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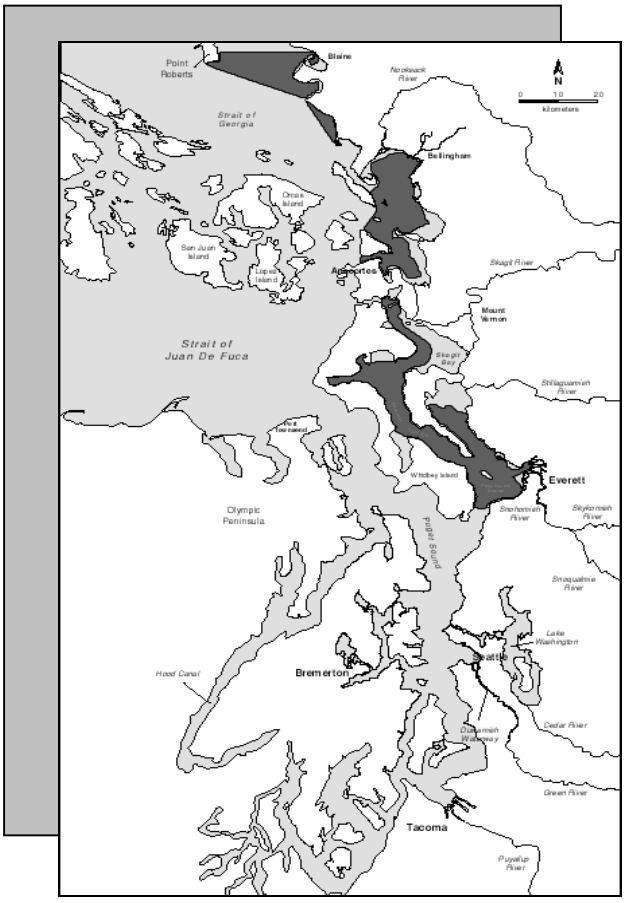
WASHINGTON STATE DEPARTMENT OF ECOLOGY

Sediment Quality in Puget Sound

Year 1 - Northern Puget Sound

December 1999



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by

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WA-07-1005	

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Acronyms and Abbreviations

AVS/SEM – acid volatile sulfides/ simultaneously-extracted metals
b[a]p – benzo[a]pyrene
BNA – base/neutral/acid organic compound analysis
CAS – Columbia Analytical Services
CLIS – Central Long Island Sound
COH – chlorinated organic hydrocarbons
CSL – cleanup screening level (Washington State Sediment Management Standards – chapter 173-204 WAC)
CV – coefficient of variation
DCM – dichloromethane
DMSO – dimethylsulfoxide
EC50 – 50% effective concentration; concentrations of the extract that inhibited luminescence by 50% after a 5-minute exposure period (Microtox™ analysis)
ERL – effects range low (Long et al., 1995)
ERM – effects range median (Long et al., 1995)
LC50 – lethal concentration for 50% of test animals
LOEC – lowest observable effects concentration
LPL – lower prediction limit
MEL – Manchester Environmental Laboratory
MSMT – Marine Sediment Monitoring Team
NOAA – National Oceanic and Atmospheric Administration
NOEC – no observable effects concentration
NS&T – National Status and Trends Program
PAH – polynuclear aromatic hydrocarbon
PCB – polychlorinated biphenyl
PSAMP – Puget Sound Ambient Monitoring Program
QL – quantitation limit reported by Manchester Environmental Laboratory for chemistry data
RGS – reporter gene system
RLU – relative light unit
SDI – Swartz's Dominance Index
SDS – sodium dodecyl sulfate
SMS – Sediment Management Standards
SQS – sediment quality standard (Washington State Sediment Management Standards – chapter 173-204 WAC)
TAN – total ammonia nitrogen
TCDD – tetrachlorodibenzo-p-dioxin
TEQ – total equivalency quotients
TOC – total organic carbon
UAN – un-ionized ammonia
UPL – upper prediction limit

