seattle Waterfront; Table 16).

Analyses for Chlorinated Butadienes (CBD's). Most fish livers (14 of 17 samples) from Commencement Bay had measureable levels of CBD's (0.002 µg/g to 9.1 µg/g), with the highest levels being found in samples from the Hylebos Waterway subarea (avg. 1.7 µg/g; Table 17). Chlorinated butadienes were found in liver samples from all other subareas except for West Point,

although the concentrations were at or below 0.012  $\mu\text{g/g}$ . Thus, only the fish from Commencement Bay showed consistently elevated levels of CBD's, especially those from the Hylebos Waterway (Table 17).

With the exception of two shrimp samples from Port Madison and Case Inlet, and one worm sample from Sinclair Inlet, all with levels of CBD's at or below 0.01  $\mu\text{g/g}$ , the invertebrates with measurable levels of CBD's were found exclusively in Commencement Bay. The highest levels of CBD's in invertebrates were found in crabs, worms, and shrimp in the Hylebos Waterway (0.07  $\mu\text{g/g}$ , 0.2  $\mu\text{g/g}$ , and 0.2  $\mu\text{g/g}$ , respectively; Table 17). Other samples of invertebrates from the remaining subareas of Commencement Bay had levels of CBD's from 0.002  $\mu\text{g/g}$  to 0.1  $\mu\text{g/g}$ .

Analyses for Hexachlorobenzene (HCB). Hexachlorobenzene was found in all fish liver samples from Commencement and Elliott Bays at levels ranging from 0.010  $\mu\text{g/g}$  to 3.7  $\mu\text{g/g}$  in the former area and from 0.0040  $\mu\text{g/g}$  to 0.050  $\mu\text{g/g}$  in the latter (Table 18). Fish livers from the other embayments had HCB concentrations at or below 0.01  $\mu\text{g/g}$ . The highest levels in the livers of English and rock sole in Elliott Bay were in samples from the Duwamish Waterway (0.01  $\mu\text{g/g}$  to 0.05  $\mu\text{g/g}$ ) and Seattle Waterfront (0.008  $\mu\text{g/g}$  to 0.02  $\mu\text{g/g}$ ) subareas.

Within Commencement Bay, the levels of HCB in fish livers ranged from 0.010  $\mu\text{g/g}$  to 3.7  $\mu\text{g/g}$  with 10 of 17 samples having above 0.10  $\mu\text{g/g}$  (Table 18 and Appendix Tables D-12 to D-14). Five of six liver samples from the Hylebos Waterway contained levels over 1.0  $\mu\text{g/g}$  (Appendix Tables D-12 to D-14). Samples from the other stations in the Bay had levels less than 0.2  $\mu\text{g/g}$ .

The levels of HCB found in invertebrates from Commencement Bay ranged from 0.010  $\mu\text{g/g}$  to 0.37  $\mu\text{g/g}$ , with the exception of one crab hepatopancreas sample from the Hylebos Waterway which had 1.8  $\mu\text{g/g}$ . Similarly, the levels of HCB in invertebrate samples from Elliott Bay ranged from those too low to be detected to 0.030  $\mu\text{g/g}$ . The samples of invertebrates from the other sampling areas had levels of HCB at or below 0.001  $\mu\text{g/g}$  (Table 18 and Appendix Tables D-15 and D-16).

Analyses for Pesticides. Chlorinated hydrocarbon pesticides were found in all fish liver samples analyzed (Table 19 and Appendix Tables D-9 to D-15). The highest average levels were found in samples from the Duwamish Waterway, Hylebos Waterway and Seattle Waterfront subareas (2.0  $\mu\text{g/g}$ , 0.8  $\mu\text{g/g}$ , and 0.7  $\mu\text{g/g}$ , respectively). Intermediate levels were found in samples from Sinclair Inlet, Brown's Point, Southwest Commencement Bay, and West Point subareas (averaging 0.3  $\mu\text{g/g}$  to 0.5  $\mu\text{g/g}$ ). Lowest levels were found in samples from the Outer Elliott, Port Madison, Budd Inlet and Case Inlet subareas (averaging 0.1  $\mu\text{g/g}$  to 0.2  $\mu\text{g/g}$ ).

Crab hepatopancreas samples from the Duwamish Waterway, Hylebos Waterway and Commencement Waterways subareas showed higher levels of pesticides (averaging 1.8  $\mu\text{g/g}$  to 3.2  $\mu\text{g/g}$ ) than samples from Sinclair Inlet, Budd Inlet, and Case Inlet (averaging 0.05  $\mu\text{g/g}$  to 0.4  $\mu\text{g/g}$ ).

All other biota samples showed levels of chlorinated pesticides at or below 0.05 µg/g, except a clam composite from the Commencement Waterways subarea, and a worm sample and a shrimp sample from the Hylebos Waterway (Table 19).

Analyses of Fish Liver, Crab Hepatopancreas and Edible (Muscle) Tissue for PCBs, HCB, and HCBD. Analyses of fish livers, crab hepatopancreas and the edible (muscle) tissue of these animals, all from Commencement Bay, revealed chlorinated hydrocarbons (PCB's, HCBD, and HCB) in all samples of English sole; HCB and PCB were detected in crab muscle tissues. The results of these analyses are presented in Table 20. English sole livers contained from 7 to 30 times the concentrations of HCB or PCB's found in the muscle tissues and from 6 to 100 times the concentrations of HCBD. Crab hepatopancreas showed concentrations of HCB 2 and 90 times those found in the muscle tissue, and 6 and 25 times the concentrations of PCB's.

### 3.2 Fish Pathology

During 1979, 2,951 fish from six central and southern Puget Sound embayments were examined for externally visible abnormalities and were necropsied. The only major externally visible lesion was the epidermal papilloma of flatfish. The cause of these skin tumors is not known, but they are not considered to be related to pollution (Wellings et al. 1976). However, numerous microscopic lesions were observed, and they were of three basic categories: (1) idiopathic lesions [lesions of unknown cause(s)], (2) parasitic infections and infestations, and (3) lesions found in three or less fish from various embayments. These latter conditions will not be described here, but if they continue to be observed during subsequent sample collections, they will be described in later reports.

Most of the idiopathic lesions were found in the liver, gills, and kidneys. The liver lesions included megalocytic hepatosis (MH), adenomatous foci (AF), cholangioproliferative (bile duct proliferative) foci (CF), nuclear pleomorphism (NP), focal hepatocellular hyperplasia (FHH), hepatic sclerotic foci (HSF), and hepatocellular necrosis (HN). With the exception of the latter two types of abnormalities, these lesions are provisionally considered to be toxicopathic since these anomalies closely resemble changes induced in the livers of other vertebrate species exposed to toxic chemicals under laboratory conditions (Jones and Butler 1975, Koller and Zinkl 1973, Hinton et al. 1978, Ashley 1967). Adenomatous foci and CF in English sole from Puget Sound have been described as "tumors" in previous reports from this laboratory. Although the term "tumor" has been and continues to be used extensively in pathological and popular literature, its loose application creates confusion in understanding the type of lesion being discussed. For example, "tumor" may be applied equally to an area of inflammation or a cancerous growth. Consequently, the use of "tumor" has been avoided in this report. To refer to excessive, uncoordinated tissue growth, the term "neoplasm" or "neoplastic growth" is used. Neoplasms may be benign or malignant, depending on the rate of growth, the ability to disseminate throughout the body (metastasize), and potential to kill the organism. Names of pathologic lesions reported in this study are merely descriptive

of the microscopic morphology of each lesion. Information concerning the functional effects of each lesion within the individual fish is not known yet. The major gill lesion was respiratory epithelial hyperplasia, and glomerular disruption was the most common kidney lesion.

The gross and microscopic characteristics and geographic distribution of the lesions are described below. In some cases, the lesions were grossly visible; however, most were only microscopically detectable.

### 3.2.1 Liver Lesions

The summary of the main gross and microscopic properties of the liver lesions is given in Table 21.

Megalocytic Hepatosis (MH). MH lesions were grossly visible as regions of hepatic mottling in only the most severe cases. Colors of affected livers varied from tan to brown as compared with the reddish-brown color of normal livers. Microscopically all MH lesions possessed hepatocytes with enlarged nuclei and increased cell size (cytomegaly) (Figure 8). Increase in nuclear size was up to five times the normal diameter and cell diameters ranged up to three times normal. Cellular morphology was similar to that described for hepatic cytomegaly in animals exposed to pyrrolizidine alkaloids (Jubb and Kennedy 1970, McLean 1970). Nuclei frequently exhibited bizarre characteristics such as hyperchromasia, irregular shape, and unusual chromatin distribution. The cytoplasm of these cells was usually granular or fibrillar in appearance (Figure 9). Sinusoidal compression was nearly always present, but there was no thickening of the sinusoidal walls (muralia) due to hyperplasia of hepatocytes. Lesions occurred in any portion of the parenchyma and ranged from focal to diffuse. Occasionally, hepatocellular degeneration and necrosis with cytoplasmic hyalin body formation and fibrosis were also present.

MH was found in English sole, rock sole, and Pacific staghorn sculpin. Highest annual frequencies were among English sole in the Duwamish Waterway subarea (12%, 26/209) (Figure 10) and rock sole in the Seattle Waterway subarea (10%, 7/71) (Figure 11). MH was also found in these three species in Commencement Bay (Figures 10 and 11, and Table 22).

Focal Hypertrophy (FH). The principal microscopic characteristic of this lesion was hepatocellular hypertrophy (up to four times the normal cellular diameter) with no change in nuclear size. Cytoplasm with increased eosinophilic or basophilic staining qualities distinguished two subcategories of focal hypertrophy. No hepatocellular hyperplasia was present. Lesions were focal with indistinct boundaries. There was no compression of adjacent tissue or encapsulation of the lesion. Eosinophilic focal hypertrophy was frequently associated with MH. Fibrosis was often found within foci of basophilic focal hypertrophy. Annual frequencies were the highest among English sole in the Hylebos and Waterway subareas of Commencement Bay (6%, 8 of 129 and 7%, 10 of 138, respectively) (Figure 12). Rock sole from the Duwamish River and Pacific tomcod from Commencement Bay were much less affected (Figure 13 and Table 22). No cases were found in Budd Inlet or the reference areas (Case Inlet and Port Madison).

Adenomatous Foci (AF). Adenomatous foci were visible grossly as smooth, pale (tan, yellow, or white) nodules or nodes, 1 mm to 5 mm in diameter, on the surface and within the liver parenchyma (Figure 14). Histologically, the nodules displayed an increase in cellular size (up to two times the normal diameter), and a variable increase in nuclear diameter (up to four times the normal diameter) (Figure 15). Nuclei typically possessed prominent nucleoli occupying up to 40% of the nuclear area. Narrowing of the sinusoidal spaces was always present. Hepatocellular hyperplasia was often seen, resulting in compression of the surrounding parenchyma. Frequently, disarray of the muralial architecture and fibrosis were seen within the nodule, along with invasiveness characteristic of carcinomas.

Only English sole in the Duwamish, Hylebos, and Commencement Waterway subareas possessed these lesions (Figure 16).

Cholangioproliferative Foci (CF). Two types of CF were observed:

(a) Organized cholangioproliferation - This type of proliferation was seen as a focus of excessive numbers of normal-appearing cholangioles (bile ducts), sometimes with associated fibrosis or abundant stroma. The tubular ducts occasionally had dilated lumina. The lesion was differentiated from a Myxidium (a protozoan parasite)-associated bile duct proliferation primarily by the absence of Myxidium plasmodia within the lumina and a lack of compression atrophy of the bile duct epithelia usually seen in Myxidium infections.

(b) Disorganized cholangioproliferation - Grossly, this type of hepatic lesion appeared as a pale green or cream area, usually less than 1 mm in diameter. Microscopically, a proliferation of bile duct epithelial cells was seen, but with a major or complete loss of ductular structure and organization. Heavy fibrosis and melanin-macrophage centers (Roberts, 1975) were usually seen at the perimeter of the lesion. Often lesions were nodular in appearance (Figure 17).

Duct-forming CF and disorganized CF were found only in Elliott and Commencement Bays among rock sole, English sole, and Pacific tomcod (Figures 18 and 19 and Table 22). Highest annual frequency was among rock sole of the Duwamish subarea. One rock sole from the Duwamish Waterway possessed both types of CF. One Pacific staghorn sculpin from the Hylebos subarea also had disorganized CF (Table 22).

Focal Hepatocellular Hyperplasia (FHH). Areas of focal hepatocellular hyperplasia (FHH) were grossly visible as smooth white nodules. Microscopically, these areas consisted of thickening of the muralia to greater than five cell-layers thick (normal muralia are one to three cell-layers thick). These foci were generally nodular in appearance and usually exerted compression upon surrounding tissue. Individual cytologic morphology was generally normal-appearing.

Rock sole were most frequently found with this condition, and each of the six embayments contained affected individuals (Figure 20). English sole (Figure 21) and Pacific staghorn sculpin (Table 22) were also found to have focal hyperplasia.

Hepatocellular Necrosis (HN). Nonspecific coagulation necrosis of the hepatic parenchyma in English and rock sole was most frequently focal, and the foci were randomly distributed in the parenchyma. Usually necrosis was accompanied by a mononuclear cell infiltrate. Focal liquefactive necrosis also occurred in individuals of all species examined and in most of the subareas (Figures 22 to 23 and Table 22).

Hepatocellular Nuclear Pleomorphism (NP). The distinctive microscopic characteristics of NP included nuclear enlargement (up to three times the normal size) with no increase in cell diameter, nuclear hyperchromasia, and occasional binucleate cells (Figure 24). No hepatocellular hyperplasia or sinusoidal compression was observed. Individuals of all four target species in Elliott and Commencement Bays were found to have this condition. Because the number of fish with this lesion was so small the geographical distribution was summarized on the basis of annual prevalence and by individual sampling station (Figures 25A and B).

Hepatic Sclerotic Foci (HSF). Sclerotic foci were found in the liver of several Pacific tomcod and in one case each of Pacific staghorn sculpin and quillback rockfish. These foci were characterized by dense collagenous fibrosis in the parenchyma, and occasional central necrosis and dystrophic calcification associated with bile ducts. Often bile duct epithelium could be seen within the foci. Similar lesions were sometimes closely associated with encysted parasites and granulomata in other tissues and organs of Pacific tomcod, but no causative agents were found associated with the hepatic foci. The lesion was found in all embayments, except Budd and Case Inlets (Table 22).

Parasitic Lesions. The most frequently-occurring hepatic parasitic infection was by members of the sporozoan genus Myxidium. Plasmodial forms commonly occurred in the lumina of intrahepatic bile ducts of English sole, rock sole, Pacific staghorn sculpin, and quillback rockfish. Immature and mature spore forms were also seen within bile ducts (intra- and extrahepatic), as well as in the lumen of the gall bladder. Associated lesions included peribiliary lymphoid infiltrate, fibrosis, compression atrophy of the cholangiolar epithelium, and proliferation of small bile ducts containing plasmodia. Myxidium-infected fish were found in all embayments.

The Occurrence of Multiple Liver Lesions. Individual fish with two or more of the above-mentioned toxicopathic liver lesions were most frequently from the Duwamish, Hylebos, and Commencement Bay Waterways subareas (Table 23). Livers with three and four (the highest number found per liver) lesions were only in fish from these subareas (Table 24). The two lesions most commonly found in the same liver were MH and FH, although MH was also present in combination with all the other toxicopathic lesions, and was present in all cases where four lesions were in one liver (Table 24). English sole was the only species which had livers with four different types of lesions.

Because no evidence has been found to suggest that any of the toxicopathic liver lesions have common etiologies, the prevalence of these lesions are presented in this report, with one exception, as if they are independent of each other. The one exception, presented in Table 25, is an effort to simplify the prevalence data for tumor-bearing fish. Fish

with AF, CF, or both conditions were treated as individual fish so as to give the actual number of tumor-bearing animals from each subarea.

#### Statistical Analysis of the Distribution of Fish with Hepatic Lesions.

The annual frequencies of the seven hepatic lesions found in all four target species were significantly higher at four sampling stations than would be expected if the frequencies of hepatic lesions were equal at all stations sampled (Table 26). These stations were in the Hylebos and Sitcum Waterways in Commencement Bay and two stations in the Duwamish Waterway in Elliott Bay. Conversely, the lesion frequencies were significantly lower at sampling stations in Sinclair Inlet (Station 08006), off the Tacoma Yacht Club (09036) and Brown's Point (09037) in Commencement Bay, and off West (10023) and Alki (10028) Points and Magnolia Bluff (10014) in Elliott Bay.

#### 3.2.2 Kidney Lesions

A variety of kidney lesions were found in a small number of all the target species. The most severe lesion was glomerular disruption (GD), characterized by dilation of glomeruli and capillaries (sometimes with rupture, and resultant hemorrhage into Bowman's space) and/or loss of mesangial cells and matrix and basement membrane (Figure 26). This lesion occurred in all the target species and in all the sampling areas. English and rock sole were the most affected, and the highest prevalence was found in the SW Commencement Bay subarea (10%, 4/40) (Figures 27 and 28). The other kidney lesions appeared to be less severe and included glomerular hypercellularity and hypermembranous glomeruli. Additional kidney lesions were observed in a limited number of fish and will be characterized and described in subsequent reports.

#### 3.2.3 Gill Lesions

Several types of lesions were observed in gills, most of which were associated with parasitic infestations. One exception was respiratory epithelial hyperplasia (REH). Single or multiple foci of moderate to severe REH (> 5 cells thick) were seen on gill lamellae (Figure 29A). The structure of normal-appearing gill lamellae is shown in Figure 29B. These areas were found frequently with lamellar fusion and/or edema. All target species were affected and nearly all areas contained animals with abnormalities (Figures 30 and 31).

#### 3.2.4 Parasitic Lesions

Descriptions of parasitic infections and infestations will be concerned primarily with the characteristics of associated lesions. Prevalence data of the major infestations will be included in future reports. Parasites commonly occur in all animals and are not necessarily associated with elevated contaminant levels.

Gills. Parasitism of the connective tissue, filament and respiratory epithelium by larval digenetic trematodes was usually accompanied by fibrosis and mononuclear cell infiltrates in the surrounding tissue. Each of the target species had infected individuals, and parasitism was found in all six

embayments. Monogenetic trematode infestations were heaviest on the gill lamellae of quillback rockfish (14.7%, 19/129 for all the sampling areas). These trematodes were determined to be members of the suborders Monopisthocotylea and Polyopisthocotylea. Host response was most extreme in quillback rockfish, usually displaying moderate to severe lymphoid infiltrates, severe edema of the respiratory epithelium, and REH, often with lamellar fusion.

Microscopic respiratory epithelial lesions closely resembling the epitheliocystis lesions described by Hoffman et al. (1969) were commonly observed. This condition is believed to be caused by a rickettsium-like organism. All target species and quillback rockfish were affected by epitheliocystis.

Crustacean parasites were generally attached to the arch epithelium or to the base of the gill filament in both target and nontarget species. Attachment sites had an accompanying lymphoid infiltrate, necrosis, and hyperplasia of the epithelium. On gross inspection most of these parasites were classified as copepods.

Gastrointestinal Tract. A variety of helminths, consisting primarily of nematodes and acanthocephalids, were found within all layers of the alimentary tract wall and within the lumen of some fish of each species examined. Host response was variable, depending on the species of helminth, location within the tract, and species of the host. The most severe host reactions included chronic inflammation, fibrosis, and granuloma formation.

Several species of amoebae coccidia, adult digenetic trematodes, and cestodes were also found as gastrointestinal parasites.

Heart. Larval digenetic trematodes (metacercaria) were found in the ventricular myocardium of English sole, rock sole, and Pacific staghorn sculpin. Mononuclear infiltrates and fibrosis were usually associated with the parasitic foci. English sole had the highest frequency of affected animals in the summer quarter (21.9%, 44/201).

Skin and Fin. Members of the genus Philometra were readily visible upon gross inspection. These blood feeding nematodes were located within the body musculature and peritoneal cavity, in the subcutaneous tissue of the fin and skin, and occasionally in the serosa of internal organs and the mesenteries. Regardless of the species of the host, typical histologic response to Philometra was inflammation with fibrosis. Microscopic examination showed that most of the parasites observed were females bearing filariae. All target species had affected individuals in all embayments.

### 3.2.5 Hematology and Blood Chemistry

As part of the necropsy procedure, blood samples were taken for hematological tests and for blood chemistry analyses (see section 2.3.1 for methodology). Hemoglobin values for blood from 2,435 fish were measured. Statistical comparisons of hemoglobin values for fish with pathological conditions and for normal fish of the same species are being performed, but are not yet completed.

Chemical analyses of 667 blood samples were performed by Biomedical Laboratory, Seattle, for the 12 chemicals and enzymes described in Methods and Materials. In addition, 1,379 blood samples were analyzed by our own laboratory for serum albumin and total protein. A preliminary statistical treatment of the blood chemistry data from 100 fish was performed in which analysis of variance was used to compare these data for fish with liver lesions against similar data for normal-appearing fish. No significant differences were found. Statistical tests with these data for additional fish are currently being performed and the results will be reported in subsequent reports.

### 3.2.6. Biological Characteristics of Diseased Fish

Another part of the necropsy procedure was the determination of the sex, length, weight, and age of each fish. A preliminary summarization of these data for English sole and rock sole with hepatic lesions are presented in Tables 27 and 28. In general, most English and rock sole with hepatic lesions were from 5 to 8 years of age. A relatively small number of affected juveniles (ages 1 to 3) had the toxicopathic types of hepatic lesions (e.g., MH and NP). A more complete treatment of these biological data will be presented in subsequent reports.

### 3.2.7 Electron Microscopic Examination of Abnormal Tissues

Tissues from 372 fish were excised, preserved, and processed for electron microscopic examination. Tissues from 76 fish have been embedded in plastic, sectioned, examined with the light microscope, and preliminary electron microscopic studies were initiated on tissues of fish with lesions of the gill, skin, and liver. Selected samples of the remaining tissues will be examined as a means of further characterizing the ultrastructural properties of lesions observed at the light microscopic level. Data will be reported in subsequent reports.

## 3.3 Invertebrate Pathology

The invertebrate species initially chosen for examination of microscopically detectable lesions were found to be unsatisfactory for this study. The initial species were Cancer magister (Dungeness crab), Macoma carlottensis (a bivalve), Crangon alaskensis (a shrimp), and an unspecified species of Terebellid polychaete. At many stations sampled during the first sampling trip (winter quarter) Cancer gracilis proved to be more numerous than C. magister. At some stations Cancer productus was most numerous. The larger Pandalid shrimp (Pandalus danae and Pandalus jordani) were taken in higher numbers by otter trawl than the smaller target species C. alaskensis (see Section 3.5.6 for the abundance and distribution of crustacea). The yield of benthic invertebrates, taken with the sediment grab, was always very small. In most instances, there were fewer than five Macoma carlottensis available for histopathological examination. Macoma nasuta and Acila castrensis, being the next most commonly encountered species, were added as target species. Terebellid polychaetes were also very scarce. Glycera capitata, Capitella capitata, and Prionospio pinnata proved to be the most widely distributed species.

The numbers of animals subjected to microscopic examination are summarized in Table 29.

Most of the microscopic lesions detected in the tissues of the 618 invertebrates examined so far were in shrimp and crabs. No lesions were observed in polychaetes, and very few bivalves had detectable abnormalities. The most severe lesions in the crustaceans were in the gills, hepatopancreas, connective tissue, and the bladder. A description of the structure and function of these organs is presented in Appendix F.

Because of the great variability in sample sizes of target species from station to station and from one sampling quarter to the next, these data may be of more value in a qualitative than a quantitative usage. They are most appropriate as descriptions of the characteristics of microscopically detectable parasites and lesions found in particular sampling environments. In addition these data can be helpful in selection of species and sampling stations for subsequent sampling efforts.

### 3.3.1. Abnormalities in Crustacea

Hepatopancreatic necrosis. This condition was found frequently in P. danae and C. magister and occasionally in C. gracilis, C. productus, C. alaskensis, and P. jordani. It was characterized by abnormally high numbers of necrotic cells and cellular destruction in the tubular epithelium of the hepatopancreas (Figure 32). Affected P. danae were found in the following subareas at the indicated annual frequencies: Seattle Waterfront of Elliott Bay (56%, 5 of 9), Sinclair Inlet (17%, 1 of 6), Hylebos Waterway (18%, 8 of 45), and Commencement Bay Waterways (21%, 3 of 14) (Figure 33). This condition was not found in neither the eight P. danae from Case Inlet nor the four from Budd Inlet. Annual frequencies of affected C. alaskensis were found in Case Inlet (8%, 3 of 36), Budd Inlet (7%, 2 of 30), and Sinclair Inlet (4%, 2 of 48). P. jordani with hepatopancreatic necrosis were also found at the deepest station [Station 7 (10044)] in Elliott Bay with an annual frequency of 8% (3 of 39).

Tubular Metaplasia of the Hepatopancreas. Tubular metaplasia of the hepatopancreas was observed in C. gracilis, P. jordani, and C. alaskensis. This lesion involved a change in shape of the tubular epithelial cells from columnar to cuboidal (Figure 34). This condition was often widespread throughout the organ and frequently metaplastic tubules appeared to be covered with flattened hemocytes. Necrosis of the tubules within the same organ was often observed. C. gracilis with this lesion were captured in the Seattle Waterfront, Hylebos Waterway, and Commencement Bay Waterways subareas at annual frequencies of 28% (2 of 7), 10% (1 of 10), and 27% (3 of 36), respectively (Figure 35). Affected C. alaskensis were found in Case Inlet (8%, 3 of 36) and Sinclair Inlet (23%, 11 of 48). Only two affected P. jordani were found, one in the Duwamish Waterway (1 of 8) and the other along the Seattle Waterfront (1 of 56).

Melanized Nodules. Melanized nodules were nodule-like lesions consisting of one to six layers of flattened concentrically arranged hemocytes about a central melanized core (Figure 36). These nodules occurred within the parenchyma of the gill stem and occasionally within

the intrafilamental spaces, within the loose connective tissue surrounding various organs, and within the tegmental glands associated with the epidermis, gill stem, esophagus, and midgut ampulla. Because of their similar structure and degree of melanization, and because they all involve a hemocytic encapsulation response they will be presented as a single group (Figure 37). Nevertheless the prevalence of the individual lesions will be described below. The formation of melanized modules in various tissues is commonly associated with injury by physical trauma, particulate, or foreign agents in crustaceans (Fontaine and Lightner, 1974; Fontaine et al., 1975). Melanized nodules were not seen in crustaceans which were in apparently good health.

Melanized nodules were observed in the connective tissues occupying the main gill stem of P. danae, C. gracilis, and C. magister. This condition was detected in P. danae from the Duwamish Waterway and Hylebos Waterway subareas at annual frequencies of 7% (3 of 41) and 16% (4 of 25), respectively. This same condition was found in C. gracilis with the following annual frequencies: Duwamish Waterway 20% (1 of 5), Hylebos Waterway 10% (1 of 10), and Commencement Bay Waterways 8% (1 of 13).

Melanized nodules of the gill stem and intrafilamental channel were observed only in C. magister from the Duwamish Waterway subarea with an annual frequency of 28% (7 of 25). This condition was occasionally accompanied by the filling of intrafilamental spaces with a dense hemocytic infiltrate. Fibrosis and melanization of the gill filaments sometimes accompanied this infiltrate.

Small numbers of both C. gracilis and C. magister had melanized nodules in loose connective tissues. This condition was observed only in the subareas of Duwamish Waterway, Seattle, Waterfront (Elliott Bay), and Commencement Bay Waterways.

Melanized nodules of the tegmental glands were only seen in C. magister from Elliott and Commencement Bays. This species was not captured from other areas, thus the significance of its occurrence here is unclear.

Bladder Lesions. Two basic types of bladder lesions were found in C. gracilis and C. magister: one was epithelial necrosis and the other was nuclear enlargement in epithelial cells. Crabs with bladder necrosis (Figure 38) were found only in Elliott and Commencement Bays. C. gracilis with bladder necrosis followed a similar distribution. Affected C. magister and C. gracilis were observed in the following subareas at the indicated annual frequencies (the first value is for C. magister): Duwamish Waterway, 20% (5 of 25) and 80% (4 of 5); Hylebos Waterway, 25% (1 of 4) and 20% (2 of 10); and Commencement Bay Waterways, 60% (3 of 5) and 18% (2 of 11) (Figures 39 and 40). C. gracilis with bladder necrosis were also captured at Downtown Elliott Bay 14% (1 of 7), and two affected C. magister (2 of 2) were observed at West Point (Figure 39 and 40).

The degree of enlargement of nuclei in bladder epithelial cells varied considerably. This lesion was not detected in normal-appearing (free of other lesions) crab. Affected C. gracilis were found mainly in Commencement Bay in the Hylebos Waterway, 40% (4 of 10), and Commencement Bay Waterways,

36% (4 of 11) (Figure 41). One affected C. gracilis was also found at the Downtown Elliott Bay subarea, 14% (1 of 7), and one was found in Budd Inlet, 14% (1 of 7). C. magister with this condition were from the Duwamish Waterway, 32% (8 of 25), the Hylebos Waterway, 50% (2 of 4), and the Commencement Bay Waterway subarea, 40% (2 of 5).

Vesicular Hepatopancreas. Individuals of each of the target shrimp and crab species had vesiculated hepatopancreatic cells. This condition was typified by the appearance of a much greater number of empty vesicles than normally present in the cytoplasm of tubular epithelium (Figure 42). These vesicles are thought to be vacancies caused by the loss of droplet-like inclusions of material lost during normal histologic processing. Affected individuals of one or more species were found in all six embayments (Figures 43 to 46). The prevalence of this condition in crabs was generally consistent from season to season. However, marked seasonal fluctuations in prevalence (0 to 100%) were observed for the three species of shrimp with this condition.

Mycotic Gill Infection. Mycotic gill infection of P. danae was characterized by proliferation of fungal hyphae, with the highest concentration of hypae and associated melanization localized in the gill filaments (Figure 47). Filaments distal to the lesion were usually necrotic, and a heavy hemocytic infiltrate was observed proximal to the site of infection. This fungal infection may have been a secondary infection resulting from injury to the gills by physical or chemical agents. The annual frequencies of this lesion were quite low, with the Duwamish Waterway subarea having 2% (1 of 41) and the Hylebos Waterway subarea having 7% (3 of 45).

Miscellaneous Abnormalities of Crustacea. A number of other conditions were observed in shrimp and crabs. These conditions are considered to be less important than those described above either because so few affected animals were found or because the conditions were associated with minimal histopathological changes.

The majority of C. alaskensis were captured in Budd, Case, and Sinclair Inlets. Specimens were rarely collected in Port Madison, Elliott Bay, or Commencement Bay. A microsporidian infection was seen in animals from Sinclair and Budd Inlets. The annual frequency of affected C. alaskensis in Sinclair Inlet was 23% (11 of 48) and in Budd Inlet it was 12% (5 of 42) (Figure 48). Specimens with infestations of stalked ciliates on the surfaces of gill filaments were encountered at all sites with high frequencies at all times of the year except winter. This condition is not generally regarded as harmful to the animal.

As was the situation with C. alaskensis, infestation of gills of P. danae with stalked ciliates occurred at most stations much of the year and is considered of minor importance. Flaking and darkening of the chitinous covering of gill filaments also occurred in animals from numerous locations most of the year though it was absent from animals collected during spring quarter and was more prevalent in animals collected during the summer and fall quarters.

### 3.3.2 Abnormalities of Polychaetes

Capitella capitata, Glycera capitata, and Prionospio pinnata were collected from sampling stations in most sampling areas. All specimens have been examined and no microscopic abnormalities were found.

### 3.3.3 Abnormalities of Bivalves

Acila castrensis and Macoma carlottensis were both collected in Port Madison and Sinclair Inlet. M. carlottensis were also collected in Case Inlet, the Duwamish Waterway, and the Commencement Bay Waterways. Animals from Port Madison and Case Inlet were free of detectable lesions. However, 21% (3 of 14) of the A. castrensis and 100% (3 of 3) of the M. carlottensis from Sinclair Inlet had necrotic digestive tubules. In addition, 100% (2 of 2) of M. carlottensis from the Duwamish Waterway and the only individual of this species examined from the Commencement Bay Waterways had this condition. The observed necrosis involved a disruption of nuclei and cellular membranes, and extensive loss of cytoplasm in the epithelial cells of the tubules.

## 3.4 Fish Ecology

A primary objective during the first year of this project was to compare the biological characteristics of five target species common in Puget Sound and several parameters of fish community structure. These parameters included species composition, relative abundance, species diversity, and species richness.

At the beginning of this study, published catch rates of Puget Sound fishes were lacking. However, information consolidated from species occurrence patterns within Washington waters catch records of local fishing vessels by Miller and Borton (1979) suggested that English sole, rock sole, Pacific tomcod, staghorn sculpin, and quillback rockfish were common to most areas and best represented benthic and midwater fish assemblages.

Results from the first year of this study show that English sole and rock sole were the most appropriate target species due to their broad distribution, high abundance, and seasonal availability. Of the six areas studied, Commencement and Elliott Bays had the highest average catches of all species, the most consistent catches; and the greatest richness and diversity. These two areas were the only embayments with major rivers and thus will be referred to as estuarine bays in the remainder of this report.

### 3.4.1 Catch Rates

Total Catch per Unit Effort. The average seasonal CPUE for all species from the stations in each area, ranged from a winter low of 6.0 in Case Inlet to an autumn high of 551.2 in Commencement Bay (Figure 49). The highest seasonal CPUE values in Commencement Bay were observed during the spring and fall sampling periods. In Elliott Bay, the highest values

were measured in the winter and fall. The CPUE values, combined over all areas by season, steadily increased from a winter minimum to a fall maximum. Data from catches in Port Madison and Sinclair Inlet clearly followed that trend, while Budd Inlet and Case Inlet had a single peak during the summer, and Elliott Bay had highest catches during the winter and fall. During the winter and spring sampling periods the catches in the two estuarine areas (Commencement Bay and Elliott Bay) were markedly higher than the other areas.

Target Species Catch per Unit Effort. Catch per unit effort for each of the target species is presented in Figures 50 to 54 and Appendix Table G-1. English sole (Figure 50) and rock sole (Figure 51) were the most widespread, while the other three species were rare or absent in some areas or seasons. Pacific tomcod (Figure 52) were the next most widespread and abundant target species, but were rarely captured in the winter and spring. Catch rates for Pacific staghorn sculpin (Figure 53) were generally low, and like Pacific tomcod, they were seldom caught in the winter and spring. Staghorn sculpin were not often captured in the urban estuaries during any season. Quillback rockfish (Figure 54) were the least widespread and abundant target species, as they were absent in catches from Case and Budd Inlets and only found in the fall in Sinclair Inlet.

Seasonal Movements and Recruitment. Only English sole and rock sole were widespread and abundant enough for observations of seasonal migration and recruitment. Figures 55 and 56 show the proportion of juveniles (<150 mm) per area and season for English sole and rock sole, respectively. For English sole in Elliott Bay, Commencement Bay, and Port Madison subareas the highest proportion of juveniles was observed in the winter. This proportion was lower during the spring and summer, and became higher again in the fall. In the other areas, juveniles were absent in winter and increased in abundance during the remainder of the year. For rock sole a pattern similar to English sole was evident with the exception that catches in the fall were smaller.

### 3.4.2 Community Characteristics

Species Composition. English sole (Parophrys vetulus) and rock sole (Lepidopsetta bilineata) were the species most frequent among the ten most abundant species throughout the sampled regions of Puget Sound during most of the year (Appendix Table G-2). Sand sole (Psettichthys melanostictus) were present throughout the year, primarily in the inlets and deeper waters of the bays, although some were present in the estuaries. Shiner perch (Cymatogaster aggregata), flathead sole (Hippoglossoides elassodon), Dover sole (Microstomus pacificus), Pacific herring (Clupea harengus pallasii), and rex sole (Glyptocephalus zachirus) appeared to be present all year in the estuaries. Species consistently present in the inlets included starry flounder (Platichthys stellatus), plainfin midshipman (Porichthys notatus), Pacific staghorn sculpin (Leptocottus armatus), and speckled sanddab (Citharichthys stigmaeus). Roughback sculpin (Chitonotus pugetensis) were also present during most of the year in many areas.

Species Richness. The highest number of species caught in any area during the year was 44; the least number in any area was 8.

Elliott Bay and Commencement Bay had the greatest richness of all the areas and had similar species numbers and patterns during the year. The highest number of species observed during the winter was 44 species in Elliott Bay and 39 in Commencement Bay; throughout the rest of the year the number of species was 36 to 38 (Appendix Table G-3). Species richness was greatest in deeper water (>15 m) except during the summer. Budd and Sinclair Inlets had the least number of species in the winter (9-10 species), and then the number increased through the year to a high in the fall of 19-22 species. Species richness in Case Inlet was highest in the summer (19 species) after increasing from lesser values in winter and spring (8-11 species). Port Madison had a maximum richness in the fall (24 species) and a minimum in the spring (11 species).

Species Diversity. Commencement and Elliott Bays generally had the highest species diversity values, with maximum Shannon-Weaver diversity indices of 2.7 and 2.8 in summer and fall (Appendix Table G-3). The diversity values for these two estuarine bays were similar throughout the year.

Port Madison had relatively high values of species diversity considering the low sampling effort and low species richness. Although only 17 species were captured here in the winter, the diversity index of 2.3 was comparable to that of the estuarine bays. This high value was probably due to the fact that the Shannon-Weaver diversity index is a function of not only the number of species involved, but the evenness with which the species are distributed. The diversity indices for Sinclair and Budd Inlets were similar to each other in value and in trend, increasing throughout the year from a winter minimum. Low diversity values were found in Case Inlet throughout the year.

### 3.5 Invertebrate Ecology

The benthic communities in Central Puget Sound form an important food source for fish and crustacean species. The extent to which these benthic communities are affected by urban-associated pollution was investigated. Portions of the benthic communities examined during this survey have been previously investigated by Lie (1968), Thom et al. (1979), and Harman and Serwold (1974). In addition to comparing the results of the present study to this previous work, the usefulness of several community indices as indications of concentrations of toxic pollutants in the marine benthic environment will also be evaluated.

#### 3.5.1 Water Quality

Values for water temperature, salinity, and dissolved oxygen are presented in Appendix Tables H-1 to H-3. The range of values encountered during a single sampling quarter was small. However, average water temperature rose from 6.6°C to 12.6°C during the period from winter through fall.

### 3.5.2 Sediment Analysis

Sediment grain size, sand-to-mud ratio and the percent organic matter in the sediment are given in Appendix Table D-7. Eight of the 34 infaunal sampling stations (24%) had a sand-to-mud ratio greater than 1.0 and hence should be considered sandy stations. Other sediment characteristics, such as the presence of an oily film on the surface of wash water during sieving, are noted in Appendix Table H-4.

### 3.5.3 Abundance and Species Composition

The average abundance of fauna per 1,000 cm<sup>3</sup> sediment sample for the 792 samples taken during this study was 40 organisms. The mean and standard deviation of the abundance of organisms per 1,000 cm<sup>3</sup> for each station are given in Appendix Table H-5. The average abundance of organisms per sample was 29.9, 35.3, 45.8, and 46.3 for all sites for winter, spring, summer, and fall sampling periods, respectively. Six samples were taken in all cases except stations 09036 and 12133 during the fall sampling period where four samples were taken.

Species or taxa which were found to be most widely distributed during the duration of this study were the Spionidae, Axinopsida serricata, Cirratulidae, Macoma sp., and Capitellidae. These organisms were present in at least 30 out of 33 stations during the single sampling season. Axinopsida serricata was consistently the most abundant organism sampled in this study. Other abundant organisms were ostracods, Macoma sp., Cirratulidae, Capitellidae, and Terebellidae.

### 3.5.4 Infaunal Trophic Index Values

Infaunal Trophic Index (ITI) values obtained in this study ranged from a low of 13, indicating a community dominated by subsurface deposit feeding organisms, to a high of 95, indicating a community dominated by suspension feeding organisms (Table 30). Thom et al. (1979) reported that the ITI values obtained from reference stations in Puget Sound ranged from 59 to 82. This range represents the usual range found in this area. Values below this range identify infaunal communities in which subsurface deposit feeders are unusually abundant. ITI values calculated in this study which were outside of the control range at some point of the year were encountered in 15 out of 34 stations.

Little variation was seen among the average ITI values calculated for all sites for each sampling season (Table 30). Average values were 66.0, 67.6, 67.8, and 66.3 for winter, spring, summer and fall quarters, respectively. Average ITI values of 71, 72, and 73 were obtained from the deepest sampling sites (135 ft to 155 ft) at West Point, Magnolia Bluff and Alki Point, respectively, during winter quarter 1979. These values compare closely to values of 68, 68, and 75 reported by Thom et al. (1979) for the same sites (at a depth of 150 ft) which they sampled during winter 1979.

### 3.5.5. Species Richness

Taxon richness values calculated from the taxonomic groups used in the infaunal index ranged from a low of zero to a high of thirty (Appendix Table H-6). The average richness values for each station during each sampling season are given in Figures 57 through 61. The average number of ITI taxa present at each station increased from 10.7 in winter to 15.8, 16.1 and 15.2 for spring, summer and fall quarters, respectively.

### 3.5.6 The Abundance and Distribution of Crustacea

Three species of shrimp (Pandalus and Crangon) and three of crab (Cancer), a total of 3,955 animals, were captured (Table 31). The most abundant species (2,909) was Pandalus jordani (Figure 62), however, this species was captured only in 3 areas and 14 stations. The three most widely distributed species were P. danae (6 areas, 26 stations) (Figure 63), Crangon alaskensis (6 areas, 22 stations) (Figure 64), and Cancer gracilis (5 areas, 17 stations) (Figure 65). The two species with the most restricted distribution were Cancer magister (4 areas, 8 stations) (Figure 66) and Cancer productus (2 areas, 7 stations) (Figure 67).

## 4. DISCUSSION

In addition to addressing the results from the individual phases of this study, parts of the Discussion will deal with comparisons of the prevalence of histopathological lesions in fish and crustacea and the taxon richness values of benthic infauna from stations grouped according to levels and types of chemicals (Appendix E has a description of the results of grouping the sediment chemistry stations using principal components and cluster analyses).

### 4.1 Analytical Chemistry

The chemical analyses provide data for the first time on the presence of a broad spectrum of organic chemicals and metals in sediments and organisms from various geographic regions of Puget Sound. The concentrations of organic compounds in sediment samples were generally highest in the Commencement Waterways, Duwamish Waterway, Seattle Waterfront and West Point subareas and near Point Herron (Sinclair Inlet) and Old Tacoma (Southwest Commencement Bay). The concentrations of pollutants found in the tissue samples from the various subareas generally reflected concentrations in the sediments.

This study shows that sediments from the reference sites (Case Inlet and Port Madison) are generally less contaminated with organic chemicals and certain metals (i.e., lead, arsenic, silver, copper, mercury) than sediments from the urban areas of Commencement and Elliott Bays. However, the concentrations of certain toxic metals, such as cadmium, nickel, and

chromium, did not greatly differ in sediments from these two types of marine environments and may represent naturally occurring levels.

The PCB's, HCB, and chlorinated pesticides were generally found in higher concentrations in tissue samples than in sediments. This finding can be explained by the fact that these compounds are readily accumulated by organisms and are not rapidly metabolized and excreted (Kalmaz and Kalmaz 1979). In contrast to these chlorinated organic compounds, PAH's were generally found in tissues at concentrations lower than those in the corresponding sediments. In this regard, it is noteworthy that PAH's are extensively converted to other products in many marine organisms (Varanasi and Malins 1977). However, these conversion products are presently not routinely detected by even the most sophisticated analytical techniques, such as those used in this study. Accordingly, it must be assumed that substantial concentrations of conversion products of PAH were also present in the tissues, together with the parent hydrocarbons.

Some PAH's, such as the carcinogen, benzo[a]pyrene, are converted in fish to compounds that readily react with DNA (Varanasi and Gmur 1980). This reaction with genetic material is believed to lead to tumor formation, based on a variety of studies with mammals (Ambient Water Quality Criteria 1979). Bearing this in mind, the presence of benzo[a]pyrene, benz[a]anthracene and even the weaker carcinogen, phenanthrene, in sediments and tissues deserves special attention.

Although higher levels of contaminants were found in the more urbanized and industrialized areas in this study, areas of Puget Sound far removed from industrial influences, or known point sources of pollution, do not appear to be free from the impact of xenobiotics. The findings also cast doubt upon the view that potentially toxic chemicals in Puget Sound are largely restricted to industrialized areas and other point sources of entry of man-related chemicals. For example, shrimp samples from Case Inlet and Port Madison were found to contain dry weight levels of 1.4 ppm and 0.1 ppm of 3- to 5-ring aromatic hydrocarbons, respectively, and a clam sample from Port Madison contained 0.20 ppm of these aromatic hydrocarbons. In particular, the shrimp sample from Case Inlet contained 160 ppb (0.16 ppm), 90 ppb (0.090 ppm), and 170 ppb (0.17 ppm) benz[a]anthracene, benzo[a]pyrene and phenanthrene, respectively (Tables 13-15). Much of the data on organism accumulation of toxicants suffers from a lack of sufficient samples and thus must be evaluated in this context. It should also be recognized that the chemicals analyzed in the present work represent only a small fraction of the total number of xenobiotics present in the samples studied.

The relatively wide distribution of the xenobiotics throughout the areas studied may be attributed to a number of factors, including aerial dispersion, the influence of currents, transport by suspended particles, other oceanographic events and the migration of organisms from highly polluted areas into less polluted areas.

The detection limits for organic compounds in sediment are lower than for tissue samples because about 10 to 100 times more sediment was used for analysis (in many cases only 1 gram of tissue was available for analysis).

Thirty-six tissue samples (including fish liver, crab hepatopancreas, shrimp, clam, and worm) contained enough sample for metals analysis in addition to analysis for organics. Tissue samples were not analyzed for mercury due to limited amount of sample. The data for chemicals was not corrected for losses on sample handling.

#### 4.1.1 Possible Sources of Contaminants

Aside from the levels occurring naturally, metals may enter the marine environment from a number of sources which include municipal and industrial effluents, anti-fouling paint, leaded gasoline, land runoff, ocean dumping, and atmospheric fallout. The disposal of small amounts of metallic wastes in the ocean probably would result in little change in background concentrations. However, a large influx of toxic metals in a relatively confined area, such as Puget Sound, could have a pronounced effect on the aquatic environment. Elemental metals usually present the least hazard to aquatic biota, while the ionic forms of metals and organo-metallic compounds are generally the more toxic forms (Waldichuk 1974). A considerable amount of data is available on the effects of specific metals on individual species (Waldichuk 1974, Clark 1976). Less is known about the effects of metals on marine ecosystems.

Polynuclear aromatic hydrocarbons (PAH's) are a diverse class of compounds consisting of substituted and unsubstituted polycyclic and heterocyclic aromatic rings. These compounds are present in fossil fuels and are products of incomplete combustion of hydrocarbons. They enter the marine environment by runoff, atmospheric fallout, spillage, and industrial or municipal discharge. Combustion processes associated with industry, automobiles, home heating, etc. are concentrated in urban and industrial areas and thus PAH's, as a class or as specific members of a class, reflect the extent to which combustion pollutants have accumulated in an area (Ambient Water Quality Criteria 1979). Among these PAH's are compounds such as BaP and BaA which are known for their carcinogenic effects on experimental animals (Ambient Water Quality Criteria 1979).

Polychlorinated biphenyls (PCB's) have been widely used in industry as heat exchanger and dielectric fluids, hydraulic and lubricating fluids, plasticizers for plastics and coatings, ingredients of caulking compounds, printing inks, paints, adhesives, and carbonless duplicating paper, flame retardants, and extender for pesticides. For many years these materials were released rather indiscriminately into the environment and have become ubiquitous (Ambient Water Quality Criteria 1979, Wasserman et al. 1979). PCB's are known to be toxic, and substantially bioconcentrate in food chains (Ambient Water Quality Criteria 1979, Wasserman et al. 1979, and Fishbein 1974).

Chlorinated pesticides, such as DDT, were used extensively in the United States prior to 1972. Although their use is now restricted in this country, a substantial dispersion of pesticides throughout the world has occurred. Many chlorinated pesticides and their metabolites show long term persistence in soil and water. They are only slightly soluble in water and tend to be concentrated in sediments. These pesticides are

readily accumulated in the fatty tissues of marine biota where they can remain for long periods (Ambient Water Quality Criteria 1979).

Hexachlorobenzene (HCB) has had widespread use as an agricultural fungicide, as the starting material for the production of pentachlorophenol, for the synthesis of chlorinated hydrocarbons, as a plasticizer, and as a flame retardant. Commercial production of HCB in the United States was discontinued in 1976, but it is still a major byproduct in the industrial preparation of chlorinated hydrocarbons. It is also used in the production of chlorine gas from sodium chloride. Hexachlorobenzene is very stable in the environment, is known to bioaccumulate, and its toxic effects have been well established (Ambient Water Quality Criteria 1979).

Another group of pollutants measured in this study are the chlorinated butadienes (CBD's). One of the isomers of the CBD's, [e.g., hexachlorobutadiene (HCBd)] is toxic to aquatic organisms at sub part per million levels in water. Hexachlorobutadiene is fetotoxic, neurotoxic, nephrotoxic, and carcinogenic. It appears to be rapidly adsorbed into soil and sediment from contaminated water (Ambient Water Quality Criteria 1979).

#### 4.1.2 Comparisons with Other Studies

Previous studies conducted in Puget Sound involved analyses of samples for PCB's (Mowrer et al. 1977, Pavlou et al. 1978, Stout and Lewis 1977, Pavlou and Hom 1979, Blazevich et al. 1977, Pavlou and Dexter 1979); PCB's and DDE (Sherwood and McCain 1976); hydrocarbons and sulfur- and nitrogen-containing hydrocarbons (Carpenter and Fairhall 1978); and arsenic, antimony, and mercury (Creclius et al. 1975).

Average concentrations of specific metals found in sediments in this study were compared with those from previous studies (Table 32). Chester and Aston (1976) reviewed levels of metals in nearshore sediments from marine areas throughout the world. Metal analyses of sediment from Puget Sound were reported by Creclius (1975) and Schell and Nevissi (1977). Comparing the results of this study to average levels of metals in sediments from deep cores (Schell and Nevissi 1977), and central basin areas (Creclius 1975) reported in the above studies (referred to hereafter as "reference levels"), substantially higher levels of lead in sediments from Elliott Bay, Commencement Bay, and Sinclair Inlet were found. The highest levels were in the Commencement Bay Waterways and Duwamish River subareas (12 and 10 times reference levels, respectively). Arsenic levels were also several times reference values in the Commencement Waterways, the Duwamish Waterway, and Budd Inlet (6, 5, and 4 times reference levels, respectively). Mercury levels were high in Sinclair Inlet, the Seattle Waterfront, and Duwamish Waterway subareas (9, 7, and 6 times reference levels, respectively). Mercury levels were about 3 times higher in Commencement Bay than the reference levels. Copper levels in Sinclair Inlet, Seattle Waterfront, and Commencement Bay outside of the Sitcum Waterway were about twice the reference levels. Sitcum Waterway contained copper levels 32 times the reference levels for Puget Sound sediments. Even taking into account the low efficiency for the recovery of chromium and manganese inherent in the acid extraction used in this study, the levels of chromium, manganese, and nickel were not appreciably above the reference levels.

A review and summary of the existing literature on the aquatic fate of compounds listed by the EPA as environmental pollutants, and the toxic effects of these compounds on freshwater and marine organisms, has been prepared (Chapman et al. 1979).

A study was undertaken in 1978 by the National Analytical Facility to identify pollutants in urban areas of Central Puget Sound (Appendix A). Sub-tidal sediment samples were collected from sites in Elliott Bay, Commencement Bay, Budd Inlet, and Sinclair Inlet. These samples were analyzed for selected metals and organic compounds. The concentrations of the metals varied considerably between sites and PAH's and PCB's were found in most of the samples. Moreover, hexachlorobenzene (HCB) and chlorinated butadienes (CBD's), along with more than one hundred additional halogenated compounds (most not yet identified), were found in sediment samples from Commencement Bay. The data from this preliminary study are presented in Appendix A.

Riley et al. (1980) recently analyzed water and suspended solids from nine Puget Sound stations that corresponded to those used in the present study. These workers analyzed hydrocarbons, halogenated hydrocarbons (including PCB's), and purgeable organic compounds. Suspended solids from all nine stations contained aromatic hydrocarbons; those from Hylebos and Blair Waterways contained HCB in concentrations as high as 148 ppb (ng/g). Water samples from these waterways also contained HCB in concentrations as high as 2.4 parts per trillion (ppt; picograms/gram, pg/g).

A comparison of the Puget Sound data with the data from the New York Bight is appropriate because the chemical analyses for both projects were performed by the National Analytical Facility. Significantly, in many instances the concentrations of the organic chemicals in sediments and biota from Puget Sound bore interesting similarities to concentrations of the xenobiotics in samples from the New York Bight (MacLeod et al. 1979). That is, sediments from Puget Sound's Elliott and Commencement Bays had concentrations of PAH's and PCB's that were comparable to the most contaminated sediments from New York Bight. Similarly, some livers of English sole from these Puget Sound bays had concentrations of PCB's and pesticides (e.g., DDE, chlordane, and nonachlor) that were roughly comparable to those of the most contaminated winter flounder collected at Raritan Bay in the New York Bight. Moreover, English sole muscle from Puget Sound's Commencement Bay contained considerably higher concentrations of PCB's than did muscle from either winter flounder or windowpane flounder from New York Bight. Hexachlorobenzene and CBD's found in Puget Sound were not detected in New York Bight samples.

#### 4.2 Fish Pathology

Although lesions in fish specimens were found in several organ systems during this study, idiopathic lesions were most significant and frequent in hepatic tissues. Several of the hepatic lesions, such as adenomatous foci (AF), megalocytic hepatosis (MH) and cholangioproliferative foci (CF), were found almost exclusively in fish from the most contaminated areas of the embayments in central and southern Puget Sound. The other hepatic lesions,

which were found in heavily contaminated as well as moderately or minimally polluted areas, included hepatocellular necrosis (HN), focal hyperplasia (FH), nuclear pleomorphism (NP), and parenchymal/biliary sclerotic foci (HSF). A small number of kidney and gill lesions were classified into this latter category of widely distributed lesions. The following discussion will consist of comparisons of these lesions with similar lesions described for mammals and other teleosts, and a brief overview of their prevalence, geographical distribution, and possible relationships to pollution.

#### 4.2.1 Comparative Pathology

Histopathological conditions similar to the lesions observed in this study have been reported in other animal species exposed to toxic chemicals under laboratory conditions. These observations are summarized in Table 33. AF, a condition unique to English sole, was found only in the Duwamish, Hylebos, and Commencement Waterway subareas. In another study, Smith et al. (1979) reported hepatocellular carcinomas, neoplasms resembling some forms of AF, in Atlantic tomcod (*Microgadus tomcod*) in the Hudson River estuary in New York. Spontaneous nodules and nodules induced by DDT, dieldrin, acetylaminofluorene, nitrosamine, and phenobarbitone in mice resemble these foci histologically (Jones and Butler 1975). Likewise, trabecular carcinomas induced by aflatoxin B<sub>1</sub> in rainbow trout displayed a similar cytologic morphology (Ashley 1967, Sinnhuber 1977).

Mammals, such as rats, mice, rabbits, and monkeys, exposed to acute and chronic levels of commercial mixtures of PCB's have developed lesions with characteristics similar to MH (Koller and Zinkl 1973, Nishizumi 1970). Hepatocytomegaly was also found in channel catfish acutely and subacutely exposed to Aroclor mixtures (Hinton et al. 1978), and in rainbow trout exposed to dietary cyclopropenoids (J. Hendricks, Oregon State Univ., Per. Comm.). In all these cases, cellular enlargement was a result of accumulation of intracellular products, such as glycogen or lipid, proliferation of endoplasmic reticulum and nuclear enlargement. Mice treated with phenobarbitone and other microsomal enzyme-inducing drugs exhibited marked cytomegaly and cellular hypertrophy, originating in the centrilobular regions (Jones and Butler 1975). In our study eosinophilic focal hypertrophy (without nuclear enlargement) was frequently found in association with MH. These foci most probably represent areas of hepatocellular degeneration. It is of interest that unlike the observed anomalies induced by toxic chemicals in mice, MH in sole was infrequently associated with hepatocellular necrosis.

Organized CF have been previously described as cholangiomas, bile duct hyperplasia, cholangiofibrosis, and adenofibrosis (Dawe et al. 1976, Falkmer et al. 1976 and 1977, Kimbrough et al. 1972). Disorganized CF have also been referred to as cholangiocellular carcinoma (Falkmer et al. 1977). Falkmer et al. (1977) found lesions similar to both organized and disorganized bile duct proliferation in hagfish, together with high PCB levels in their livers. Proliferation of bile duct epithelial cells has been described commonly in a variety of lesions induced by toxic chemicals. Kasza et al. (1976) reported bile duct hyperplasia in rats treated with dietary PCB's. Kimbrough et al. (1972) described adenofibrosis, the most prominent hepatic lesion in rats exposed to PCB's, as possibly cholangioproliferative.

Rainbow trout, mammals, and birds exposed to dietary aflatoxin all developed bile duct hyperplasia and proliferation, with and without fibrosis (Ashley 1967, Simon et al. 1967, Newberne 1967). Arsenic, which accumulates in the liver and kidney of mammals and is excreted in the bile, has been linked with various bile duct changes (Beliles 1975). The significance of whether a cholangioproliferative lesion was organized (duct-forming) or disorganized is not clear.

Other hepatic lesions widely distributed in Puget Sound have also been described in other species exposed to toxic chemicals. Nonspecific hepatocellular necrosis is a common response to poisoning in many vertebrates (Plaa 1975) including teleosts. Couch (1975), and Walsh and Ribelin (1975) found coagulation necrosis to be a general reaction in fish exposed to a spectrum of compounds, including organophosphate, organochlorine and chlorinated cyclodiene pesticides and PCB's.

Focal hepatic hypertrophy, focal hyperplasia, and nuclear pleomorphism have been demonstrated in dogs and rats administered dietary Aroclor (Fishbein 1974, Kimbrough et al. 1972, Kasza et al. 1976). Newberne (1967) reported that aflatoxin-exposed mammals and birds developed bizarre pleomorphic nuclei. Cutthroat trout exposed to organochlorine pesticide in both the water and diet demonstrated several toxic liver changes including cellular and nuclear pleomorphism (Eller 1971).

Focal hyperplasia has been implicated as a potential preneoplastic condition (Falkmer 1976, Jones and Butler 1975, Sinnhuber et al. 1977). However, the potential for neoplastic transformation of this lesion in English and rock sole has not been established.

A variety of metals including arsenic, chromium, silver, indium, iron, molybdenum, selenium, tellurium, and thallium possess hepatotoxic properties in humans and mammals (Beliles 1975). Chromium, in the form of chromite particulates, may accumulate in the reticuloendothelial cells lining liver sinusoids. Excessive iron uptake is hepatotoxic, producing hemosiderosis, hemochromatosis, and fibrotic changes with accompanying increase in serum glutamine oxaloacetic transaminase (SGOT) and serum glutamic-pyruvic transaminase (SGPT). Ultrastructurally, damage and degeneration of the hepatocellular mitochondria has been seen with iron toxicity. Molybdenum and selenium accumulate in the kidneys and liver, producing fatty degeneration and necrosis, and often resulting in cirrhosis in chronic exposures. Selenium has also been implicated as a hepatocarcinogen in rodents. Tellurium, which is often associated with selenium as a contaminant, can produce hepatic and renal necrosis in chronic exposures. Thallium, often present in rodenticides and insecticides as thallium sulfate, produces mitochondrial damage in the livers of exposed rats. In humans, thallium produces a fatty infiltration and necrosis of the liver (Beliles 1975).

The disrupted glomeruli observed sporadically in the kidneys of all target species apparently have not been described previously in lower animals or man.

Hyperplasia of gill respiratory epithelium (REH) is a common, nonspecific response to many irritants. Chronic exposure to ammonia, a pollutant frequently discharged into river systems via domestic waste waters and agricultural and urban drainage water, has been shown to cause epithelial proliferation and aneurysms in the gills of salmonid fishes (Burrows 1964, Smith and Piper 1975). Gill epithelial proliferation has also been reported in fish exposed to pesticides such as mirex (Van Valin et al. 1968), parathion (Wood, cited by Walsh and Ribelin 1975) and toxaphene (Lowe 1964); herbicides including dichlobenil (Cope et al. 1969), diuron (McCraren et al. 1969) and endothal (Eller 1969); and heavy metals such as iron salts (Ashley 1970). Additionally, REH has been associated with infectious agents such as bacteria, parasites and fungi (Eller 1975).

#### 4.2.2 Prevalence and Distribution of Diseased Animals

MH was more common in English sole than in any other target species. The condition was most prevalent in the Duwamish Waterway (12%) and Seattle Waterfront (9%) subareas of Elliott Bay and in the waterways of Commencement Bay (9%). English sole with MH from Elliott Bay were most prevalent in the summer and fall quarters, while the reverse was true of rock sole with MH. The prevalence of fish with MH in the Commencement Bay stations declined gradually from winter to summer quarters, then increased in the fall quarter. Only Sitcum Waterway consistently produced diseased fish each quarter. During the winter quarter, the single case of MH in English sole outside of Elliott and Commencement Bays was found in Port Madison.

The geographic distribution of MH among Rock sole in Elliott and Commencement Bays closely paralleled that of English sole with a few exceptions. Like English sole, rock sole in the Duwamish Waterway (8%), Seattle Waterfront (10%), and Commencement Bay Waterways (9%) subareas were most heavily affected. However, rock sole with MH were not found in the Hylebos Waterway subarea.

Although Pacific staghorn sculpin were not collected in abundance in any of the embayments, MH was detected in this species. With the exception of one case in Budd Inlet, all other occurrences of the disease were in the Duwamish, Hylebos, and Commencement Bay Waterways subareas. The normal histology of Pacific staghorn sculpin livers differed markedly from that of flatfish, having wide variations in cell and nuclear size, and in staining characteristics. Only unequivocal cases of MH were reported in this study. It may be that less severe MH is difficult to detect in Pacific staghorn sculpin without laborious morphometric calculations. Consequently, it is conceivable that MH occurs in frequencies greater than those we have reported. No instances of MH were detected among Pacific tomcod and quillback rockfish sampled.

A close association between MH and eosinophilic hepatocellular focal hypertrophy was observed in the livers of English and rock sole. The prevalence of English sole with either focal hypertrophy or MH was approximately the same in the Duwamish, Hylebos and Commencement Bay Waterways. In Commencement Bay, the livers of English sole with MH often had focal hypertrophy. These observations support the possibility that focal hypertrophy may be etiologically associated with MH.

A few cases of hepatic eosinophilic focal hypertrophy in Pacific tomcod were found in the Hylebos Waterway and Brown's Point subareas, but not at any other location. No cases of this anomaly were detected in Pacific staghorn sculpin and quillback rockfish.

Basophilic focal hypertrophy occurred rarely and only in English sole from the Duwamish and Hylebos Waterways subareas. Regions of hepatic tissue with this morphology were often seen adjacent to areas of MH, but the association with MH or any hepatic lesion remains unclear.

The frequencies of CF in sole in Elliott and Commencement Bays, the only embayments in which this condition was found, were inversely related. Average annual frequencies among English sole were higher in Commencement (1.6%) than in Elliott (0.3%) Bays, whereas frequencies among rock sole were higher in Elliott (1.6%) than in Commencement Bay (0.4%). The Duwamish Waterway, Seattle Waterfront, Hylebos Waterway, and Commencement Bay Waterways subareas had the highest prevalence of affected English sole and rock sole. The solitary case of bile duct proliferation in Commencement rock sole was located in the S.W. Commencement subarea (Station 09036). Bile duct proliferation and hyperplasia were also found in Pacific tomcod exclusively in the Duwamish and Hylebos subareas, and in Pacific staghorn sculpin solely in the Hylebos subarea. Quillback rockfish were not found to exhibit this lesion. Although both types of cholangioproliferative foci occurred in rock and English sole and Pacific tomcod, the flatfish species most often had the duct-forming (organized) type, whereas Pacific tomcod tended to have the disorganized form. Only the disorganized type was found in Pacific staghorn sculpin.

In previous studies conducted in the Duwamish Waterway, at West Point, and at Alki Point, 32% of the adult English sole in the Duwamish Waterway were found to have liver tumors (Pierce et al. 1978). Although these tumors were not classified by the same criteria used in the present study, they corresponded to AF, CF, FHH, and possibly MH. By combining the number of English sole from the Duwamish Waterway subarea having these four conditions, an average prevalence of 15% (26 of 178) is obtained. Almost all of the fish examined by Pierce et al. (1978) were adults (average length 261 mm), while in the present study, individuals from all age groups were examined. Since we have shown in this study that tumor-bearing English sole are usually older than 4 years, the value of 32% was an overestimate for all age groups. Most of the tumor-bearing fish examined by Pierce et al. were captured in the upper reaches of the Waterway at least one mile above the sampling stations in the present study. Therefore, two important factors can influence the prevalence of English sole with liver neoplasms: the age of the fish and the geographical location in the waterway from which they were captured. The latter factor cannot be solely due to differences in age composition of fish in different parts of the waterway.

The widespread geographical distribution of hepatocellular necrosis and focal hepatocellular hyperplasia among the target species may be indicative of multiple causative factors or of an agent or agents that are extensive in Puget Sound. The implications of the distribution of these conditions with respect to pollution in Puget Sound are not yet understood because the

presence or absence of these lesions in the same species in nonpolluted areas outside of Puget Sound is not known. Nonetheless, these conditions should not be considered normal. In fact, focal hyperplasia may be a pre-neoplastic condition.

### 4.3 Invertebrate Pathology

Among the invertebrates, the bulk of knowledge on the effect of toxins has been developed for the insects (Sparks 1972), with research on the toxic properties of the numerous deleterious agents and the tissue vulnerability of other invertebrates being of recent origin. The effect of a toxic chemical on the body of any animal, invertebrate, as well as vertebrate, depends on three variables: (1) the vulnerability of individual tissues, (2) the mode of action of the agent, and (3) the concentration of the agent. Tissues and cells within an individual vary greatly in their vulnerability and there is far greater variation among the divergent invertebrate groups (Sparks 1972). The mode of action largely determines the site of major damage, the portal of entry, site of storage, portal of excretion, or a combination of site of storage and portal of excretion. Because highly lethal agents kill the affected animal before cellular defense mechanisms can be activated, chronic injury is more likely to be detected histologically.

Most of the abnormalities encountered to date in this investigation occurred in the crustacean target species. Although crustaceans, penaeid shrimp for example, are highly susceptible to a wide variety of xenobiotics (Couch 1979), and have been reported to be 800 to 1,000 times as susceptible to organophosphorus compounds as oysters (Butler 1966), the small number of bivalves examined precludes the assumption that the molluscs are more resistant to pollution-related effects. Indeed, the paucity of molluscan target species may have been due to high mortalities prior to sampling. Also Cardwell et al. (1979) have shown that dinoflagellates in the water in many of the bays in Southern Puget Sound cause mortalities in bivalve larvae during the summer. The polychaetes were often severely traumatized during collecting, making detection of epidermal lesions difficult.

Crustaceans are known to be highly sensitive to the lethal and histopathological effects of chlorinated hydrocarbons (e.g., pesticides and PCB's), an unsurprising fact since most pesticides were developed to control the phylogenetically related insects. Nimmo et al. (1975) reported lethal effects in penaeid shrimp (Penaeus duorarum and P. aztecus) exposed to 1 ppb PCB (Aroclor 1254) for two weeks in flow-through bioassays. At the light microscopy level, no lesions were consistently found that were indicative of PCB exposure, but electron microscopy revealed cytopathic changes in the hepatopancreas (Couch and Nimmo 1974). High levels of mortality occurred in blue crabs (Callinectes sapidus) exposed to 5 ppb Aroclor 1254 for 24 days (Nimmo et al. 1971).

A number of heavy metals have been shown to be toxic to invertebrates, especially crustaceans (Couch 1979). Cadmium (760 ug/liter as CdCl<sub>2</sub>) exposure for nine days or longer causes grossly observable blackening of the gills of pink shrimp (Nimmo et al. 1977) and death after exposure for 30 days. Histopathological studies (Couch 1979) revealed that the blackening

was caused by necrosis of the subcuticular tissues (gill epithelium) in the distal gill filaments, subsequently involving the entire filament. Mandelli (1971) found that 0.05 mg/l of copper was lethal to nauplii, protozoa and mysis stages of penaeid shrimp. Lead is known to cause lesions in the hemopoietic tissues, gastrointestinal tract and nervous systems of a number of invertebrates and arsenic is a strong protoplasmic poison that causes necrosis and subsequent desquamation of the gastrointestinal epithelium of insects (Sparks 1972).

Theoretically, the three organ systems in crustaceans most vulnerable to the effect of toxic chemicals are the gills, hepatopancreas and antennal gland. The gills, though covered by a thin chitinous cuticle, are an absorptive organ for oxygen and presumably other substances and, therefore, serve as a portal of entry for toxins. They also function as an excretory organ because of the podocytes in the gill stem and lamellae. Thus damage to the gills by toxic chemicals could occur as the agent is absorbed or by destruction of podocytes during excretion of a metabolized toxin. The antennal gland, however, is the major excretory organ and should be an organ of potential vulnerability.

Most of the gastrointestinal tract is covered by a protective chitinous lining, with only the midgut and its appendages (the anterior and posterior caeca and the hepatopancreas) exposed to potential toxins. The hepatopancreas is particularly vulnerable because it serves as the principal organ of absorption, storage and secretion. Thus, it could be damaged as a portal of entry or as a storage site for toxic chemicals.

Metaplasia, the modification of one cell type to another less vulnerable, is common under conditions of chronic irritation. There are, to our knowledge, no previous reports linking metaplastic changes in the hepatopancreatic epithelium to toxic chemicals.

Hepatopancreatic necrosis has been shown to result from chemical injury in both oysters (Pauley and Sparks 1965) and shrimp (Fontaine et al. 1975). Both the above studies involved transport of turpentine injected into muscle to the hepatopancreas, but it is believed that hepatopancreatic necrosis is a generalized result of chemical injury rather than a specific effect of turpentine. As mentioned previously, the role of the hepatopancreas in the storage and metabolism of xenobiotics should predispose it to chemical injury.

Although other invertebrates, such as oysters, encapsulate foreign or necrotic material with layers of flattened hemocytes (Sparks 1972), the formation of melanized nodules is characteristic of the arthropods. Melanized nodule formation has been observed in insects as a response to a variety of agents including various sorts of particles injected into the haemocoel (Salt 1970). Melanized nodules have been observed in tegmental glands and spongy connective tissue of experimentally wounded penaeid shrimp (Fontaine and Lightner 1973), in spongy connective tissue of penaeid shrimp injected with talc (Fontaine and Lightner 1974), within gill lamellae, heart, and hepatopancreas of penaeid shrimp injected with turpentine, and in gill lamellae of penaeid shrimp experimentally infected with the pathogenic fungus Fusarium sp. (Solangi and Lightner 1976). Melanized nodules and large granulomas

with melanized centers of unknown etiology are relatively common in the midgut of the Dungeness crab (Sparks 1980).

In the present study, melanized nodules were found in all the above mentioned organs in C. gracilis and C. magister, and in the gills of P. danae. It has not been determined whether these nodules resulted from a generalized response of host tissue to injury, particulate matter, or to specific chemicals.

The most frequently encountered abnormality of this survey was vesiculation of hepatopancreatic cells. It was encountered in all crustacean species at most major geographic areas with somewhat higher frequencies in Budd Inlet, Elliott Bay and Commencement Bay. The hepatopancreas may be affected by a variety of physiologic factors unrelated to pollution which could cause vacuolation and lipid accumulation. Intermolt crabs have higher levels of lipid and more numerous vacuoles (Johnson 1980) than do molting crabs. Smith and Taylor (1968) reported that prolonged deprivation of food resulted in marked vacuolation and necrosis of hepatopancreas in ghost shrimp, Callinassa affinis, due to an absence of fat mobilizing substances in the diet and subsequent accumulation of fat. While none of the animals examined in the present study appeared to be starving, normal cyclic changes in vesiculation of storage cells (termed R-cells) and number of secretory cells with large vacuoles (termed B-Cells) cannot be dismissed as a contributory factor in the occurrence of this lesion.

Mycotic infections were seen only in P. danae captured from Hylebos and Duwamish Waterways. The lesion appeared to involve the invasion of a fungus into an area of gill which had been previously injured. The geographical distribution of animals with this lesion was similar to that of P. danae, C. gracilis, and C. magister with melanized nodules in the gills. The fungal growth was accompanied by a strong hemocytic and melanization response. Such a response is typical to most fungi attempting to invade live tissue (Solangi and Lightner 1976, Unestam and Beskow 1976).

#### 4.4 Fish Ecology

The selected study areas of this project included two estuaries (Elliott and Commencement Bays), three inlets with little freshwater influx (Case, Budd, and Sinclair Inlets), and a deep, open bay also without a major river flowing directly into it (Port Madison). Since some fishes utilize estuaries as spawning and nursery grounds and many use shallow waters for part of their life cycles (Hart 1973, Miller et al. 1977), differences in species occurrence and abundance might be expected in the inlets, estuaries, and the open bays selected for study.

On the basis of catch rates, species composition, species richness, and species diversity the six different sampling areas can be grouped into inlets, estuarine bays and open bays. Total CPUE values were highest in estuarine bays, lowest in the inlets, and intermediate in Port Madison (Figure 49).

Greatest target species CPUE's usually were in the estuaries with the exception of Pacific staghorn sculpin which frequented Sinclair and Budd

Inlets the most. Additionally, the abundance of rock sole in Budd Inlet was comparable to that found in the estuarine bays. The abundance of English sole, Pacific tomcod, and quillback rockfish in the inlets and Port Madison was also much less than in the estuarine bays.

The number and diversity of fish species in the three groups of sampling areas were also quite different. Although the species richness and diversity values may partially have been a result of greater sampling intensity in some areas, usually the highest values occurred in the estuarine bays. Deep water stations in Elliott and Commencement Bay had greater species diversities and richness than those stations in the waterways of these bays, inlets or Port Madison.

Methods and sampling regimes often are accompanied by assumptions that may bias any inferences made from the data. The use of the otter trawl to collect benthic fishes has such biases which must be considered in relation to the data analyses. Not all fishes in the path of the otter trawl will be caught. Many fishes sense the net and will swim out of its path or even out of the net once in it. However, since the analyses do not estimate total biomass or numbers within a sampling area and as long as the vulnerability of the fishes between areas remains the same, then the catch in a standard tow may be used as a relative abundance indicator between stations, areas, and seasons. Other factors may influence inter-station fish vulnerability. Bottom type may afford the escape of some species to areas of physical relief not available to the otter trawl. This bias may be minimal as the survey boat's limitations confined the trawl path to only sandy or muddy bottoms. Differing visibility may have enabled fishes to avoid the net in clear, well lit water, possibly explaining the greater diversities and CPUE's in deeper water. While this may in part be true, shallow waters often are more turbid in wave churned areas, areas of plankton blooms, and particularly in the waterways near silt laden rivers. The validity of this visibility assumption can only be checked by photometric sampling.

Net selectivity may have biased the length frequency data. It is possible that more mobile (larger size classes) fishes could swim out of the net's path more readily than smaller fishes. Also, the post larval fishes may have escaped the fine mesh cod end by swimming through the coarser mesh net wings. While the largest and smallest size classes may be underrepresented, enough of these fishes were caught for the primary pathological project objectives and to ascertain the general recruitment and population structure patterns. The possibility that the net preferentially selected diseased fishes could also affect the disease frequency data. If the fishes with lesions were debilitated by being less mobile, then the frequencies may be artificially high.

For the ecological variables discussed, the sampling intensity at a station or even within an area may not have been sufficient to accurately assess the numbers and kinds of species. For the inlets which generally received low coverage, more species were expected to be present than were usually caught. But in cases where comparable numbers of hauls were made in estuarine and inlet shallow water stations, the inlets still had fewer species and lower species diversities. Low sampling effort may also have

inaccurately represented catch rates, but the three tows often taken at the stations had generally consistent fish abundances.

The pathological and ecological inter-area comparisons of fishes assume that these fishes inhabited their respective areas all year. The recruitment patterns of the flatfishes and tomcod certainly suggest mass movement to other, presumably deeper water, and does not preclude some inter-area dispersion. However, studies by Menasveta (1958) and by Day (1976) indicated that tagged adult English sole generally remained in the same local areas of capture. Further, English sole demonstrated some degree of homing ability by often being caught in the area of initial capture after being released in a different area (Day 1976). Inferences about flatfish dispersion and migration can be made by considering the liver lesions as natural tags. Assuming these fishes are as mobile as healthy fish, then given a sufficient sampling effort, one might expect to collect diseased fishes in adjacent reference areas as Port Madison for Elliott Bay and Case Inlet for Commencement Bay. Few diseased fishes were caught in these areas.

Because of the high prevalence of diseased fish in the Duwamish, Hylebos, and Commencement Bay Waterways, the fish ecology in these areas warrants additional comment. These stations are characterized as being shallow, generally less than 20 meters deep, often within the freshwater marine areas of contributing rivers, and adjacent to the greatest industrial development. The patterns of target species abundance at these stations are summarized as follows: (1) English sole occurred throughout these waterways, but in generally lower numbers than the deeper areas of the estuarine bays; (2) rock sole and quillback rockfish were caught less frequently in the waterways than in stations in the rest of the estuarine bays; (3) Pacific tomcod occurred as commonly, when present, within the waterways as at the deeper stations in the estuarine bays; (4) staghorn sculpin frequented the waterways and shallower waters more than the deeper waters of the estuarine bays.

Analyses of species occurrence and richness data demonstrated that the waterways differed from nonwaterway stations in the estuarine bays. Species richness was always lower in the waterways than in the outer stations, differing in Elliott Bay stations by 3 to 20 species, and in Commencement Bay by 7 to 16 species. The absence of certain species in the waterways could have resulted from the avoidance by these species of the more brackish water, and/or polluted sediment and water in these industrialized areas. Also, the lower species richness could have resulted from the preference of some species for intermediate and deeper water.

Since the estuarine bays had greater total catch rates, species diversities, and species richnesses, the suitability of the shallow water Case Inlet and deep water Port Madison control areas must be addressed. Specifically, the influx of freshwater into these estuarine embayments may cause differences in species occurrence due to different nutrients, siltation rates and salinity regimes, and current flow patterns not experienced in the chosen reference areas. The differences between the estuaries and the saltwater inlets may cause variation in the susceptibility to and hence the frequency of occurrence of pathological abnormalities. Therefore to effectively match the impacted estuarine areas and to reduce statistical variation in the pathological

frequency data, a pristine reference area with a river flowing into a confined embayment must be found. Unfortunately, most estuarine bays in Puget Sound have various industrial facilities at the river mouths. Many other non-developed areas tend to be unnavigable or without sufficient characteristics to satisfy other project objectives. Possible estuarine bay reference sites might be the mouths of the Nisqually, Stillaguamish, Skokomish or Nooksack Rivers in Puget Sound.

#### 4.5 Invertebrate Ecology

As was pointed out by Armstrong et al. (1978) the results of field surveys of benthic invertebrates can provide important information in documenting the cumulative effects of pollutants on the distribution, abundance, growth rate, food habits and community structure of the organisms present. Various community indices and indicator species have been used to define areas impacted by pollution because they provide means of defining the zone of impact of a pollution source (Word 1978, Mearns and Green 1976, Moore 1979, Freeman and Dickie 1979, Grassle and Grassle 1974). Other authors have objected to the use of diversity indices because they feel that the variability of the natural environment, even without the influences of pollution, leads to the formation of communities which cannot be assessed by a generalized hypothesis (Hurlbert 1971, Eagle and Hardiman 1977).

In interpreting the results of studies of infaunal benthic marine invertebrates, it is useful to consider a simple conceptual model of invertebrate distribution which is termed the "fluctuating patch" model (Figure 68). This model summarizes in a general way insights provided by more precise models of patch dynamics (Levin and Paine 1974), and is consistent with present knowledge in the fields of island biogeography (MacArthur and Wilson 1967) and population biology (Christianson and Fenchel 1977). The fluctuating patch model simply states that benthic marine invertebrates can be viewed as being distributed in patches, and that community or assemblage parameters such as total abundance, biomass, species richness, and species diversity fluctuate or follow irregular trajectories through time within such patches. This is particularly true if one considers a small patch such as that sampled by a grab. The fluctuations of an individual patch may be due to seasonal variation in the numbers and size of organisms inhabiting the patch, to succession within the patch during long undisturbed periods, and to removal or extinction of individuals or species by physical-chemical-disturbance or predation. Since physical-chemical disturbance and predation in particular are often haphazard rather than systematic processes, one would expect to find patches at various points on their trajectories at any given time even in a homogeneous natural environment.

Therefore, statistical analysis of the amplitude of fluctuation of a community parameter (as measured, for example, by the coefficient of variation) observed in a patch should be based on replicate samples. One can expect to find sporadic low values of community indices even in homogeneous natural environments highly favorable for benthic marine invertebrates. The absence of high values in replicate samples suggests an unfavorable environment

(except, of course, in the case of the community parameter, J, or evenness, where low values suggest favorable and high values suggest unfavorable conditions).

Seasonal variations in abundance in infauna observed in this study were similar to the trends reported by Lie (1968) in Puget Sound. Lowest abundance values were observed during the winter and higher values were observed in the summer and fall. A similar trend was seen in the number of taxa represented in the infaunal index. Average Infaunal Trophic Index (ITI) values for each season were stable throughout the year, implying that whereas the abundance and species make-up of a community may change during the year, in general the dominant feeding strategy of those organisms present at a site does not change from season to season.

A study of sites in Southern Puget Sound conducted by Thom et al. (1979) reported the "normal" range of ITI values to be 59 to 82. The benthic communities at 56% of the stations in the present study were found to have ITI values consistently within these limits throughout the year of sampling. The remaining stations had at least one season in which the ITI was outside the "normal" range in Southern Puget Sound. The ITI values at the stations in the City Waterway and off the mouth of the Puyallup River in Commencement Bay were consistently lower than the "normal" range, while station 2 near the mouth of the Hylebos Waterway had ITI values lower than the "normal" range in 3 out of 4 sampling periods. The benthic communities in these latter regions were dominated by surface and subsurface deposit feeding organisms. These organisms probably predominate due to their ability to capitalize on increased levels of organic material which were found in these areas. Stations with index values above the "normal" range included stations in the northeast portion of Elliott Bay (stations 7, 8, and 9) and the Case Inlet stations. These stations were dominated by predominately suspension feeding communities at some point during the year.

Consistently high levels of total abundance were noted at stations 7 and 8 just outside of the mouth of the Hylebos Waterway in Commencement Bay, at station 1, in the Duwamish Waterway and at the stations off Alki and West Points. High total abundance values were generally related to large numbers of the mollusks Axinopsida serricata and Macoma sp. or polychaetes in the family Cirratulidae or Capitellidae.

High values for richness of infaunal index taxa were found at station 2 in Port Madison, in stations at the outer portions of Commencement Bay (stations 9 and 11) and Elliott Bay (stations 9, 10, 11 and 12). Partial explanation for this diversity lies in the fact that all of these communities were sampled over a depth gradient which allows for the interception of a wider variety of substrate types and organisms. These areas are also characterized by high sand-to-mud ratios and low levels of pollutants.

Variations in the water quality parameters of temperature, salinity, and dissolved oxygen were probably not responsible for the observed variations in invertebrate species richness and abundance. The small variation observed in these parameters in stations sampled during a single quarter was well within the range which the benthic organisms can tolerate.

The seasonal water temperatures were very similar to those reported by Lie for Puget Sound (1968).

The sand-to-mud ratio calculated at each station was found to be negatively correlated with carbon levels (correlation coefficient -0.490). A strong negative correlation between sand-to-mud ratios and carbon would be expected since the currents which carry fine sediment particles away from these areas would also not allow organic material to settle.

It appears from this study that generalizations may be made about the infaunal communities at certain groups of stations. The three stations in Sinclair Inlet appeared very similar in terms of their dominant feeding strategy and total abundance. However, values for taxon richness were in general below average. The moderately high levels of pollutants (Appendix Table E-2) may have contributed to the lowered taxon richness values. Stations 7 and 8 in Commencement Bay which were geographically close also had similar infaunal community parameters. The total abundance values were consistently high and the values for taxon richness were average to above average. ITI values showed parallel trends throughout the seasons. These values were within the "normal" range for the first three quarters of this study but during the fall dropped sharply due primarily to the appearance of large numbers of Macoma. Moderate to high levels of pollutants were found at these stations.

Another pair of adjacent stations which are similar in terms of seasonal variation of total abundance, ITI values, and taxon richness values were stations 5 and 6 in Elliott Bay. These two stations on the Seattle waterfront had almost no organisms at any depth studied during the winter sampling period. The number of organisms and richness of species both increased gradually during succeeding sampling periods. These stations were found to have moderately high levels of pollutants (Appendix Table E-2). The results observed in this study concur with the results obtained by Harman and Serwold (1974) for Elliott Bay in that the western portion of the Bay and the region of Alki Point showed a greater richness of infaunal species than did the eastern portion of the Bay.

The ITI values at the remaining stations suggest that they should be considered as independent of each other. The stations in Case Inlet and Port Madison had low to moderate levels of pollutants, and the ITI values were in the "normal" range to above the "normal" limits. Extensive beds of the ophiuroid Amphiodia utrica were encountered in Case Inlet which tended to raise ITI values in this area. The shallower of the two Port Madison stations (station 2) consistently had high ITI and taxon richness values. The Budd Inlet stations were characterized by wide fluctuations in ITI and abundance values. These fluctuations may have been due to the shallow water and shoaling conditions encountered at the stations we studied in this Inlet and to widely varying pollution levels between stations.

As will be discussed in greater detail in Section 4.6, multiple linear regression applied to the variables used in this study revealed that taxon richness values was the most sensitive measure of urban-associated pollution in benthic marine communities in Southern Puget Sound. The ITI was less useful, perhaps because it was developed for investigation of the effects of

organic enrichment, whereas our study has dealt mainly with the effects of toxic pollutants.

#### 4.6 Comparisons between Sediment Chemical Data and Biological Parameters

The value of comparisons between biological and chemical parameters is limited by the fact that not all sediment-associated chemicals were, or can presently be, identified or quantified. Even if one or more of those sediment-bound chemicals measured in this study directly or indirectly caused some of the observed biological anomalies, the mechanisms of change may have involved synergistic and antagonistic interactions between a variety of unrelated chemicals (i.e., a metal acting synergistically with a chlorinated hydrocarbon compound might cause a type of liver lesion in a fish). In addition, such comparisons with the prevalence of lesions in fish and crustacea suffer another limitation due to the mobility of these animals. Although they are not known to migrate major distances within Puget Sound, the exposure times of fish and crustacea to the sediment at the station from which they were captured are not known. Nevertheless, as a first step in maximally utilizing the data presently available, these comparisons are justified.

##### 4.6.1 Relationships between Indicators of Biological Anomalies and Sediment Chemical Composition

Principal components analysis and cluster analysis of the sediment contaminants produced seven groups of sampling stations (see Appendix Table E-2). However, these groups cannot readily be ordered in a series according to levels or types of contaminants because the biological significance and relative toxicities of many of the sediment contaminants is unknown and only a restricted number of chemicals were identified and quantified. Nevertheless, it is reasonable to hypothesize that certain suites of chemicals may have toxic effects on several species of marine fish and invertebrates. The prevalence of hepatic lesions in fish at a particular sampling station may correlate positively with the prevalence of hepatopancreatic lesions in crabs or with low taxon richness of the benthic infauna from the same station. The values of all three indices may also reflect the composition and concentrations of toxic chemicals in the sediment from that station.

This hypothesis can be evaluated by plotting the values of two indices for each station or cluster group against one another. This has been done for fish hepatic lesions and crab hepatopancreas abnormalities in Figure 69 and for fish hepatic lesions and benthic infaunal invertebrate taxon richness in Figure 70 using 1979 annual data for the seven cluster groups (Appendix Table E-2). In both cases there is a significant correlation (positive in the first case, negative in the second) between the pairs of indices. Significance was determined by computing the value of  $r_s$ , the Spearman rank correlation coefficient (this is a nonparametric statistical test; unlike the parametric correlation coefficient  $r$ ,  $r_s$  does not indicate the proportion of the variability in the data explained by the correlation between the two variables). Figures 69 and 70 suggest

that three distinctly different biological indices respond in a similar way to levels of contaminants. A more detailed comparison is shown in Table 34, in which cluster groups are ranked on the basis of fish hepatic lesions, crab hepatopancreas abnormalities, and invertebrate taxon richness. It is clear from Table 34 that cluster groups III, V and VI rank in the top three in each case. While the similarities in the ranking suggest that certain types of contaminants are associated with high incidences of biological anomalies, differences in the rankings are also important. These suggest that a more detailed analysis should be performed to investigate the subtleties of the interactions of the various contaminants and the biological indices.

#### 4.6.2 Statistical Correlations among Physical, Chemical, and Ecological Variables: Correlations among Physical and Chemical Variables

In assessing the relationships of various physical and chemical parameters to biological community parameters in bottom sediments, it is important to consider correlations among the physical and chemical parameters themselves. Such correlations can arise for several reasons. For example, the concentrations of lead and zinc might be positively correlated because they may be emitted by the same point source. Sediment particle size and chemical levels might also be correlated because pollutants settle out in silty areas and are swept away in sandy areas by the same hydrodynamic processes.

Simple correlation coefficients for mean sediment particle size (expressed in Phi units), a group of selected arenes, PCB's, CBD's, and seven metals of known biological importance are given in Table 35. It can be seen that concentrations of PCB's and many metals are significantly correlated with mean Phi size, although the relationships are weak. Since mean Phi size is high when particle size is small, higher chemical concentrations tended to be found in muddier areas.

Concentrations of PCB's and CBD's are significantly positively correlated, as are arsenic and lead levels. Zinc and copper concentrations are strongly correlated, but inspection of scattergrams reveals that this and other strong correlations are often greatly influenced by the extremely high concentrations of metals found in the Sitcum Waterway of Commencement Bay (Station 09030). For example, when Station 09030 was omitted from the analysis, the correlation coefficient for zinc and copper dropped from 0.9934 to 0.9254 (the significance level was unchanged).