Abstract

As a component of a three-year cooperative effort of the Washington State Department of Ecology and the National Oceanic and Atmospheric Administration, sediments from 100 locations in northern Puget Sound were tested to determine their relative quality. The purpose of this survey was to determine the quality of sediments in terms of the severity, spatial patterns, and spatial extent of chemical contamination, toxicity, and alterations to benthic infauna. The survey area encompassed the region from Port Gardner Bay north to the US/Canada border, excluding the San Juan Islands. Surficial sediments were tested and analyzed from each of the 100 locations. Data from the chemical analyses indicated that toxicologically significant contamination was restricted in scope to a relatively small portion of the region. The spatial extent of relatively severe contamination varied considerably among chemicals; however, less than 2% of the area was considered "contaminated" for most substances. Sediments from several sampling locations within Everett Harbor often had the highest chemical concentrations. In addition, samples from some stations in Bellingham Bay and other locations scattered throughout the study area had elevated concentrations of some substances. Data from four kinds of toxicity tests indicated a similar pattern: the degree of toxicity was highest in samples from Everett Harbor followed by those from other locations scattered within the survey region. The spatial extent of significant toxicity ranged from 0% to 5% among the toxicity tests. Wide ranges in several numerical indices of benthic infaunal structure indicated good correspondence with tests of toxicity and the concentrations of numerous chemical substances. That is, there was evidence of altered benthic populations in some areas nearest urban centers. Chemical contamination and toxicity of sediments were less severe in northern Puget Sound than in many other estuarine areas studied in the U.S. by NOAA. Results from similar analyses of samples from the central Puget Sound (sampled in 1998) and southern Puget Sound (sampled in 1999) will be compiled with the data from northern Puget Sound, to provide a broad-scale evaluation and quantitation of the spatial scales and patterns in sediment quality throughout the entire region.

Executive Summary

Numerous studies of Puget Sound have documented the degree of chemical contamination and associated adverse biological effects within many different urbanized bays and harbors. Data from previous research have shown that contamination occurred in sediments, water, sea surface microlayers, fishes, benthic invertebrates, sea birds, and marine mammals in parts of Puget Sound. In addition, the occurrence of severe toxicity of sediments in laboratory tests, significant alterations to resident benthic populations, histopathological conditions in the organs of demersal fishes, reduced reproductive success of demersal fishes and marine mammals, acute toxicity of sea surface microlayers, and bioaccumulation of toxicants in sea birds and marine mammals suggested that chemical contamination was toxicologically significant in Puget Sound. None of the previous surveys, however, attempted to quantify and report the areal or spatial extent of contamination or toxicant-related effects.

The overall goal of the cooperative program – initiated by the Washington State Department of Ecology (Ecology) as a part of the Puget Sound Ambient Monitoring Program (PSAMP), and the National Oceanic and Atmospheric Administration (NOAA) as a part of its National Status and Trends (NS&T) Program – was to quantify the percentage of Puget Sound in which sediment quality is significantly degraded. The approach selected to accomplish this goal was to measure the components of the sediment quality triad at sampling locations chosen with a stratified-random design. In the first year of this three-year study, one hundred samples were collected during June-July 1997, at locations selected randomly within 33 geographic strata that covered the area from Port Gardner Bay near Everett to the US/Canada border (i.e., northern Puget Sound). Strata were selected to represent conditions near four major urban centers (Everett, Anacortes, Bellingham, Blaine) and marine areas between these cities. The 33 strata were determined to encompass an area of 774 km^2.

A battery of four toxicity tests was performed on all samples to provide information from a variety of toxicological endpoints. Results were obtained from an acute test of survival among marine amphipods exposed to solid phase sediments, a test of fertilization success among sea urchin gametes exposed to pore waters, a microbial bioluminescence test of metabolic activity in exposures to organic solvent extracts, and a Cytochrome P450 RGS activity test in exposures to portions of the same solvent extracts. Chemical analyses were performed on all samples to quantify the concentrations of trace metals, petroleum constituents, chlorinated pesticides, other organic compounds, and the physical characteristics of the sediments. Chemical concentrations were compared to applicable numerical guidelines from NOAA and state criteria for Washington. Resident benthic infauna were collected to determine the relative abundance, species richness, species composition, and other characteristics of animals living in the sediments at each site.