Correlations among chemical and physical variables, particularly strong ones, can make it difficult to assess the biological effect of any individual physical or chemical variable since, for example, high levels of cadmium may usually be accompanied by high levels of arsenic and selenium, which may also have important effects.

Comparisons of Community Indices. Correlations between three community indices and a number of physical and chemical variables are shown in Table 36. Samples for physical and chemical analysis were taken in spring, 1979. The community indices for infaunal samples included taxon richness, abundance, and ITI. Abundance is significantly correlated with concentrations of PCB's, mercury, and chromium. Taxon richness values are based on ITI

taxa only. Taxon richness is significantly correlated with seven physical or chemical variables (mean Phi size, PCB's, arsenic, mercury, selenium, chromium, and cadmium), while the ITI is significantly correlated only with mean Phi size and cadmium levels. All significant correlations are negative. On the basis of these analyses, it would appear that taxon richness is a community index influenced strongly by a variety of physical and chemical variables.

However, when a number of related variables are involved, pair-wise analysis of variables considered separately is not an adequate method on which to base conclusions (Kleinbaum and Kupper 1978). Methods capable of taking into account a number of variables simultaneously, such as multiple linear regression, are necessary.

Comparison of Community Indices using Multiple Regression. When it is suspected that a dependent variable (such as a community index) is influenced by a number of variables which are themselves interrelated, it is desirable to use methods which can take into account all variables simultaneously. Multiple linear regression is such a method, and can properly be employed when all the variables of interest are continuous; all interrelationships are linear; values of the dependent variable are independent of one another; and the dependent variable is homoscedastic (has the same variance throughout its range). Also, for any fixed combination of values of the independent variables, the dependent variable must be randomly drawn from a normal distribution (Kleinbaum and Kupper 1978). This method is relatively robust to departures from the last two assumptions (i.e., it is reliable and accurate even when the assumptions are not perfectly met). Kleinbaum and Kupper (1978) state that on the basis of both theoretical and experimental evidence, "... only extreme departures of the distribution of Y from normality can yield spurious results ..." in parametric hypothesis testing in regression analysis. Multiple linear regression is also useful when curvilinear interrelationships exist, since interaction terms can be incorporated in the regression model and their contribution and significance evaluated.

The utility of multiple regression is that it permits the investigator to take into account the possibility that a correlation between two variables exists because both are correlated with a third. Stepwise multiple regression using a backward selection procedure eliminates variables from the multiple regression equation if they do not contribute significantly to the analysis. The resulting subset is the minimal group of variables contributing significantly to the regression equation.

Unfortunately, when some independent variables are highly correlated, as in the case with the metals data (Table 35), this minimal subset of variables may be unstable (Nie et al. 1975); i.e., the selection of one of a pair of highly correlated variables and the elimination of the other is somewhat arbitrary, and slight changes in the method of analysis can result in the selection of different subsets of variables (Nie et al. 1975). This does not indicate that a relationship between the dependent variable and the independent variables does not exist, but does suggest some difficulty in determining the exact nature of this relationship.

To compare the usefulness of community indices in a more appropriate manner, stepwise multiple regression with a backward selection procedure was performed for the Infaunal Trophic Index, taxon richness, and total abundance using as independent variables all of the physical and chemical variables listed in Table 36. The computer programs of Nie et al. (1975) were used for this purpose. The significance level for retention of variables in the regression equation was 0.05.

When no organisms are present in a sample, total abundance and taxon richness are both zero, but the value of the ITI is undefined because both numerator and denominator are zero. An undefined value of the ITI is uninterpretable; it cannot properly be equated with a value of zero, since this would imply a community dominated by subsurface deposit feeders. Thus samples in which no organisms were found had to be deleted from the analysis in selecting the best multiple regression equation for the ITI as a function of the physical and chemical variables of interest. This is a limitation of the ITI in studies of toxic pollution (as opposed to enrichment pollution). Station 09037 (Brown's Point, Commencement Bay) was omitted because no organisms were found in the two infaunal samples from the site at which the samples for physical and chemical analysis were taken. Stations 10016 (Harbor Island N., Elliott Bay) and 12133 (Budd Inlet, Dofflemyer Pt) were excluded from the analysis for all indices because no sediment particle size data were available for the former and no chemistry data were available for the latter.

The best multiple regression equations obtained for the various indices are given in Appendix I. The usefulness of the indices can be judged by comparing the coefficients of determination (multiple- $r^2$ ) of these regression equations. The coefficient of determination is the proportion of the variation in the dependent variable which is explained by the independent variables in the equation, i.e., the predictive power of the regression equation.

As shown in Table 37, taxon richness ranks highest in the coefficient of determination obtained with the physical and chemical variables remaining in the best multiple regression equation for spring infaunal samples. The ITI ranks below taxon richness in coefficient of determination, and total abundance ranks even lower.

Coefficients of determination were also obtained in a similar manner for the indices calculated from the infaunal samples collected in the winter sampling. In addition to taxon richness, ITI, and total abundance, the indices taxon diversity (Shannon-Weaver index), taxon evenness, and total dry-weight biomass were also calculated. The coefficients of determination of these indices were 0.434 ( $\alpha = 0.001$ ), 0.280 ( $\alpha = 0.001$ ), 0.146 ( $\alpha = 0.05$ ), 0.350 ( $\alpha = 0.001$ ), 0.296 ( $\alpha = 0.001$ ), and 0.111 ( $\alpha = 0.05$ ), respectively. Although these coefficients of determination are based on physical and chemical data for sediment collected in the spring, they provide an indication of the usefulness of the additional indices. For both winter and spring data, the coefficient of determination for taxon richness was highest, ITI was intermediate, and total abundance was low.

Thus, taxon richness can be considered a useful index in studying effects of toxic pollutants on infaunal benthic marine communities. Taxon richness was not perfectly correlated with the physical and chemical variables used in the analysis, but this is to be expected since, as discussed in connection with the fluctuating patch model, physical disturbance and biological variables such as predation and recruitment, which were not measured in this study, can be expected to exert an important influence on the value of a community index. Error is probably also introduced because the oxidation states of metals are not known; a metal may be more toxic in one oxidation state than in another.

It is of interest that mercury is included in the best regression equation for taxon richness for spring infaunal samples (Appendix Table I-7). The inference that the concentration of mercury is important in determining the number of infaunal taxa inhabiting an area is strengthened by the observation that mercury was the only variable significantly correlated with total abundance in the infaunal samples (Appendix Table I-9).

The simple correlation between taxon richness and the concentrations of mercury and the other variables (chromium, cadmium, and arsenic) included in the multiple regression equation for this index for the infaunal samples are given in Figures 71 to 74. Stations 09037 and 10016 are included in these plots. Correlation coefficients and statistical significance are given in Table 36, and are more accurate than the plotted confidence belts, which are influenced by the distribution of the data points.

While the concentration of PCB's, CBD's, and selected arenes did not contribute significantly to the regression equation for taxon richness for the spring infaunal samples, it is not clear whether this is because these pollutants do not reach toxic levels in the areas sampled or because the correlations among variables (Table 35) make some effects difficult to assess. Plots showing the relationships between taxon richness and the levels of selected arenes (Figure 75), of PCB's (Figure 76), and of CBD's (Figure 77) suggest that there is negligible effect of arenes on this index. On the other hand, Figures 76 and 77 suggest that taxon richness tends to decline as concentrations of PCB's and CBD's rise. Even though these effects are not statistically significant when concentrations of selected metals are considered simultaneously (Appendix Table I-7), it is possible that effects are actually present but are obscured by physical disturbance and biological interactions.

While the multiple linear regression analysis presented is reasonable as a first approach in exploring relationships between benthic infaunal community indices and chemical concentrations, examination of Figures 71 through 74 suggests curvilinear rather than linear relationships in some cases and reveals violations of the assumptions that taxon richness is normally distributed and homoscedastic. The robustness of hypothesis testing in regression analysis to departures from these assumptions makes it unlikely that the conclusion that a relationship exists between chemical and biological variables is erroneous (Kleinbaum and Kupper 1978), but it is desirable to refine the analysis. This can be done either by transforming dependent variables in appropriate ways (Zar 1974) or by employing a nonparametric analog to multiple linear regression. The high correlations between the

concentrations of many chemicals (Table 35) suggests that factor analysis (Nie et al. 1975) may also be desirable as a method for the analysis of this data.

#### 4.6.3 Comparisons of the Composition of Xenobiotics in Tissue of Normal-appearing and Diseased Fish

Statistical comparisons between the prevalence and types of lesions in fish and crustacean species and the tissue levels of xenobiotics in these same species from the same areas are also hampered by many of the same factors described for comparisons based on sediment chemistry as stated previously (see section 4.1). However, simple graphic comparisons of the tissue levels of the four major groups of hydrocarbons (PCB's, aromatic hydrocarbons, HCB, and CBD's) in normal-appearing versus diseased fish have been made. An example of one such set of comparisons for English sole is shown in Figure 78 and Table 38. Major differences were observed between the chemicals in livers from both normal and diseased English sole from Hylebos Waterway and sole from the other sampling areas.

## 5. CONCLUSIONS

### 5.1 Analytical Chemistry

A broad spectrum of organic chemicals and metals has been documented in sediments and tissues of marine organisms obtained from nonurban and urban areas of Puget Sound. Generally, chemical contaminants associated with sediments of a particular location were also present in tissues of biota from that location. The chlorinated hydrocarbons were more abundant in tissue relative to sediment, whereas the reverse was true for petroleum hydrocarbons.

Not surprisingly, the highest levels of chemical contamination in both sediment and biota were associated with sampling sites near urban areas, particularly in Commencement and Elliott Bays, and Sinclair Inlet. An unanticipated finding, however, was the high concentrations of chlorinated organic compounds found in Commencement Bay. Some of the contaminants found in this area (e.g., hexachlorobenzene, hexachlorobutadiene, benz[a]anthracene, and benzo[a]pyrene) are known to be mutagens and carcinogens in laboratory animals; however, very little is known about the effects of these compounds on marine organisms. Marine organisms from the reference areas, Case Inlet and Port Madison, had detectable levels of some of these carcinogenic compounds.

On the basis of these findings, it is now questionable whether areas, such as Case Inlet and Port Madison, can be justifiably considered "clean" and thus suitable as reference sites in studies of the effects of pollution on marine environments.

## 5.2 Fish Pathology

Several types of liver lesions were found more frequently in fish from sampling areas with the sediments most highly contaminated by toxic chemicals. These hepatic lesions, megalocytic hepatosis, focal hypertrophy, adenomatous foci, and cholangioproliferative foci, have also been described elsewhere in laboratory rodents and fish exposed to toxic chemicals. Therefore, these two types of evidence support the hypothesis that the hepatic lesions found in this study were caused or enhanced by exposure of fish to one or more toxic chemicals found in their environment. The identification of the specific etiological agents must await laboratory bioassays involving long-term exposures of flatfish to individual or mixtures of compounds.

## 5.3 Invertebrate Pathology

The highest frequencies of abnormalities were found in the hepatopancreas, gill, and bladder tissues of shrimp and crab species. Several of these abnormalities were found only, or were most prevalent, in the most polluted areas. However, the restricted abundance and geographical distribution of these species in Puget Sound make difficult any comparisons between the prevalence of diseased animals and pollution levels at the present time.

## 5.4 Fish Ecology

The fish catch statistics reflected very well the physical characteristics of the six sampling areas. The estuarine embayments, Commencement and Elliott Bays, had the highest catch rates and species diversity; the values in the inlets (Sinclair, Budd, and Case Inlets) were lowest, and Port Madison was intermediate. If future studies of a similar nature are to be performed in Commencement and Elliott Bays, then more appropriate estuarine embayments should be used as reference areas.

## 5.5 Invertebrate Ecology

Taxon richness was found to be the most sensitive measure of urban-associated pollution in benthic marine communities in Southern and Central Puget Sound. Low taxon richness values were correlated with high levels of arsenic, mercury, selenium, and cadmium. Seasonal variation was observed in average taxon richness and abundance values but not in Infaunal Trophic Index values. Low taxon richness and abundance was characteristic of the winter sampling period.

The sampling stations in Elliott Bay with the lowest taxon richness values were in the Duwamish Waterway, while the highest values were in sediment samples from outside the Bay (i.e., Alki and West Points). In Commencement Bay a similar pattern was observed. Among stations sampled during four seasons, the lowest taxon richness values were in the turning basin in the Hylebos Waterway. The highest were near the mouth of the Bay (e.g. Brown's Point, Tacoma Yacht Club).

## 5.6 Summary of Conclusions

The study described in this report constitutes a first step in better understanding the impact of human activities on Puget Sound. The most sophisticated techniques available were used to identify and quantify xenobiotics in sediments and organisms. Yet even these approaches have their limitations. Thus, it should be understood that possibly hundreds of potentially toxic chemicals were also present in the sediment and tissue samples in addition to those analyzed.

The findings on tissue accumulations clearly suggest that a more detailed study of xenobiotic accumulations in marine organisms of Puget Sound is warranted. The intent of such a study would be to permit more extensive sampling to obtain a more comprehensive perspective of xenobiotic accumulations.

In future work there is a need to examine more samples of sediment and biota at each site. There is also a requirement to expand the spectrum of chemicals analyzed by applying new techniques and/or modifying existing ones.

The crucial question of establishing cause-and-effect relations between chemicals in the environment and the etiology of pathological conditions is of foremost importance. Despite the revelation that organisms in Puget Sound are impacted by extremely complex mixtures of xenobiotics, there are still ways to elucidate which compounds or groups of compounds are likely to be causative agents in observed pathologies. These approaches, which will not be delineated here, involve both interdisciplinary laboratory and field studies. The continuing phases of this program are taking into account the above-mentioned priorities.

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Table 1. Description of sampling stations in Elliott Bay.

MESA Station Number	Approximate locations	Type of station	Depth Range (m)	Comments	Depth ranges (m) of other trawls
10031	Duwamish Waterway, Harbor Island So.	Complete	10-20	Corresponds to METRO station #14	Maximum of 3 trawls at 10-20
10038	West Channel, Duwamish R.	Complete	15-20	Corresponds to EPA Pass-through station A	As above - 15-20
10039	East Channel, Duwamish R.	Complete	12-16	Corresponds to METRO station #13	As above - 12-16
10016	Harbor Island, North End	Complete	12-50		10 to 20, 20-40, >40
10015	Elliott Bay, Pier 54	Complete	20-60	Corresponds to METRO station #12, near combined-sewer overflow (CSO) near Madison St.	20-30, 30-50, >50
10040	Elliott Bay, Pier 70	Complete	20-60	Near CSO near Wall St.	As above
10044	Elliott Bay, midway between Duwamish Head and Pier 91	Complete	120-170	Corresponds to METRO station W2	120-150, 150-170, >170
10041	Elliott Bay, No. of Pier 71	Complete	15-65	Corresponds to METRO station #11, near CSO near Denny Way	15-30, 30-50 >50
10014	Elliott Bay, Magnolia Bluff	Complete	15-60	Near Four-Mile Rock, where dredge spoils from the Duwamish R. have been dumped	As above
10045	Elliott Bay, Duwamish Head	Complete	12-50	Erosional area, corresponds to METRO station #16	10 to 20, 20-40, >40
10028	Alki Point, South Side	Complete	15-60	Erosional area	15-30, 30-50 >50
10023	West Point, North Side	Complete	10-50		10-20, 20-40, >40
10046	Elliott Bay, Pier 42	Sediment Chemistry Only	20-60		
10043	Elliott Bay, near Corps of Engineers Experimental dump site	Sediment Chemistry Only	70-85		
10042	Elliott Bay, near Pier 86	Sediment Chemistry Only	30-50		
10019	Duwamish Waterway, 14th Ave. Bridge	Sediment Chemistry Only	3-15	Corresponds to station G in EPA- Pass through study	

Table 2. Description of the sampling stations in Commencement Bay.

Station Number MESA Project	Approximate Locations	Type of Station	Depth Range (m)	Comments	Depth ranges (m) of other trawls
09027	1 Hylebos Waterway, just downstream from Lower Turning Basin	Complete	10-12		Maximum of 3 trawls at 10-12
09028	2 Hylebos Waterway, just downstream from E. 11th St. Bridge	Complete	10-12		As above
09029	3 Blair Waterway, just downstream from E. 11th St. Bridge	Complete	10-12		As above
09030	4 Sitcum Waterway	Complete	10-15		As above, except 10-15
09031	5 City Waterway	Complete	7-11		As above, except 7-11
09032	6 Puyallup Waterway, at right angle to waterway in disposal area	Complete	20-60		Sampled winter, spring, and summer only. 20-30, 30-50, >50
09033	7 Commencement Bay, between Hylebos and Blair Waterways	Complete	20-50		20-30, 30-40, >50
09034	8 Commencement Bay, south of Browns Point about 1/2 Naut. Mile	Complete	100-150		100-120, 120-140 >140
09035	9 Commencement Bay, creek at sewage plant	Complete	20-100		Erosional area 20-50, 50-80, >80
09036	10 Commencement Bay, Tacoma Yacht Club	Complete	20-60		Erosional area 20-30, 30-50, >50
09037	11 Browns Pt.	Complete	20-60		As above
09038	12 Commencement Bay, Hylebos Waterway, outside, to NW	Sediment Chemistry Only	20-60		As above
09039	13 Commencement Bay, just north of Old Tacoma	Complete	20-100		Sampled in the spring as a sediment chemistry only station, and in the fall as a complete station. 20-50, 50-80, >80
09040	14 Blair Waterway, near Turning Basin	Complete	10-12		
09042	22 Near Old Tacoma	Complete	20-100		Sampled only in the fall same as station 13

Table 3. Description of the sampling stations in Budd, Sinclair, and Case Inlets and Port Madison.

Station Numbers MESA Project	Approximate Location	Type of Station	Depth range (m)	Depth ranges (m) of other trawls
12130	1 Budd Inlet, Entrance channel, south end	Sediment Chemistry Only	5-6	
12131	2 Budd Inlet, Priest Point	Complete	15-25	Maximum of 3 trawls
12132	3 Budd Inlet, N.E. of Olympia Shoal	Complete		As above
12133	4 Budd Inlet, Dufflenyer Pt. south end	Complete	10-12	As above
08004	1 Sinclair Inlet, S.W. end of inlet	Complete	8-10	As above
08005	2 Sinclair Inlet, Drydock area	Complete	10-12	As above
08006	3 Sinclair Inlet, Point Turner, S.W. side	Complete	13-15	As above, except 13 to 15
08007	4 South of Pt. Herron	Sediment Chemistry Only	15-30	
12062	1 Case Inlet near Reach Island	Complete	20-45	As above, except 10 to 20
12063	2 Case Inlet, Stretch Island	Complete	25-50	As above, except 24 to 30
08106	1 Port Madison, midway between Pt. Jefferson and Pt. Monroe	Complete	120-300	
08107	2 Port Madison, S.W. of Indianola	Complete	10-35	

Table 4. Description of the sampling stations within each geographical subarea.

Name of subarea	Stations within subarea Unique MESA number	Location description
Case Inlet	12062	Reach Island
	12063	Stretch Island
Port Madison	08106	Midway from Pt. Monroe to Pt. Jefferson.
	08107	Indianola, southwest
Sinclair Inlet	08004	Southwest end
	08005	Drydock area
	08006	Point Turner, southwest side
Budd Inlet	12130	Entrance channel, south end
	12131	Priest Point
	12132	Olympia Shoal
Duwamish Waterway (Elliott Bay)	10019	Duwamish Waterway, 14th St. Bridge*
	10031	Duwamish Waterway, near lumber mill
	10038	Duwamish Waterway, west channel
	10039	Duwamish Waterway, east channel
	10016	Harbor Island, north end
	10045	Duwamish Head, southeast side
Seattle Waterfront (Elliott Bay)	10046	Pier 42*
	10015	Pier 54
	10040	Pier 70
	10041	North of Pier 71
	10042	Pier 86*
Outer Elliott Bay	10044	Midway from Pier 91 to Duwamish Head
	10014	Magnolia Bluff
	10028	Alki Point, south side
	10043	Corps Dump site*

Table 4. (Continued)

Name of Subarea	Stations within subarea Unique MESA number	Location description
West Point (Elliott Bay)	10023	West Point, north side
Hylebos Waterway (Commencement Bay)	09027	Hylebos Waterway, lower turning basin
	09028	Hylebos Waterway, E. 11th St. Bridge
	09033	Between Hylebos and Blair
	09034	Brown's Point, south side
	09038	Hylebos Waterway, outside, to N.W.*
Commencement Bay Waterways	09029	Blair Waterway, south side
	09030	Sitcum Waterway
	09031	City Waterway
	09032	Puyallup disposal site
	09040	Blair Waterway, turning basin
Southwest Commencement Bay	09035	Creek at sewage plant
	09036	Tacoma Yacht Club
	09039	Old Tacoma
	09042	Old Tacoma Alternate
Brown's Point (Commencement Bay)	09037	Brown's Point

\*Sediment-only sampling stations

Table 5. Collection dates for 1979 sampling areas.

Area	Season			
	Winter	Spring	Summer	Fall
Elliott Bay	16, 23 Feb	27 Apr	5 Jul	18-19, 25 Oct
Commencement Bay	7-8 Feb	2-3 May	10-11 Jul	23-24 Oct
Case Inlet	6 Feb	1 May	9 Jul	22 Oct
Sinclair Inlet	12 Feb	24 Apr	12 Jul	25 Oct
Budd Inlet	5 Feb	1 May	9 Jul	22 Oct
Port Madison	12 Feb	24 Apr	12 Jul	25 Oct

Table 6. Compounds analyzed for by gas chromatography.

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+ <i>i</i> -Propylbenzene	*Hexachlorobenzene
+ <i>n</i> -Propylbenzene	*Lindane ( $\gamma$ -BHC)
+ Indan	*Heptachlor
+*Naphthalene	*Aldrin
+ Benzothiophene	o,p'-DDE
+ 2-Methylnaphthalene	* $\gamma$ -Chlordane
+ 1-Methylnaphthalene	* <i>trans</i> -Nonachlor
+ Biphenyl	*p,p'-DDE
+ 2,6-Dimethylnaphthalene	o,p'-DDD
†*Acenaphthylene	m,p'-DDD
†*Acenaphthene	p,p'-DDD
† 2,3,5-Trimethylnaphthalene	o,p'-DDT
†*Fluorene	p,p'-DDT
† Dibenzothiophene	**Chlorobiphenyls
†*Phenanthrene	**Dichlorobiphenyls
†*Anthracene	**Trichlorobiphenyls
†*Fluoranthene	**Tetrachlorobiphenyls
†*Pyrene	**Pentachlorobiphenyls
†*Benz[a]anthracene	**Hexachlorobiphenyls
†*Chrysene	**Heptachlorobiphenyls
†*Benzofluoranthene	**Octachlorobiphenyls
† Benzo[e]pyrene	**Nonachlorobiphenyls
†*Benzo[a]pyrene	*Dichlorobenzene
† Perylene	Trichlorobutadiene
†*Indeno [1,2,3- <i>cd</i> ]pyrene	Tetrachlorobutadiene
	Pentachlorobutadiene
	Hexachlorobutadiene

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\*Compounds are on EPA Priority Pollutant list.

\*\*Included in EPA Priority Pollutant list under "Polychlorinated biphenyl."

+ 1- or 2-ring aromatic compounds.

† 3- to 5-ring aromatic compounds.

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Table 7. Metallic elements analyzed. All were done by inductively coupled argon plasma (ICAP) emission spectroscopy except mercury, which was determined by cold vapor flameless atomic absorption spectroscopy.

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Aluminum <sup>a</sup>	*Mercury
Antimony	Molybdenum
*Arsenic	*Nickel <sup>a</sup>
Barium <sup>a</sup>	Phosphorus <sup>a</sup>
*Beryllium	Potassium
Bismuth	Scandium
Boron <sup>a</sup>	*Selenium
*Cadmium <sup>a</sup>	Silicon
Calcium	*Silver <sup>a</sup>
*Chromium <sup>a</sup>	Sodium
Cobalt	Strontium <sup>a</sup>
*Copper <sup>a</sup>	Tin
Gallium	Titanium
Germanium	Tungsten
Iron <sup>a</sup>	Vanadium <sup>a</sup>
*Lead <sup>a</sup>	Yttrium
Lithium <sup>a</sup>	*Zinc <sup>a</sup>
Manganese <sup>a</sup>	Zirconium
Magnesium <sup>a</sup>	

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<sup>a</sup>Determined in tissue.

\*Elements on EPA Priority Pollutant List.

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Table 8. Groups of benthic invertebrates used to calculate the Infaunal Trophic Index (from Thom et al. 1979).

	Group 1	Group 2	Group 3	Group 4
Organisms	<u>Ampharetidae</u> <u>Maldanidae</u> <u>Onuphidae</u> <u>Owenia</u> <u>Sabellidae</u> <u>Serpulidae</u> <u>Terebellidae</u> <u>Rhomboidella</u> <u>Nemocardium</u> <u>Ampelisca</u> <u>Byblis</u> <u>Caprellidae</u> <u>Phoxocephalidae</u> <u>Amphipolis</u> <u>Amphiodia</u> <u>Cucumaria</u>	<u>Capitellidae</u> <u>Cirratulidae</u> <u>Goniadidae</u> <u>Magelonidae</u> <u>Myriochele</u> <u>Nephtidae</u> <u>Orbiniidae</u> <u>Spionidae</u> <u>Syllidae</u> <u>Axinopsida</u> <u>Mysella</u> <u>cumaceans</u> <u>ostracods</u> <u>Photis</u> <u>tanais</u> <u>Golfingia</u> <u>Pectinaria</u>	<u>Chaetopteridae</u> <u>Nereidae</u> <u>Travisia</u> <u>Bittium</u> <u>Macoma</u> <u>Nucula</u> <u>Nuculana</u> <u>Parvilucina</u> <u>Yoldia</u>	<u>Ammotrypane</u> <u>Armandia</u> <u>Capitella</u> <u>Solemya</u> <u>Stenothoidae</u> <u>oligochaete</u>

Table 9. Computational formulae for infaunal community indices.

Infaunal Trophic Index (ITI) =

$$33.3 \quad \frac{3N_1+2N_2+1N_3+0N_4}{N_1+N_2+N_3+N_4}, \text{ where } \begin{array}{l} N_1 = n_i \text{ for taxa in Group 1} \\ N_2 = n_i \text{ for taxa in Group 2} \\ N_3 = n_i \text{ for taxa in Group 3} \\ N_4 = n_i \text{ for taxa in Group 4} \end{array}$$

and  $n_i$  = number of individuals in the  $i$ th taxon present

Total abundance (TA) =  $N_1 + N_2 + N_3 + N_4$

Taxon richness (S) =  $k$ , the number of taxa present

Taxon diversity ( $H'$ ) =  $\sum_{i=1}^k (P_i \log P_i)$ , where  $P_i = \frac{n_i}{TA}$

Taxon evenness (J) =  $\frac{H'}{\log k}$

Table 10. Illustration of properties of community indices using hypothetical data for numbers of individuals collected in a sample. Hypothetical samples A through D show that changing taxon membership can alter the ITI without affecting TA, S, H', or J. E and F show that samples differing in S, H', and J can have the same ITI. G and H show that samples differing in TA can have the same ITI.

Group	Taxon	Hypothetical Sample							
		A	B	C	D	E	F	G	H
Group 1:									
Suspension	<u>Nemocardium</u>	10				10	4	29	20
feeders	<u>Ampelisca</u>	10					3	1	20
	<u>Amphiodia</u>	10					3		20
Group 2:									
Suspension	<u>Axinopsida</u>		10			10	4		
and surface	Spionidae		10				3		
detritus	Ostracods		10				3		
feeders									
Group 3:									
Surface	<u>Macoma sp.</u>			10		5	2		
detritus	Chaetopteridae			10			2		
feeders	<u>Yoldia</u>			10			1		
Group 4:									
Subsurface	<u>Armandia</u>				10	5	2		
deposit	<u>Capitella</u>				10		2		
feeders	Stenothoidae				10		1		
Total abundance (TA):		30	30	30	30	30	30	30	60
Infaunal Trophic Index (ITI):		100	67	33	0	61	61	100	100
Taxon diversity (H')		0.48	0.48	0.48	0.48	0.58	1.05	0.06	0.48
Taxon richness (S):		3	3	3	3	4	12	2	3
Taxon evenness (J):		1.0	1.0	1.0	1.0	0.96	0.97	0.21	1.0

Table 11. Concentration in  $\mu\text{g/g}$  (ppm) dry weight of 1- and 2-ring aromatic hydrocarbons found at various locations in Central Puget Sound.

Subarea	Sediment avg. (# samples) <sup>a</sup> [range]	Fish Livers <sup>b</sup> avg. (# samples) <sup>a</sup> [range]	Crab Hepato- pancreas	Worm avg. (# samples) <sup>a</sup> [range]	Shrimp	Clam
Case Inlet	0.01 (2) [0.10, 0.0076]	NC(2)	0.01 (1)	- <sup>d</sup>	0.1 (1)	N (1)
Port Madison	0.08 (2) [0.10, 0.060]	N (2)	-	0.03 (1)	0.02 (1)	0.01 (1)
Sinclair Inlet	0.6 (4) [1.7, 0.15]	0.01 (1/2)	N (1)	0.06 (1)	0.09 (1)	0.1 (1)
Budd Inlet	0.1 (3) [0.18, 0.079]	0.03 (2) [0.030, 0.020]	0.02 (1)	-	0.09 (1)	-
Duwamish Waterway	0.5 (6) [1.3, 0.29]	0.4 (3/6) [0.73, 0.050]	0.7 (1)	0.09 (1)	0.2 (1)	0.2 (1)
Seattle Waterfront	0.9 (6) [3.3, 0.12]	0.3 (2) [0.58, 0.060]	-	-	-	0.04 (1)
Outer Elliott Bay	0.3 (4) [0.49, 0.094]	0.1 (4) [0.24, 0.060]	-	0.02 (1/2)	0.04 (1)	-
West Point	1.7 (1)	0.6 (1/2)	-	-	-	-
Hylebos Waterway	2.0 (5) [5.2, 0.22]	0.2 (8/11) [0.31, 0.070]	0.4 (1)	0.2 (2) [0.20, 0.13]	0.08 (1)	0.3 (1)
Commencement Waterways	2.1 (5) [8.8, 0.16]	-	1.1 (1)	0.3 (1)	-	0.3 (1)
Southwest Commencement Bay	1.0 (3) [2.8, 0.066]	0.2 (3/4) [0.24, 0.050]	-	-	-	-
Brown's Point	0.2 (1)	0.1 (2) [0.16, 0.12]	-	-	0.02 (1)	-

<sup>a</sup> Where nondetectable levels of material were observed, a ratio of the number of samples with detectable levels to the total number of samples was substituted.  
<sup>b</sup> English and rock sole species.  
<sup>c</sup> N signifies that detectable levels were not observed.  
<sup>d</sup> - signifies that no sample was taken.

Table 12. Concentration in  $\mu\text{g/g}$  (ppm) dry weight of 3- to 5- ring aromatic hydrocarbons found at various locations in Central Puget Sound.

Subarea	Sediment avg. (# samples) <sup>a</sup> [range]	Fish Livers <sup>b</sup> avg. (# samples) <sup>a</sup> [range]	Crab Hepato- pancreas	Worm avg. (# samples) <sup>a</sup> [range]	Shrimp	Clam
Case Inlet	0.3 (2) [0.57, 0.051]	0.05 <sup>c</sup> (1/2)	NC(1)	- <sup>d</sup>	1.4 (1)	N (1)
Port Madison	0.4 (2) [0.60, 0.20]	N (2)	-	0.2 (1)	0.1 (1)	0.2 (1)
Sinclair Inlet	5.6 (4) [16, 1.3]	N (2)	0.2 (1)	0.5 (1)	0.9 (1)	1.8 (1)
Budd Inlet	0.8 (3) [0.95, 0.48]	N (2)	0.01 (1)	-	0.3 (1)	-
Duwamish Waterway	10 (6) [28, 1.3]	0.1 (1/6)	0.5 (1)	6.5 (1)	0.5 (1)	4.9 (1)
Seattle Waterfront	9.8 (6) [46, 0.21]	N (2)	-	-	-	1.6 (1)
Outer Elliott Bay	1.6 (4) [3.3, 0.12]	0.2 (1/4)	-	0.6 (2) [0.94, 0.34]	0.2 (1)	-
West Point	43 (1)	N (2)	-	-	-	-
Hylebos Waterway	14 (5) [42, 0.61]	0.4 (6/11) [1.2, 0.020]	0.9 (1)	8.4 (2) [16, 0.91]	1.2 (1)	1.0 (1)
Commencement Waterways	11 (5) [46, 0.14]	-	0.4 (1)	3.2 (1)	-	4.6 (1)
Southwest Com- mencement Bay	4.8 (3) [14, 0.20]	1.6 (2/4) [2.8, 0.53]	-	-	-	-
Brown's Point	0.5 (1)	1.3 (1/2)	-	-	0.3 (1)	-

<sup>a</sup> Where nondetectable levels of material were observed, a ratio of the number of samples with detectable levels to the total number of samples was substituted.  
<sup>b</sup> English and rock sole species.  
<sup>c</sup> N signifies that detectable levels were not observed.  
<sup>d</sup> - signifies that no sample was taken.

Table 13. Concentration in  $\mu\text{g/g}$  (ppm) dry weight of phenanthrene found at various locations in Central Puget Sound.

Subarea	Sediment avg. (# samples) <sup>a</sup> [range]	Fish Livers <sup>b</sup>	Crab Hepato- pancreas	Worm	Shrimp	Clam
Case Inlet	0.027 (2) [0.050, 0.040]	<0.005 (2)	<0.005 (1)	- <sup>c</sup>	0.17 (1)	N <sup>d</sup> (1)
Port Madison	0.040 (2) [0.060, 0.020]	<0.010 (2)	-	<0.010 (1)	N (1)	N (1)
Sinclair Inlet	0.48 (4) [1.4, 0.070]	<0.010 (2)	0.020 (1)	<0.020 (1)	0.12 (1)	<0.080 (1)
Budd Inlet	0.067 (3) [0.090, 0.040]	<0.005 (2)	<0.010 (1)	-	<0.080 (1)	-
Duwamish Waterway	1.0 (6) [2.6, 0.14]	0.080 (1/6)	0.21 (1)	0.51 (1)	N (1)	N (1)
Seattle Waterfront	1.3 (6) [6.8, 0.02]	<0.030 (2)	-	-	-	N (1)
Outer Elliott Bay	0.17 (4) [0.32, 0.010]	<0.020 (4)	-	0.40 (1/2)	<0.050 (1)	-
West Point	4.2 (1)	<0.040 (2)	-	-	-	-
Hylebos Waterway	1.9 (5) [7.3, 0.090]	N (11)	0.50 (1)	0.15 (1/2)	N (1)	N (1)
Commencement Waterways	1.2 (5) [4.8, 0.050]	-	0.10 (1)	N (1)	-	0.41 (1)
Southwest Commencement Bay	0.67 (3) [1.9, 0.030]	N (4)	-	-	-	-
Brown's Point	0.090 (1)	0.16 (1/2)	-	-	<0.070 (1)	-

<sup>a</sup> Where nondetectable levels of material were observed, a ratio of the number of samples with detectable levels to the total number of samples was substituted.

<sup>b</sup> English and rock sole species.

<sup>c</sup> - signifies that no sample was taken.

<sup>d</sup> N signifies that detectable levels were not observed.

Table 14. Concentration in µg/g (ppm) dry weight of benz[a]anthracene found at various locations in Central Puget Sound.

Subarea	Sediment avg. (# samples) <sup>a</sup> [range]	Fish Livers <sup>b</sup> avg. (# samples) <sup>a</sup> [range]	Crab H. Hepato- pancreas	Worm avg. (# samples) <sup>a</sup> [range]	Shrimp	Clam
Case Inlet	0.022 (2) [0.040, 0.0030]	<0.010 (2)	<0.010 (1)	- <sup>c</sup>	0.16 (1)	<0.030 (1)
Port Madison	0.045 (2) [0.070, 0.020]	<0.030 (2)	-	0.020 (1)	0.010 (1)	<0.020 (1)
Sinclair Inlet	0.72 (4) [2.1, 0.14]	<0.040 (2)	0.070 (1)	0.050 (1)	0.12 (1)	0.45 (1)
Budd Inlet	0.080 (3) [0.11, 0.050]	<0.010 (2)	<0.020 (1)	-	0.040 (1)	-
Duwamish Waterway	1.1 (6) [1.4, 0.10]	<0.090 (6)	0.060 (1)	1.3 (1)	0.080 (1)	1.0 (1)
Seattle Waterfront	1.3 (6) [6.8, 0.030]	<0.040 (2)	-	-	-	0.28 (1)
Outer Elliott Bay	0.13 (4) [0.29, 0.010]	0.050 (1/4)	-	0.22 (2) [0.25, 0.19]	0.020 (1)	-
West Point	4.8 (1)	<0.11 (2)	-	-	-	-
Hylebos Waterway	1.2 (5) [3.2, 0.060]	0.14 (2/11) [0.22, 0.060]	<0.020 (1)	1.6 (2) [3.0, 0.20]	0.12 (1)	0.14 (1)
Commencement Waterways	1.2 (5) [4.7, 0.010]	-	0.090 (1)	0.53 (1)	-	0.73 (1)
Southwest Commencement Bay	0.72 (3) [2.1, 0.020]	0.050 (1/4)	-	-	-	-
Brown's Point	0.040 (1)	0.0030 (1/2)	-	-	0.050 (1)	-

<sup>a</sup> where nondetectable levels of material were observed, a ratio of the number of samples with detectable levels to the total number of samples was substituted.  
<sup>b</sup> English and rock sole species.  
<sup>c</sup> - signifies that no sample was taken.

Table 15. Concentration in µg/g (ppm) dry weight of benzo[a]pyrene found at various locations in Central Puget Sound.

Subarea	Sediment avg. (# samples) <sup>a</sup> [range]	Fish Livers <sup>b</sup>	Crab Hepato- pancreas	Worm	Shrimp	Clam
Case Inlet	0.019 (2) [0.030, 0.0070]	<0.0090 (2)	<0.010 (1)	- <sup>c</sup>	0.090 (1)	<0.010 (1)
Port Madison	0.020 (2) [0.030, 0.0090]	<0.020 (2)	-	<0.010 (1)	<0.010 (1)	<0.010 (1)
Sinclair Inlet	0.30 (4) [0.83, 0.070]	<0.020 (2)	<0.0050 (1)	<0.010 (1)	0.070 (1)	0.12 (1)
Budd Inlet	0.027 (3) [0.040, 0.010]	<0.0070 (2)	<0.010 (1)	-	0.030 (1)	-
Duwamish Waterway	0.56 (6) [1.5, 0.040]	<0.040 (6)	0.020 (1)	0.35 (1)	<0.010 (1)	0.23 (1)
Seattle Waterfront	0.52 (6) [2.2, 0.010]	<0.030 (2)	-	-	-	0.10 (1)
Outer Elliott Bay	0.077 (4) [0.18, 0.0060]	<0.090 (4)	-	<0.030 (2)	<0.010 (1)	-
West Point	4.0 (1)	<0.070 (2)	-	-	-	-
Hylebos Waterway	0.53 (5) [1.7, 0.020]	0.37 (1/11)	<0.010 (1)	0.73 (1/2)	0.050 (1)	<0.020 (1)
Commencement Waterways	0.58 (5) [2.6, 0.0020]	-	<0.0050 (1)	0.25 (1)	-	0.25 (1)
Southwest Commencement Bay	0.12 (3) [0.34, 0.0060]	<0.080 (3/4)	-	-	-	-
Brown's Point	0.010 (1)	0.21 (1/2)	-	-	<0.010 (1)	-

<sup>a</sup> Where nondetectable levels of material were observed, a ratio of the number of samples with detectable levels to the total number of samples was substituted.

<sup>b</sup> English and rock sole species.

<sup>c</sup> - signifies that no sample was taken.

Table 16. Concentration in  $\mu\text{g/g}$  (ppm) dry weight of polychlorinated biphenyls found at various locations in Central Puget Sound.

Subarea	Sediment avg. (# samples) <sup>a</sup> [range]	Fish Livers <sup>b</sup> avg. (# samples) <sup>a</sup> [range]	Crab Hepato- pancreas	Worm avg. (# samples) <sup>a</sup> [range]	Shrimp	Clam
Case Inlet	0.002 (2) [0.0025, 0.0005]	1.1 (2) [1.6, 0.55]	0.4 (1)	- <sup>c</sup>	0.1 (1)	0.02 (1)
Port Madison	0.006 (2) [0.0091, 0.0027]	2.4 (2) [3.0, 1.8]	-	0.2 (1)	0.3 (1)	0.02 (1)
Sinclair Inlet	0.1 (4) [0.22, 0.028]	6.3 (2) [8.6, 4.1]	4.2 (1)	1.3 (1)	0.7 (1)	1.3 (1)
Budd Inlet	0.01 (3) [0.019, 0.005]	1.6 (2) [1.9, 1.2]	1.5 (1)	-	0.2 (1)	-
Duwamish Waterway	0.3 (6) [0.67, 0.099]	17 (6) [35, 2.3]	33 (1)	1.8 (1)	2.1 (1)	0.3 (1)
Seattle Waterfront	0.3 (4/6) [0.49, 0.16]	6.4 (2) [9.2, 3.7]	-	-	-	1.3 (1)
Outer Elliott Bay	0.2 (3/4) [0.32, 0.035]	2.5 (4) [4.0, 1.4]	-	0.8 (2) [0.85, 0.83]	0.7 (1)	-
West Point	0.06 (1)	3.9 (2) [5.0, 2.9]	-	-	-	-
Hylebos Waterway	0.5 (4/5) [1.2, 0.027]	11 (11) [19, 0.21]	28 (1)	0.8 (2) [1.2, 0.38]	3.0 (1)	0.3 (1)
Commencement Waterways	0.1 (5) [0.39, 0.015]	-	10 (1)	0.6 (1)	-	0.9 (1)
Southwest Commencement Bay	0.04 (2/3) [0.099, 0.00054]	4.7 (4) [7.1, 3.4]	-	-	-	-
Brown's Point	0.002 (1)	9.4 (2) [12, 6.4]	-	-	0.3 (1)	-

<sup>a</sup> Where nondetectable levels of material were observed, a ratio of the number of samples with detectable levels to the total number of samples was substituted.

<sup>b</sup> English and rock sole species.

<sup>c</sup> - signifies that no sample was taken.

Table 17. Concentration in µg/g (ppm) dry weight of chlorinated butadienes found at various locations in Central Puget Sound.

Subarea	Sediment avg. (# samples) <sup>a</sup> [range]	Fish Livers <sup>b</sup> avg. (# samples) <sup>a</sup> [range]	Crab Hepato- pancreas	Worm avg. (# samples) <sup>a</sup> [range]	Shrimp	Clam
Case Inlet	0.007 (1/2) [0.0080, 0.0050]	0.007 (2) [0.0080, 0.0050]	NC(1)	- <sup>d</sup>	0.005 (1)	N (1)
Port Madison	0.002 (2) [0.0028, 0.0019]	0.003 (2) [0.0040, 0.0070]	-	N (1)	0.01 (1)	N (1)
Sinclair Inlet	0.05 (4) [0.090, 0.019]	0.003 (2) [0.0030, 0.0020]	N (1)	0.005 (1)	N (1)	N (1)
Budd Inlet	0.003 (3) [0.0053, 0.0025]	0.008 (2) [0.012, 0.0030]	N (1)	-	N (1)	-
Duwamish Waterway	0.02 (4/6) [0.042, 0.0070]	0.005 (4/6) [0.010, 0.0020]	N (1)	N (1)	N (1)	N (1)
Seattle Waterfront	0.02 (4/6) [0.053, 0.0070]	0.001 (2) [0.0020, 0.0006]	-	-	-	N (1)
Outer Elliott Bay	0.01 (4) [0.042, 0.0030]	0.003 (1/4)	-	N (2)	N (1)	-
West Point	0.003 (1)	N (0/2)	-	-	-	-
Hylebos Waterway	0.4 (5) [1.0, 0.070]	1.7 (11) [9.1, 0.0020]	0.07 (1)	0.2 (2) [0.36, 0.040]	0.2 (1)	0.06 (1)
Commencement Waterways	0.03 (5) [0.052, 0.0050]	-	N (1)	0.1 (1)	-	0.009 (1)
Southwest Commencement Bay	3.0 (3) [9.0, 0.014]	0.01 (2/4) [0.010, 0.010]	-	-	-	-
Brown's Point	0.04 (1)	0.01 (1/2)	-	-	0.002 (1)	-

<sup>a</sup> Where nondetectable levels of material were observed, a ratio of the number of samples with detectable levels to the total number of samples was substituted.

<sup>b</sup> English and rock sole species.

<sup>c</sup> N signifies that detectable levels were not observed.

<sup>d</sup> - signifies that no sample was taken.

Table 18. Concentration in µg/g (ppm) dry weight of hexachlorobenzene found at various locations in Central Puget Sound.

Subarea	Sediment avg. (# samples) <sup>a</sup> [range]	Fish Livers <sup>b</sup> avg. (# samples) <sup>a</sup> [range]	Crab Hepato- pancreas	Worm avg. (# samples) <sup>a</sup> [range]	Shrimp	Clam
Case Inlet	0.000025 (2) [0.000040, 0.000010]	0.0075 (2) [0.010, 0.0050]	0.0020 (1)	- <sup>c</sup>	<0.00030 (1)	<0.00030 (1)
Port Madison	0.000065 (2) [0.00010, 0.000030]	0.010 (2) [0.010, 0.010]	-	<0.0010 (1)	0.0010 (1)	<0.00030 (1)
Sinclair Inlet	0.00025 (4) [0.00040, 0.00020]	0.010 (2) [0.010, 0.010]	0.0020 (1)	<0.0010 (1)	0.00040 (1)	0.0010 (1)
Budd Inlet	0.000070 (3) [0.00010, 0.000010]	0.010 (2) [0.010, 0.010]	0.0030 (1)	-	0.0010 (1)	-
Duwamish Waterway	0.00018 (6) [0.00040, 0.000070]	0.025 (6) [0.050, 0.010]	0.030 (1)	0.0020 (1)	0.0020 (1)	0.00040 (1)
Seattle Waterfront	0.00033 (4/6) [0.00050, 0.00010]	0.014 (2) [0.020, 0.0080]	-	-	-	<0.0020 (1)
Outer Elliott Bay	0.00010 (4) [0.00020, 0.000070]	0.0098 (4) [0.010, 0.0090]	-	0.0010 (2) [0.0010, 0.0010]	0.0010 (1)	-
West Point	0.000030 (1)	0.0060 (2) [0.0080, 0.0040]	-	-	-	-
Hylebos Waterway	0.028 (5) [0.060, 0.00060]	0.99 (11) [3.7, 0.010]	1.8 (1)	0.26 (2) [0.37, 0.14]	0.080 (1)	0.13 (1)
Commencement Waterways	0.0022 (5) [0.0030, 0.0010]	-	0.12 (1)	0.12 (1)	-	0.010 (1)
Southwest Commencement Bay	0.083 (3) [0.25, 0.00010]	0.040 (4) [0.060, 0.010]	-	-	-	-
Brown's Point	0.00010 (1)	0.085 (2) [0.12, 0.050]	-	-	0.020 (1)	-

a Where nondetectable levels of material were observed, a ratio of the number of samples with detectable levels to the total number of samples was substituted.  
 b English and rock sole species.  
 c - signifies that no sample was taken.

Table 19. Concentration in µg/g (ppm) dry weight of chlorinated pesticides found at various locations in Central Puget Sound.

Subarea	Sediment avg. (# samples) <sup>a</sup> [range]	Fish Livers <sup>b</sup> avg. (# samples) <sup>a</sup> [range]	Crab Hepato- pancreas	Worm avg. (# samples) <sup>a</sup> [range]	Shrimp	Clam
Case Inlet	0.0003 (1/2)	0.1 (2) [0.16, 0.70]	0.05 (1)	- <sup>c</sup>	0.001 (1)	N (1)
Port Madison	0.008 (2) [0.015, 0.00070]	0.2 (2) [0.25, 0.15]	-	0.005 (1)	0.009 (1)	0.003 (1)
Sinclair Inlet	0.01 (4) [0.021, 0.0064]	0.5 (2) [0.64, 0.29]	0.4 (1)	0.03 (1)	0.04 (1)	0.05 (1)
Budd Inlet	0.002 (2/3) [0.0024, 0.0014]	0.2 (2) [0.19, 0.14]	0.2 (1)	-	0.02 (1)	-
Duwamish Waterway	0.03 (6) [0.042, 0.013]	2.0 (6) [6.0, 0.19]	3.2 (1)	0.06 (1)	0.01 (1)	0.04 (1)
Seattle Waterfront	0.01 (5/6) [0.022, 0.00024]	0.7 (2) [0.99, 0.32]	-	-	-	0.03 (1)
Outer Elliott Bay	0.01 (3/4) [0.021, 0.0008]	0.2 (4) [0.26, 0.14]	-	0.03 (2) [0.028, 0.026]	0.02 (1)	-
West Point	0.005 (1)	0.4 (2) [0.35, 0.34]	-	-	-	-
Hylebos Waterway	0.08 (5) [0.17, 0.016]	0.8 (11) [1.8, 0.018]	3.0 (1)	0.06 (2) [0.094, 0.018]	0.1 (1)	0.02 (1)
Commencement Waterways	0.03 (5) [0.081, 0.0046]	-	1.8 (1)	0.03 (1)	-	0.2 (1)
Southwest Commencement Bay	0.04 (2/3) [0.087, 0.00054]	0.3 (4) [0.51, 0.14]	-	-	-	-
Brown's Point	0.003 (1)	0.4 (2) [0.48, 0.28]	-	-	0.01 (1)	-

<sup>a</sup> Where nondetectable levels of material were observed, a ratio of the number of samples with detectable levels to the total number of samples was substituted.

<sup>b</sup> English and rock sole species.

<sup>c</sup> - signifies that no sample was taken.

Table 20. Comparison of concentrations of selected chlorinated hydrocarbons in individual English sole livers vs. muscle tissue and *Cancer gracilis* hepatopancreas vs. muscle in  $\mu\text{g/g}$  dry weight. All samples were from Commencement Bay.

	English sole					
	Muscle			Liver		
	Individual			Individual		
	A	B	C	A	B	C
Chlorinated Hydrocarbons:						
Hexachlorobenzene	0.05	0.2	0.04	1.6	1.4	0.4
PCBs	3.8	4.6	4.5	120	26	26
Hexachlorobutadiene	0.01	0.3	0.07	1.1	1.7	0.8
% Dry Weight:	16	14	19	20	12	15
	<i>Cancer gracilis</i>					
	Muscle		Hepatopancreas			
	Individual		Individual			
	A	B	A	B		
Chlorinated Hydrocarbons:						
Hexachlorobenzene	0.01	0.05	0.9	0.1		
PCBs	0.06	0.4	10	2.4		
Hexachlorobutadiene	<0.0004	<0.0006	0.003	<0.0006		
% Dry Weight:	20	21	21	17		

Table 21. The gross and microscopic characteristics of liver lesions in the four target fish species.

Liver Lesion	Gross Appearance	Cell Type	Microscopic Characteristic of Individual Cells			Lesion Characteristics			Presence of fibrosis, fibroplasia			
			Nuclei	Cytoplasm	Cell Size	Sinusoidal Compression	Cord Structure	Distribution		Ductular, glandular structure	Presence of cellular necrosis, degeneration	Presence of regenerative tissue
MH	Mottling	Hep	*Highly enlarged, aberrant chromatin distribution	granular, fibrillar or "ground glass"	*Increased up to 5x	Usually	Normal	focal to diffuse	Occasionally	Usually	Occasionally	
FH	ND <sup>1</sup>	Hep	*Normal size	eosinophilic or basophilic	*Increased up to 4x	Usually	Normal	focal, usually with distinct boundaries	Occasionally	No	No	
AF	1 to 5 mm nodules	Hep	*Enlarged with prominent nucleoli	*generally increased basophilia	*Increased up to 2x	Yes	*Loss of normal structure, expansive and/or invasive, loss of cell polarity	nodular, focal to multifocal	Occasionally	Occasionally, from invasion into surrounding parenchyma or due to ischemia	Occasionally	
CF (organized)	ND	Bile D	Normal	Normal	Normal	-	-	focal to multi-focal	*Yes	No	Yes	
CF (disorganized)	pale nodules, variable size	Bile D	occasionally enlarged	Normal	Occasionally enlarged	-	-	focal to multi-focal	*No, or dis-organized ductular structure	Occasionally	Yes	
FHH	White nodules 2mm sometimes containing cystic areas	Hep	Normal, often smaller than normal	Normal	Normal, sometimes smaller	Occasionally	*thickened cord (up to 10 cell layers thick)	nodular, focal to multifocal	No	No	No	
HK	small focus; ND large focus; pale soft area	Hep	Pyknotic, karyorrhectic	*eosinophilic, fragmented, lysed	often reduced	-	-	focal to diffuse	No	*Yes	Occasionally	
NP	ND	Hep	Variable nuclear diameter and chromatin distribution	Normal	*Normal	None	Normal	usually diffuse	No	Occasionally	No	
HSF	ND	Bile D	usually normal but occasionally pyknotic, karyorrhectic	usually normal, but occasionally degenerate/necrotic	Normal	-	-	focal to multi-focal	No	Occasionally, with dystrophic calcification	No (but occasional hyperplasia of biliary epithelium)	*Yes (extreme degree)

1 ND denotes not detectable  
 \* denotes key characteristic used in diagnosis  
 - denotes not applicable  
 HEP denotes hepatocellular  
 Bile D denotes bile duct epithelium

LIVER LESION KEY:  
 MH - megakaryocytic hepatocyst  
 FH - focal hyperplasia  
 AF - adenomatous foci  
 CF - cholangioepithelioma foci

FHH - focal hepatocellular hyperplasia  
 HN - hepatic necrosis  
 NP - nuclear pleomorphism  
 HSF - hepatic sclerotic foci

Table 22. Annual lesion frequency in Pacific staghorn sculpin, Pacific tomcod and quillback rockfish.

Lesion Types	Case	Budd	Port Madison	Sinclair	Duwamish	Seattle Waterfront	Outer Elliott	West Point	Hylebos Waterway	Commencement Waterways	S.W. Commencement	Brown's Point
<u>Pacific Staghorn Sculpin</u>												
Megalocytic Hepatosis	(0/13)	4(1/25)	(0/0)	(0/9)	9.5(2/21)	(0/13)	(0/0)	(0/1)	1.7(1/58)	4.0(2/50)	(0/5)	(0/14)
Focal hypertrophy	(0/13)	(0/25)	(0/0)	(0/9)	(0/21)	(0/13)	(0/0)	(0/1)	(0/58)	(0/50)	(0/5)	(0/14)
Hepatocellular Necrosis	15.4(2/13)	28.0(7/25)	(0/0)	22.2(2/9)	4.5(2/21)	(0/13)	(0/0)	(0/1)	8.6(5/58)	12.0(6/50)	(0/5)	(0/14)
Cholangioproliferative Foci	(0/13)	(0/25)	(0/0)	(0/9)	(0/21)	(0/13)	(0/0)	(0/1)	1.7(1/58)	(0/50)	(0/5)	(0/14)
Focal Hyperplasia	(0/13)	(0/25)	(0/0)	(0/9)	(0/21)	(0/13)	(0/0)	(0/1)	1.7(1/58)	(0/50)	(0/5)	(0/14)
Sclerotic Foci	(0/13)	(0/25)	(0/0)	(0/9)	(0/21)	(0/13)	(0/0)	(0/1)	1.7(1/58)	(0/50)	(0/5)	(0/14)
Nuclear Pleomorphism	(0/13)	(0/25)	(0/0)	(0/9)	(0/21)	(0/13)	(0/0)	(0/1)	1.7(1/58)	(0/50)	(0/5)	(0/14)
<u>Pacific Tomcod</u>												
Megalocytic Hepatosis	(0/5)	(0/9)	(0/20)	(0/27)	(0/59)	(0/59)	(0/2)	(0/8)	(0/111)	(0/82)	(0/34)	(0/17)
Focal hypertrophy	(0/5)	(0/9)	(0/20)	(0/27)	(0/59)	(0/59)	(0/2)	(0/8)	0.9%(1/111)	(0/82)	(0/34)	5.9%(1/17)
Hepatocellular Necrosis	(0/5)	(0/9)	10.0%(2/20)	3.7%(1/27)	1.7%(1/59)	1.9%(1/53)	(0/2)	(0/8)	3.6%(4/111)	6.1%(5/82)	2.9%(1/34)	5.9%(1/17)
Cholangioproliferative Foci	(0/5)	(0/9)	(0/20)	(0/27)	1.7%(1/59)	(0/53)	(0/2)	(0/8)	2.7%(3/111)	(0/82)	(0/34)	(0/17)
Focal Hyperplasia	(0/5)	(0/9)	(0/20)	(0/27)	(0/59)	(0/53)	(0/2)	(0/8)	(0/111)	(0/82)	(0/34)	(0/17)
Sclerotic Foci	(0/5)	(0/9)	10.0%(2/20)	3.7%(1/27)	1.7%(1/59)	5.7%(3/53)	(0/2)	(0/8)	6.3%(7/111)	6.1%(5/82)	11.8%(4/34)	(0/17)
Nuclear Pleomorphism	(0/5)	(0/9)	(0/20)	(0/27)	(0/59)	(0/53)	(0/2)	(0/8)	(0/111)	1.2%(1/82)	(0/34)	(0/17)
<u>Quillback rockfish</u>												
Hepatocellular necrosis	(0/0)	(0/0)	(0/14)	(0/0)	(0/21)	6(3/47)	3(1/32)	(0/17)	(0/9)	(0/2)	(0/6)	(0/4)
RLH (Gill)	(0/0)	(0/0)	(0/14)	(0/0)	11(2/19)	36(14/39)	17(4/24)	(0/15)	43(3/7)	100(2/2)	(0/3)	50(1/2)
Glomerular disruption (Kidney)	(0/0)	(0/0)	(0/1)	(0/0)	14(2/14)	3(1/29)	(0/20)	(0/19)	7(1/15)	(0/2)	(0/1)	(0/3)
Sclerotic foci	(0/0)	(0/0)	(0/14)	(0/0)	(0/21)	(0/47)	3(1/32)	(0/17)	(0/9)	(0/2)	(0/6)	(0/4)

Table 23. Mean number of hepatic lesions among diseased fish. Values indicated are ratios of the total number of incidences of hepatic lesions to the total number of animals diagnosed with one or more of the conditions. A mean lesion frequency of 1.00 indicated no multiple lesions occurred. Only subareas with multiple lesion-bearing fish are shown. Cells containing a dashed line indicate no occurrence of any of the considered lesions.

Total # lesions  
# affected animals

Species	Budd	Duwamish	Seattle Waterfront	Outer Elliott	Hylebos	Commencement Waterways	Southwest Commencement	Brown's Point
English sole	-- (0/0)	1.44 (39/27)	1.00 (6/6)	-- (0/0)	1.86 (26/14)	1.82 (40/22)	-- (0/0)	1.50 (3/2)
Rock sole	2.00 (2/1)	1.36 (30/22)	1.11 (10/9)	2.00 (2/1)	1.33 (4/3)	1.10 (11/10)	1.00 (5/5)	-- (0/0)
Pacific tomcod	-- (0/0)	2.00 (2/1)	-- (0/0)	-- (0/0)	1.00 (5/5)	2.00 (2/1)	-- (0/0)	-- (0/0)



Table 24. Combinations of multiple hepatic lesions, location of affected animals, and frequency of occurrence of combinations.

No. of Lesions in Combination	Combinations Multiple of Lesions	Subarea	Species	No. of animals affected
2	Megalocytic hepatitis (MH) and Focal Hypertrophy (FH)	Duwamish	English sole	3
		Hylebos	English sole	1
		" "	Rock sole	1
		Commencement Waterways	English sole	1
		" "	Pacific tomcod	1
2	MH and Focal Hyperplasia (FHH)	Duwamish	Rock sole	2
		Commencement Waterways	Rock sole	2
2	MH and Adenomatous Foci (AF)	Duwamish	English sole	2
2	MH and Cholangioproliferative Foci (CF)	Duwamish	Rock sole	1
		Seattle Waterfront	Rock sole	1
2	MH and Nuclear Pleomorphism (NP)	Outer Elliott	Rock sole	1
		Brown's Point	English sole	1
2	FH and NP	Budd Inlet	Rock sole	1
		Hylebos	English sole	1
2	NP and CF	Duwamish	Rock sole	1
3	MH, FH, and FHH	Duwamish	Rock sole	1
		Hylebos	English sole	1
		Commencement Waterways	English sole	1
3	MH, FH, and NP	Duwamish	English sole	1
		Commencement Waterways	English sole	2
3	MH, FH, and CF	Duwamish	Rock sole	1

Table 24. (Continued)

No. of Lesions in Combination	Combinations of Multiple Lesions	Subarea	Species	No. of animals affected
3	MH, FH, and AF	Duwamish	English sole	1
3	MH, NP, and FHH	Commencement Waterways	English sole	1
3	FH, CF, and AF	Hylebos	English sole	1
4	MH, FH, FHH and AF	Hylebos	English sole	1
4	MH, FH, FHH and AF	Commencement Waterways	English sole	1
4	MH, FH, CF, and AF	Duwamish	English sole	1
4	MH, FH, CF, and FHH	Commencement Waterways	English sole	1
4	MH, FH, CF, and NP	Commencement Waterways	English sole	1
4	MH, NP, CF, and FHH	Hylebos	English sole	1

Table 25. Annual neoplastic lesion frequency by subarea among target fish species. Values indicated are ratios of the total number of animals afflicted by Adenomatous Foci (AF) and/or Cholangioproliferative Foci (CF) to the total number of animals examined, multiplied by 100. Cells containing a dashed line indicate no occurrence of neoplastic lesions.

Total Annual Neoplastic Lesions Frequency

$$\frac{\# \text{ animals} = \text{AF and/or CF}}{\# \text{ animals examined}} \times 100$$

Species	Subarea				
	Duwamish	Seattle Waterfront	Hylebos	Commencement Waterways	Southwest Commencement
English sole	2.4% (5/210)	--	2.3% (3/129)	2.2% (3/138)	--
Rock sole	2.1% (3/142)	1.4% (1/71)	--	--	2.7% (2/75)
Pacific staghorn sculpin	--	--	1.7 % (1/58)	--	--
Pacific tomcod	3.4% (2/59)	--	2.6% (3/111)	--	--

Table 26. Summary of hepatic lesions found in English sole, rock sole, starry flounder, and Pacific tomcod at 33 MESA sampling stations during 1979. Data are number of fish with each type of lesion. MH, megacalyptic hepatitis; HN, necrosis; FHH, focal hyperplasia; NP, nuclear pleomorphism; AF, adenomatous foci; FH, focal hypertrophy; CF, bile duct proliferation; SF, sclerotic foci; G, value of the G-statistic. Percentage of fish affected by hepatic lesions is less than incidence of hepatic lesions due to occurrence of multiple lesions in some fish. [ $\chi^2(0.05,1) = 3.841$ ;  $\chi^2(0.01,1) = 6.635$ ;  $\chi^2(0.001,1) = 10.828$ ].

Embayment	Station Number	MH	HN	FHH	NP	AF	FH	CF	HSF	Total No. Hepatic Lesions	Number of Fish Examined	Incidence (%)	Value of G Statistic
Sinclair Inlet	8004	0	4	1	0	0	1	0	0	6	45	12.2	.517
"	8005	0	5	1	0	0	0	0	1	7	59	11.9	.818
"	8006	0	2	2	0	0	0	0	0	4	58	6.9	3.945*
Port Madison	8106	0	1	0	0	0	0	0	0	1	12	8.3	.179
"	8107	1	3	3	0	0	0	0	2	9	57	15.8	.015
Commencement Bay													
Hylebos Waterway	9027	4	8	3	2	1	3	4	1	26	93	28.0	4.872*
"	9028	3	5	1	0	1	1	0	1	12	53	12.9	.912
Blair Waterway	9029	5	4	2	0	0	2	0	4	17	97	17.5	.006
Sitcum Waterway	9030	10	10	7	5	1	7	2	0	42	81	51.9	37.068***
City Waterway	9031	4	3	2	2	0	1	1	0	13	95	13.7	.589
Puyallup	9032	1	8	2	1	0	0	1	1	14	66	21.2	.364
Between Hylebos and Blair Waterway	9033	1	4	4	1	0	4	1	2	17	83	20.5	.310
Brown's Pt. S. side	9034	1	3	0	0	0	0	1	4	9	95	9.5	3.600
Sewage Plant	9035	0	3	0	3	0	0	0	1	7	92	7.6	5.753*
Tacoma Yacht Club	9036	0	4	0	0	0	0	2	3	9	93	9.7	3.299
Brown's Pt. N. side	9037	3	4	0	1	0	1	0	1	10	107	9.3	4.305*
Old Tacoma	9039	0	0	0	0	0	0	0	0	0	9	0	.984
Elliott Bay													
Magnolia Bluff	10014	0	4	0	1	0	1	0	0	6	78	7.7	4.638*
Pier 54	10015	2	3	1	3	0	0	0	2	11	70	15.7	.034
Harbor Is. N. end	10016	10	9	0	3	1	4	3	0	30	80	37.5	13.933***
West Point	10023	0	4	0	0	0	0	0	0	4	68	5.9	6.035*
Alki Point	10028	0	2	0	0	0	0	0	0	2	59	3.4	8.552**
Duwamish Waterway	10031	14	8	2	2	3	5	3	0	37	111	33.3	13.038***
"	10038	9	8	1	3	0	4	0	0	25	116	21.6	.953
"	10039	3	7	0	2	0	2	1	1	16	60	26.7	2.243
Pier 70	10040	3	7	0	2	0	0	0	1	13	64	20.3	.178
N. of Pier 70	10041	10	6	1	1	0	0	1	0	19	85	22.4	.931
Mid. Elliott	10044	0	1	0	0	0	0	0	0	1	21	4.8	1.630
Duwamish Head	10045	4	7	0	0	1	0	0	0	12	66	18.2	.000
Case Inlet	12062	0	3	1	0	0	0	0	0	4	38	10.5	.753
"	12063	0	4	0	0	0	0	0	0	4	37	10.8	.645
"	12131	0	6	0	0	0	0	0	0	6	63	9.5	2.141
Budd Inlet	12132	1	6	0	0	0	0	0	0	7	54	13.0	.404
SUM		89	156	34	32	8	36	20	25	400	2309	15.697	
MEAN		2.70	4.73	1.03	.97	.24	1.09	.61	.76	12.12	69.97		

\* - Result significant at the 0.05 level  
 \*\* - Result significant at the 0.01 level  
 \*\*\* - Result significant at the 0.001 level

Table 27. Size and age of English sole with and without abnormalities captured in winter and spring.

Condition	Number of adults (>150 mm)	Avg. length (mm)	Range	Avg. Age	Range	Numbers of juveniles	Avg. Length	Range	Avg. Age	Range
MH	16	287.7	235-377	8.0	5-11	2	131.0	122-140	3	3
AF	7	305.0	228-350	7.2	6-9					
FH	7	283.86	228-313	7.4	6-9	1	122		3	
FHH	8	301.38	183-377	7.6	4-12					
CF	1	301		9						
Normal-appearing	284	266.73								

Table 28. Size and age of rock sole with and without abnormalities captured in winter and spring.

Condition	Number of adults (>150 mm)	Avg. Length (mm)	Range	Avg. Age	Range	Numbers of juveniles	Avg. Length	Range	Avg. Age	Range
MH	20	229.6	170-348	5.5	3-13	1	72.0		1.0	
CF	3	202.3	195-210	5.3	5-6					
FH	3	216.3	195-252	6.7	5-9					
NP	3	209.0	196-221	5.3	4-6	2	90.0	87-93	1.0	
FHH	5	268.8	196-348	7.6	5-13					
Normal-appearing	229	216.5								



Table 29. Numbers and types of invertebrates examined for gross and microscopic lesions.

	Port Madison	Case Inlet	Budd Inlet	Sinclair Inlet	Elliott Bay	Commencement Bay
Bivalves <sup>a</sup>	19	8	6	18	2	7
<u>Crangon alaskensis</u>	0	36	42	48	4	0
<u>Pandalus danae</u>	0	8	4	9	56	59
<u>Pandalus jordani</u>	<u>9</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>103</u>	<u>0</u>
Total shrimp	9	44	46	57	163	59
<u>Cancer gracilis</u>	0	6	7	5	12	21
<u>Cancer magister</u>	0	0	0	0	26	9
<u>Cancer productus</u>	<u>0</u>	<u>4</u>	<u>0</u>	<u>1</u>	<u>4</u>	<u>0</u>
Total crabs	0	10	7	6	42	30
Polychaetes <sup>b</sup>	3	0	8	2	8	64

<sup>a</sup> Bivalves = (Acila castrensis, Macoma carlottensis and Macoma nasuta combined)

<sup>b</sup> Polychaetes = (Capitella capitata, Glycera capitata, Prionospio pinnata)

Table 30. Infaunal Trophic Index values for all sampling stations.

Embayment	MESA Number	Station Number	Approx. Location	Infaunal Index Mean and (Standard Deviation) Sampling Time			
				Winter	Spring	Summer	Fall
Sinclair Inlet	08004	1	S.W. Sinclair Inlet	67 (0/8)	67 (5.0)	68 (1.5)	68 (2.1)
"	08005	2	Sinclair Inlet	65 (1.7)	68 (3.7)	70 (4.8)	68 (5.4)
"	08006	3	Point Turner	67 (5.9)	67 (3.8)	69 (4.2)	67 (1.5)
Port Madison	08106	1	Port Madison	55 (5.8)	58 (6.0)	65 (2.0)	65 (2.6)
"	08107	2	Indianola	73 (4.3)	74 (7.8)	66 (3.8)	66 (3.2)
Commencement Bay	09027	1	Hylebos Basin	67 (1.7)	61 (6.4)	67 (0.0)	67 (6.5)
"	09028	2	Hylebos Bridge	52 (11)	63 (7.6)	51 (6.7)	55 (11)
"	09029	3	Blair Waterway	66 (2.2)	69 (2.5)	65 (3.0)	64 (3.1)
"	09030	4	Sitcum Waterway	65 (2.4)	63 (5.0)	45 (19)	42 (3.3)
"	09031	5	City Waterway	57 (6.5)	56 (4.8)	58 (4.6)	58 (8.7)
"	09032	6	Puyallup Waterway	24 (29)	30 (15)	13 (20)	None*
"	09033	7	Hylebos Outer	64 (3.6)	66 (2.0)	60 (1.9)	52 (2.0)
"	09034	8	Browns Point South	59 (7.6)	64 (3.4)	64 (3.3)	42 (3.3)
"	09035	9	Tacoma Corinthian Y.C.	None	72 (4.3)	71 (3.4)	64 (7.4)
"	09036	10	Tacoma Yacht Club	68 (7.2)	76 (4.7)	75 (6.6)	66 (11)
"	09037	11	Browns Point	None	71 (1.7)	75 (6.2)	67 (2.8)
"	09042	22	Tacoma Stadium H.S.	None	None	None	59 (1.9)

\* No organisms found

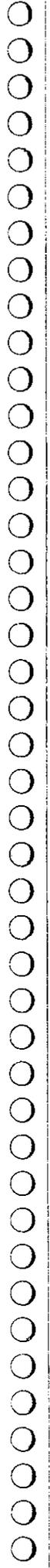


Table 30. (Continued)

Embayment	MESA Number	Station Number	Approx. Location	Infaunal Index Mean and (Standard Deviation)			
				Winter	Spring	Summer	Fall
Elliott Bay	10031	1	Harbor Island South	70 (7.7)	67 (7.4)	72 (3.9)	67 (1.7)
"	10038	2	West Waterway	65 (2.9)	65 (4.5)	63 (5.7)	60 (5.2)
"	10039	3	East Waterway	66 (2.5)	65 (3.0)	59 (4.9)	61 (6.5)
"	10016	4	Harbor Island North	64 (6.0)	72 (9.3)	70 (5.3)	63 (6.5)
"	10015	5	Pier 54	None	72 (6.2)	72 (7.4)	70 (7.7)
"	10040	6	Pier 69	None	68 (7.2)	71 (5.0)	69 (9.5)
"	10044	7	Elliott Bay	70 (4.0)	77 (5.0)	75 (6.1)	83 (14)
"	10041	8	Myrtle Edwards Park	70 (13)	67 (0.0)	77 (3.2)	83 (11)
"	10014	9	Magnolia Bluff	72 (3.9)	75 (4.6)	86 (5.0)	78 (5.2)
"	10045	10	Pier 3	66 (3.0)	65 (6.6)	67 (3.0)	63 (5.5)
"	10028	11	Alki Point	70 (6.3)	79 (10)	67 (6.0)	70 (4.0)
"	10023	12	West Point	69 (6.6)	69 (7.4)	68 (3.8)	66 (2.2)
Case Inlet	12062	1	Reach Island	85 (8.5)	83 (11)	73 (10)	None
"	12063	2	Stretch Island	95 (5.8)	79 (5.7)	69 (13)	89 (5.8)
Budd Inlet	12131	2	Ellis Creek	82 (15)	47 (33)	67 (5.8)	None
"	12132	3	Olympia Shoal	28 (14)	42 (30)	75 (6.1)	77 (11)
"	12133	4	Dofflemeyer Point	50 (15)	75 (6.6)	70 (5.4)	78 (7.6)
	$\bar{x}$			66.0	67.6	67.8	66.3

Table 31. The number of individuals of crab and shrimp species collected at each area during each season.

Area	<i>Pandalus danae</i>	<i>Pandalus jordani</i>	<i>Crangon alaskensis</i>	<i>Cancer gracilis</i>	<i>Cancer magister</i>	<i>Cancer productus</i>
Elliott Bay						
Fall	55	1,723	0	4	11	1
Winter	25	98	0	0	1	1
Spring	10	10	17	0	2	0
Summer	9	516	4	4	13	1
Commencement Bay						
Fall	69	214	2	6	0	0
Winter	42	9	7	3	3	0
Spring	14	1	4	8	6	0
Summer	41	91	5	5	1	0
Sinclair Inlet						
Fall	204	0	17	3	0	2
Winter	1	0	6	0	0	0
Spring	2	0	3	4	0	0
Summer	11	0	37	1	0	1
Budd Inlet						
Fall	55	0	11	5	0	2
Winter	2	0	2	0	0	0
Spring	4	0	11	2	0	0
Summer	1	0	98	4	0	0
Case Inlet						
Fall	17	0	51	5	0	0
Winter	0	0	6	0	0	0
Spring	2	0	13	0	0	3
Summer	8	0	71	2	0	0
Port Madison						
Fall	2	69	1	0	0	0
Winter	0	10	0	0	0	0
Spring	0	10	0	0	0	0
Summer	0	158	2	0	0	0

Table 32. Ratio of the average sediment concentrations of selected metals in subareas of Central Puget Sound to previously reported concentrations of nearshore sediments from Puget Sound and other marine areas.

Subarea	Metal						
	As	Cr <sup>a</sup>	Cu	Hg	Mn <sup>a</sup>	Ni	Pb
Case Inlet	-	0.7	0.6	0.7	0.6	0.6	0.8
Port Madison	-	0.7	0.4	0.8	0.6	0.6	0.8
Budd Inlet	4	0.9	1	2	0.5	0.8	2
Sinclair Inlet	-	1	3	9	0.8	0.9	5
Outer Elliott	-	0.7	0.8	2	0.9	0.6	2
West Point	-	0.7	0.4	1	0.6	0.8	0.8
Seattle Waterfront	-	1	2	7	0.9	1	4
Duwamish Waterway	5	1	2	6	1	0.7	10
Brown's Point	-	0.6	0.5	0.6	0.5	0.4	0.9
Southwest Commencement Bay	-	0.6	2	2	1	0.6	4
Commencement Bay Waterways	6 <sup>b</sup>	0.8	8 <sup>c</sup>	4	0.4	0.5	12
Hylebos Waterway	-	0.7	2	3	0.5	0.7	4
Average concentration (ug/g dry weight) for nearshore sediments	15 <sup>d</sup>	100 <sup>e,f</sup>	50 <sup>e,f</sup>	0.1 <sup>d</sup>	850 <sup>e</sup>	55 <sup>e,f</sup>	20 <sup>e,f</sup>

<sup>a</sup> Concentrations from Figure 1 multiplied by 2, to approximate concentration in total digest of sediment sample (Riley 1980).

<sup>b</sup> Only 1 sample of 5 (Sitcum Waterway) contained measurable amounts of "As" (470 µg/g, approximately 30 times average).

<sup>c</sup> Only 1 sample of 5 contained more than 4 times the average for nearshore sediments; Sitcum Waterway, 1,600 µg/g = 32 times average.

<sup>d</sup> Crecelius (1975)

<sup>e</sup> Chester and Aston (1976)

<sup>f</sup> Schell and Nevissi (1977)

Table 33. Etiologies and neoplastic potential of lesions observed in other studies with similar morphology to those found in this study.

Lesions	Results of toxic exposures in other studies	Reported as pre-neoplastic or neoplastic	Possible parasitic etiology	Reference
MH	X			Koller and Zinkl 1973, Hinton et al. 1978
FH	X			Fishbein 1974, Kasza et al. 1976
HN	X		X*	Couch 1975, Walsh and Ribelin 1975
FHH	X	X (preneoplastic)		Jones and Butler 1975, Sinnhuber et al. 1977
CF (organized)	X	X (neoplastic)	X*	Falkmer et al. 1976, 1977; Moulton 1978
CF (disorganized)	X	X (neoplastic)	X**	Falkmer et al. 1977, Moulton 1978
AF	X	X (neoplastic)		Jones and Butler 1975, Ashley 1967
NP	X			Newberne 1967, Eller 1971
HSF			unknown	
GD				
REH	X		X	Smith and Piper 1975, Eller 1975

\* Parasite - related necrosis and organized bile duct proliferation were observed in our study but were not reported with the idiopathic lesion frequency data.

\*\* Not observed in our study but reported to occur in other vertebrates

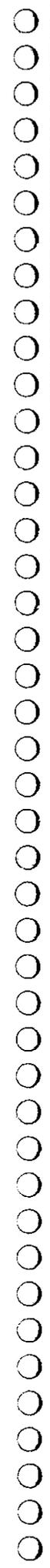


Table 34. Ranking of seven groups of sampling stations on the basis of three biological indices of toxic pollution. Groups were obtained by cluster analysis based on chemical data (Appendix E). Groups are ranked from most contaminated to least contaminated.

Fish hepatic lesions	Hepatopancreas abnormalities in crabs	No. of benthic infaunal invertebrate taxa
VI	V	III
III	III	VI
V	VI	V
II	II	II
IB	IB <sup>a</sup>	IV
IV	IV <sup>a</sup>	IB
IA	IA	IA

<sup>a</sup> Ranks tied; order arbitrary.

Table 35. Correlations among selected physical and chemical variables at 33 Puget Sound stations, spring, 1979 (depth data collected winter, 1979). Values are simple correlation coefficient (r), n (in parentheses), and significance level (S).

	DEPTH	MEANPHI	ARCNES	PCBS	CBDS	AS	PB	HG	CU	ZN	SE	CP
MEANPHI	-.0686 ( 32) S= .355											
ARCNES	-.1032 ( 32) S= .287	.1365 ( 32) S= .228										
PCBS	-.1571 ( 32) S= .145	.4364 ( 32) S= .006	.3842 ( 33) S= .014									
CBDS	-.0621 ( 32) S= .360	.1621 ( 32) S= .188	-.0247 ( 33) S= .446	.4513 ( 33) S= .004								
AS	-.1744 ( 32) S= .170	.3039 ( 32) S= .045	-.1009 ( 33) S= .288	.0501 ( 33) S= .391	-.1157 ( 33) S= .261							
PB	-.1400 ( 32) S= .149	.3386 ( 32) S= .029	.2150 ( 33) S= .115	.3710 ( 33) S= .017	-.0577 ( 33) S= .375	.7243 ( 33) S= .001						
HG	-.1184 ( 32) S= .254	.5653 ( 32) S= .001	.3862 ( 33) S= .013	.4524 ( 33) S= .003	-.0051 ( 33) S= .489	-.0001 ( 33) S= .500	.3179 ( 33) S= .036					
CU	-.1639 ( 32) S= .185	.1949 ( 32) S= .142	-.0228 ( 33) S= .450	.1129 ( 33) S= .260	.0030 ( 33) S= .493	.8124 ( 33) S= .001	.8145 ( 33) S= .001	.1762 ( 33) S= .163				
ZN	-.1681 ( 32) S= .179	.2348 ( 32) S= .098	.0007 ( 33) S= .498	.1408 ( 33) S= .217	-.0086 ( 33) S= .481	.8186 ( 33) S= .001	.8448 ( 33) S= .001	.2116 ( 33) S= .119	.9934 ( 33) S= .001			
SE	-.1332 ( 32) S= .234	.6663 ( 32) S= .001	.0427 ( 33) S= .407	.3656 ( 33) S= .018	-.0767 ( 33) S= .336	.4885 ( 33) S= .002	.3203 ( 33) S= .035	.1521 ( 33) S= .199	.0354 ( 33) S= .422	.0800 ( 33) S= .327		
CP	.0432 ( 32) S= .407	.6388 ( 32) S= .001	.1145 ( 33) S= .263	.3169 ( 33) S= .036	-.1498 ( 33) S= .203	.2709 ( 33) S= .064	.4752 ( 33) S= .003	.5705 ( 33) S= .001	.3223 ( 33) S= .034	.3630 ( 33) S= .012	.4226 ( 33) S= .007	
CD	-.1857 ( 32) S= .154	.7048 ( 32) S= .001	.0901 ( 33) S= .309	.3976 ( 33) S= .011	-.0435 ( 33) S= .405	.8066 ( 33) S= .001	.6719 ( 33) S= .001	.2773 ( 33) S= .059	.5603 ( 33) S= .001	.5938 ( 33) S= .001	.8693 ( 33) S= .001	.5761 ( 33) S= .001

Table 36. Correlations of three community indices for spring, 1979, infaunal samples with selected physical and chemical variables (physical and chemical data also collected spring, 1979). Values are simple correlation coefficient (r), n (in parentheses), and significance level (S).

	RICHNESS	TA	ITI
MEANPHI	-.4846 ( 64) S= .001	-.1651 ( 64) S= .096	-.3096 ( 62) S= .007
ARENES	-.0323 ( 64) S= .399	.0014 ( 64) S= .496	.0175 ( 62) S= .446
PCRS	-.2790 ( 64) S= .013	-.2181 ( 64) S= .042	-.0194 ( 62) S= .441
CBDS	.0059 ( 64) S= .482	.0044 ( 64) S= .486	-.0020 ( 62) S= .494
AS	-.2116 ( 64) S= .047	-.0353 ( 64) S= .391	-.0330 ( 62) S= .382
PS	-.1879 ( 64) S= .068	-.1102 ( 64) S= .193	-.0290 ( 62) S= .411
HG	-.3232 ( 64) S= .005	-.3485 ( 64) S= .002	.0230 ( 62) S= .430
CU	-.1274 ( 64) S= .159	-.0252 ( 64) S= .422	-.0102 ( 62) S= .469
7N	-.1411 ( 64) S= .133	-.0423 ( 64) S= .370	-.0108 ( 62) S= .467
SE	-.4279 ( 64) S= .001	-.1690 ( 64) S= .090	-.2047 ( 62) S= .055
CR	-.2227 ( 64) S= .038	-.2627 ( 64) S= .018	-.0739 ( 62) S= .284
CD	-.4539 ( 64) S= .001	-.1410 ( 64) S= .133	-.2240 ( 62) S= .040

Table 37. Coefficients of determination (multiple- $r^2$ ), significance level, and n (in parentheses) for best multiple regression equations for spring, 1979, infaunal sample community indices as functions of selected physical and chemical variables (physical and chemical data collected spring, 1979).

Community index	Spring, 1979 infaunal samples
Taxon richness	0.344 <sup>1</sup> (62)
Infaunal Trophic Index	0.288 <sup>2</sup> (60)
Total abundance	0.120 <sup>2</sup> (62)

<sup>1</sup> Overall regression significant at the 0.001 level.  
<sup>2</sup> Overall regression significant at the 0.01 level.

Table 38. Histologic condition of livers of English sole specimens described in Figure 78.

Specimen No.	Sample size (grams)	Site of Collection (subarea)	Liver Condition
120	2	Duwamish Waterway	Adenomatous foci
121	3	Duwamish Waterway	Adenomatous foci Focal Hypertrophy Megalocytic hepatitis
102*	11	Duwamish Waterway	2 with megalocytic hepatitis, 12 normal
104*	5	Outer Elliott	Normal
174	1	Hylebos Waterway	Adenomatous foci Focal hypertrophy Megalocytic hepatitis
178	2	Hylebos Waterway	Adenomatous foci Megalocytic hepatitis
180	2	Hylebos Waterway	Megalocytic hepatitis
113*	6	Hylebos Waterway	Normal
114*	2	Brown's Point	Normal
93*	10	Case Inlet	Normal
89*	10	Port Madison	Normal

\* denotes composite samples

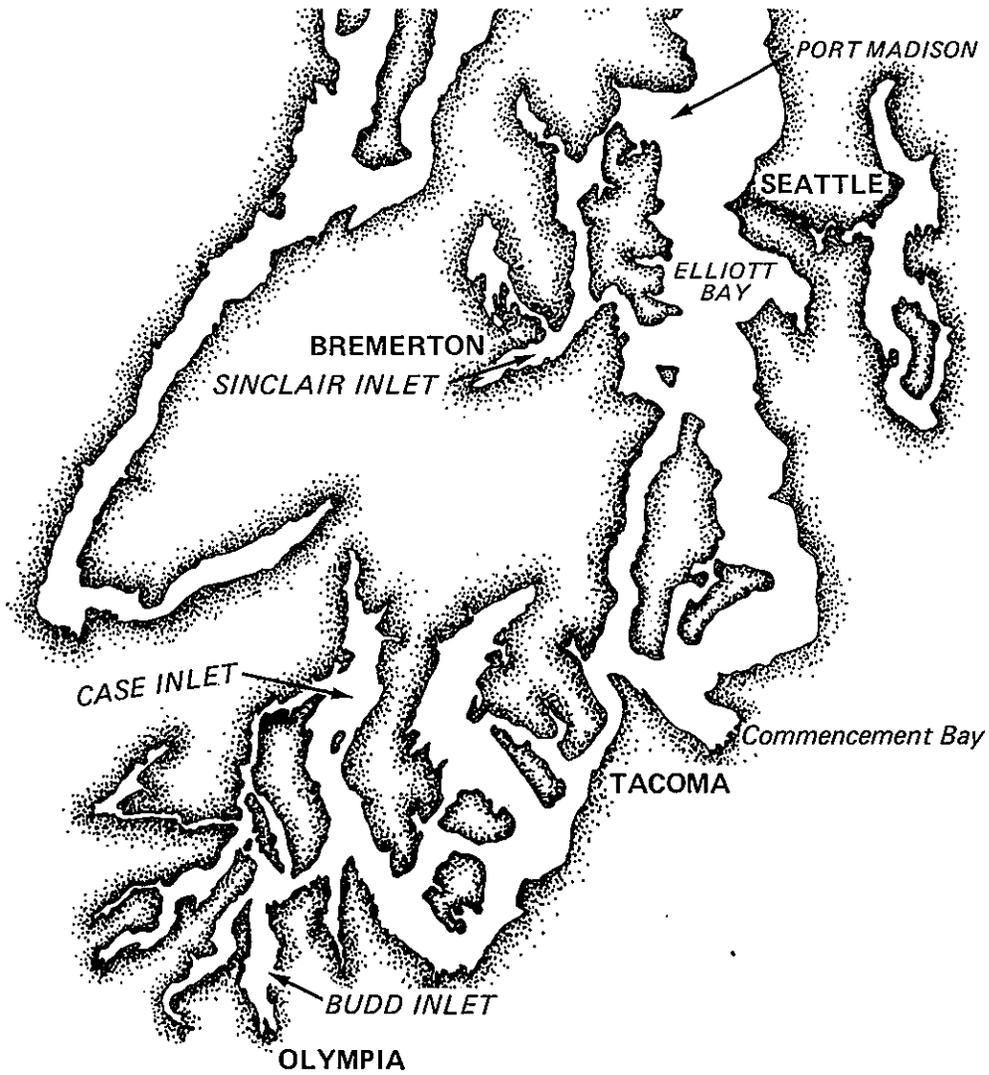


Figure 1. Locations of studied embayments in Central and Southern Puget Sound.

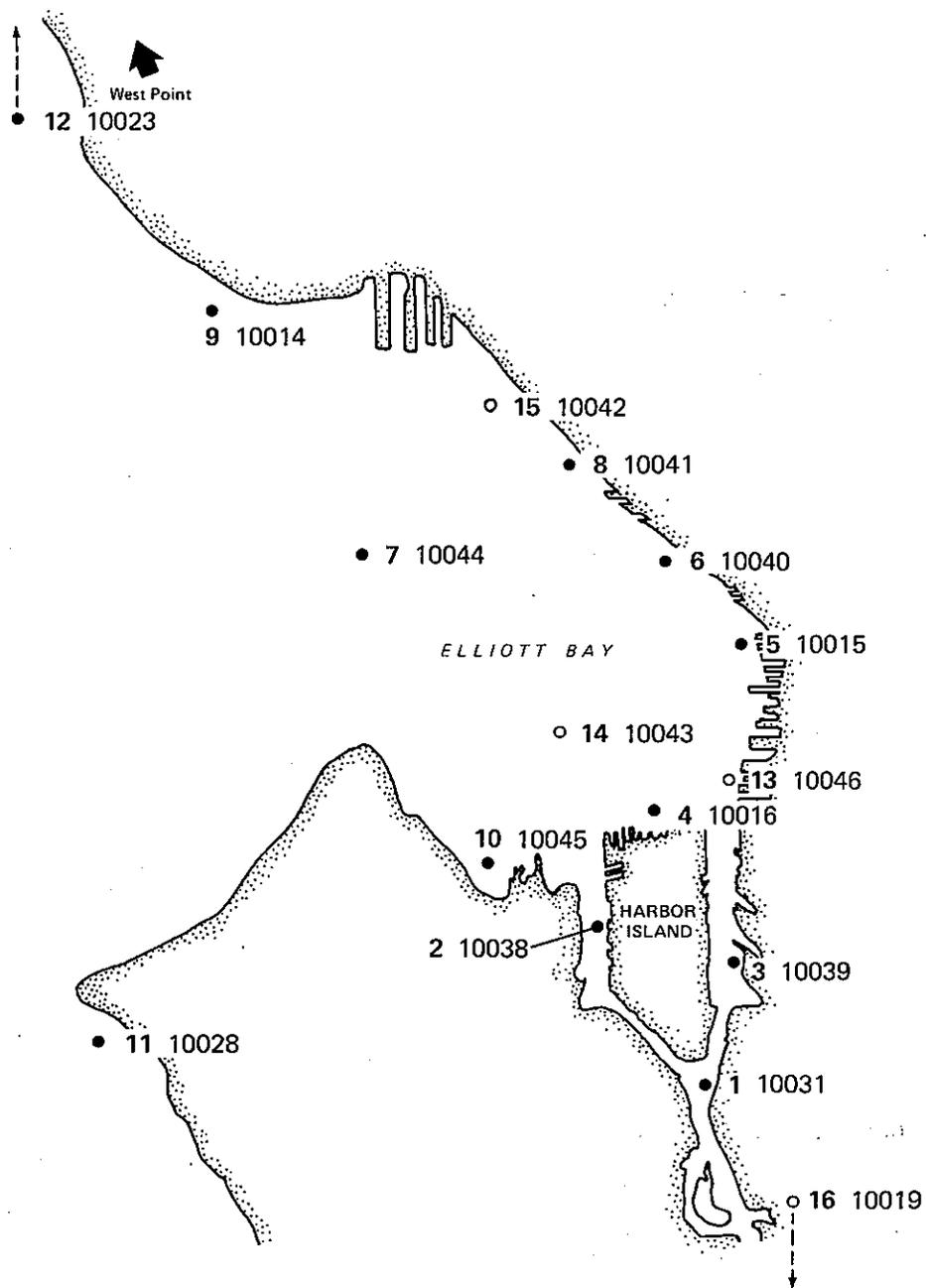


Figure 2. Locations of sampling stations in Elliott Bay. The first number at each station is the project identification number, and the second number is the MESA identification number. Closed circles (●) designate complete stations, while open circles (○) designate stations where sediment samples only were taken.

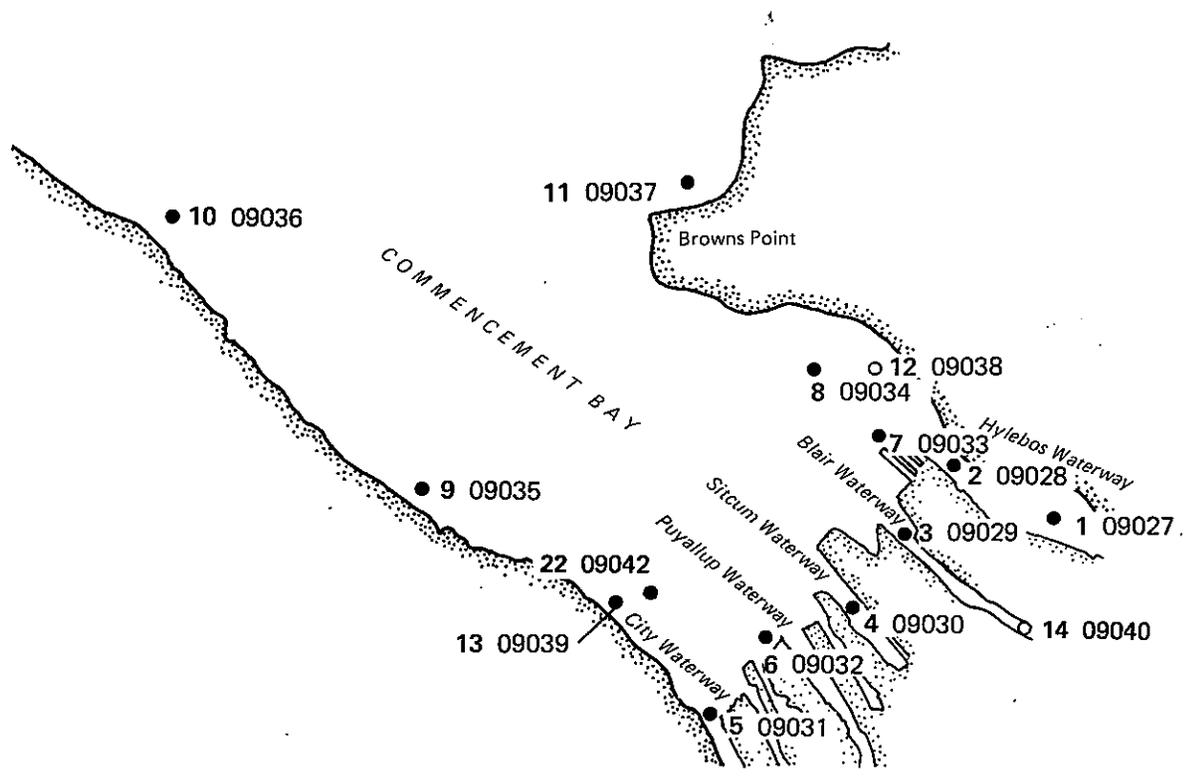


Figure 3. Locations of sampling stations in Commencement Bay. The first number at each station is the project identification number, and the second number is the MESA identification number. Closed circles (●) designate complete stations, while open circles (○) designate stations where sediment samples only were taken.

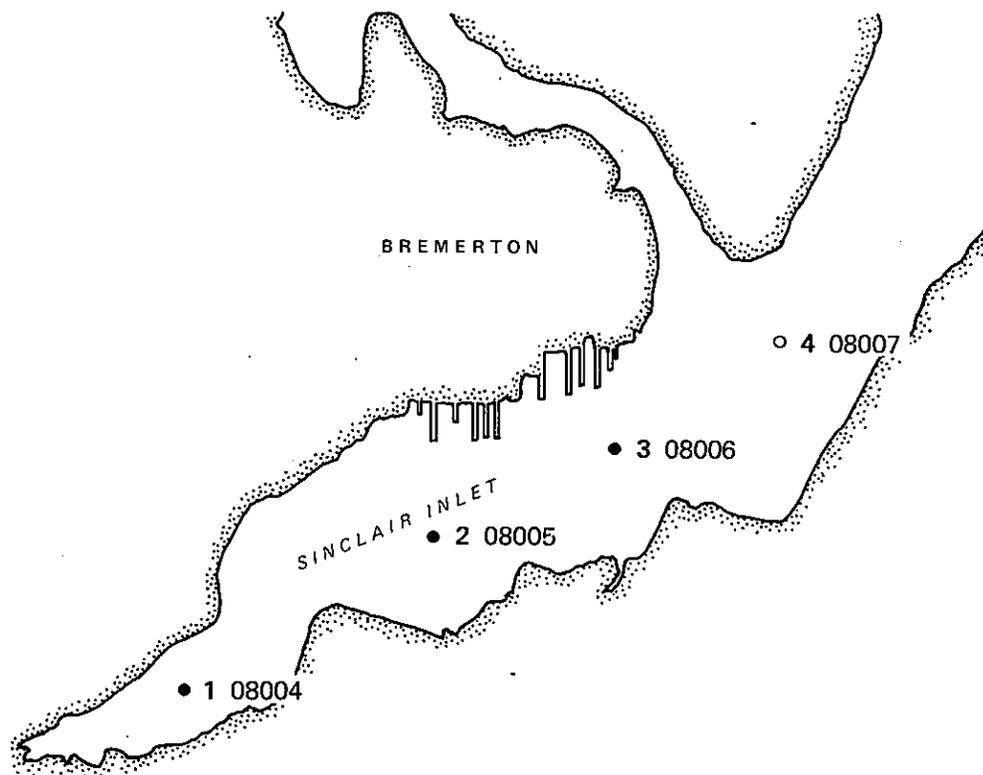


Figure 4. Locations of sampling stations in Sinclair Inlet. The first number at each station is the project identification number, and the second number is the MESA identification number. Closed circles (●) designate complete stations, while open circles (○) designate stations where sediment samples only were taken.

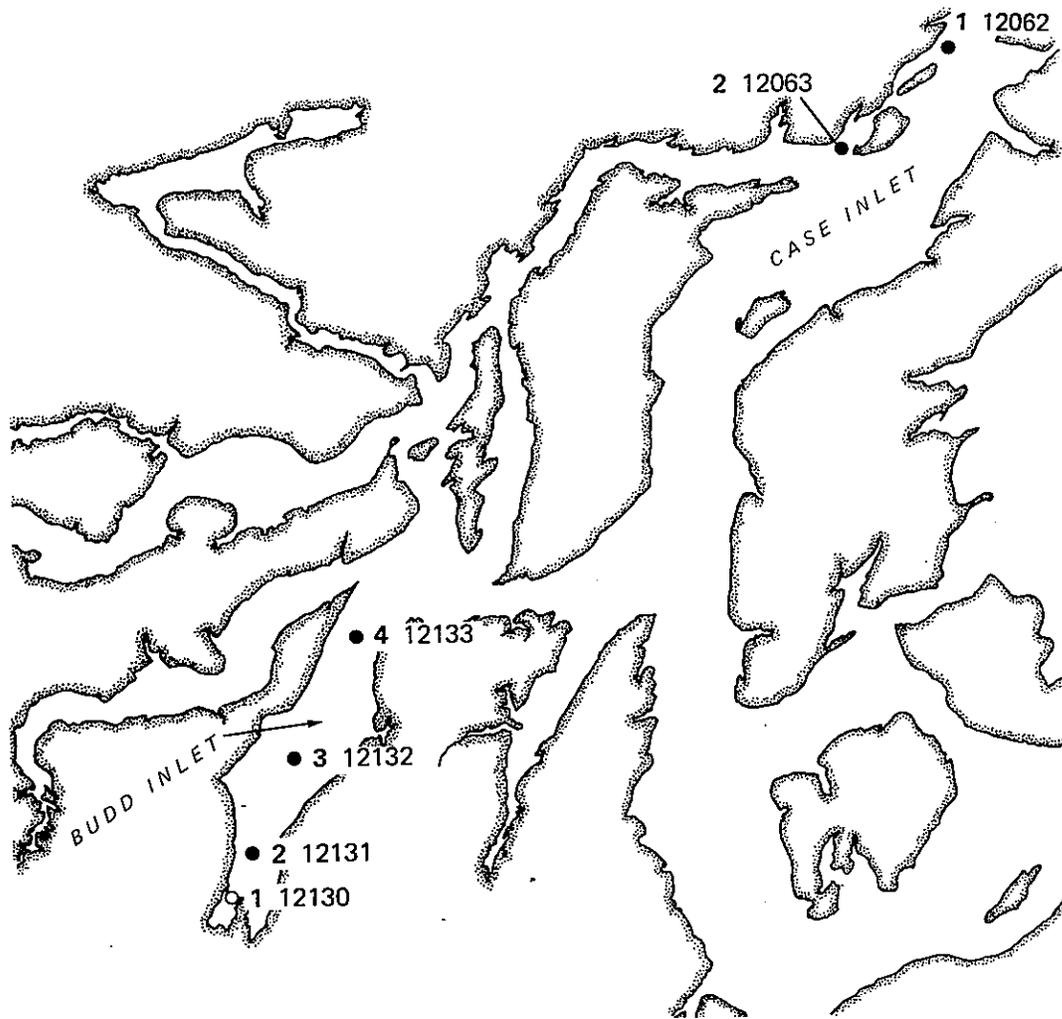
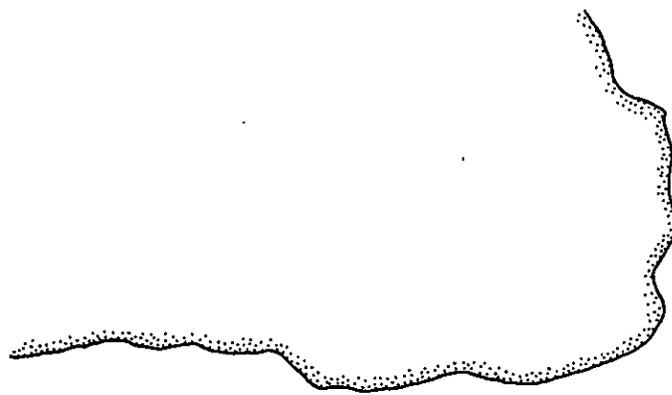


Figure 5. Locations of sampling stations in Case Inlet and Budd Inlet. The first number at each station is the project identification number, and the second number is the MESA identification number. Closed circles (●) designate complete stations, while open circles (○) designate stations where sediment samples only were taken.



● 2 08107

PORT MADISON

● 1 08106

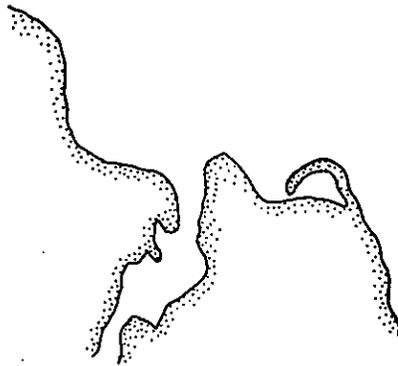


Figure 6. Locations of sampling stations in Port Madison. The first number at each station is the project identification number, and the second number is the MESA identification number. Closed circles (●) designate complete stations, while open circles (○) designate stations where sediment samples only were taken.

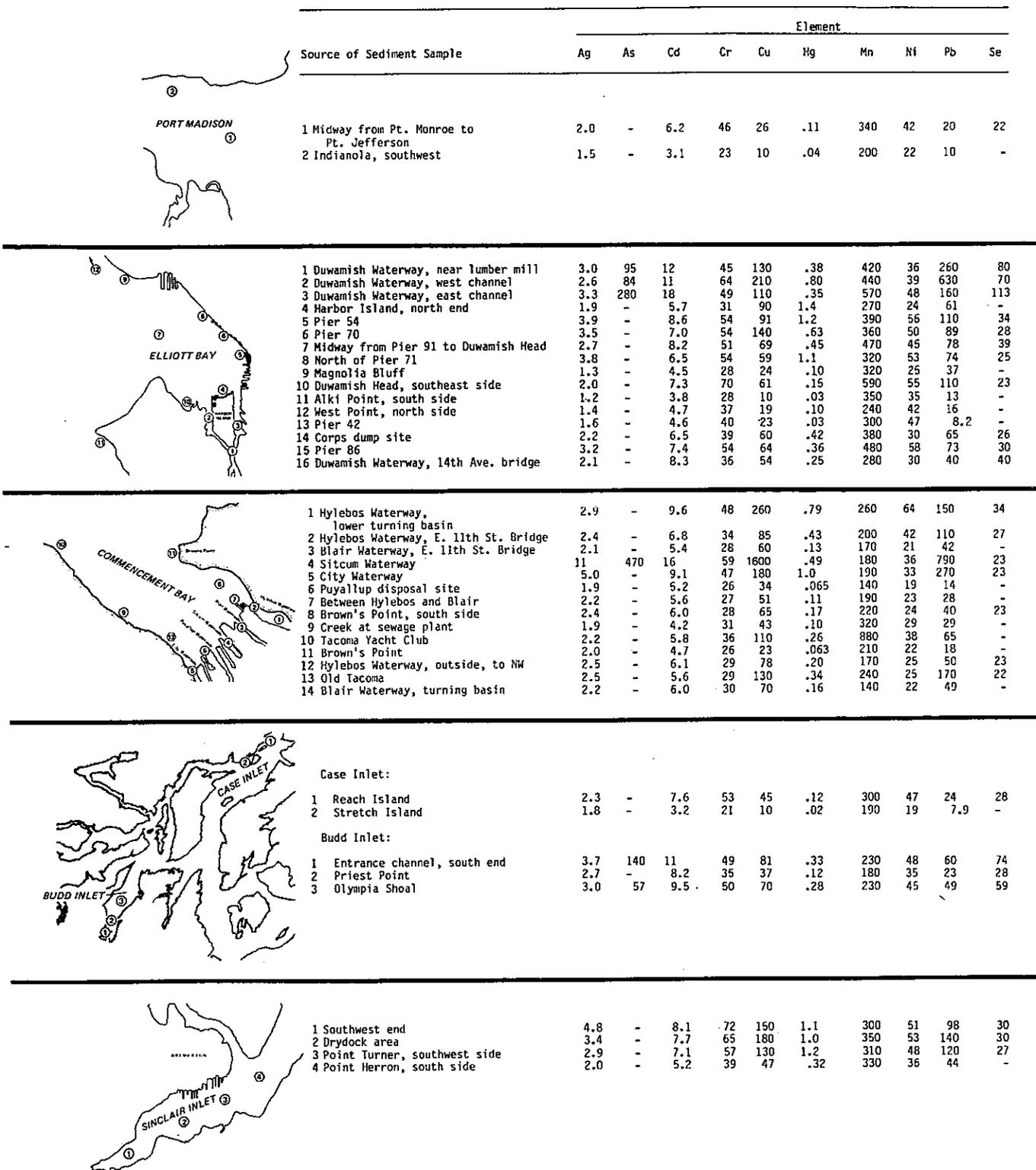


Figure 7. Concentrations, in  $\mu\text{g/g}$  dry weight (ppm), of selected metals in sediments from Central Puget Sound.

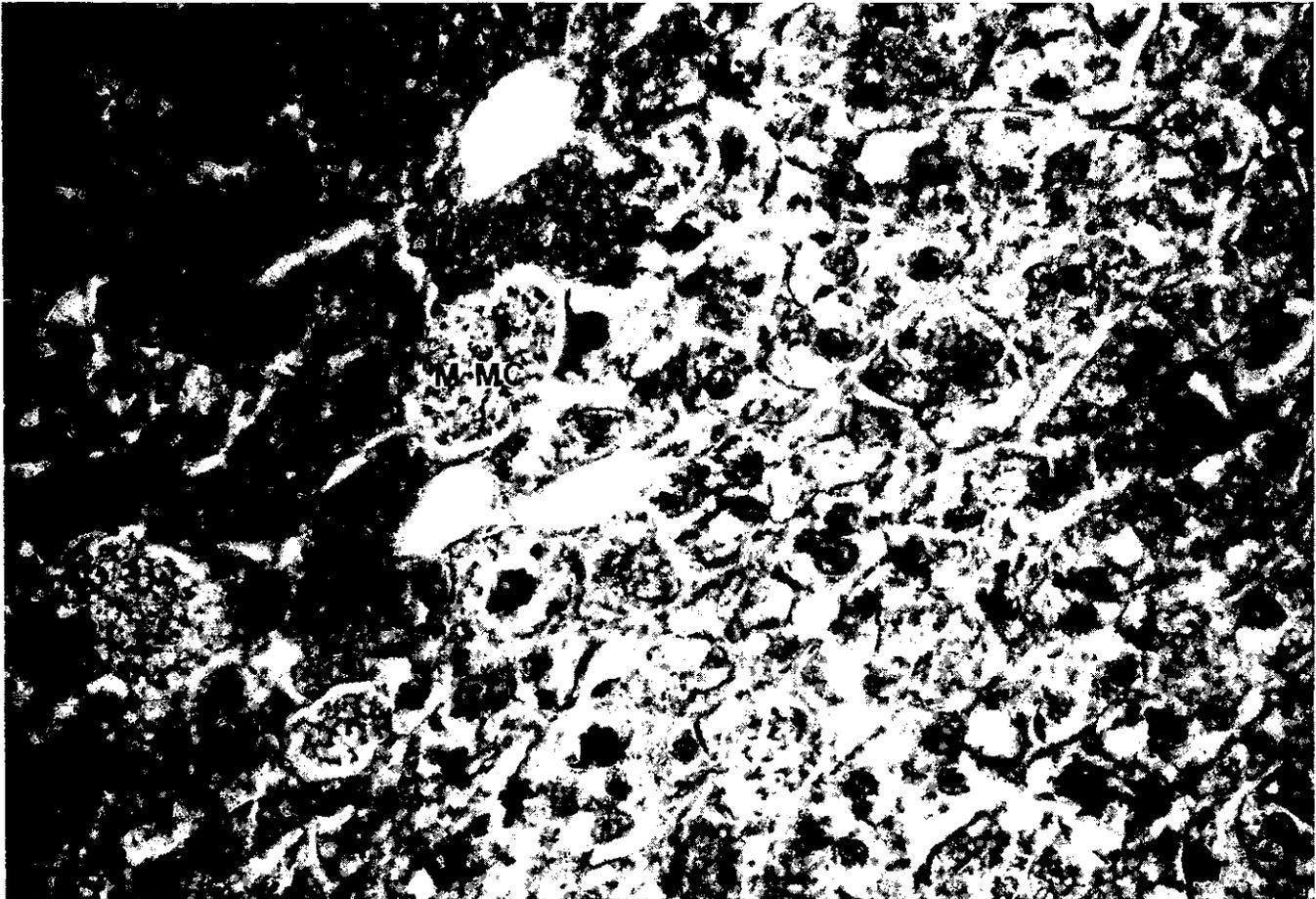


Figure 8. Megalocytic hepatosis in the liver of an English sole from station 4 (09030), Sitcum Waterway, in Commencement Bay. Cells in the center and right of the field have increased cell size and nuclear diameter. Normal hepatocytes are located to the upper left edge of the field. Several melanin-macrophage centers are also present. (M-MC) H & E 960X.

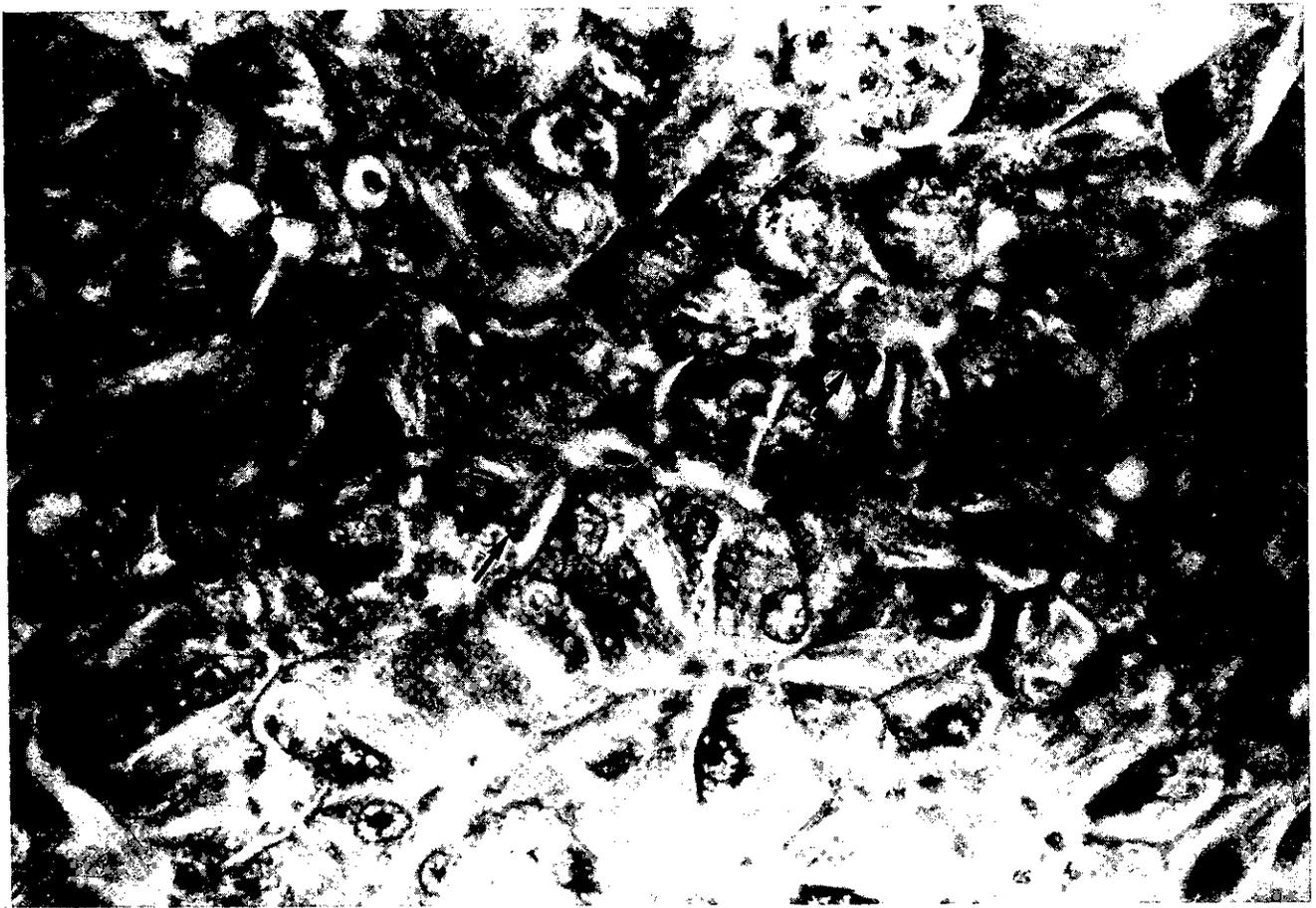


Figure 9. Megalocytic hepatitis in the liver of a rock sole from station 4 (10016) at the north end of Harbor Island in Elliott Bay. The cytoplasm of the enlarged hepatocytes has a fibrillar appearance. Spherical inclusions (arrows) and sinusoidal compression were also present. H & E 1920X.

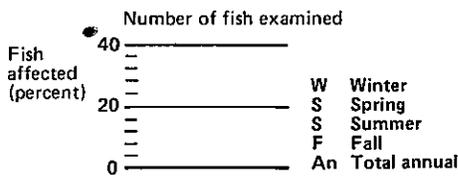
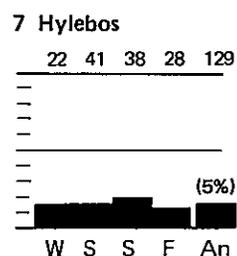
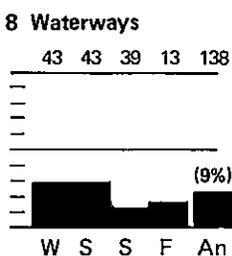
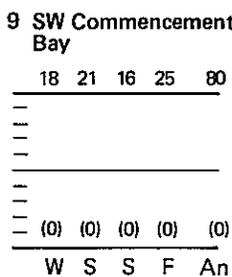
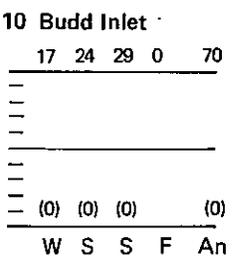
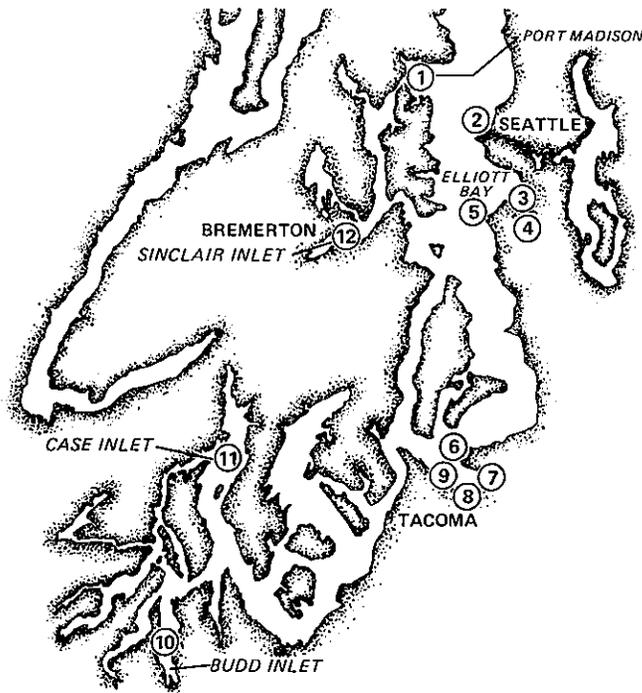
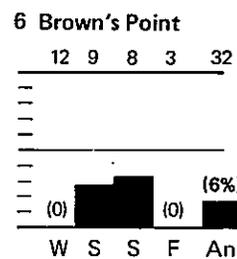
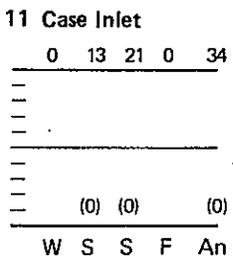
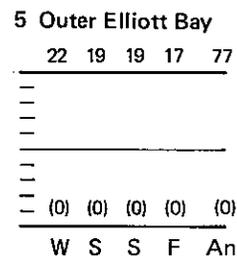
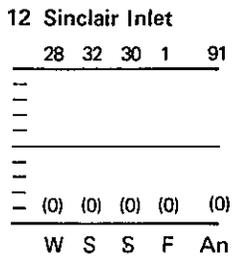
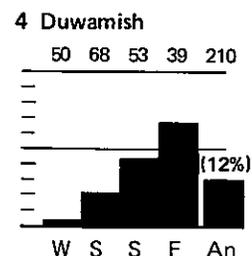
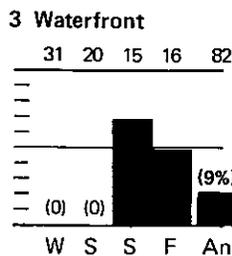
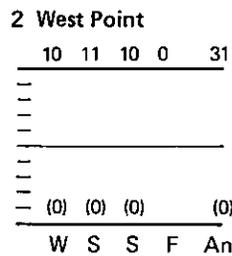
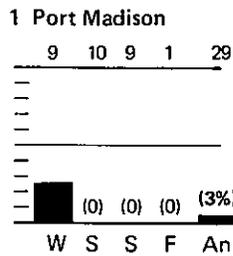


Figure 10. Seasonal and annual incidence of megalocytic hepatitis in English sole from each embayment or embayment subarea sampled.

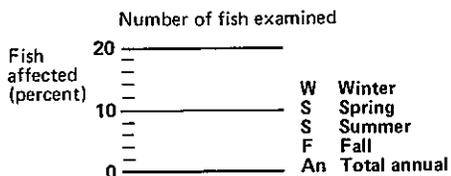
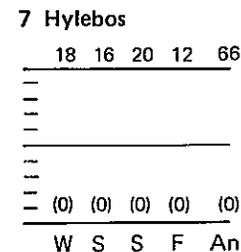
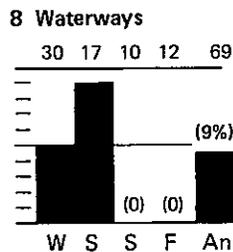
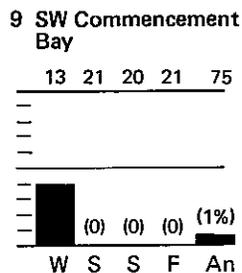
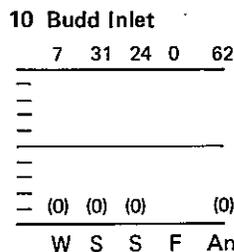
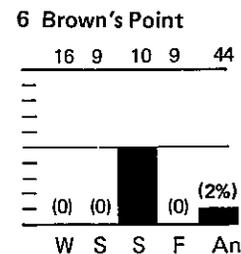
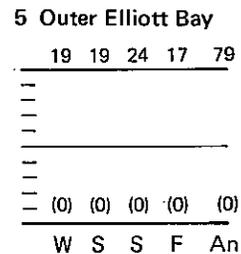
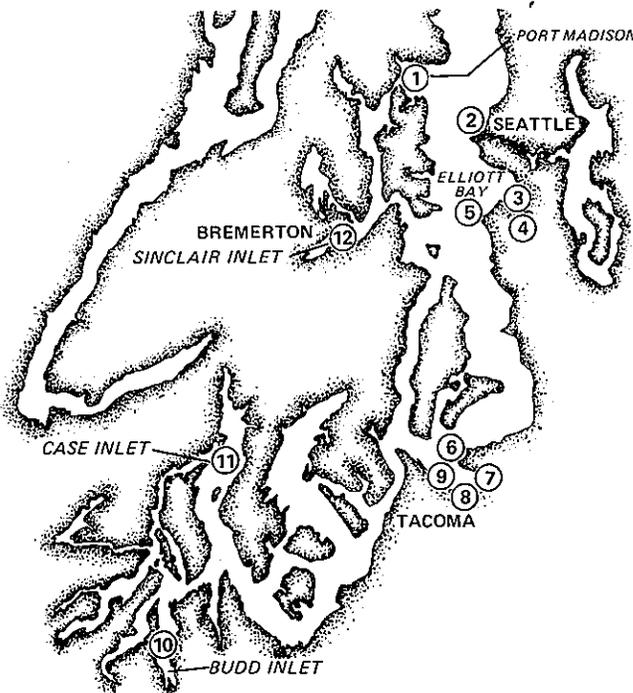
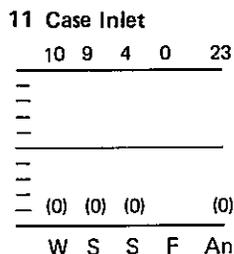
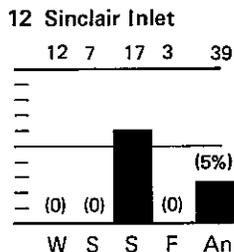
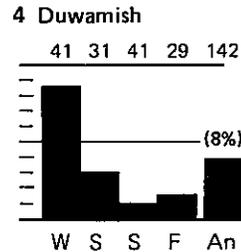
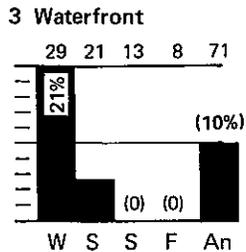
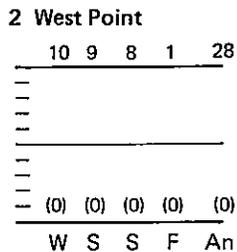
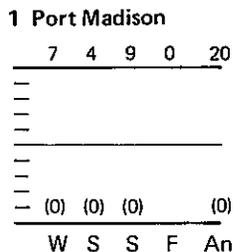


Figure 11. Seasonal and annual incidence of megalocytic hepatitis in rock sole from each embayment or embayment subarea sampled.

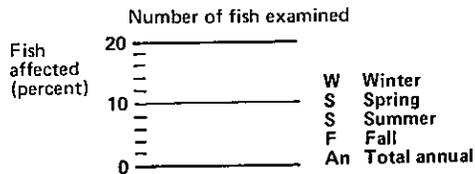
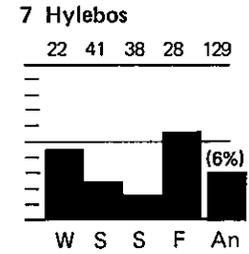
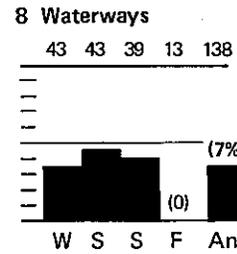
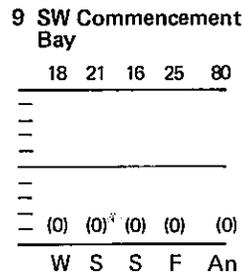
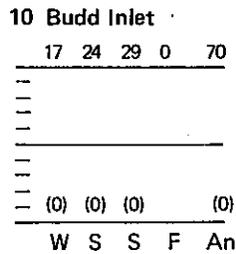
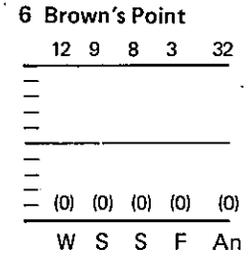
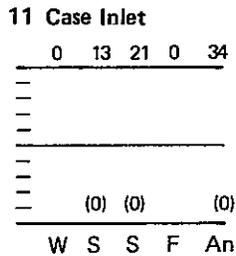
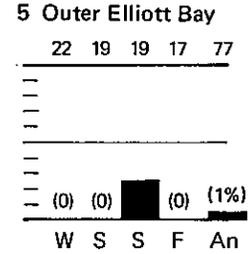
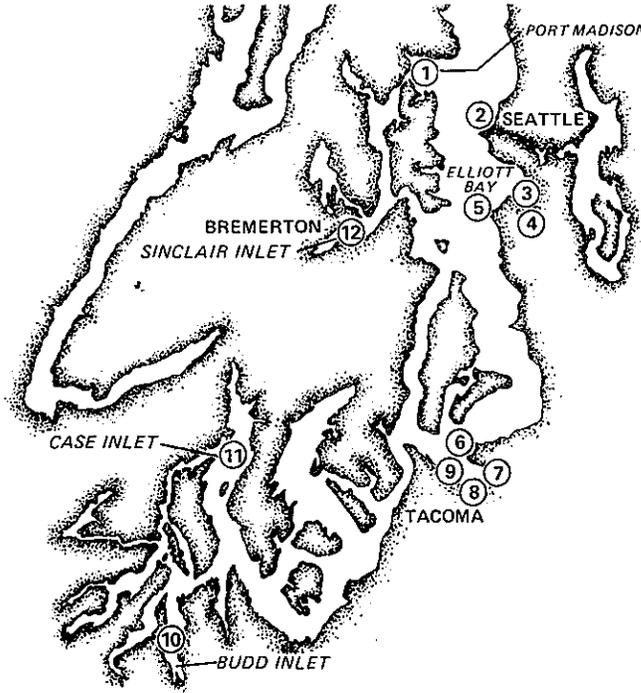
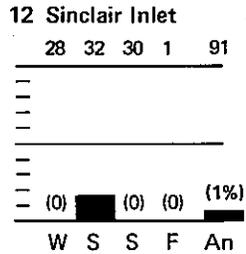
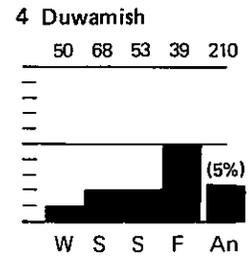
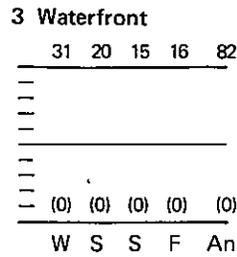
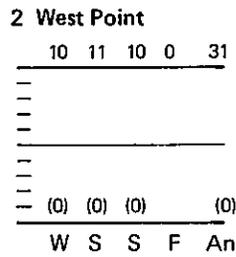
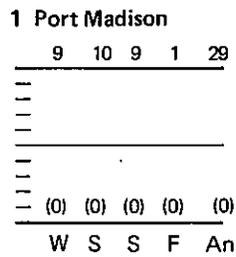


Figure 12. Seasonal and annual incidence of focal hepatocellular hyper-trophy in English sole from each embayment or embayment subarea sampled.

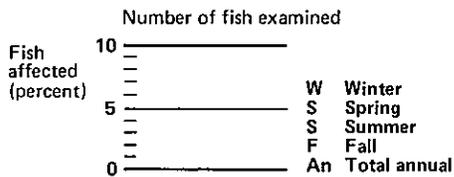
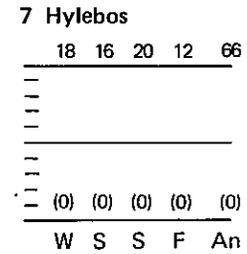
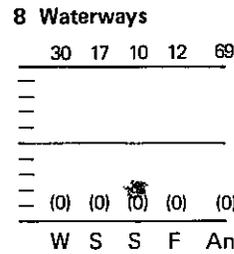
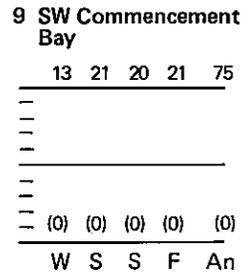
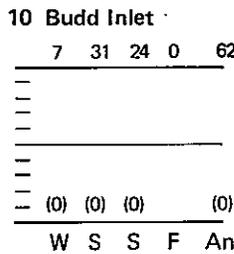
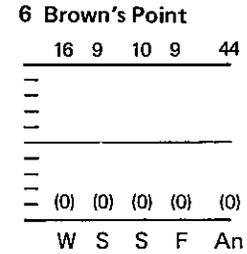
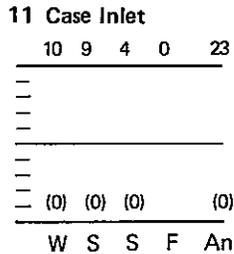
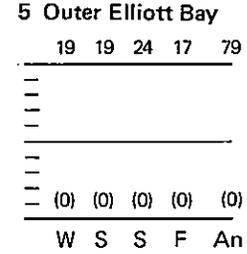
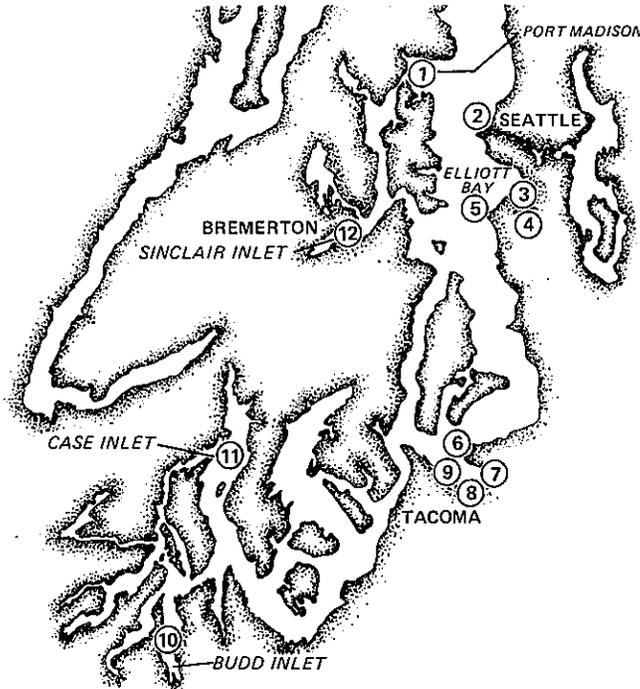
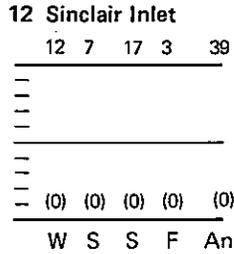
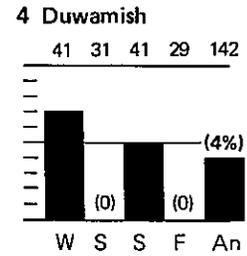
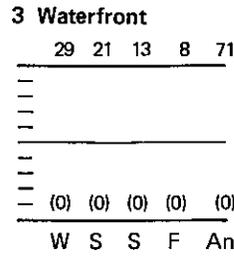
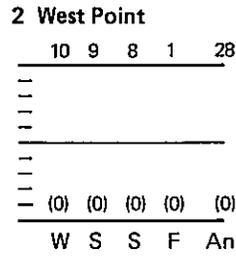
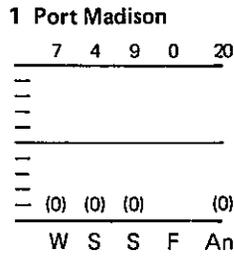


Figure 13. Seasonal and annual incidence of focal hepatocellular hypertrophy in rock sole from each embayment or embayment subarea sampled.



Figure 14. Liver of an English sole from the Duwamish Waterway. The three white surface nodes represent adenomatous foci (arrows). Darker mottling down the center and across the anterior of the liver (double arrows) corresponds to areas of severe megalocytic hepatitis.

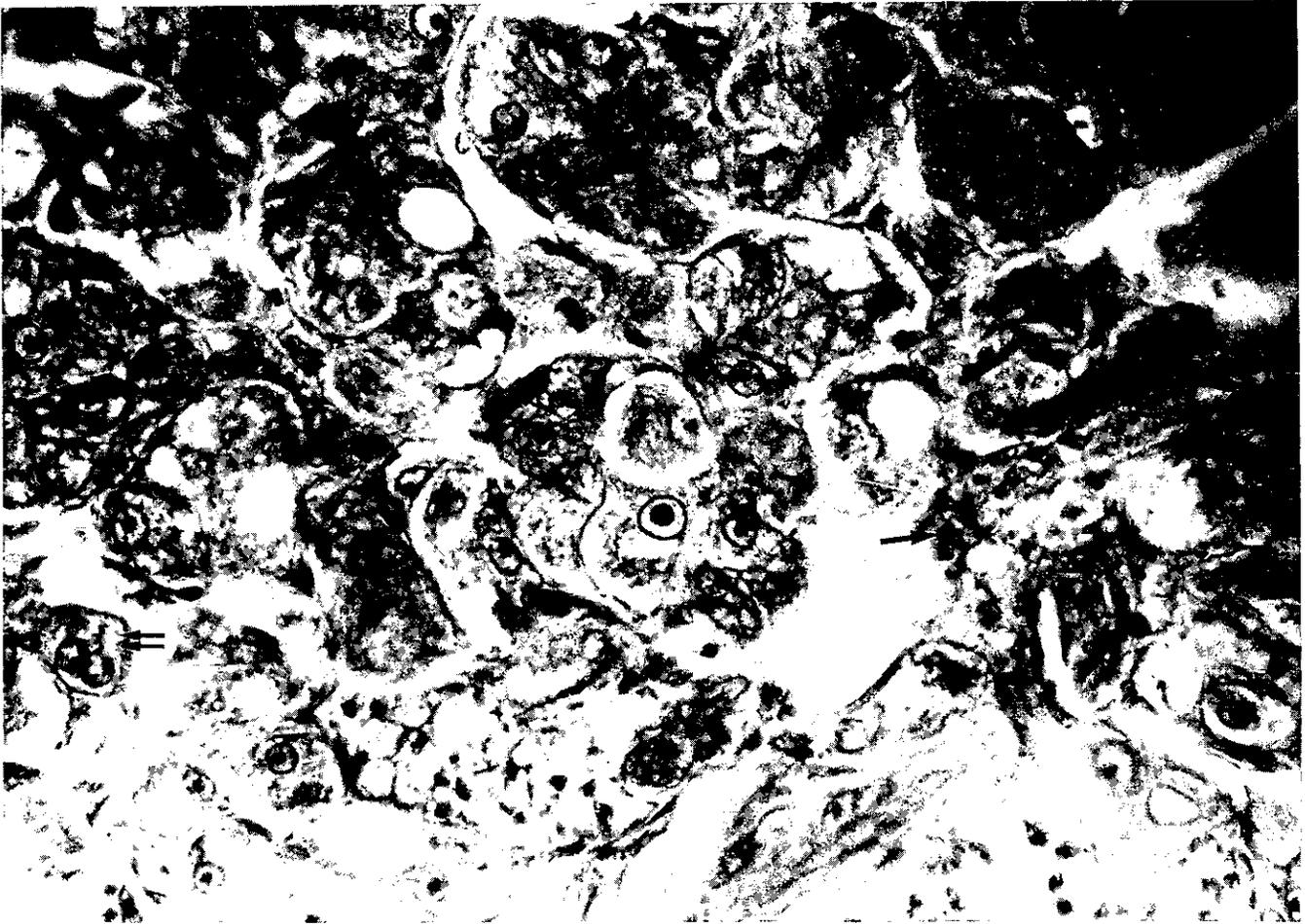


Figure 15. Adenomatous focus in the liver of an English sole from the Duwamish River in Elliott Bay. Loss of the normal muralial architecture is evident. Fibrosis is apparent in the central and lower areas at the right of the field of view (arrow). An occasional binucleate cell can be seen (double arrow). H & E 1920X.

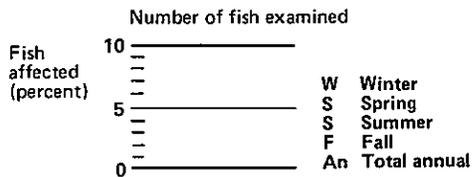
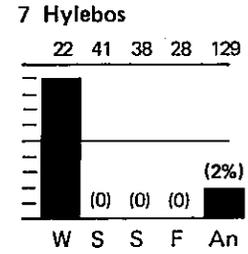
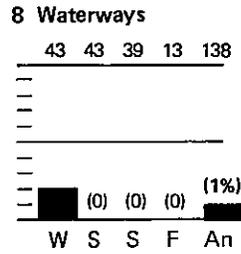
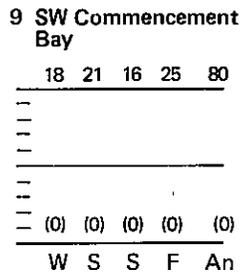
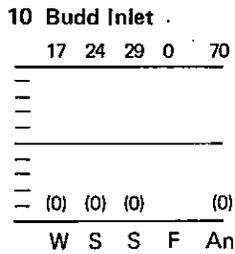
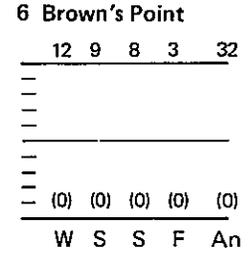
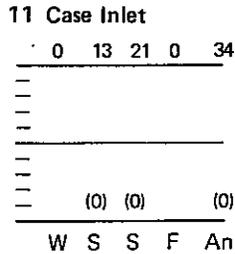
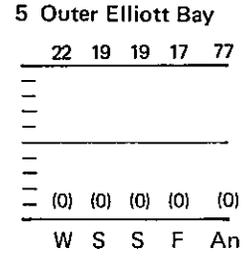
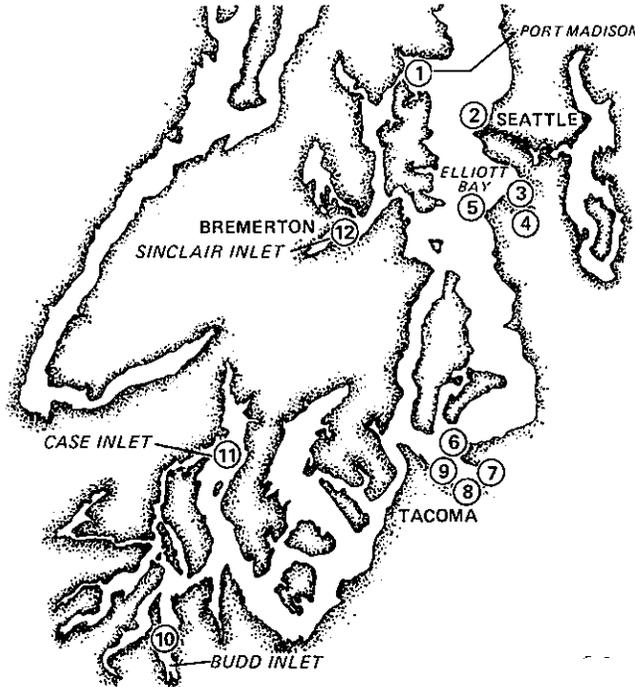
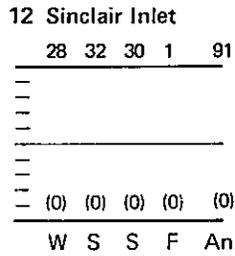
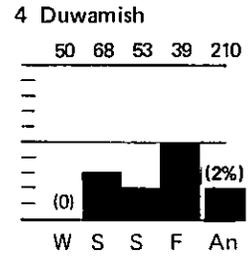
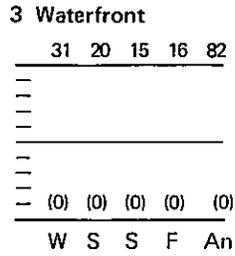
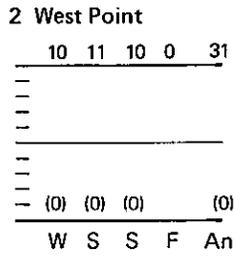
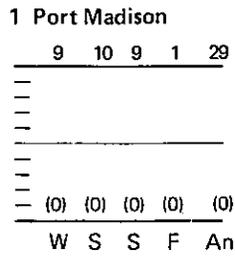


Figure 16. Seasonal and annual incidence of hepatocellular adenomatous foci in English sole from each embayment or embayment subarea sampled.

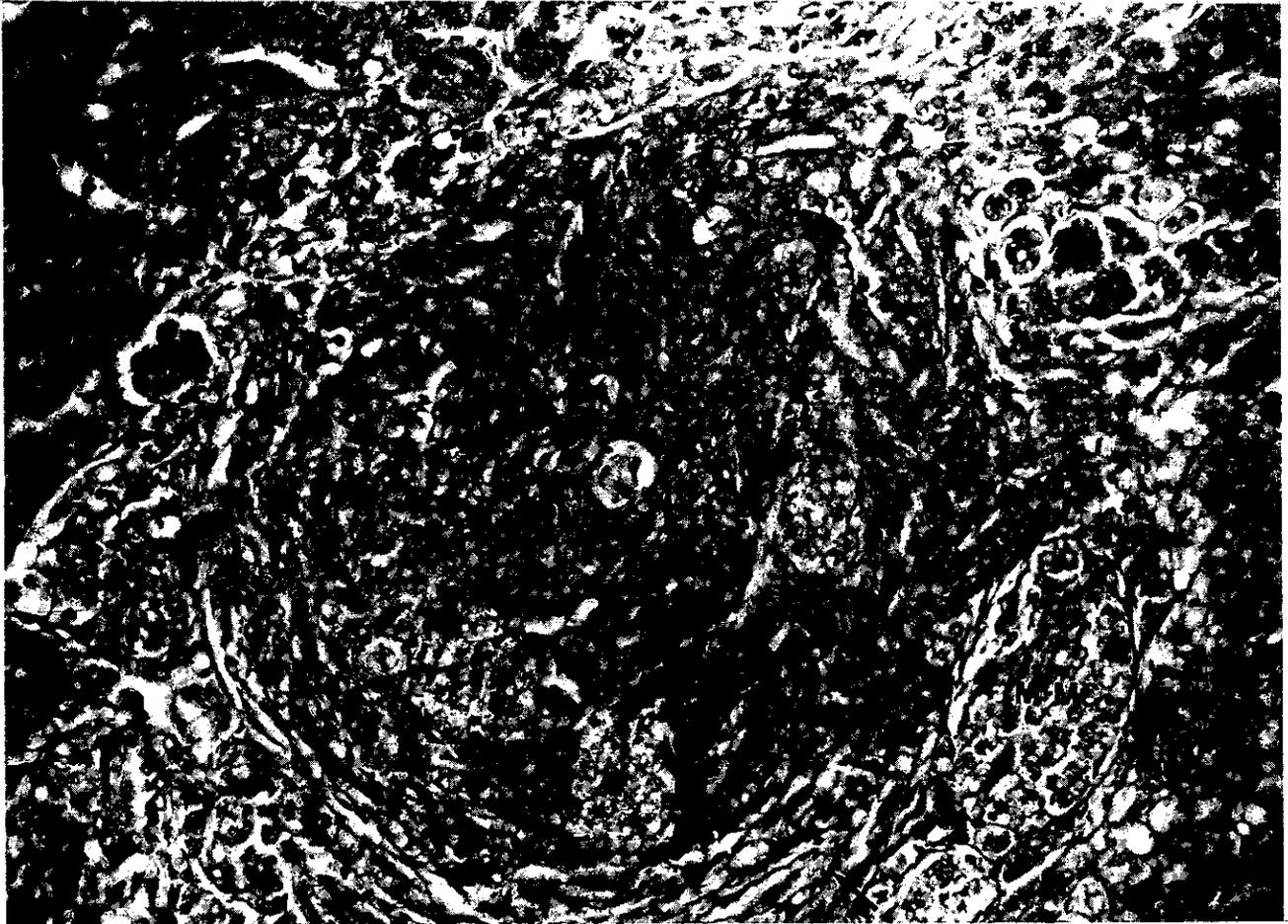


Figure 17. Focus of disorganized cholangioproliferation in the liver of a rock sole from station 4 (10016) the north end of Harbor Island in Elliott Bay. The lesion is surrounded by fibrosis (arrow) and melanin-macrophage centers (MMC). Normal hepatic tissue is located in the upper left corner of the field. H & E 960X.

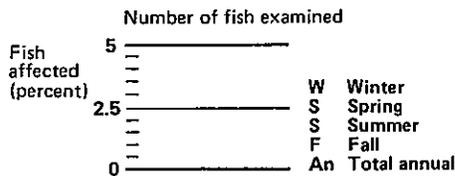
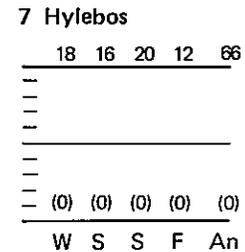
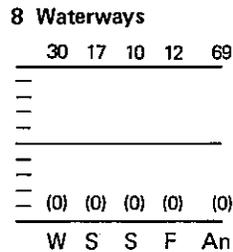
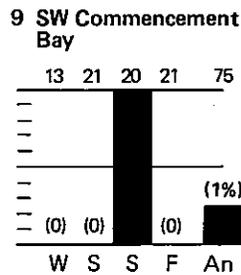
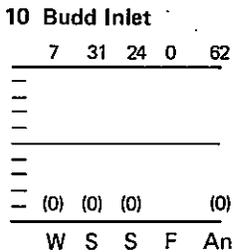
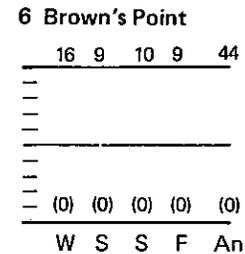
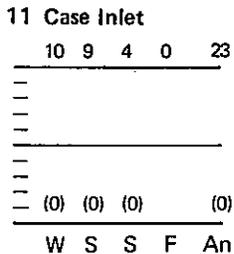
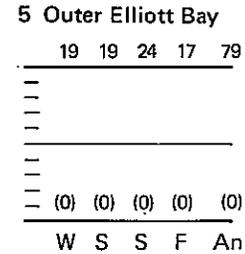
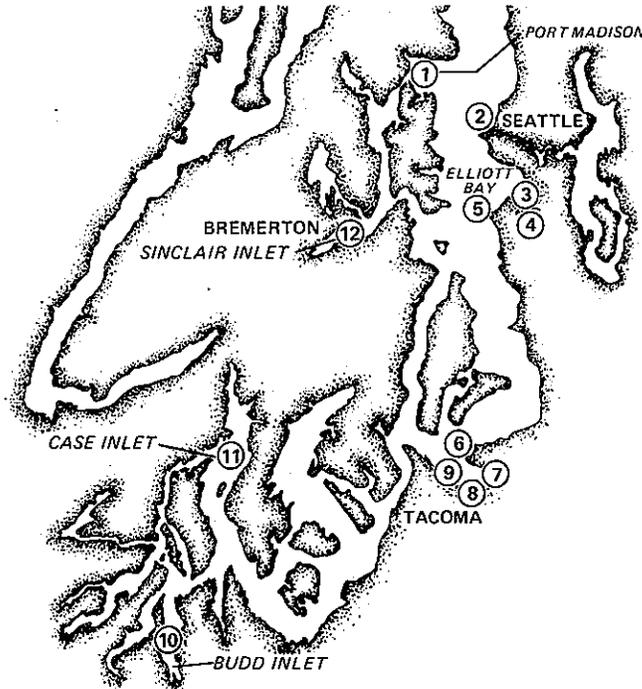
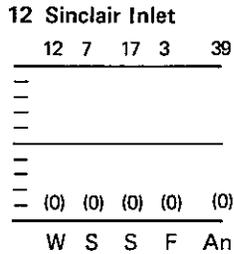
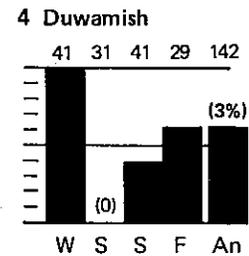
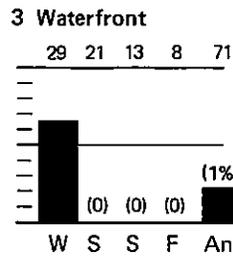
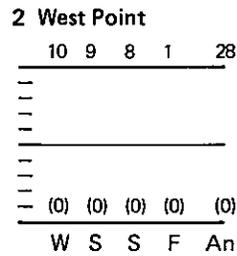
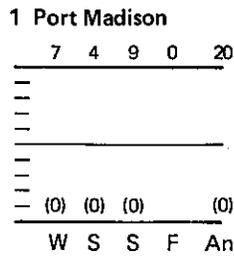


Figure 18. Seasonal and annual incidence of cholangioproliferative foci in rock sole from each embayment or embayment subarea sampled.

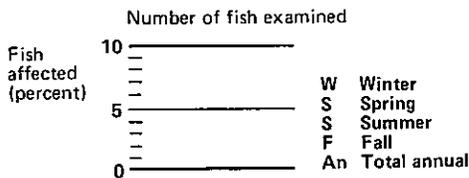
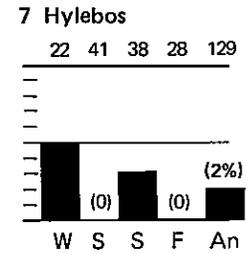
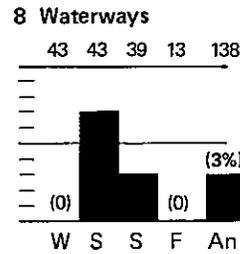
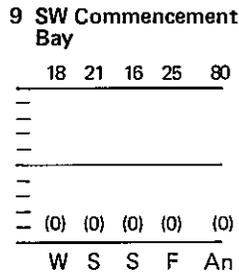
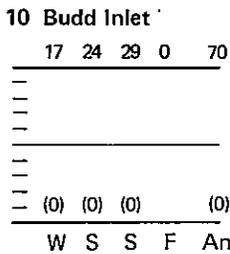
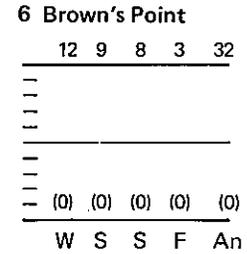
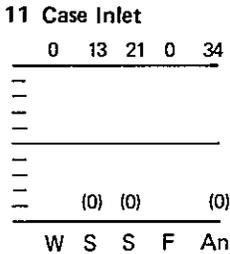
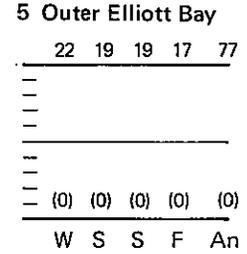
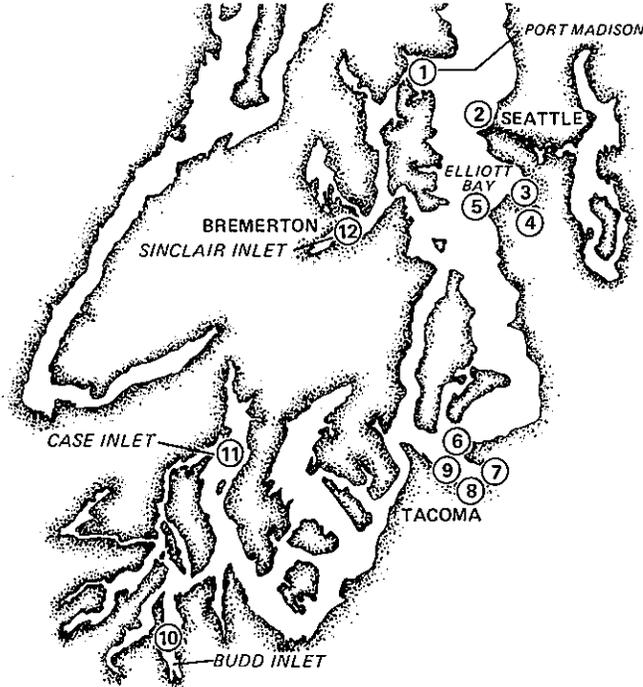
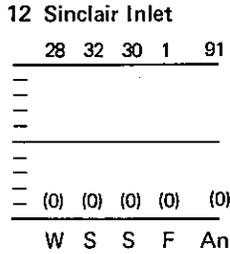
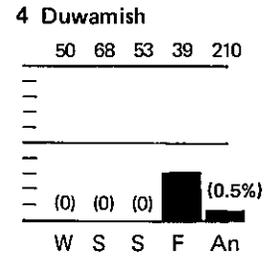
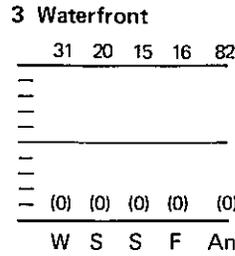
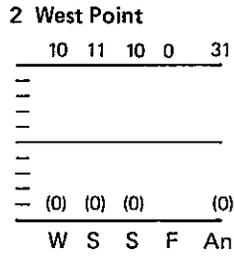
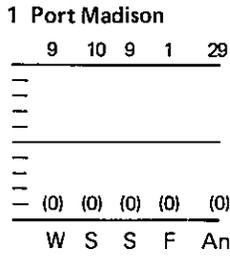


Figure 19. Seasonal and annual incidence of cholangioproliferative foci in English sole from each embayment or embayment subarea sampled.

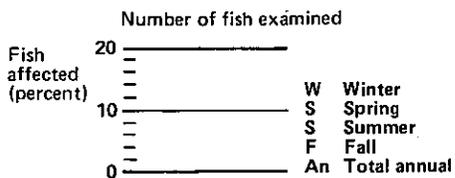
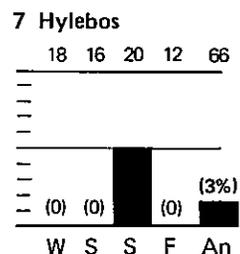
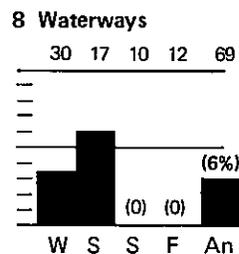
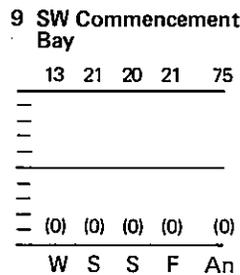
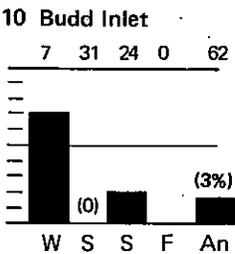
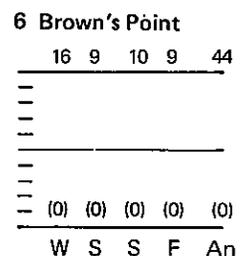
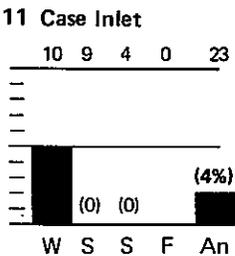
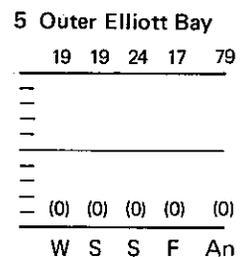
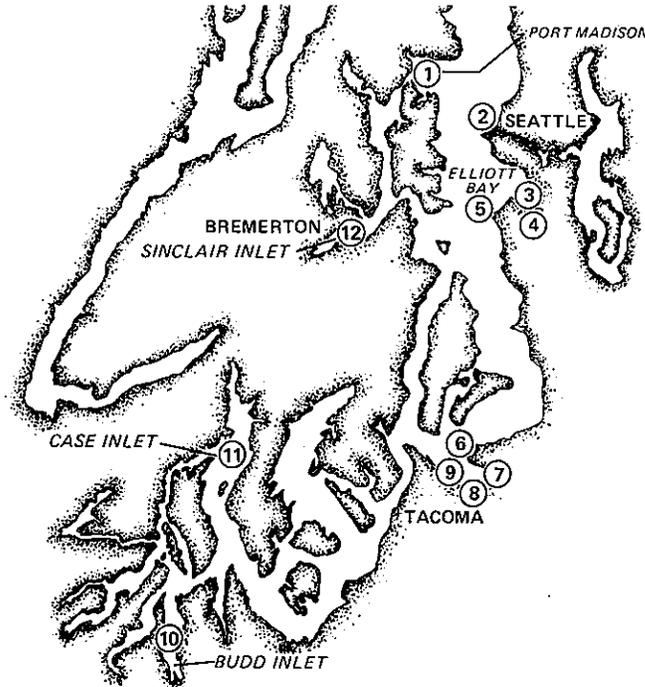
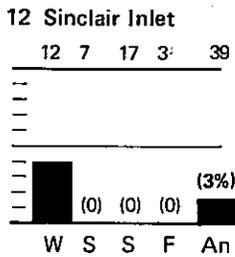
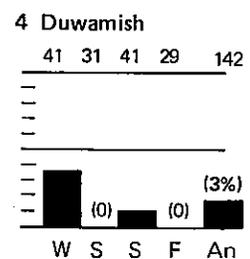
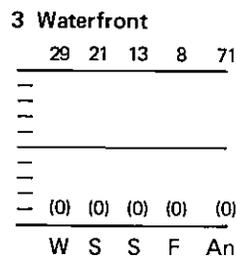
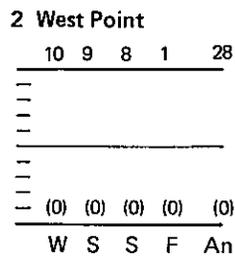
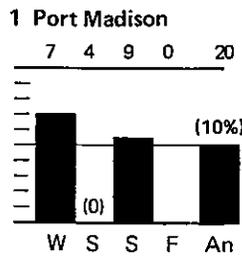


Figure 20. Seasonal and annual incidence of focal hepatocellular hyperplasia in rock sole from each embayment or embayment subarea sampled.

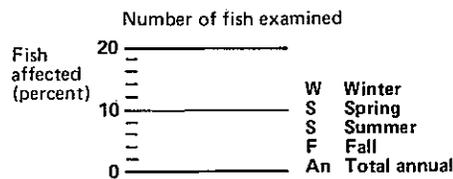
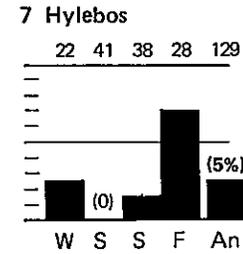
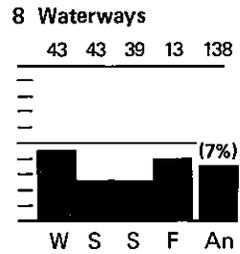
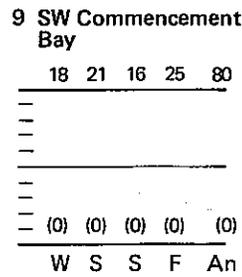
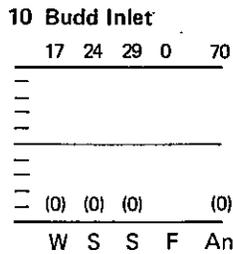
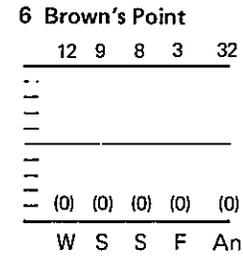
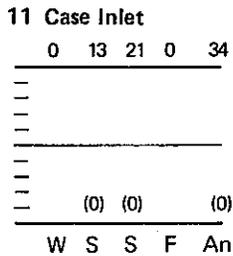
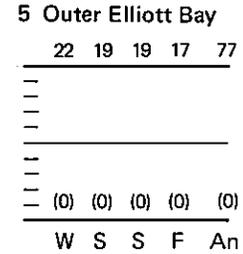
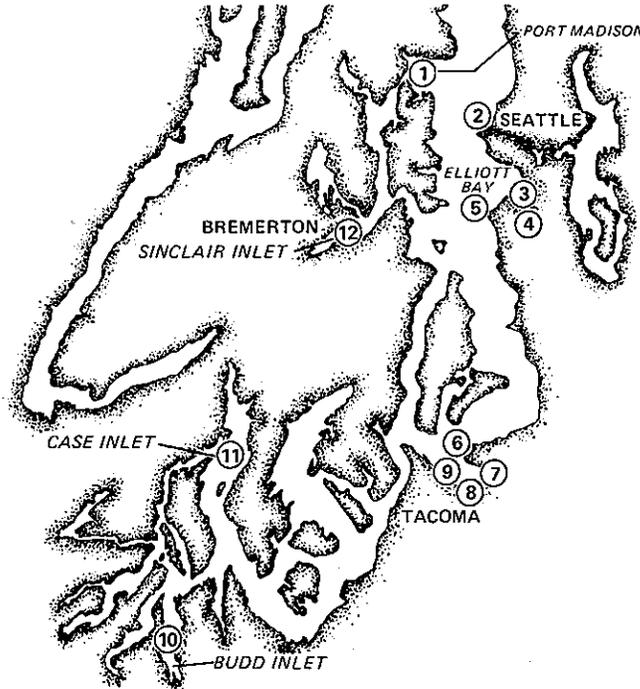
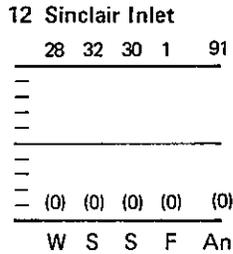
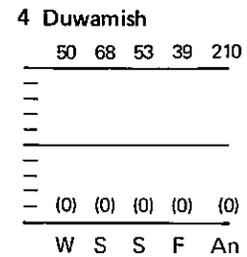
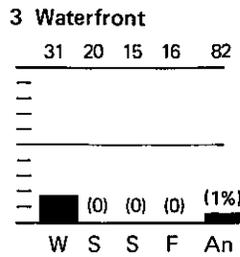
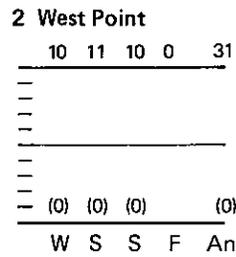
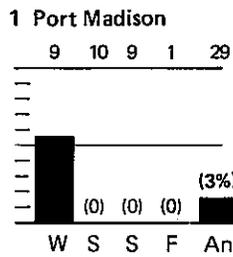


Figure 21. Seasonal and annual incidence of focal hepatocellular hyperplasia in English sole from each embayment or embayment subarea sampled.

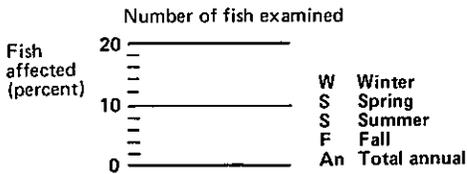
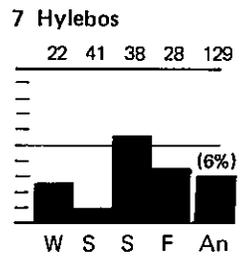
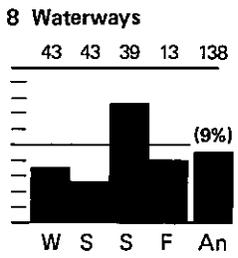
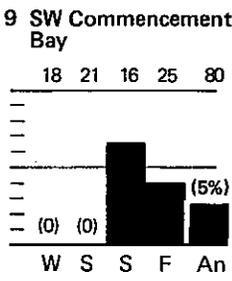
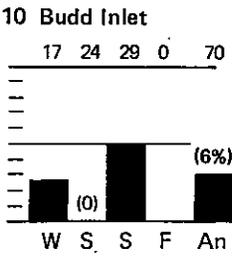
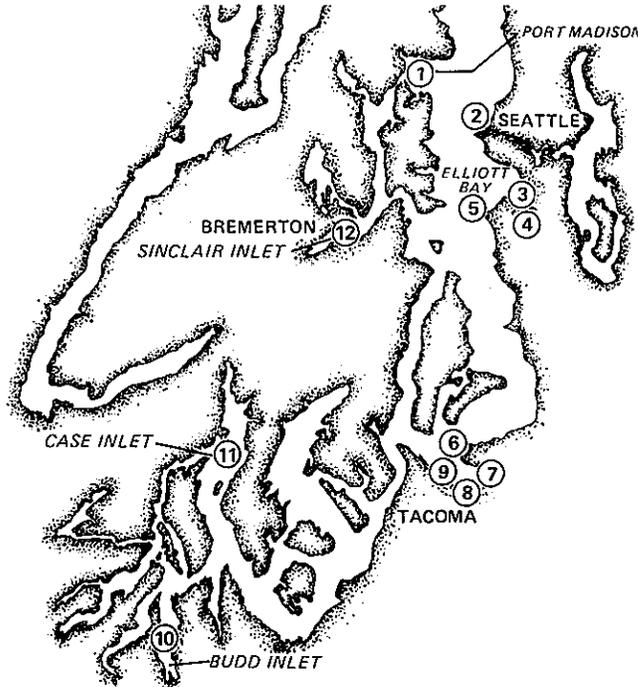
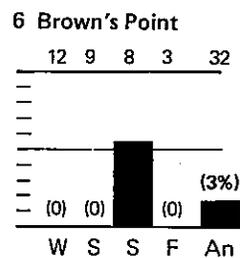
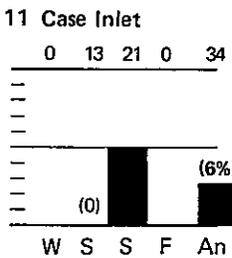
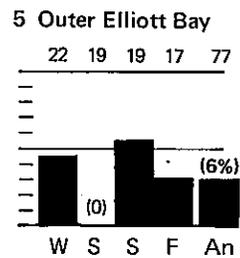
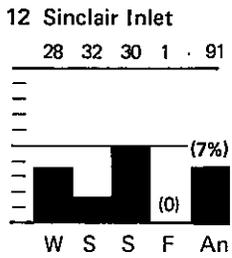
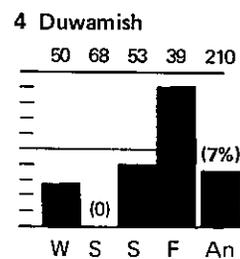
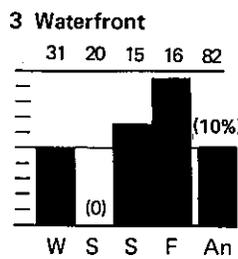
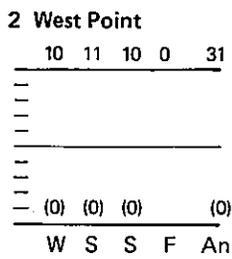
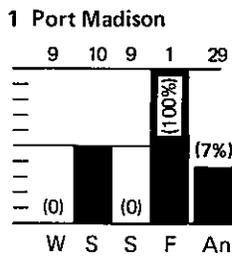


Figure 22. Seasonal and annual incidence of hepatocellular necrosis in English sole from each embayment or embayment subarea sampled.

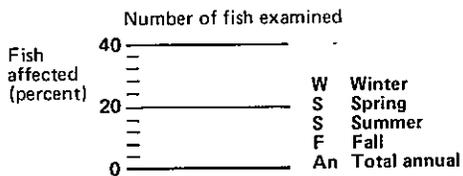
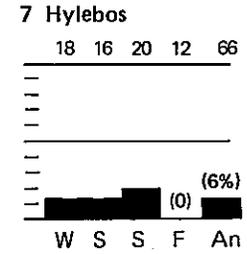
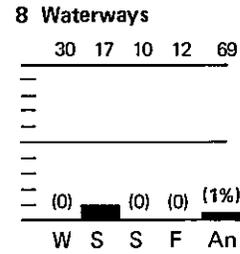
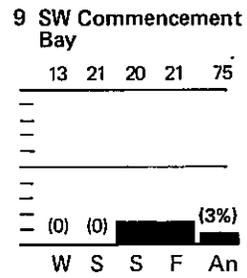
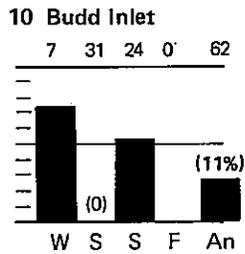
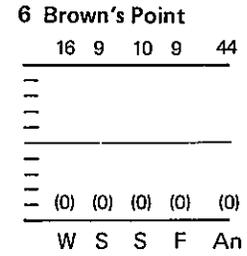
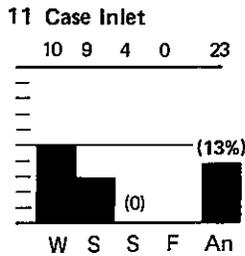
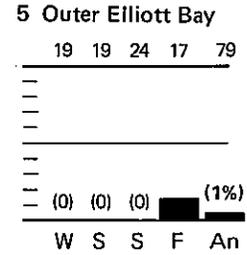
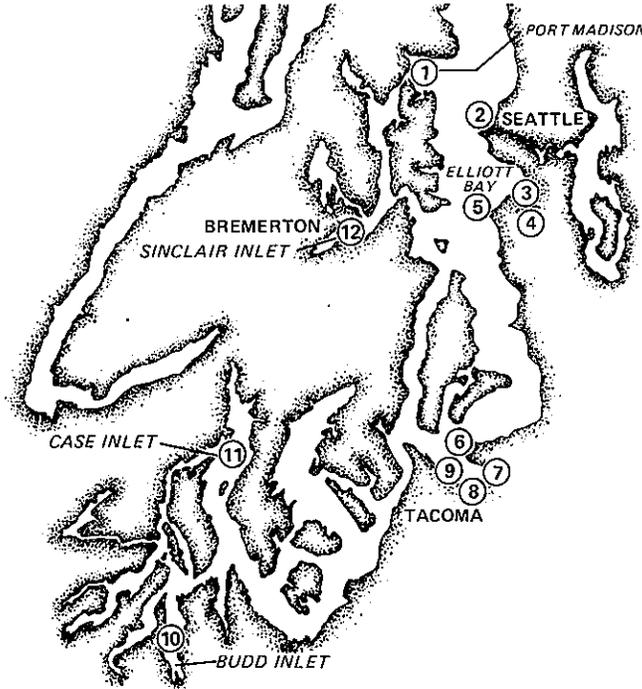
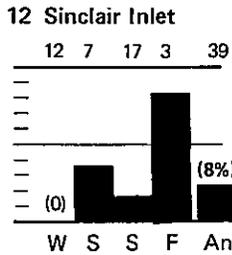
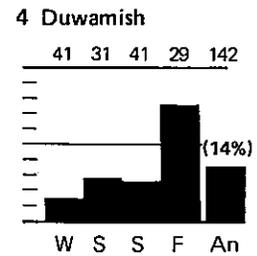
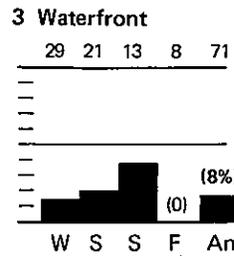
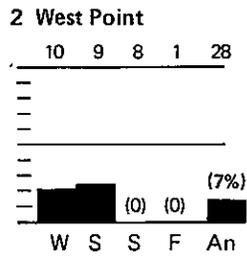
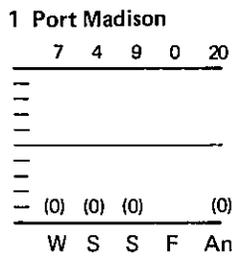


Figure 23. Seasonal and annual incidence of hepatocellular necrosis in rock sole from each embayment or embayment subarea sampled.

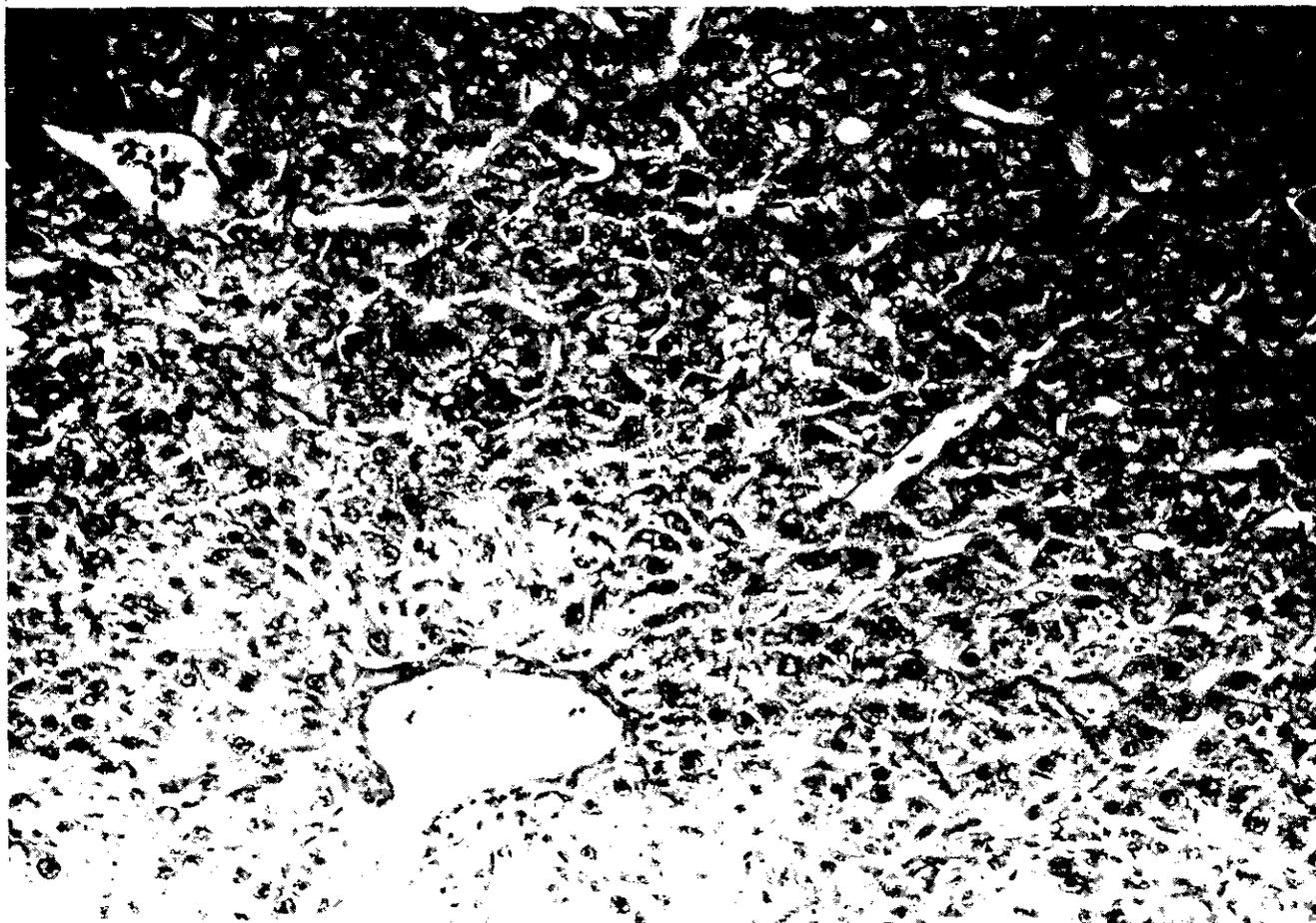
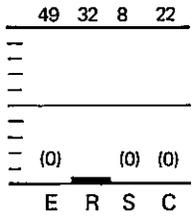
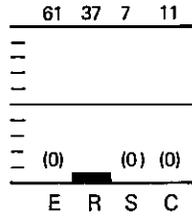


Figure 24. Nuclear pleomorphism in the liver of a rock sole from the Seattle Waterfront in Elliott Bay. Note the great variation in size and shape of hepatocellular nuclei. H & E 960X.

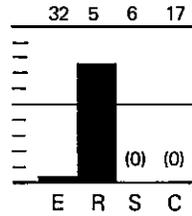
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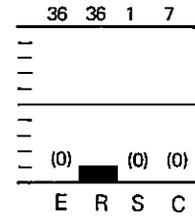
**2 West Waterway**



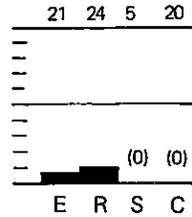
**3 East Waterway**



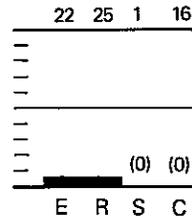
**4 Harbor Island North**



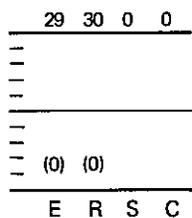
**5 Pier 54**



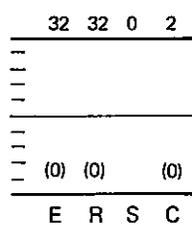
**6 Pier 70**



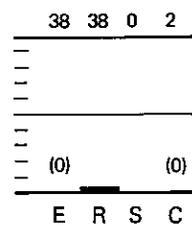
**11 Alki Point**



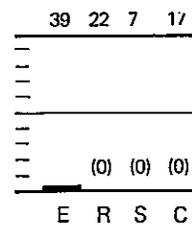
**10 Duwamish Head S.E.**



**9 Magnolia Bluff**



**8 North Pier 71**



**7 Elliott Bay**

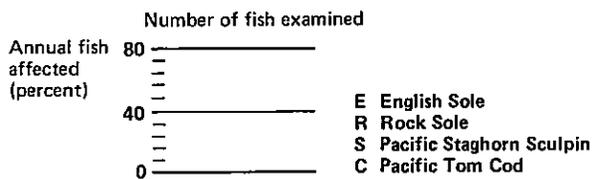
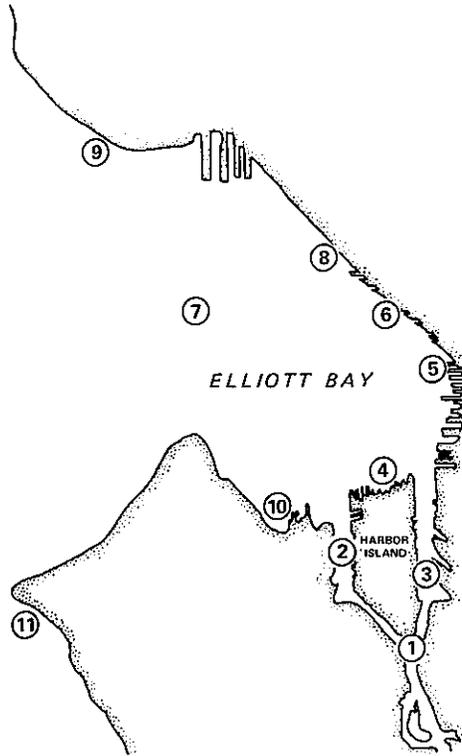
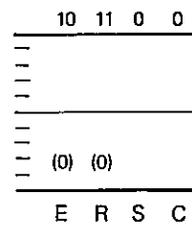


Figure 25A. Annual prevalence of hepatocellular nuclear pleomorphism in the four target fish species in Elliott Bay.