Mean percent survival of the amphipods was statistically significantly different from negative (non-toxic) controls in 13 of the 100 samples. However, none of the results were “highly” significant (i.e., mean survival less than 80% of Central Long Island Sound (CLIS) controls); therefore, the spatial extent of toxicity was estimated to be 0% in this test. In the sea urchin fertilization tests performed with 100% pore waters, 15% of the samples were “highly” toxic

relative to Redfish Bay, Texas controls. The incidence of toxicity decreased to 8% and 5% in tests performed with 50% and 25% strength porewater concentrations, respectively. The stations in which highly significant results were recorded in the three porewater concentrations represented approximately 5.2%, 1.5%, and 0.8%, respectively, of the study area.

In the microbial bioluminescence (Microtox^{TM}) tests, results from 97 of the 100 samples were significantly different from the negative controls collected in Redfish Bay, Texas. However, the control response was determined to be highly unusual relative to those reported in many previous surveys in which this test was performed. Comparisons of the results with the negative control had the effect of exaggerating the degree of toxicity in the Puget Sound samples. Therefore, other procedures more suitable to the Puget Sound data were developed to aid in data interpretation. Using these, the spatial extent of toxicity in the microbial bioluminescence tests was determined to be approximately 2.3% of the area (significant response) and 0% of the area (highly elevated response). Using a similar set of statistical tools, the results of the Cytochrome P450 RGS assay indicated significant induction in samples representing approximately 2.6% of the area and highly elevated induction in samples representing 0.03% of the area.

Results of the four toxicity tests indicated a very small proportion (<5.2%) of the survey area (the total encompassing 774 km^2) was highly toxic. Although the amphipod survival tests failed to show any samples as highly toxic, the three other tests indicated samples from Everett Harbor were the most toxic. The Cytochrome P450 RGS and Microtox^{TM} tests showed a very clear gradient of increasing toxicity from the entrance to the head of Everett Harbor. Less severe toxicity was observed in samples from stations scattered throughout the survey area; including some from Drayton Harbor, Whatcom Waterway, other portions of Bellingham Bay, inner Padilla Bay, March Point, Fidalgo Bay, Port Susan, and Port Gardner. Sediments from Saratoga Passage, Possession Sound, and most of Port Gardner Bay were among the least toxic in these tests.

Based upon results of the same kinds of tests performed by NOAA elsewhere in U.S. estuaries, sediments from northern Puget Sound were among the least toxic. Highly significant toxicity was restricted in scope to relatively small strata sampled nearest the urban centers.

Results of chemical analyses indicated that relatively wide ranges in concentrations of some substances occurred among the 100 samples. However, only a small proportion of the samples had elevated concentrations of most substances. There were only five samples in which at least one trace metal concentration equaled or exceeded the State of Washington Sediment Quality Standard (SQS) and only two samples in which a trace metal concentration equaled or exceeded a NOAA Effects Range-Median (ERM) value. These stations represented about 13 km^2 and 9 km^2, respectively, equivalent to approximately 1.7% and 1.2% of the total study area. The state Cleanup Screening Levels (CSL) for arsenic, copper, and mercury were exceeded in one sample each. The sums of low and high molecular weight polynuclear aromatic hydrocarbons (PAH) exceeded respective ERM values in 8 samples and one sample, respectively, representing in both cases <0.1% of the total area. None of the PAH concentrations exceeded Washington SQS or CSL levels. Total PCB concentrations exceeded the ERM and the SQS values in the same sample (inner Everett Harbor), representing <0.1% of the total study area.

In contrast to this pattern of highly localized contamination and toxicity indicated by most of the data, concentrations of phenols, phthalate esters, and benzoic acid were elevated above SQS and CSL values in many of the samples and indicated much more widespread contamination (i.e., in excess of state standards). Samples with high concentrations of these substances were collected throughout the area.

Overall, chemical concentrations were highest in sediments from the two most urbanized embayments: Everett Harbor and Bellingham Bay. This pattern was most evident for several trace metals and two classes of PAHs. PAH concentrations also were above NOAA Effects Range-Low (ERL) concentrations in sediments collected in Fidalgo Bay. In contrast to these patterns, one sample with a very high mercury concentration was collected in southern Boundary Bay, far from obvious nearby sources.