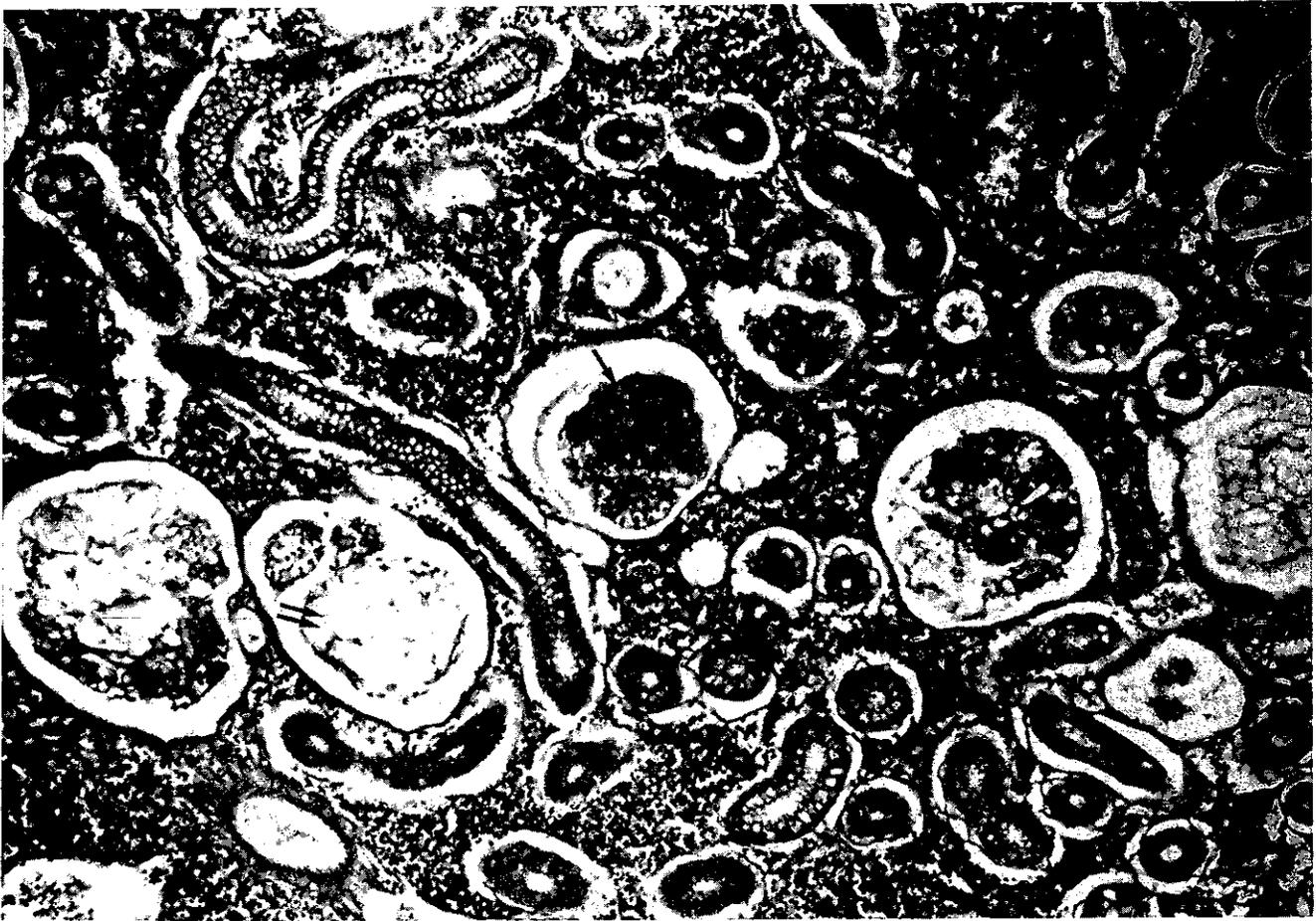


Figure 26. Several disrupted glomeruli in the kidney of an English sole from station 10 (10045) southeast of the Duwamish Head in Elliott Bay. One glomerulus demonstrates the severe dilation and congestion of glomerular capillaries (arrow) while other glomeruli exhibit varying degrees of loss of cellularity, mesangial matrix, and basement membrane (double arrows). H & E 960X.

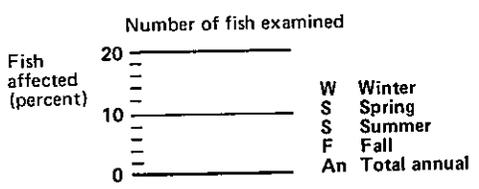
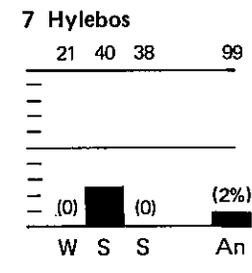
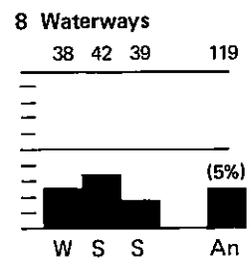
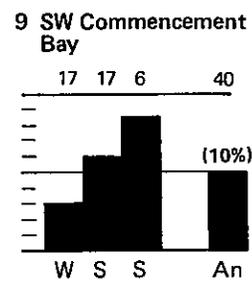
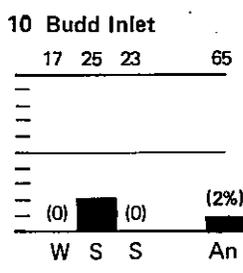
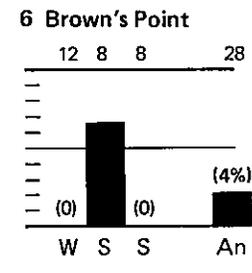
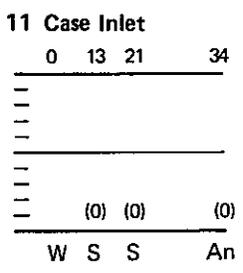
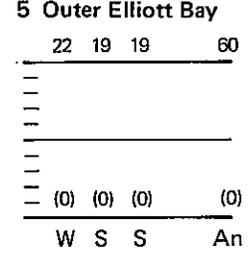
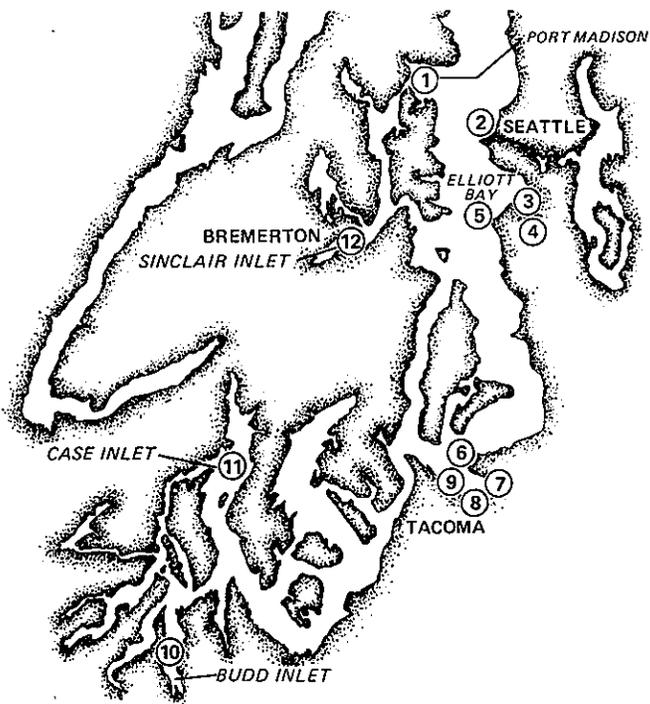
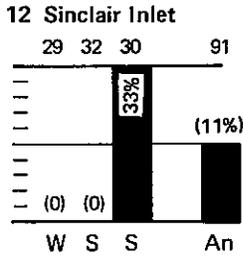
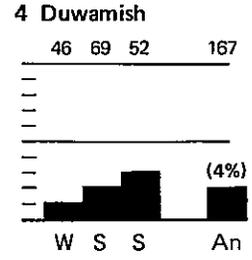
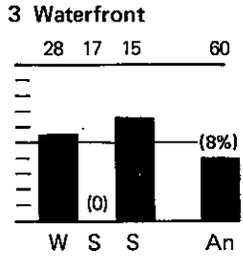
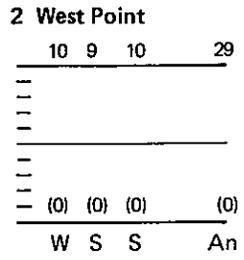
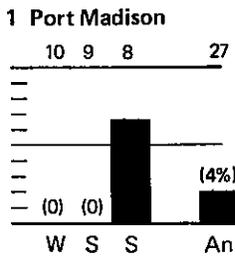


Figure 27. Seasonal and annual incidence of kidney glomerular disruption in English sole from each embayment or embayment subarea sampled.

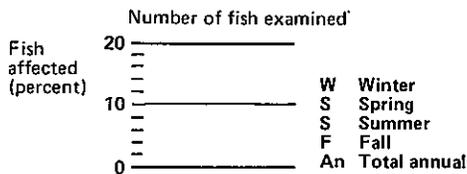
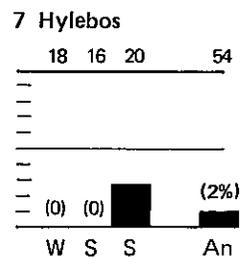
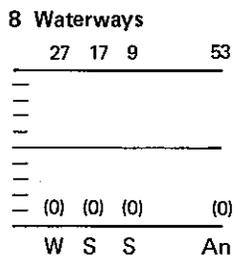
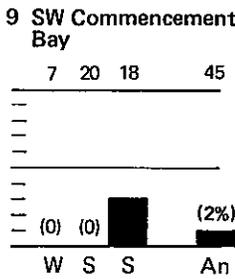
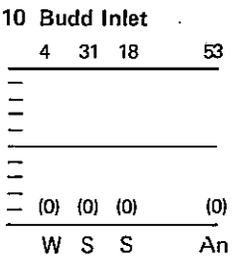
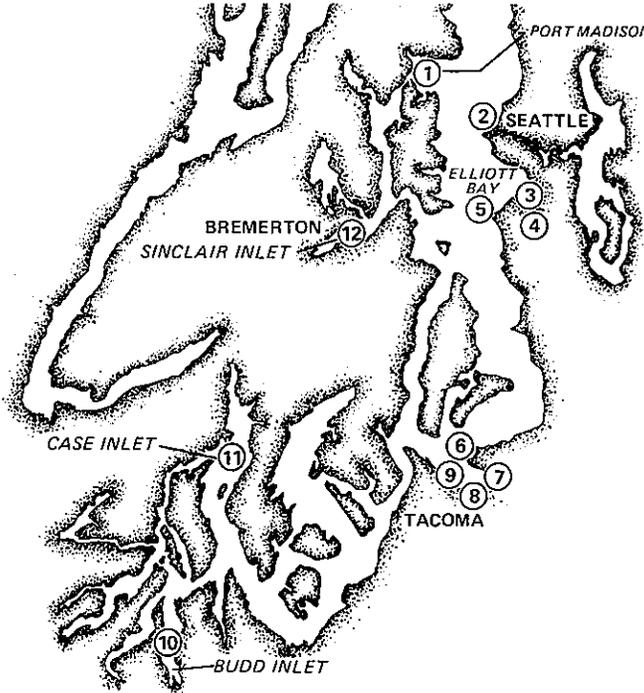
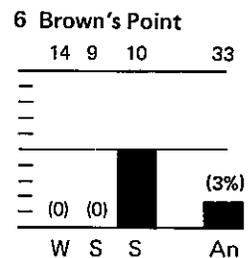
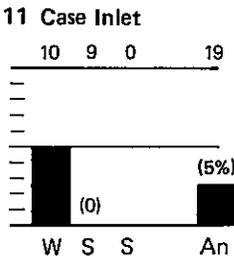
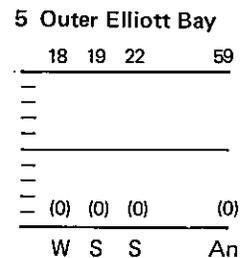
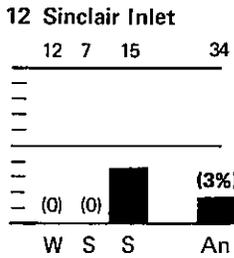
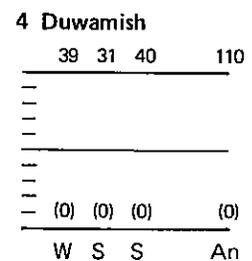
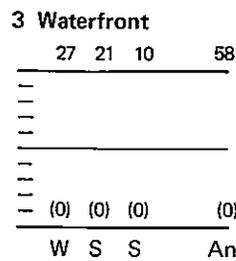
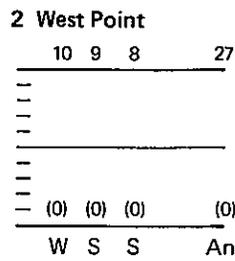
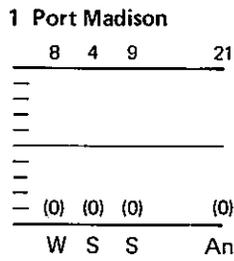


Figure 28. Seasonal and annual incidence of kidney glomerular disruption in rock sole from each embayment or embayment subarea sampled.



Figure 29A. Severe respiratory epithelial hyperplasia with fusion of lamellae and filaments in the gills of a rock sole from Elliott Bay. H & E 192X.

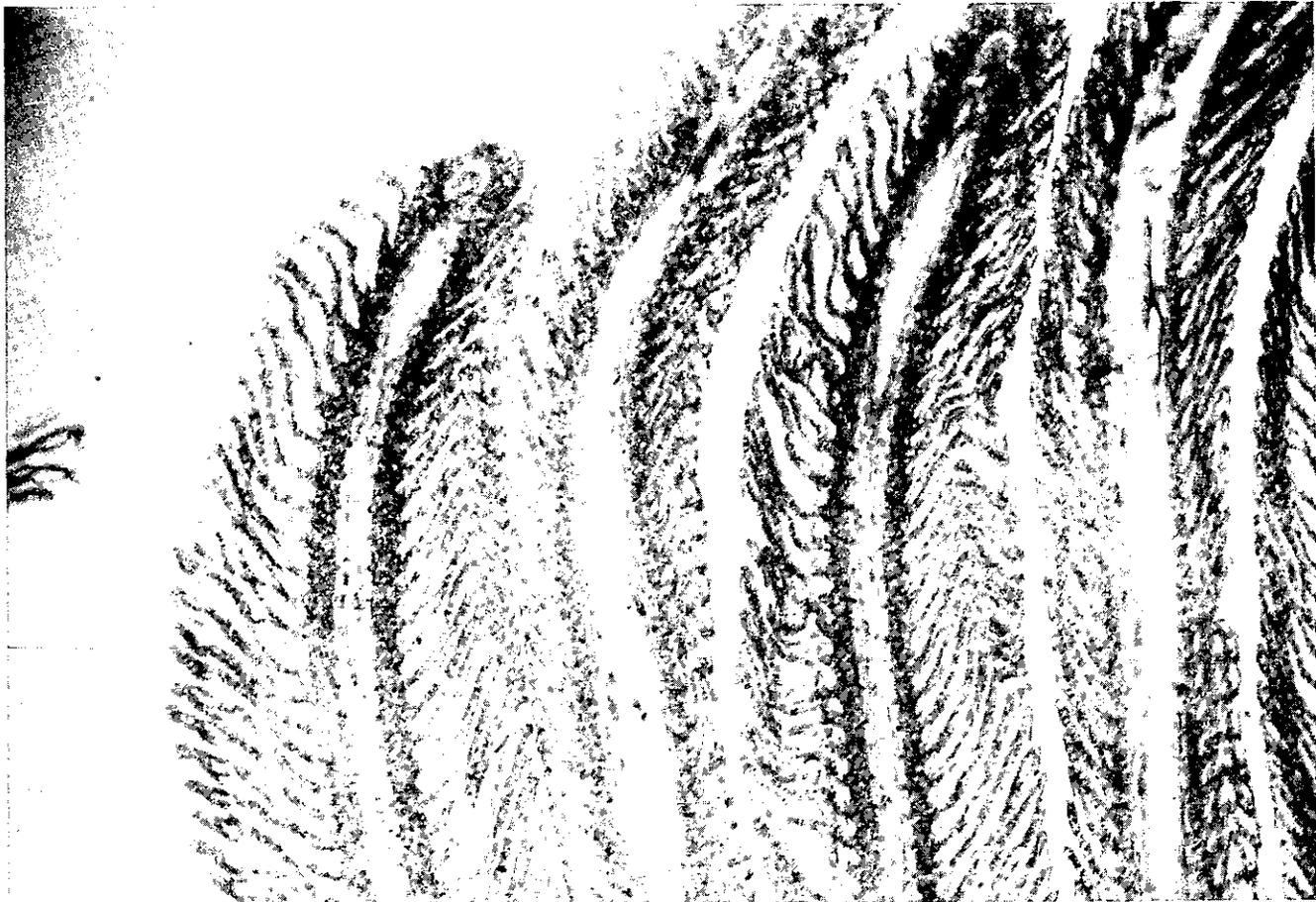


Figure 29B. Gill filaments of a rock sole from Commencement Bay with normal structure (Separation of respiratory epithelium from underlying filament connective tissue is artifactual). H & E 192X.

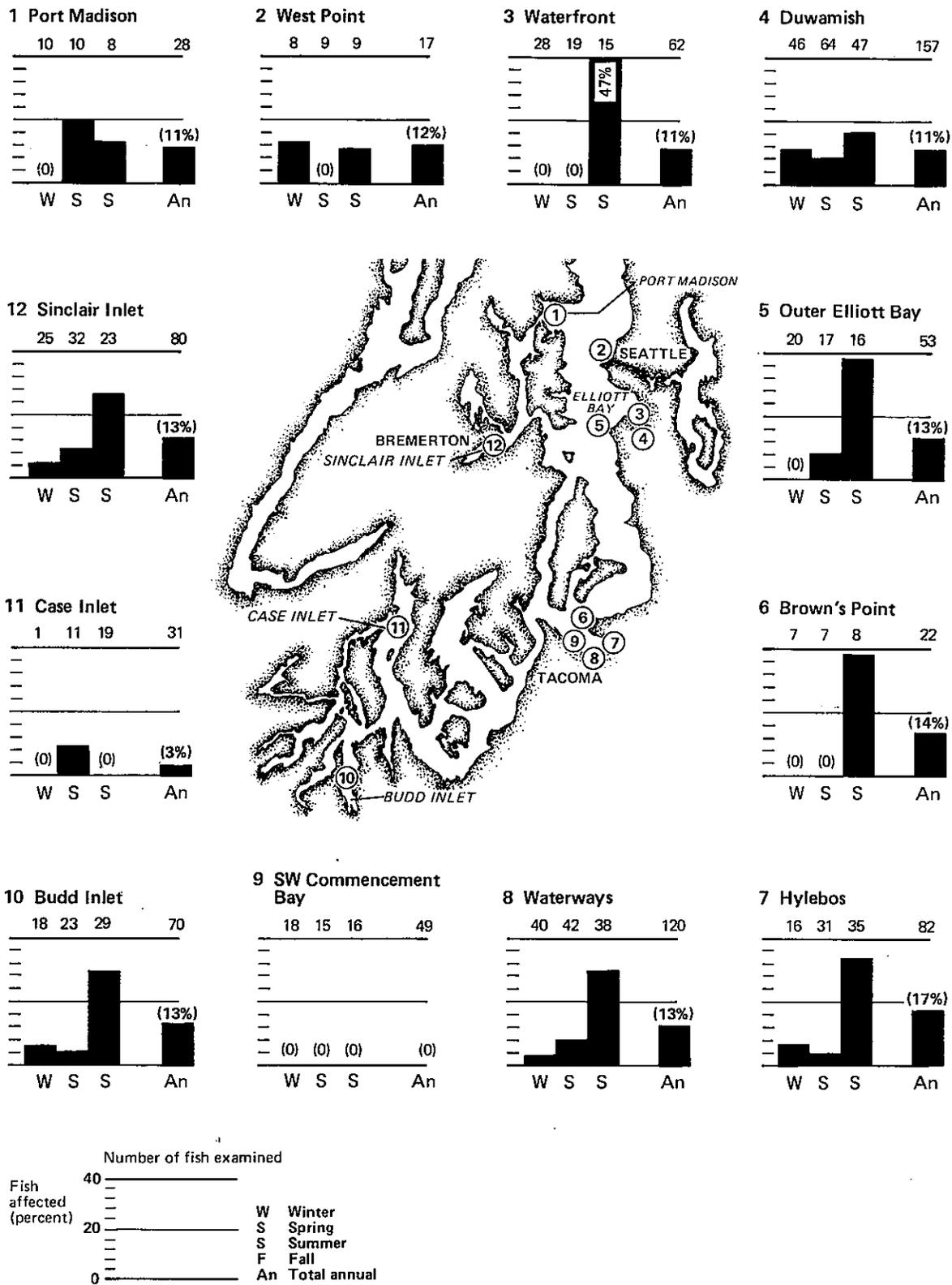


Figure 30. Seasonal and annual incidence of gill respiratory epithelial hyperplasia in English sole from each embayment or embayment subarea sampled.

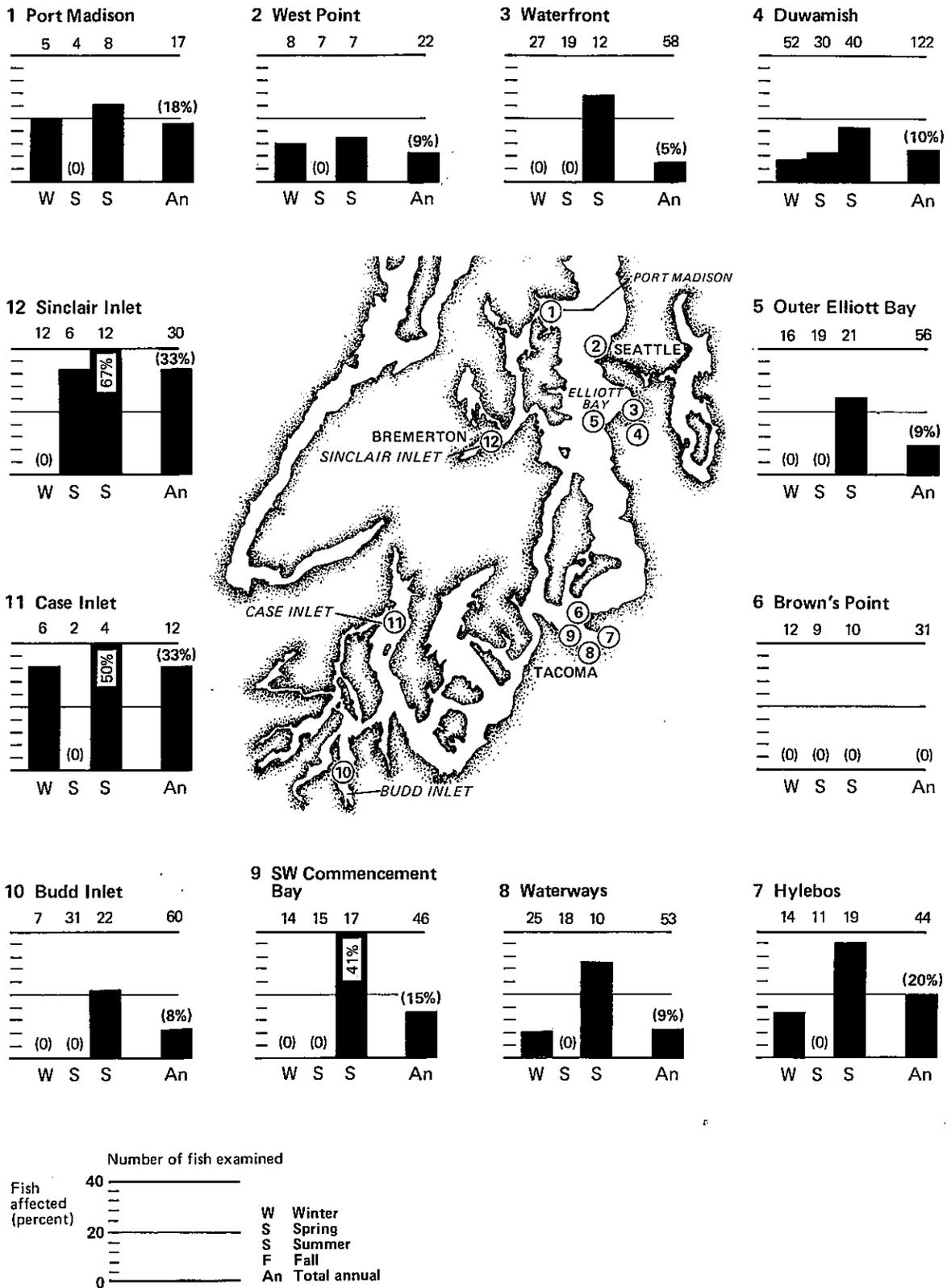


Figure 31. Seasonal and annual incidence of gill respiratory epithelial hyperplasia in rock sole from each embayment or embayment subarea sampled.

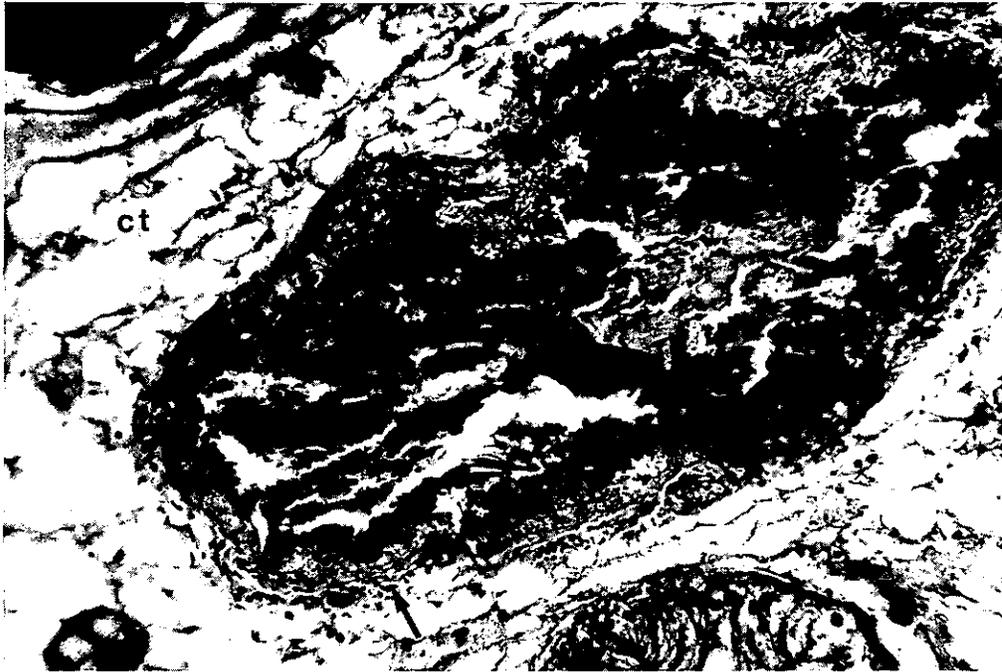


Figure 32. A necrotic tubule encapsulated by hemocytes (arrow) and surrounded by connective tissue (ct) in the hepatopancreas of a C. magister. H & E 200X.

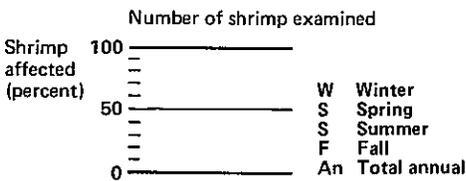
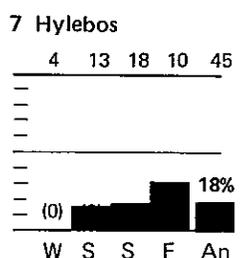
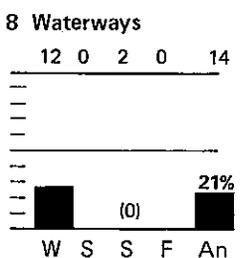
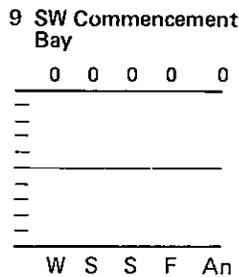
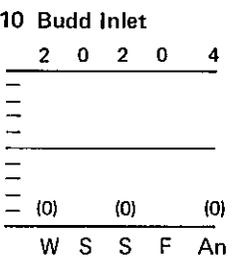
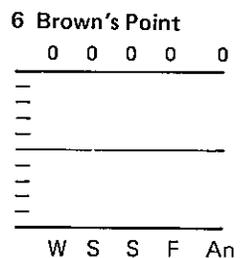
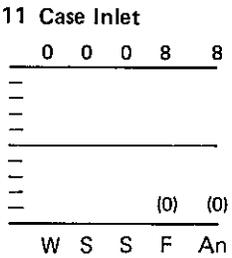
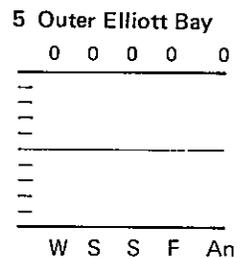
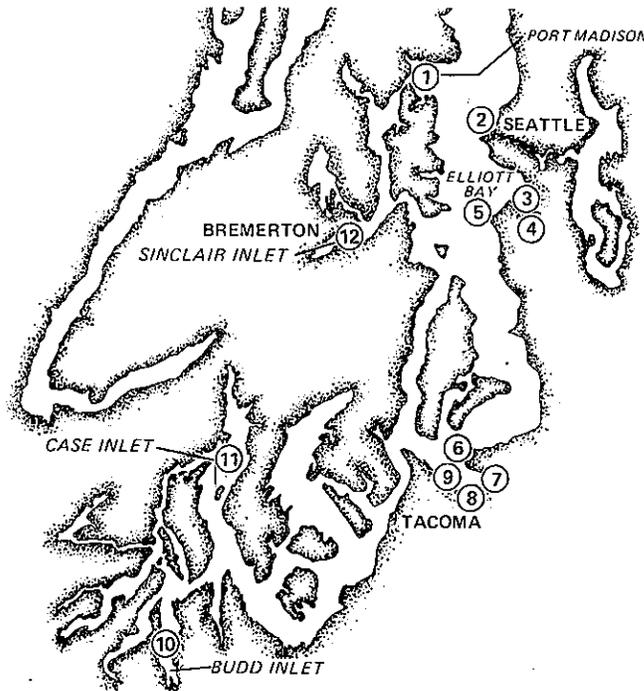
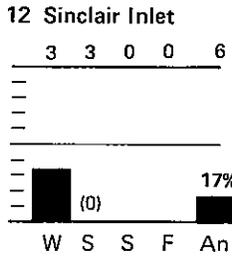
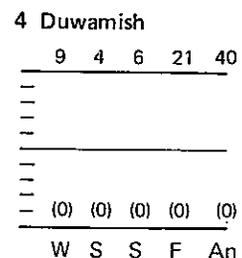
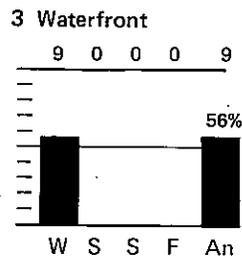
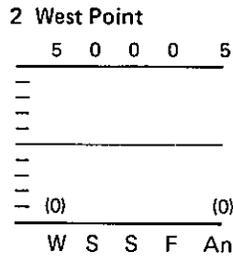
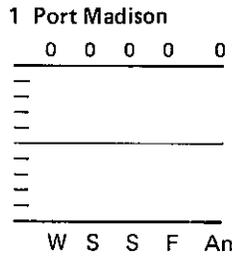


Figure 33. Seasonal and annual incidence of *P. danae* with hepatopancreatic necrosis in each embayment or embayment subarea sampled.

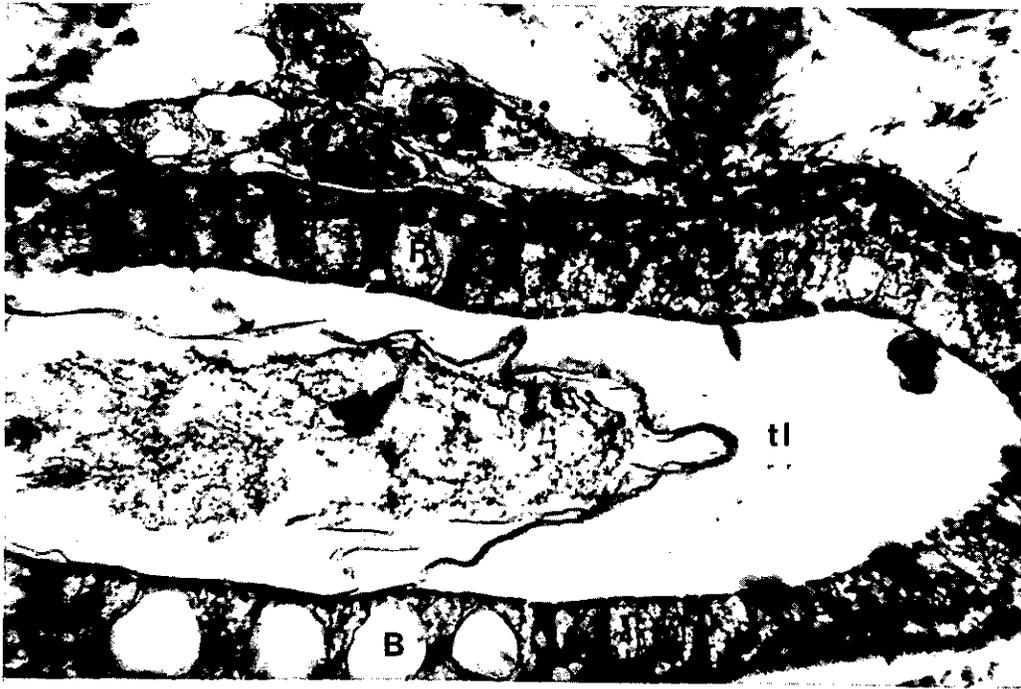


Figure 34. Tubular metaplasia of the hepatopancreas of a *C. magister* (R, R-cell; B, B-cell; tl, tubule lumen; and ct, connective tissue). H & E 200X.

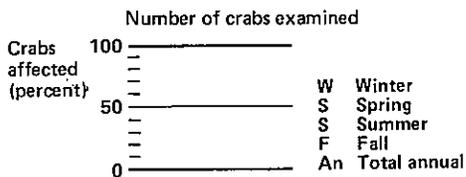
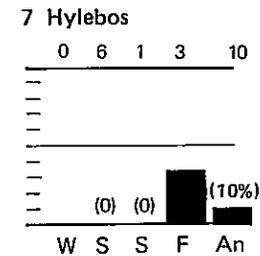
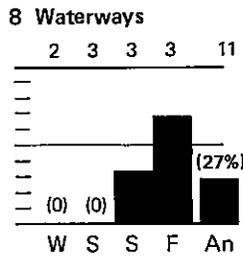
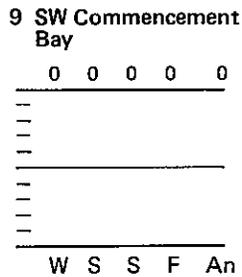
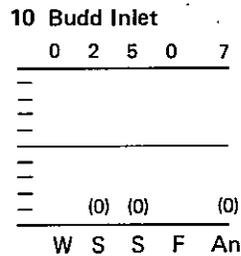
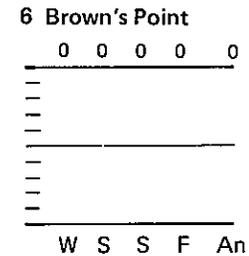
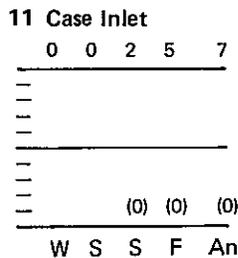
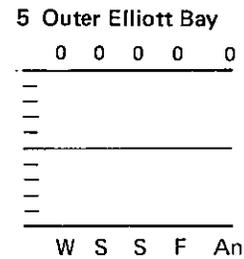
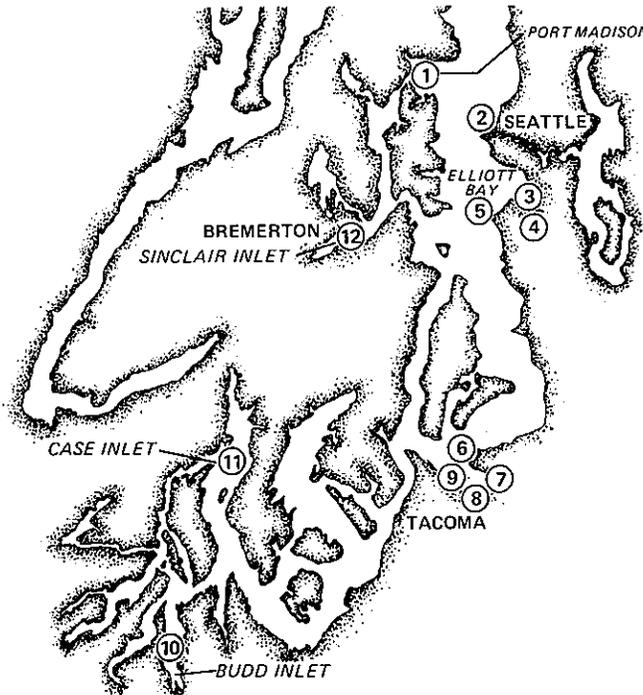
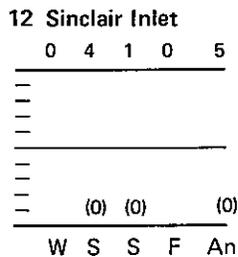
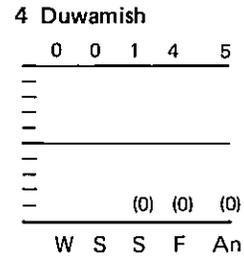
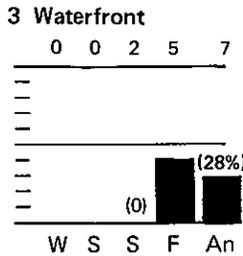
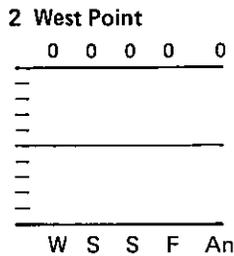
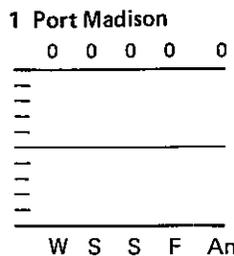


Figure 35. Seasonal and annual incidence of *C. gracilis* with tubular metaplasia of the hepatopancreas in each embayment or embayment subarea sampled.



Figure 36. A melanized nodule (MN) in the gill stem of a C. magister.  
H & E 200X.

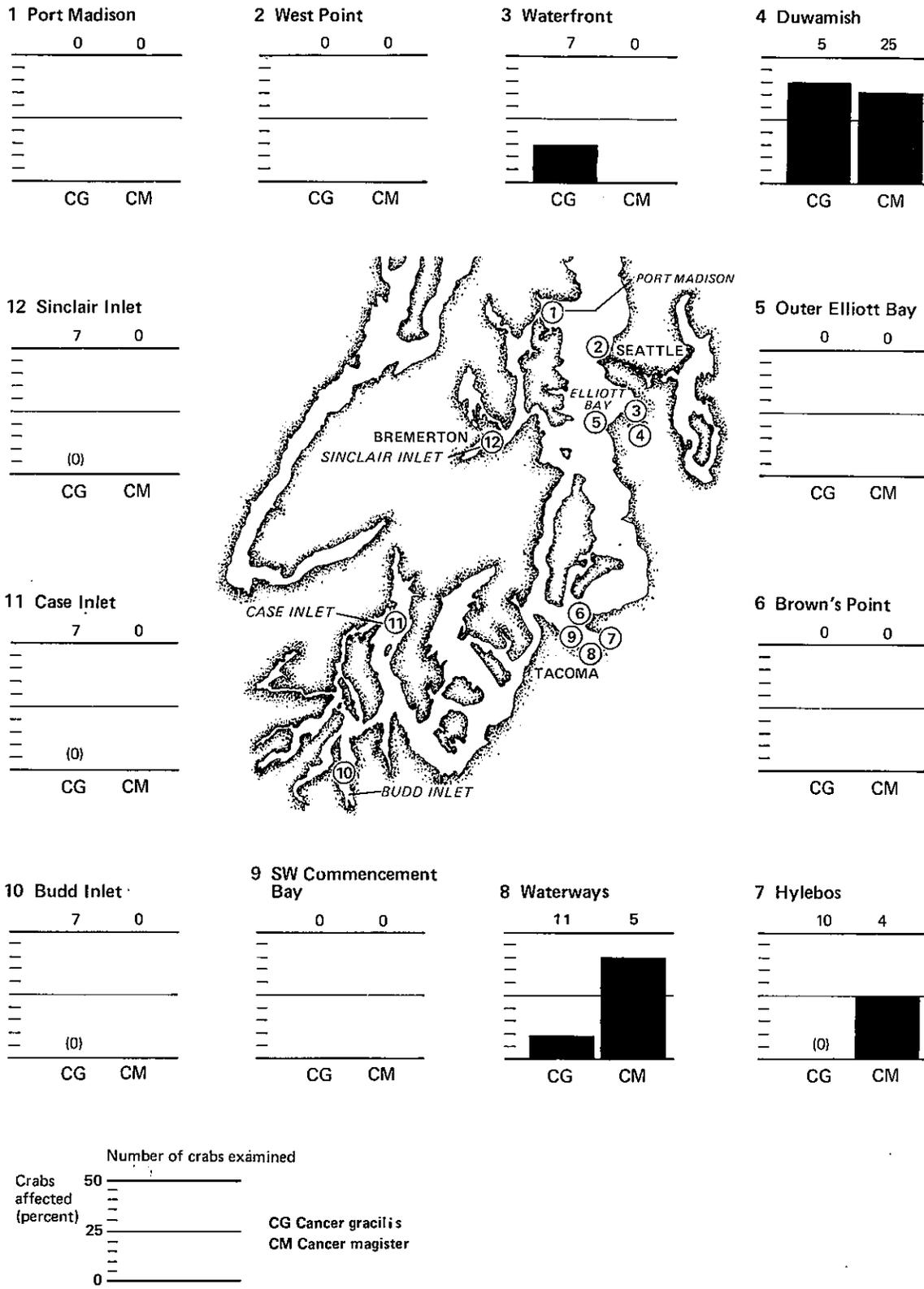


Figure 37. Annual incidence of melanized nodules in the gill stem, loose connective tissue, or tegmental glands of *C. gracilis* and *C. magister* from each embayment or embayment subarea sampled.



Figure 38. Necrosis of the bladder epithelium (be) in the bladder of a C. gracilis. H & E 500X.

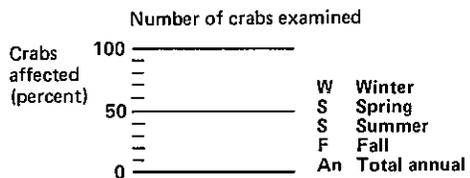
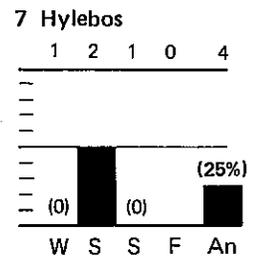
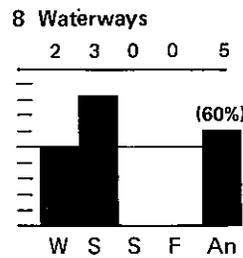
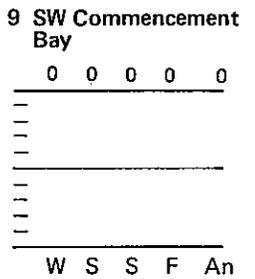
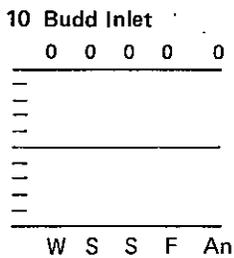
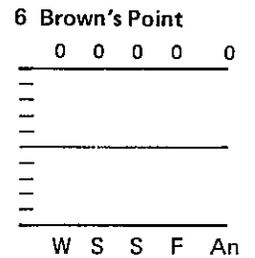
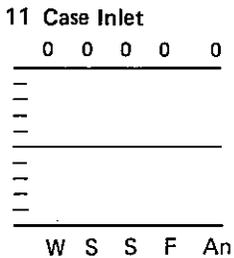
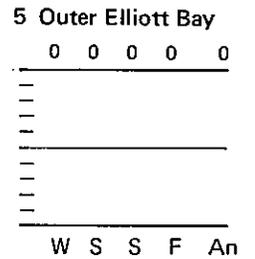
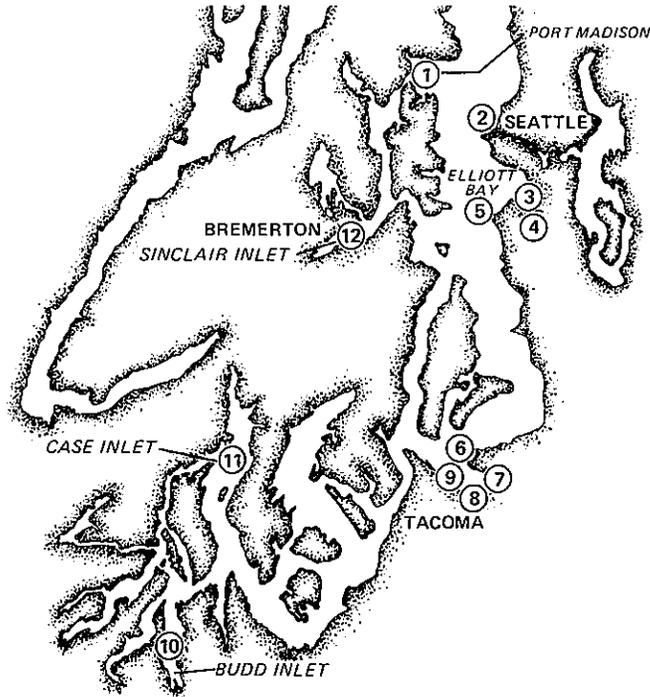
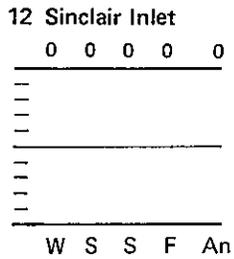
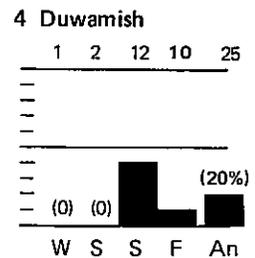
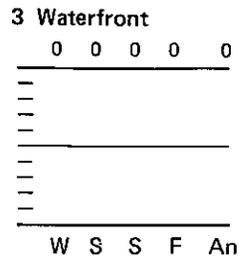
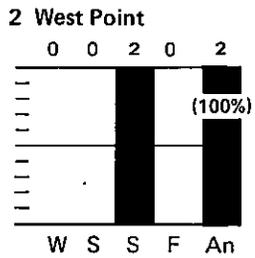
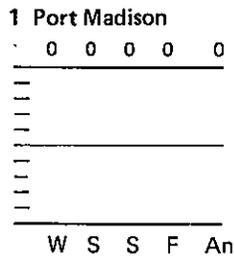


Figure 39. Seasonal and annual incidence of bladder necrosis in *C. magister* from each embayment of embayment subarea sampled.

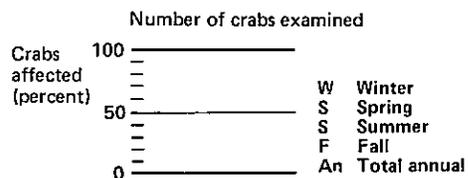
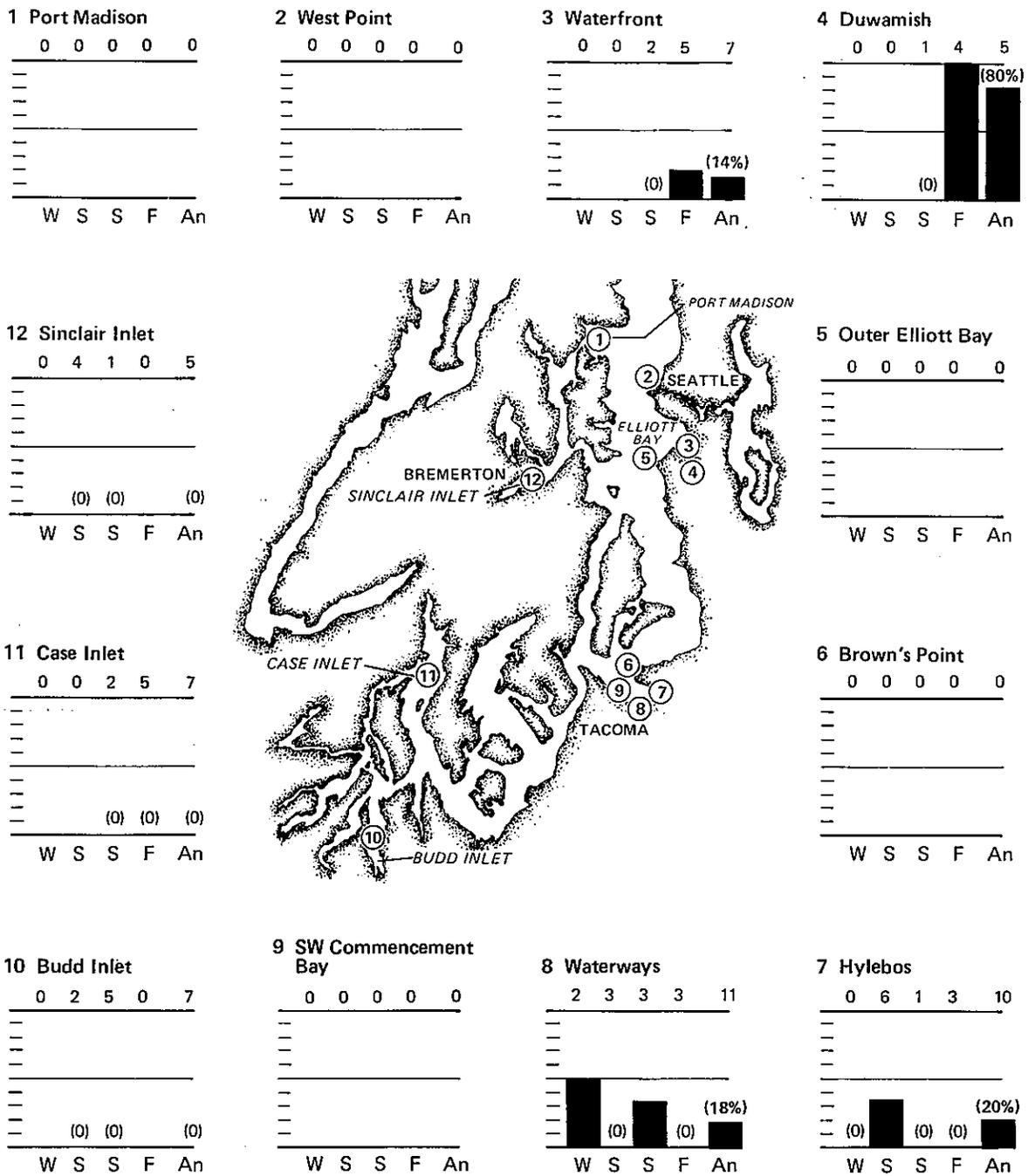


Figure 40. Seasonal and annual incidence of bladder necrosis in *C. gracilis* from each embayment or embayment subarea sampled.

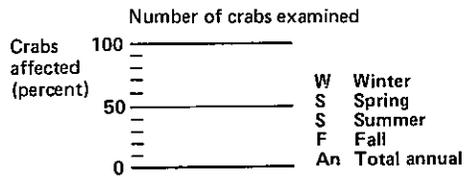
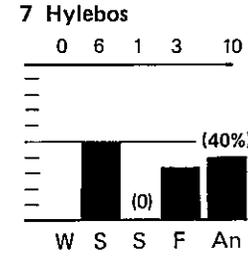
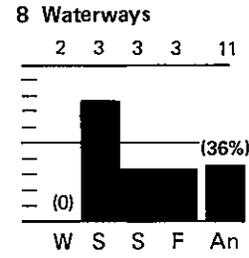
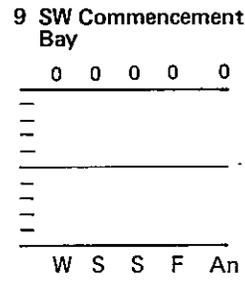
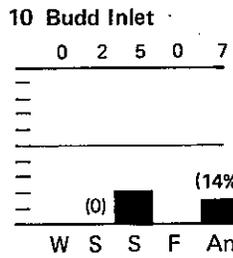
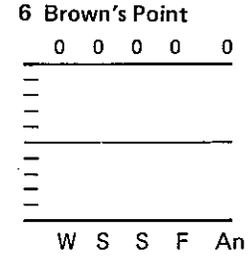
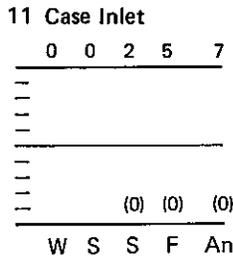
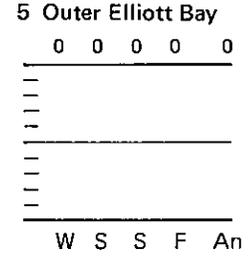
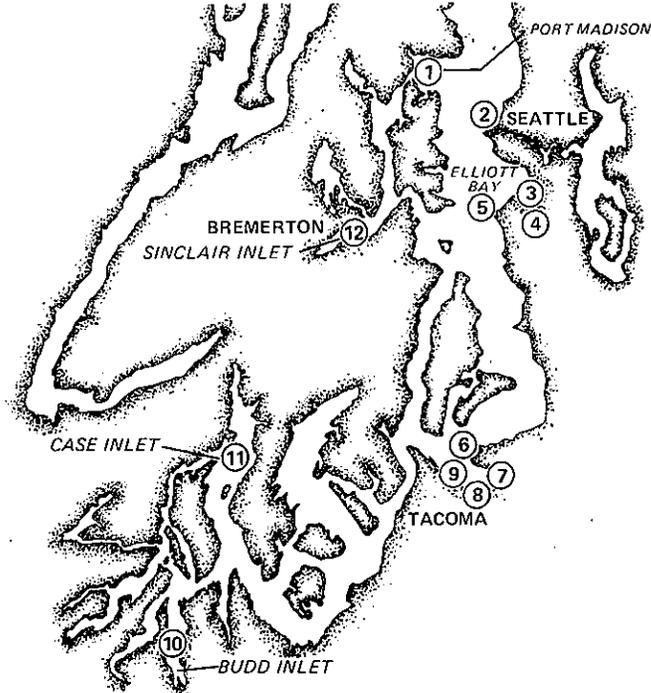
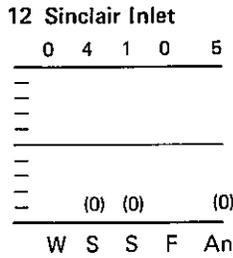
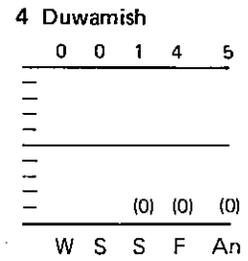
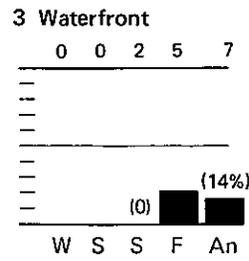
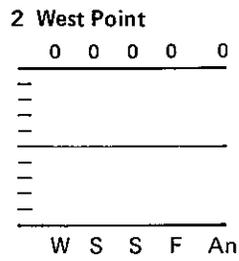
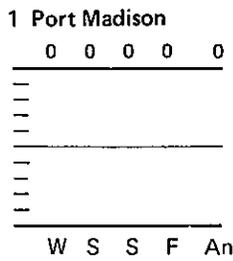


Figure 41. Seasonal and annual incidence of bladder epithelium nuclear enlargement in *C. gracilis* from each embayment or embayment subarea sampled.

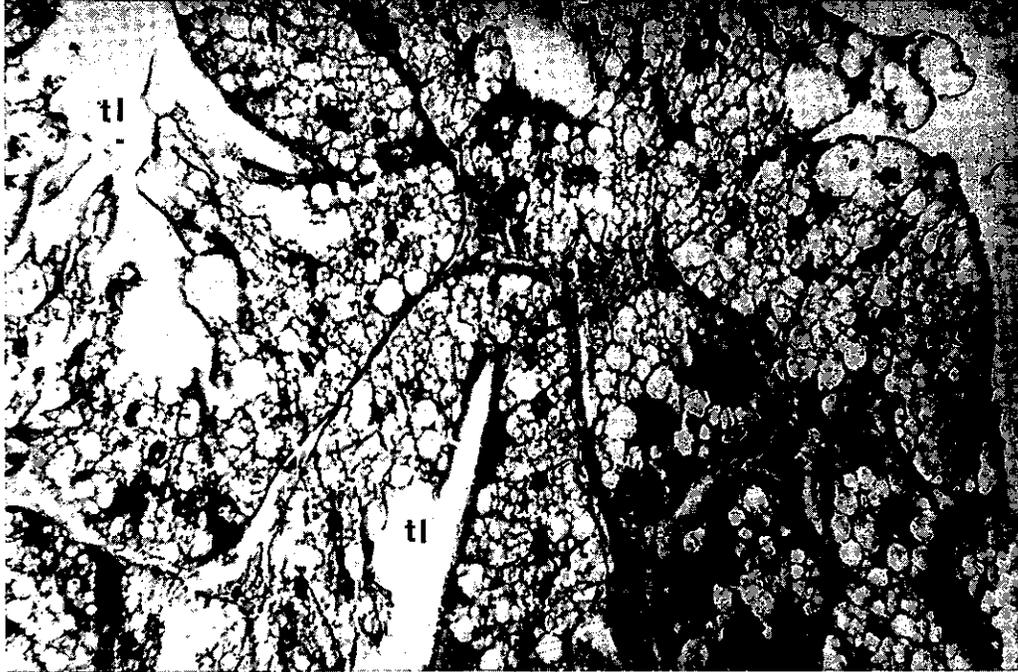


Figure 42. The hepatopancreas of a P. danae with extensive vesiculation (tl, tubule lumen). H & E 200X.

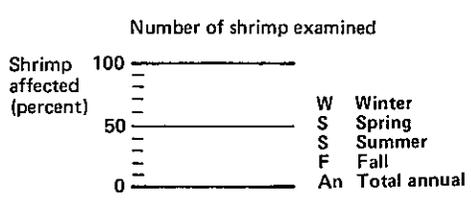
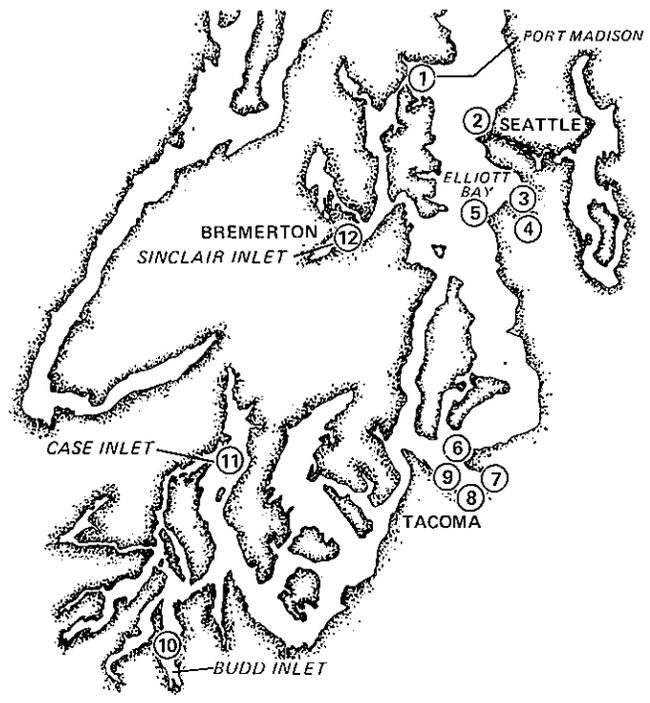
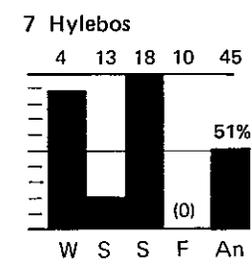
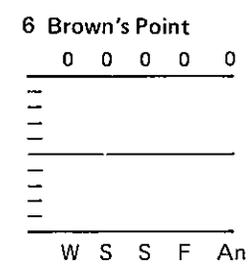
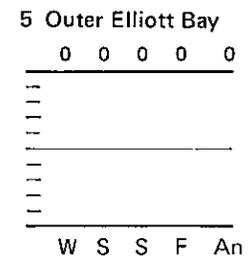
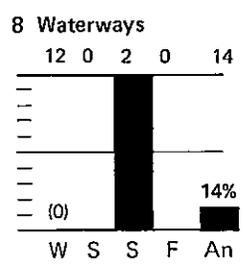
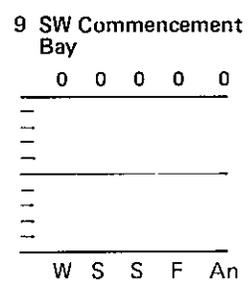
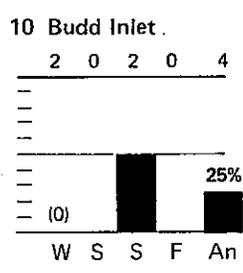
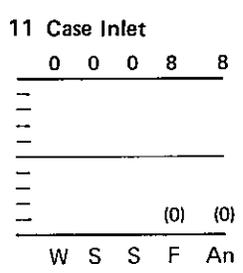
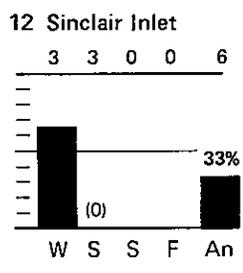
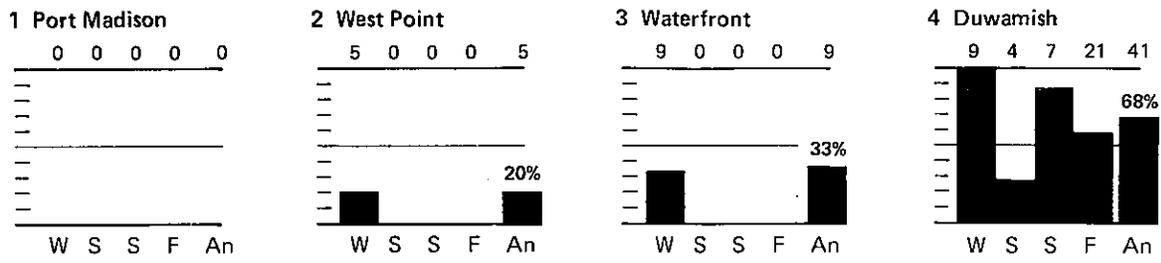


Figure 43. Seasonal and annual incidence of vesicular hepatopancreas in *P. danae* from each embayment or embayment subarea sampled.

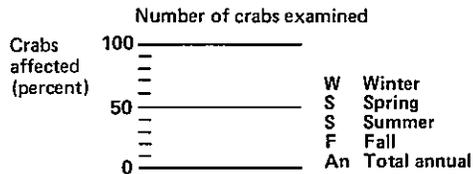
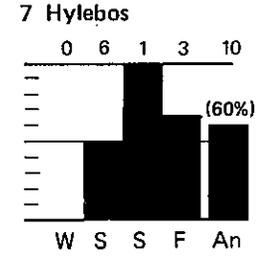
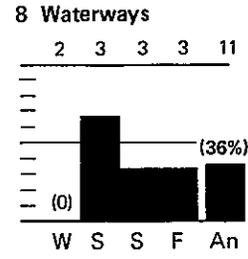
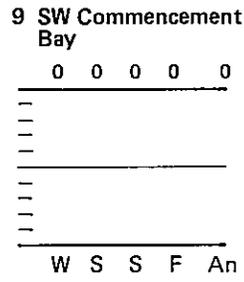
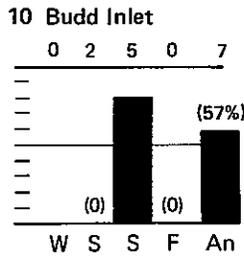
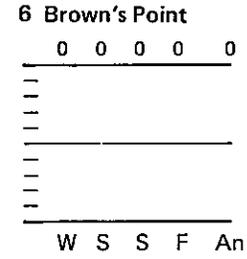
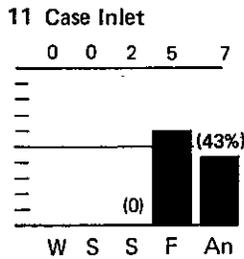
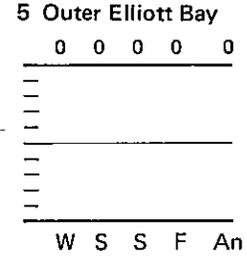
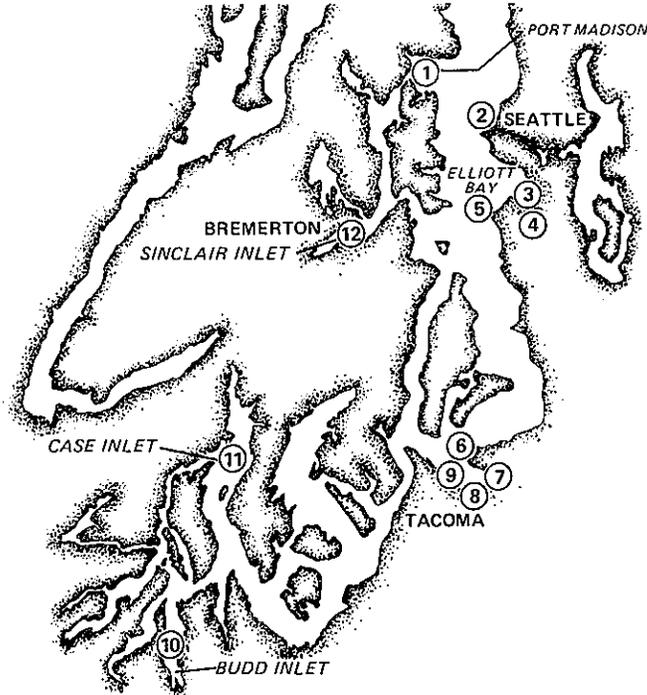
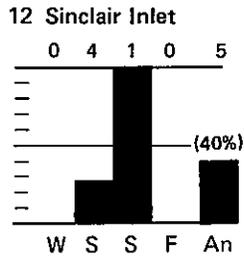
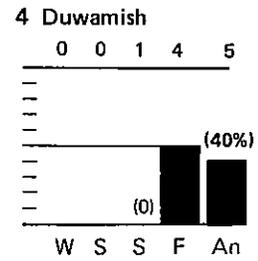
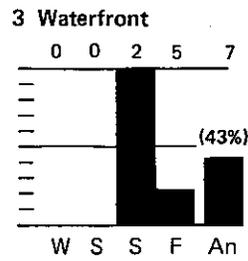
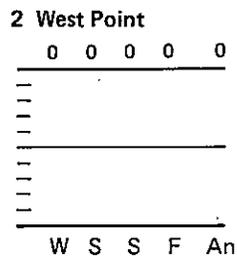
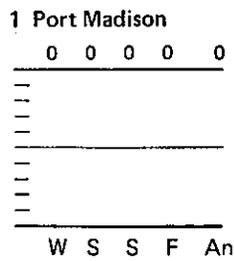


Figure 44. Seasonal and annual incidence of vesicular hepatopancreas in *C. gracilis* from each embayment or embayment subarea sampled.

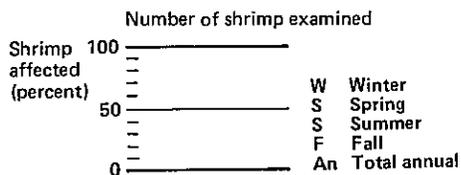
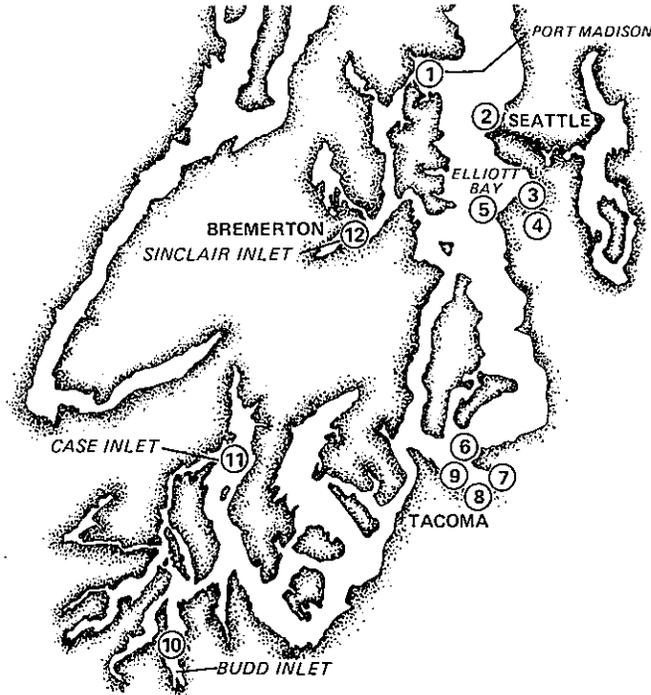
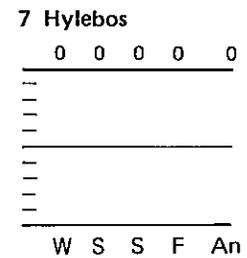
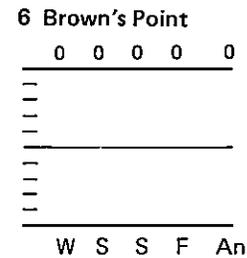
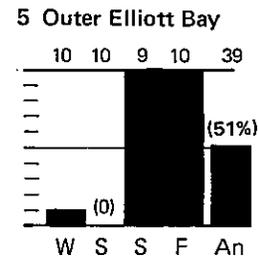
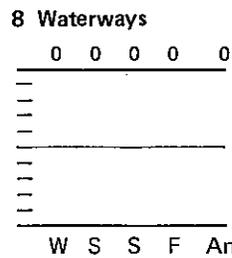
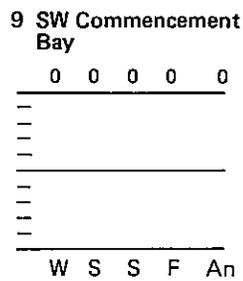
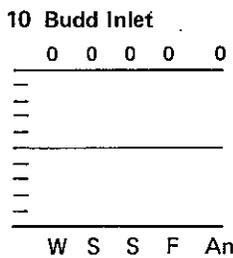
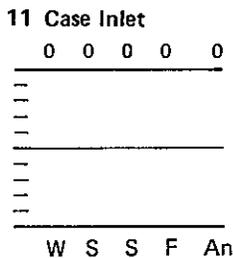
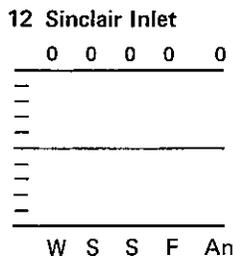
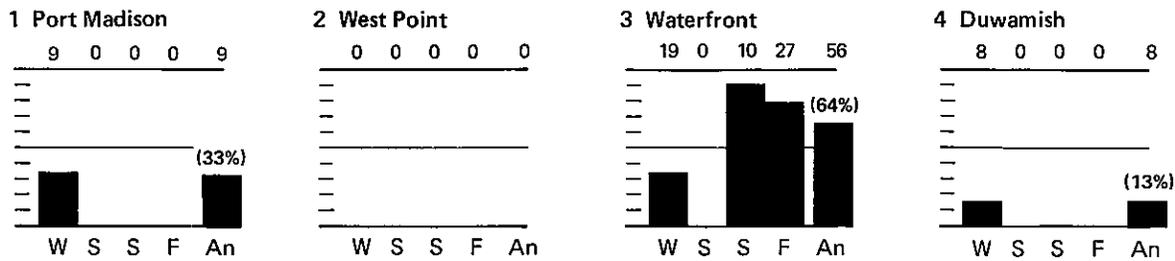


Figure 45. Seasonal and annual incidence of vesicular hepatopancreas in *P. jordani* from each embayment or embayment subarea sampled.

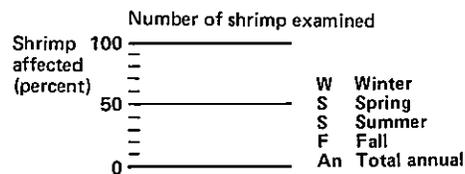
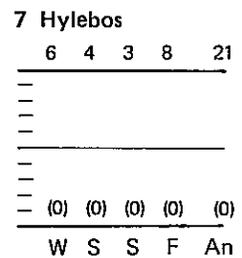
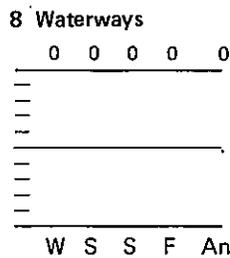
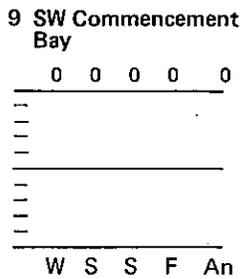
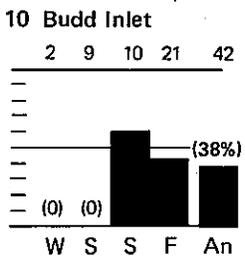
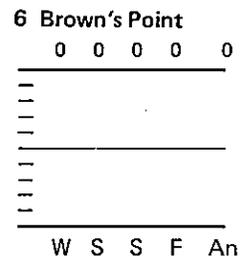
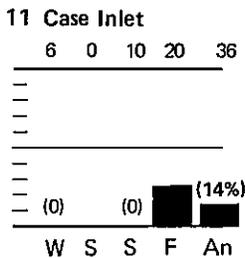
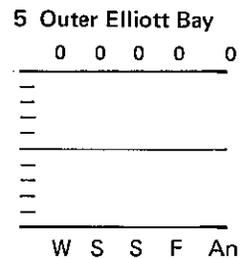
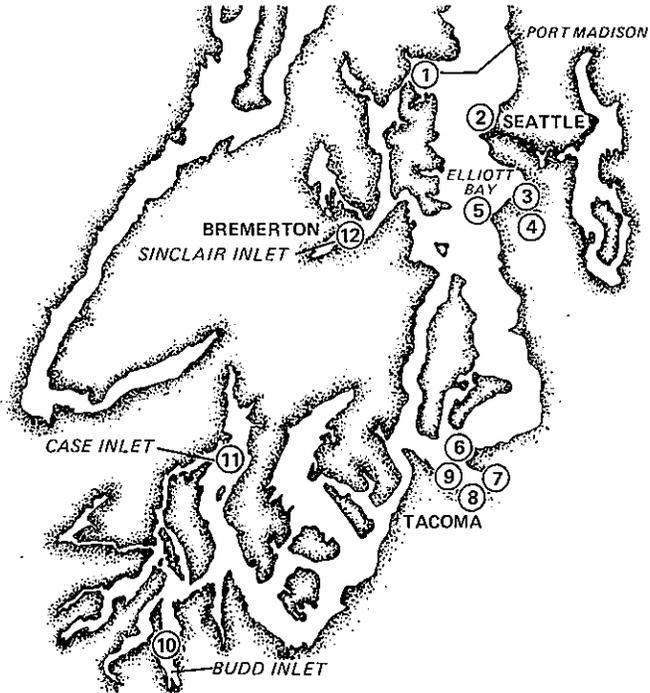
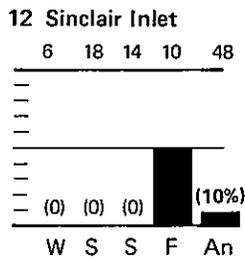
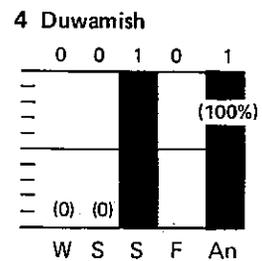
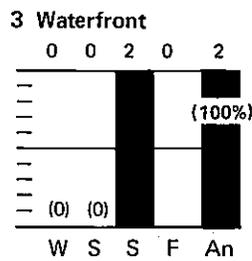
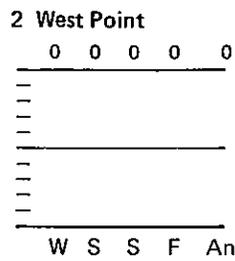
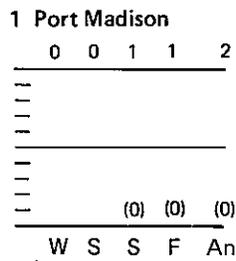


Figure 46. Seasonal and annual incidence of vesicular hepatopancreas in *C. alaskensis* from each embayment or embayment subarea sampled.



Figure 47. Gill filaments of a *P. danae* with a mycotic lesion. Both melanzed hyphae (mh) and nonmelanzed hyphae (h) are present. GMS stain, 200X.



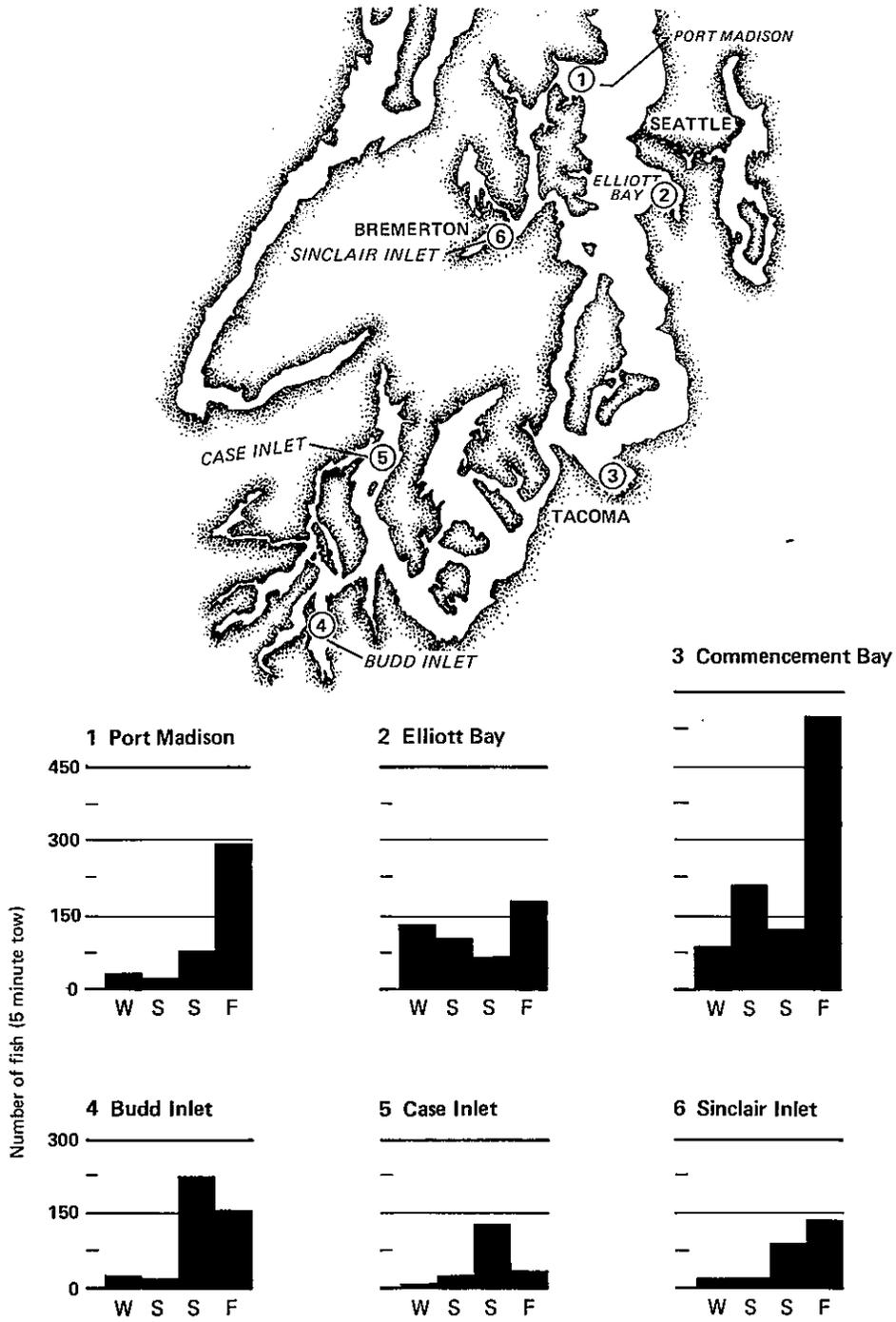


Figure 49. Average seasonal CPUE by season for all target fish species for each of the embayments sampled.

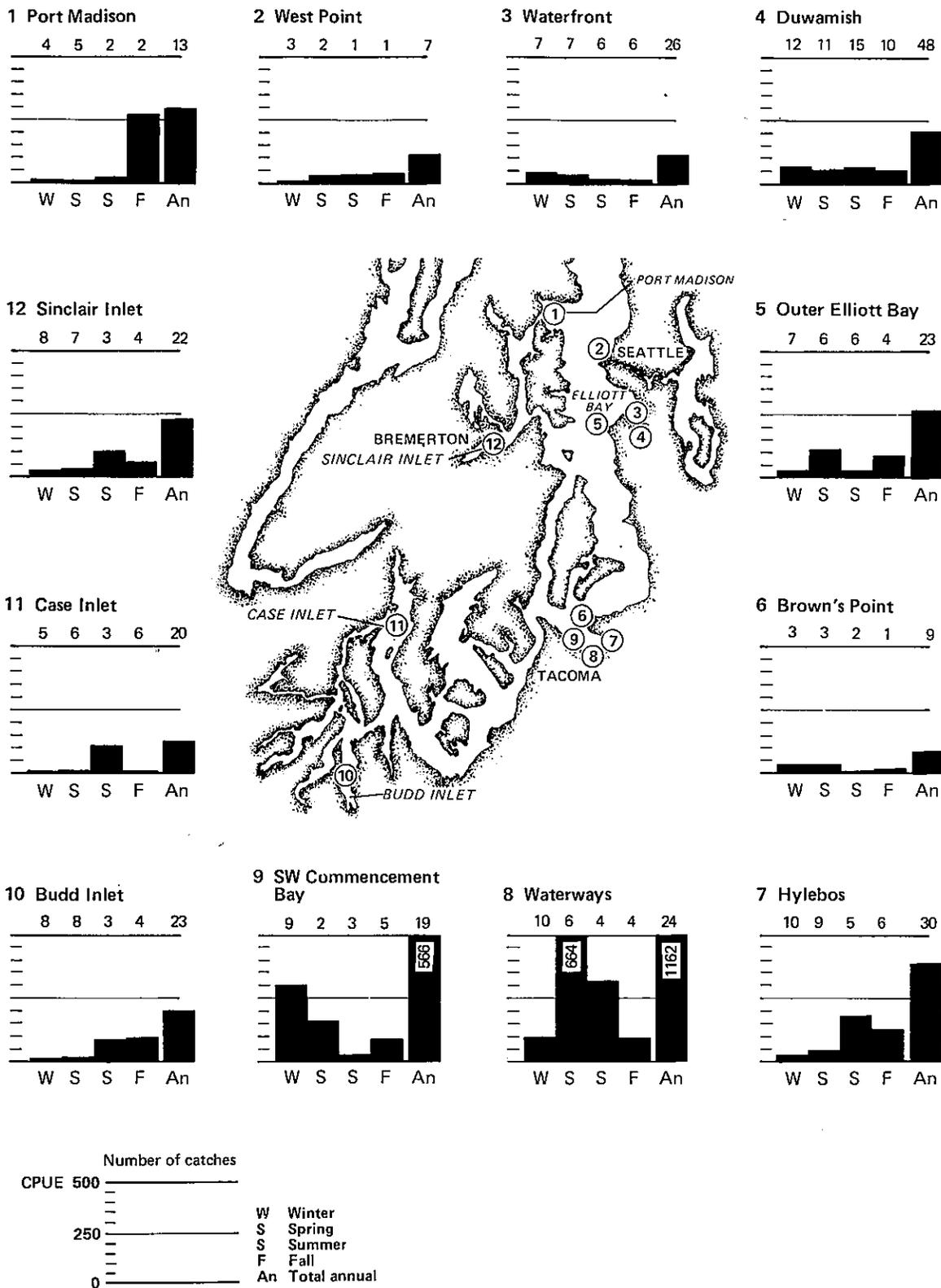


Figure 50. Seasonal and annual catch rates (CPUE) for English sole in each of the embayments or subareas of the embayments.

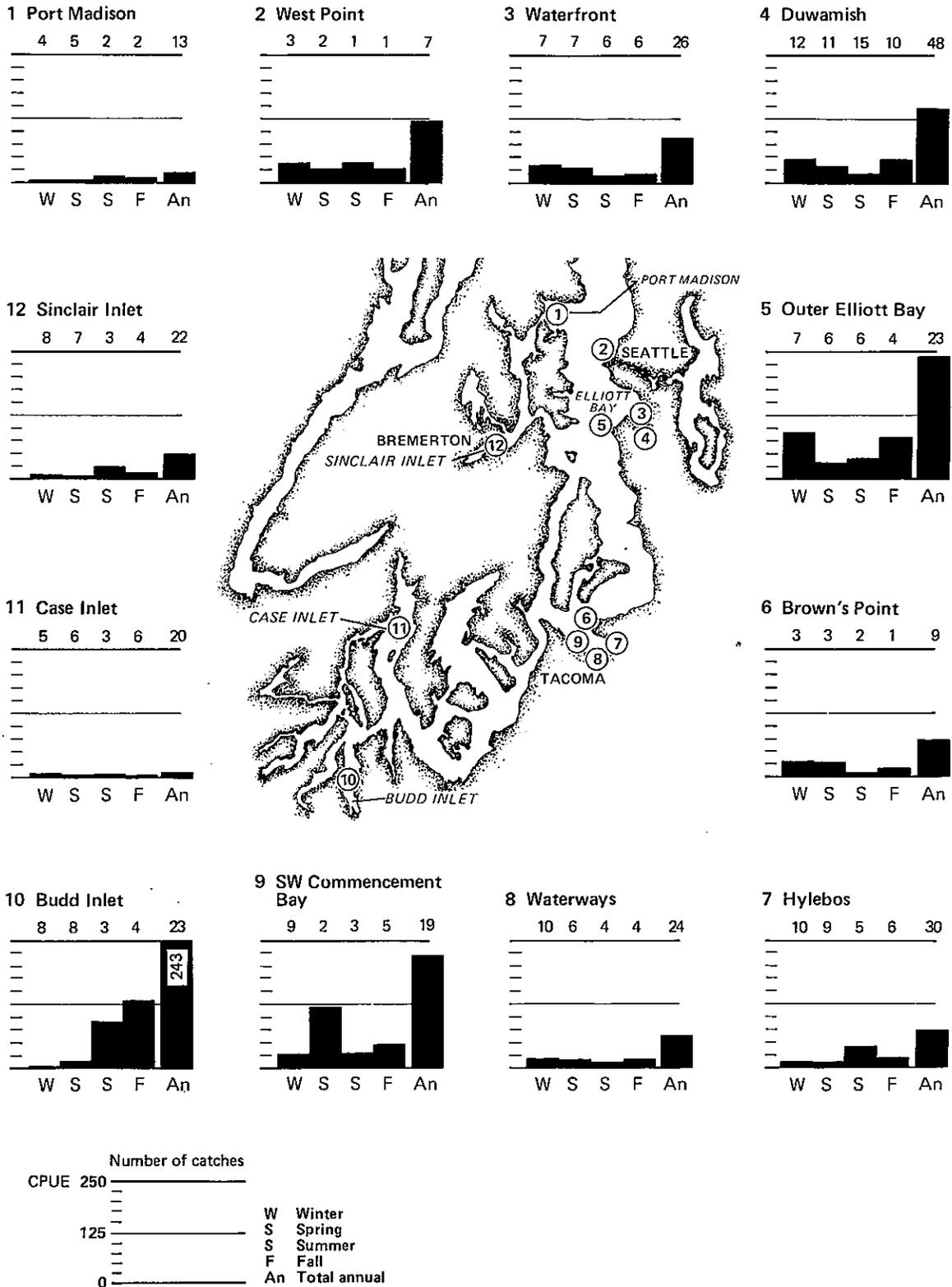


Figure 51. Seasonal and annual catch rates (CPUE) for rock sole in each of the embayments or subareas of the embayments.

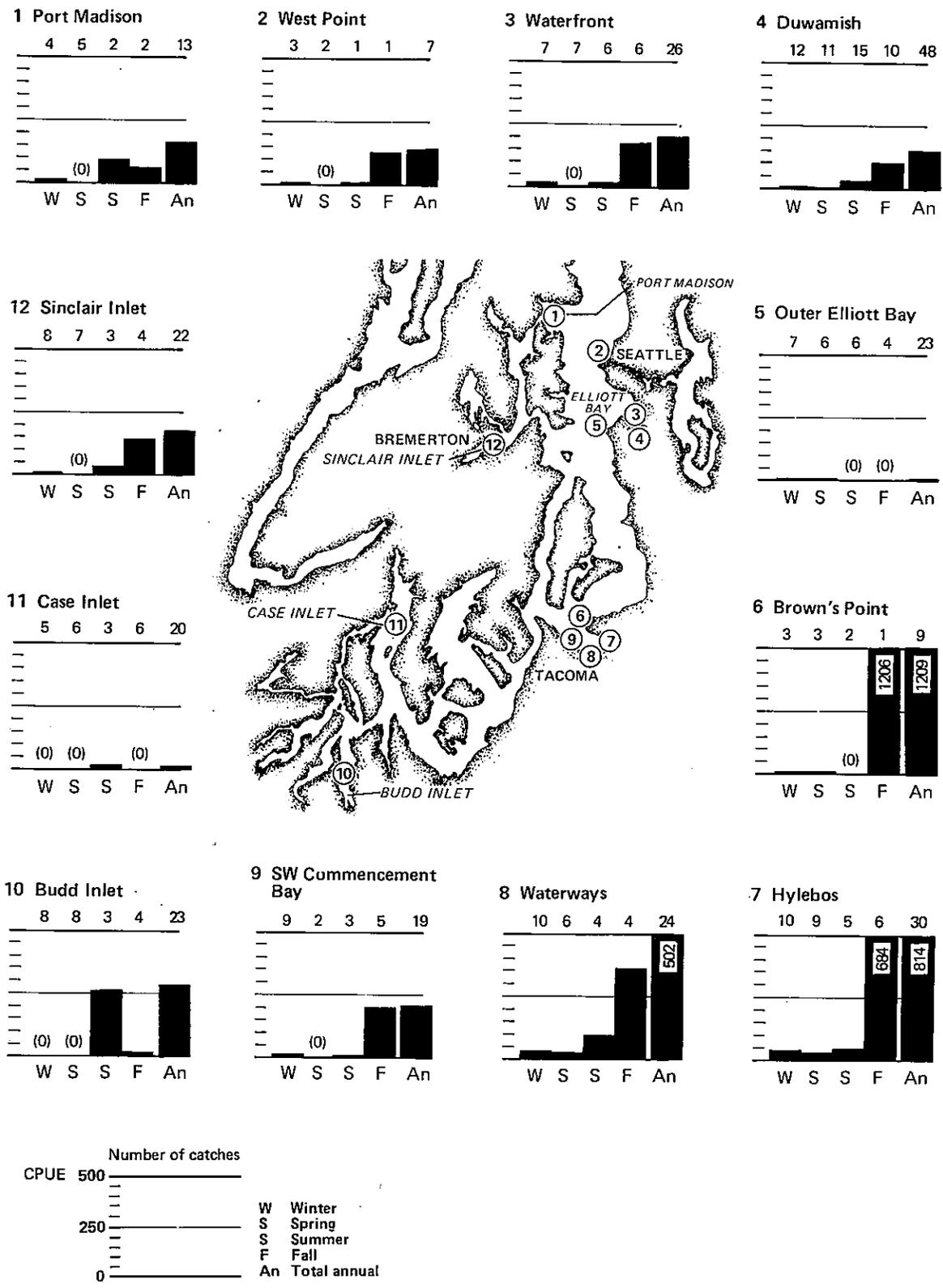


Figure 52. Seasonal and annual catch rates (CPUE) for Pacific tomcod in each of the embayments or subareas of the embayments.

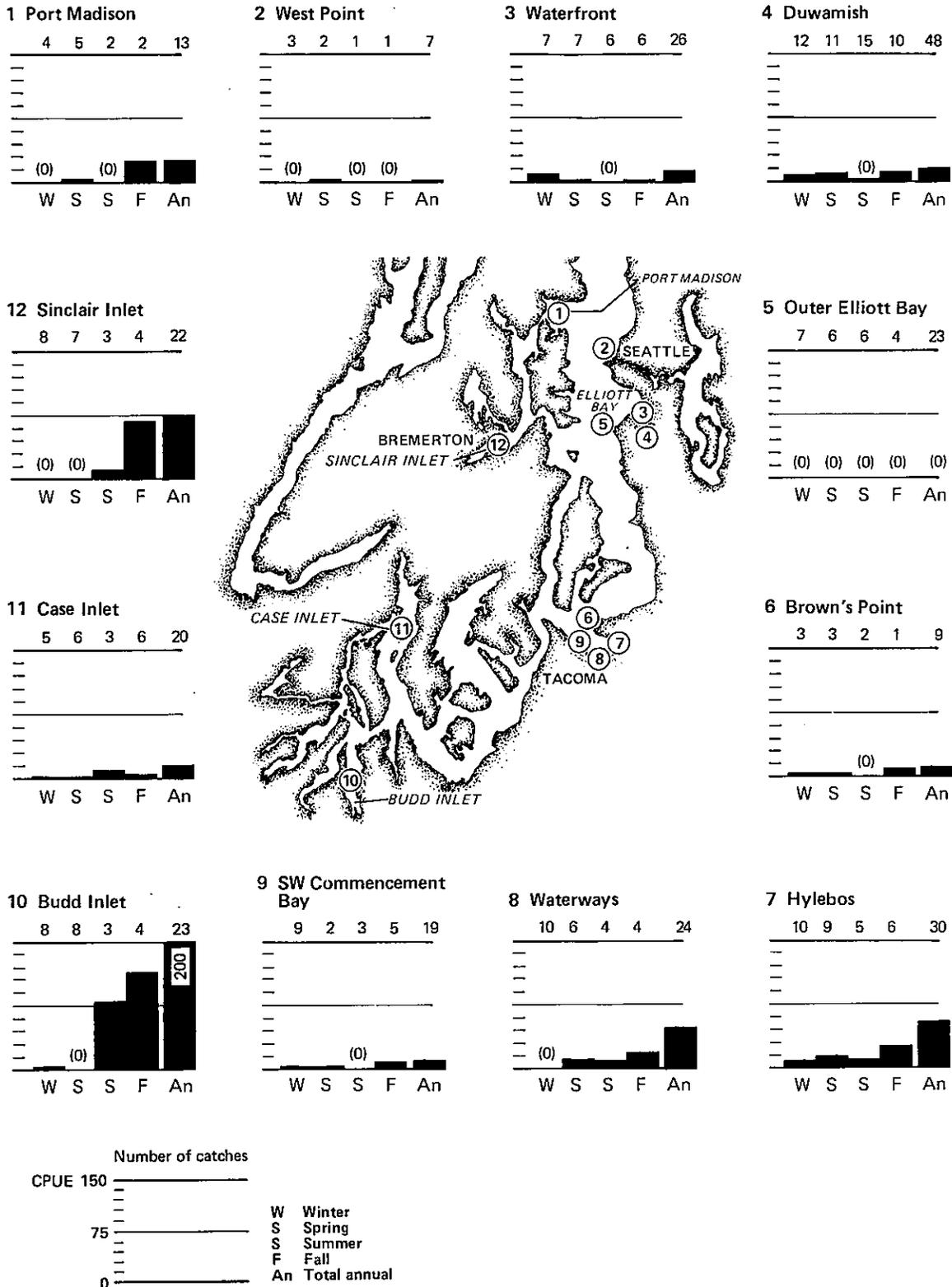


Figure 53. Seasonal and annual catch rates (CPUE) for Pacific staghorn sculpin in each of the embayments or subareas of the embayments.

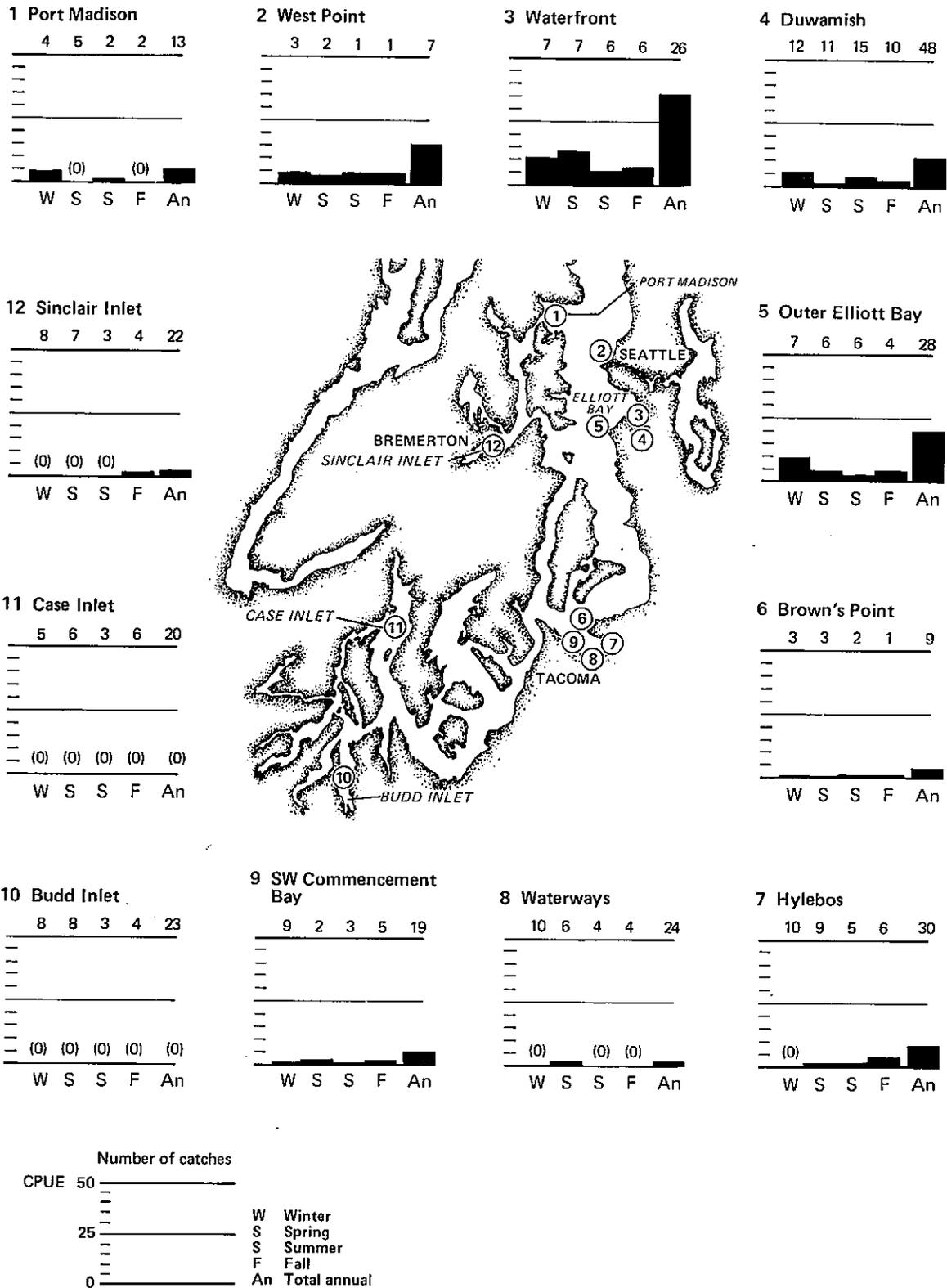


Figure 54. Seasonal and annual catch rates (CPUE) for quillback rockfish in each of the embayments or subareas of the embayments.

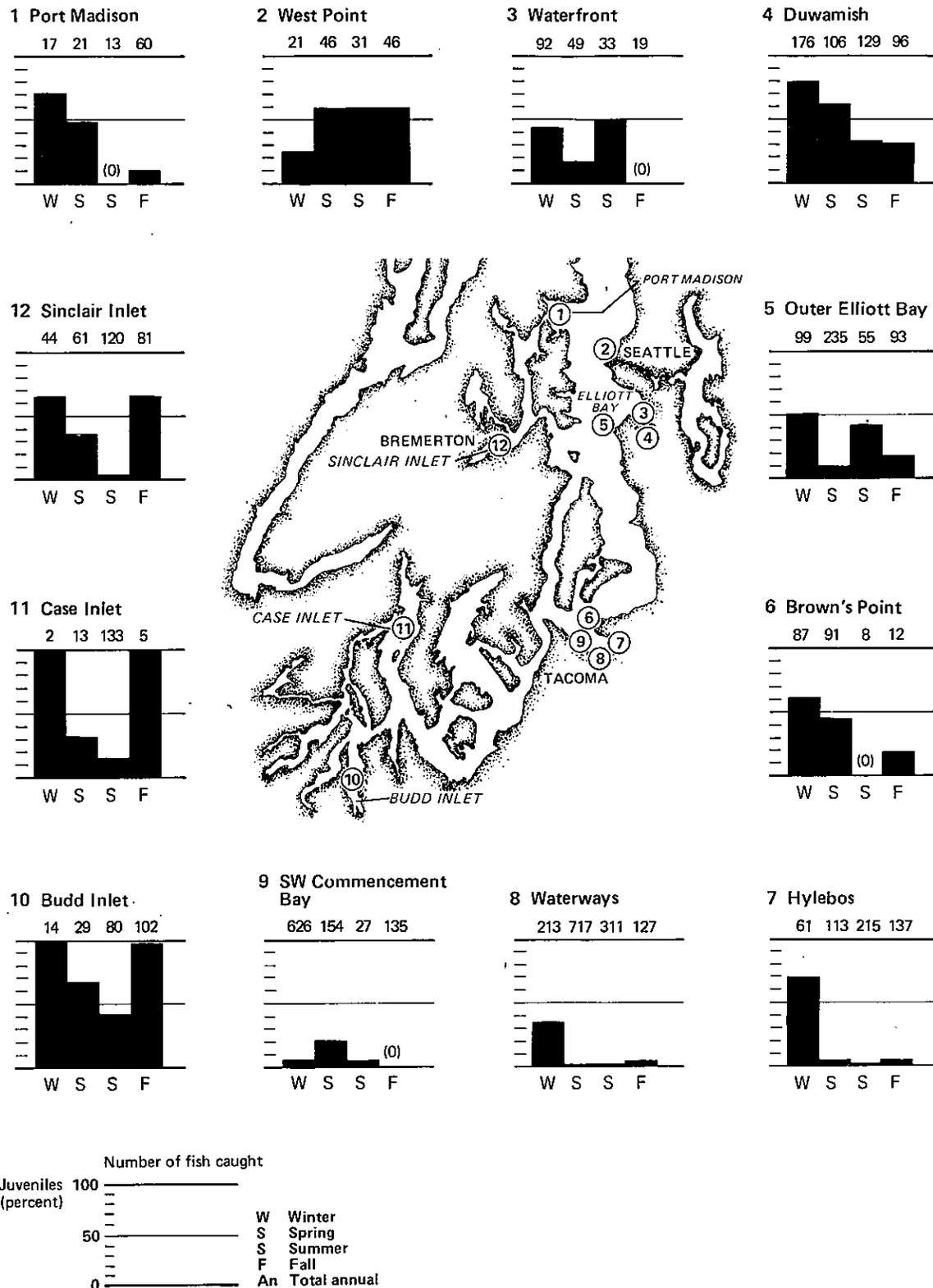


Figure 55. The proportion of juvenile English sole (< 150 mm) for each season in each embayment or subareas of each embayment.

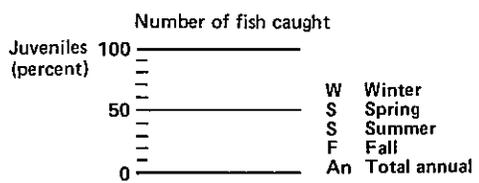
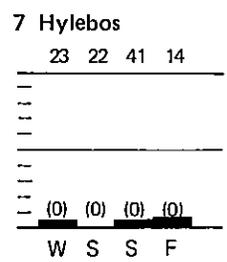
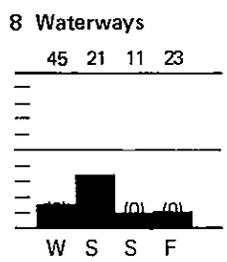
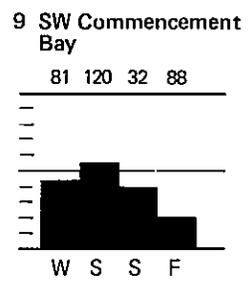
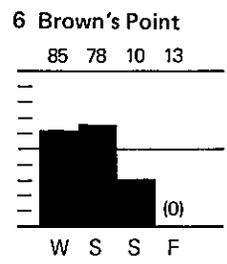
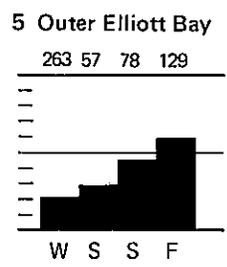
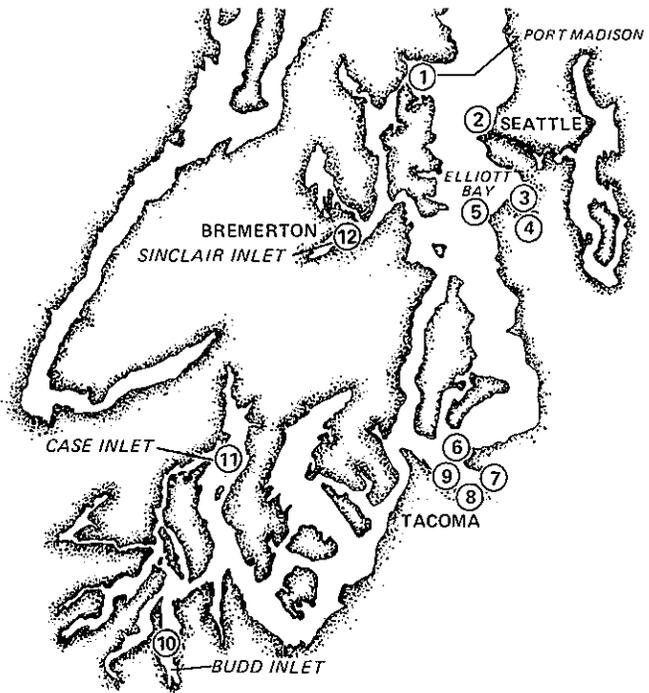
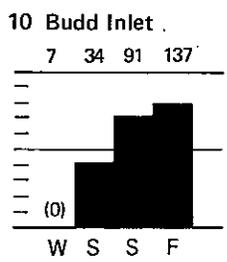
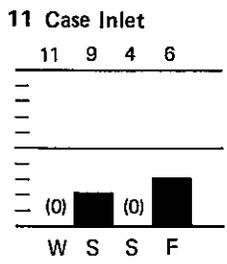
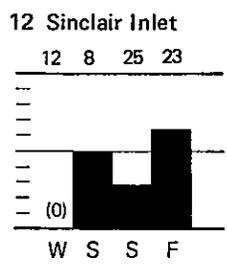
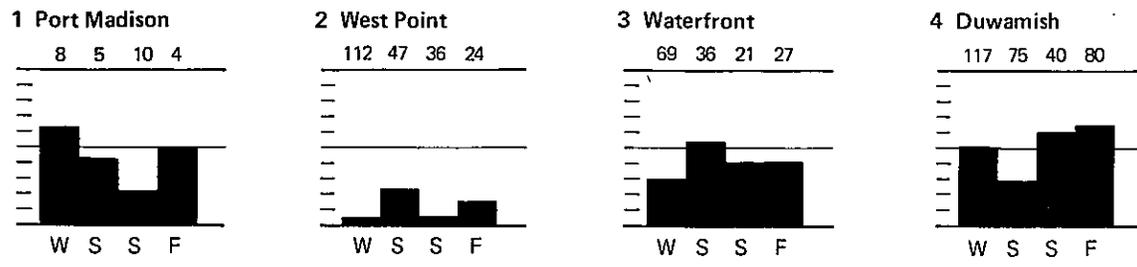


Figure 56. The proportion of juvenile rock sole ( $\leq 150$  mm) for each season in each embayment or subareas of each embayment.

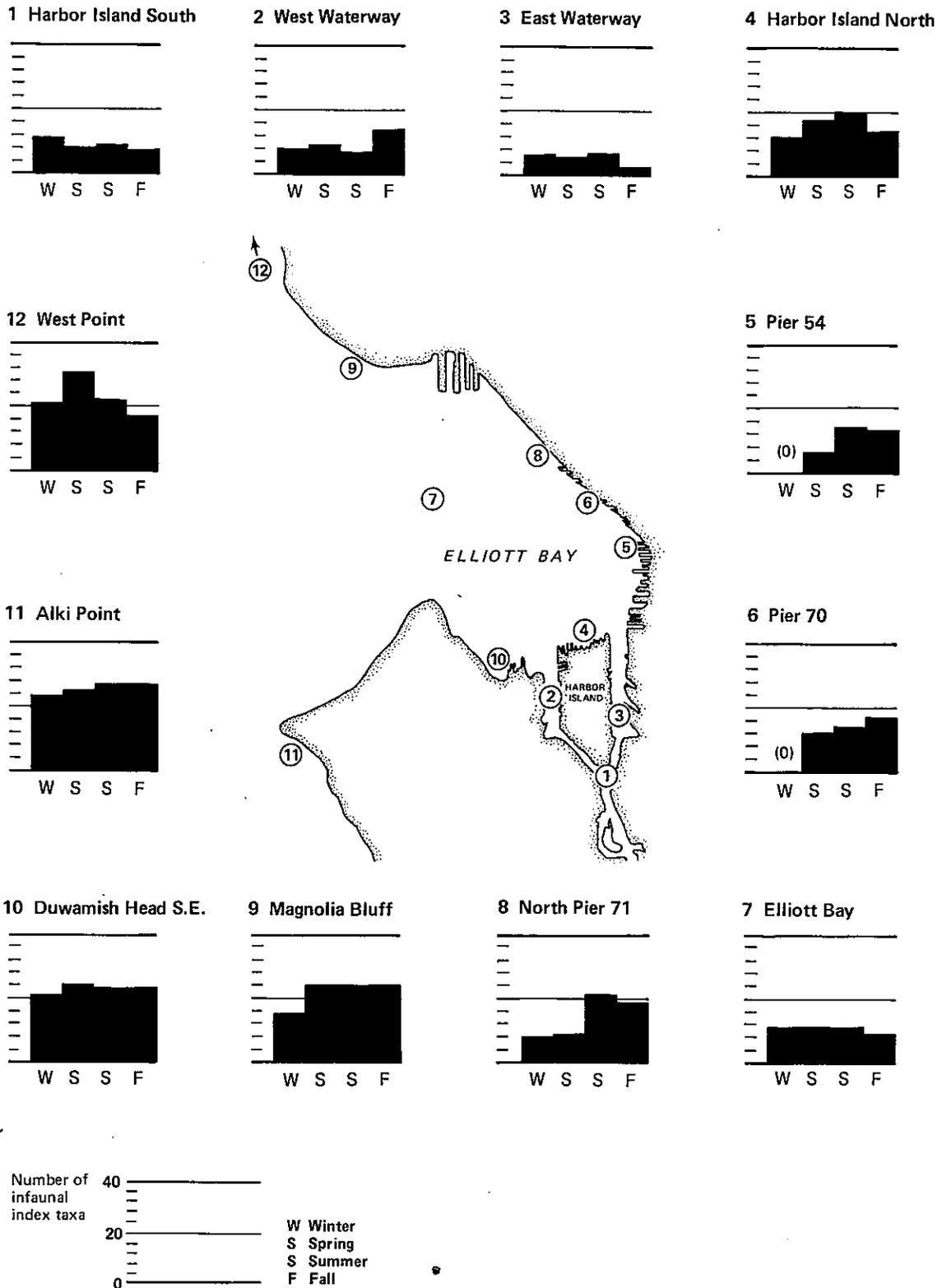


Figure 57. The average infaunal taxon richness values for each station in Elliott Bay by season. Taxon richness values were obtained using the taxonomic groups used in the Infaunal Trophic Index.

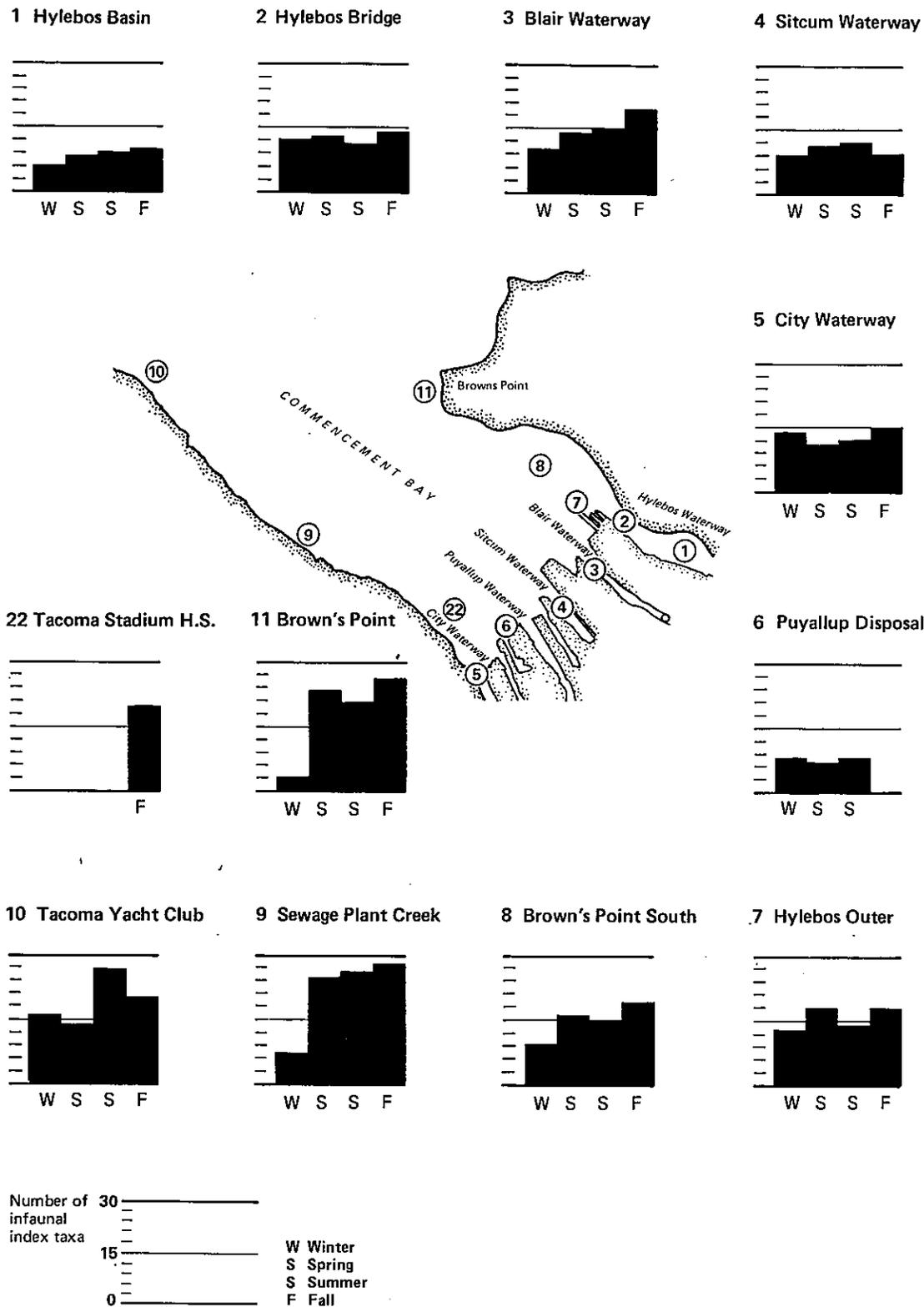


Figure 58. The average infaunal taxon richness values for each station in Commencement Bay by season. Taxon richness values were obtained using the taxonomic groups used in the Infaunal Trophic Index.

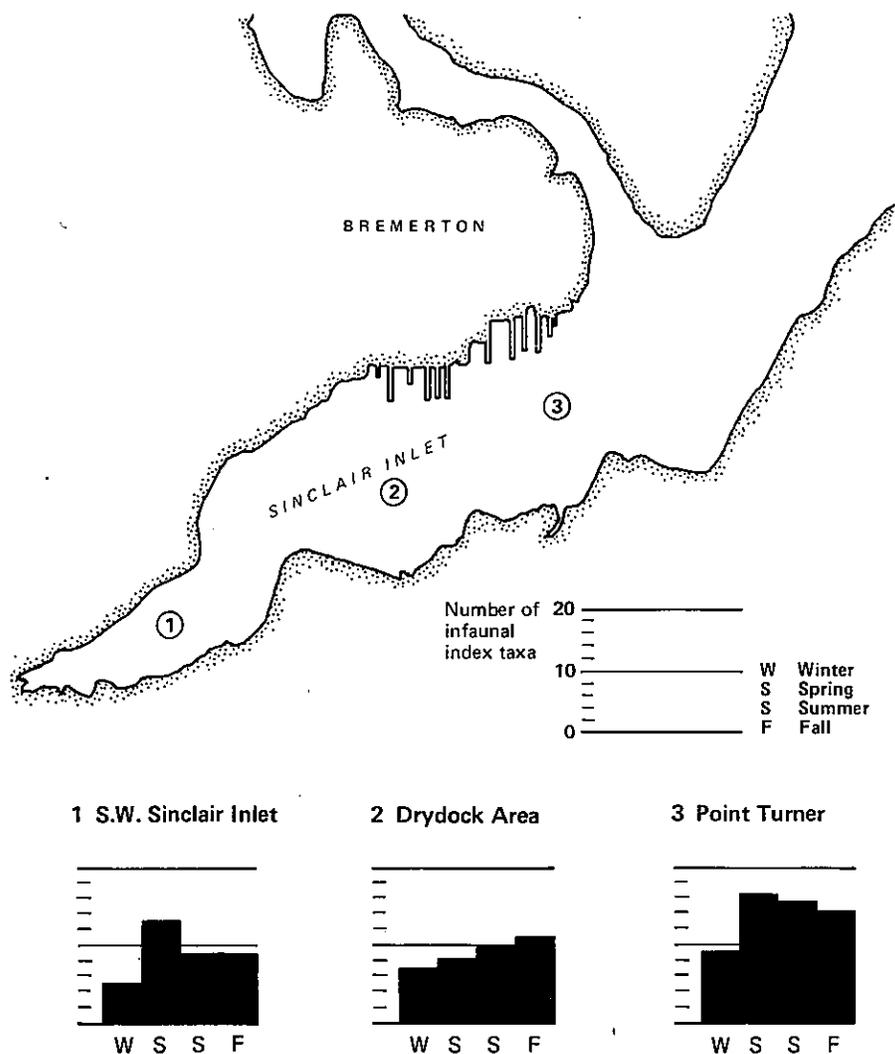


Figure 59. The average infaunal taxon richness values for each station in Sinclair Inlet by season. Taxon richness values were obtained using the taxonomic groups used in the Infaunal Trophic Index.

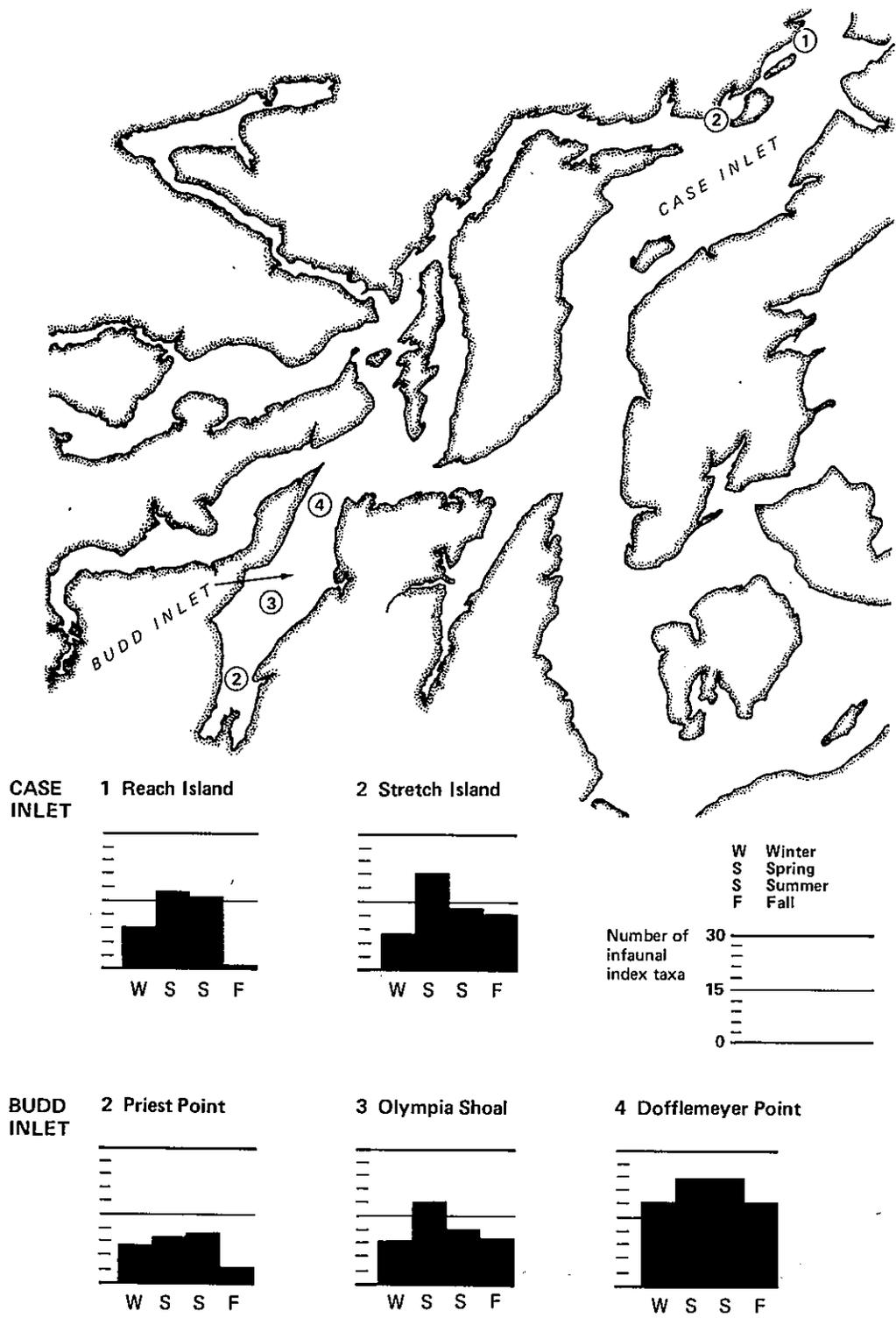


Figure 60. The average infaunal taxon richness values for each station in Case and Budd Inlets by season. Taxon richness values were obtained using the taxonomic groups used in the Infaunal Trophic Index.

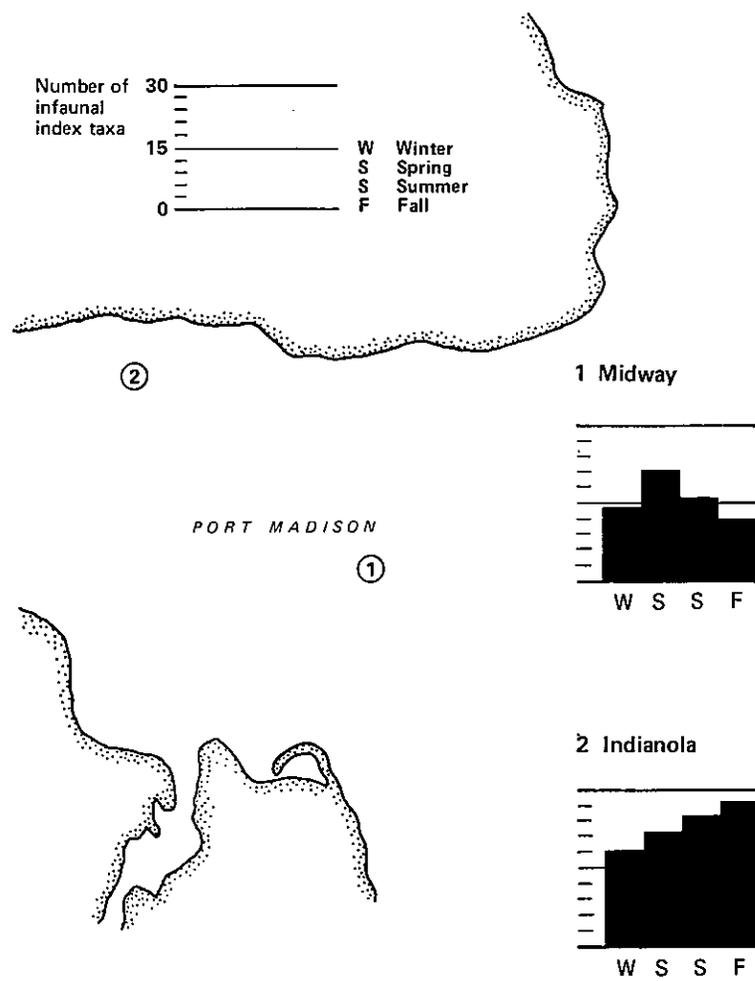


Figure 61. The average infaunal taxon richness values for each station in Port Madison by season. Taxon richness values were obtained using the taxonomic groups used in the Infaunal Trophic Index.

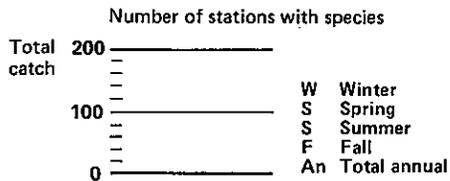
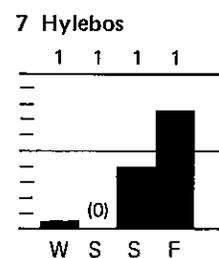
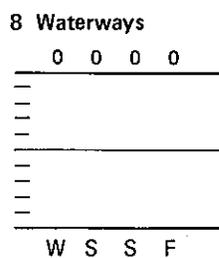
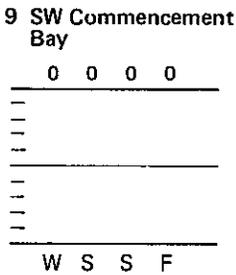
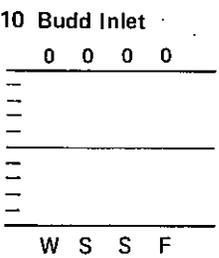
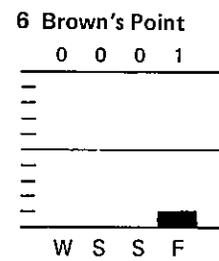
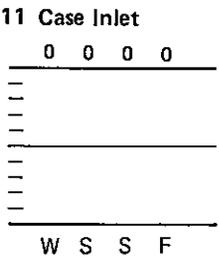
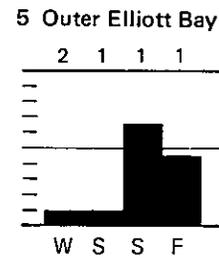
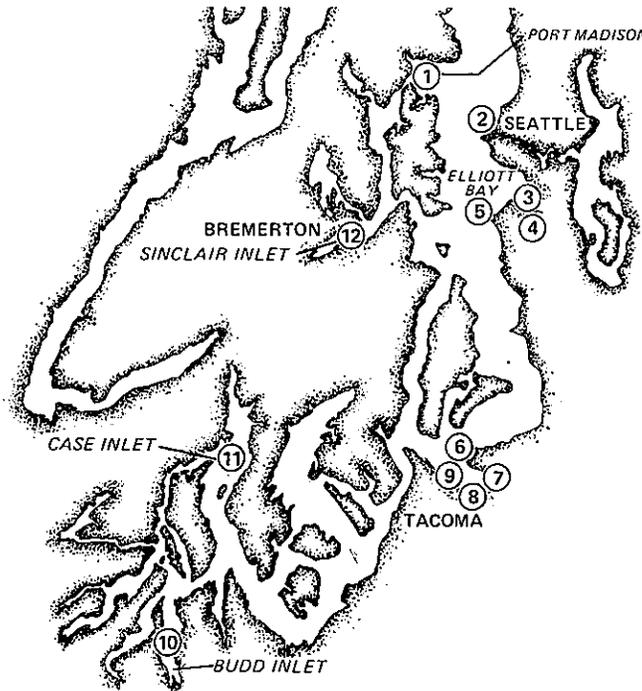
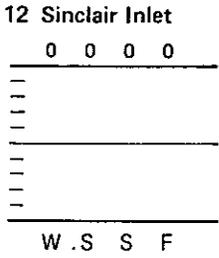
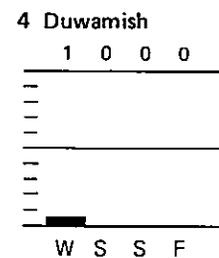
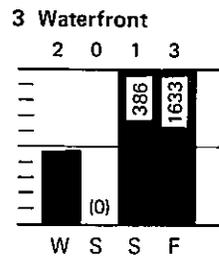
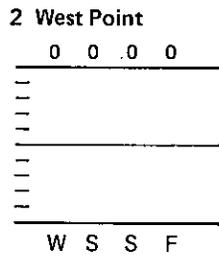
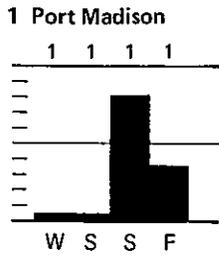


Figure 62. The seasonal and annual total catch values for *P. jordani* in each of the embayments or subareas of the embayments.

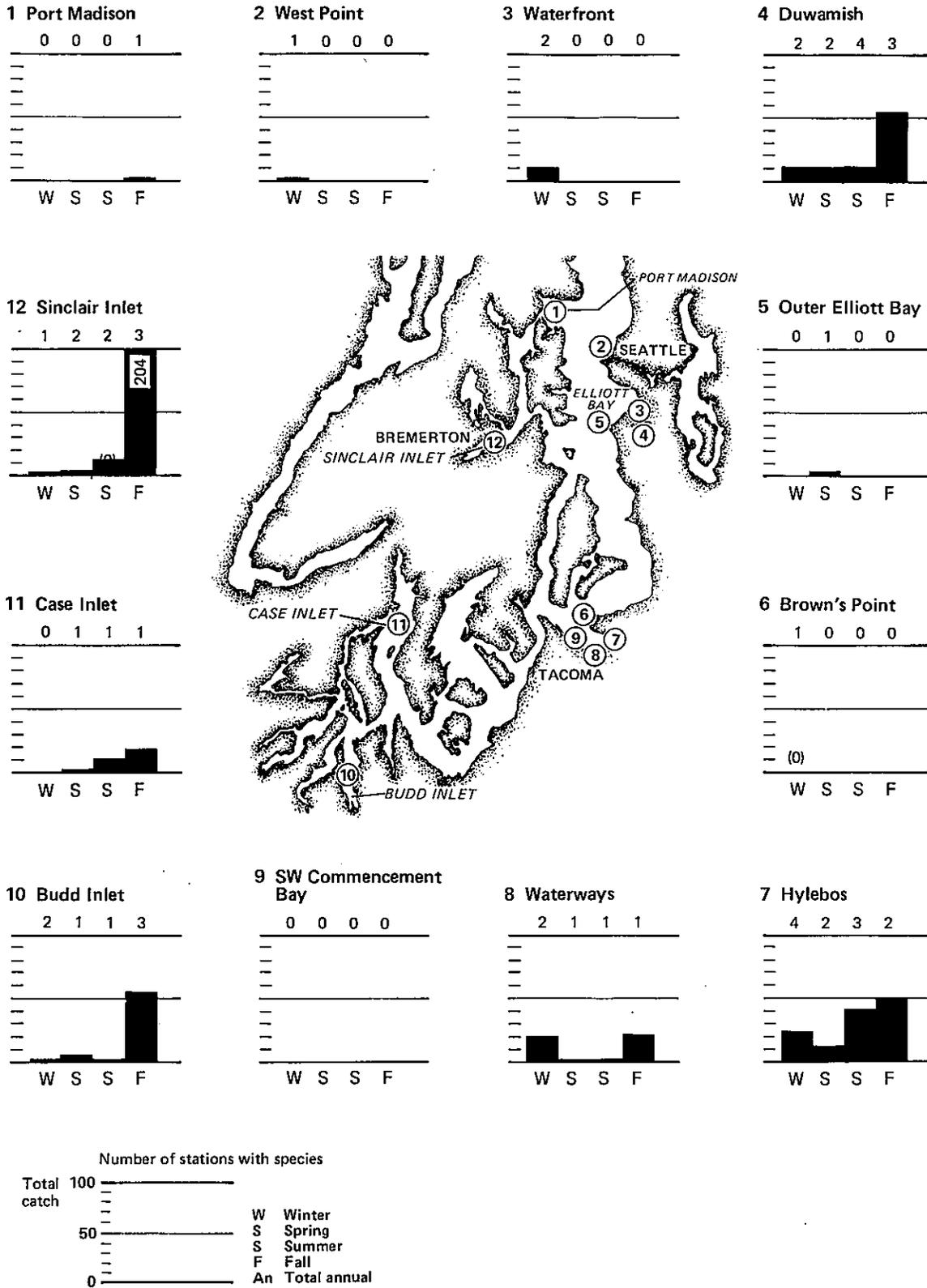


Figure 63. The seasonal and annual total catch values for *P. danae* in each of the embayments or subareas of the embayments.

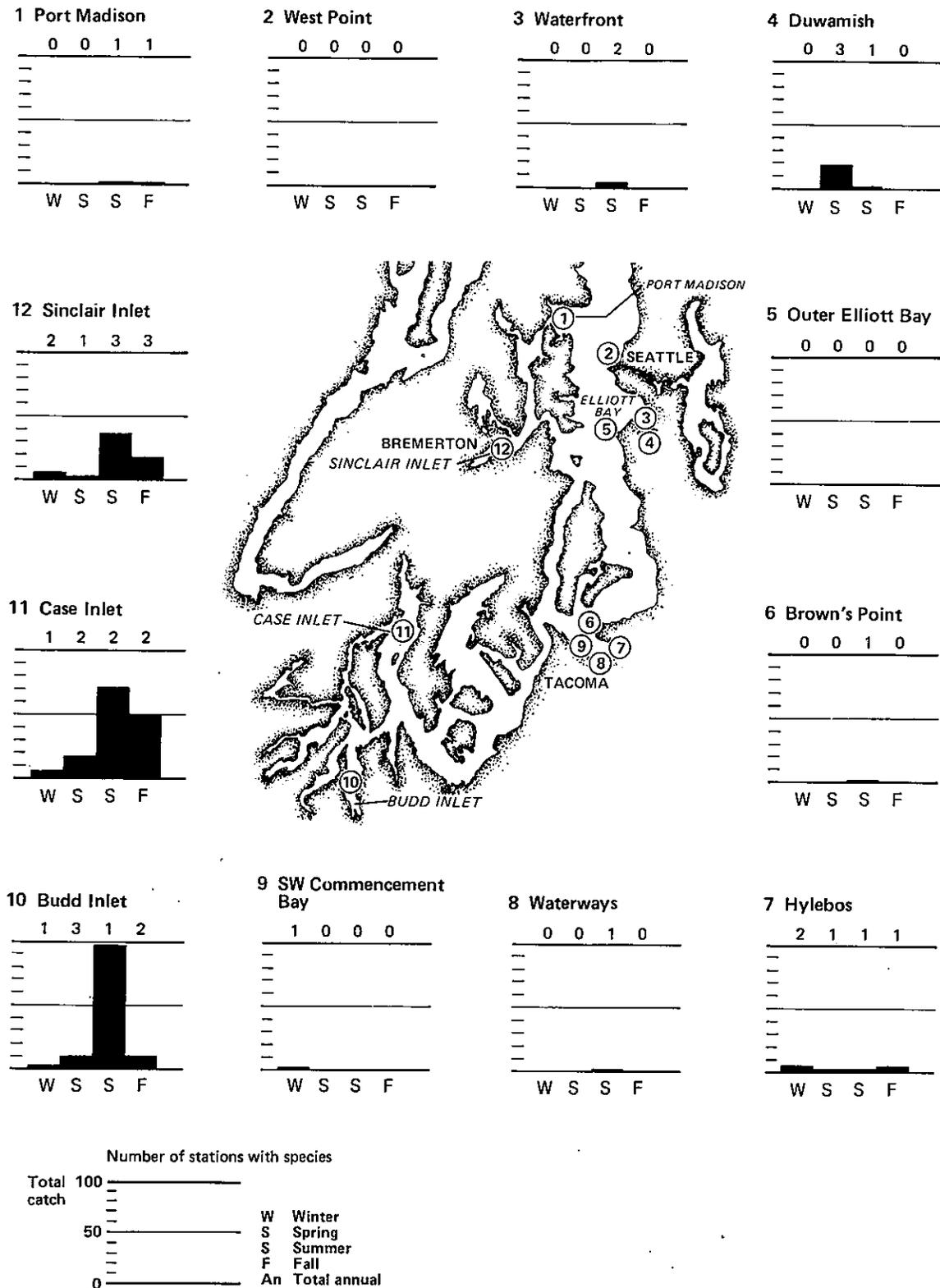


Figure 64. The seasonal and annual total catch values for *C. alaskensis* in each of the embayments or subareas of the embayments..

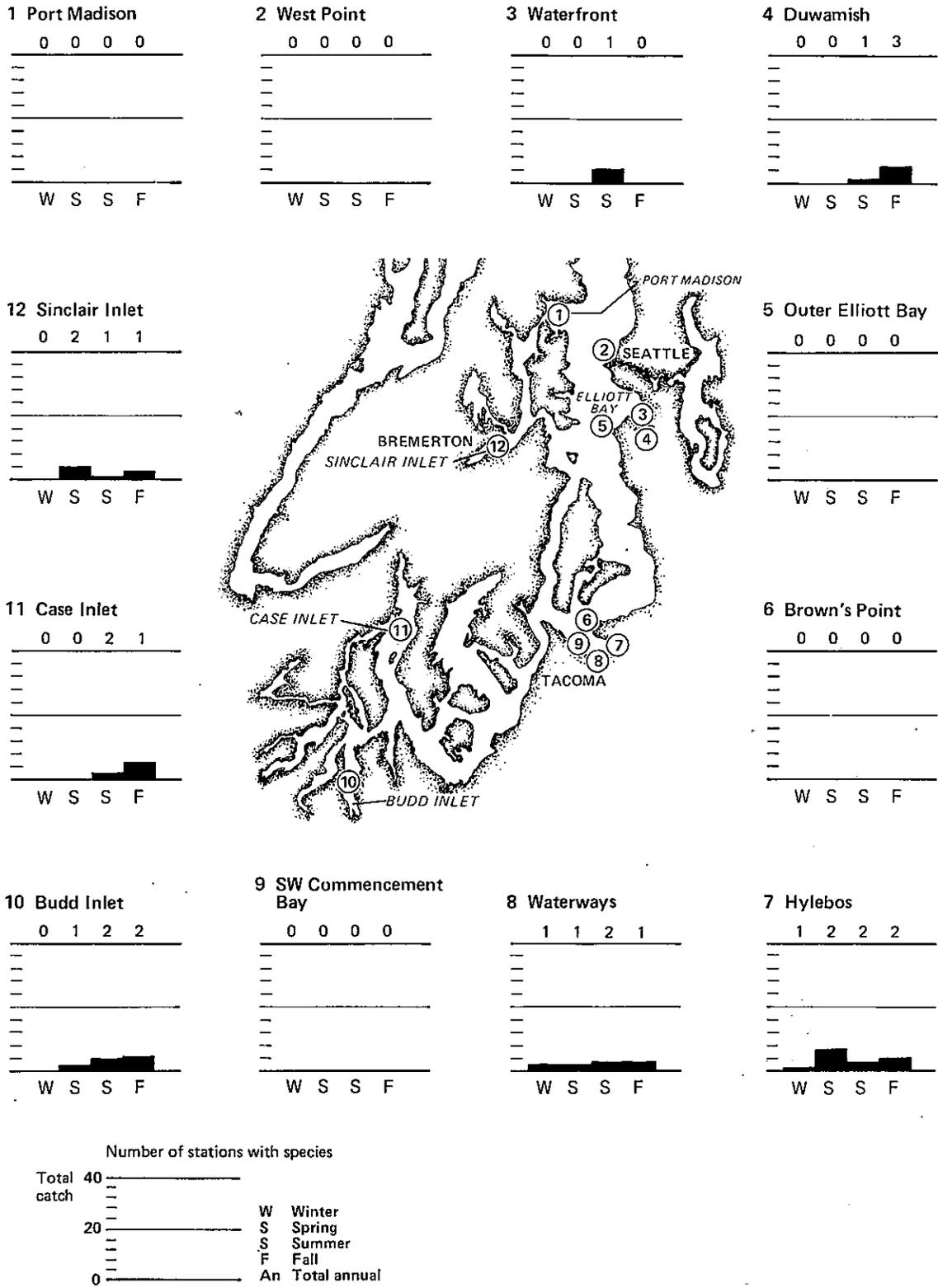


Figure 65. The seasonal and annual total catch values for *C. gracilis* in each of the embayments or subareas of the embayments.

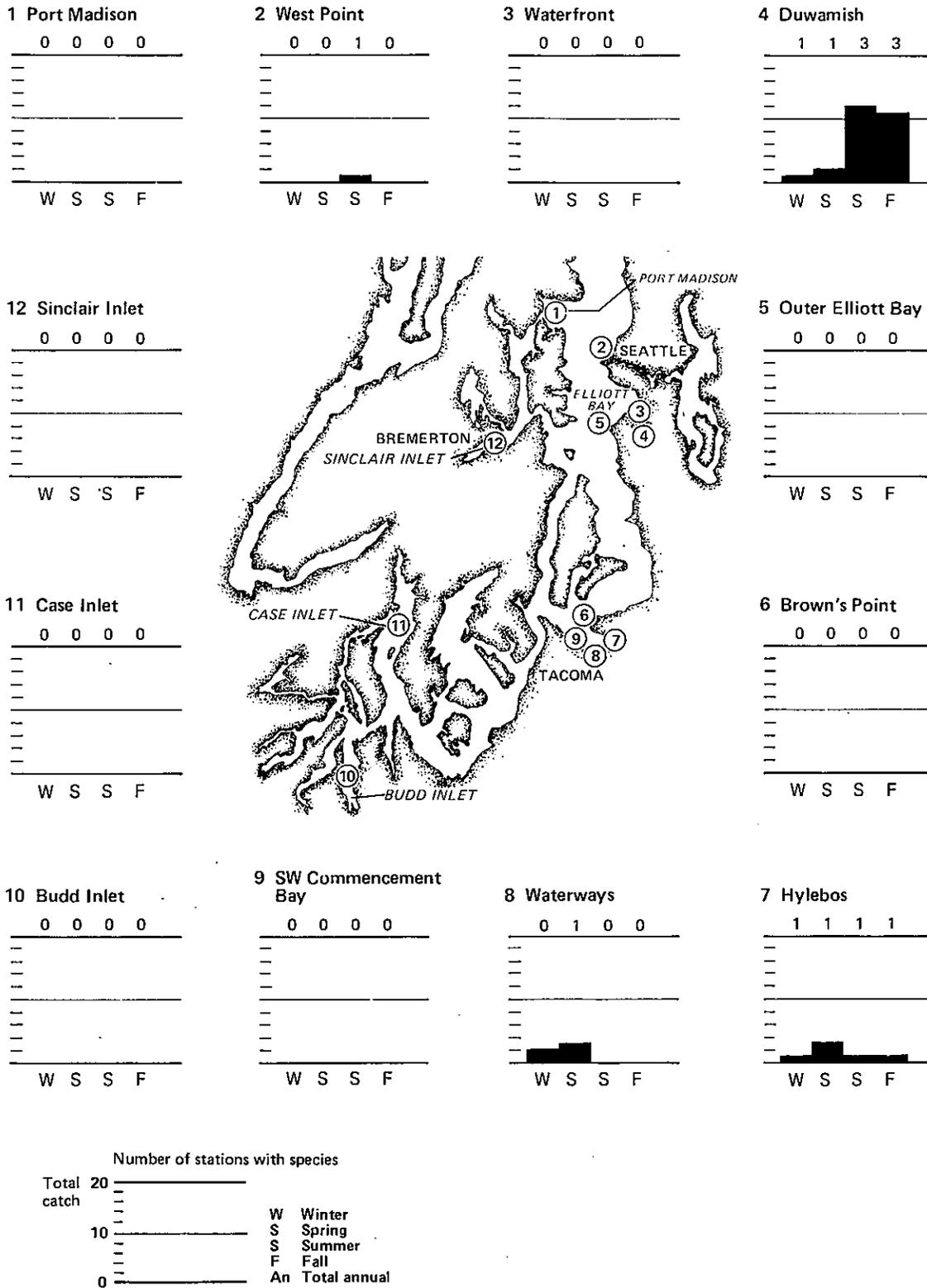


Figure 66. The seasonal and annual total catch values for *C. magister* in each of the embayments or subareas of the embayments.

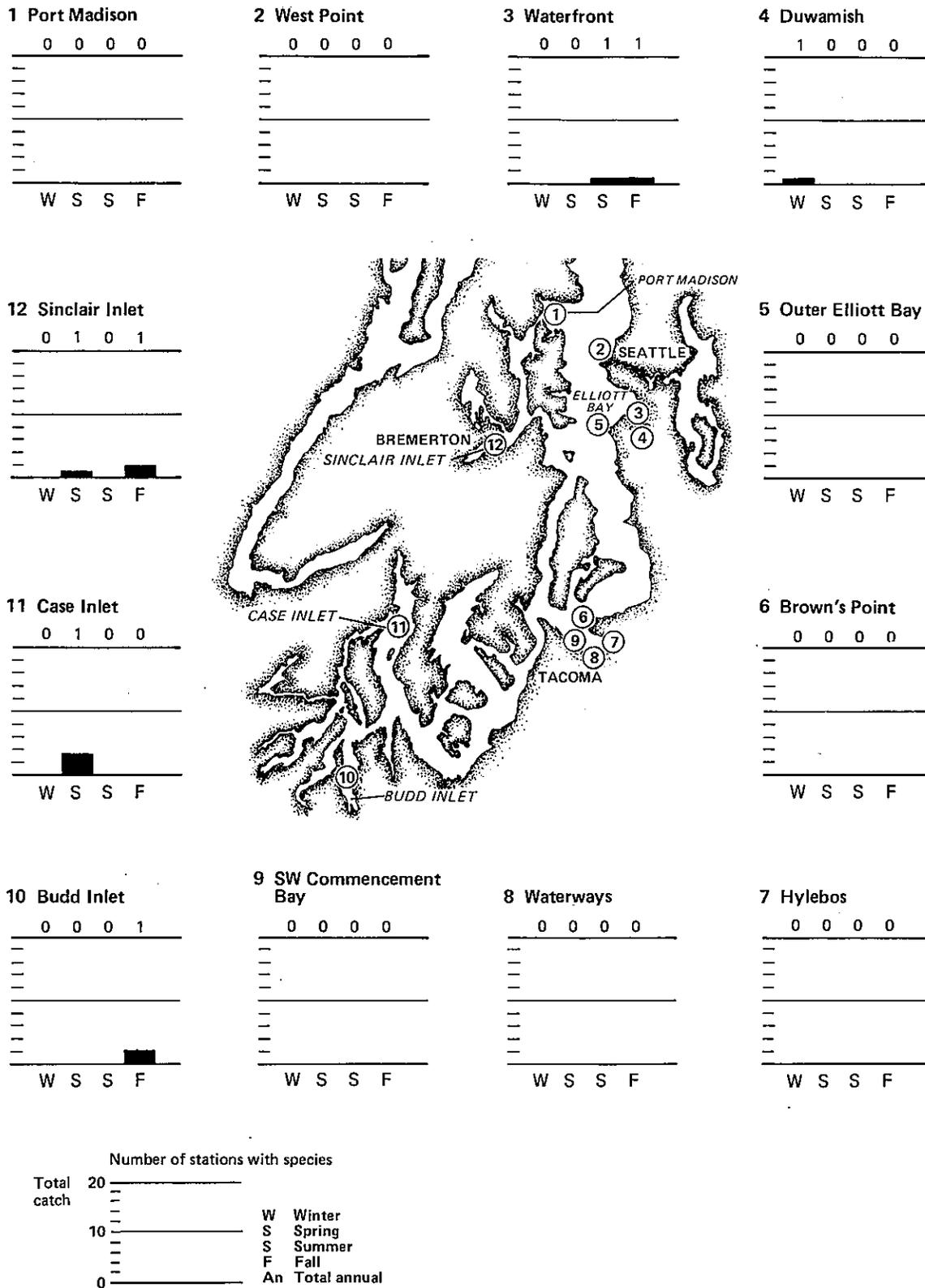


Figure 67. The seasonal and annual total catch values for *C. productus* in each of the embayments or subareas of the embayments.

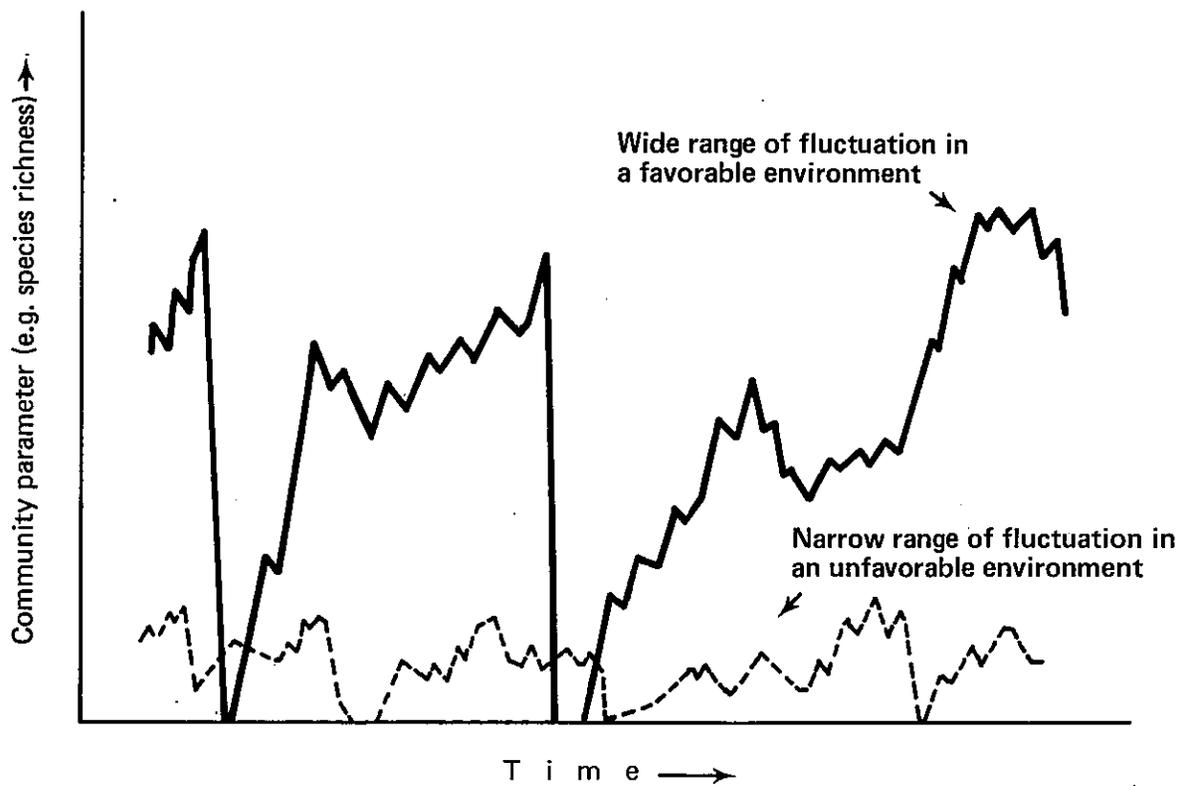


Figure 68. Fluctuating patch model.

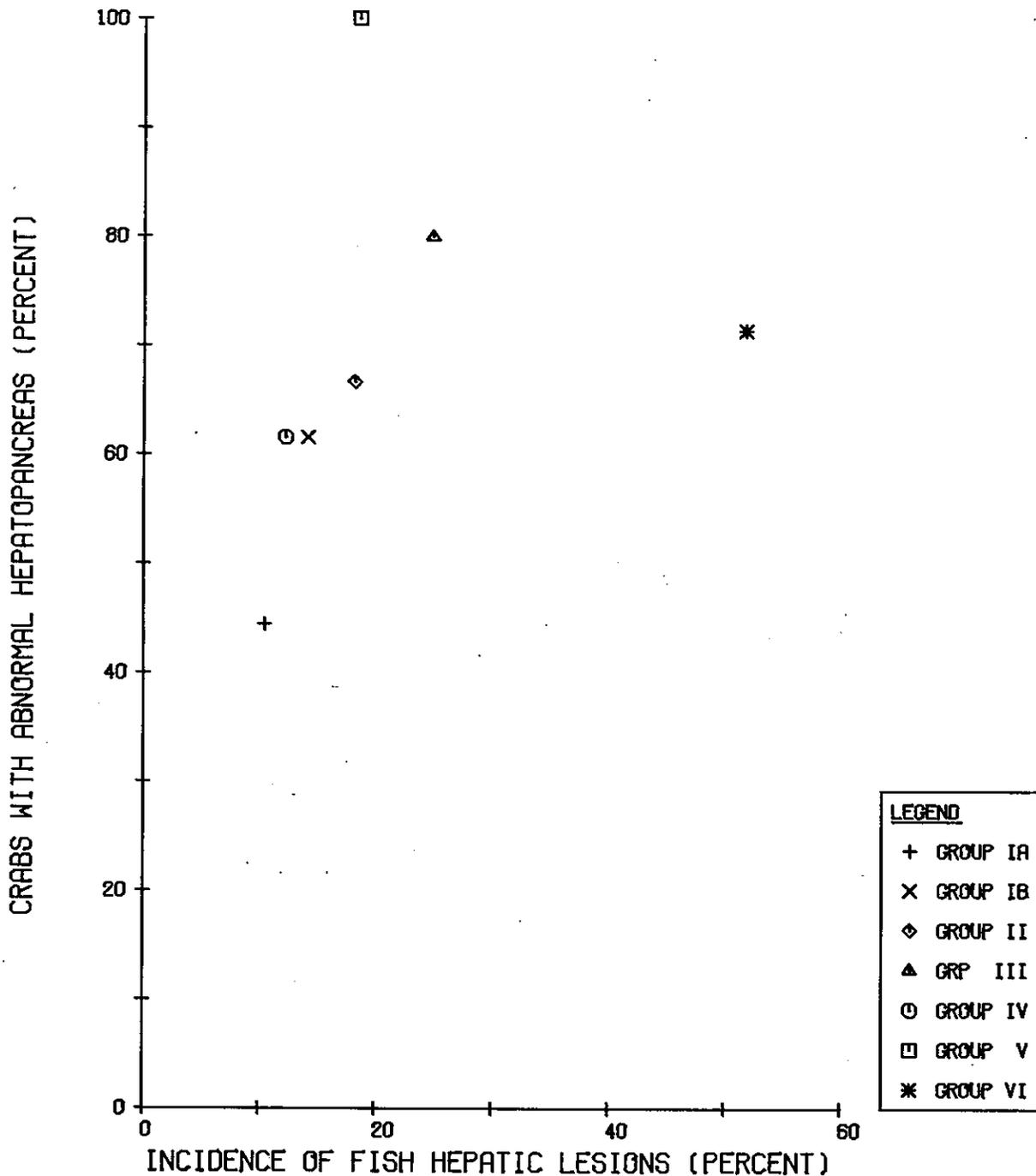


Figure 69. Positive correlation ( $r_s = 0.85, p = 0.009$ ) between incidence of seven hepatic lesions in four target fish species and incidence of hepatopancreas abnormalities in two crab species in seven groups of sampling stations. Groups were obtained by cluster analysis based on chemical data (Appendix E). Lesion incidence is annual frequency for 1979 for both fish and crabs.

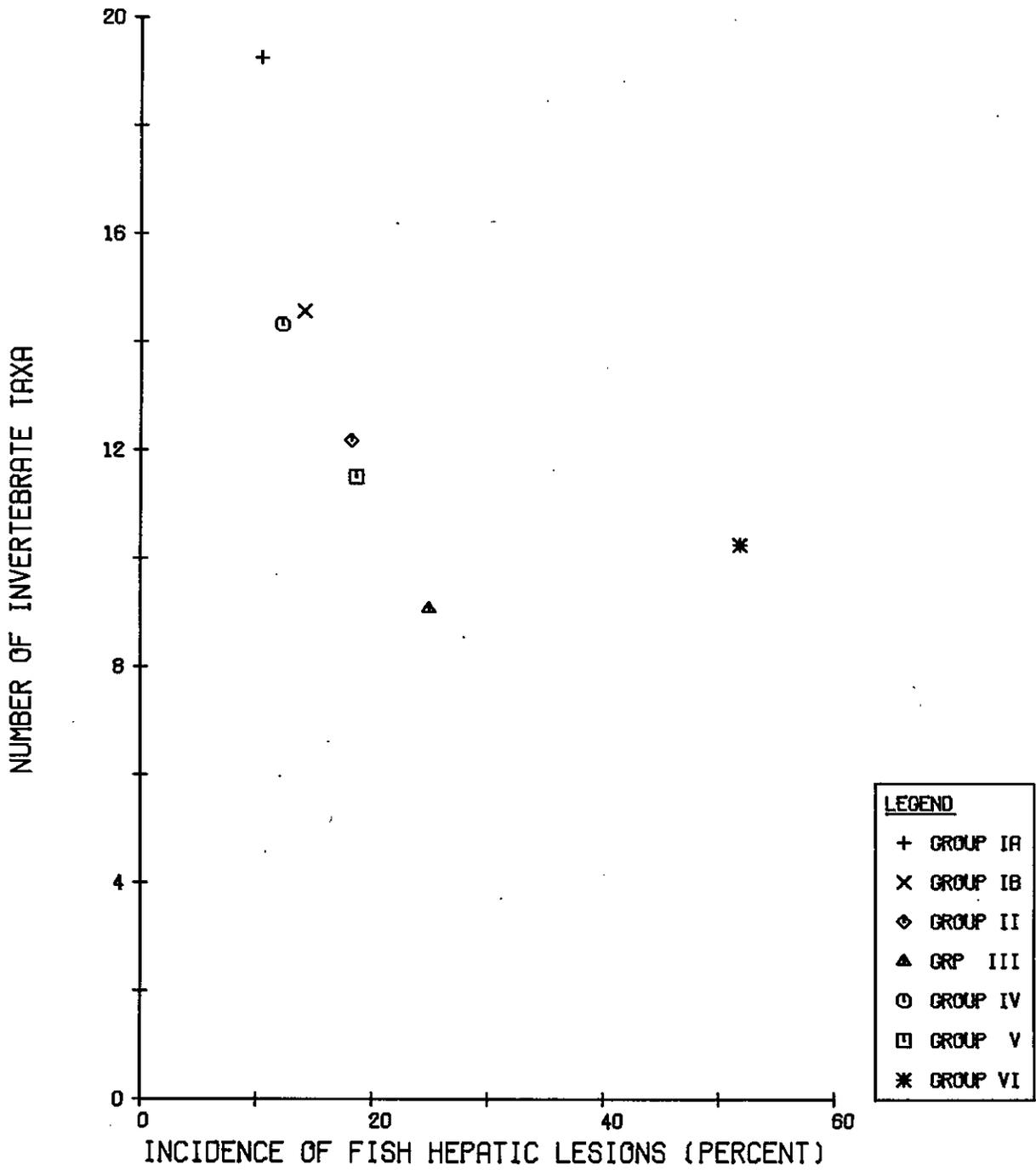


Figure 70. Negative correlation ( $r_s = -0.93$ ,  $p = 0.02$ ) between incidence of seven hepatic lesions (as in Table 26) in four target fish species and average taxon richness of benthic infaunal invertebrates in seven groups of sampling stations. Groups were obtained by cluster analysis based on chemical data (Appendix E). Lesion incidence is annual frequency for 1979; taxon richness is annual average for three sites at each station.

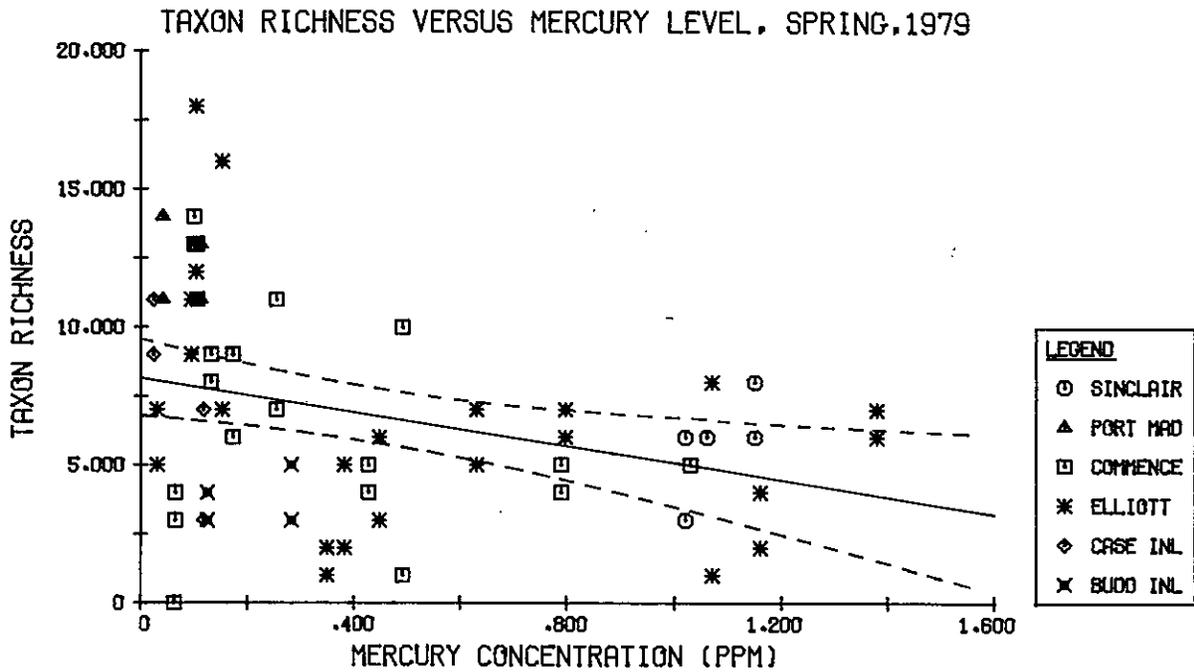


Figure 71. Regression line and 95% confidence belts for taxon richness in spring, 1979, infaunal samples as a function of mercury concentration.

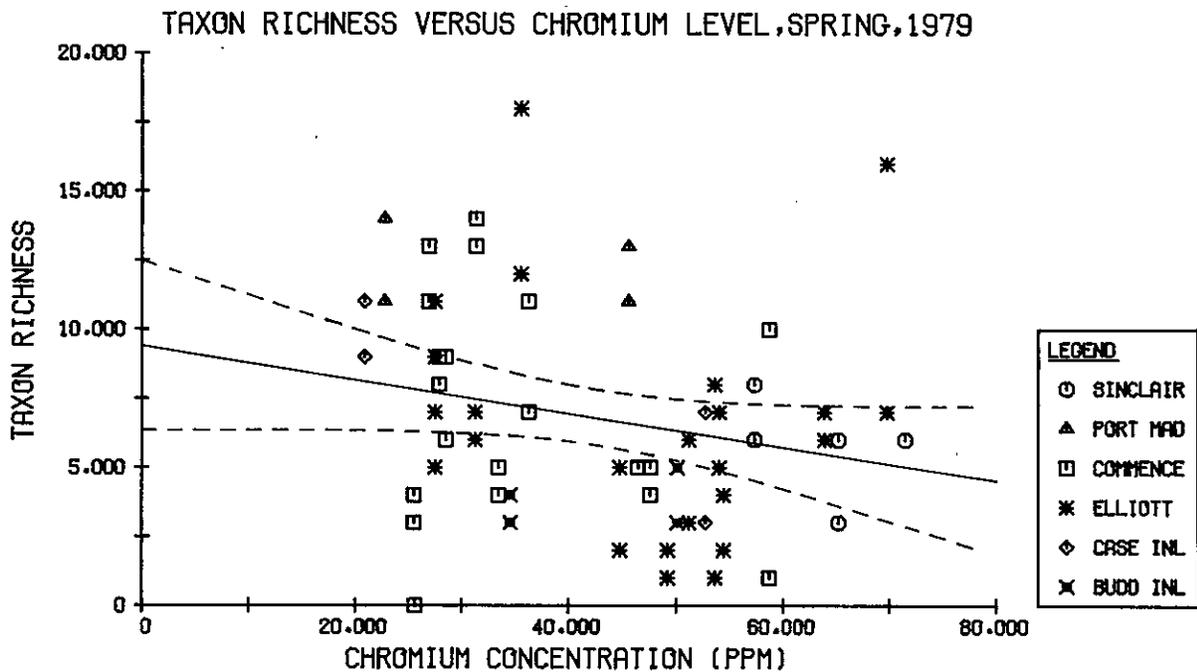


Figure 72. Regression line and 95% confidence belts for taxon richness in spring, 1979, infaunal samples as a function of chromium concentration.

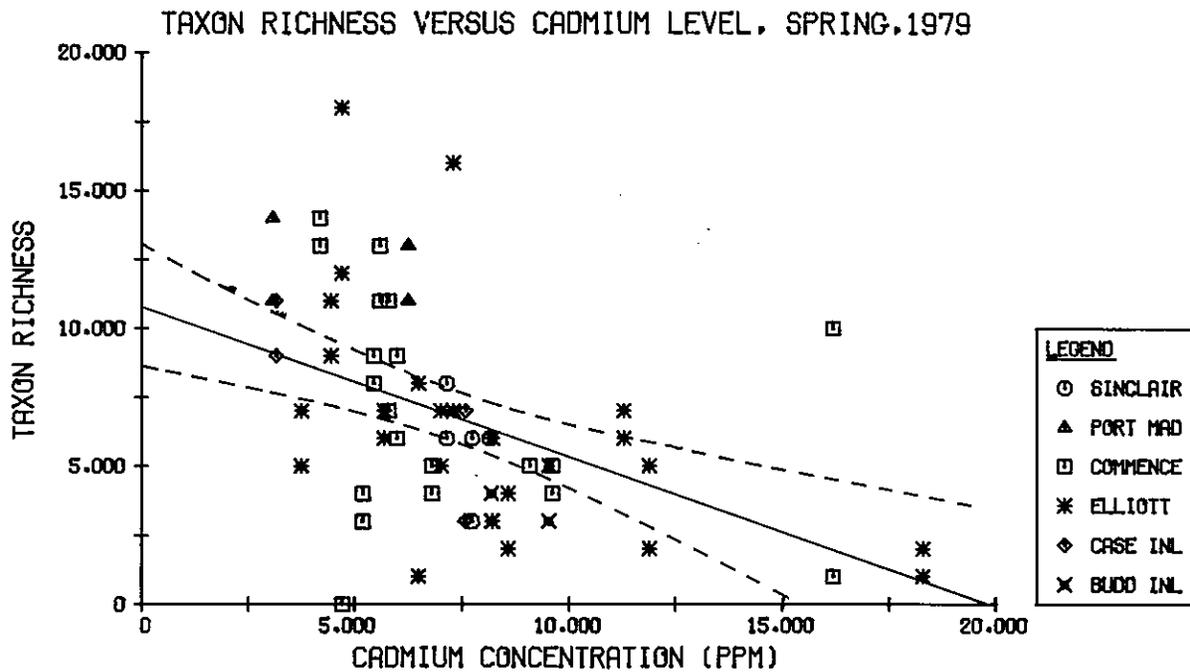


Figure 73. Regression line and 95% confidence belts for taxon richness in spring, 1979, infaunal samples as a function of cadmium concentration.

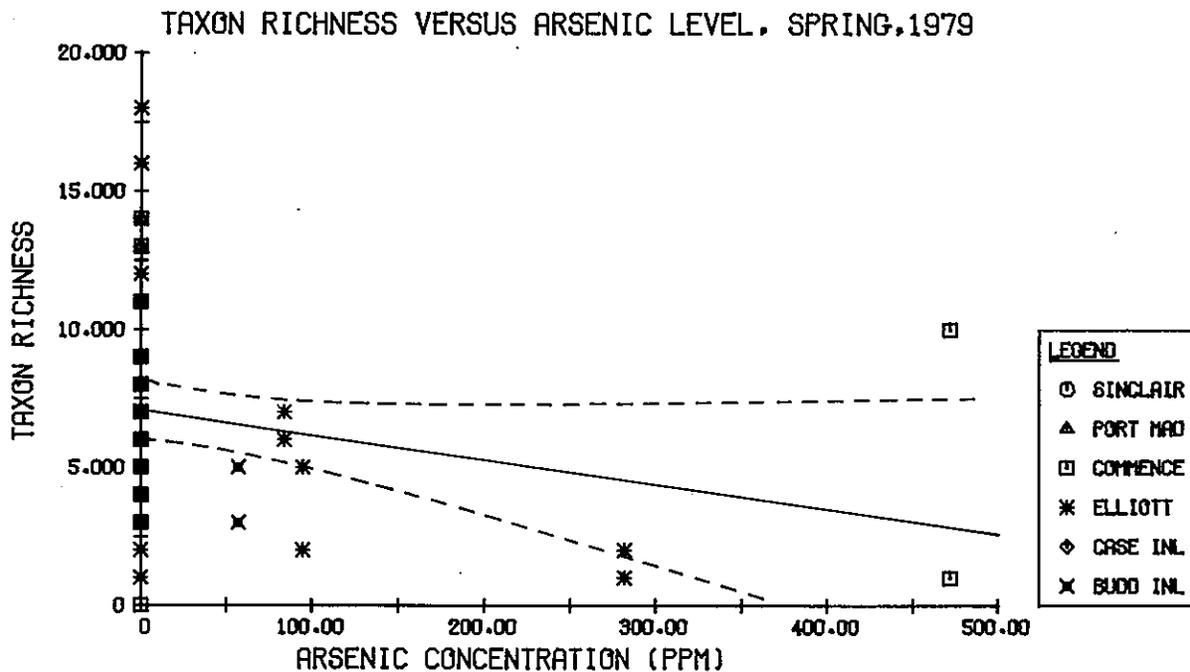


Figure 74. Regression line and 95% confidence belts for taxon richness in spring, 1979, infaunal samples as a function of arsenic concentration.

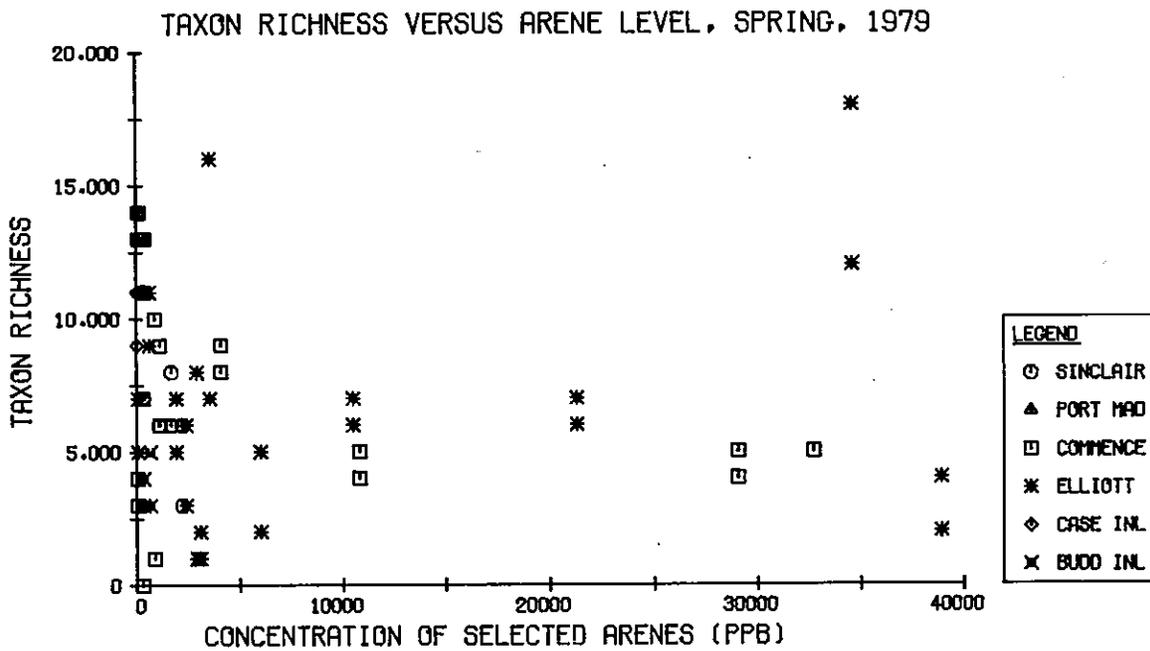


Figure 75. Taxon richness in spring, 1979, infaunal samples as a function of concentration of selected arenes.

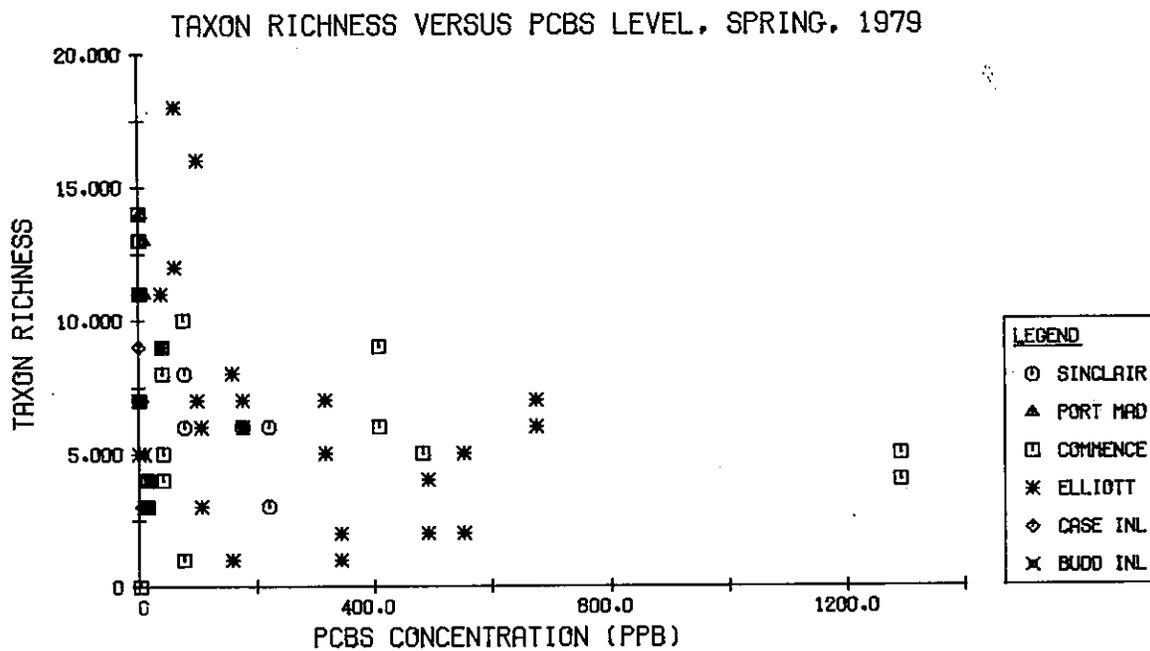


Figure 76. Taxon richness in spring, 1979, infaunal samples as a function of PCB's concentration.

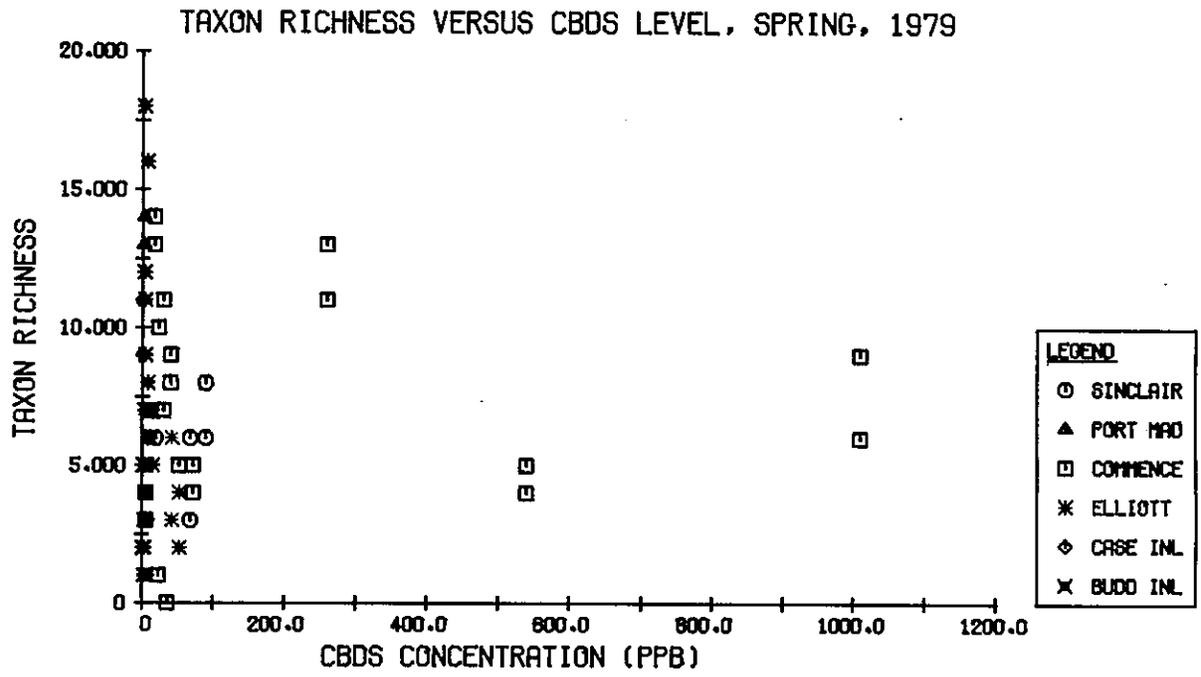


Figure 77. Taxon richness in spring, 1979, infaunal samples as a function of CBD's concentration.

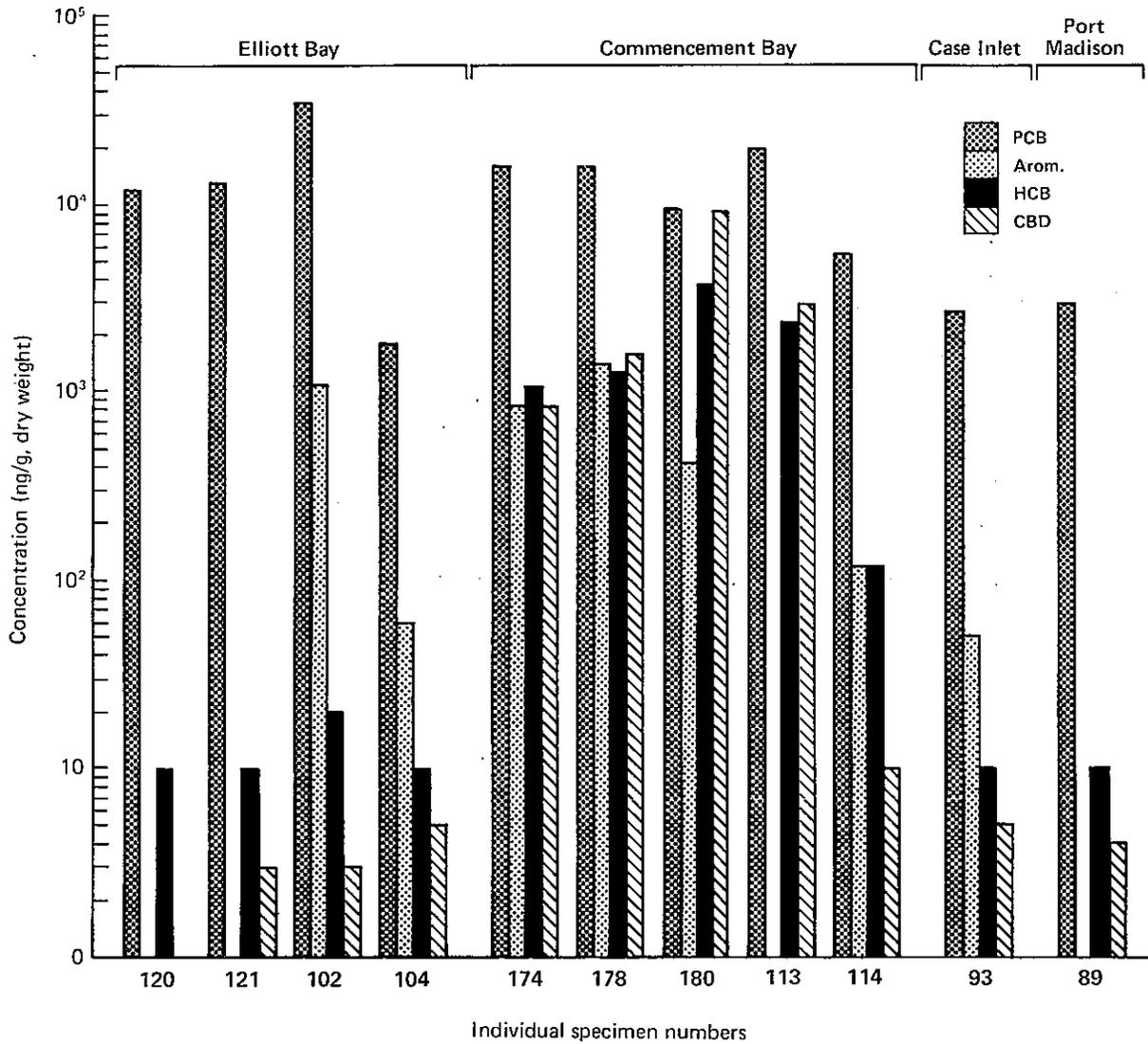


Figure 78. Concentrations of polychlorinated biphenyls (PCB), aromatic hydrocarbons (Arom.), hexachlorobenzene (HCB) and chlorinated butadienes (CBD) in individual English sole livers. See Table 38 for a description of each specimen number.