Although the study was not intended to determine the causes of toxicity in the tests, a number of statistical analyses were conducted to estimate which chemicals, if any, were correlated with toxicity. As expected, strong statistical associations between measures of toxicity and complex mixtures of PAHs, pesticides, phenols, other organic compounds, and several trace metals were observed. The chemistry-toxicity relationships were most apparent among the samples from Everett Harbor. It was apparent that the statistical associations observed throughout the study area were driven in large part by the data from Everett Harbor. Samples from Everett Harbor that indicated highest toxicity in the Cytochrome P450 RGS, Microtox™, and sea urchin tests also had high concentrations of PAHs, other organics, and several trace metals. One sample from the innermost station in Everett Harbor that indicated the highest induction level in the Cytochrome P450 RGS assay also had quantifiable concentrations of dioxins.

Results of the benthic population analyses indicated a very wide range in abundance and diversity among sampling stations. Total abundance of benthic infauna ranged over two orders of magnitude among stations. The abundance of arthropods ranged over four orders of magnitude from 2062 animals per sample to none. The infauna in sediments from Everett Harbor stations often were devoid of molluscs and/or echinoderms, had low species richness, and were dominated by annelids. In contrast, the infauna in samples from some locations in Padilla Bay were among the most abundant and diverse. Several indices of benthic infauna structure showed strong statistical associations with the concentrations of several groups of toxicants. For example, indices of taxa richness and mollusc abundance were negatively correlated with the concentrations of many organics (particularly mixtures of pesticides) and metals. Benthic population indices also were correlated significantly with some measures of toxicity. There was a particularly strong correlation between the results of the sea urchin fertilization tests and the abundance of echinoderms (the phylum in which sea urchins belong) in the benthos.

Collectively, the data from the chemical analyses, toxicity tests, and benthic analyses indicated that sediment quality throughout much of the study area was very good. In the majority of samples, most chemical concentrations were below effects-based numerical guidelines or criteria, most toxicity tests showed non-significant results, and most benthic populations were abundant and diverse. Expressed as the proportion of the study area, most indices of sediment quality indicated that less than 5% of the area was either highly toxic or significantly contaminated. Sediments from inner Everett Harbor, however, had much higher concentrations of many

toxicants, were highly toxic in three of the four toxicity tests, and had benthic populations with low species richness and abundance relative to other sampling locations.

Among the 100 sampling stations, there were eighteen locations (Drayton Harbor, Bellingham Bay, Padilla Bay, Fidalgo Bay, Everett Harbor, and Port Gardner) in which at least one chemical concentration exceeded a guideline value, at least one of the toxicity tests indicated highly toxic conditions, and several indices of benthic community structure showed reduced infaunal diversity and abundance. Of these eighteen stations, the combined suite of triad data from the nine Everett Harbor stations and possibly station 97 in Port Gardner display characteristics that provide "strong evidence of pollution-induced degradation".

In contrast, 16 of the 100 stations, scattered throughout the study area, display no significant toxicity or chemistry values, and have a wide range of infaunal parameters that could be attributed to naturally occurring environmental variables. For these stations, the triad parameters provide "strong evidence against pollution-induced degradation". The 66 other stations in the study area displayed relatively poor correspondence among the data from the three components of the triad. Additional statistical analyses are required to fully describe the multivariate relationships among the different types of sediment quality data.

Data from this study conducted in 1997 provide the basis for quantifying changes in sediment quality, if any, in northern Puget Sound in future years. By using the same sampling and analytical design and, therefore, generating comparable data, the state of Washington can measure improvements or losses in sediment quality in terms of the percentage of the area that is degraded. Data from this area can be merged with those from central Puget Sound (sampled in 1998) and southern Puget Sound (sampled in 1999) to provided an area-wide assessment of the quality of sediments in the entire Puget Sound Basin.

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Introduction

Project Background

In October 1996, the Washington State Department of Ecology (Ecology) and the National Oceanic and Atmospheric Administration (NOAA) entered into a three-year Cooperative Agreement to quantify the magnitude and extent of toxicity and chemical contamination of sediments in Puget Sound. This agreement combined the efforts of the two agencies' ongoing sediment monitoring and assessment programs.