APPENDIX A

A copy of a report from the National Analytical Facility to MESA describing the results of chemical analyses of sediment from 11 sites in Central Puget Sound.

### Note of Clarification

The objective of this study was to obtain data about the presence and distribution of chemicals in sediments in selected areas of Puget Sound. These samples were collected near urban and industrial areas, chosen to represent worst case situations relative to possible pollution. Resulting data were used to plan the larger study reported in this document (1979 study). Several of these eleven sites are the same in the 1979 study.



**UNITED STATES DEPARTMENT OF COMMERCE**  
**National Oceanic and Atmospheric Administration**  
NATIONAL MARINE FISHERIES SERVICE  
National Analytical Facility  
Northwest & Alaska Fisheries Center  
2725 Montlake Boulevard East  
Seattle, Washington 98112

DATE: September 7, 1978

TO: Ed Long, MESA, Puget Sound Project,  
NOAA/ERL, Seattle

THRU: Neva Karrick, Acting Director, *NK*  
E.C. Division, NWAFC, F116

THRU: William MacLeod, National Analytical *WML*  
Facility, NOAA, F116

FROM: Don Brown, National Analytical *DB*  
Facility, NOAA, F116

SUBJECT: Analysis of Central Puget Sound Samples

Sediment samples were collected at eleven sites in Central Puget Sound (See Ramos memo, attached) for analysis for metals and organic contaminants.

The samples were analyzed for metals by plasma emission spectroscopy (by URD-Erich Gauglitz)--these results are in Table 1.

The sediment samples were processed for organic contaminants according to the flow chart in Figure 1 to give three fractions.

- Fraction 1 - saturated hydrocarbons
- Fraction 2,3 (F23) - unsaturated hydrocarbons, chlorinated biphenyls, pesticides, and similar compounds
- Fraction 4 - polar compounds

Fraction F23 was analyzed by glass capillary gas chromatography (GC) using the following detectors:

- Flame ionization - detects presence of organic compounds
- Electron capture - specific and especially sensitive to halogenated compounds
- Mass spectrometer - to identify compounds

The West Point sewage influent sample was acidified and extracted with dichloromethane-diethyl ether. The total extract was separated into fractions using column chromatography and analyzed as above.



All compounds were identified using the mass spectrometer--data was compared to reference spectra or standards as run in our lab. Except for the Point Pully sample, the extracts contained hundreds of compounds; only the representative compounds listed were identified by MS and quantitated. Table 2 contains the results of the organic analyses. Table 3 lists additional compounds in 4 selected samples.

There was not enough of the West Point composited sewage sample collected to split between the contract laboratory (Battelle) and NAF. Thus, we did not have enough sample to analyze. Battelle later sent us some of the raw sewage sample. We did not have the sample in time to complete the analysis and we feel that our data should not be used for interlaboratory comparison because of the time the sample was stored between the two analyses. We did find chlorotoluene and endosulfan in the West Point sewage sample. Metro personnel suggested collecting and splitting another sewage sample for analysis--at this time I recommend that be done.

### CONCLUSIONS

1. Based on GC results for the fraction (F23), Pier 54 contained the most extractable material. Harbor Island 2nd, Puyallup, 3rd. Point Pully contained very little extractable material. Also, see gravimetric data for fraction F23 (Table 2). See Table 2 for comparison of concentrations of representative PAH compounds.
2. The four Elliott Bay samples all contained PCBs at levels 2 to 3 times higher than other sites; the two Sinclair sediments also contained elevated levels of PCBs. It is known that biota bioconcentrate PCBs and that certain isomers of PCBs are quite toxic.
3. The Hylebos sample contained several highly chlorinated compounds--they appear to be byproducts of a manufacturing process. Based on electron capture GC, the Hylebos sample contains 25 chlorinated compounds at concentration of about 30 ppb and a total of about 100 chlorinated compounds (all in addition to the chlorinated biphenyls). Reference spectra are not available for identification of most of these compounds; however, W. Shackelford, Environmental Research Laboratory, EPA, Athens, Ga., is cooperating to help identify these compounds using the best available mass spectral matching programs. These compounds would possibly be absorbed by biota somewhat like PCBs. Many highly chlorinated compounds are quite toxic.
4. The samples from Elliott Bay, Sinclair, and Hylebos contain the highest concentrations of extractable materials and high concentrations of polynuclear aromatic hydrocarbons, e.g., some of these samples contain about 7 micrograms per gram (ppm) benzo(a)pyrene, a carcinogen. These samples contain many aromatic hydrocarbons. Some of the aromatic hydrocarbons have been shown to bioconcentrate as much as 1700 times in some flatfish (Roubal et al., copy attached).

5. The more common chlorinated pesticides were not present at levels that (A) could be identified using the gas chromatograph-mass spectrometer, or (B) they were masked by the presence of PCBs.

#### RECOMMENDATIONS

- Analyze additional sediment and biota samples to determine the extent of contamination of the chlorinated compounds found in the Hylebos samples, work with EPA to identify the source of these compounds.
- Determine the extent of PCB contamination in Elliott Bay both in sediment and biota (Corps of Engineers is developing a program for PCB in sediment in Elliott Bay).
- Analyze samples to determine the bioconcentration of PAH in selected biota
- Analyze the polar fraction and the saturated hydrocarbon fraction from selected samples such as Hylebos, Sinclair Shipyards, Pier 54, and Duwamish East.
- Do detailed analysis on a properly collected and split sample from the sewage treatment plant.

## COMMENTS ON COMPOUNDS IN CENTRAL PUGET SOUND SEDIMENTS

Sediments are considered a major factor in removal of contaminants from the water column. The concentration of contaminants that occurs from this process is only the beginning of the story but we know very little about the additional processes or the effects that concentration of these compounds have on marine ecosystems. Processes that will affect ecological impacts include absorption by biota, biological transformation, excretion, food-web transport of compounds and their metabolic products, recycling into the water column, covering with new sediments, and movement of sediments. The various processes and interactions among them will have a greater effect on the toxicity of the compounds present, than will the concentration of the compounds.

The type of sediment is important in evaluating possible impacts from potentially toxic contaminants. For example, a fine, muddy sediment with a significant amount of organic material will bind compounds tightly. This binding has two opposing results; the concentration of compounds will increase but the compound will be less available to the animals. The type of sediment also affects the biological communities in and on the sediments and this in turn will affect the biogradability of the compounds.

Other environmental factors affect toxicity. Conditions that are near the limits of tolerance for a species will cause stress on the animals so that they may be more susceptible to the actions of the xenobiotic than the species would be if they were in a more favorable environment.

Species differences, life stage, general health of the animal, individual variation, and past exposure to xenobiotics, and the type of exposure are among the biological conditions that will affect toxic reactions.

### Organic Contaminants

The compounds listed in Table 2 are indicative of human activity; most of the compounds other than the methyl esters of fatty acids, are considered toxic to some degree. The toxicity, however, is not additive for several reasons. First, the different compounds have different manifestations of toxicity and will affect different organs and different physiological processes. Compounds of similar structure have different biological effects. For example, benzo(a)pyrene is mutagenic and a carcinogen, while benzo(e)pyrene is not mutagenic. The different polychlorinated biphenyls (PCB's) have different toxicities, are absorbed and metabolized at different rates, and are retained to varying degrees by the animals.

The concept is well established that synergism and antagonism will change physiological reactions when multiple xenobiotics are present. For example, cadmium, lead or PCB's along with aromatic hydrocarbons will

affect the metabolism of the hydrocarbons and the cellular structures of some tissues. A critical gap in our knowledge relates to biological effects when multiple contaminants are present.

The persistence of toxic contaminants is important in evaluation of their potential impacts and in decisions about the rate and amount of contaminants that can be safely added to aquatic systems. Chlorinated compounds and especially chlorinated aromatics are in general persistent, with the persistence increasing with the number of Cl- in the molecule.

The polar fraction from the sediments undoubtedly contains oxygenated compounds that have potential toxicity to biological systems. The endosulfan detected in the sewage influent is acutely toxic to fish, in fact is probably the most acutely toxic of the pesticides in current use.

### METALS

Many metals are both essential to life and toxic. The toxicity is related primarily to five factors, namely, the chemistry of the area of exposure, the chemical form(s), the concentration of the toxic chemical, the bioavailability to and excretion from the exposed organisms, and the sparing action of one metal on another. Since these (and other) factors do not act independently, the amounts of metal present cannot be used to assess the potential toxicity of an area. EPA uses a safety factor when they prepare water quality standards in order to ensure that the levels of contaminants present will not be toxic to aquatic life under possible combinations of conditions.

Of the 36 metals analyzed in the sediments of the Central Basin of Puget Sound, the list below usually is considered non-toxic; although conditions are known where some of this list do cause adverse reactions, e.g., vanadium.

#### METALS USUALLY CONSIDERED NON-TOXIC

Bismuth	Potassium
Boron	Silicon
Calcium	Sodium
Magnesium	Strontium
Molybdenum	Vanadium

We have no information on toxicity in the aquatic environment of the following metals: gallium, germanium, scandium, or yttrium.

EPA included a number of metals in their priority consent list to establish criteria for a water environment that would be safe for aquatic organisms. Their criteria are for the amounts in water (usually fresh-water) and are not applicable to amounts in marine sediments. The metals

presumably are included in this initial list, however, because they are considered to be potentially hazardous to the biological life or to have the greatest potential for bioconcentration in the animals.

METALS IN EPA'S PRIORITY LIST OF TOXIC CHEMICALS

Antimony  
Arsenic  
Beryllium  
Cadmium  
Chromium  
Copper

Lead  
Mercury  
Nickel  
Selenium  
Silver  
Zinc

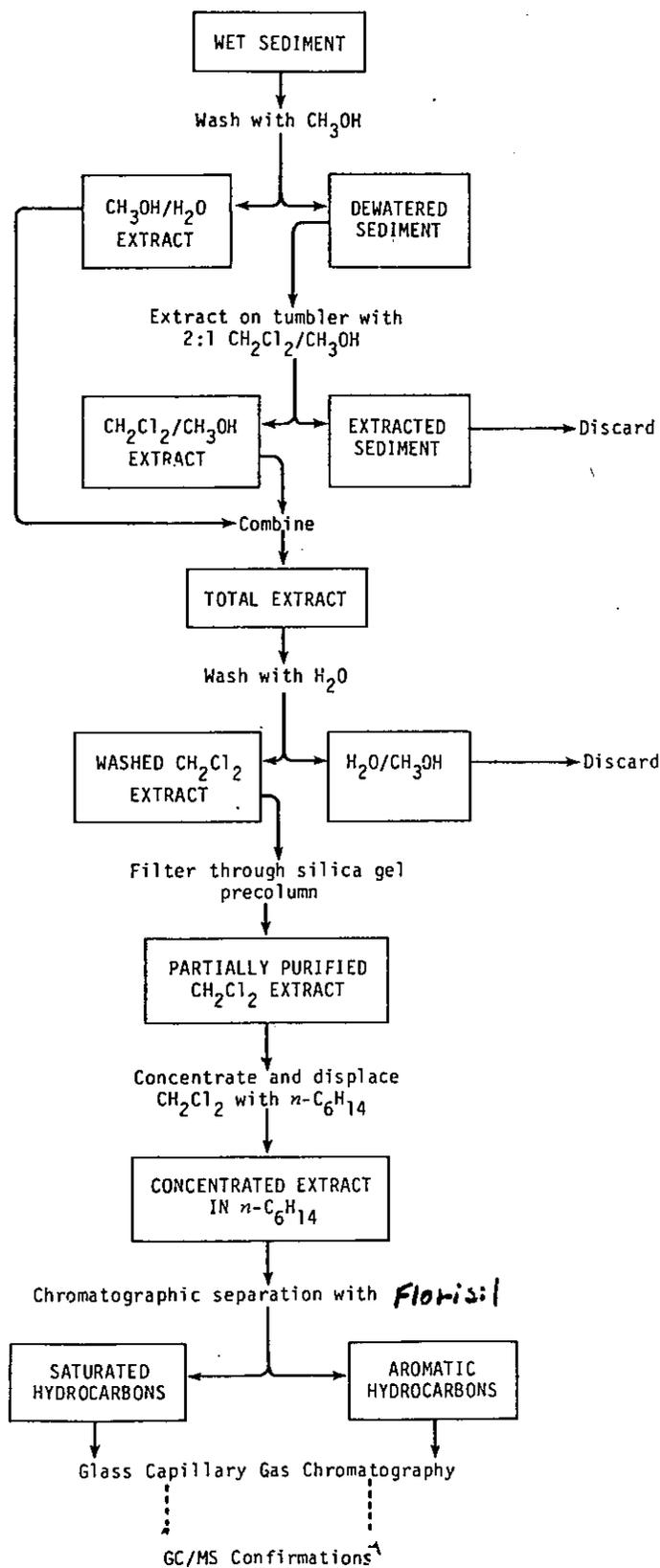


Figure 1.

Table A-1. Metals in sediments (ppm).

	<u>Ag</u>	<u>Al</u>	<u>As</u>	<u>B</u>	<u>Ba</u>	<u>Be</u>	<u>Bi</u>	<u>Ca</u>	<u>Cd</u>
Duwamish E.	1	17,000	ND	22	67	1	27	4,900	4
Duwamish W.	3	20,000	640	65	270	1	150	>18,000	17
Harbor Island	1	10,000	ND	17	150	0.5	33	4,800	3
Pt. Pulley (3T pt.)	NQ	5,600	ND	14	14	NQ	NQ	2,300	3
Pier 54	6	20,000	ND	32	120	1	51	7,800	7
Sinclair Ship Yds.	2	15,000	ND	46	63	1	33	6,700	4
Upper Sinclair	3	15,000	ND	51	65	1	32	8,500	5
Puyallup	NQ	9,300	ND	20	37	0.5	26	4,600	3
Hylebos	1	10,000	ND	27	33	0.5	22	6,000	3
Olympia Spit	NQ	8,400	ND	18	16	NQ	25	7,400	3
Blair	1	11,000	ND	31	33	1	25	6,200	3

NQ= Not quantifiable, though trace detected

ND= Not detected

Table A-1. (Continued)

	<u>Co</u>	<u>Cr</u>	<u>Cu</u>	<u>Fe</u>	<u>Ga</u>	<u>Ce</u>	<u>Hg</u>	<u>K</u>	<u>Li</u>
Duwamish E.	50	30	55	29,000	48	36	0.2	150	16
Duwamish W.	280	160	870	>50,000	120	210	0.6	170	18
Harbor Island	37	32	110	23,000	41	NQ	0.5	100	11
Pt. Pulley (3T pt.)	16	23	11	12,000	NQ	NQ	0.01	40	9
Pier 54	78	66	150	43,000	51	51	1	200	20
Sinclair Ship Yds.	44	57	170	27,000	39	38	1	200	21
Upper Sinclair	41	66	192	28,000	41	41	1	200	23
Puyallup	30	17	35	20,000	41	NQ	0.1	79	6.3
Hylebos	31	33	88	20,000	34	NQ	0.3	110	11
Olympia Spit	26	21	23	16,000	28	NQ	0.1	71	13
Elair	37	22	65	22,000	36	NQ	0.1	98	11

Table A-1. (Continued)

	<u>Si</u>	<u>Sn</u>	<u>Sr</u>	<u>Ti</u>	<u>V</u>	<u>W</u>	<u>Y</u>	<u>Zn</u>	<u>Zr</u>
Duwamish E.	420	32	91	1200	68	15	10	66	7
Duwamish W.	3800	170	140	1200	83	77	12	2000	13
Harbor Island	420	26	53	920	54	12	7	110	6
Pt. Pulley (3T pt.)	230	25	13	430	24	NQ	3	25	2
Pier 54	390	80	130	1100	86	22	13	190	7
Sinclair Ship Yds.	330	37	61	710	57	17	8	220	4
Upper Sinclair	250	38	81	743	56	17	9	181	4
Puyallup	770	22	58	920	57	9	3	30	4
Hylebos	250	30	63	690	55	10	7	110	4
Olympia Spit	290	NQ	49	640	28	7	4	39	4
Blair	340	31	66	760	59	11	8	110	4

Table A-1. (Continued)

	<u>Mg</u>	<u>Mn</u>	<u>Mo</u>	<u>Na</u>	<u>Ni</u>	<u>P</u>	<u>Pb</u>	<u>Sc</u>	<u>Se</u>
Duwamish E.	7,300	350	5	12,000	28	780	39	8	15
Duwamish W.	10,000	1500	56	8,000	130	1000	800	8	62
Harbor Island	5,100	210	4	9,000	25	720	75	4	NQ
Pt. Pulley (3F pt.)	5,000	130	NQ	3,100	27	300	8	2	NQ
Pier 54	10,000	570	11	19,000	49	1700	240	9	22
Sinclair Ship Yds.	9,100	300	7	22,000	50	680	130	5	15
Upper Sinclair	9,100	230	7	23,000	44	1000	110	5	19
Puyallup	4,400	160	NQ	10,000	13	750	8	3	NQ
Hylebos	5,400	120	5	12,000	26	810	68	3	NQ
Glympla Spit	4,700	120	2	6,300	22	410	8	3	NQ
Blair	5,300	140	4	11,000	20	900	35	4	NQ

Table A-2.

Concentration of arenes in Central Puget Sound Samples

Checked by \_\_\_\_\_ Date \_\_\_\_\_

	Units: mg/g dry									West Point		
	Du West	East	Pt Pulley	Sinclair	Upper Sinclair	Hylebos Olympia	Blair Is.	Harbor Is.	Du West			
	1	2	3	4	5	6	7	8	9	Puyallup	Pier 54	West Point
										10	11	14
Indan	2	<1	10	20	10	10	5	1	20	10	10	
1,2,3,4-Tetramethylbenzene	<1	<1	6	2	6	2	10	1	7	2	10	
Naphthalene	70	4	80	80	300	200	300	300	100	70	500	
Benzothiophene	6	3	10	10	30	10	10	2	<1	2	40	
2-Methylnaphthalene	30	<1	60	50	100	30	100	300	70	30	200	
1-Methylnaphthalene	10	<1	30	20	60	10	60	80	40	20	100	
Biphenyl	<1	<1	10	10	50	10	40	100	20	40	100	
2,6-Dimethylnaphthalene	4	1	10	10	100	<1	100	200	50	300	200	
2,3,5-Trimethylnaphthalene	20	<1	90	80	100	10	100	90	40	10	1	
Fluorene	40	<1	30	30	300	30	100	2400	200	40	600	
Dibenzothiophene	70	<1	300	300	400	100	200	1000	300	200	400	
Phenanthrene	200	<1	300	300	1600	90	400	11000	1500	90	2200	
Anthracene	60	<1	200	300	400	100	100	5400	300	1200	2	
1-Methylphenanthrene	20	<1	50	50	<1	<1	<1	1000	400	2	2	
Fluoranthene	400	30	800	1200	2000	300	800	14000	2900	2	4900	
Pyrene	600	20	1100	1600	1600	400	700	8700	2000	100	4300	
Benz[a]anthracene	1300	5	1100	3800	3000	200	1000	8700	4500	4	13000	
Chrysene	600	8	500	1500	1790	100	700	5500	2300	2	6000	
Benz[b]pyrene	200	<1	200	2300	1400	5	100	2500	1500	0	7200	
Benz[k]pyrene	200	<1	400	2200	1200	40	100	2500	1800	2	5700	
Perylene	400	<1	260	1200	800	100	100	2100	900	2	7600	
Micrograms/g of extractable material in F23	62	5	161	200	104	46	65	161	92	133	680	110* (110 ug/ml total extractable material)
Percent Dry Weight	57	77	38	34	60	68	61	65	67	57	44	
Polychlorinated Biphenyl mg/g	1300	<40	300	400	207	50	100	600	900	52	500	

Table A-2. (Continued)

Concentration of

Units: n/g/gm dry wt.

	Duw. East	Pt. Pulley	Sinclair	Upper Sinclair	Hylebos	Ollymbia Blair	Harbor Is.	DuW West	Puyalup	Pier 54	Sewage West Pt
Fatty acid methyl esters (from C14 → C24)	1	2	3	4	5	6	8	9	10	11	14
N-methylaniline	300	(b)	(b)	(b)	(b)	(b)	1500	550		(b)	500
N-N, dimethylaniline	20										
(C2H5)naphthalenes	1800						340	52			
(C3 substituted) naphthalenes	30						180	40			70
trichlorobenzene					30						
dichlorobenzene					10						
C3 phenol					20						
trichlorobutadiene					80						
tetrachlorobutadiene					5						
pentachlorobutadiene					5						
Hexachlorobutadiene					5						
tetrachlorobenzene					100						
dibenzofuran					trace						
Hexachlorobenzene					(c)						
methylphenylacetate						30					
organic carbon	1.7%	0.2%	3.2%	3.4%	3.7%	2.2%	1.9%	1.5%		3.8%	4.1%
(b) fatty acid methyl esters were found at levels similar to those found in Elliott Bay											
(c) from GC data using electron capture detector, there are 25 or so chlorinated compounds at about 30 ppb that are not PCBs in Hylebos sample, there are about 100 chlorinated compounds present that are not PCBs.											

Table A-3. Compounds found in sediment samples collected in Puget Sound 6-78. The list is not exhaustive and is exclusive of those listed in Table 1.

Compounds	Pier 54	Upper Sinclair	Duwamish East	Hylebos
Trichlorobutadiene				
C <sub>3</sub> -benzene	3	2	3	5
Benzofuran				4
C <sub>4</sub> -benzene		1	2	1
Tetrachlorobutadiene		1		5
Pentachlorobutadiene				5
*Naphthalene	1	1	1	1
*Hexachlorobutadiene				1
2-methylnaphthalene	1	1	1	1
1-methylnaphthalene	1	1	1	1
Tetrachlorobenzene				3
Biphenyl	1	1	1	1
C <sub>2</sub> -naphthalene	4	4	4	3
*Acenaphthylene				
Methylbiphenyl	2			1
C <sub>3</sub> -naphthalene	5	4	4	2
Dibenzofuran	1	1	1	5
*Fluorene	1	1	1	1
Benzothiophene	1			
*Acenaphthene	1	1	1	1
C <sub>2</sub> -fluorene	2			
Methyldibenzofuran	3	3	2	1
C <sub>4</sub> -naphthalene		2	4	1
Methylfluorene	2		1	1
*Hexachlorobenzene				1
Dibenzothiophene	1	1	1	1
Methoxyfluorene		3	1	1
*Phenanthrene	1	1	1	1
*Anthracene	1	1	1	1
Methyl-(phenanthrene or anthracene)	5	4	5	5
Phenylnaphthalene	1	1		1
C <sub>2</sub> -(phenanthrene or anthracene)	7	3	5	7
*Fluoranthene	1	1	1	1
*Pyrene	1	1	1	1
C <sub>3</sub> -(phenanthrene or anthracene)	1	1	2	3
C <sub>4</sub> -(phenanthrene or anthracene)	1	1	1	1
Methyl-(pyrene or fluoranthene)	7	7	5	4

Compounds	Number of Isomers Found at			
	Pier 54	Upper Sinclair	Duwamish East	Hylebos
2,4-dichloro-6-methylphenol				1
C2-(pyrene or fluoranthene)		5	4	1
Benzo(ghi)fluoranthene	1	1	1	1
*Benz[ $\alpha$ ]anthracene	1	1	1	1
*Chrysene	1	1	1	1
Triphenylene or benzophenanthrene	1	1	1	1
Methyl-(benz[ $\alpha$ ]anthracene or chrysene)	8	4	1	5
Binaphthalene	2	2		1
C2-(benz[ $\alpha$ ]anthracene or chrysene)	6			4
*Benzo[ ]fluoranthenes	2	2	2	4
Benzo[e]pyrene [BEP]	1	1	1	1
*Benzo[ $\alpha$ ]pyrene [BAP]	1	1	1	1
Perylene	1	1	1	1
*Dibenzanthracene	1			1
*Benzo(ghi)perylene	1		1	1
*Indeno(1,2,3,-cd)pyrene	1		1	1
Benzonaphthothiophene	3			
Methyl-(BEP, BAP, or perylene)	7	1	1	1
Methyldibenzothiophene		1		
Terphenyl		2		
Carbazole			1	
*Polychlorinated biphenyls	1	1	1	1
C5-naphthalene			3	
*Dichlorobenzene				
†Ethanol				
*Trichloroethene				
*Toluene				
*Tetrachloroethene				
Xylenes				
Benzaldehyde				
Decahydronaphthalene				
Palmitic acid	1	1		1
Stearic acid	1	1		1
*Ethylbenzene				

\*On EPA Priority Pollutant List

† Not all samples analyzed for compounds below this mark.



UNITED STATES DEPARTMENT OF COMMERCE  
National Oceanic and Atmospheric Administration  
NATIONAL MARINE FISHERIES SERVICE  
Northwest and Alaska Fisheries Center  
2725 Montlake Blvd. East  
Seattle WA 98112

Date : June 9, 1978

To : W. D. MacLeod

From : S. Ramos

Subject: Central Puget Sound sub-tidal sediment survey  
Trip report of 6/6 and 6/7/78 cruises

Sampling crew consisted of:

Bill High	RACE
Bob Loghry	RACE
Nate Golly	RACE
Ed Long	MESA Puget Sound
Scott Ramos	EC/NAF

NMFS vessel SEA URCHIN was utilized for both trips.

6/6/78 0700 Departure from Shilshole Bay marina, Seattle

0930 Arrive Commencement Bay, Tacoma

Air temperature 24°C

Wind less than 2 k

Seas calm, skies clear

1015 HYLEBOS Waterway site

Location: west side, mouth of waterway, 15 m from Pier 25  
at edge of channel; bottom depth - 35 feet

Diving crew: Loghry and Golly

Substrate: silt and fine sand; light brown

1030 BLAIR waterway site

Location: west side, mouth of waterway, 10 m from Pier 1 at  
edge of channel; bottom depth - 40 feet

Diving crew: Loghry and Golly

Substrate: silt and sand; light brown to gray

1115 PUYALLUP River site

Location: east slope off alluvial deposit at river mouth, 10 m  
from surface of bank exposed at low tide. Bank slopes  
into bay beyond the alluvial flat at steep gradient.  
River runoff created turbulence at surface, outside  
of channel.

Bottom depth - 30 feet

Diving crew: Loghry and Golly

Substrate: silt and fine sand, mixed debris; brown



- 6/6/78 1130 Leave Commencement Bay  
 cont. 1245 Arrive Point Pulley (Three Tree Point); control site  
 Air temperature 26°C  
 Wind 2-4 k  
 Seas calm; sky partially cloudy
- 1300 Point PULLEY site  
 Location: 100 m offshore, 1/4 mile east of Point, fronting gray house with white chimney, behind concrete wall; bottom depth - 56'. Several small pleasure craft anchored in vicinity.  
 Diving crew: Loghry and Golly  
 Substrate: sand; gray, gray-brown, to dark gray
- 1345 Arrive Elliot Bay, Seattle  
 Air temperature 24°C  
 Wind 4-8 k  
 Seas calm to 2 feet; overcast
- 1400 DUWAMISH Waterway--WEST Channel site  
 Location: west side, mouth of channel, 20 m north of last pier, at edge of channel; bottom depth-40 feet.  
 Diving crew: High and Loghry  
 Substrate: Silt and fine sand, mixed debris, light brown to gray (Note: upon compositing subsamples, small oil-like sheen developed on surface, which quickly dissipated)
- 1420 HARBOR Island site  
 Location: north end of island, off 13th Ave S, 10 m west of west-most dolphin in slip; bottom depth-40 feet  
 Diving crew: High and Loghry  
 Substrate: silt and sand, with some 1-2 mm black, soot-like particles, light brown to gray (Note: upon compositing subsamples, small oil-like sheen developed on surface, which quickly dissipated)
- 6/7/78 1530 Arrive Shilshole Bay  
 0700 Depart Shilshole Bay  
 0840 Arrive Sinclair Inlet, Bremerton  
 Air temperature 16°C  
 Wind 2-4K  
 Seas calm to 1 foot; overcast
- 0900 UPPER SINCLAIR Inlet site  
 Location: 200 m southwest of float "A-13," 1/2 miles offshore from sewer outfall; bottom depth-38 feet  
 Diving crew: Loghry and Golly  
 Substrate: silt, brown to light brown
- 0930 SINCLAIR Inlet-Shipyards site  
 Location: ca. 1/2 mile south of marker for measured 1/2 nautical mile, west of Pier 3; bottom depth-44 feet  
 Diving crew: Loghry and Golly  
 Substrate: silt and fine sand, light brown to gray brown

6/7/78 1040 Arrive Elliot Bay, Seattle  
cont. Air temperature 10°C  
Wind 2-4 k  
Seas calm, overcast  
1100 DUWAMISH Waterway-EAST Channel site  
Location: west side, mouth of waterway, 30 m east of end of pier;  
bottom depth-54 feet  
Diving crew: High and Loghry  
Substrate: silt and sand, brown to gray-brown  
1120 PIER 54  
Location: 30 m west of middle of Pier 54; bottom depth-55 feet  
Diving crew: High and Loghry  
Substrate: silt and sand, with mixed debris, light brown to gray  
(Note: upon compositing subsamples, oil-like region within sediment  
was exposed that did not dissipate)

SUMMARY OF SAMPLING SCHEME:

Two divers followed anchor line to bottom, carrying 10 wide-mouth jars, 120 ml, with Teflon-lined, screw-caps. Suitable area and substrate was located. Subsamples collected by scraping bottom surface with the open jar used sideways as a scoop and buried to approximately 1/2 of its diameter. Enough sediment was collected to nearly fill jar, and lid was placed on jar for transfer to surface. On board, five subsamples were combined into a 32 oz. wide-mouth jar and covered with a foil-lined screw-cap. Composite samples were placed in an ice-cooled chest. Subsample jars were rinsed with distilled water, acetone, dichloromethane and acetone between collections. Chilled samples were transferred to NWAFC and frozen at -70°C.

CC: N. Karrick EC  
✓ B. Brown EC  
E. Long MESA  
M. Hayes RACE  
B. High RACE

ER

30'

123°

30'

122° 30'

WHIDBEY ISLAND

PORT TOWNSEND

PORT ANGELES

48°

EVERETT

- 1. Duwamish East
- 2. Duwamish West
- 3. Harbor Island
- 4. Pier 54
- 5. Pt. Pully
- 6. Sinclair Shipyards
- 7. Upper Sinclair
- 8. Puyallup
- 9. Hylebos
- 10. Blair
- 11. Olympia Spit

BREMERTON

SEATTLE

30'

TACOMA

OLYMPIA

47°

30'

123°

207

30'

122°

APPENDIX B

Materials and Methods used for Chemical Analyses

## Materials

### Apparatus:

Tissue Homogenizer - Tekmar Tissumizer with SDT motor and 182 EN shaft and generator.  
Ball-Mill Tumblers - . Model 8-PA with frame, roller bars, and motor. Scott-Murray Manufacturing, 8511 Roosevelt Way N.E., Seattle, WA 98115.  
Dessicator - Corning No. 3120.  
Drying Oven  
Muffle Furnace  
Forced Draft Oven. - Precision Model 18.  
Hot Plate.  
Water Bath.  
Tube Heaters. - Kontes No. K-720000, 6-tube model with aluminum inserts for heating from the tip of the tube.  
Tube Inserts. - Custom made from 7/8-in-diameter aluminum rod, 2 inches high, with a hole the same diameter as the tube tip, 7/8-in deep at the center of one end.  
Mortar and Pestle. - Coors No. 531.  
Aluminum Weighing Dish. - Disposable  
Spatulas.  
Stainless Steel Sieve. - Tyler Equivalent 20.  
Scalpels.  
Hemostats.  
Glass Wool.  
Aluminum Foil.  
Boiling Stones. - Teflon. Bel-Art Products No. 41001.  
Gas Chromatograph. - Microprocessor-controlled, with automatic sampling and injection. FID and ECD. Hewlett-Packard, Model 5840A.  
Mass Spectrometer. - EI with data system, Finnigan 3200 Mass Spectrometer, INCOS NOVA 3 computer.  
Infrared Heat Lamp.  
Ultraviolet Light. - Mineralight.

### Glassware:

Tumbler Bottles. - 1-L glass bottle for tumbler - Wheaton No. 219180, equipped with a solid Teflon cap custom-machined from 3.8 cm diameter rod, 3.0 cm high.  
Snyder Distilling Columns. - 3-section, 24/40 STJ. Kontes No. K5030000, size 121.  
Concentrator Tubes. - 25 mL, 19/22 STJ. Kontes No. k-570050, size 2525.  
Chromatography Columns. - 19 mm i.d., with reservoir and Teflon stopcock. Kontes No. k-420280, size 232.  
Buchner Funnels. - Fritted disc, coarse porosity, 150 mL.  
Beakers. - 250, 400, 600, 1000, and 2000 mL.  
Boiling Flask. - 125 mL, Corning No. 4100.  
Erlenmeyer Flasks. - Wide-mouth, 500 mL.  
Volumetric Flasks. - 10, 25, and 100 mL, Corning No. 5641.  
Glass Capillary Columns. - 30 m x 0.25 i.d., coated with SE-54. J & W Scientific.

Reflux Condenser. - Corning No. 2400.  
Separatory Funnels. - Pear-shaped, with Teflon stopcock, 250 mL and 1 L.  
Funnels. - Powder.  
Funnels. - Long-stem.  
Funnel. - Custom-made ca. 170 mL capacity, stem 10.5-mm i.d. x 100 mm bent 45° in middle.  
Funnels. - 90-mm curved stem, bent 45° in middle.  
Filter Papers. - Whatman No. 40.  
Cylinders. - Graduated, 50 mL, 100 mL.  
Pipets. - 1 and 10 mL, Kimble No. 37010  
Pipets. - Disposable, Pasteur- type, 2 mL.  
Wash Bottles. - Teflon, 500 mL. Naige, No. 2403-0500.  
Centrifuge Tubes. - With Teflon-lined screw-cap, 50 mL, 100 mL.  
Vycor Crucibles. - 50 mL, Corning No. 12940.  
Glass Rods.  
Watch Glasses. - 50 mm, Corning No. 9985.  
Syringes. - 250 and 500  $\mu$ l, 1 mL.  
Vials. - With Teflon-lined septa, screw caps. Varian, No. 96-000099-00.  
Vials. - 16 mL, Wheaton No. 225536.

#### Solvents and Reagents:

Azulene.  
Copper. - Fine granular, Mallinckrodt No. 4649.  
Cyclohexane.  
Dichloromethane ( $\text{CH}_2\text{Cl}_2$ ).  
Distilled Water. - Filtered, distilled in glass.  
Hexamethylbenzene.  
Hexane ( $\text{C}_6\text{H}_{14}$ ).  
Hydrochloric Acid (HCl).  
Nitric Acid ( $\text{HNO}_3$ ).  
2-Propanol.  
Methanol ( $\text{CH}_3\text{OH}$ ).  
Pentane (n- $\text{C}_5\text{H}_{12}$ ).  
Perylene.  
Sand, Ottawa. - Kiln-dried, 30-40 mesh.  
Sephadex LH-20.  
Silica Gel. - Grade 923 (Davison), 100-200 mesh (nominal).  
Sodium Sulfate. - Anhydrous ( $\text{Na}_2\text{SO}_4$ ).  
Tecnazene (2,3,5,6-Tetrachloronitrobenzene).  
1,3,5-Triisopropylbenzene.

#### Standards, Blanks, and Spikes:

Recovery/Internal Standard (R/I-Std). An aromatic Recovery I-Std was added to each sample to assess recovery efficiency: methanol solution containing ca. 50 ng/ $\mu$ l 1,3,5-triisopropylbenzene (the exact concentration of which was known).

Reagent blank. A "reagent blank" analysis was done with each set of samples (i.e., an analytical run with only sample omitted).

Reagent blank with added standard compounds (reagent spike). A reagent blank analysis with added standard compounds (reagent spike) was run with each set of samples. Reagent spike solution contained all of the target compounds to be measured.

GC internal standard (GC/I-Std). The GC internal standard contained 80 ng/uL hexamethylbenzene and 4 ng/uL technazene (2,3,5,6-tetra-chloronitrobenzene) in hexane.

#### Preparation of Apparatus and Reagents:

Solvent purity. Solvents were of highest purity commercially obtainable. Each was checked for interfering contaminants.

Decontamination of apparatus. All materials contacting sample or reagents were glass, Teflon or metal. All surfaces that contacted sample were washed with  $\text{CH}_2\text{Cl}_2$  before use.

Preparation of activated silica gel. Silica gel was heated at  $150^\circ\text{C}$  for 24 h and then cooled to room temperature in a desiccator prior to use.

Preparation of sand. Sand was washed with  $\text{CH}_2\text{Cl}_2$  and allowed to dry. Dry sand was heated at  $150^\circ\text{C}$  for 24 h and cooled to room temperature in desiccator prior to use.

Preparation of  $\text{Na}_2\text{SO}_4$ . Same as the preparation of sand.

Preparation of activated copper. Copper granules were covered with 12 N HCl for ca. 3 min. The copper granules were washed thoroughly with  $\text{CH}_3\text{OH}$  to remove HCl. They were washed thoroughly with  $\text{CH}_2\text{Cl}_2$  to remove  $\text{CH}_3\text{OH}$ , and dried at room temperature. Activated copper was prepared just prior to use.

Preparation of 2% NaCl. 20 g  $\text{CH}_2\text{Cl}_2$ -washed NaCl was dissolved in distilled water and diluted to 1L.

Preparation of cyclohexane/methanol/methylene chloride (6/4/3) solution. Cyclohexane and methanol (azeotropic mixture 6/4) were co-distilled and the resulting mixture was combined with methylene chloride in volumes of 10/3, respectively.

Azulene-perylene calibrating solution. 25 mg/mL of each compound in cyclohexane/methanol/methylene chloride (6/4/3) solution.

## Organic Analysis

### Sediment Extraction:

Sediment samples were collected (see Section 2.1) frozen at 0°C and taken to the laboratory where they were stored at -20°C until needed for analysis. The sediment samples were thawed immediately prior to being analyzed. The water was decanted and discarded, and 100 ± 1 g of the sediment were weighed into a 1 L bottle supplied with a Teflon screw cap. Fifty milliliters of methanol were added and the bottle swirled gently. The sediment was allowed to settle for 20 min, and then the methanol was decanted into a 600 mL beaker. Another 50 mL of methanol were added to the bottle; it was again swirled gently, allowed to settle for 20 min, and then decanted into the same 600 mL beaker containing the previous methanol extract. The beaker was then covered with aluminum foil. One hundred milliliters of a dichloromethane/methanol (2/1 v/v) solution were added to the 1-L bottle containing the sediment. The Teflon cap was secured and the bottle rolled for 16 h (overnight) on a ball-mill tumbler. The sediment was allowed to settle (20 min), and then the dichloromethane/methanol extract was decanted into the 600-mL beaker containing the methanol extracts. An additional 100 mL of the dichloromethane/methanol (2/1) solution were added to the sediment, the cap secured, and the bottle rolled for another 6 h. The sediment was again allowed to settle for 20 min and then decanted into the 600-mL beaker. The sediment was washed with about 15 mL of dichloromethane. The dichloromethane was decanted into the 600-mL beaker, another 100 mL of dichloromethane/methanol (2/1) added to the sediment, the cap secured, and the bottle rolled for another 16 h (overnight). The sediment was again allowed to settle for 20 min and the extract decanted into the 600-mL beaker. About 15 mL of dichloromethane were added to wash the sediment. The solvent was decanted into the 600-mL beaker and then the sediment was discarded.

The contents of the 600-mL beaker containing the combined sediment extracts were poured through a coarse fritted-glass filter into a 1-L separatory funnel. The beaker and the filter were each washed twice with about 5 mL of dichloromethane which were also drained into the separatory funnel. Five hundred milliliters of 2% NaCl in water was added and the funnel was inverted and swirled gently for 2 min with frequent venting. The funnel was righted, and the two phases allowed to separate. The lower (dichloromethane) layer was drained into a 500-mL Erlenmeyer flask. Twenty milliliters of dichloromethane were added to the remaining (aqueous) phase, and the funnel shaken for 2 min. The layers were allowed to separate, and then the lower one was drained into the Erlenmeyer flask containing the previous dichloromethane extract. The aqueous layer was then discarded, and the contents of the Erlenmeyer flask were poured back into the separatory funnel. The flask was washed twice with about 5 mL of dichloromethane, which were also added to the funnel. Another 500 mL of 2% sodium chloride in water were added, the funnel inverted and swirled for 2 min, righted and solvents allowed to separate. The lower layer was drained into a dichloromethane-rinsed, 500-mL Erlenmeyer flask. Another 20 mL of dichloromethane were added to the funnel, which was shaken for 2 min, then the layers were allowed to separate. The lower (dichloromethane) layer was then drained into the 500-mL Erlenmeyer flask containing the previous extract. The extract was now ready for silica-gel cleanup.

#### Tissue Extraction:

Tissues were homogenized, and a  $10 \pm 0.5$ -g portion was taken for extraction. The 10-g sample was placed in a dichloromethane-rinsed, 100-mL centrifuge tube, and 15 mL of 2% sodium chloride in water was added. The sample was homogenized again for about 20 sec. Fifty milliliters of dichloromethane/methanol (2/1 v/v) were added, and the sample was extracted for 1 min at medium speed using a Tekmar Tissumizer. The probe was washed with 2% sodium chloride in water in the 100-mL centrifuge tube and centrifuged for 10 min at 3,000 rpm. The aqueous and organic layers were decanted into a 250-mL separatory funnel, leaving the pellet in the centrifuge tube. Another 50 mL of dichloromethane/methanol (2/1) were added to the 100-mL centrifuge tube containing the pellet. The sample was again extracted for 1 min on the Tissumizer at medium speed, washing the probe, this time with dichloromethane/methanol (2/1). The mixture was centrifuged for 10 min at 3,000 rpm, and the liquid layer decanted into the separatory funnel containing the previous extracts.

Fifty milliliters of 2% sodium chloride in water were added to the 250-mL separatory funnel. The funnel was inverted and swirled gently for 2 min with frequent venting. The phases were allowed to separate, and the lower (dichloromethane) layer was drained into a second 250-mL separatory funnel. Ten milliliters of dichloromethane were added to the separatory funnel containing the aqueous layer. The funnel was then swirled for 1 min with frequent venting. The layers were allowed to separate, and the lower (dichloromethane) layer was drained into the second separatory funnel containing the previous dichloromethane extract. One hundred milliliters of 2% sodium chloride in water were added to the separatory funnel containing the dichloromethane extracts. The funnel was inverted and swirled for 2 min with frequent venting, and then the layers were allowed to separate. The lower (dichloromethane) layer was drained into a dichloromethane-rinsed Erlenmeyer flask, and another 20 mL of dichloromethane were added to the separatory funnel. The funnel was swirled for 1 min, the phases were allowed to separate, and then the lower (dichloromethane) phase was drained into the Erlenmeyer flask containing the previous extract. The extract was now ready for the silica-gel cleanup.

#### Silica-Gel Cleanup:

A 19-mm x 300-mm chromatograph column was filled with 80 mL of dichloromethane, and a glass-wool plug fitted into the bottom. Fifteen milliliters of silica gel, activated at 125°C, were mixed with about 25 mL of dichloromethane, swirled to remove air bubbles, and the slurry was poured into the column and allowed to settle with the stopcock closed. The stopcock was then opened and either (a) 3 cm of activated copper (sediments only) or (b) 3 cm of anhydrous sodium sulfate (tissues only) were added to the top of the silica gel. The solvent level was allowed to drain until it just reached the top of the column packing. The sample was then poured into the column which drained into a 500-mL Erlenmeyer flask with a 24/40 STJ. When the sample level had drained until it just reached the top of the column packing, the column was rinsed with about 3 mL of dichloromethane. This was allowed to drain into the Erlenmeyer flask until the level just reached the column packing. The column was rinsed again with about 3 mL of dichloromethane which also were allowed to drain until the solvent level just reached the column packing. Then sufficient dichloromethane was added to equal twice the volume of the column packing and the eluate was allowed to drain completely into the Erlenmeyer flask.

The Erlenmeyer flask was fitted with a three-ball Snyder column and placed on a 60°C water bath and the mixture evaporated to approximately 15 mL. The sample was transferred into a 25-mL concentrator tube with two rinses of dichloromethane. A Teflon boiling chip was added, and the concentrator tube was placed in a heating block which heated from the tip. The solution was concentrated to 1 mL, 2 mL of n-hexane were added and then the solution concentrated to 2 mL. The sample was now ready for silica-gel chromatography.

### Silica-Gel Chromatography:

A 19-mm x 300-mm chromatography column was filled with 100 mL of dichloromethane, and a glass-wool plug fitted into the bottom. Twenty grams of silica gel, activated at 125°C, were placed in a dichloromethane-rinsed 250-mL beaker and 25 mL of dichloromethane added. The beaker was swirled to remove air bubbles and then allowed to stand for 5 min. A funnel with a 30° bend in the stem was inserted into the chromatography column. The silica gel slurry was swirled gently and then poured into the funnel. The beaker was rinsed twice with dichloromethane, which was also poured through the funnel, and finally the funnel was rinsed twice with dichloromethane. The silica gel was allowed to settle, and then the stopcock was opened and a three-centimeter layer of either (a) activated copper (sediment only) or (b) anhydrous sodium sulfate (tissues only) added. The solvent layer was allowed to drain into a waste beaker until the solvent just reached the top of the column packing. Then, 40 mL of pentane was added and allowed to drain until it just reached the top of the packing.

The sample was placed on top of the column packing using a transfer pipet. It was eluted into the column until the sample meniscus just reached the column packing. The concentrator tube was washed twice with 0.5 mL of pentane, and each rinse was eluted into the column until the solvent meniscus was at the top of the column packing. The tip of the chromatography column was rinsed with dichloromethane and a 50-mL graduated cylinder placed beneath the column, 30 mL of pentane were added to the column, and the stopcock opened to permit a flow of about 5 mL per minute. Twenty-eight milliliters were collected, and then the graduated cylinder was removed. This contained the aliphatic hydrocarbons. A 100-mL graduated cylinder was placed beneath the chromatography column, and the remainder of the pentane was eluted into it. When the pentane meniscus reached the column packing, 100 mL of 50% dichloromethane in pentane (v/v) was added. The column was then eluted until 82 mL had been collected in the 100-mL graduated cylinder. This portion was then transferred to a 500-mL Erlenmeyer flask with a 24/40 STJ, rinsing twice with dichloromethane. The flask was then fitted with a three-ball Snyder column and the contents evaporated to approximately 15 mL in a water bath at 60°C. The sample was transferred with two washes of dichloromethane into a 25-mL concentrator tube. A Teflon boiling chip was added, and the tube was placed in a heating block (which was heated from the tip). The sample was concentrated to about 1 mL, 2 mL of n-hexane were added, and it was concentrated to 1 mL. A mixture of methanol (0.66 mL) and dichloromethane (0.5 mL) were added. The extract was now ready for Sephadex chromatography.

## LH-20 Sephadex Chromatography:

Column Preparation: Twenty two grams of Sephadex LH-20 were swelled overnight in a cyclohexane/ methanol/dichloromethane (6/4/3) solution. A 19-mm x 300-mm chromatography column was rinsed with dichloromethane and a glass-wool plug fitted in the bottom. A small layer (approximately 3 mm) of sand was placed on top of the glass-wool plug, and the column was tapped until the sand formed an even surface. The Sephadex was poured into the column with care to avoid the formation of air bubbles. It was allowed to settle, and a 3-mm layer of sand was placed on top of the Sephadex.

Column Calibration: A mixture of azulene and perylene in cyclohexane/methanol/dichloromethane was prepared of such strength that the azulene and perylene gave sufficient color as to be easily ascertained. Two milliliters of this sample were placed on top of the Sephadex column, using a transfer pipet and with care not to disturb the sand layer. The sample was eluted until it just entered the column, leaving just the top of the sand layer exposed. A 100-mL graduated cylinder was then placed beneath the column and 0.5 mL of cyclohexane/methanol/dichloromethane (6/4/3) was added to the top of the column. This was eluted until the sand layer was exposed, and then another 0.5 mL was added and eluted until the sand was just exposed. Then 100mL of cyclohexane/methanol/dichlormethane (6/4/3) were added (with care not to disturb the sand layer), and the column eluted until both the azulene and the perylene had come through. The volumes of eluent were recorded when each compound began to elute and when it finished. If there was a distinct break between where azulene finished eluting and perylene began, and azulene eluted between 50 mL and 60 mL and perylene eluted between 60 mL and 70 mL, the column was judged acceptable. If a column was acceptable, a "real sample" (i.e., a sample previously extracted and analyzed as per our procedure) of known content, was eluted through the column to be certain that the actual elution volumes corresponded to those needed for analysis. If this was found to be the case, the column was used in sample chromatography.

Columns were rechecked periodically with azulene and perylene to assure that the elution volumes had not changed significantly.

Sample Chromatography: The sample was transferred with a pipet to the top of the Sephadex column and eluted into the packing until the sand was barely exposed. The sample container was rinsed with 0.5 mL of cyclohexane/methanol/dichloromethane (6/4/3), and this was transferred to the top of the column. The tip of the chromatography column was then rinsed with dichloromethane and a solvent-rinsed, 50-mL graduated cylinder was placed beneath the column. The 0.5 mL of solvent was eluted until the sand was barely exposed. Then, another 0.5 mL of solvent was used to rinse the sample container, and this, too, was placed on top of the column. The column was eluted until the sand was barely exposed, and then 200 mL of solvent were placed on top of the column. The column was eluted until 40 mL had been collected. Then the 50-mL graduated cylinder was removed, and a 100-mL graduated cylinder placed beneath the column and another 60 mL collected. This 60-mL fraction contained the aromatic and chlorinated compounds. When 60-mL had been collected, the graduated cylinder was removed and a 50-mL cylinder replaced it until 50 mL more had been eluted. The column was then stopped, sealed, and stored for further use.

The second (60-mL) fraction was transferred to a 24/40 STJ 500-mL Erlenmeyer flask which was fitted with a three-ball Snyder column, and the contents were evaporated in a 75°C water bath to about 15 mL. The sample was then transferred to a 25-mL concentrator tube with two rinses of dichloromethane. One milliliter of methanol and a Teflon boiling chip were added and the tube placed in a heating block that heated from the tip. The sample was concentrated to 1 mL. Then 5 mL of hexane were added, and it was concentrated to 1 mL. The sample was transferred to a vial, and 4,000 ng of hexamethylbenzene and 200 ng of technazene were added. The extract was now ready for gas chromatography or gas chromatography/mass spectrometry.

#### Gas Chromatography/Mass Spectrometry:

The extracts were analyzed for the hydrocarbons listed in Table 1 using a Hewlett-Packard (model 5840A) microprocessor-controlled gas chromatograph (GC) equipped with an automatic sample injector (model 7671A), glass capillary column (20- to 30-m long and 0.25-mm i.d.) coated with either SE-30 or SE-54, and either a hydrogen flame ionization or electron capture detector. The GC injection port was modified for splitless injections using capillary columns, as described by Ramos et al. (1979). Column temperature was programmed at 4° C/min from 50° to 280°C and held at 280°C for 20 min. Peak areas were automatically integrated and the concentrations calculated using internal standards. The identity of compounds detected and quantitated by GC were confirmed by gas chromatography-mass spectrometry (GC-MS) as necessary, using an identical GC system interfaced with a Finnigan 3200 mass spectrometer used with an Incos 2300 data system.

## Metal Analysis

### Sediment:

Sediment samples were placed in acid-washed glass containers and dried at 70°C in a forced-draft oven for 48 h. They were then broken up by mortar and pestle and very gently passed through a 20-mesh stainless steel sieve to remove small rocks and any shell fragments. The dried, sieved material was returned to the same container it was dried in, tightly capped, and stored at room temperature until analyzed.

A modified procedure based on the Dow Chemical method for mercury analysis in sediments was used to prepare digests of these samples. After thoroughly mixing the sediment in the storage container, a 1-g + 1 mg sample was immediately weighed into a 125-ml boiling flask and 5 ml of aqua regia (1:3/ HNO<sub>3</sub>:HCl v/v) were added. The mixture was refluxed for 1 h, cooled for 10 min, and the reflux condenser surfaces rinsed into the boiling flask with distilled-deionized water. The digest was filtered through #40 Whatman filter paper into a 100-ml volumetric flask. The boiling flask was rinsed several times with distilled-deionized water to remove residual material. After final rinsing of the filter, the volume in the flask was brought to 100 ml with deionized-distilled water. After mixing, a 10-ml aliquot was removed for multi-element analysis, and the remaining 90 ml were used for mercury analysis.

Standards for the 36 elements determined by Inductively Coupled Argon Plasma (ICAP) emission spectroscopy (Table 2) were made up in the same acid strength as the digested sediment samples in order to minimize matrix effects. Calibration of the instrument and analysis of the sediment samples by ICAP emission spectroscopy were performed using background and inter-element corrections. All results are stated in parts per million (ppm) on a dry-weight basis.

Mercury was determined by flameless spectroscopy using a Perkin-Elmer Model 403 Atomic Absorption Spectrometer. Standards for the calibration curve were made up in the same acid strength as the digested sediment samples. Mercury results are stated in ppm on a dry-weight basis.

### Tissues:

Tissue samples were homogenized and frozen in small glass vials. Sample weights were 10 g where possible. The entire sample was used in cases where less than 10 g was available. The samples were weighed into 50-ml Vycor crucibles and placed under infrared heat lamps until the tissues were charred. The charred samples were transferred to a muffle furnace where the temperature was raised slowly to 450°C. After 18 h, the samples were removed, cooled, and 0.5 ml of HNO<sub>3</sub> was added. The crucibles were covered with watch glasses and heated on a hot plate at low temperature for 45 min. The samples were brought to dryness under infrared lamps and returned to the muffle furnace for 18 h. Some carbon was still visible; therefore, samples were removed from the furnace, cooled, and 0.5 ml of HNO<sub>3</sub> was added. The same heating and drying procedures were repeated. Upon return to the furnace, complete ashing was achieved in 30 min.

After cooling in a desiccator, the ash was dissolved in 2 ml of 2.8%  $\text{HNO}_3$  by heating to near-the-boiling point on a hot plate. The sample was cooled and then filtered through Whatman #40 ashless filter paper into either a 10- or 25-ml volumetric flask (depending on sample weight), followed by several rinsings of the crucible and filter paper with 2.8%  $\text{HNO}_3$ . The flasks were brought to volume with 2.8%  $\text{HNO}_3$  and mixed with vigorous shaking.

Standards for the 18 elements determined by Inductively Coupled Argon Plasma (ICAP) emission spectroscopy were made up in the same acid strength as the samples in order to minimize matrix effects. Calibration of the instrument and analysis of the samples by ICAP emission spectroscopy was performed using background and inter-element corrections. All results are stated in parts per million (ppm) on a wet-weight basis as received.

APPENDIX C

Formula for Dietrich's Fixative

Formula:

2% glacial acetic acid  
10% 40% formaldehyde  
30% 95% ethanol  
58% distilled water

APPENDIX D

Results of Chemical Analyses

Table D-1. Central Puget Sound contaminant study (MESA) sampling locations, identifications, and coordinates.

Location Description	Station Numbers		Latitude	Longitude
	MESA	Project		
Sinclair Inlet,				
Southwest end	08004	1	47 32 11	122 41 41
Drydock area	08005	2	47 33 03	122 38 38
Point Turner, southwest side	08006	3	47 33 17	122 37 42
Point Herron, south side	08007	4	47 33 42	122 36 34
Port Madison,				
Midway from Pt. Monroe to Pt. Jefferson	08106	1		
Indianola, southwest	08107	2		
Commencement Bay,				
Hylebos Waterway, lower turning basin	09027	1	47 16 16	122 22 33
Hylebos Waterway, E. 11th St. Bridge	09028	2	47 16 44	122 23 49
Blair Waterway, E. 11th St. Bridge	09029	3	47 16 32	122 24 24
Sitcum Waterway	09030	4	47 16 13	122 25 02
City Waterway	09031	5	47 15 25	122 26 00
Puyallup disposal site	09032	6	47 16 28	122 26 02
Between Hylebos & Blair	09033	7	47 17 06	122 24 58
Brown's Point, south side	09034	8	47 17 28	122 25 11
Creek at sewage plant	09035	9	47 17 17	122 28 43
Tacoma Yacht Club	09036	10	47 18 28	122 30 12
Brown's Point	09037	11	47 18 41	122 26 04
Hylebos Waterway, outside, to NW	09038	12	47 17 22	122 24 42
Old Tacoma	09039	13	47 16 44	122 27 29
Blair Waterway, turning basin	09040	14	47 15 45	122 23 10
Elliott Bay,				
Duwamish Waterway, near lumber mill	10031	1 & B	47 34 01	122 20 48
Duwamish Waterway, west channel	10038	2 & A	47 34 45	122 21 31
Duwamish Waterway, east channel	10039	3	47 34 50	122 20 36
Harbor Island, north end	10016	4	47 35 26	122 21 11
Pier 54	10015	5	47 36 12	122 20 33
Pier 70	10040	6	47 36 47	122 21 16
Midway from Pier 91 to Duwamish Head	10044	7	47 36 07	122 22 17
North of Pier 71	10041	8	47 37 07	122 21 47
Magnolia Bluff	10014	9	47 37 52	122 24 04
Duwamish Head, southeast side	10045	10	47 35 12	122 22 16
Alki Point, south side	10028	11	47 34 12	122 25 08
West Point, north side	10023	12	47 39 57	122 25 55
Pier 42	10046	13	47 35 47	122 20 25
Corps dump site	10043	14	47 35 43	122 21 45
Pier 86	10042	15	47 37 22	122 22 15
Duwamish waterway, 14th St. Bridge	10019	16 & D	47 32 33	122 19 52
Case Inlet,				
Reach Island	12062	1		
Stretch Island	12063	2		
Budd Inlet,				
Entrance channel, south end	12130	1	47 02 49	122 54 20
Priest Point	12131	2	47 04 13	122 54 23
Olympia Shoal	12132	3	47 04 45	122 54 34
Dofflemyer Point, south end	12133	4	47 07 53	122 54 53

Table D-2. Concentrations of metals in sediments from Central Puget Sound in May, 1979, in µg/g dry weight (ppm).

SOURCE OF SEDIMENT SAMPLE	ELEMENT										
	Ag	Al	As	B	Ba	Be	Bi	Ca	Cd	Co	
<b>SINCLAIR INLET:</b>											
Southwest end	4.76	18811		67.4	54.0	557		19103	8.14	14.0	
Drydock area	3.42	19650		50.0	65.2	633		8507	7.73	13.8	
Point Turner, southwest side	2.92	17796		50.8	59.6	585		13097	7.14	13.2	
Point Herron, south side	2.02	13070		38.5	30.2	420		7785	5.24	9.66	
Midway from Pt. Monroe to Pt. Jefferson	1.97	13712		29.4	34.3	490		6511	6.25	13.5	
Indianola, southwest	1.48	7309		23.6	16.3	221		5003	3.08	5.71	
Hylebos Waterway, lower turning basin	2.93	>20000		99.6	51.2	703	90	12340	9.61	20.6	
Hylebos Waterway, E. 11th St. bridge	2.35	13060		81.4	38.8	546		>20000	6.80	11.0	
Blair Waterway, E. 11th St. bridge	2.14	12857		23.4	25.6	481		7279	5.45	8.46	
Sitcum Waterway	10.8	12104	472	16.8	34.8	453		7022	16.2	47.8	
City Waterway	5.02	16471		40.9	79.3	549		8411	9.09	11.8	
Puyallup disposal site	1.90	12027		17.5	34.9	484		6209	5.20	10.6	
Between Hylebos & Blair	2.20	15027		20.2	31.8	530		8044	5.60	12.6	
Brown's Point, south side	2.37	15671		23.9	35.1	592		7668	5.99	15.6	
Creek at sewage plant	1.94	8503		14.3	17.4	327		4915	4.20	12.6	
Tacoma Yacht Club	2.22	9359		25.0	24.4	426		6144	5.80	20.0	
Brown's Point	1.95	9178		28.8	16.9	407		4293	4.72	14.1	
Hylebos Waterway, outside, to NW	2.52	16666		30.4	36.5	613		8467	6.06	15.5	
Old Tacoma	2.46	13009		36.5	58.1	475		7019	5.57	14.3	
Blair Waterway, turning basin	2.18	14110		20.0	32.7	544		7741	6.02	18.8	
Magnolia Bluff	1.31	9953		26.1	25.8	494		5063	4.46	8.76	
Pier 54	3.92	>20000		36.6	115	866		7169	8.58	17.6	
Harbor Island, north end	1.89	14586		18.8	103	574		6590	5.70	9.45	
Duwamish Waterway, 14th Ave. bridge	2.07	>20000		24.5	74.6	878		6607	8.29	16.5	
West Point, north side	1.45	10114		15.8	131	377		5229	4.71	6.86	
Alki Point, south side	1.25	7829		16.6	16.0	276		4261	3.77	5.33	
Duwamish Waterway, near lumber mill	2.99	>20000	95	28.3	119	995		8986	11.9	17.3	
Duwamish Waterway, west channel	2.56	>20000	84	25.4	283	963		9654	11.3	13.5	
Duwamish Waterway, east channel	3.27	>20000	282	45.5	97.0	1.10		8886	18.3	29.7	
Pier 70	3.49	18433		23.2	76.3	604		6223	7.01	9.88	
North of Pier 71	3.80	17423		28.5	75.7	569		6521	6.49	10.8	
Pier 86	3.20	19801		25.9	67.6	6928		6928	7.39	14.2	
Corps dump site	2.22	17152		29.2	63.3	556		6685	6.46	8.04	
Midway from Pier 91 to Duwamish Head	2.73	>20000		41.8	75.8	708		7773	8.21	15.4	
Duwamish Head, southeast side	2.05	14520		23.8	73.7	487		7109	7.30	12.0	
Pier 42	1.58	10923		15.7	28.4	359		5733	4.57	7.64	
Pier 42	1.62	10790		12.0	27.5	349		5807	7.52	10.2	
Reach Island	2.26	18280		55.8	32.1	588		8563	7.58	18.6	
Stretch Island	1.83	6430		15.6	11.7	160		4643	3.16	8.60	
Entrance channel, south end	3.67	>20000	140	39.9	31.1	759		8934	11.2	28.1	
Priest Point	2.66	17415		34.4	20.1	433		8575	8.19	17.8	
Olympia Shoal	2.97	>20000	57	48.5	29.2	684	81	7635	9.53	25.8	

Table D-2. (Continued)

SOURCE OF SEDIMENT SAMPLE		ELEMENT										
		Cr	Cu	Fe	Ga	Ge	Hg	K	Li	Mg	Mn	
SINCLAIR INLET:	Southwest end	71.5	151	31817			1.06	190	20.9	10500	301	
	Drydock area	65.2	184	32320			1.02	193	20.4	10543	352	
	Point Herrer, southwest side	57.3	132	30289			1.15	181	19.2	9437	308	
	Point Herrer, south side	39.4	46.8	22666			.315	136	13.4	6895	334	
PORT MADISON:	Midway from Pt. Monroe to Pt. Jefferson	45.6	25.8	28968			.113	128	15.7	8676	345	
	Indianola, southwest	22.8	10.4	12687			.042	58.4	7.42	4220	204	
COMMENCEMENT BAY:	Hylebos Waterway, lower turning basin	47.6	259	39405			.790	149	15.5	11301	258	
	Hylebos Waterway, E. 11th St. bridge	33.5	84.8	23507			.428	87.7	9.91	12961	202	
	Blair Waterway,	27.9	25138				.132	88.1	9.72	5172	166	
	Sitcum Waterway	58.7	1602	43354			.492	85.1	8.96	4904	184	
	City Waterway	46.5	178	27176			1.03	125	13.4	7381	190	
	Puyallup disposal site	25.5	33.7	22625			.065	71.0	7.53	4259	141	
	Between Hylebos & Blair	26.9	50.6	25445			1.06	98.1	11.0	5639	186	
	Brown's Point, south side	28.5	64.8	26758			.173	105	11.5	6405	217	
	Creek at sewage plant	31.4	43.0	18233			.100	60.1	8.83	5245	320	
	Tacoma Yacht Club	36.3	110	26063			.255	88.6	8.98	5675	87	
	Brown's Point	25.6	22.7	22530			.063	141	7.68	4251	213	
	Hylebos Waterway, outside, to NW	29.1	77.7	26558			.197	125	12.5	7290	173	
ELLIOTT BAY:	Old Tacoma	28.7	126	22732			.336	98.2	10.7	5997	244	
	Blair Waterway, turning basin	29.5	69.9	29914			.157	102	10.6	6110	143	
	Magnolia Bluff	27.5	23.9	19055			.095	179	8.56	4963	315	
	Pier 54	54.4	91.2	33076			1.16	102	19.3	9561	391	
	Harbor Island, north end	31.3	90.2	24636			1.38	116	11.9	5435	268	
	Duwamish Waterway, 14th Ave. bridge	35.5	54.5	34037			.250	167	15.4	7639	285	
	West Point, north side	35.6	18.9	19052			.104	76.2	9.99	7090	243	
	Alki Point, south side	27.5	10.2	15836			.031	69.4	8.90	5582	352	
	Duwamish Waterway, near lumber mill	44.8	131	45569		119	.383	222	21.4	9891	416	
	Duwamish Waterway, west channel	63.9	206	45659		88	.798	226	21.6	9785	439	
	Duwamish Waterway, east channel	49.2	109	>50000		188	.350	269	25.4	11363	567	
	Pier 70	54.0	135	32640		86	.632	148	16.3	8891	355	
	North of Pier 71	53.6	58.8	29460			1.07	154	16.5	9304	323	
	Pier 86	54.0	63.7	34013			.355	166	17.4	9735	473	
Corps dump site	38.7	59.6	30267			.423	139	14.0	7163	382		
Midway from Pier 91 to Duwamish Head	51.2	69.1	37278		44	.449	210	21.9	10652	471		
Duwamish Head, southeast side	69.8	60.7	35247			.153	108	13.4	8095	591		
Pier 42	40.4	21.2	20926			.026	63.0	7.46	6830	295		
Pier 42	41.1	22.5	22214			.026	62.6	7.66	6919	318		
Reach Island	52.7	45.0	28108		43	.118	167	20.5	9962	298		
Stretch Island	20.9	10.2	11120			.024	44.3	7.22	3533	192		
Entrance channel, south end	49.4	81.2	36217		101	.329	167	26.8	10407	230		
Priest Point	34.6	36.6	24748		46	.125	105	16.4	7078	184		
Olympia Shoal	50.1	70.3	34800		89	.283	164	24.7	10248	229		

Table D-2. (Continued)

SOURCE OF SEDIMENT SAMPLE	ELEMENT											
	Mo	Na	Ni	P	Pb	Sb	Sc	Se	Si	Sr	Sn	
<b>SINCLAIR INLET:</b>												
Southwest end	13.5	>20000	51.4	1227	97.6	43.5	7.13	30	137		37	
Drydock area	14.4	>20000	52.9	985	136	52.0	7.48	30	150		35	
Point Turner, southwest side	12.9	>20000	48.1	893	125	48.6	6.81	27	169		29	
Point Herron, south side	8.02	1128	35.5	697	44.2	31.1	5.02	133	133		40	
Midway from Pt. Monroe to Pt. Jefferson	8.47	12521	42.0	705	20.1	32.4	5.92	22	144		20	
Indianola, southwest		4458	21.5	405	10.3	17.8	3.00		140		12	
Hylebos Waterway, lower turning basin	17.2	>20000	64.4	1098	154	64.1	6.35	34	189		36	
Hylebos Waterway, E. 11th St. bridge	11.2	12846	41.9	813	111	43.2	4.06	27	149		32	
Blair Waterway, E. 11th St. bridge	8.44	9770	21.1	812	42.5	35.1	4.17		137		22	
Sitcum Waterway	11.4	10398	36.1	739	793	338	3.77	23	121		65	
City Waterway	13.1	17059	33.3	1017	269	44.0	5.26	23	146		31	
Puyallup disposal site	8.19	7972	18.7	737	14.0	29.2	3.88		207		19	
Between Hylebos & Blair	9.04	10966	22.8	858	27.6	38.7	4.84		135		19	
Brown's Point, south side	10.3	1348	24.0	917	39.9	29.4	3.15	23	137		20	
Creek at sewage plant	7.24	3860	29.4	428	28.8	27.4	3.55		133		15	
Tacoma Yacht Club	10.4	4198	38.5	557	65.1	52.6	3.88		117		20	
Brown's Point	7.23	4198	22.2	491	18.3	25.7	3.81		103		15	
Hylebos Waterway, outside, to NW	12.8	19112	24.8	940	50.1	41.5	5.42	23	121		19	
Old Tacoma	14.1	12356	25.4	800	170	36.1	4.43	22	101		70	
Blair Waterway, turning basin	12.1	14268	22.4	1474	49.0	39.2	4.53		101		18	
Magnolia Bluff	6.16	5029	24.6	551	37.1	25.9	3.82	34	100		36	
Harbor Island, north end	7.94	9584	24.2	680	60.8	34.8	8.40		88		22	
Duwamish Waterway, 14th Ave. bridge	14.8	13984	29.6	878	40.1	48.5	9.89	40	132		30	
West Point, north side	6.24	5799	41.7	473	16.1	21.1	3.75		117		19	
Alki Point, south side		4750	34.8	394	13.0	17.0	2.95		110		14	
Duwamish Waterway, near lumber mill	29.5	15823	36.0	1174	265	73.5	13.1	80	101		52	
Duwamish Waterway, west channel	26.4	18383	38.9	1020	627	80.4	12.4	70	101		52	
Duwamish Waterway, east channel	41.3	19744	47.9	1378	160	81.8	16.1	113	200		65	
Pier 70	10.9	11705	50.4	817	88.6	41.5	7.44	25	156		32	
North of Pier 71	9.98	12377	52.9	686	74.3	39.3	6.92	25	160		31	
Pier 86	11.4	16370	57.5	879	72.8	45.4	7.72	30	150		32	
Corps dump site	10.2	12604	30.0	798	65.1	47.0	8.87	26	153		26	
Midway from Pier 91 to Duwamish Head	14.8	>20000	45.0	968	78.0	51.1	8.60	39	185		37	
Duwamish Head, southeast side	9.93	6440	55.2	649	111	34.9	5.83	23	152		29	
Pier 42	6.71	4244	46.5	371	8.18	25.7	4.28		216		15	
Pier 42	6.00	5286	47.0	398	9.37	24.8	4.32		178		20	
Reanch Island	13.3	>20000	47.0	398	9.37	24.8	4.32	28	117		26	
Stretch Island	5.85	4935	19.4	303	7.93	19.0	2.89		143		9.6	
Entrance channel, south end	29.7	>20000	47.6	917	60.1	68.6	9.49	74	105		38	
Priest Point	11.6	14058	34.8	670	22.6	43.7	6.16	28	123		26	
Olympia Shoal	19.7	>20000	44.7	1051	49.3	61.0	8.75	59	142		38	

Table D-2. (Continued)

SOURCE OF SEDIMENT SAMPLE	ELEMENT							
	Str	Ti	V	W	Y	Zn	Zr	
<b>SINCLAIR INLET:</b>								
Southwest end	183	1058	64.5	21	10.1	156	7.36	
Drydock area	87.3	1117	70.4	26	10.4	238	6.36	
Point Turner, southwest side	99.6	1051	67.0	24	9.99	292	6.29	
Point Herron, south side	64.7	903	50.9	14	7.97	83.2	4.36	
Midway from Pt. Monroe to Pt. Jefferson	51.1	1060	60.1	16	8.27	61.9	5.95	
Indianola, southwest	30.4	731	30.3	7.9	4.86	26.8	4.34	
<b>COMMENCEMENT BAY:</b>								
Hylebos Waterway, lower turning basin	298	1065	80.2	29	9.73	324	12.3	
Hylebos Waterway, E. 11th St. bridge	51.3	942	66.7	19	7.76	134	11.6	
Blair Waterway, E. 11th St. bridge	85.6	1046	66.9	14	7.34	75.4	9.12	
Sitcum Waterway	109	834	59.1	51	6.44	1720	9.56	
City Waterway	81.8	1009	66.5	22	9.14	224	9.24	
Puyallup disposal site	102	1135	68.6	14	6.77	40.5	6.50	
Between Hylebos & Blair	104	1123	69.7	17	8.27	57.0	7.52	
Brown's Point, south side	32.9	1084	71.3	18	8.68	63.9	7.80	
Creek at sewage plant	47.4	849	56.4	14	6.18	46.5	5.52	
Tacoma Yacht Club	39.4	730	45.5	10	6.97	140	4.78	
Brown's Point	113	730	45.5	10	6.97	35.1	5.99	
Hylebos Waterway, outside, to NW	103	1066	71.3	19	9.16	81.8	9.33	
Old Tacoma	113	865	60.5	18	7.93	208	5.83	
Blair Waterway, turning basin	43.9	900	70.0	17	8.19	92.2	7.34	
Magnolia Bluff	105	834	47.4	10	6.24	58.3	4.64	
Pier 54	73.3	1308	81.5	26	11.6	133	8.91	
Harbor Island, north end	94.9	1099	64.1	13	8.19	106	7.01	
Duwamish Waterway, 14th Ave. bridge	37.4	1331	84.1	30	13.8	96.2	9.33	
West Point, north side	26.5	915	45.8	9.4	5.39	44.0	4.76	
Alki Point, south side	124	699	34.9	8.2	4.64	30.3	3.90	
Duwamish Waterway, near lumber mill	123	1649	95.9	61	15.7	204	9.07	
Duwamish Waterway, west channel	142	1534	92.2	56	14.8	319	9.30	
Duwamish Waterway, east channel	68.7	1931	107	81	18.1	175	12.2	
Pier 70	62.3	1289	75.7	20	9.92	97.2	7.73	
North of Pier 71	77.8	1211	67.9	19	9.48	97.8	8.36	
Pier 86	95.5	1284	75.0	22	10.3	91.0	7.96	
Corps dump site	62.8	1248	81.2	31	11.6	115	7.94	
Midway from Pier 91 to Duwamish Head	33.1	1070	56.3	11	5.99	29.7	7.29	
Duwamish Head, southeast side	86.5	1099	60.7	23	9.81	82.5	6.34	
Pier 42	26.4	679	28.0	8.0	4.26	23.2	4.04	
Pier 42	89.9	1326	71.3	58	10.7	118	10.7	
Reach Island	70.2	1122	49.2	23	7.57	55.1	9.12	
Stretch Island	85.3	1233	68.9	45	10.4	101	10.5	
<b>CASE INLET:</b>								
Entrance channel, south end								
<b>BUDD INLET:</b>								
Priest Point								
Olympia Shoal								

Table D-3. Concentrations of target organic compounds in sediments from Elliott Bay, in ng/g dry weight (ppb).

SAMPLE NUMBER STATION NUMBER	88 10014	64 10015	60 10016	31 10019	83 10023	86 10028	34 10031	37 10038	38 10039	32 10040	59 10041	87 10042	78 10043	73 10044	81 10045	58 10046	67 10046
I-PROPYLBENZENE	2.0	< 6.0	2.0	40	10	.60	< 50	7.0	1.0	2.0	4.0	.60	.30	3.0	< .50	1.0	1.0
N-PROPYLBENZENE	.80	< 6.0	< 2.0	.70	< 10	1.0	< 60	< 1.0	2.0	1.0	9.0	3.0	2.0	2.0	3.0	1.0	2.0
INDAN	1.0	30	7.0	6.0	< 80	.30	2.0	20	4.0	.90	7.0	20	4.0	4.0	2.0	50	1.0
NAPHTHALENE	50	8.0	610	20	680	8.0	80	310	70	80	220	160	140	210	90	5.0	10
BENZOTHIOPHENE	2.0	80	8.0	.90	20	< .10	< 90	< 2.0	3.0	4.0	7.0	6.0	4.0	5.0	< .90	< .20	< 20
2-METHYLNAPHTHALENE	20	1300	250	20	280	5.0	60	150	50	40	90	70	50	80	50	3.0	4.0
1-METHYLNAPHTHALENE	20	540	110	10	130	2.0	30	90	20	20	40	40	30	40	20	1.0	2.0
BIPHENYL	6.0	430	50	6.0	70	2.0	20	40	10	10	30	30	20	30	9.0	70	.80
2,6-DIMETHYLNAPHTHALENE	20	600	110	30	210	3.0	50	80	40	20	60	60	40	60	30	1.0	2.0
ACENAPHTHALENE	4.0	190	10	< .10	270	< .10	< .50	10	1.0	< .10	20	10	5.0	10	3.0	< .10	< .10
ACENAPHTHENE	4.0	1300	210	20	150	1.0	140	350	30	20	50	40	50	30	20	2.0	4.0
FLUORENE	10	970	210	30	270	.60	170	350	60	30	60	60	40	30	70	3.0	6.0
DIBENZOTHIOPHENE	1.0	340	50	5.0	690	.60	80	140	80	30	80	30	70	40	150	2.0	3.0
PHENANTHRENE	80	6800	1600	140	4200	10	940	2600	370	190	400	520	270	320	410	20	30
ANTHRACENE	30	2400	1200	180	1200	3.0	290	630	160	70	230	190	70	90	580	7.0	5.0
FLUORANTHENE	130	7600	3200	160	6100	20	1700	3700	770	240	490	730	330	450	700	30	50
PYRENE	160	11000	2800	170	8500	20	1200	3200	570	340	640	810	410	540	720	30	40
BENZ(A)ANTHRACENE	80	6800	1400	100	4800	10	1100	2700	510	180	310	660	140	290	670	30	30
CHRYSENE	70	6000	900	70	3900	9.0	920	2400	450	200	360	660	130	260	610	30	30
BENZOFLUORANTHENE	130	4700	2500	110	6800	20	1360	8400	730	480	710	1300	260	570	810	30	40
BENZO(E)PYRENE	60	4000	1100	40	2800	9.0	480	1700	300	250	330	590	120	250	390	10	10
BENZO(A)PYRENE	40	2200	960	40	4000	6.0	440	1500	240	220	260	440	80	180	170	10	10
PERYLENE	60	1700	370	270	1400	8.0	270	530	150	150	170	210	130	200	70	8.0	2.0
INDENO(1,2,3-CD)PYRENE	30	2500	480	20	2400	5.0	240	870	160	120	150	280	50	130	120	8.0	10
2,3,5 TRIMETHYLNAPHTHALENE	140	1000	100	50	320	4.0	50	70	30	30	60	50	60	60	40	< .20	.30
HEXACHLOROBEZENE	.070	.30	.10	.10	.030	.020	.20	.40	.20	.20	.30	.50	.10	.20	.070	< .010	< .010
LINDANE	< .010	< .10	< .020	< .10	< .020	< .010	< .10	< .060	< .080	2.0	< .020	< .050	< .060	< .020	< .030	< .010	< .010
HEPTACHLOR	< .020	< .80	< .50	< .20	< .020	< .010	< .80	< .20	3.0	.10	< .40	< .30	< .40	< .10	< .050	< .010	< .010
ALDRIN	< .020	< .10	< .040	< .020	< .020	< .010	< .20	< .10	< .30	< .020	< .020	< .040	< .080	< .030	< .10	< .010	< .010
D,P' - DDE	< .40	< 2.0	< .80	< 1.0	.40	< .050	< 1.0	< 2.0	4.0	< .50	< .70	< .70	< 2.0	3.0	2.0	< .050	.10
A-CHLORDANE	< .20	< 2.0	< .40	< .40	.20	< .030	< 2.0	< 1.0	3.0	< .60	< .50	< .60	< .50	.20	.30	< .010	< .010
TRANS-NONACHLOR	< .20	< 2.0	< .40	< .40	.10	< .030	< 2.0	< 1.0	2.0	< .60	< .50	< .60	< .50	.20	.30	< .010	< .010
P,P' - DDE	< .40	2.0	.80	2.0	.20	< .040	2.0	1.0	2.0	1.0	1.0	< .30	1.0	1.0	.50	< .030	.040
D,P' - DDD	< .40	< 40	< 2.0	< 3.0	.20	< .050	< 3.0	< 4.0	2.0	< 1.0	< 1.0	< 1.0	< 2.0	.70	4.0	< .070	.040
M,P' - DDD	< .60	< 9.0	< 3.0	< 2.0	.40	< .070	< 3.0	< 4.0	9.0	< 1.0	< 2.0	< 3.0	< 3.0	1.0	2.0	< .10	< .070
P,P' - DDD/D,P' - DDT	.80	< 10	30	10	3.0	< .040	7.0	20	10	1.0	2.0	20	20	3.0	3.0	< .060	< .040
P,P' - DDT	< .40	20	10	3.0	.90	< .050	7.0	10	7.0	4.0	6.0	10	< 8.0	2.0	.70	< .080	.060
DICHLOROBIPHENYLS	.40	2.0	.40	5.0	.50	< .050	7.0	1.0	2.0	20	.80	.50	2.0	.70	2.0	< .050	< .040
TRICHLOROBIPHENYLS	2.0	10	5.0	40	1.0	< .040	70	9.0	8.0	20	6.0	5.0	20	2.0	10	< .050	< .10
TETRACHLOROBIPHENYLS	5.0	50	20	100	5.0	< .10	120	50	30	50	20	20	50	10	20	< .10	< .30
PENTACHLOROBIPHENYLS	10	100	40	160	7.0	< .080	160	160	50	90	40	40	70	32	20	< .090	< .30
HEXACHLOROBIPHENYLS	8.0	140	40	110	9.0	< .080	100	210	90	80	50	60	60	30	20	< .080	< .30
HEPTACHLOROBIPHENYLS	8.0	140	50	30	30	< .060	70	190	110	50	30	30	30	30	20	< .060	< .20
OCTACHLOROBIPHENYLS	2.0	30	10	1.0	8.0	< .050	< 4.0	40	40	3.0	10	10	8.0	30	3.0	< .050	< .20
NONACHLOROBIPHENYLS	< .40	20	6.0	< .30	< .20	< .020	< 2.0	5.0	8.0	< 1.0	2.0	3.0	80	5.0	4.0	< .020	< .050
DICHLOROBENZENE	< .030	1.0	< .20	< .20	.90	< .030	< .40	< .40	.050	20	< .20	30	< 20	< 10	< .20	< .040	< .040
TRICHLOROBADIENE	.40	8.0	.70	< .10	.40	.50	< .20	1.0	70	3.0	1.0	2.0	1.0	6.0	1.0	< .040	< .070
TETRACHLOROBADIENE	3.0	40	8.0	< .10	2.0	2.0	< .60	5.0	2.0	10	5.0	7.0	5.0	30	5.0	< .030	< .040
PENTACHLOROBADIENE	.20	4.0	1.0	< .10	.080	.10	< .20	.60	.20	1.0	1.0	1.0	1.0	3.0	.40	< .030	< .030
HEXACHLOROBUTADIENE	.20	1.0	.40	< .10	.40	.20	< .20	.60	.20	.60	40	70	60	3.0	30	< .010	< .010
% DRY WT	78	48	61	57	74	77	47	45	42	57	57	51	55	38	63	76	79
SAMPLE WT .GRAMS	97.7	98.3	102	100	101	97.1	100	100	101	100	100	100	102	101	98.1	101	103

Table D-4. Concentrations of target organic compounds in sediments from Commencement Bay, in ng/g dry weight (ppb).

SAMPLE NUMBER STATION NUMBER	45 9027	48 9028	46 9029	43 9030	52 9031	50 9032	49 9033	82 9034	61 9035	55 9036	62 9037	63 9038	44 9039	51 9040
1-PROPYLBENZENE	1.0	5.0	6.0	3.0	3.0	.50	2.0	2.0	.80	.90	< .50	50	640	.70
N-PROPLYLBENZENE	6.0	20	8.0	1.0	40	1.0	.90	2.0	1.0	< .40	< .50	3.0	730	1.0
INDAN	< .80	9.0	6.0	3.0	80	.90	.50	5.0	.60	< .40	< .50	6.0	3.0	3.0
NAPHTHALENE	100	2600	440	170	4000	70	80	310	30	50	80	1300	400	60
BENZOTHIOPHENE	6.0	5.0	20	9.0	230	2.0	2.0	10	.60	< .60	< .80	20	50	2.0
2-METHYLNAPHTHALENE	60	880	110	40	1600	20	20	220	10	10	30	710	270	20
1-METHYLNAPHTHALENE	20	550	90	30	720	20	20	90	4.0	8.0	20	240	110	10
BIPHENYL	20	270	70	20	490	8.0	10	40	4.0	2.0	6.0	180	150	10
2,6-DIMETHYLNAPHTHALENE	40	430	130	50	820	40	40	170	6.0	10	30	540	210	30
ACENAPHTHALENE	< .70	280	30	20	310	10	20	30	< .10	3.0	6.0	110	1.0	.10
ACENAPHTHENE	40	310	90	100	710	3.0	7.0	30	4.0	3.0	3.0	90	280	10
FLUORENE	40	820	80	80	810	30	20	40	2.0	4.0	3.0	190	310	7.0
DIBENZOTHIOPHENE	90	370	40	70	220	4.0	5.0	3.0	6.0	8.0	3.0	30	310	30
PHENANTHRENE	400	7300	630	390	4800	50	90	300	30	80	90	1300	1900	130
ANTHRACENE	200	670	170	100	2200	8.0	20	60	9.0	20	20	290	600	40
FLUORANTHENE	1700	6400	900	380	6100	30	110	300	40	90	90	2000	2600	230
PYRENE	1600	6700	870	320	10000	20	100	340	40	90	100	1800	2100	190
BENZ(A)ANTHRACENE	1600	3200	710	220	4700	10	60	110	20	50	40	780	2100	180
CHRYSENE	2400	3000	750	170	3800	10	60	180	20	30	40	1200	1700	260
BENZOFLUORANTHENES	2700	11000	720	200	6600	4.0	70	250	20	70	70	1800	1100	250
BENZO(E)PYRENE	1200	1900	450	120	3100	6.0	40	100	10	30	30	770	790	170
BENZO(A)PYRENE	500	1700	190	70	2600	2.0	20	60	6.0	20	10	350	340	60
PERYLENE	200	470	220	50	630	5.0	20	70	6.0	20	20	160	140	100
INDENO(1,2,3-CD)PYRENE	430	1100	180	60	1300	.40	20	30	5.0	10	< .90	150	280	70
2,3,5 TRIMETHYLNAPHTHALENE	40	450	170	40	800	60	50	190	9.0	20	50	420	240	30
HEXACHLOROBENZENE	20	.60	3.0	2.0	3.0	1.0	10	60	.10	.20	1.0	50	250	2.0
LINDANE	< 2.0	< .020	< .10	< .090	< 2.0	< .10	.50	2.0	< .010	< .010	< .010	2.0	7.0	< .060
HEPTACHLOR	< 1.0	< .050	< .20	< .10	< 2.0	< .10	< .10	1.0	< .010	< .020	< .010	< .10	20	< .20
ALDRIN	< 1.0	< .060	< .20	2.0	< 2.0	< .10	1.0	70	< .030	< .040	.70	4.0	< 1.0	< .090
O, P' - DDE	20	1.0	2.0	2.0	9.0	.40	< .20	< 10	< .080	.10	< .040	< .60	3.0	.60
A-CHLORDANE	2.0	.30	3.0	1.0	< 2.0	< .20	.90	10	< .040	.10	< .010	.90	20	.10
TRANS-NONACHLOR	2.0	.30	.50	.60	4.0	< .20	.80	5.0	< .040	.10	.050	8.0	10	.10
P, P' - DDE	10	.20	1.0	.60	5.0	.20	.50	.70	< .050	.040	< .010	.50	7.0	.20
O, P' - DDD	6.0	.30	.40	.50	3.0	< .20	< .50	< .90	< .10	< .030	< .020	< .50	.90	< .20
M, P' - DDD	8.0	1.0	1.0	1.0	10	< .30	< .50	< 1.0	< .20	< .050	.40	< .70	< 4.0	.50
P, P' - DDD/O, P' - DDT	50	10	6.0	9.0	30	2.0	2.0	10	< .10	.20	.50	5.0	10	2.0
P, P' - DDT	70	3.0	3.0	3.0	20	2.0	1.0	9.0	< .20	< .050	1.0	3.0	10	2.0
DICHLOROBIPHENYLS	< 10	1.0	< .30	< .40	1.0	.40	< .30	3.0	< .060	.10	.040	2.0	20	.30
TRICHLOROBIPHENYLS	60	3.0	.90	1.0	10	3.0	N	60	< .050	< .080	.40	60	140	2.0
TETRACHLOROBIPHENYLS	190	9.0	1.0	20	60	9.0	N	150	< .10	< .50	.1.0	100	250	7.0
PENTACHLOROBIPHENYLS	250	8.0	10	20	100	2.0	N	90	< .10	< .40	.40	70	230	4.0
HEXACHLOROBIPHENYLS	440	6.0	10	20	130	.80	N	60	< .10	< .40	< .50	30	160	8.0
HEPTACHLOROBIPHENYLS	100	< 2.0	10	< 3.0	60	< .30	N	30	< .080	< .30	< .40	10	120	1.0
OCTACHLOROBIPHENYLS	110	< 2.0	2.0	< 2.0	20	< .20	N	10	< .060	< .20	< .20	4.0	70	< .90
NONACHLOROBIPHENYLS	< 20	< 1.0	1.0	< .80	< 2.0	< .10	N	3.0	< .020	< .070	< .040	.70	2.0	< .50
DICHLOROBENZENE	20	2.0	< .30	< .20	.20	.060	.90	< .70	.080	< .060	< .050	.40	.60	< .060
TRICHLOROBUTADIENE	90	20	10	4.0	4.0	1.0	40	270	2.0	5.0	7.0	70	3900	4.0
TETRACHLOROBUTADIENE	270	40	20	10	40	2.0	140	460	10	20	20	120	2800	10
PENTACHLOROBUTADIENE	90	8.0	4.0	7.0	6.0	.90	50	140	4.0	3.0	5.0	50	1200	2.0
HEXACHLOROBUTADIENE	90	2.0	6.0	2.0	2.0	.90	30	140	1.0	2.0	4.0	60	1100	2.0
% DRY WT	35	45	59	56	41	62	57	52	78	74	76	42	43	56
SAMPLE WT. , GRAMS	100	100	99.6	101	101	100	99.6	102	101	99.6	101	98.7	104	99.3

Table D-5. Concentrations of target organic compounds in sediments from other sites, in ng/g dry weight (ppb).