Ecology's Marine Sediment Monitoring Team (MSMT) has conducted the Sediment Monitoring Component of the Puget Sound Ambient Monitoring Program (PSAMP) since 1989, utilizing the Sediment Quality Triad approach (Long and Chapman, 1985). Baseline data were established for toxicity and chemical contamination of Puget Sound sediments (Llansó et al., 1998a), and infaunal invertebrate assemblages were characterized (Llansó et al., 1998b) at 76 selected monitoring stations throughout Puget Sound. A portion of this baseline work is continuing at a subset of ten of these original stations.

NOAA's National Status and Trends (NS&T) Program has conducted bioeffects assessments in more than 30 estuaries nationwide since 1990 (Long et al., 1996). NOAA's surveys use a random-stratified sampling design and the Sediment Quality Triad approach to determine the spatial extent and patterns of toxicity, and the relationships among toxicity, chemistry, and infauna of sediments sampled from strata chosen within an estuary. In 1997, NOAA chose to initiate these bioeffects assessments in Puget Sound for three reasons: the presence of toxicants in sufficiently high concentrations to cause adverse biological effects, the lack of quantitative data on the spatial extent of effects, and the presence and experience of a state-level partner (Ecology) in performing the study

The current joint PSAMP/NOAA project utilizes NOAA's random-stratified sampling design and the Sediment Quality Triad approach for collection and analysis of sediment and infauna in northern Puget Sound in 1997, central Puget Sound in 1998, and southern Puget Sound in 1999. Results of the 1997 sampling and analysis efforts are the focus of this report.

Site Description

Puget Sound is a fjord-like estuary located in northwestern Washington. It is bounded by three major mountain ranges: the Olympics to the west, the mountains of Vancouver Island and the Coast Mountains to the northwest, and the Cascade Range to the east. The northern end of Puget Sound is open to the Strait of Juan de Fuca and Strait of Georgia, connecting it with the Pacific Ocean (Konasewich et al., 1982). The estuary extends for about 130 km from Admiralty Inlet at the northern end, to Olympia at the southern tip, and varies from 10 to 40 km in width (Kennish, 1998).

The Puget Sound Basin is glacially scoured, with depths to approximately 300 meters, and has an area of 2600 km^2 and a volume of 169 km^3 (Kennish, 1998). Circulation patterns in Puget Sound are driven largely by freshwater inputs, tides, and winds. Puget Sound is characterized by a two-layered estuarine system with marine waters entering the Sound through the Strait of Juan de Fuca at depths of 100 to 200 m with net surface outflow. The mean residence time for water in the central basin is approximately 120-140 days, but is much longer in isolated inlets and in restricted, deep basins (Kennish, 1998). Freshwater enters the Puget Sound estuary via precipitation, surface runoff, groundwater inflow and various rivers. Major rivers include the Skagit, Snohomish, Cedar, Duwamish, Puyallup, Stillaguamish, and the Nisqually (Figure 1). The Skagit, Stillaguamish, and Snohomish rivers account for more than 75% of the freshwater input into the Sound (Kennish, 1998).

The bottom sediments of Puget Sound are composed primarily of compact, glacially formed clay layers and relict glacial tills (Crandell et al., 1965). Major sources of sediments to Puget Sound are derived from shoreline erosion and from river discharge.

The Puget Sound estuary is a highly complex, biologically important ecosystem with numerous commercial and recreational uses. The Sound is surrounded by both rural and urban areas. The major urban centers include the cities of Bellingham, Everett, Seattle, Bremerton, Tacoma, and Olympia (Figure 1).

This report focuses on analyses of sediment samples collected in northern Puget Sound. The study area (Figure 1) ranged from Boundary Bay at the Canadian border, south through Everett Harbor, and excluded Admiralty Inlet, eastern Strait of Juan de Fuca, and the San Juan Islands. Information available for southern Strait of Georgia, the San Juan Islands, Rosario Strait, Haro Strait, Deception Pass, and eastern Strait of Juan de Fuca indicated they were not likely to be contaminated or they were not depositional areas. Therefore, they were excluded from the study area. Also excluded were areas in which water depths were less than 6 feet, to avoid grounding the sampling vessel. The northern Puget Sound study area included most of the protected basins of the area and three major urban centers: the cities of Bellingham, Anacortes, and Everett. This study area also included areas influenced by four major sources of freshwater: the Nooksack, Skagit, Stillaguamish, and Snohomish Rivers.