SAMPLE NUMBER STATION NUMBER	P. MADISON		BUDD INLET			CASE INLET		SINCLAIR INLET			
	70 B106	57 B107	35 12130	33 12131	39 12132	36 12062	40 12063	80 B004	56 B005	77 B006	77 B007
I-PROPYLBENZENE	2.0	1.0	7.0	7.0	<.30	1.0	.20	30	3.0	2.0	70
N-PROPLYLBENZENE	30	2.0	.50	.50	<.40	2.0	1.0	.40	3.0	3.0	4.0
INDAN	1.0	.30	1.0	4.0	4.0	4.0	.40	5.0	4.0	5.0	10
NAPHTHALENE	30	8.0	30	50	80	20	3.0	40	50	80	360
BENZOTHIOPHENE	.60	<.20	.30	1.0	40	.50	<.20	2.0	2.0	4.0	20
2-METHYLNAPHTHALENE	20	7.0	10	20	20	20	1.0	30	40	70	360
1-METHYLNAPHTHALENE	10	3.0	6.0	6.0	9.0	10	1.0	10	20	30	150
BIPHENYL	6.0	2.0	5.0	6.0	8.0	4.0	<.10	10	10	20	90
2,6-DIMETHYLNAPHTHALENE	10	3.0	10	9.0	10	20	1.0	20	30	50	280
ACENAPHTHALENE	<.10	<.10	<.20	<.20	<.30	<.40	<.10	<.20	<.30	<.20	3.0
ACENAPHTHENE	3.0	<.10	10	10	9.0	5.0	.20	6.0	20	20	80
FLUORENE	10	.40	7.0	9.0	5.0	1.0	<.10	4.0	20	30	90
DIBENZOTHIOPHENE	10	3.0	20	10	10	2.0	<.30	20	50	10	280
PHENANTHRENE	60	20	70	40	90	50	4.0	70	260	170	1400
ANTHRACENE	10	3.0	20	10	20	8.0	.30	20	80	60	780
FLUDRANTHENE	80	30	160	80	130	100	7.0	160	460	280	2300
PYRENE	110	30	170	100	180	90	8.0	190	460	350	3100
BENZ(A)ANTHRACENE	70	20	110	50	80	40	3.0	140	370	270	2100
CHRYSENE	50	20	90	30	50	40	3.0	120	290	220	1500
BENZOFLUORANTHENE	80	40	110	70	120	60	7.0	290	420	310	1800
BENZO(E)PYRENE	40	10	50	30	60	50	4.0	120	240	170	930
BENZO(A)PYRENE	30	9.0	30	10	40	30	7.0	70	170	140	830
PERYLENE	40	10	120	50	90	40	4.0	70	110	90	510
INDENO(1,2,3-CD)PYRENE	30	10	20	10	40	30	2.0	90	170	130	670
2,3,5 TRIMETHYLNAPHTHALENE	20	4.0	10	10	9.0	20	2.0	30	50	40	320
HEXACHLOROBENZENE	.10	.030	.10	.10	.010	.040	.010	.20	.40	.20	.20
LINDANE	<.060	<.010	<.020	<.010	<.030	<.030	<.010	<.040	<.060	<.030	<.040
HEPTACHLOR	<.010	<.010	<.10	<.10	<.050	<.030	<.010	<.030	<.050	<.020	<.030
ALDRIN	<.010	<.010	<.020	<.010	<.040	<.030	<.010	<.040	<.050	<.020	<.030
O,P' - DDE	.30	<.040	<.10	<.10	<.070	<.10	<.050	3.0	4.0	2.0	.70
A-CHLORDANE	.20	<.020	<.30	<.20	<.20	<.10	<.020	.60	.80	.40	.20
TRANS-NONACHLOR	.20	<.020	<.30	<.20	<.10	<.10	<.020	.60	.90	.40	.10
P,P' - DDE	.20	<.020	.20	.70	<.040	<.10	<.030	.50	2.0	.60	.20
O,P' - DDD	.080	<.040	<.30	<.20	<.10	<.10	<.020	.80	1.0	.60	.20
M,P' - DDD	.10	<.060	.20	<.20	<.10	<.30	<.030	<1.0	<2.0	<.60	<.30
P,P' - DDD/O,P' - DDT	.30	.10	1.0	.60	<.40	.30	<.030	8.0	9.0	4.0	1.0
P,P' - DDT	.10	.60	1.0	.10	<.080	<.20	<.020	2.0	3.0	.90	4.0
DICHLOROBIPHENYLS	.20	.10	.30	.30	.20	.20	.020	.60	.20	.010	.20
TRICHLOROBIPHENYLS	.40	.40	.60	.40	.50	.50	.10	3.0	3.0	2.0	1.0
TETRACHLOROBIPHENYLS	2.0	1.0	4.0	2.0	3.0	.90	.040	10	10	8.0	3.0
PENTACHLOROBIPHENYLS	2.0	1.0	8.0	6.0	.70	1.1	.20	30	40	20	7.0
HEXACHLOROBIPHENYLS	2.0	.20	5.0	3.0	.60	.90	.10	50	70	20	6.0
HEPTACHLOROBIPHENYLS	2.0	<.20	.60	3.0	<.30	<.30	.050	40	70	20	7.0
OCTACHLOROBIPHENYLS	.40	<.10	<.40	.30	<.20	<.10	<.040	40	20	3.0	2.0
NONACHLOROBIPHENYLS	.080	<.040	<.20	<.10	<.10	<.10	<.020	2.0	5.0	4.0	2.0
DICHLOROBENZENE	.070	<.10	<.10	<.10	<.4.0	<.10	<.060	<.20	<.20	<.10	<.20
TRICHLOROBUTADIENE	.30	.50	.20	.40	.30	.40	<.030	4.0	10	20	10
TETRACHLOROBUTADIENE	.90	2.0	2.0	4.0	2.0	6.0	<.040	10	40	50	30
PENTACHLOROBUTADIENE	.40	.050	.20	.70	.30	.90	<.040	2.0	8.0	10	5.0
HEXACHLOROBUTADIENE	.30	.20	.10	.20	.050	.20	<.030	3.0	10	10	6.0
% DRY WT	55	73	28	37	27	25	71	32	33	38	50
SAMPLE WT., GRAMS	101	99.1	99.4	101	100	100	100	102	99.2	103	101

Table D-6. Halogenated compounds found in some sediment samples from Central Puget Sound.

chlorobenzene	trichlorophenanthrene or
dichlorobenzene	trichloroanthracene
trichlorobenzene	tetrachlorophenanthrene or
tetrachlorobenzene	tetrachloroanthracene
bromonaphthalene	trichloroterphenyl
chloronaphthalene	tetrachloroterphenyl
dichloronaphthalene	dibromopyrene or
trichloronaphthalene	dibromofluoranthene
tetrachloronaphthalene	chloropyrene or
pentachloronaphthalene	chlorofluoranthene
hexachloronaphthalene	dichloropyrene or
heptachloronaphthalene	dichlorofluoranthene
dichlorofluorene	trichloropyrene or
tetrachlorodibenzofuran	trichlorofluoranthene
pentachlorodibenzofuran	tetrachloropyrene or
hexachlorodibenzofuran	tetrachlorofluoranthene
bromophenanthrene or bromoanthracene	pentachloropyrene or pentachlorofluoranthene
chlorophenanthrene or chloroanthracene	dichlorochrysene or dichlorobenz[a]anthracene
dichlorophenanthrene or dichloroanthracene	

Table D-7. Total organic carbon and grain size analyses of sediments from Central Puget Sound.

Location Description	Station Number	Grain Size (% by weight)					Mean Grain Size $\phi$	Sand/Mud Ratio	% Organic Carbon
		>-2	-2 to 0	0 to +4	+2 to +4	+4 to +8			
Sinclair Inlet:									
Southwest end	08004		0.48	0.47	0.84	65.03	33.20	0.02	4.42
Drydock area	08005		0.21	0.41	2.75	46.80	49.84	0.03	3.44
Point Turner, southwest side	08006		0.73	7.55	9.14	46.49	36.11	0.21	4.90
Point Herron, south side	08007		0.03	2.51	53.69	20.95	22.82	1.28	1.61
Port Madison:									
Midway from Pt. Monroe to Pt. Jefferson	08106		1.44	9.83	34.23	35.56	18.93	0.83	1.26
Indianola, southwest	08107		0.06	21.26	57.33	15.12	6.21	3.68	0.41
Commencement Bay:									
Hylebos Waterway, lower turning basin	09027		0.03	0.42	2.60	77.54	19.41	0.03	4.00
" " " " , E. 11th St. Bridge	09028		1.45	16.06	19.21	52.84	10.44	0.58	2.82
Blair Waterway	09029		0.25	16.08	19.27	46.85	18.14	0.55	1.64
Sitcum Waterway	09030			1.34	14.88	64.15	19.64	0.19	1.78
City Waterway	09031			1.41	6.32	66.57	25.70	0.08	5.17
Puyallup disposal site	09032		0.01	0.67	42.99	49.80	6.54	0.78	1.56
Between Hylebos and Blair	09033		0.10	3.48	9.98	66.99	19.45	0.16	1.51
Brown's Point, south side	09034		0.23	2.05	12.08	61.97	23.67	0.17	2.49
Creek at sewage plant	09035	0.56	3.84	52.54	36.14	2.98	3.95	13.47	0.40
Tacoma Yacht Club	09036	1.92	7.31	40.03	42.07	3.53	5.15	10.54	1.72
Brown's Point	09037		6.65	56.81	22.49	7.64	6.41	6.12	0.48
Hylebos Waterway, outside, to NW	09038		0.37	10.37	21.01	70.07	27.51	6.69	2.64
Old Tacoma	09039		0.02	3.22	17.16	44.34	23.92	0.47	6.98
Blair Waterway, turning basin	09040					52.48	27.11	0.26	1.60

Table D-7. (Continued)

Location Description	Station Number	Grain Size (% by weight)							Mean Grain Size $\phi$	Sand/Mud Ratio	% Organic Carbon
		>-2	-2 to 0	0 to +4	+2 to +4	+4 to +8	< +8				
Elliott Bay:											
Magnolia Bluff	10014		0.54	25.18	59.96	6.95	7.38	2.63	5.98	1.13	
Pier 54	10015		0.21	3.57	6.70	58.33	31.19	7.02	0.12	1.63	
Harbor Island, north end	10016	no data						no data			
Duwamish Waterway, 1st Ave Bridge	10019		0.84	20.02	11.76	52.35	15.04	4.84	0.48	1.50	
West Point, north side	10023		0.01	3.59	80.07	11.11	5.22	3.26	5.12	0.50	
Alki Point, south side	10028		0.09	38.07	57.52	1.28	3.02	2.23	22.23	0.39	
Duwamish Waterway, near Lumber mill	10031		0.03	3.13	12.29	46.45	38.09	7.11	0.18	1.83	
" , west channel	10038		0.11	2.99	15.02	40.73	41.15	7.07	0.22	1.82	
" , east channel	10039			0.58	2.82	43.76	52.83	8.52	0.04	1.76	
Pier 70	10040		2.38	14.08	10.69	49.11	23.74	5.26	0.37	1.33	
North of Pier 71	10041		1.33	9.72	25.36	50.08	13.51	5.03	0.57	1.83	
Pier 86	10042		0.07	2.40	9.44	59.33	28.76	6.77	0.14	1.33	
Corps dump site	10043		2.84	20.16	22.09	42.90	12.01	4.63	0.82	1.99	
Midway from Pier 91 to Duwamish Head	10044		0.01	1.09	4.15	49.43	45.32	7.31	0.06	2.15	
Duwamish Head, southeast side	10045	0.91	10.62	26.56	22.79	23.70	15.42	3.77	1.56	1.53	
Pier 42	10046		1.98	24.82	60.74	10.45	2.01	2.62	7.02	0.14	
Case Inlet:											
Reach Island.	12062			1.26	4.67	59.00	35.07	7.39	0.06	3.10	
Stretch Island	12063		0.04	24.35	65.36	5.97	4.28	2.56	8.75	0.36	
Budd Inlet:											
Entrance channel, south end	12130			0.18	4.73	67.23	27.86	6.95	0.05	3.10	
Priest Point	12131		0.02	10.28	35.38	29.00	25.32	5.65	0.84	2.05	
Olympia Shoal	12132			0.45	0.93	47.85	50.77	---	0.01	3.41	

Table D-8. Concentrations of metals in biota taken from Central Puget Sound in May, 1979, in µg/g wet weight (ppm).

SAMPLE STATION	SAMPLE	Ag	Al	B	Ba	Ca	Cd	Co	Cr	Cu	Fe	Li	Ni	Hn	Nf	P	Pb	Sc	Sr	V	Zn	
Port Madison	Rock Sole liver	1.65				56.5	.932	.932	17.6	436			231	1.31		3620			.586	.823	47.9	
Budd Inlet	English Sole liver	2.03		.362		2851	.639	.639	4.89	218			245	2.37		5020			17.6	.827	33.2	
Budd Inlet	Rock Sole liver	1.57			.133	62.6	.749	.749	9.64	234			217	1.84		3795			.327	.822	36.9	
Case Inlet	English Sole liver	3.87		.561		188	1.49	1.49	3.08	242			221	1.76		3795			1.43	1.92	28.4	
Case Inlet	Rock Sole liver	2.12			.191	68.1	1.40	1.40	11.5	184			194	1.86		3390			.629	1.83	38.7	
Sinclair Inlet	English Sole liver	1.98		.389		63.3	.694	.694	12.6	385			215	1.69		3528			.456	1.02	34.8	
Sinclair Inlet	Rock Sole liver	1.92		.990		67.0	.560	.560	10.1	334			215	1.27		3570			.439	.677	37.8	
Duwamish River	English Sole liver	4.02				73.1	.895	.895	.459	3.51	661		219	1.15		3603			.560	3.44	29.4	
Downtown	English Sole liver	2.82		.923		173	.907	.907	1.09	5.45	328		219	1.16	1.21	3535			1.02	.728	30.7	
Downwash River	Rock Sole liver	1.40		.431		86.8	.658	.658	6.63	204			248	1.08		3933			.427	.497	31.1	
Commencement Bay																						
Hylebos Waterway	English Sole liver	3.00		1.37	.149	96.0	.685	.685	4.49	545			248	1.26		3856			.697	1.16	36.5	
Hylebos Waterway	English Sole liver	2.95		.623	.143	73.5	1.43	1.43	11.8	473			217	1.29		3629			.568	1.56	38.9	
Sicum Waterway	English Sole liver	2.87		.658		80.2	1.15	1.15	5.59	440			240	1.18	.637	3662			.685	1.72	35.9	
Elliott Bay																						
Duwamish River	Crab hepatopancreas	1.20		.839	.217	2950	.382	.382	1.55	34.9	41.4		542	2.17		4167			43.0	.453	27.6	
Commencement Bay																						
Hylebos Waterway	Crab hepatopancreas	.996	1.62	2.76	.276	> 4873	.631	.631	1.22	53.4	77.4	.171	745	3.84	1.26	>7310			84.9	.472	48.9	
Sicum Waterway	Crab hepatopancreas	2.18	3.23	.718	.238	2350	1.89	1.89	.722	104	143		547	1.68	1.02	3729	11.4		32.7	.388	43.4	
Sinclair Inlet	Crab hepatopancreas	6.07	1.67	3.28	.281	> 4690	11.4	11.4	3.11	140	208	.225	1271	4.34	.648	>7036			154	.185	69.0	
Case Inlet	Crab hepatopancreas	5.43	1.46	3.35	.290	> 4678	53.4	53.4	.777	223	70.8		1329	12.3		>7317			185	.109	57.7	
Elliott Bay																						
Duwamish River	Worm	>1156	3.42	6.78	6.78	808	.754	.754	1.93	7.73	2071	1.06	899	21.0	1.44	1067	7.93		.676	8.18	3.82	24.4
Commencement Bay																						
Brown's Point (south)	Worm	1125	4.10	2.83	2.83	1058	.781	.781	1.57	6.54	1344	1.46	1353	26.7	1.41	1280			.312	11.6	2.76	29.3
Blair City, Hylebos Waterways	Worm	1106	2.07	.986	3.59	1205	.766	.766	1.83	10.0	1241	1.34	1027	13.3	1.38	1211	4.51		.327	12.5	2.71	21.8
Sinclair Inlet	Worm	237	1.81	1.81	.690	866	.286	.286	.844	7.10	434	.499	806	7.25	.933	1584			7.86	.968	34.7	
Port Madison	Worm	824	2.10	3.15	> 3731		.737	.737	2.97	4.38	1247	.770	1223	40.7	2.91	3542			.292	16.2	2.52	35.0
Elliott Bay																						
---	Shrimp	.423	13.4	1.63	.827	> 8927	.286	.286	5.58	14.7	43.3	.095	991	2.53	3.22	2636			169	.091	10.3	
---	Shrimp	44.6	6.42	6.42	1.86	>16732	.127	.127	.903	15.9	77.1	.165	2138	2.78	.577	4713	1.51		404	.434	22.4	
Commencement Bay																						
Hylebos Waterway	Shrimp	61.2	3.55	1.24	1.24	>14613	.117	.117	2.73	18.6	114	.165	1465	3.26	1.53	3307			267	.378	17.7	
Brown's Point	Shrimp	25.6	1.73	.787	1.408	11408	.112	.112	6.33	24.6	46.8	.147	920	2.41	2.28	2772			170	.180	12.9	
Port Madison	Shrimp	634	31.5	2.23	1.24	12366	.355	.355	1.53	19.4	46.4	.144	888	2.47	.918	2990			100	.107	13.1	
Case Inlet	Shrimp	.310	27.1	2.58	1.07	14209	.444	.444	2.03	16.3	44.3	.153	843	6.87	1.10	3684			217	.120	18.9	
Budd Inlet	Shrimp	.229	26.9	2.59	.877	>10906	.117	.117	3.32	12.2	68.3	.136	1228	2.88	1.61	2925			215	.116	15.9	
Sinclair Inlet	Shrimp	.445	71.0	2.22	1.13	>12117	.324	.324	1.85	15.7	103	.173	786	2.98	1.06	3439			247	.269	17.2	
Commencement Bay																						
City Waterway	Clam	.318	364	.923	2.53	>13903	.319	.319	1.29	48.7	523	.371	623	5.77	1.03	1023	22.9		.092	56.2	1.03	27.4
Port Madison	Clam	1.59	529	1.61	2.16	> 9382	.301	.301	8.14	41.9	845	.441	408	22.2	4.81	578	.599		.139	181	1.56	10.2
Sinclair Inlet	Clam	.645	468	1.23	1.62	5901	.180	.180	3.45	79.7	763	.466	950	8.60	2.77	999	5.08		.139	27.2	1.32	19.0
Budd Inlet	Clam			.795	1.06	> 9470	.247	.247	1.94	4.10	525	.462	509	9.21	1.33	1162			.120	50.2	.858	13.6
Case Inlet	Clam	.470	29.4	1.97	.195	> 1021	.119	.119	.310	2.58	57.9	.562	769	6.13	.528	875			11.4	.133	18.5	

1/ Bismuth, potassium, molybdenum, sodium and yttrium were dropped from the table since their results were either below detection limits (bismuth, molybdenum, and yttrium), or else their presence was ubiquitous at high levels, which precluded finding significant differences (potassium and sodium).

Table D-9. Concentrations of target organic compounds in individual fish livers from Elliott Bay, in ng/g dry weight (ppb).

SAMPLE NUMBER STATION NUMBER	ENGLISH SOLE				R SOLE			PAC. STAG. SCULP.			QUILLBACK ROCKFISH					
	120	121	176	181	10045	10031	10038	10023	10044	10015	10038	10014	175	187	188	189
1-PROPYLBENZENE	< 40	< 30	N	N	160	10	< 30	< 30	40	10	< 20					
N-PROPLYLBENZENE	< 50	< 40	N	N	N	< 30	< 110	< 40	< 70	< 40	< 70					
INDAN	< 40	< 30	N	N	< 100	< 10	< 30	< 110	< 10	< 10	< 20					
NAPHTHALENE	< 50	< 60	N	N	< 410	50	< 90	< 120	< 70	< 50	< 90					
BENZOTIOPHENE	< 50	< 40	180	< 7.0	< 120	< 10	< 40	60	< 20	< 10	< 50					
2-METHYLNAPHTHALENE	< 40	< 30	< 140	< 60	< 230	10	< 60	< 70	< 50	< 40	< 80					
1-METHYLNAPHTHALENE	< 30	< 30	10	< 130	< 80	30	< 20	< 30	< 10	< 10	< 20					
BIPHENYL	< 40	< 30	50	< 190	< 90	40	< 30	< 40	30	20	50					
2,6-DIMETHYLNAPHTHALENE	< 40	< 30	< 80	< 180	< 90	10	< 30	10	< 10	80	< 20					
ACENAPHTHALENE	< 40	< 30	N	N	< 90	< 10	< 30	N	< 10	< 10	< 20					
ACENAPHTHENE	< 40	< 30	< 1.0	< 5.0	90	50	< 30	< 1.0	< 10	< 10	< 20					
FLUORENE	< 40	< 30	< 5.0	10	< 90	30	< 30	5.0	< 10	< 10	< 20					
DIBENZOTHIOPHENE	< 70	< 60	2.0	< 9.0	< 170	< 10	< 50	< 1.0	< 20	< 20	< 40					
PHENANTHRENE	N	N	N	N	N	N	N	N	N	N	N					
ANTHRACENE	< 40	< 30	10	< 40	< 90	< 10	70	10	< 10	< 10	< 20					
FLUORANTHENE	< 40	< 30	50	< 230	< 100	70	100	< 40	< 10	30	< 20					
PYRENE	< 40	< 30	20	N	< 100	240	570	230	100	250	< 20					
BENZ(A)ANTHRACENE	< 90	< 70	50	< 10	< 220	< 10	< 70	30	< 30	< 20	< 50					
CHRYSENE	< 50	< 40	60	< 10	< 110	< 10	< 40	80	< 20	< 10	< 30					
BENZOFUORANTHENES	< 50	< 40	< 1.0	< 10	< 120	< 10	< 40	< 1.0	< 20	< 10	< 30					
BENZO(E)PYRENE	< 50	< 40	< 1.0	N	< 130	< 10	< 40	< 40	< 20	< 10	< 30					
BENZO(A)PYRENE	< 40	< 30	< 90	N	< 120	< 10	< 40	< 60	< 20	< 10	< 30					
PERYLENE	< 60	< 40	< 1.0	< 150	< 150	< 10	< 50	< 1.0	< 20	< 20	< 40					
INDENO(1,2,3-CD)PYRENE	< 60	< 40	< 1.0	< 10	< 150	< 10	< 50	< 1.0	< 20	< 20	< 40					
2,3,5 TRIMETHYLNAPHTHALENE	< 40	< 30	9.0	< 5.0	< 90	< 10	< 30	< 1.0	< 10	< 10	< 20					
HEXACHLOROBENZENE	10	10	10	50	10	60	20	10	10	30	10					
LINDANE	< 2.0	< 1.0	< 10	< 20	< 10	< 4.0	< 3.0	< 3.0	< 1.0	< 10	< 2.0					
HEPTACHLOR	< 1.0	< 1.0	< 10	< 20	< 10	< 3.0	< 3.0	< 3.0	< 1.0	< 10	< 2.0					
ALDRIN	< 1.0	< 1.0	< 4.0	< 10	< 10	< 3.0	< 2.0	< 2.0	< 1.0	< 10	< 2.0					
D,P' - DDE	5700	150	< 10	< 20	20	20	10	30	10	30	3.0					
A-CHLORDANE	4.0	30	10	20	30	180	100	60	20	70	10					
TRANS-NONACHLOR	50	50	30	40	20	130	30	110	10	60	10					
P,P' - DDE	60	230	70	130	290	870	630	280	220	1000	150					
D,P' - DDD	10	10	< 10	< 30	20	20	10	3.0	4.0	30	< 4.0					
M,P' - DDD	10	90	< 10	< 50	< 20	140	140	40	40	240	20					
P,P' - DDD/D,P' - DDT	80	280	30	< 10	90	150	110	50	130	310	40					
P,P' - DDT	90	30	90	< 40	20	40	30	290	20	60	10					
DICHLOROBIPHENYLS	< 10	20	< 20	< 50	< 40	310	< 10	10	10	50	30					
TRICHLOROBIPHENYLS	70	60	< 10	< 50	< 20	310	130	40	20	170	20					
TETRACHLOROBIPHENYLS	1300	760	450	220	2000	1700	1500	550	380	2200	230					
PENTACHLOROBIPHENYLS	3400	3400	1100	580	3700	4900	3300	1700	2000	8500	900					
HEXACHLOROBIPHENYLS	4400	5800	1300	980	4200	7300	4700	4700	4100	15000	1500					
HEPTACHLOROBIPHENYLS	2600	3000	950	390	1600	3300	2400	3600	3500	8900	950					
OCTACHLOROBIPHENYLS	470	50	210	80	350	560	310	940	790	1200	170					
NONACHLOROBIPHENYLS	30	20	20	< 20	< 10	40	20	75	420	60	10					
DICHLOROBENZENE	< 10	< 5.0	< 20	< 50	< 35	< 20	< 4.0	< 10	< 5.0	< 30	< 5.0					
TRICHLOROBUTADIENE	< 3.0	< 2.0	< 10	< 20	< 20	< 10	< 4.0	< 3.0	< 2.0	< 10	4.0					
TETRACHLOROBUTADIENE	< 3.0	< 2.0	< 10	< 20	< 10	< 10	< 4.0	< 3.0	< 2.0	< 10	4.0					
PENTACHLOROBUTADIENE	< 3.0	< 2.0	< 10	< 20	< 10	< 10	< 4.0	< 3.0	< 2.0	< 10	3.0					
HEXACHLOROBUTADIENE	< 3.0	3.0	< 10	< 20	< 10	20	< 4.0	< 3.0	< 2.0	< 10	3.0					
% DRY WT	24	24	24	24	23	23	23	24	23	23	23					
% LIPID																
SAMPLE WT., GRAMS	2.0	3.0	1.0	3.0	.50	7.0	1.0	3.0	3.0	4.0	2.0					

Table D-10. Concentrations of target organic compounds in composited fish livers from Elliott Bay, in ng/g dry weight (ppb).

SAMPLE NUMBER STATION	ENGLISH SOLE							ROCK SOLE				E-1 = DUWAMISH WATERWAY E-2 = SEATTLE WATERFRONT E-3 = OUTER ELLIOTT E-4 = WEST POINT
	164 E-3	105 E-4	104 E-3	102 E-1	103 E-2	101 E-1	110 E-4	109 E-3	106 E-1	107 E-2		
I-PROPYLBENZENE	< 20	< 10	< 8.0	70	330	20	420	20	< 7.0	10		
N-PROPYLBENZENE	< 60	< 10	10	< 4.0	< 9.0	250	70	50	< 8.0	20		
INDAN	< 20	< 10	< 9.0	50	170	< 20	70	< 20	< 7.0	< 10		
NAPHTHALENE	< 100	< 10	40	160	80	30	< 40	< 20	50	30		
BENZOTHIOPHENE	< 20	< 20	< 10	< 5.0	< 10	< 20	< 50	< 20	< 5.0	< 20		
2-METHYLNAPHTHALENE	70	< 10	< 8.0	240	< 8.0	< 10	< 40	< 20	< 7.0	< 10		
1-METHYLNAPHTHALENE	30	< 10	20	80	< 7.0	< 10	< 30	< 10	< 6.0	< 10		
BIPHENYL	< 20	< 10	< 8.0	130	< 8.0	< 10	< 30	< 20	< 7.0	< 10		
2,6-DIMETHYLNAPHTHALENE	< 20	< 10	< 8.0	6.0	< 7.0	< 10	< 30	< 20	< 6.0	< 10		
ACENAPHTHALENE	< 20	< 10	< 8.0	< 4.0	< 7.0	< 10	< 30	< 20	< 6.0	< 10		
ACENAPHTHENE	< 20	< 10	< 9.0	270	20	< 10	< 40	< 20	< 7.0	< 10		
FLUORENE	< 20	< 10	< 8.0	40	< 8.0	< 10	< 40	< 20	< 7.0	< 10		
DIBENZOTHIOPHENE	< 30	< 30	< 20	< 7.0	< 10	< 30	< 70	< 30	< 10	< 30		
PHENANTHRENE	N	< 10	< 9.0	80	< 8.0	< 20	< 40	< 20	< 7.0	< 20		
ANTHRACENE	< 20	< 10	< 9.0	30	< 9.0	< 20	< 40	< 20	< 7.0	< 20		
FLUORANTHENE	< 20	< 20	< 10	< 4.0	< 9.0	< 20	< 40	< 20	< 8.0	< 20		
PYRENE	< 20	< 20	< 10	< 5.0	< 9.0	< 20	< 40	< 20	< 8.0	< 20		
BENZ(A)ANTHRACENE	< 40	< 40	< 30	< 10	< 20	< 40	< 110	< 50	< 20	< 40		
CHRYSENE	< 20	< 20	< 10	< 6.0	< 10	< 20	< 60	< 20	< 10	< 20		
BENZOFLUORANTHENE	< 20	< 30	< 20	< 8.0	< 20	< 30	< 70	< 30	< 10	< 30		
BENZO(E)PYRENE	< 30	< 30	< 20	< 8.0	< 20	< 30	< 70	< 30	< 10	< 30		
BENZO(A)PYRENE	< 20	< 30	< 20	< 8.0	< 20	< 30	< 70	< 30	< 20	< 30		
PERYLENE	< 30	< 30	< 20	< 9.0	< 20	< 30	< 80	< 30	< 10	< 30		
INDENO(1,2,3-CD)PYRENE	< 30	< 30	< 20	< 9.0	< 20	< 30	< 80	< 30	< 10	< 30		
2,3,5 TRIMETHYLNAPHTHALENE	< 20	< 10	< 9.0	< 10	< 8.0	< 10	< 40	< 20	< 7.0	< 10		
HEXACHLOROENZENE	10	4.0	10	20	20	50	8.0	9.0	10	8.0		
LINDANE	< 2.0	< 1.0	< 2.0	< 2.0	< 2.0	< 5.0	< 3.0	< 2.0	< 2.0	< 2.0		
HEPTACHLOR	< 2.0	< 1.0	< 1.0	< 3.0	< 3.0	< 1.0	< 1.0	< 1.0	< 2.0	< 1.0		
ALDRIN	< 2.0	< 2.0	< 1.0	< 2.0	< 2.0	< 5.0	< 4.0	< 2.0	< 2.0	< 2.0		
O, P' - DDE	10	2.0	1.0	30	7.0	30	3.0	< 1.0	3.0	2.0		
A-CHLORDANE	20	20	30	30	50	30	5.0	2.0	6.0	4.0		
TRANS-NONACHLOR	40	40	50	190	120	150	70	30	60	60		
P, P' - DDE	90	80	50	700	370	530	20	30	120	100		
O, P' - DDD	4.0	< 2.0	1.0	40	< 6.0	< 200	< 7.0	< 5.0	4.0	3.0		
M, P' - DDD	10	20	20	290	70	260	30	9.0	40	20		
P, P' - DDD/O, P' - DDT	30	120	40	630	200	650	90	20	90	40		
P, P' - DDT	60	60	40	630	180	560	130	30	130	90		
DICHLOROBIPHENYLS	10	2.0	30	70	30	30	< 10	< 3.0	30	4.0		
TRICHLOROBIPHENYLS	40	50	30	1200	120	910	40	20	270	20		
TETRACHLOROBIPHENYLS	430	370	180	5900	950	5600	410	110	830	230		
PENTACHLOROBIPHENYLS	560	840	480	9800	2200	9700	1400	380	1500	800		
HEXACHLOROBIPHENYLS	1100	950	640	11000	3400	10000	2200	550	2000	1400		
HEPTACHLOROBIPHENYLS	600	570	380	6300	2100	5200	680	270	1500	820		
OCTACHLOROBIPHENYLS	110	70	70	790	380	480	260	40	250	110		
NONACHLOROBIPHENYLS	10	3.0	5.0	30	30	8.0	20	4.0	9.0	4.0		
DICHLOROBENZENE	< 10	< 10	< 1.0	< 10	< 7.0	< 10	< 10	< 5.0	< 3.0	< 4.0		
TRICHLOROBUTADIENE	< 3.0	< 4.0	2.0	< 3.0	10	< 20	< 5.0	< 2.0	5.0	< 2.0		
TETRACHLOROBUTADIENE	< 3.0	< 7.0	< 2.0	< 6.0	< 10	< 20	< 8.0	< 4.0	< 4.0	< 3.0		
PENTACHLOROBUTADIENE	< 2.0	< 3.0	1.0	< 2.0	< 10	< 9.0	< 4.0	< 2.0	< 2.0	< 1.0		
HEXACHLOROBUTADIENE	< 3.0	< 2.0	2.0	3.0	2.0	10	< 2.0	< 1.0	2.0	1.0		
% DRY WT	21	23	24	22	23	25	23	23	23	21		
% LIPID				31					23			
SAMPLE WT	3.0	4.0	5.0	11	6.1	3.0	2.0	3.0	6.0	4.0		

Table D-11. Concentrations of target organic compounds in various biota from Elliott Bay, in ng/g dry weight (ppb).

SAMPLE NUMBER STATION	CRAB		WORMS			SHRIMP		CLAMS		E-1 = DUWAMISH WATERWAY E-2 = SEATTLE WATERFRONT E-3 = OUTER ELLIOTT E-4 = WEST POINT
	12B E-1	136 E-3	135 E-3	134 E-1	144 E-3	145 E-1	153 E-1	154 E-2		
1-PROPYLBENZENE	5.0	< 50	< 50	< 60	< 10	< 20	< 50	< 40		
N-PROPYLBENZENE	< 20	< 90	< 50	N	< 20	< 10	< 80	< 70		
INDAN	30	< 20	< 10	< 20	< 10	20	80	40		
NAPHTHALENE	110	N	< 80	30	10	120	N	< 80		
BENZOTIOPHENE	60	< 40	< 20	< 30	< 10	< 10	< 30	< 30		
2-METHYLNAPHTHALENE	130	< 70	< 50	< 90	< 20	10	< 80	< 50		
1-METHYLNAPHTHALENE	110	< 20	20	30	10	20	30	< 20		
BIPHENYL	90	< 30	< 20	10	10	10	30	< 20		
2,6-DIMETHYLNAPHTHALENE	50	< 40	< 20	< 10	10	10	60	< 20		
ACENAPHTHALENE	< 5.0	< 20	< 10	< 10	< 5.0	< 10	< 20	< 20		
ACENAPHTHENE	530	< 20	< 10	60	< 90	30	170	< 330		
FLUORENE	220	< 20	< 10	80	10	30	70	< 20		
DIBENZOTHIOPHENE	100	< 40	< 20	160	< 10	< 10	< 40	< 40		
PHENANTHRENE	210	< 20	400	510	< 50	N	N	N		
ANTHRACENE	60	< 20	30	210	< 10	40	130	40		
FLUORANTHENE	30	50	80	1500	40	140	1300	100		
PYRENE	20	40	60	1600	60	150	980	510		
BENZ(A)ANTHRACENE	60	250	190	1300	20	80	1000	280		
CHRYSENE	< 30	< 150	60	780	20	70	640	80		
BENZOFLUORANTHENE	< 5.0	< 30	< 20	< 10	< 10	< 10	230	240		
BENZO(E)PYRENE	30	< 30	120	510	< 20	< 10	370	250		
BENZO(A)PYRENE	20	< 30	< 20	350	< 10	< 10	230	100		
PERYLENE	30	< 40	< 20	230	< 10	< 10	< 30	< 40		
INDENO(1,2,3-CD)PYRENE	< 5.0	< 40	< 20	< 20	< 10	< 10	< 30	< 40		
2,3,5 TRIMETHYLNAPHTHALENE	90	< 20	< 10	20	< 10	< 10	< 20	< 20		
HEXACHLOROBENZENE	30	1.0	1.0	2.0	1.0	2.0	.40	< 2.0		
LINDANE	2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 3.0		
HEPTACHLOR	N	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 3.0		
ALDRIN	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 3.0		
O, P' - DDE	40	< 2.0	< 2.0	2.0	< 1.0	< 1.0	< 2.0	< 10		
A-CHLORDANE	50	1.0	1.0	1.0	1.0	< 1.0	1.0	3.0		
TRANS-NONACHLOR	60	2.0	1.0	2.0	1.0	< 1.0	.20	< 3.0		
P, P' - DDE	1900	10	10	15	10	N	10	10		
O, P' - DDD	50	< 2.0	< 2.0	2.0	< 1.0	< 1.0	< 1.0	< 10		
M, P' - DDD	460	5.0	4.0	10	4.0	< 2.0	5.0	10		
P, P' - DDD/D, P' - DDT	510	10	10	20	2.0	10	1.0	4.0		
P, P' - DDT	120	< 2.0	< 3.0	3.0	< 2.0	< 2.0	< 1.0	< 10		
DICHLOROBIPHENYLS	70	< 4.0	4.0	10	< 3.0	10	< 5.0	< 10		
TRICHLOROBIPHENYLS	560	20	10	60	10	40	< 2.0			
TETRACHLOROBIPHENYLS	3800	150	110	350	80	210	70	200		
PENTACHLOROBIPHENYLS	7300	240	190	500	160	870	90	500		
HEXACHLOROBIPHENYLS	11000	280	310	550	300	680	100	410		
HEPTACHLOROBIPHENYLS	7800	130	170	250	130	220	40	180		
OCTACHLOROBIPHENYLS	1100	30	40	60	20	20	10	20		
NONACHLOROBIPHENYLS	< 3.0	< 3.0	< 2.0	< 2.0	< 1.0	< 1.0	2.0	< 5.0		
DICHLOROBENZENE	< 10	< 10	< 5.0	< 4.0	< 3.0	< 3.0	< 5.0	< 10		
TRICHLOROBUTADIENE	< 3.0	< 4.0	< 2.0	< 2.0	< 1.0	< 2.0	< 2.0	< 2.0		
TETRACHLOROBUTADIENE	< 3.0	< 3.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 5.0		
PENTACHLOROBUTADIENE	< 3.0	< 3.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 5.0		
HEXACHLOROBUTADIENE	< 3.0	< 3.0	< 2.0	< 2.0	< 1.0	< 1.0	< 2.0	< 10		
% DRY WT	30	21	15	14	16	23	16	14		
% LIPID	65				5.8					
SAMPLE WT., GRAMS	10	2.0	4.0	5.0	10	4.0	6.0	3.0		

Table D-12. Concentrations of target organic compounds in individual fish livers from Commencement Bay, in ng/g dry weight (ppb).

SAMPLE NUMBER STATION NUMBER	ENGLISH SOLE					ROCK SOLE			P.	ST.	SCUL.	GRF*
	174 9027	178 9027	180 9028	206 9028	177 9034	205 9033	204 9036	182 9037	193 9027	194 9035	195 9037	
I-PROPYLBENZENE	< 50	< 60	< 130	< 80	< 140	< 50	< 40	< 330	< 20	< 140	40	
N-PROPYLBENZENE	< 120	< 100	< 1.0	< 160	< 50	< 90	< 100	< 360	< 60	< 400	< 90	
INDAN	< 110	< 90	< 40	< 30	< 330	< 20	< 30	< 460	< 20	< 150	< 30	
NAPHTHALENE	< 340	< 110	< 240	< 20	< 250	50	180	< 380	< 70	< 440	< 90	
BENZOTHIOPHENE	210	80	180	< 30	240	< 20	< 40	80	< 30	< 170	< 30	
2-METHYLNAPHTHALENE	< 220	< 90	50	< 30	< 80	< 20	< 30	< 220	< 40	< 140	< 50	
1-METHYLNAPHTHALENE	< 80	< 30	80	< 20	< 180	< 20	< 20	10	< 20	< 120	< 20	
BIPHENYL	< 70	< 40	< 20	< 20	< 180	< 20	< 30	30	< 20	< 130	80	
2,6-DIMETHYLNAPHTHALENE	< 120	70	5.0	220	< 50	140	< 30	< 130	< 20	< 130	< 20	
ACENAPHTHALENE	N	N	N	N	N	N	N	N	< 20	< 130	< 20	
ACENAPHTHENE	< 2.0	< 1.0	< 1.0	< 30	< 3.0	< 20	< 30	< 1.0	< 20	< 140	< 20	
FLUORENE	20	20	60	< 20	9.0	< 20	< 30	10	< 20	< 130	< 20	
DIBENZOTHIOPHENE	10	40	20	< 50	< 6.0	< 30	< 50	< 2.0	< 40	< 250	< 40	
PHENANTHRENE	N	N	< 60	N	N	N	N	N	N	N	N	
ANTHRACENE	30	60	< 1.0	< 30	60	20	180	< 20	< 20	< 140	< 20	
FLUORANTHENE	40	120	10	< 30	< 190	< 20	< 30	< 110	< 20	< 150	< 30	
PYRENE	370	610	10	< 30	1100	< 20	350	300	80	< 150	< 30	
BENZ(A)ANTHRACENE	60	220	< 2.0	< 70	50	< 50	< 70	3.0	< 50	< 340	< 60	
CHRYSENE	70	110	< 1.0	< 40	150	< 30	< 40	30	< 30	< 170	< 30	
BENZOFLUORANTHENE	< 3.0	< 1.0	< 1.0	< 40	< 5.0	< 30	< 40	< 2.0	< 30	< 170	< 30	
BENZO(E)PYRENE	< 90	< 2.0	< 1.0	< 40	< 380	< 30	< 40	580	< 30	< 190	< 30	
BENZO(A)PYRENE	< 60	< 110	< 1.0	370	< 710	< 30	< 40	210	< 30	< 170	< 30	
PERYLENE	< 3.0	70	< 1.0	< 50	1300	< 30	< 50	10	< 30	< 220	< 40	
INDENO(1,2,3-CD)PYRENE	< 3.0	< 2.0	< 1.0	< 5.0	< 6.0	< 30	< 50	< 2.0	< 30	< 220	< 40	
2,3,5 TRIMETHYLNAPHTHALENE	10	20	< 1.0	< 30	4.0	< 20	< 30	20	< 20	< 140	< 20	
HEXACHLORO BENZENE	1100	1300	3700	840	60	80	10	50	290	20	40	
LINDANE	< 20	N	100	< 3.0	< 10	< 2.0	< 3.0	< 10	< 2.0	< 20	< 3.0	
HEPTACHLOR	< 10	N	50	< 3.0	< 10	< 3.0	< 2.0	< 10	< 2.0	< 10	< 2.0	
ALDRIN	< 10	N	290	< 5.0	< 10	< 1.0	< 2.0	< 5.0	< 2.0	< 10	< 2.0	
O, P' - DDE	60	90	20	20	< 10	10	4.0	< 10	20	50	< 4.0	
A-CHLORDANE	60	20	30	50	60	10	5.0	30	N	N	N	
TRANS-NONACHLOR	110	40	60	20	130	20	4.0	60	70	360	40	
P, P' - DDE	710	310	240	370	210	390	100	120	310	780	80	
O, P' - DDD	< 10	< 4.0	< 5.0	10	< 10	10	< 4.0	< 10	10	< 20	< 4.0	
M, P' - DDD	90	80	30	80	< 30	60	20	< 20	100	< 40	< 10	
P, P' - DDD/O, P' - DDT	270	160	50	170	60	140	20	20	70	300	20	
P, P' - DDT	340	290	210	20	150	20	< 5.0	50	30	60	< 6.0	
DICHLOROBIPHENYLS	< 20	< 10	80	< 20	70	10	40	20	< 10	< 60	20	
TRICHLOROBIPHENYLS	< 10	80	60	200	70	70	50	30	10	< 30	10	
TETRACHLOROBIPHENYLS	1700	1800	1100	1600	1300	390	210	270	500	910	120	
PENTACHLOROBIPHENYLS	3500	3400	1600	2900	1400	2200	570	530	2400	5900	640	
HEXACHLOROBIPHENYLS	6700	5900	3500	5400	2900	5600	1300	11000	3700	15000	980	
HEPTACHLOROBIPHENYLS	3100	3400	2200	2700	1100	5500	880	450	1300	8500	370	
OCTACHLOROBIPHENYLS	1000	1200	970	850	200	2100	280	80	260	1200	80	
NONACHLOROBIPHENYLS	190	160	150	150	10	410	50	< 10	30	30	10	
DICHLOROBENZENE	< 20	< 10	< 10	< 10	< 30	< 10	< 10	< 20	< 10	< 60	< 10	
TRICHLOROBUTADIENE	< 10	< 4.0	10	10	< 10	< 3.0	< 5.0	< 10	< 4.0	< 30	< 10	
TETRACHLOROBUTADIENE	< 10	30	110	220	< 10	10	< 4.0	< 10	20	< 20	< 4.0	
PENTACHLOROBUTADIENE	30	40	410	70	< 10	10	< 3.0	< 10	30	< 20	< 4.0	
HEXACHLOROBUTADIENE	790	1500	8600	1600	< 10	60	< 4.0	< 30	600	< 20	< 4.0	
% DRY WT	24	24	24	24	24	24	24	24	23	20	23	
% LIPID												
SAMPLE Wt., GRAMS	1.0	2.0	2.0	2.0	1.0	2.0	2.0	1.0	2.0	.30	2.0	

Table D-13. Concentrations of target organic compounds in composited fish livers from Commencement Bay, in ng/g dry weight (ppb).

SAMPLE NUMBER STATION	ENGLISH SOLE				ROCK SOLE				PAC. STAGHORN		SCULPIN		GRF*	PTC*	
	113 C-2	114 C-2	115 C-4	114 C-1	117 C-2	165 C-2	166 C-2	171 C-2	118 C-4	169 C-2	168 C-2	167 C-2	186 C-1	170 C-2	179 C-2
I-PROPYLBENZENE	< 10	< 10	30	40	< 50	< 110	< 10	< 160	< 70	< 20	< 30	20	120	< 30	< 90
N-PROPYLBENZENE	< 10	< 30	< 60	< 70	< 50	< 190	< 10	N	< 180	< 30	< 50	20	N	< 60	< 120
INDAN	< 10	< 10	< 20	< 30	< 50	< 50	< 10	< 60	< 80	< 10	20	60	< 40	< 10	< 150
NAPHTHALENE	< 40	< 50	< 50	< 70	< 40	N	< 10	N	< 130	< 40	< 70	10	N	< 60	< 130
BENZOTHIOPHENE	< 10	< 20	< 30	< 30	< 60	< 60	< 10	< 40	< 90	< 10	< 20	< 20	< 50	< 10	50
2-METHYLNAPHTHALENE	< 10	50	< 20	60	< 40	110	< 10	150	< 70	30	40	80	< 170	50	< 90
1-METHYLNAPHTHALENE	< 9.0	20	20	60	< 40	< 40	< 5.0	< 50	< 60	< 5.0	30	50	< 30	< 10	2.0
BIPHENYL	< 10	< 10	< 20	< 20	< 40	< 50	< 10	< 50	< 70	40	< 10	30	< 40	60	< 40
2,6-DIMETHYLNAPHTHALENE	< 10	< 10	< 20	< 20	< 40	< 50	< 10	< 50	< 70	< 5.0	< 10	< 10	< 40	< 10	< 50
ACENAPHTHALENE	< 10	< 10	< 20	< 20	< 40	< 50	< 10	< 50	< 70	< 5.0	< 10	< 10	< 40	< 10	N
ACENAPHTHENE	< 10	< 10	< 20	< 20	< 40	< 50	< 10	< 50	< 70	30	< 10	< 10	< 40	< 10	< 1.0
FLUORENE	< 10	< 10	< 20	< 20	< 40	< 50	< 10	< 50	< 70	< 5.0	< 10	< 10	< 40	< 10	10
DIBENZOTHIOPHENE	< 20	< 20	< 40	< 50	< 80	< 90	20	< 100	< 120	< 10	< 20	< 20	< 70	< 20	20
PHENANTHRENE	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
ANTHRACENE	< 10	< 10	< 20	< 30	< 40	< 50	20	< 60	< 70	< 10	< 10	< 10	< 40	< 10	50
FLUORANTHENE	< 50	< 30	< 90	< 140	< 40	< 50	< 10	< 60	< 70	160	< 10	< 10	< 40	< 10	< 50
PYRENE	< 10	< 10	< 20	< 30	< 50	< 50	< 10	< 60	< 70	< 10	< 10	< 10	< 40	< 10	< 1.0
BENZ(A)ANTHRACENE	< 20	< 30	< 40	< 60	< 100	< 120	< 10	< 140	< 160	< 10	< 30	< 30	< 90	< 30	70
CHRYSENE	< 10	< 10	< 20	< 30	< 50	< 60	< 20	< 70	< 80	< 10	< 20	< 20	< 50	< 20	120
BENZOFLUORANTHENE	< 10	< 10	< 20	< 30	< 50	< 60	< 20	< 70	< 80	< 10	< 20	< 20	< 50	< 20	< 1.0
BENZO(E)PYRENE	< 10	< 20	< 30	< 30	< 50	< 70	< 10	< 80	< 90	< 10	< 20	270	< 50	< 20	< 1.0
BENZO(A)PYRENE	< 10	< 10	< 20	< 30	< 50	< 70	< 10	< 70	< 80	< 10	< 20	< 20	< 50	< 10	< 40
PERYLENE	< 20	< 20	< 30	< 40	< 60	< 80	< 10	< 90	< 100	< 10	< 20	< 20	< 60	< 20	< 20
INDENO(1,2,3-CD)PYRENE	< 20	< 20	< 30	< 40	< 20	< 80	< 10	< 90	< 100	< 10	< 20	< 20	< 60	< 20	< 20
2,3,5 TRIMETHYLNAPHTHALENE	< 10	< 10	< 20	< 30	< 40	< 50	< 10	< 60	< 70	< 10	< 10	< 10	< 40	< 10	10
HEXACHLOROBENZENE	2300	270	60	120	1000	150	10	160	30	810	2500	130	230	70	600
LINDANE	< 4.0	N	< 2.0	< 2.0	N	< 10	< 1.0	< 10	< 4.0	N	N	< 10	< 4.0	< 2.0	N
HEPTACHLOR	< 3.0	N	< 1.0	< 2.0	N	< 10	< 1.0	< 10	< 3.0	N	N	< 10	< 3.0	< 2.0	N
ALDRIN	< 10	N	< 1.0	< 1.0	N	< 5.0	< 1.0	< 10	< 3.0	N	N	< 10	N	< 1.0	< 2.0
O,P' - DDE	620	170	120	130	340	< 10	< 50	< 10	< 110	1000	1400	70	10	30	30
A-CHLORDANE	90	40	50	1.0	60	10	< 1.0	10	< 3.0	60	140	150	140	90	20
TRANS-NDACHLOR	170	80	120	2.0	90	20	4.0	30	50	110	280	300	40	190	40
P,P' - DDE	460	160	270	200	180	130	10	90	130	490	50	800	630	710	490
O,P' - DDD	< 10	< 4.0	10	10	10	< 10	< 2.0	< 10	< 10	< 5.0	< 10	< 20	10	10	< 4.0
M,P' - DDD	140	< 40	70	70	30	< 20	< 4.0	< 20	< 10	80	120	30	90	70	110
P,P' - DDD/O,P' - DDT	110	50	60	60	340	< 10	< 1.0	< 10	20	140	170	160	70	60	160
P,P' - DDT	190	70	10	10	40	40	4.0	50	50	230	190	410	700	360	310
DICHLOROBIPHENYLS	< 10	30	10	10	30	< 20	< 10	< 20	< 10	< 10	< 30	< 40	40	20	< 10
TRICHLOROBIPHENYLS	740	30	80	100	2100	< 20	< 3.0	< 20	30	250	770	< 20	110	10	170
TETRACHLOROBIPHENYLS	330	860	230	270	2100	250	20	230	190	1200	3700	2500	480	1200	1500
PENTACHLOROBIPHENYLS	6700	1500	1600	1900	5700	540	50	450	770	6000	7000	4400	3000	2600	3900
HEXACHLOROBIPHENYLS	7000	2000	1900	2300	5000	650	90	1000	1600	6800	8600	12000	4800	7400	7400
HEPTACHLOROBIPHENYLS	3700	1400	860	1300	2900	310	40	430	610	2100	5000	5700	2200	3400	2800
OCTACHLOROBIPHENYLS	1400	290	260	430	930	80	10	120	140	420	1400	1200	460	1000	690
NDACHLOROBIPHENYLS	330	30	20	40	260	< 10	< 2.0	20	10	60	230	110	10	220	90
DICHLOROBENZENE	< 10	< 3.0	< 4.0	< 10	< 9.0	< 20	< 10	< 20	< 10	< 10	< 30	< 5.0	10	N	< 10
TRICHLOROBUTADIENE	2.0	< 1.0	< 2.0	< 3.0	2.0	< 10	< 3.0	< 10	< 10	< 10	< 10	< 2.0	10	10	< 5.0
TETRACHLOROBUTADIENE	50	40	< 2.0	< 3.0	60	< 10	< 2.0	< 10	< 10	< 4.0	< 10	10	5.0	10	< 4.0
PENTACHLOROBUTADIENE	80	5.0	< 2.0	< 3.0	40	< 10	< 2.0	20	< 10	30	60	10	4.0	10	10
HEXACHLOROBUTADIENE	2800	220	10	10	1660	80	2.0	40	10	1260	3040	60	20	10	30
% DRY WT	23	25	25	24	24	24	24	24	24	26	24	24	23	24	24
% LIPID															
SAMPLE WT., GRAMS	6.0	5.0	3.0	2.0	3.0	1.0	4.0	1.0	1.0	5.0	3.0	3.0	1.0	3.0	2.0

C-1 = BROWN'S POINT  
 C-2 = HYLEBOS WATERWAY  
 C-3 = COMMENCEMENT BAY  
 WATERWAYS  
 C-4 = SOUTHWEST  
 COMMENCEMENT BAY

Table D-14. Concentrations of target organic compounds in various biota from Commencement Bay, in ng/g dry weight (ppb).

SAMPLE NUMBER STATION	CRAB		WORMS			SHRIMP		CLAMS	
	129 C-2	130 C-3	137 C-2	141 C-3	140 C-2	145 C-2	147 C-1	155 C-3	156 C-2
I-PROPYLBENZENE	< 20	20	< 10	< 40	< 40	10	< 10	< 20	< 50
N-PROPYLBENZENE	< 30	< 30	< 30	< 50	< 50	< 10	< 20	< 40	< 60
INDAN	10	60	< 10	< 10	< 10	10	< 5.0	10	20
NAPHTHALENE	60	190	< 50	70	30	20	< 20	90	< 80
BENZOTHIOPHENE	40	250	< 30	< 10	< 20	< 4.0	< 10	< 10	< 20
2-METHYLNAPHTHALENE	70	200	< 50	50	< 60	10	< 20	40	< 70
1-METHYLNAPHTHALENE	60	150	< 10	40	20	10	10	30	< 10
BIPHENYL	50	180	< 10	40	20	10	10	50	20
2,6-DIMETHYLNAPHTHALENE	70	80	130	80	130	10	5.0	120	200
ACENAPHTHALENE	< 10	< 5.0	< 10	< 10	< 10	< 3.0	< 4.0	< 10	< 20
ACENAPHTHENE	260	230	40	N	N	< 30	< 20	N	N
FLUORENE	< 10	< 5.0	30	70	< 10	20	< 4.0	60	50
DIBENZOTHIOPHENE	330	< 5.0	< 20	40	40	20	< 10	90	< 30
PHENANTHRENE	500	100	150	N	< 10	N	< 70	410	N
ANTHRACENE	270	110	90	140	30	40	< 4.0	130	110
FLUORANTHENE	100	30	2000	380	180	280	80	790	280
PYRENE	70	40	2300	730	270	390	90	1300	280
BENZ(A)ANTHRACENE	< 20	90	3000	530	200	120	50	730	140
CHRYSENE	< 10	40	3500	350	230	150	40	490	160
BENZOFLUORANTHENE	< 10	< 5.0	2910	330	< 20	80	< 10	200	< 90
BENZ(D,E)PYRENE	< 10	< 5.0	1500	340	< 20	70	30	260	80
BENZO(A)PYRENE	< 10	< 5.0	730	250	< 20	50	< 10	250	< 20
PERYLENE	< 10	< 5.0	220	100	< 20	30	< 10	70	< 20
INDENO(1,2,3-CD)PYRENE	< 10	< 5.0	< 10	< 20	< 20	< 10	< 10	< 10	< 20
2,3,5-TRIMETHYLNAPHTHALENE	< 10	< 5.0	< 10	< 10	< 10	< 4.0	< 5.0	< 10	< 20
HEXACHLOROBENZENE	1800	120	140	120	370	80	20	10	130
LINDANE	< 10	< 3.0	< 1.0	N	N	< 1.0	< 1.0	< 2.0	N
HEPTACHLOR	< 10	< 2.0	N	N	N	N	< 1.0	< 1.0	N
ALDRIN	< 4.0	< 1.0	N	N	N	< 4.0	< 1.0	< 1.0	N
O,P' - DDE	80	20	3.0	< 2.0	< 3.0	4.0	< 1.0	< 2.0	< 2.0
A-CHLORDANE	N	N	N	< 1.0	< 1.0	1.0	1.0	20	5.0
TRANS-NONACHLOR	250	230	3.0	< 1.0	< 1.0	2.0	1.0	2.0	1.0
P,P' - DDE	1500	1100	50	10	10	40	10	20	10
O,P' - DDD	20	10	4.0	< 2.0	< 3.0	10	< 1.0	< 3.0	< 2.0
M,P' - DDD	730	240	10	10	5.0	40	< 2.0	10	3.0
P,P' - DDD/O,P' - DDT	320	120	20	10	3.0	5.0	1.0	40	2.0
P,P' - DDT	80	40	4.0	< 4.0	< 5.0	< 5.0	< 2.0	80	< 2.0
DICHLOROBIPHENYLS	50	60	< 3.0	< 10	< 10	10	10	10	10
TRICHLOROBIPHENYLS	640	190	< 1.0	2.0	20	50	5.0	N	< 2.0
TETRACHLOROBIPHENYLS	340	1200	120	70	60	310	30	220	30
PENTACHLOROBIPHENYLS	11000	3600	450	250	130	1400	100	310	100
HEXACHLOROBIPHENYLS	9200	2900	440	180	110	930	110	240	130
HEPTACHLOROBIPHENYLS	4900	1800	160	90	50	290	40	80	50
OCTACHLOROBIPHENYLS	1200	350	40	30	10	40	10	10	20
NONACHLOROBIPHENYLS	230	40	10	5.0	2.0	4.0	< 1.0	4.0	4.0
DICHLOROBENZENE	< 20	< 10	< 3.0	< 10	< 7.0	10	< 2.0	< 7.0	4.0
TRICHLOROBUTADIENE	< 30	< 3.0	< 3.0	< 3.0	< 3.0	10	< 1.0	< 2.0	< 2.0
TETRACHLOROBUTADIENE	30	< 3.0	10	1.0	10	30	< 1.0	4.0	1.0
PENTACHLOROBUTADIENE	30	< 2.0	40	1.0	10	20	< 1.0	< 2.0	1.0
HEXACHLOROBUTADIENE	10	< 2.0	310	110	20	90	2.0	3.0	60
% DRY WT	13	29	21	14	17	21	18	14	16
% LIPID	86	56				6.3	8.5		
SAMPLE WT , GRAMS	9.0	10	5.0	5.0	4.0	10	10	6.0	7.0

C-1 = BROWN'S POINT  
 C-2 = HYLEBOS WATERWAY  
 C-3 = COMMENCEMENT BAY  
 WATERWAYS  
 C-4 = SOUTHWEST  
 COMMENCEMENT BAY

Table D-15. Concentrations of target organic compounds in composited fish livers from all other sites, in ng/g dry weight (ppb).

SAMPLE NUMBER STATION	ENGLISH SOLE				ROCK SOLE			
	89 PM	91 BI	93 CI	95 SI	90 PM	92 BI	94 CI	96 SI
1-PROPYLBENZENE	< 5.0	< 4.0	< 5.0	< 4.0	< 10	< 4.0	< 4.0	< 10
N-PROPYLBENZENE	< 7.0	< 5.0	< 6.0	< 5.0	< 10	< 5.0	< 4.0	< 10
INDAN	< 6.0	< 5.0	< 5.0	< 5.0	< 10	< 4.0	< 4.0	< 10
NAPHTHALENE	< 6.0	20	< 5.0	10	< 10	20	< 4.0	< 10
BENZOTHIOPHENE	< 8.0	< 6.0	< 6.0	< 6.0	< 10	< 5.0	< 5.0	< 20
2-METHYLNAPHTHALENE	< 6.0	< 5.0	< 5.0	< 5.0	< 10	< 4.0	< 4.0	< 10
1-METHYLNAPHTHALENE	< 6.0	< 4.0	< 5.0	< 4.0	< 9.0	10	< 3.0	< 10
BIPHENYL	< 6.0	< 4.0	< 5.0	< 4.0	< 10	< 4.0	< 4.0	< 10
2,6-DIMETHYLNAPHTHALENE	< 6.0	< 4.0	< 5.0	< 4.0	< 10	< 4.0	< 4.0	< 10
ACENAPHTHALENE	< 6.0	< 4.0	< 5.0	< 4.0	< 10	< 4.0	< 4.0	< 10
ACENAPHTHENE	< 6.0	10	< 5.0	20	< 10	< 4.0	< 4.0	< 10
FLUORENE	< 6.0	< 4.0	< 5.0	< 4.0	< 10	< 4.0	< 4.0	< 10
DIBENZOTHIOPHENE	< 10	< 9.0	< 10	< 9.0	< 20	< 8.0	< 8.0	< 20
PHENANTHRENE	< 6.0	< 5.0	< 5.0	< 5.0	< 10	< 5.0	< 4.0	< 10
ANTHRACENE	< 7.0	< 5.0	< 6.0	< 5.0	< 10	< 5.0	< 5.0	< 10
FLUORANTHRENE	< 7.0	< 5.0	< 6.0	< 5.0	< 10	< 5.0	< 5.0	< 10
PYRENE	< 7.0	< 5.0	50	< 3.0	< 10	< 5.0	< 5.0	< 10
BENZ(A)ANTHRACENE	< 20	< 10	< 10	< 10	< 30	< 10	< 10	< 40
CHRYBENE	< 9.0	< 7.0	< 8.0	< 7.0	< 20	< 6.0	< 6.0	< 20
BENZOFUORANTHRENE	< 10	< 8.0	< 9.0	< 8.0	< 20	< 7.0	< 7.0	< 20
BENZO(E)PYRENE	< 10	< 8.0	< 9.0	< 8.0	< 20	< 7.0	< 7.0	< 20
BENZO(A)PYRENE	< 10	< 7.0	< 9.0	< 8.0	< 20	< 7.0	< 7.0	< 20
PERYLENE	< 10	< 9.0	< 10	< 9.0	< 20	< 8.0	< 8.0	< 20
INDENO(1,2,3-CD)PYRENE	< 10	< 9.0	< 10	< 9.0	< 20	< 8.0	< 8.0	< 20
2,3,5 TRIMETHYLNAPHTHALENE	< 6.0	< 5.0	< 5.0	< 5.0	< 10	< 4.0	< 4.0	< 10
HEXACHLOROBENZENE	10	10	10	10	10	10	5.0	10
LINDANE	.40	< .40	< .30	< 1.0	< .50	< .50	< .50	< 1.0
HEPTACHLOR	< .40	< .30	< .30	< .40	< .40	< .30	< .30	< 1.0
ALDRIN	< .40	< .30	< .20	< 1.0	< 2.0	< .40	< .40	< 2.0
O,P' - DDE	< 10	< 10	< 10	< 2.0	< 10	< 10	< 3.0	< 20
A-CHLORDANE	< 10	10	10	< 20	< 10	10	10	30
TRANS-NONACHLOR	40	30	20	60	20	20	10	50
P,P' - DDE	100	80	60	130	70	60	30	90
O,P' - DDD	3.0	2.0	1.0	10	2.0	1.0	.40	3.0
M,P' - DDD	10	10	10	80	10	5.0	2.0	20
P,P' - DDD/O,P' - DDT	40	30	30	170	20	20	10	40
P,P' - DDT	60	30	30	190	30	20	10	60
DICHLOROBIPHENYLS	10	10	20	10	10	30	30	10
TRICHLOROBIPHENYLS	20	20	20	70	20	10	10	30
TETRACHLOROBIPHENYLS	190	120	140	490	140	80	50	230
PENTACHLOROBIPHENYLS	730	430	360	2000	440	290	120	820
HEXACHLOROBIPHENYLS	1100	640	520	3100	700	430	200	1600
HEPTACHLOROBIPHENYLS	730	490	400	2300	400	310	110	1100
OCTACHLOROBIPHENYLS	180	160	120	510	90	70	30	260
NONACHLOROBIPHENYLS	10	30	20	70	10	10	5.0	30
DICHLOROBENZENE	10	20	4.0	< 2.0	< 1.0	< 2.0	< 1.0	3.0
TRICHLOROBUTADIENE	3.0	10	1.0	1.0	< 1.0	< 1.0	2.0	1.0
TETRACHLOROBUTADIENE	< 3.0	< 3.0	< 3.0	< 3.0	< 3.0	< 3.0	3.0	< 8.0
PENTACHLOROBUTADIENE	< 1.0	< 1.0	3.0	< 1.0	< 1.0	< 1.0	1.0	< 3.0
HEXACHLOROBUTADIENE	1.0	2.0	1.0	2.0	1.0	3.0	2.0	1.0
% DRY WT	20	22	21	20	21	25	24	20
% LIPID	24	28	26	25	17	30	34	20
SAMPLE WT. GRAMS	10	10	10	10	5.0	10	10	4.0

PM = PORT MADISON  
 BI = BUDD INLET  
 CI = CASE INLET  
 SI = SINCLAIR INLET

Table D-16. Concentrations of target organic compounds in various biota from all other sites, in ng/g dry weight (ppb).

SAMPLE NUMBER STATION	CRAB HEPATOPANCREAS			WORMS		SHRIMP				CLAMS			PM = PORT MADISON BI = BUDD INLET CI = CASE INLET SI = SINCLAIR INLET
	131 SI	132 CI	133 BI	142 SI	143 PM	148 PM	149 CI	152 BI	161 SI	157 PM	160 CI	158 SI	
I-PROPYLBENZENE	< 10	< 20	10	20	< 20	< 20	10	< 10	< 10	< 10	< 10	< 20	
N-PROPYLBENZENE	< 20	< 30	< 50	< 50	< 20	< 10	< 20	< 30	< 20	< 10	< 10	< 20	
INDAN	< 5.0	< 10	< 10	< 10	< 10	< 5.0	10	30	20	< 10	< 10	< 10	
NAPHTHALENE	< 20	< 30	< 60	< 50	< 30	< 20	40	20	30	< 30	< 10	< 30	
BENZOTHIOPHENE	< 10	< 10	< 20	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 20	
2-METHYLNAPHTHALENE	< 20	< 20	< 40	< 40	< 20	< 20	10	5.0	10	< 20	< 10	< 50	
1-METHYLNAPHTHALENE	< 5.0	10	10	< 10	10	10	10	10	10	< 10	< 10	< 10	
BIPHENYL	< 5.0	< 10	< 10	20	10	< 5.0	10	10	10	< 10	< 10	130	
2,6-DIMETHYLNAPHTHALENE	< 5.0	< 5.0	< 10	20	10	10	10	10	10	< 10	< 10	< 10	
ACENAPHTHALENE	< 5.0	< 5.0	< 10	< 10	< 10	< 5.0	< 5.0	< 4.0	< 10	< 10	< 10	< 10	
ACENAPHTHENE	< 5.0	< 5.0	< 10	70	< 50	< 5.0	< 30	80	< 10	< 90	< 20	30	
FLUORENE	10	5.0	< 10	< 10	< 10	5.0	50	10	< 40	< 10	< 10	< 10	
DIBENZOTHIOPHENE	< 10	< 10	< 10	< 20	< 10	< 10	10	10	10	< 20	< 20	< 20	
PHENANTHRENE	20	< 5.0	< 10	N	< 10	N	170	< 80	120	N	N	< 80	
ANTHRACENE	5.0	< 5.0	< 10	< 10	< 10	< 5.0	40	20	50	< 10	< 10	40	
FLUORANTHENE	40	< 20	< 30	80	40	30	270	70	200	40	< 10	280	
PYRENE	80	< 5.0	10	210	80	40	250	90	190	60	< 10	N	
BENZ(A)ANTHRACENE	70	< 10	< 20	50	20	10	160	40	120	< 20	< 30	450	
CHRYSENE	20	< 10	< 10	90	30	20	150	50	100	20	< 10	360	
BENZOFLUORANTHENE	< 5.0	< 10	< 10	< 10	< 10	< 10	170	< 5.0	30	< 30	< 40	240	
BENZO(E)PYRENE	< 10	< 10	< 10	90	< 10	20	80	40	60	30	< 20	230	
BENZO(A)PYRENE	< 5.0	< 10	< 10	< 10	< 10	< 10	90	30	70	< 10	< 10	120	
PERYLENE	< 10	< 10	< 10	< 20	< 10	< 10	< 10	< 10	< 10	< 10	< 20	110	
INDENO(1,2,3-CD)PYRENE	< 10	< 10	< 10	< 20	< 10	< 10	< 10	< 10	< 10	< 10	< 20	< 20	
2,3,5 TRIMETHYLNAPHTHALENE	< 5.0	< 5.0	< 10	< 10	< 10	< 5.0	< 5.0	< 4.0	< 10	< 10	< 10	< 10	
HEXACHLOROBENZENE	2.0	2.0	3.0	< 1.0	< 1.0	1.0	< .30	1.0	.40	< .30	< .30	1.0	
LINDANE	1.0	1.0	1.0	< 2.0	< 1.0	< 1.0	< 1.0	< .50	< 1.0	< 1.0	< .80	< 2.0	
HEPTACHLOR	N	< .40	< .50	< 2.0	< 1.0	< 1.0	< 1.0	< .40	< 1.0	< .50	< 1.0	< 3.0	
ALDRIN	N	< .40	< .50	< 1.0	< 1.0	< .50	< 1.0	< .40	< .50	< .50	< .50	< 1.0	
O,P' - DDE	5.0	< .60	2.0	< 3.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	
A-CHLORDANE	10	1.0	3.0	< 1.0	< 1.0	1.0	< .50	.50	1.0	.30	< .50	2.0	
TRANS-NONACHLOR	10	3.0	5.0	< 1.0	< 1.0	1.0	< .50	1.0	2.0	.30	< .50	6.0	
P,P' - DDE	190	30	140	10	5.0	4.0	10	10	10	2.0	< 1.0	14	
O,P' - DDD	10	< 1.0	< 1.0	< 3.0	< 2.0	< 1.0	< 1.0	< 1.0	1.0	< .90	< 1.0	< 3.0	
M,P' - DDD	60	3.0	20	10	< 2.0	2.0	< 2.0	2.0	10	< 1.0	< 2.0	10	
P,P' - DDD/D,P' - DDT	50	10	20	10	< 1.0	1.0	< .50	2.0	10	< 1.0	< 1.0	10	
P,P' - DDT	10	1.0	4.0	< 5.0	< 3.0	< 2.0	< 2.0	< 1.0	3.0	< 1.0	< 2.0	3.0	
DICHLOROBIPHENYLS	20	N	N	< 10	< 4.0	10	N	10	10	< 3.0	< 2.0	10	
TRICHLOROBIPHENYLS	20	10	10	10	10	4.0	3.0	4.0	N	< 1.0	< 1.0	< 3.0	
TETRACHLOROBIPHENYLS	310	70	210	110	40	20	20	30	30	20	4.0	90	
PENTACHLOROBIPHENYLS	1200	160	480	220	60	90	40	80	170	60	10	250	
HEXACHLOROBIPHENYLS	1500	160	470	500	50	120	60	80	280	60	10	440	
HEPTACHLOROBIPHENYLS	970	70	200	320	30	50	10	20	160	20	< 1.0	250	
OCTACHLOROBIPHENYLS	210	10	30	90	2.0	10	1.0	2.0	30	3.0	< 1.0	80	
NONACHLOROBIPHENYLS	10	< .60	< 1.0	20	< 2.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	10	
DICHLOROBENZENE	< 1.0	< 1.0	< 2.0	< 10	< 4.0	< 2.0	< 20	< 2.0	< 30	< 2.0	< 30	< 80	
TRICHLOROBUTADIENE	< .60	< .60	< 1.0	< 3.0	< 2.0	< 1.0	< 1.0	< 1.0	< 2.0	< 1.0	< 1.0	< 3.0	
TETRACHLOROBUTADIENE	< .50	< .60	< 1.0	< 3.0	< 2.0	< 1.0	< 1.0	< 1.0	< 2.0	< 1.0	< 1.0	< 2.0	
PENTACHLOROBUTADIENE	< .50	< .50	< 1.0	2.0	< 1.0	10	4.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	
HEXACHLOROBUTADIENE	< .50	< .60	< 1.0	3.0	< 2.0	< 1.0	1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 2.0	
% DRY WT	23	27	17	13	23	18	20	17	22	10	7.3	15	
% LIPID	13			8.5		7.0	7.6						
SAMPLE WT., GRAMS	10	7.0	6.0	5.0	6.0	10	10	6.0	8.0	6.0	10	8.0	

APPENDIX E

Principal Components Analysis and Cluster Analysis  
of Sediment Sampling Stations using Chemical Data

For various reasons, it is desirable to divide the MESA sampling stations into groups to facilitate analysis of pathology and biology data. It is easy, and useful from several standpoints, to group the stations into embayments or subareas according to geographic location. However, the chemical analyses reveal great variability in the concentrations of hydrocarbons and metals within embayments. This variability can be illustrated by comparing metals profiles (graphs in which concentrations of metals have been joined with lines) of sampling stations within the same geographic subarea (Figure 1). This suggests that it may be preferable for some purposes to group stations according to chemical similarity.

Because of the large number of hydrocarbons and metals measured, it is difficult to determine the chemical similarities of stations simply by inspecting tables of chemical data. While the data on chemical concentrations at each station may be summarized in several ways (e.g., by summing concentrations, normal scores of concentrations, or ranks for all chemicals) to create an overall index of chemical levels, this procedure can be misleading because stations with similar total concentrations, normal scores, or ranks may have quite different chemical profiles (e.g., Figure 2). Methods of analysis capable of considering all chemical variables simultaneously without loss of information on variability are more useful. Principal components analysis and cluster analysis are mathematical methods frequently employed when a large number of variables or characteristics have been measured for a series of units such as stations or individuals (Jeffers 1978). These methods have the advantage of being objective and the groups obtained are reproducible.

To reduce the number of chemical variables forming the basis for this preliminary analysis, only eight metals (chosen because of their known toxic effects) were included and the concentrations of several classes of hydrocarbon compounds in sediment at each station were summed to provide overall measures of arene, PCB, and CBD concentrations (Table 1). Since the toxicity of the hydrocarbon compound classes selected is the subject of this investigation, no rationale could be proposed for weighting chemical concentrations to correspond with their biological significance. Concentrations of pesticides and HCB were not included; later statistical analyses will likely incorporate these groups.

Once chemical variables of interest had been selected, a cluster analysis was performed using the programs of Wishart (1975). The data were standardized to a mean of zero and unit variance. Clustering was performed using Ward's method (Everitt 1974), a hierarchical agglomerative technique. This method can be thought of as attempting to match stations with similar chemical profiles. Simple Euclidean distance was used as a dissimilarity measure, permitting clustering of stations least dissimilar. The dendrogram of chemical similarity obtained by cluster analysis is shown in Figure 3.

All stations for which chemical data were available were included in the analysis, regardless of whether or not biological samples were collected there. This inclusion is desirable from a statistical standpoint, and also makes it possible to predict which chemistry-only stations might be of interest for future biological sampling.

Station groupings on the basis of cluster analysis are given in Table 2. For ease of comparison, groups are described by listing the hydrocarbons and metals with high mean concentrations. Mean concentrations of all chemical variables used in the analysis are given by group in Table 3.

The six-cluster level was chosen because the number of stations in most groups was judged small enough that the groups could be considered reasonably homogeneous. However, one group contained 16 stations which had been clustered into groups of 7 and 9 at a lower level. To ensure homogeneity, this group was divided into two (groups IA and IB) on the basis of these subgroups. This subdivision may be unnecessary, but it does make it possible to compare the least polluted stations with a group of stations only slightly more polluted.

Although cluster analysis provides objective groupings of the stations on the basis of the chemical variables, it is difficult to interpret these groupings on the basis of the dendrogram alone. For this reason, principal components analysis was used to plot the stations on a small number of orthogonal (statistically independent) axes which summarize most of the available information (i.e., which account for most of the chemical variability between stations). The utility of principal components analysis can be illustrated by an example using hypothetical data for three metals generated in such a manner that the concentrations of two are highly correlated while that of the third is independent of the others (Table 4). Principal components analysis shows that, as expected, lead and copper concentrations are highly correlated since both load (or are weighted) about equally on the first eigenvector, an axis summarizing 72% of the variance of the data (Table 4). The second axis is independent of the first, summarizes 28% of the variance of the data, and reflects primarily mercury concentration. The third axis summarizes the small amount of variability due to the fact that lead and copper concentrations are not perfectly correlated.

The 10 hypothetical stations are plotted on the first two axes in Figure 4. It is evident that they are arranged in order of increasing concentrations of lead and copper on the first axis, and in order of increasing mercury concentrations on the second axis. The exact location of each station on the first axis reflects the levels of lead and copper combined.

In this example, the use of principal components analysis has achieved a reduction in the number of variables to be considered from three to two, since the two highly correlated metals are replaced by a single composite variable: the first principal component. While the simplification is trivial in this case, it is non-trivial when more variables are involved.

Principal components analysis reveals which variables are correlated or associated with one another and which are independent. This is important because it is obviously impossible to sort out the individual effects of more highly correlated variables, since variation in one is accompanied by similar variation in the others. Principal components analysis also reveals which variables have the largest standard deviations, and hence account for a large portion of the variability in data. It is easier to identify the effects of a variable which fluctuates widely than of one which changes little from sample to sample.

In its simplest form, principal components analysis is used only to describe the variability of a set of data. No statistical hypotheses are tested, and hence no particular body of statistical assumptions must be met.

To clarify the results of the cluster analysis of the forty-one Central Puget Sound sampling stations and to obtain information on the relationships between the chemical variables, principal components analysis was performed using the programs of Wishart (1975). Plots of the stations and groupings on the first and second and first and third principal components axes are given in Figures 5 and 6. The eigenvector loadings for the first three principal components axes are in Table 5. The first principal component reflects primarily increasing concentrations of lead, cadmium, zinc, arsenic, and copper. The second axis reflects increasing concentrations of PCBs, selected arenes, and mercury. The third axis contrasts selenium and CBDs: selenium concentration rises and CBD concentration falls as one proceeds along the axis. As Table 5 shows, the first axis accounts for 43% of the total variability in chemical concentrations, and the first three axes combined account for 74% of the total variability.

To confirm the results of the principal components analysis, the concentrations of arsenic, copper, zinc, and cadmium were plotted against lead concentration, and the correlations indicated for Axis 1 in Table 5 were evident both on a low-resolution plot (Figure 7) and on a higher-resolution plot near the origin (Figure 8). The concentration of mercury, which loaded on the second axis (Table 5), was indeed independent of that of lead (Figure 9).

It must be emphasized that groups IA through VI do not represent a series of increasing pollution. The purpose of cluster analysis is to identify groups, not to order them in a sequence. Examination of Figures 5 and 6 makes it clear that Station 9030 (Sitcum Waterway, Commencement Bay) is unique in its chemical profile and is best considered individually, as the cluster analysis suggests. Groups I and II are clearly tighter clusters than groups III, IV, or V. The stations of group IA are lower on the first two axes than those group IB, indicating that they are less contaminated.

Figure 5 shows that groups IA through III and group VI can be considered a series with increasing mean scores on the first principal components axis, i.e., a series with increasing mean concentrations of lead, cadmium, zinc, arsenic, and copper. Groups IV and V lie nearer group II than group III in their mean concentrations of these metals. Figures 5 and 6 show that groups IV and V separate from group II during cluster analysis because they have higher levels of PCBs, selected arenes, and mercury, and that group V separates from group IV because of higher levels of CBDs. Table 3 shows that the stations of group IA are rather sandy, as indicated by the mean Phi size of sediment particles, and hence their sediments have less adsorptive area per unit volume. However, inspection of the data reveals considerable variation in mean Phi size within the remaining groups.

Table E-1. Variables selected for inclusion in principal components analysis and cluster analysis. Statistics are for the 41 MESA stations for which data are available.

	Mean Concentration (ppm)	Minimum Concentration (ppm)	Maximum Concentration (ppm)	Coefficient of variation (%)
Metal:				
Arsenic	27.56	0.00	472.00	319
Lead	103.84	7.93	793.00	148
Copper	116.59	10.20	1602.00	210
Zinc	153.99	23.20	1720.00	170
Mercury	0.40	0.02	1.38	95
Selenium	29.47	9.30	113.00	72
Cadmium	7.27	3.08	18.30	43
Chromium	41.87	20.90	71.50	33
Organic Compound Class:				
Selected Arenes <sup>a</sup>	6.1133	0.038	38.9	167
PCB's <sup>b</sup>	0.17896	0.00078	1.290	141
CBD's <sup>c</sup>	0.07161	0.00011	1.010	252

<sup>a</sup> Selected arenes = sum of the concentrations of; pyrene, benz[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[e]pyrene, benzo[a]pyrene, perylene, and indeno (1,2,3-cd)pyrene.

<sup>b</sup> PCB's = sum of the concentrations of the dichloro-thru nonachlorobiphenyls.

<sup>c</sup> CBD's = sum of the concentrations of the trichlorobutadienes, tetrachlorobutadienes, pentachlorobutadienes, and hexachlorobutadiene.

Table E-2. Groupings of MESA stations by cluster analysis based on similarity of concentrations of selected arenes, PCBs, CBDs, and selected metals.

Group	Station Number	Location	Name
IA, least polluted	8107	Port Madison 2	Indianola SW
	9032	Commencement Bay 6	Puyallup disposal site
	9035	" " 9	Sewage plant
	9037	" " 11	Brown's Point
	10014	Elliott Bay 9	Magnolia Bluff
	10028	" " 11	Alki Point
	12063	Case Inlet 2	Stretch Island
IB, slightly polluted; high CBDS	8007	Sinclair Inlet 4	Point Herron
	9029	Commencement Bay 3	Blair Waterway
	9033	" " 7	Between Hylebos and Blair
	9036	" " 10	Tacoma Yacht Club
	9038	" " 12	Outside Hylebos Waterway
	9039	" " 13	Old Tacoma
	9040	" " 14	Blair turning basin
	10046	Elliott Bay 13	Pier 42
	12131	Budd Inlet 2	Priest Point
	II, moderately polluted; high mercury, chromium	8004	Sinclair Inlet 1
8005		" " 2	Drydock area
8006		" " 3	Point Turner
8106		Port Madison 1	Midway
10016		Elliott Bay 4	Harbor Island N
10019		" "	Duwamish 1st Ave. Bridge
10040		" " 6	Pier 70
10041		" " 8	North of Pier 71
10042		" " 15	Pier 86
10043		" " 14	Corps dump site
10044		" " 7	Midway
10045		" " 10	Duwamish Head
12062		Case Inlet 1	Reach Island
III, high organics, high selenium, cadmium, and arsenic		10031	Elliott Bay 1
	10038	" " 2	Duwamish Waterway W
	10039	" " 3	Duwamish Waterway E
	12130	Budd Inlet 1	Entrance channel
	12132	" " 3	Olympia Shoal
IV high arenes	9028	Commencement Bay 2	Hylebos 11th St. Bridge
	9031	" " 5	City Waterway
	10015	Elliott Bay 5	Pier 54
	10023	" " 12	West Point

Table E-2. (Continued)

Group	Station Number	Location	Name
V, High PCBs, CBDs, copper, zinc, selenium	9027 9034	Commencement Bay 1 " " " 8	Hylebos turning basin Brown's Point S
VI, high arsenic, lead, copper, zinc, chromium, cadmium	9030	Commencement Bay 4	Sitcum Waterway

Table E-3. Mean, minimum (MIN), maximum (MAX), standard deviation (STDEV), and sample size (VALIDN) for sediment particle size (MEANPHI) and concentrations selected arenes, PCBs, CbDS, and eight metals by station group. Groups were obtained by cluster analysis based on similarity of chemical concentrations.

	MEANPHI	ARENES	PCBS	CBDS	AS	PB	CU	ZN	HG	SE	CO	CR
GROUP 1A												
MEAN	2.0224	194.96	9.124	9.013	6	16.490	22.014	37.243	.06000	12.443	4.0644	25.886
MIN	1.00	30	.8	.1	6	7.9	10.2	23.2	.024	9.3	3.08	20.9
MAX	4.20	630	38.8	36.0	6	37.1	43.0	58.3	.100	16.0	5.20	31.4
STDEV	.0327	204.95	13.994	12.052	6	10.658	12.878	12.239	.02978	2.606	.7922	3.421
VALIDN	7	7	7	7	7	7	7	7	7	7	7	7
GROUP 1B												
MEAN	4.0050	3091.78	00.828	90.357	6	53.253	66.711	91.378	.18322	20.333	5.8333	32.533
MIN	1.09	156	2.2	.1	6	8.2	23.2	29.7	.026	16.0	4.57	26.9
MAX	5.99	11440	278.7	300.0	6	170.0	126.0	208.0	.336	28.0	8.19	40.4
STDEV	1.0030	4503.72	99.359	112.590	6	46.938	33.590	93.246	.10212	3.742	.9912	5.201
VALIDN	4	4	4	4	4	4	4	4	4	4	4	4
GROUP 2												
MEAN	6.2344	2636.92	110.276	21.992	6	76.408	00.877	128.508	.62869	28.077	7.2069	52.336
MIN	3.77	380	5.0	.4	6	20.1	25.8	61.9	.113	17.0	5.70	31.3
MAX	7.06	10216	420.3	90.0	6	136.0	184.0	292.0	1.380	40.0	8.29	71.5
STDEV	1.4447	2695.96	121.996	27.702	6	35.759	47.001	65.469	.44871	6.278	.8060	12.343
VALIDN	9	13	13	13	13	13	13	13	13	13	13	13
GROUP 3												
MEAN	7.5200	6306.00	320.740	3.370	131.00	232.280	119.480	183.400	.42860	79.200	12.4460	51.480
MIN	6.00	600	9.0	1.0	57	49.3	70.3	101.0	.283	59.0	9.53	44.8
MAX	8.02	21300	675.0	7.4	282	627.0	400.0	319.0	.798	113.0	18.30	63.9
STDEV	.0900	8637.33	302.481	2.361	69.25	237.290	53.898	86.529	.20966	20.389	3.3868	7.251
VALIDN	5	5	5	5	5	5	5	5	5	5	5	5
GROUP 4												
MEAN	5.4375	3325.00	269.925	44.970	6	126.775	93.225	133.750	.68050	24.250	7.2950	42.500
MIN	3.40	29070	42.0	2.9	6	16.1	16.9	44.0	.104	13.0	4.71	33.5
MAX	7.02	38900	422.0	72.0	6	269.0	176.0	225.0	1.160	34.0	9.09	54.4
STDEV	1.7030	4089.23	251.403	29.530	6	104.841	65.234	73.486	.49939	6.770	1.9833	9.768
VALIDN	4	4	4	4	4	4	4	4	4	4	4	4
GROUP 5												
MEAN	0.2130	5405.00	849.500	715.000	6	96.950	161.900	193.950	.48150	28.500	7.8000	38.050
MIN	0.10	1140	409.0	540.0	6	39.9	64.0	63.9	.173	23.0	5.99	28.5
MAX	0.80	10830	1290.0	1010.0	6	154.0	259.0	324.0	.790	34.0	9.61	47.6
STDEV	.5262	6691.06	622.961	332.340	6	60.681	137.320	183.918	.43628	7.776	2.5997	13.506
VALIDN	2	2	2	2	2	2	2	2	2	2	2	2
GROUP 6												
MEAN	6.0000	690.00	76.200	23.000	472.00	793.000	1602.000	1720.000	.49200	23.000	16.2000	58.700
MIN	6.00	690	76.2	23.0	472	793.0	1602.0	1720.0	.492	23.0	16.20	58.7
MAX	6.00	690	76.2	23.0	472	793.0	1602.0	1720.0	.492	23.0	16.20	58.7
STDEV	M	M	M	M	M	M	M	M	M	M	M	M
VALIDN	1	1	1	1	1	1	1	1	1	1	1	1
TOTAL												
MEAN	5.3651	6113.30	178.904	71.613	27.56	103.839	116.585	153.990	.40395	29.406	7.2680	41.668
MIN	1.25	36	.0	.1	6	7.9	10.2	23.2	.024	9.3	3.08	20.9
MAX	8.52	38900	2290.0	1010.0	472	793.0	1602.0	1720.0	1.380	113.0	18.30	71.5
STDEV	2.0000	10230.77	253.073	160.008	69.007	153.443	244.441	262.472	.38312	21.156	3.1131	13.754
VALIDN	32	41	41	41	41	41	41	41	41	41	41	41

Table E-4. Example of principal components analysis using hypothetical data. Copper concentration is 1.2 times lead concentration plus a random number between -50 and 50, resulting in a high correlation ( $r^2 = 0.99$ ). Mercury concentration is a random number between 0.01 and 1.0, and is uncorrelated with either lead and copper ( $r^2 = 0.09$  in both cases). Loadings of variables judged to contribute most to each axis are underlined.

Sample	Pb	Cu	Hg
<u>Hypothetical Concentration (ppm)</u>			
A	100	121	0.99
B	200	275	0.70
C	300	324	0.55
D	400	501	0.69
E	500	638	0.33
F	600	735	0.66
G	700	895	0.77
H	800	917	0.76
I	900	1076	1.00
J	1000	1189	0.06

Chemical Variable	Axis 1	Axis 2	Axis 3
<u>Eigenvector Loadings</u>			
Pb	<u>0.663</u>	0.246	<u>-0.707</u>
Cu	<u>0.664</u>	0.243	<u>0.707</u>
Hg	-0.346	<u>0.938</u>	0.002
Eigenvalue	2.15	0.84	0.00
Percentage of variance	71.78	28.10	0.13
Cumulative variance	71.78	99.87	100.00

Table E-5. Eigenvector loadings for the first three principal component axes. Loadings of variables judged to contribute most to each axis are underlined. Percentage of variance is the amount of variability in the entire data set explained by the axis.

Chemical variable	Axis 1	Axis 2	Axis 3
Selected arenes	0.076	<u>0.405</u>	-0.235
PCBs	0.189	<u>0.498</u>	-0.210
CBDS	-0.015	0.191	<u>-0.491</u>
Arsenic	<u>0.386</u>	-0.298	0.103
Lead	<u>0.410</u>	-0.057	-0.169
Copper	<u>0.377</u>	-0.301	-0.295
Zinc	<u>0.390</u>	-0.273	-0.275
Mercury	0.200	<u>0.430</u>	-0.111
Selenium	0.248	0.221	<u>0.557</u>
Cadmium	<u>0.406</u>	0.071	0.285
Chromium	0.283	0.235	0.233
Eigenvalue	4.78	1.99	1.39
Percentage of variance	43.44	18.11	12.63
Cumulative variance	43.44	61.55	74.18

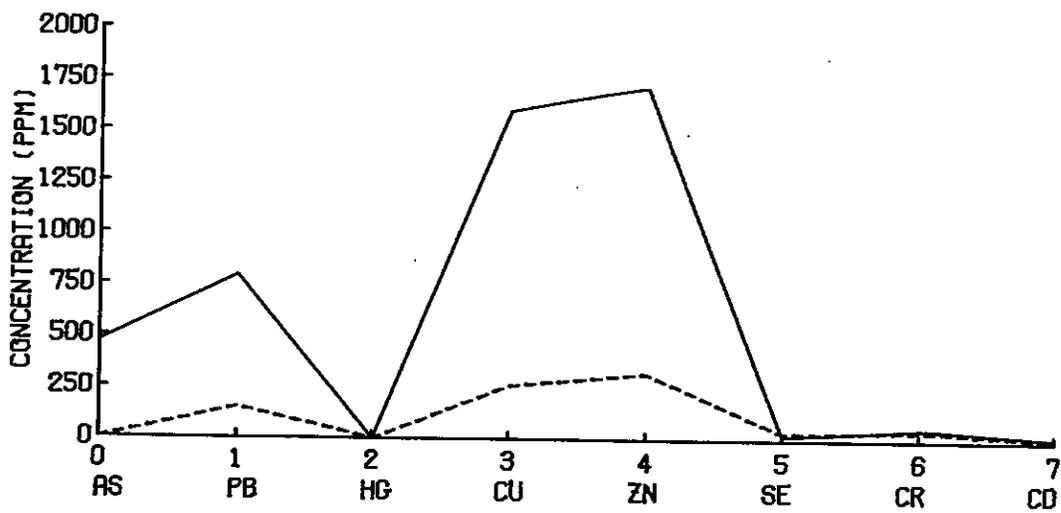


Figure E-1. Metals profiles of two Commencement Bay waterway stations-- Sitcum Waterway (solid line) and Hylebos turning basin (dashed line)--- illustrating chemical concentration differences within geographic locations.

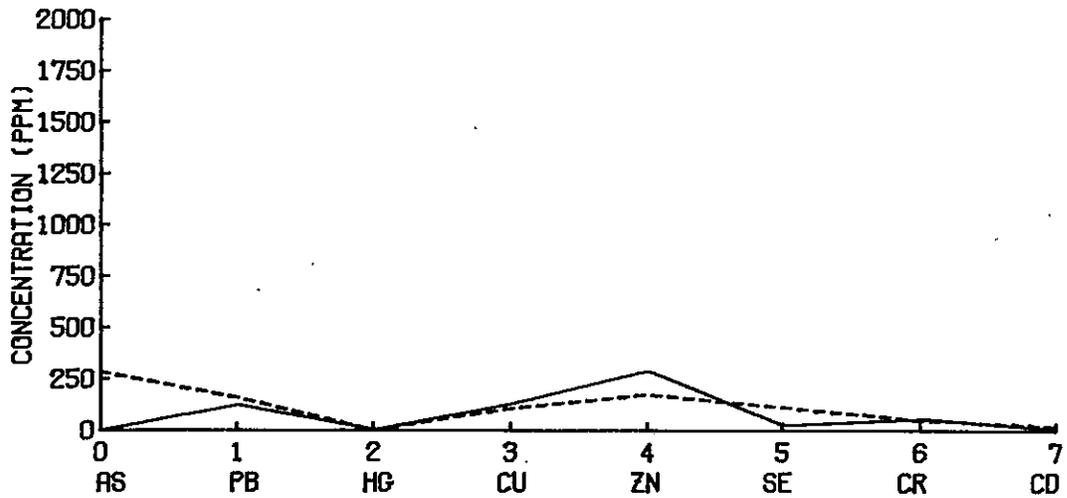


Figure E-2. Metals profiles of two stations with similar overall ranks: Sinclair Inlet Station 3 (solid line) and Duwamish Waterway E (dashed line). Overall ranks, based on summed ranks of individual chemical concentrations among 41 MESA sampling stations, are 7 and 8 respectively, but arsenic is present at one station and absent at the other.

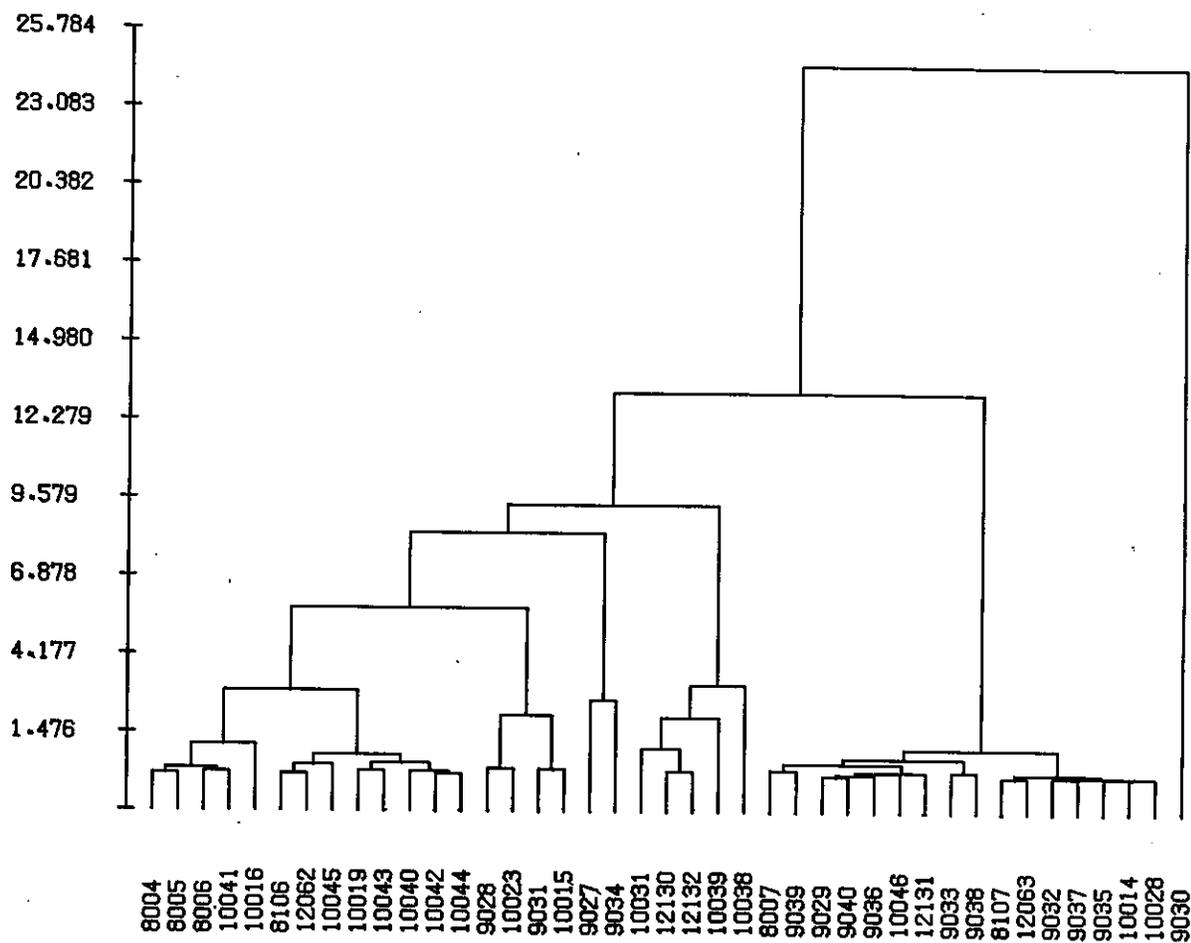
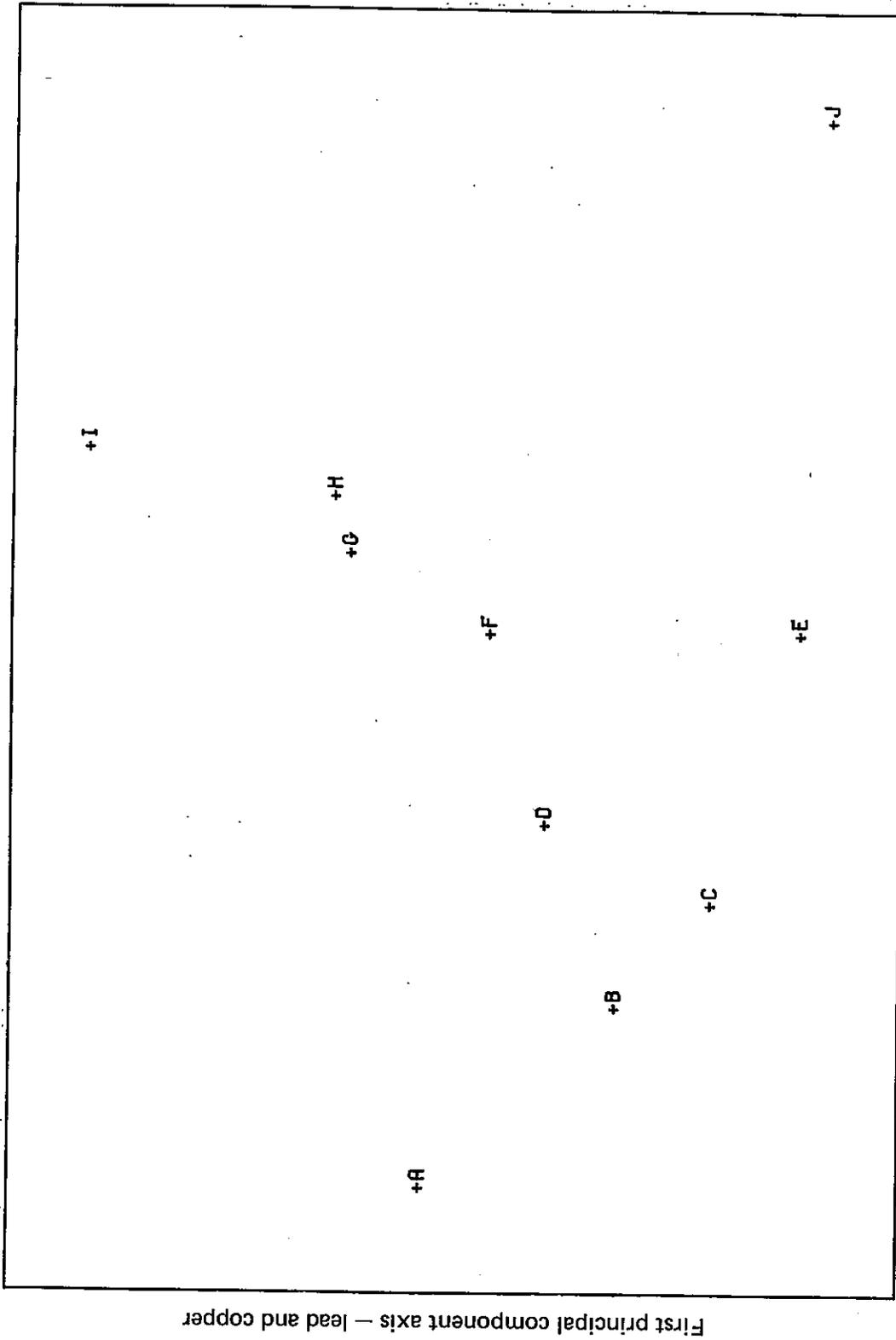


Figure E-3. Dendrogram of 41 MESA stations grouped by similarity of chemical concentrations using cluster analysis. Ordinate is threshold distance between clusters.



Second principal component axis — mercury

Figure E-4. Example of principal components plot showing locations of 10 hypothetical sampling stations on a combined lead-copper axis and a mercury axis.



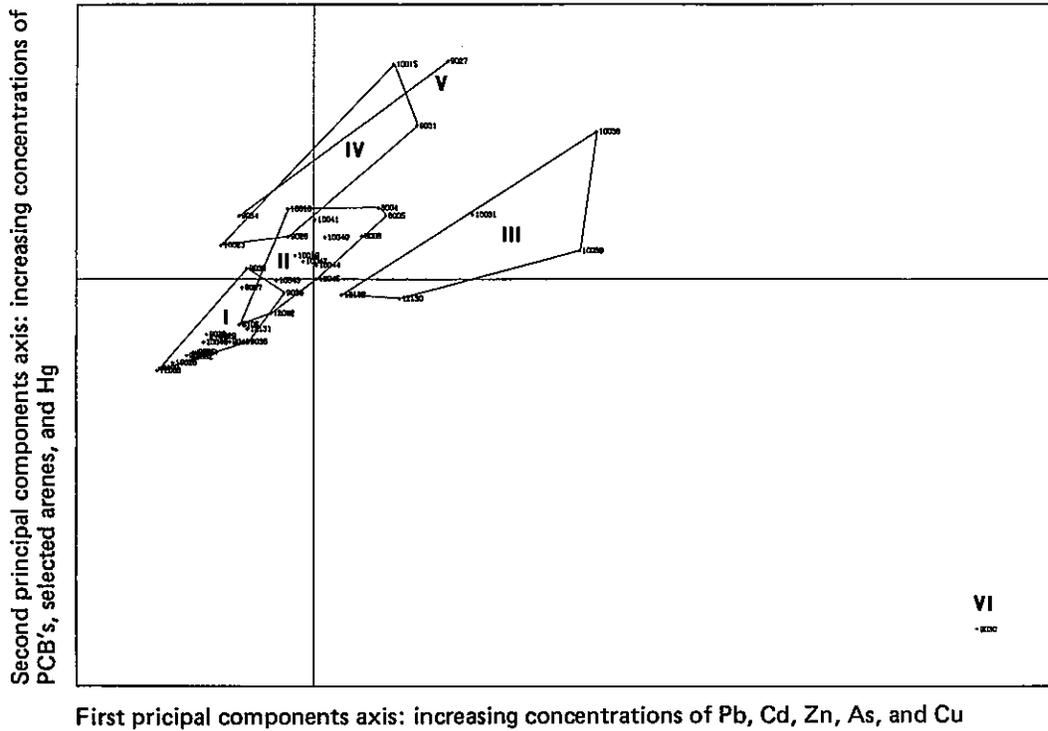


Figure E-5. Groupings of 41 MESA stations obtained by cluster analysis plotted on the first and second principal component axes.

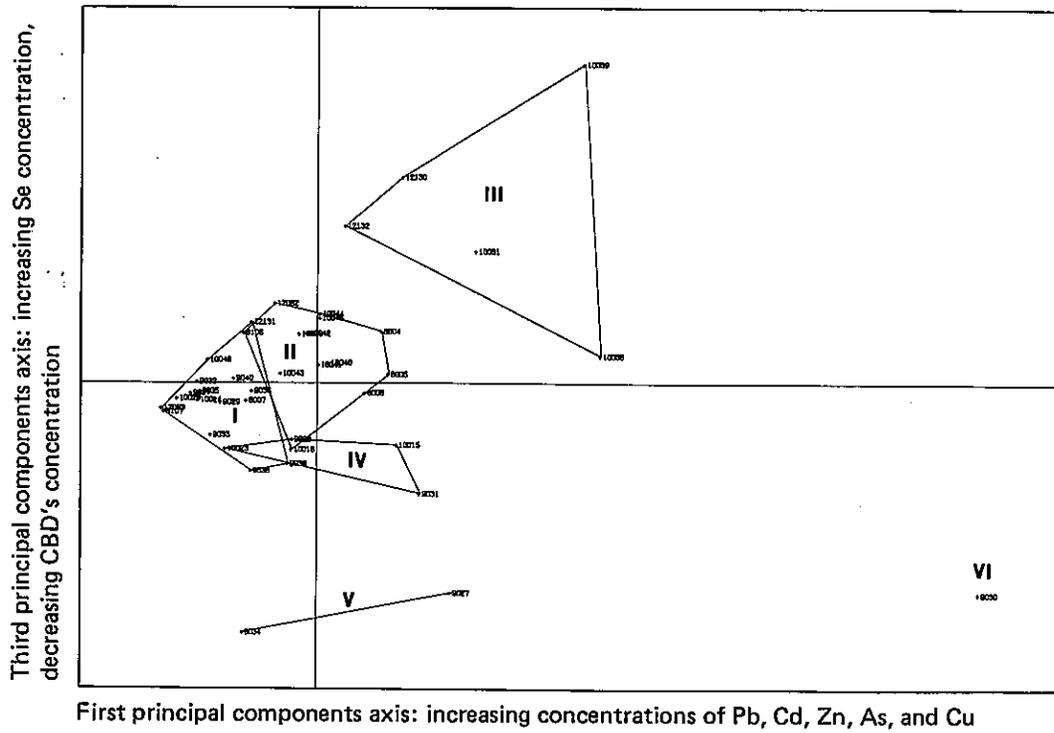


Figure E-6. Groupings of 41 MESA stations obtained by cluster analysis plotted on the second, first, and third principal component axes.

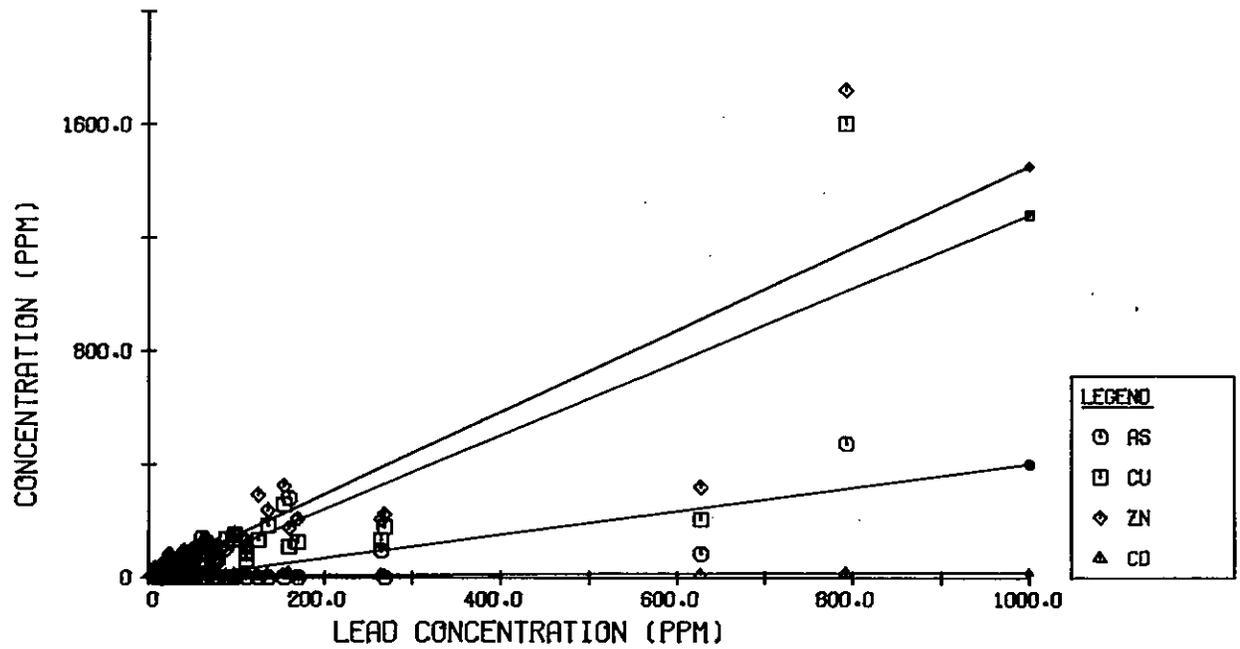


Figure E-7. Concentrations of arsenic, copper, zinc, and cadmium plotted against lead concentration for 41 MESA sampling stations showing that levels of all five metals are correlated.

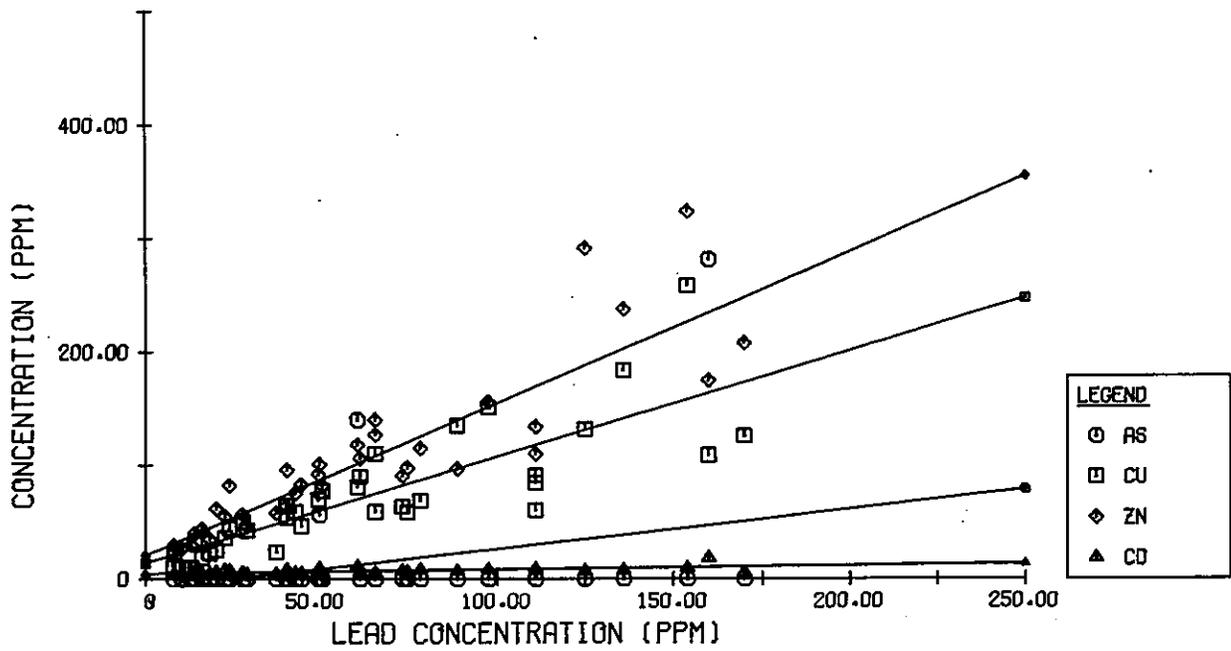


Figure E-8. Higher resolution plot of indicated region of Figure 7 showing the correlations between levels of four metals and lead concentration in more detail.



APPENDIX F

Structure and Function of Invertebrate Organs



## Structure and Function of Affected Crustacean Organs

In order to comprehend an organ's pathological responses to an injurious agent in the environment, it is necessary to know that organ's normal structure and function, and normal cyclic changes that might be expected. All of these factors contribute to the susceptibility and resistance of the organ to an injurious agent.

Gill. The gills of crabs and shrimp are similar in design and function. The decapod gill consists of a central stem (raphe) that bears serially paired flattened sacks called gill lamellae. The stem contains afferent and efferent blood vessels and is filled with spongy connective tissue and tegmental glands. Lamellae are lined with a single layer of epithelium and contain spongy connective tissue as well. The entire organ is covered with a thin cuticle which provides protection and is replaced during molting. Functions of the gill include: osmotic control, respiration, excretion, and storage of waste materials (Johnson, 1980).

Bladder. The bladder is connected to the antennal gland by a convoluted tubular structure termed the labyrinth. The bladder is the largest portion of the above complex which serves as the excretory system. All of these regions are made up of a simple cuboidal to columnar epithelium and are probably continuous. The labyrinth performs the main functions of ultrafiltration, processing and resorption of proteins, and secretion of primary urine. These functions are the final modification of urine and perhaps, absorption of glycogen (Johnson 1980).

Hepatopancreas. The hepatopancreas is the largest organ within the body cavity. It derives its name from its dual roles of storage and of providing digestive enzymes. The organ is a complex of blindly ended tubules which arise from large tubular structures. These ultimately communicate with the midgut receiving food contents and providing enzymes which aid in digestion.

The main functions of the hepatopancreas may be summarized as follows: absorption of nutrients, storage of lipids, production of digestive enzymes, glycogen storage, and some digestion of triturated food.

Loose Connective Tissue. Loose connective tissue in crustaceans has an appearance similar to Leydig tissue in molluscs. There are two main types of loose connective tissue: fibrous loose connective tissue and spongy loose connective tissue. Fibrous loose connective tissue is composed mainly of fibrocytes and associated fibers. It functions mainly in encapsulation of various organs and in encapsulation of spongy loose connective tissue. Spongy loose connective tissue contains large regular storage cells interspersed with fibers of reticulin. It fills spaces and surrounds organs. Spongy loose connective tissue functions as the major site of glycogen storage and may produce collagen in response to injury (Johnson 1980).

Tegmental Glands. Tegmental glands are among the most enigmatic of crustacean structures. They are acinar glands located in the epidermis, gill stem, outside of the esophagus, and surrounding the midgut ampulla. They are usually closely packed together and lie within spongy and fibrous loose connective tissues. Each gland consists of a central duct surrounded by radially arranged secretory cells and is surrounded by a thin sheath of fibrous connective tissue. These glands go through a series of secretory changes associated with different phases of the molting cycle. They are thought by some histologists to participate some way in cuticle formation (Johnson 1980).

APPENDIX G

Fish Ecology Data

Table G-1. Target species catch per 5 minute tow by station.

Station and Season	# of Tows	English sole	Rock sole	Staghorn sculpin	Pacific Tomcod	Quillback rockfish	
<u>Elliott Bay CPUE of Target Species</u>							
1	W	2	5.5	13.0	2.5	1.0	1.0
	SP	2	13.0	2.0	0.5	0.5	0
	S	3	2.0	1.0	0	16.0	0
	F	2	13.5	16.0	0.5	38.5	0
2	W	2	5.0	5.0	0.5	0	0
	SP	3	9.3	2.7	1.0	0	0.3
	S	3	11.3	4.7	0	2.3	0
	F	2	9.0	10.0	1.0	11.5	0
3	W	3	25.0	1.3	0.3	1.0	0
	SP	2	11.0	0	1.5	0	0
	S	2	35.0	0	0.5	8.0	0
	F	2	13.5	1.5	4.0	30.5	0
4	W	3	16.7	17.3	0	0	0.3
	SP	2	5.0	15.5	0.5	0	0
	S	2	7.5	6.5	0	1.5	0.5
	F	2	5.0	7.0	0	30.5	1.5
5	W	2	12.0	13.5	2.0	6.0	2.0
	SP	2	7.5	5.5	0	3.0	4.0
	S	2	0.5	1.5	0	0.5	1.0
	F	2	0	0.5	0.5	30.5	1.0
6	W	3	6.3	6.7	0.3	3.7	3.0
	SP	2	4.0	5.0	0	0	0
	S	2	2.0	6.0	0	7.0	4.0
	F	2	5.5	12.5	0	97.0	4.0
7	W	2	0.5	0	0	0	0
	SP	2	0	0	0	0	0.5
	S	1	9.0	11.0	0	0	0
	F	1	0	0	0	0	1.5
8	W	2	24.5	11.0	3.5	2.0	6.0
	SP	1	26.0	15.0	1.0	0	9.0
	S	2	14.0	3.0	0	4.5	0
	F	2	4.0	0.5	0.5	47.0	2.0
9	W	3	26.0	79.3	0	0.3	5.3
	SP	2	28.0	5.5	0	0.5	3.0
	S	2	11.0	10.5	0	0	1.5
	F	1	76.0	29.0	0	0	2.0

Table G-1. (Continued)

Station and Season	# of Tows	English sole	Rock sole	Staghorn sculpin	Pacific Tomcod	Quillback rockfish
10 W	2	10.0	7.5	0	1.0	5.0
10 SP	2	10.0	16.0	0	0	0.5
10 S	2	2.0	5.0	0	0	2.5
10 F	2	7.0	12.5	0	5.0	0.5
11 W	2	5.0	12.5	0	0	4.0
11 SP	2	89.5	23.0	0	0	0
11 S	3	8.0	15.3	0	0	0
11 F	2	8.5	50.0	0	0	0
12 W	3	7.0	37.3	0	2.0	3.7
12 SP	2	23.0	23.5	0.5	0	3.0
12 S	1	31.0	36.0	0	3.0	4.0
12 F	1	46.0	24.0	0	80.0	4.0

Commencement Bay CPUE of Target Species

1 W	2	19.0	0	3.5	8	0
1 SP	2	6.0	0	7	2	0
1 S	1	19.0	0	7	16	0
1 F	2	6.0	0	10.5	118.0	0
2 W	3	1.7	1.3	1.7	8.7	0
2 SP	2	14.5	2.0	2.5	0	0
2 S	1	26.0	29.0	1.0	17.0	0
2 F	1	9.0	5.0	9.0	128.0	0
3 W	3	14.7	5.0	1.7	6.3	0
3 SP	2	23.0	0	2.0	5.5	0
3 S	1	39.0	2.0	3.0	43.0	0
3 F	2	36.5	5.0	1.5	152.0	0
4 W	2	12.5	8.5	2.5	2.0	0
4 SP	2	29.5	3.0	0.5	0.5	0
4 S	1	59.0	1.0	2.0	8.0	0
4 F	1	21.0	10.0	4.0	121.0	0
5 W	3	5.7	3.0	3.3	0	0
5 SP	1	240.0	13.0	6.0	1.0	0
5 S	1	75.0	8.0	2.0	20.0	0
5 F	1	33.0	3.0	12.0	87.0	0
6 W	2	63.5	2.0	4.0	21.5	0
6 SP	1	372.0	0	0	17.0	2.0
6 S	1	138.0	0	0	2.0	0
6 F	0	0	0	0	0	0

Table G-1. (Continued)

Station and Season	# of Tows	English sole	Rock sole	Staghorn sculpin	Pacific Tomcod	Quillback rockfish	
<u>Port Madison CPUE of Target Species</u>							
1	W	1	0	0	0	0	
	SP	2	0	0	10.0	0	
	S	1	0	0	0	0	
	F	1	0	0	0	1.0	
2	W	3	8.0	2.7	0	4.0	
	SP	3	7.0	1.7	0.3	0	
	S	1	13.0	10.0	0	0	
	F	1	269.0	4.0	19.0	92.0	0
<u>Sinclair Inlet CPUE of Target Species</u>							
1	W	2	4.0	3.5	0	0	
	SP	2	18.0	2.0	0	0	
	S	1	62.0	0	3.0	2.0	
	F	1	33.0	3.0	45.0	123.0	0
2	W	3	9.7	1.0	0	0	
	SP	3.7	1.0	0	0	0	
	S	1	18.0	16.0	1.0	14.0	0
	F	1	20.0	0	22.0	12.0	2.0
3	W	3	9.3	1.3	0	0	
	SP	2	10.5	0.5	0	0	
	S	1	20.0	9.0	2.0	15.0	0
	F	2	13.5	8.5	1.0	7.0	0.5
<u>Bud Inlet CPUE of Target Species</u>							
2	W	2	4.5	0	0.5	0	
	SP	3	4.0	4.3	0	0	
	S	1	29.0	43.0	57.0	9.0	
	F	1	21.0	47.0	5.0	0	
3	W	3	1.0	1.0	0.7	0	
	SP	2	7.0	5.0	0	0	
	S	1	40.0	10.0	25.0	255.0	
	F	1	68.0	71.0	107.0	21.0	
4	W	3	1.3	1.0	0	0	
	SP	3	2.0	4.3	0	0	
	S	1	19.0	39.0	4.0	0	
	F	2	5.5	16.5	1.0	0	

Table G-1. (Continued)

Station and Season	# of Tows	English sole	Rock sole	Staghorn sculpin	Pacific Tomcod	Quillback rockfish	
7	W	3	0.7	1.7	0.3	1.3	0
	SP	3	20.7	5.3	1.7	0	0
	S	1	110.0	11.0	1.0	10.0	1.0
	F	1	107.0	8.0	6.0	410.0	3.0
8	W	2	3.0	7.0	2.5	24.5	0
	SP	2	5.0	1.0	0	14.5	1.5
	S	2	30.0	0.5	0	10.0	1.0
	F	2	4.5	0.5	0.5	28.5	1.0
9	W	3	16.3	16.3	0	6.7	1.0
	SP	1	126.0	42.0	1.0	0	2.0
	S	2	3.0	5.0	0	2.5	0.5
	F	2	9.0	7.0	0	102.0	0.5
10	W	3	192.3	10.7	0.7	5.0	0
	SP	1	25.0	78.0	0	0	0
	S	1	21.0	22.0	0	0	0
	F	2	10.0	35.5	1.0	45.0	1.0
11	W	3	29.0	28.3	1.3	2.7	0.7
	SP	3	30.3	26.0	1.0	1.0	0.3
	S	2	4.0	5.0	0	0	1.0
	F	1	12.0	13.0	8.0	1206.0	1.0
13	F	1	48.5	1.5	0	45.5	0
<u>Case Inlet CPUE of Target Species</u>							
1	W	2	0	3.0	0	0	0
	SP	3	3.3	0.7	0	0	0
	S	2	23.0	0.5	5.5	0.5	0
	F	3	0.3	1.0	0.3	0	0
2	W	3	0.7	1.7	0.3	0	0
	SP	3	1.0	2.3	0.7	0	0
	S	1	117.0	3.0	2.0	15.0	0
	F	3	1.3	1.0	2.0	0	0

Table G-2. The ten most abundant species (CPUE) from all stations (combined) in Elliott Bay and Commencement Bay.  
 (\* = target species).

Elliott Bay	Commencement Bay
	<u>Winter</u>
Shiner perch (33.7)	*English sole (14.3)
*Rock sole (18.3)	Shiner perch (9.4)
*English sole (1.6)	*Rock sole (8.1)
Pacific herring (7.4)	*Pacific tomcod (7.0)
Roughback sculpin (5.1)	Pacific herring (5.0)
Flathead sole (4.3)	Rex sole (2.2)
*Quillback rockfish (2.4)	Ratfish (1.9)
Rex sole (1.8)	*Staghorn sculpin (1.8)
Longfin smelt (1.8)	Roughback sculpin (1.6)
Pile perch (1.6)	Sand sole (1.2)
	<u>Spring</u>
*English sole (18.2)	*English sole (59.7)
Shiner perch (16.0)	*Rock sole (11.5)
Pacific herring (8.4)	Shiner perch (9.1)
*Rock sole (8.1)	Ratfish (6.6)
Roughback sculpin (3.9)	Blackbelly eelpout (6.0)
Flathead sole (2.8)	Flathead sole (5.6)
Blackbelly eelpout (1.6)	Rex sole (4.3)
Dover sole (1.4)	*Pacific tomcod (3.7)
*Quillback rockfish (1.3)	Dover sole (3.4)
Pile perch (1.3)	Roughback sculpin (3.2)
	<u>Summer</u>
Dover sole (12.9)	*English sole (40.1)
*English sole (9.9)	Rex sole (11.7)
*Rock sole (6.7)	*Pacific tomcod (10.1)
Flathead sole (5.2)	Flathead sole (7.2)
*Pacific tomcod (4.0)	*Rock sole (6.4)
Roughback sculpin (3.3)	Roughback sculpin (6.2)
Surf smelt (2.8)	Dover sole (5.9)
Rex sole (2.2)	Ratfish (5.3)
Plainfin midshipman (2.1)	Blackbelly eelpout (5.1)
Snake prickleback (1.8)	Slender sole (2.2)
	<u>Fall</u>
*Pacific tomcod (31.5)	*Pacific tomcod (183.4)
Dover sole (20.1)	Shiner perch (90.2)
Flathead sole (14.7)	Pacific herring (55.5)
*English sole (12.1)	*English sole (25.7)
*Rock sole (12.0)	Walleye pollock
Shiner perch (7.9)	Flathead sole (10.9)
Bay goby (7.8)	*Rock sole (8.6)
Walleye pollock (6.5)	Dover sole (7.9)
Pacific Herring (6.2)	Rex sole (5.1)
Longfin smelt (5.9)	Sanke prickleback (4.4)

Table G-2A. The ten most abundant species (CPUE) in shallow waters (< 50 ft) of Central Puget Sound (Elliott Bay, Sinclair Inlet) (\* = target species).

Elliott Bay		Sinclair Inlet
	<u>Winter</u>	
*English sole (16.0)		*English sole (8.1)
Longfin smelt (9.3)		Sand sole (5.6)
*Rock sole (6.7)		Starry flounder (2.0)
Herring (4.5)		*Rock sole (1.8)
Sand sole (3.8)		Copper rockfish (0.8)
Flathead sole (2.3)		Brown rockfish (0.6)
*Staghorn sculpin (1.2)		Herring (0.5)
Shiner perch (1.0)		*Pacific tomcod (0.3)
*Pacific tomcod (0.8)		
Ratfish (0.7)		
	<u>Spring</u>	
Herring (14.9)		*English sole (9.7)
*English sole (10.0)		Sand sole (3.1)
Longfin smelt (3.7)		Brown rockfish (1.7)
*Rock sole (1.7)		*Rock sole (1.1)
Pile perch (1.7)		Starry flounder (0.7)
Sand sole (1.1)		Roughback sculpin (0.6)
*Staghorn sculpin (1.0)		Plainfin midshipman (0.6)
Starry flounder (0.7)		Ratfish (0.3)
Roughback sculpin (0.6)		Speckled sanddab (0.3)
Snake prickleback (0.6)		7 species (0.1)
	<u>Summer</u>	
*English sole (16.1)		*English sole (33.3)
*Rock sole (7.1)		Herring (14.3)
*Pacific tomcod (6.7)		*Pacific tomcod (10.3)
Surf smelt (6.4)		*Rock sole (8.3)
Dover sole (5.9)		Shiner perch (8.0)
Flathead sole (4.0)		Sand sole (3.7)
Snake prickleback (3.8)		Plainfin midshipman (3.0)
Herring (1.7)		Starry flounder (2.7)
Bay goby (1.6)		*Staghorn sculpin (2.0)
Sand sole (1.3)		Pile perch (1.3)
	<u>Fall</u>	
*Rock sole (23.4)		*Pacific tomcod (37.3)
*Pacific tomcod (20.0)		Shiner perch (33.3)
Shiner perch (11.8)		*English sole (20.0)
*English sole (11.6)		*Staghorn sculpin (17.3)
Pacific herring (9.4)		Pacific herring (10.0)
C-0 turbot (2.8)		*Rock sole (5.0)
Roughback sculpin (2.4)		Pile surfperch (4.5)
Dover sole (2.4)		Sand sole (4.3)
Snake Prickleback (2.2)		Plainfin midshipman (3.0)
Bay goby (2.0)		Snake prickleback (3.0)

Table G-2B. The ten most abundant species (CPUE) in shallow waters (< 50 ft) of South Puget Sound (Commencement Bay, Budd Inlet, Case Inlet).

Areas	Winter	Spring	Summer	Fall
Commencement Bay	<ul style="list-style-type: none"> <li>*English sole (9.9)</li> <li>Herring (6.5)</li> <li>*Pacific tomcod (5.0)</li> <li>*Rock sole (3.5)</li> <li>Shiner perch (2.8)</li> <li>Surf smelt (2.3)</li> <li>Ratfish (2.3)</li> <li>*Staghorn sculpin (2.1)</li> <li>Sand sole (0.0)</li> <li>Flathead sole (0.0)</li> </ul>	<ul style="list-style-type: none"> <li>*English sole (39.7)</li> <li>Shiner perch (10.0)</li> <li>*Rock sole (3.8)</li> <li>*Staghorn sculpin (3.3)</li> <li>Snake prickleback (2.4)</li> <li>Flathead sole (1.9)</li> <li>*Pacific tomcod (1.8)</li> <li>Starry flounder (1.5)</li> <li>Sand sole (1.0)</li> <li>Ratfish (0.9)</li> </ul>	<ul style="list-style-type: none"> <li>*English sole (37.3)</li> <li>*Pacific tomcod (18.2)</li> <li>*Rock sole (8.3)</li> <li>Flathead sole (8.3)</li> <li>Starry flounder (5.0)</li> <li>Dover sole (4.8)</li> <li>Herring (3.5)</li> <li>Blackbelly eelpout (2.5)</li> <li>*Staghorn sculpin (2.3)</li> <li>Ratfish (2.3)</li> </ul>	<ul style="list-style-type: none"> <li>*Pacific tomcod (125.1)</li> <li>Shiner perch (84.3)</li> <li>*English sole (21.1)</li> <li>Pacific herring (17.9)</li> <li>Flathead sole (14.0)</li> <li>Snake Prickleback(8.7)</li> <li>*Staghorn sculpin(7.0)</li> <li>*Rock sole (4.0)</li> <li>Pile surfperch (2.6)</li> <li>Bay Goby (2.4)</li> </ul>
Budd Inlet	<ul style="list-style-type: none"> <li>Starry flounder (16.3)</li> <li>Sand sole (5.4)</li> <li>*English sole (1.8)</li> <li>*Rock sole (0.7)</li> <li>Herring (0.3)</li> <li>*Staghorn sculpin (0.3)</li> <li>Roughback sculpin (0.2)</li> <li>Speckled sanddab (0.2)</li> </ul>	<ul style="list-style-type: none"> <li>*Rock sole (4.5)</li> <li>Sand sole (4.5)</li> <li>*English sole (4.0)</li> <li>Starry flounder (3.6)</li> <li>Speckled sanddab (1.9)</li> <li>Roughback sculpin (1.1)</li> <li>C-0 sole (0.5)</li> </ul>	<ul style="list-style-type: none"> <li>*Pacific tomcod (88.0)</li> <li>*Rock sole (30.7)</li> <li>*English sole (29.3)</li> <li>*Staghorn sculpin (28.7)</li> <li>Sand sole (12.3)</li> <li>Starry flounder (10.3)</li> <li>Bay goby (6.0)</li> <li>Speckled sanddab (5.7)</li> <li>Plainfin midshipman (4.7)</li> <li>Snake prickleback (3.0)</li> </ul>	<ul style="list-style-type: none"> <li>*Rock sole (37.8)</li> <li>*English sole (25.0)</li> <li>*Staghorn sculpin (28.5)</li> <li>Plainfin midshipman (10.5)</li> <li>Speckled sanddab (9.5)</li> <li>Shiner perch (9.0)</li> <li>Starry flounder (8.3)</li> <li>Sand sole (8.0)</li> <li>Pacific tomcod (5.3)</li> <li>Roughback sculpin (3.8)</li> </ul>
Case Inlet	<ul style="list-style-type: none"> <li>*Rock sole (1.8)</li> <li>Roughback sculpin (1.3)</li> <li>Speckled sanddab (1.0)</li> <li>Starry flounder (0.8)</li> <li>*English sole (0.3)</li> <li>Sand sole (0.3)</li> </ul>	<ul style="list-style-type: none"> <li>Speckled sanddab (12.3)</li> <li>Roughback sculpin (2.5)</li> <li>*English sole (2.2)</li> <li>*Rock sole (1.5)</li> <li>Starry flounder (1.2)</li> <li>Padded sculpin (0.3)</li> <li>Brown rockfish (0.5)</li> <li>Sand sole (0.3)</li> <li>*Staghorn sculpin (0.3)</li> </ul>	<ul style="list-style-type: none"> <li>*English sole (54.3)</li> <li>Speckled sanddab (35.3)</li> <li>Plainfin midshipman (5.3)</li> <li>*Pacific tomcod (5.3)</li> <li>*Staghorn sculpin (4.3)</li> <li>Sand sole (3.3)</li> <li>Bay goby (2.3)</li> <li>Shiner perch (2.3)</li> <li>Roughback sculpin (2.0)</li> <li>*Rock sole (1.3)</li> </ul>	<ul style="list-style-type: none"> <li>Speckled sanddab (15.0)</li> <li>Roughback sculpin (6.8)</li> <li>Sand sole (3.3)</li> <li>Plainfin midshipman (1.3)</li> <li>Bay goby (1.3)</li> <li>*Staghorn sculpin (1.2)</li> <li>*Rock sole (1.0)</li> <li>Snake prickleback (0.8)</li> <li>*English sole (0.8)</li> <li>Shiner perch (0.7)</li> </ul>

\* = target species

Table G-2C. The ten most abundant species (CPUE) in intermediate and deeper waters (60-300 ft) of Central Puget Sound (Elliott Bay, Port Madison) (\* = target species).

Elliott Bay		Port Madison
	<u>Winter</u>	
Shiner perch (36.2)		*English sole (8.0)
*Rock sole (19.6)		Ratfish (7.6)
*English sole (12.4)		Roughback sculpin (4.3)
Herring (8.0)		*Quillback rockfish (4.0)
Roughback sculpin (5.5)		*Rock sole (2.6)
Flathead sole (4.6)		Sand sole (1.7)
*Quillback rockfish (2.6)		Speckled sanddab (1.0)
*Pacific tomcod (2.6)		Herring (1.0)
Rex sole (2.0)		Copper rockfish (1.0)
Longfin smelt (2.0)		Brown rockfish (0.7)
	<u>Spring</u>	
Shiner perch (33.3)		*English sole (7.0)
*English sole (13.9)		Roughback sculpin (6.3)
Herring (10.9)		Sand sole (2.7)
*Rock sole (8.8)		*Rock sole (1.7)
Roughback sculpin (7.3)		Speckled sanddab (1.0)
Flathead sole (6.8)		Copper rockfish (0.7)
Dover sole (2.8)		*Staghorn sculpin (0.3)
*Quillback rockfish (2.7)		
Blackbelly eelpout (2.1)		
Northern ronquil (2.0)		
	<u>Summer</u>	
Dover sole (18.4)		*Pacific tomcod (30.7)
*Rock sole (6.4)		Ratfish (22.7)
Flathead sole (6.2)		Slender sole (4.7)
Roughback sculpin (5.2)		*English sole (4.3)
*English sole (5.1)		*Rock sole (3.3)
Rex sole (3.9)		Blackbelly eelpout (2.7)
Plainfin midshipman (3.5)		Sand sole (2.0)
Slender sole (2.5)		Pacific sanddab (1.7)
*Pacific tomcod (1.9)		Dover sole (1.0)
Blackbelly eelpout (1.9)		*Quillback rockfish (0.7)
	<u>Fall</u>	
*Pacific tomcod (35.1)		*English sole (134.5)
Dover sole (25.7)		*Pacific tomcod (33.5)
Flathead sole (19.1)		Shiner perch (24.5)
*English sole (12.3)		Ratfish (20.0)
Bay goby (9.6)		Slender sole (17.0)
Walleye pollock (8.5)		Canary Rockfish (10.0)
*Rock sole (8.4)		*Staghorn sculpin (9.5)
Longfin smelt (7.8)		Plainfin midshipman (8.5)
Blackbelly eelpout (7.4)		Pacific sanddab (6.0)
Rex sole (6.9)		Flathead sole (4.5)

Table G-3. Seasonal changes in fish community characteristics for estuarine areas.

Parameter	Commencement Bay	Elliott Bay
	<u>Winter</u>	
No. of Hauls	28	30
Species Richness	39	44
Species Diversity*	2.44	2.36
	<u>Spring</u>	
No. of Hauls	18	24
Species Richness	36	37
Species Diversity*	2.09	2.35
	<u>Summer</u>	
No. of Hauls	14	25
Species Richness	36	38
Species Diversity*	2.48	2.72
	<u>Autumn</u>	
No. of Hauls	16	21
Species Richness	37	36
Species Diversity*	1.96	2.80

\* Shannon-Weaver diversity index

Table G-3A. Seasonal changes in fish community characteristics for shallow water areas.

SHALLOW WATER ( $\leq$  50 ft) CATCH PARAMETERS

Parameter	Commencement Bay	Elliott Bay	Budd Inlet	Sinclair Inlet	Case Inlet
<u>Winter</u>					
No. of Hauls	16	5	9	8	6
Species Richness	28	20	9	10	8
Species Diversity	2.44	2.13	1.12	1.61	1.78
<u>Spring</u>					
No. of Hauls	11	7	8	7	6
Species Richness	24	17	11	16	11
Species Diversity	1.68	1.83	1.88	1.73	1.52
<u>Summer</u>					
No. of Hauls	6	11	3	3	3
Species Richness	25	30	16	16	19
Species Diversity	2.08	2.47	1.95	2.05	1.73
<u>Autumn</u>					
No. of Hauls	7	5	4	4	6
Species Richness	24	22	22	19	15
Species Diversity	1.76	2.31	2.37	2.10	1.82

Table G-3B. Seasonal changes in fish community characteristics for intermediate and deep water areas.

INTERMEDIATE AND DEEP WATER (> 50 ft) CATCH PARAMETERS

Parameter	Commencement Bay	Elliott Bay	Port Madison
		<u>Winter</u>	
No. of Hauls	12	19	3
Species Richness	31	38	17
Species Diversity	2.25	2.10	2.26
		<u>Spring</u>	
No. of Hauls	7	13	5
Species Richness	31	29	11
Species Diversity	2.11	2.25	1.77
		<u>Summer</u>	
No. of Hauls	8	14	3
Species Richness	24	27	17
Species Diversity	2.17	2.51	1.77
		<u>Autumn</u>	
No. of Hauls	9	16	2
Species Richness	32	33	24
Species Diversity	1.94	2.75	2.07

APPENDIX H

Invertebrate Ecology

Table H-1. Water temperature (°C) values for each sampling station.

		Winter	Spring	Summer	Fall	
1)	08004	S.W. Sinclair Inlet	6.3	9.21	12.7	12.5
2)	08005	Sinclair Inlet	6.5	9.01	12.0	12.5
3)	08006	Point Turner	6.6	8.91	12.0	12.5
1)	08106	Port Madison	6.7	7.68	10.5	11.5
2)	08107	Indianola	6.5	8.1	10.5	12.0
1)	09027	Hylebos Basin	6.9	8.0	11.0	12.8
2)	09028	Hylebos Bridge	6.9	8.5	11.0	12.6
3)	09029	Blair Waterway	6.9		11.0	12.6
4)	09030	Sitcum Waterway	7.1		10.5	12.6
5)	09031	City Waterway	7.4		11.0	12.6
6)	09032	Puyallup Waterway	7.1		10.5	
7)	09033	Hylebos Outer		8.5	10.5	12.5
8)	09034	Browns Point South	7.1	8.2	10.5	12.4
9)	09035	Tacoma Corinthian	7.1	8.5	11.0	13.6
10)	09036	ASARCO	7.1	7.9	10.5	14.1
11)	09037	Browns Point	6.9	9.0	11.0	12.4
1)	10031	Harbor Island South	6.5	7.2	11.25	12.4
2)	10038	West Waterway	6.5	7.45	11.0	12.4
3)	10039	East Waterway	6.6	7.50	11.25	12.3
4)	10016	Harbor Island North	6.6	7.4	12.0	12.2
5)	10015	Pier 54	6.2	7.25	11.0	12.0
6)	10040	Pier 69	6.8	7.15	11.0	12.3
7)	10044	Elliott Bay	5.8	7.68	10.5	
8)	10041	Waterfront Park	6.8	7.5	10.0	12.2
9)	10014	Magnolia Bluff	6.4	8.0	11.0	12.2
10)	10045	Pier 3	6.5	7.88	10.75	12.2
11)	10028	Alki Point	6.5	8.00	11.0	12.2
12)	10023	West Point	6.8		11.0	11.5
1)	12062	Reach Island	5.4	10.3	12.5	14.0
2)	12063	Stratch Island	5.8	8.9	13.25	13.0
2)	12131	Ellis Creek	6.0	9.95	14.0	14.0
3)	12132	Olympia Shoal	6.0	9.30	13.5	13.8
4)	12133	Dofflemeyer Point	6.0	9.50	13.5	13.0
22)	09042	Tacoma Stadium H.S.				12.4

Table H-2. Salinity (ppt) values for each sampling station.

		Winter	Spring	Summer	Fall	
1)	08004	S.W. Sinclair Inlet	30.10	29.17	28.9	29.5
2)	08005	Sinclair Inlet	24.8	30.53	28.9	28.9
3)	08006	Point Turner	30.2	30.35	28.9	29.5
1)	08106	Port Madison	30.6	31.58	29.2	29.5
2)	08107	Indianola	30.6	30.6	29.2	29.5
1)	09027	Hylebos Basin	30.42	30.20	28.3	29.3
2)	09028	Hylebos Bridge	30.60	30.03	28.9	29.5
3)	09029	Blair Waterway	30.30		28.9	29.5
4)	09030	Sitcum Waterway	30.50		28.9	29.5
5)	09031	City Waterway	30.50		28.3	29.1
6)	09032	Puyallup Waterway	30.60		28.9	
7)	09033	Hylebos Outer		30.70	28.9	25.8
8)	09034	Browns Point South	30.80	30.25	28.9	29.5
9)	09035	Tacoma Corinthian	31.12	29.96	28.9	27.1
10)	09036	ASARCO	30.78	30.97	28.9	27.5
11)	09037	Browns Point	30.44	29.7	29.5	29.4
1)	10031	Harbor Island South	30.80	33.0	28.9	29.2
2)	10038	West Waterway	31.30	27.6	28.9	29.0
3)	10039	East Waterway	30.40	28.0	28.6	30.1
4)	10016	Harbor Island North	30.50	28.9	28.9	24.2
5)	10015	Pier 54	30.35	28.25	28.9	24.7
6)	10040	Pier 69	30.00	23.6	29.5	19.5
7)	10044	Elliott Bay	31.30	29.7	29.2	
8)	10041	Waterfront Park	30.45	29.5	29.2	29.5
9)	10014	Magnolia Bluff	30.60	31.6	28.9	28.7
10)	10045	Pier 3	30.6	29.68	29.2	29.6
11)	10028	Alki Point	30.6	29.60	28.9	29.5
12)	10023	West Point	30.6		28.9	28.9
1)	12062	Reach Island	29.78	27.12	28.9	28.3
2)	12063	Stratch Island	28.62	31.3	28.3	28.3
2)	12131	Ellis Creek	29.40	31.15	28.3	26.4
3)	12132	Olympia Shoal	29.40	31.03	28.3	23.9
4)	12133	Dofflemeyer Point	29.41	29.50	28.9	22.0
22)	09042	Tacoma Stadium H.S.				29.3

Table H-3. Dissolved oxygen (ppm) values for each sampling station.

		Winter	Spring	Summer	Fall	
1)	08004	S.W. Sinclair Inlet	9.40	9.8	6.2	6.55
2)	08005	Sinclair Inlet	4.75	9.4	7.6	7.2
3)	08006	Point Turner	9.22	9.5	7.8	7.6
1)	08106	Port Madison	9.91	9.4	6.6	6.8
2)	08107	Indianola	10.27	7.2	7.0	7.0
1)	09027	Hylebos Basin	7.87	7.0	7.1	5.9
2)	09028	Hylebos Bridge	8.20	7.5	7.7	6.22
3)	09029	Blair Waterway	8.15		7.6	6.32
4)	09030	Sitcum Waterway	8.02		7.2	6.10
5)	09031	City Waterway	7.67		7.2	5.32
6)	09032	Puyallup Waterway	8.65		7.2	
7)	09033	Hylebos Outer		7.7	7.4	6.32
8)	09034	Browns Point South	6.37	7.4	7.3	6.41
9)	09035	Tacoma Corinthian	8.45	7.8	7.9	6.01
10)	09036	ASARCO	8.26	7.0	8.2	7.6
11)	09037	Browns Point		7.7	8.4	6.57
1)	10031	Harbor Island South	9.25	8.36	7.2	7.90
2)	10038	West Waterway	8.65	8.9	8.2	7.89
3)	10039	East Waterway	8.67	8.45	7.7	8.01
4)	10016	Harbor Island North	9.28	8.1	6.5	6.91
5)	10015	Pier 54	9.68	8.6	6.5	7.56
6)	10040	Pier 69	9.40	8.6	5.5	8.2
7)	10044	Elliott Bay	8.44	7.6	6.1	
8)	10041	Waterfront Park	8.86	8.4	7.2	7.85
9)	10014	Magnolia Bluff	8.68	7.6	7.45	6.60
10)	10045	Pier 3	9.17	7.9	6.7	8.25
11)	10028	Alki Point	8.89	7.9	8.0	8.22
12)	10023	West Point	11.36		7.65	7.5
1)	12062	Ruach Island	9.47	7.9	6.2	8.5
2)	12063	Stretch Island		8.2	6.7	9.5
2)	12131	Ellis Creek	9.38	9.1	9.1	9.5
3)	12132	Olympia Shoal	8.86	9.0	6.8	8.7
4)	12133	Dofflemeyer Point		9.0	7.95	9.5
22)	09042	Tacoma Stadium H.S.				6.32

Table H-4. Sediment characteristics of each sampling station.

Sta. No.	Iden. No.	Location	Depth (ft.)	Description	Color	Odor	Appear. of Oil
1)	08004	S.W. Sinclair Inlet	20	silt	gray/green		
			20	"	"		
			20	"	"		
2)	08005	Sinclair Inlet Shipyard	40	sand and silt	brown		
			40	"	"		
			40	"	"		
3)	08006	Point Turner	45	sand and silt	gray/brown		
			45	"	"		
			45	"	"		
1)	08106	Port Madison	300	silt	brown		
			300	"	"		
			300	"	"		
2)	08107	Indianola	60	sand	gray		
			85	sand	gray		
			120	fine sand and silt	brown		
1)	09027	Hylebos Basin	40	silt	black		Sum.
			40	"	"		Sp.
			40	"	"		
2)	09028	Hylebos Bridge	40	clay	gray/brown		Sum.
			40	"	"		Sp.
			40	"	"		
3)	09029	Blair Waterway	44	silt	brown		
			44	"	"		Sum.
			44	sand and silt	"		
4)	09030	Sitcum Waterway	44	silt	gray/brown		Sum.
			44	"	"	SO <sub>2</sub>	Sp.
			44	sand and silt	"		Fall
5)	09031	City Waterway	25	silt	black		Fall
			35	"	"	SO <sub>2</sub>	Sum.
			35	fine sand	brown		
6)	09032	Puyallup Waterway	165	find sand	brown/gray		Sum.
			85	"	"	SO <sub>2</sub>	Sp.
			60	"	"		
7)	09033	Hylebos Outer	80	silt	brown		
			60	"	"		Fall
			140	"	"		
8)	09034	Browns Point South	100	silt	gray/brown		
			85	"	"		Fall
			70	"	"		
9)	09035	Tacoma Corinthian Y.C.	150	sand and gravel	brown		
			110	"	"	SO <sub>2</sub>	Fall
			40	"	"		
10)	09036	ASARCO	50	sand, shell & gravel	brown		
			90	sand	"		Sp.
			120	"	"		
11)	09037	Browns Point	60	sand	brown		
			80	"	"		
			140	"	"		
22)	09042	Tacoma Stadium H.S.	90	sand and silt	brown		
			120	"	"		
			150	"	"		

Table H-4. (Continued)

Sta. Iden. No.	No.	Location	Depth (ft.)	Description	Color	Odor	Appear. of Oil
1)	10031	Harbor Island South	45	clay	brown		Fall
			45	"	black		
			45	sand over clay	tan		
2)	10038	West Waterway	55	tan silt over clay	black		
			60	"	"		
			60	"	"		
3)	10039	East Waterway	45	silt	black		SO <sub>2</sub> odor
			40	"	"		
			45	"	"		
4)	10016	Harbor Island North	50	silt	brown		Fall
			100	sand and silt	"		
			150	silt	"		
5)	10015	Pier 54	85	silt	gray/green		Fall Sum.
			120	"	"	SO <sub>2</sub>	
			160	"	"		
6)	10040	Pier 69	75	silt	gray/green		Fall
			110	"	"		
			150	"	"		
7)	10044	Elliott Bay	300	silt	green		Fall
			300	"	"		
			330	"	"		
8)	10041	Myrtle Edwards Park	80	silt	gray/green		
			110	"	"		
			150	"	"		
9)	10014	Magnolia Bluff	65	sand and silt	brown/gray		Wint. Fall
			110	"	brown o/gray		
			115	sand	brown		
10)	10045	Pier 3	100	gravel, sand, silt	gray		
			150	sand, silt	brown		
			100	gravel, sand, silt	gray		
11)	10028	Alki Point	50	sand	gray		
			100	"	gray/brown		
			150	"	"		
12)	10023	West Point	135	sand	brown		
			70	"	"		
			35	"	"		
1)	12062	Reach Island	20	sand, shell, gravel	gray		
			35	silt	green		
			45	"	"		
2)	12063	Stretch Island	25	sand	gray		
			35	"	"		
			50	silt	green		
3)	12131	Ellis Creek	15	silt	green		
			10	"	gray/brown		
			25	"	"		
4)	12132	Olympia Shoal	35	silt	dark gray		Sum.
			20	"	"		
			10	gravel, sand & silt	"		
5)	12133	Dofflemeyer Point	40	sand and silt	dark gray		
			30	"	"		
			15	sand	"		

Table H-5. Abundance of benthic infaunal invertebrates at each sampling station.

Embayment	MESA Number	Station Number	Approx. Location	Abundance of Organisms Per 1000 cm <sup>3</sup> Mean and (Standard Deviation)			
				Winter	Spring	Summer	Fall
Sinclair Inlet	08004	1	S.W. Sinclair Inlet	42 (8.4)	28 (20)	45 (19)	30 (14)
"	08005	2	Sinclair Inlet	22 (11)	16 (5.8)	34 (14)	36 (18)
"	08006	3	Point Turner	16 (4.4)	23 (4.9)	55 (31)	36 (12)
Port Madison	08106	1	Port Madison	26 (11)	47 (16)	41 (9.5)	29 (17)
"	08107	2	Indianola	31 (12)	54 (30)	73 (19)	64 (21)
Commencement Bay	09027	1	Hylebos Basin	14 (16)	40 (22)	14 (10)	23 (16)
"	09028	2	Hylebos Bridge	17 (13)	16 (5.6)	30 (13)	28 (11)
"	09029	3	Blair Waterway	45 (43)	72 (27)	56 (7.5)	125 (72)
"	09030	4	Sitcum Waterway	46 (38)	40 (25)	14 (13)	35 (25)
"	09031	5	City Waterway	37 (21)	17 (15)	46 (32)	50 (25)
"	09032	6	Puyallup Waterway	81 (17)	30 (14)	86 (22)	None
"	09033	7	Hylebos Outer	62 (19)	112 (48)	156 (24)	179 (34)
"	09034	8	Browns Point South	40 (40)	61 (43)	99 (46)	161 (62)
"	09035	9	Tacoma Corinthian Y.C.	3 (3)	41 (7.2)	48 (12)	91 (44)
"	09036	10	Tacoma Yacht Club	12 (13)	14 (5.7)	45 (35)	24 (17)
"	09037	11	Browns Point	1 (2.8)	23 (18)	38 (15)	46 (16)
"	09042	22	Tacoma Stadium H.S.	None	None	None	236 (61)

Table H-5. (Continued)

Embayment	MESA Number	Station Number	Approx. Location	Abundance of Organisms Per 1000 cm <sup>3</sup> Mean and (Standard Deviation)			
				Winter	Spring	Summer	Fall
Elliott Bay	10031	1	Harbor Island South	58 (62)	26 (8.0)	88 (31)	66 (40)
"	10038	2	West Waterway	14 (11)	15 (15)	20 (19)	24 (25)
"	10039	3	East Waterway	16 (9.3)	-9 (7.3)	32 (17)	29 (5.9)
"	10016	4	Harbor Island North	21 (3.7)	15 (6.3)	39 (13)	24 (11)
"	10015	5	Pier 54	0 (0.0)	7 (1.9)	35 (26)	26 (12)
"	10040	6	Pier 69	0 (0.0)	13 (3.9)	27 (13)	33 (13)
"	10044	7	Elliott Bay	11 (4.7)	15 (7.4)	19 (6.9)	12 (14)
"	10041	8	Myrtle Edwards Park	9 (11)	6 (5.8)	57 (22)	16 (14)
"	10014	9	Magnolia Bluff	16 (4.2)	31 (16)	36 (19)	35 (12)
"	10045	10	Pier 3	36 (11)	40 (22)	50 (24)	45 (17)
"	10028	11	Alki Point	21 (7.6)	30 (11)	70 (61)	42 (26)
"	10023	12	West Point	89 (76)	64 (35)	92 (82)	83 (63)
Case Inlet	12062	1	Reach Island	17 (18)	44 (58)	16 (18)	5 (2.4)
"	12063	2	Stretch Island	9 (5.6)	53 (34)	29 (31)	27 (21)
Budd Inlet	12131	2	Ellis Creek	9 (11)	62 (95)	9 (5)	5 (3.1)
"	12132	3	Olympia Shoal	195 (292)	40 (25)	20 (5.7)	12 (5.5)
"	12133	4	Dofflemeyer Point	21 (27)	55 (43)	31 (13)	39 (31)
	x			29.9	35.3	45.8	46.3

Table H-6. Number of infaunal index taxa in sediment samples (1000 cm<sup>3</sup>) at each sampling station.

		Winter	Spring	Summer	Fall	
1)	08004	S.W. Sinclair Inlet	5	13	9	9
2)	08005	Sinclair Inlet	6	8	10	11
3)	08006	Point Turner	10	16	15	14
1)	08106	Port Madison	12	21	16	12
2)	08107	Indianola	18	22	25	28
1)	09027	Hylebos Basin	6	8	9	10
2)	09028	Hylebos Bridge	12	13	11	14
3)	09029	Blair Waterway	10	14	15	20
4)	09030	Sitcum Waterway	9	11	12	9
5)	09031	City Waterway	13	11	12	15
6)	09032	Puyallup Waterway	8	7	8	
7)	09033	Hylebos Outer	12	18	14	18
8)	09034	Browns Point South	8	16	15	19
9)	09035	Tacoma Corinthian	7	25	26	28
10)	09036	ASARCO	15	14	26	20
11)	09037	Browns Point	3	23	21	26
1)	10031	Harbor Island South	11	8	9	7
2)	10038	West Waterway	8	9	7	14
3)	10039	East Waterway	7	6	7	3
4)	10016	Harbor Island North	13	18	20	14
5)	10015	Pier 54	0	6	14	13
6)	10040	Pier 69	2	12	14	17
7)	10044	Millett Bay	11	11	11	9
8)	10041	Waterfront Park	8	9	21	19
9)	10014	Magnolia Bluff	16	24	24	24
10)	10045	Pier 3	21	24	23	23
11)	10028	Alki Point	19	25	27	27
12)	10023	West Point	20	30	26	17
1)	12062	Reach Island	8	17	16	1
2)	12063	Stretch Island	7	21	14	13
2)	12131	Ellis Creek	5	10	11	4
3)	12132	Olympia Shoal	9	18	12	10
4)	12133	Dofflemeyer Point	15	23	23	18
15)	09042	Tacoma Stadium H.S.				20

APPENDIX I

Best Multiple Regression Equations

DEPENDENT VARIABLE.. RICHNESS TAXON RICHNESS  
 MEAN RESPONSE 6.47931 STD. DEV. 4.67197

MULTIPLE R .65945 ANALYSIS OF VARIANCE OF SUM OF SQUARES MEAN SQUARE F SIGNIFICANCE  
 R SQUARE .43354 REGRESSION 7. 539.41219 77.05887 5.46716 .000  
 ADJUSTED R SQUARE .35425 RESIDUAL 50. 704.74307 14.09496  
 STD DEVIATION 3.75431 COEFF OF VARIABILITY 54.6 PCT

----- VARIABLES IN THE EQUATION -----					----- VARIABLES NOT IN THE EQUATION -----			
VARIABLE	B	STD ERROR B	F SIGNIFICANCE	BETA ELASTICITY	VARIABLE	PARTIAL	TOLEPANCE	F SIGNIFICANCE
DEPTH	-.15048557E-01	.78390676E-02	4.1402394	-.2336298	MEANPHI	.00906	.35655	.49561679
ARENES	.12288903E-03	.47413033E-04	6.7178567	-.13827	PCRS	.09250	.50019	.489
SE	-.95177006E-01	.25880311E-01	13.518937	.12445	CRDS	.04032	.91375	.13542983
CU	-.69392721E-01	.17729437E-01	15.319285	-.4627207	AS	.02391	.06502	.714
HG	-8.6169148	2.0219682	18.161635	-.47456	PS	.04787	.16571	.70793013E-01
CR	.12168634	.55152902E-01	4.8679589	-1.39885	CD	-.02007	.05286	.28025832E-01
ZN	.62855797E-01	.16715619E-01	14.144831	-.7233398				.868
(CONSTANT)	6.9588250	1.8094360	14.790586	-.54557				.739
			.000	.3830139				.19742091E-01
			.000	.78294				.899
			.000	4.1166449				
			.000	1.53829				

STEP	VARIABLE ENTERED	VARIABLE REMOVED	F TO ENTER OR REMOVE	SIGNIFICANCE	MULTIPLE R	R SQUARE	R SQUARE CHANGE	SIMPLE R	OVERALL F	SIGNIFICANCE
1	HG		4.34472	.042	.75833	.07200	.07200	-.26833	4.34472	.042
2	ARENES		5.31557	.025	.99215	.15378	.08178	-.14497	4.99756	.010
3	SE		2.22576	.142	.43276	.18728	.03350	-.24055	4.16788	.010
4	CR		1.88294	.176	.44305	.21516	.02788	-.16519	3.63251	.011
5	DEPTH		1.91984	.172	.49305	.24311	.02794	-.07926	3.34041	.011
6	CU		2.11974	.152	.52279	.27331	.03020	-.16291	3.19691	.010
7	ZN		14.14483	.000	.65945	.43356	.16024	-.13851	5.46716	.000

Table I-1. Best stepwise multiple regression equation for taxon richness in winter, 1979, infaunal samples as a function of selected physical and chemical variables (physical and chemical data except depth collected spring, 1979). "Meanphi" is mean sediment particle size in Phi units.

DEPENDENT VARIABLE.. DIVFVS SHANNON-WEAVER DIVERSITY INDEX

MEAN RESPONSE .53433 STD. DEV. .33444

MULTIPLE R	.59067	ANALYSIS OF VARIANCE	DF	SUM OF SQUARES	MEAN SQUARE	F	SIGNIFICANCE
R SQUARE	.34889	REGRESSION	4	2.22442	.55611	7.09999	.000
ADJUSTED R SQUARE	.29975	RESIDUAL	53	4.15172	.07932		
STD DEVIATION	.27997	COEFF OF VARIABILITY	52.4 PCT				

----- VARIABLES IN THE EQUATION -----					----- VARIABLES NOT IN THE EQUATION -----			
VARIABLE	B	STD ERROR B	F	BETA	VARIABLE	PARTIAL	TOLERANCE	F
			SIGNIFICANCE	ELASTICITY				SIGNIFICANCE
SE	-.44813524E-02	.17776011E-02	6.3412208	-.3044124	DEPTH	-.16839	.95176	1.5174714
CU	-.62279146E-02	.13155744E-02	22.410652	-.25742	MEANPHI	.03947	.37552	.81949729E-01
HG	-.31498334	.10436070	9.1096397	-1.51535	ARENES	.19960	.84452	1.9390397
ZN	.57417291E-02	.12417273E-02	21.381244	-.25676	PCBS	.05749	.65971	.17244744
(CONSTANT)	.64339352	.70751171E-01	82.696307	1.92641	CBDS	-.10974	.98005	.43390344
			0		AS	-.02884	.07004	.43784207E-01
					PS	.23774	.19348	3.1205688
					CR	.17310	.43441	.80012739
					CD	.07924	.05806	.32856611
								.569

STEP	VARIABLE ENTERED	VARIABLE REMOVED	F TO ENTER OR REMOVE	SIGNIFICANCE	MULTIPLE R	R SQUARE	R SQUARE CHANGE	SIMPLE R	OVERALL F	SIGNIFICANCE
1	HG		3.14656	.082	.23065	.05320	.05320	-.23065	3.14656	.082
2	CU		1.27274	.264	.27315	.07461	.02141	-.18479	7.21731	.019
3	ZN		14.54639	.000	.52057	.27099	.17638	-.14827	4.69102	.001
4	SE		6.34122	.015	.59067	.34889	.07790	-.15230	7.09999	.000

Table I-2. Best stepwise multiple regression equation for taxon diversity (Shannon-Weaver Index) in winter, 1979, infaunal samples as a function of selected physical and chemical variables (physical and chemical data except depth collected spring, 1979). "Meanphi" is mean sediment particle size in Phi units.

DEPENDENT VARIABLE.. EVENNESS TAXON EVENNESS  
 MEAN RESPONSE .60541 STD. DEV. .32827

MULTIPLE R .54365 ANALYSIS OF VARIANCE DF SUM OF SQUARES MEAN SQUARE F SIGNIFICANCE  
 R SQUARE .29555 REGRESSION 3. 1.81562 .60521 7.55197 .000  
 ADJUSTED R SQUARE .25641 RESIDUAL 54. 4.32756 .08014  
 STD DEVIATION .28309 COEFF OF VARIABILITY 46.8 PCT

----- VARIABLES IN THE EQUATION -----					----- VARIABLES NOT IN THE EQUATION -----			
VARIABLE	B	STD ERROR B	F	BETA	VARIABLE	PARTIAL	TOLERANCE	F
			SIGNIFICANCE	ELASTICITY				SIGNIFICANCE
CU	-.54516430E-02	.12482549E-02	19.074294	-4.7506293	DEPTH	-.01476	.96355	.11545106E-01
HG	-.35388137	.10532877	11.097536	-1.24875	MEANPHI	-.07652	.67821	.70770727E-01
ZN	.51359858E-02	.11777963E-02	19.015801	-2.5243	ARENES	.06566	.84592	.22946435
(CONSTANT)	.59351149	.50698386E-01	95.610144	1.52095	PCBS	.00168	.76047	.14801007E-03
			.000		CBDS	-.10667	.98134	.61003259
					AS	-.05980	.25768	.19019554
					PB	.10786	.73634	.62387021
					SE	-.09821	.84067	.51621397
					CP	.02851	.48687	.43118493E-01
					CD	-.08132	.56458	.35278907
								.555

STEP	VARIABLE ENTERED	VARIABLE REMOVED	F TO ENTER OR REMOVE	SIGNIFICANCE	MULTIPLE R	R SQUARE	P SQUARE CHANGE	SIMPLE R	OVERALL F	SIGNIFICANCE
1	HG		2.72092	.105	.21526	.04634		-.21526	2.72092	.105
2	CU		.06619	.798	.21791	.04748	.07115	-.07362	1.37387	.282
3	ZN		19.01580	.000	.54365	.29555	.24807	-.03019	7.55187	.000

Table I-3. Best stepwise multiple regression equation for taxon evenness in winter, 1979, infaunal samples as a function of selected physical and chemical variables (physical and chemical data except depth collected spring, 1979). "Meanphi" is mean sediment particle size in Phi units.

DEPENDENT VARIABLE.. ITI      INFAUNAL TROPHIC INDEX  
 MEAN RESPONSE      55.20933      STD. DEV.      28.74730

MULTIPLE R      .52888      ANALYSIS OF VARIANCE      DF      SUM OF SQUARES      MEAN SQUARE      F      SIGNIFICANCE  
 R SQUARE      .27971      REGRESSION      2      9708.53781      4854.26640      7.76664      .001  
 ADJUSTED R SQUARE      .24370      RESIDUAL      40      25000.58347      625.01459  
 STD DEVIATION      25.00029      COEFF OF VARIABILITY      45.3 PCT

----- VARIABLES IN THE EQUATION -----					----- VARIABLES NOT IN THE EQUATION -----			
VARIABLE	B	STD ERROR B	F	BETA	VARIABLE	PARTIAL	TOLERANCE	F
			SIGNIFICANCE	ELASTICITY				SIGNIFICANCE
ZN	.36845654E-01	.13812024E-01	7.1163600	.4482797	DEPTH	.02008	.96738	.15737329E-01
CD	-5.0493799	1.2872919	15.385870	.14141	MEANPHI	.14585	.49044	.84759670
(CONSTANT)	88.079173	9.7007803	82.439077	-.73678	ARFNES	-.03296	.96281	.42421009E-01
			.000		PCBS	.11571	.81047	.52922189
					CROS	.13155	.99585	.68684065
					AS	-.13197	.14309	.69129644
					PB	-.24243	.24727	.4352497
					HG	.07522	.90116	.10646194E-02
					CU	-.02098	.09906	.17171843E-01
					SE	-.02704	.39686	.29533212E-01
					CP	.04155	.56725	.57461026E-01
								.796

STEP	VARIABLE ENTERED	VARIABLE REMOVED	F TO ENTER OR REMOVE	SIGNIFICANCE	MULTIPLE R	R SQUARE	R SQUARE CHANGE	SIMPLE R	OVERALL F	SIGNIFICANCE
1	CD		7.32430	.010	.38931	.15157	.15157	-.38931	7.32430	.010
2	ZN		7.11636	.011	.52599	.27971	.12815	.05152	7.76664	.001

Table I-4. Best stepwise multiple regression equation for Infaunal Trophic Index in winter, 1979, infaunal samples as a function of selected physical and chemical variables (physical and chemical data except depth collected spring, 1979). "Meanphi" is mean sediment particle size in Phi units.

DEPENDENT VARIABLE.. TA TOTAL ABUNDANCE  
 MEAN RESPONSE 25.17241 STD. DEV. 29.76819

MULTIPLE R .38145 ANALYSIS OF VARIANCE DF SUM OF SQUARES MEAN SQUARE F SIGNIFICANCE  
 R SQUARE .14550 REGRESSION 2. 7349.37614 3674.68907 4.48254 .013  
 ADJUSTED R SQUARE .11443 RESIDUAL 55. 43160.89977 784.74343  
 STD DEVIATION 28.01328 COEFF OF VARIABILITY 107.0 PCT

----- VARIABLES IN THE EQUATION -----					----- VARIABLES NOT IN THE EQUATION -----			
VARIABLE	B	STD ERROR B	F SIGNIFICANCE	BETA ELASTICITY	VARIABLE	PARTIAL	TOLERANCE	F SIGNIFICANCE
CR	-.89573043	.31586149	7.8693898 .007	-.4375439 -1.43792	DEPTH	-.11736	.94432	.78042727 .381
MEANPHI	6.5196154	2.4456056	7.1067513 .010	.4159427 1.39261	ARENES	-.13412	.98793	.98914591 .324
(CONSTANT)	29.190562	12.847344	5.1644981 .027		PCBS	.04440	.81095	.10666228 .745
					CBDS	.07158	.85407	.27810714 .600
					AS	.10121	.91448	.55892097 .458
					PB	.22818	.78285	2.9659916 .091
					HG	-.01371	.50475	.101577115-01 .920
					CJ	.25067	.90189	3.6207265 .062
					ZN	.24308	.87781	3.3909912 .071
					SE	-.17879	.56070	1.7532452 .187
					CO	-.01022	.50819	.56377226E-02 .940

STEP	VARIABLE ENTERED	VARIABLE REMOVED	F TO ENTER OR REMOVE	SIGNIFICANCE	MULTIPLE R	R SQUARE	P SQUARE CHANGE	SIMPLE R	OVERALL F	SIGNIFICANCE
1	CR		2.03649	.159	.18732	.03500		-.18732	2.03649	.159
2	MEANPHI		7.10675	.010	.38145	.14550	.11041	.15276	4.68266	.013

Table I-5. Best stepwise multiple regression equation for total abundance of organisms in winter, 1979, infaunal samples as a function of selected physical and chemical variables (physical and chemical data except depth collected spring, 1979). "Meanphi" is mean sediment particle size in Phi units.

DEPENDENT VARIABLE.. DWTJTL ESTIMATED TOTAL DRY WEIGHT  
 MEAN RESPONSE .07265 STD. DEV. .15255

MULTIPLE R .33274 ANALYSIS OF VARIANCE DF SUM OF SQUARES MEAN SQUARE F SIGNIFICANCE  
 R SQUARE .11072 REGRESSION ? .14686 .07343 3.42383 .040  
 ADJUSTED R SQUARE .07838 RESIDUAL 55. 1.17950 .02145  
 STD DEVIATION .14645 COEFF OF VARIABILITY 201.6 PCT

----- VARIABLES IN THE EQUATION -----					----- VARIABLES NOT IN THE EQUATION -----			
VARIABLE	B	STD ERROR B	F SIGNIFICANCE	BETA ELASTICITY	VARIABLE	PARTIAL	TOLFRANCE	F SIGNIFICANCE
MEANPHI	.35853851E-01	.13955213E-01	6.6008319 .013	.4463884 2.73913	DEPTH	-.14690	.96749	1.1910673 .280
CD	-.16468613E-01	.77887505E-02	4.4707303 .039	-.3673693 -1.73973	ARENES	-.08970	.98979	.42825752 .4516
(CONSTANT)	.43837959E-04	.60266659E-01	.52911054E-06 .999		PCBS	-.05416	.79011	.15984160 .492
					CBDS	-.08367	.97373	.39067190 .540
					AS	.13750	.21666	1.0406151 .312
					PR	.15077	.48542	1.2560699 .267
					HG	.12666	.69767	.89040110 .352
					CU	.17475	.59524	1.7008908 .198
					ZN	.17803	.56031	1.7676041 .189
					SE	-.11568	.32942	.73237807 .396
					CP	.13893	.67547	1.0624182 .307

STEP	VARIABLE ENTERED	VARIABLE REMOVED	F TO ENTER	F TO REMOVE	SIGNIFICANCE	MULTIPLE R	R SQUARE	R SQUARE CHANGE	SIMPLE R	OVERALL F	SIGNIFICANCE
1	MEANPHI		2.23821		.140	.19504	.03843	.03843	.19504	2.23821	.140
2	CD		4.47073		.039	.33274	.11072	.07229	-.06317	3.42383	.040

Table I-6. Best stepwise multiple regression equation for biomass (estimated total dry weight) in winter, 1979, infaunal samples as a function of selected physical and chemical variables (physical and chemical data except depth collected spring, 1979). "Meanphi" is mean sediment particle size in Phi units.

DEPENDENT VARIABLE.. RICHNESS TAXON RICHNESS  
 MEAN RESPONSE 5.77417 STD. DEV. 4.07981

MULTIPLE R .58656 ANALYSIS OF VARIANCE OF SUM OF SQUARES MEAN SQUARE F SIGNIFICANCE  
 R SQUARE .34409 REGRESSION 4. 349.15812 87.29053 7.47431 .000  
 ADJUSTED R SQUARE .29802 RESIDUAL 57. 665.68759 11.67441  
 STD DEVIATION 3.41740 COEFF OF VARIABILITY 50.402

----- VARIABLES IN THE EQUATION -----					----- VARIABLES NOT IN THE EQUATION -----			
VARIABLE	B	STD ERROR B	F	BETA	VARIABLE	PARTIAL	TOLERANCE	F
			SIGNIFICANCE	ELASTICITY				SIGNIFICANCE
MS	-3.3392042	1.66424543	4.1333231	-.3147918	MEANPHI	-.30509	.28201	.19439331E-02
CP	.111146339	.47790352E-01	5.4594111	-.20344	ARFNES	.25245	.77034	3.9120160
CD	-1.0839244	.28047291	15.098415	.71294	PCRS	.18336	.52090	1.9483162
AS	.17454191E-01	.84546034E-02	4.2617043	-.070	CRDS	.11098	.90913	.52707614
(CONSTANT)	10.904157	1.7793722	37.553517	-.20135	PH	.11727	.30907	.7909904
			0	.09229	CIH	-.05994	.17436	.20174533
					ZV	-.02582	.16344	.36494917E-01
					SF	.04024	.20547	.90831065E-01
								.784

STEP	VARIABLE ENTERED	VARIABLE REMOVED	F TO ENTER OR REMOVE	SIGNIFICANCE	MULTIPLE R	R SQUARE	R SQUARE CHANGE	ADJUSTED R SQUARE	OVERALL F	SIGNIFICANCE
1	MS		15.94956	.000	.45717	.20806	.20806	-.45712	15.94956	.000
2	AS		5.17904	.027	.52230	.27279	.27279	-.21276	11.06627	.000
3	CR		1.95324	.168	.54481	.29540	.29540	-.22682	8.14781	.000
4	MS		4.13332	.047	.59555	.34405	.34405	-.34829	7.47431	.000

Table I-7. Best stepwise multiple regression equation for taxon richness in spring, 1979, infaunal samples as a function of selected physical and chemical variables. "Meanphi" is mean sediment particle size in Phi units.

DEPENDENT VARIABLE.. ITI INFANAL TROPHIC INDEX  
 MEAN RESPONSE 63.45217 STD. DEV. 19.15122

MULTIPLE R .53621 ANALYSIS OF VARIANCE DF SUM OF SQUARES MEAN SQUARE F SIGNIFICANCE  
 R SQUARE .28752 REGRESSION 5. 6221.73439 1244.34598 4.35330 .002  
 ADJUSTED R SQUARE .22155 RESIDUAL 54. 15417.64553 285.51195  
 STD DEVIATION 16.89710 COEFF OF VARIABILITY 26.6 PCT

VARIABLES IN THE EQUATION					VARIABLES NOT IN THE EQUATION				
VARIABLE	R	STD ERROR B	F SIGNIFICANCE	BETA PLASTICITY	VARIABLE	PARTIAL	TOLERANCE	F SIGNIFICANCE	
CJ	-.51241394E-01	.19117879E-01	7.1839359 .010	-.7537743 +.10941	MEANPHI	-.03233	.27832	.55446821E-01 .815	
PCRS	.34995131E-01	.11201051E-01	9.7610753 .003	.5145998 .12537	ARFNS	.17840	.83025	.63014947 .431	
CR	.71347483	.24034303	8.8124010 .004	.5454173 .60287	CBDS	-.01215	.65570	.78409877E-02 .930	
CD	-10.036465	2.1753108	21.287242 .000	-1.7835973 -1.13543	P9	-.01376	.21902	.10040497E-01 .021	
AS	.35833017	.91066891E-01	15.482666 .000	1.8518289 .18534	YS	.13403	.37855	.06953325 .329	
(CONSTANT)	96.475507	2.5036223	103.05207 .000		ZH	.04437	.01035	.47521477 .493	
					SE	-.06947	.06862	.19448055 .661	

STFP	VARIABLE ENTERED	VARIABLE REMOVED	F TO ENTER OR REMOVE	SIGNIFICANCE	MULTIPLE R	R SQUARE	R SQUARE CHANGE	SIMPLE P	OVERALL F	SIGNIFICANCE
1	CD		2.87888	.095	.21745	.04729	.04729	-.21745	2.87934	.095
2	AS		3.44530	.069	.31973	.10159	.05430	-.03392	3.22274	.047
3	PCRS		3.34304	.073	.39713	.15220	.05061	-.01865	3.35118	.025
4	CR		2.76140	.102	.43301	.19273	.04053	-.04169	3.28272	.017
5	CJ		7.18394	.010	.53521	.28752	.03479	-.00776	4.35330	.002

Table I-8. Best stepwise multiple regression equation for Infaunal Trophic Index in spring, 1979, infaunal samples as a function of selected physical and chemical variables. "Meanphi" is mean sediment particle size in Phi units.

DEPENDENT VARIABLE.. TA TOTAL ABUNDANCE  
 MEAN RESPONSE 34.45774 STD. DEV. 43.73155

MULTIPLE R .34643 ANALYSIS OF VARIANCE OF SUM OF SQUARES MEAN SQUARE F SIGNIFICANCE  
 R SQUARE .17002 REGRESSION 1. 14000.95928 14000.95928  
 ADJUSTED R SQUARE .10535 RESIDUAL 50. 102658.47620 1710.97440  
 STD DEVIATION 41.76393 COEFF OF VARIABILITY 107.5 PCT 3.14303 .006

VARIABLES IN THE EQUATION					VARIABLES NOT IN THE EQUATION			
VARIABLE	B	STD ERROR B	F SIGNIFICANCE	BETA ELASTICITY	VARIABLE	PARTIAL TOLERANCE	F SIGNIFICANCE	
HG	-38.90577	13.600634	8.1830316 .006	-.3454328 -.41741	MEANPHI	.12031 .66725	.86567416 .356	
(CONSTANT)	54.524613	7.6878740	50.300544 .000		ARENES	.16535 .86547	1.6584796 .203	
					PCRS	-.04434 .74397	.17472593 .677	
					CRDS	.00607 .99968	.21764536F-02 .963	
					AS	-.02956 .99969	.91600075E-01 .921	
					PB	.01542 .96151	.14035469E-01 .906	
					CU	.04672 .95870	.12907486 .721	
					ZN	.04414 .93879	.11515747 .736	
					SE	-.10550 .94190	.66410800 .418	
					CR	-.05265 .50852	.16401042 .687	
					CD	-.02756 .86862	.44862956E-01 .833	

STEP	VARIABLE ENTERED	VARIABLE REMOVED	F TO ENTER	F TO REMOVE	SIGNIFICANCE	MULTIPLE R	R SQUARE	R SQUARE CHANGE	SIMPLE R	OVERALL F	SIGNIFICANCE
1	HG		8.18303		.006	.34543	.12002	.12002	-.34643	8.18303	.006

Table I-9. Best stepwise multiple regression equation for total abundance of organisms in spring, 1979, infaunal samples as a function of selected physical and chemical variables. "Meanphi" is mean sediment particle size in Phi units.