Historical Background

Sources of Contaminants in Northern Puget Sound

For more than a century, Puget Sound has been a major repository of various types of wastes derived from municipal and industrial wastewater discharges, combined sewer overflows (CSOs), storm drains, dumping operations, chemical spills, and urban and agricultural runoff. These wastes, which include heavy metals, polynuclear aromatic hydrocarbons (PAHs), and chlorinated hydrocarbons (Barrick et al., 1987; Kennish, 1998), enter northern Puget Sound in both dissolved and particulate phases from both direct and indirect sources from the Strait of Juan de Fuca, rivers, streams, runoff and rainwater.

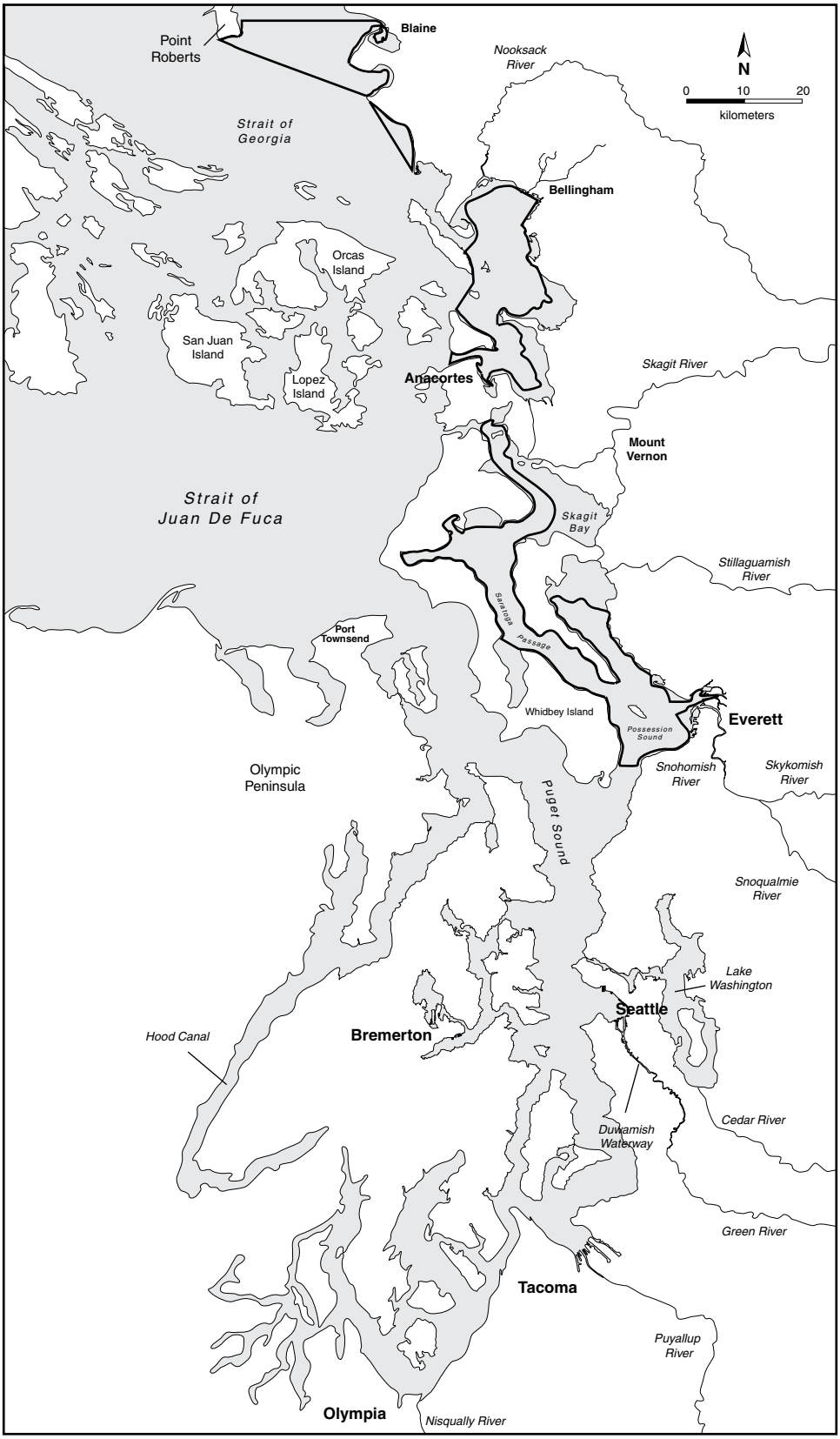

Figure 1. Map of the Puget Sound study area for the NOAA/PSAMP Cooperative Agreement. The areas sampled during 1997 are outlined.

Specific anthropogenic sources of heavy metal contamination in northern Puget Sound include sewage effluent, industrial wastewater, municipal wastewater discharge, shipping, land runoff, automobile emissions, and atmospheric deposition. Sources of PAHs in northern Puget Sound include sewage and industrial effluents, waste incineration, oil spills, asphalt production, creosote oil, and the combustion of fossil fuels. Halogenated hydrocarbons, among the most persistent, ubiquitous, and toxic pollutants found in Puget Sound, have been linked to industrial and agricultural runoff, sewage effluent, and the use of aerosol propellants, coolants, dry cleaning fluids, and industrial solvents (Kennish, 1998).

Further details concerning historical sources of chemical contamination and the physical processes that influence the fate and transport of toxicants in regions of Puget Sound are available in the following summaries: Brown et al., 1981; Dexter et al., 1981; Barrick, 1982; Konasewich et al., 1982; Long 1982; Crecelius et al., 1985; and Quinlan et al., 1985.

Toxicant-Related Research in Northern Puget Sound

Numerous studies have generated data on the presence and concentrations of toxicants and their associated adverse effects in Puget Sound, including measures of contamination, toxicity, and benthic community effects in sediments. The objectives of most of the historical studies in Puget Sound were to determine if potentially toxic substances occurred in Puget Sound, to identify where they occurred, and to measure their adverse biological effects. However, most of these studies were conducted in central Puget Sound (particularly Elliott and Commencement bays), and relatively few samples were taken in the current northern Puget Sound study area. The following is a brief summary of sampling conducted in northern Puget Sound.

In the early 1980's, studies performed by NOAA through the MESA (Marine Ecosystems Analysis) Puget Sound Project determined the concentrations of toxic substances and toxicity in sediments. The studies included a battery of acute and chronic tests performed on samples collected throughout most of the Puget Sound region. The sediment toxicity surveys were conducted in a sequence of four phases.

In the first phase (Chapman et al., 1982), samples collected from 97 locations were tested with several bioassays. The majority of samples were collected within Elliott Bay, Commencement Bay, and Sinclair Inlet, south of the current study area. In northern Puget Sound, samples were collected in Birch Bay, and were among the least toxic in the study area. In the second phase of the study, none of the samples were collected from northern Puget Sound.

In the third phase, 22 samples were collected in Everett Harbor, Bellingham Bay, and Samish Bay in northern Puget Sound and tested with the same battery of tests used in the first phase of the studies (Chapman et al., 1984a). Toxicity was less severe in these 22 samples than in comparable samples from Elliott and Commencement Bays. However, the sediments from Everett Harbor demonstrated greater toxicity than those from Bellingham Bay, and samples from Samish Bay were the least toxic.

In the fourth and final phase, sediment quality was determined with the introduction of the Sediment Quality Triad approach (Chapman et al., 1984b; Long and Chapman, 1985). Matching chemical, toxicity, and benthic data were compiled to provide a weight of evidence to rank sampling sites. Data from several locations in Case Inlet and Samish Bay were compared with data from Elliott and Commencement Bays and Sinclair Inlet. As observed in the preceding three phases, the data clearly showed a pattern of low sediment quality in samples from the urbanized areas relative to those from the more rural areas.

Other studies conducted in the 1980's supported the MESA findings. Numerous analyses of contaminant exposure and adverse effects in resident demersal fishes were conducted in most of the urbanized bays and harbors in Puget Sound (Malins et al., 1980, 1982, 1983, 1984). These studies demonstrated that toxicant-induced, adverse effects such as hepatic neoplasms, intracellular storage disorders, and lesions appeared most frequently in fish collected in the more polluted urban harbors of Puget Sound. They also showed that the incidence of these pathologies was lower in northern Puget Sound fish than in the urban bays of central Puget Sound. The occurrence of these pathologies in fish could be attributed to the presence of halogenated compounds, PCBs, chlorinated butadienes and hexachlorobenzenes in Bellingham Bay and high levels of chlorinated hydrocarbons, halogenated compounds, PCBs, chlorinated butadienes and hexachlorobenzenes in Everett Harbor. Heavy metals such as copper, lead, zinc and arsenic as well as organic compounds such as phenols, phthalate, benzoic acid, benzyl alcohol and low molecular weight PAHs also may have contributed to the presence of pathologies (Malins et al., 1982).

A study conducted in 1986 by PTI for the U.S. EPA focused on Everett Harbor (PTI, 1989). This study found that the benthic communities at the inner harbor stations had significantly lower total abundance, species richness, and a higher incidence of pollution-tolerant species than the outer harbor and control stations. These findings were supported by sediment bioassays conducted on the amphipod *Rhepoxynius abronius*. In contrast to other contaminated embayments of Puget Sound, such as Elliott Bay and Commencement Bay, where contaminated areas are more widespread, the study found that the severely contaminated areas of Everett Harbor were relatively localized, occurring mainly within the East Waterway and near Mukilteo.

The longest term and most extensive sampling of sediment conditions and infaunal invertebrate communities was conducted by the Puget Sound Ambient Monitoring Program, initiated in 1989. The program sampled 20 sites in northern Puget Sound, 15 of which were sampled yearly from 1989-95 and 5 that were sampled in 1991 and 1994. This study emphasized the sampling of relatively uncontaminated sites, and little relationship was reported between benthic community structure and the low to moderate contaminant levels found at the sampled stations (Striplin, 1988; Llansó et al., 1998a,b).

The Sediment Quality Information System (SEDQUAL) Database

Ecology's Sediment Management Unit has compiled a database that includes sediment data from over 400 Puget Sound sediment surveys of various sizes and scopes. The Sediment Quality Information System (SEDQUAL) database includes approximately 420,000 chemical, 120,000

benthic infaunal, and 23,000 bioassay analysis records from over 5000 sample collection stations throughout Puget Sound. For the northern Puget Sound study area defined in this report, the SEDQUAL database currently contains sediment data from 1472 samples (81 surveys) collected from 1950-1997. These studies showed that elevated concentrations of contaminants usually occurred near population centers, urban areas and ports such as Bellingham, Everett, and Port Gardner.

Data compiled in the SEDQUAL sediment contaminant files indicate that many different toxic chemicals have been detected in northern Puget Sound sediments. Concentrations of 40 compounds exceeded (on one or multiple occasions) Washington State Sediment Quality Standards (SQS), while 33 exceeded the state's Cleanup Screening Levels (CSL) (Appendix A), as defined in Washington State's Sediment Management Standards (SMS) Chapter 173-204 WAC. The majority of the sediment samples in which toxicant concentrations exceeded these state standards in northern Puget Sound were collected in Bellingham Bay and Everett Harbor (Figures 2a,b). A few others were located in Samish Bay, in the vicinity of Anacortes, and elsewhere.

Heavy metals such as arsenic, copper, mercury and lead, as well as PAHs, were among the toxins found in higher concentrations in the SEDQUAL database for Bellingham Bay. Concentrations of mercury, cadmium, copper, low and high molecular weight PAHs, and dibenzofuran have often exceeded the Washington State SQS values in previous studies.

Summary

The data available from previous contaminant-related research in northern Puget Sound showed a consistent pattern of relatively high chemical contamination in Everett Harbor, some portions of Bellingham Bay, and some areas near Anacortes. The makeup of chemical mixtures differed among these areas: mercury was consistently found in Bellingham Bay; trace metals and organics found in Everett Harbor; and PAHs often were detected near Anacortes and March Point.

Compared to the central basin of Puget Sound, relatively little information has been developed on adverse biological effects in the northern area. Limited toxicity tests of sediments and histopathological analyses of demersal fishes were conducted, mostly in Everett Harbor and to a lesser extent in Bellingham Bay. The chemical and bioeffects data suggest that the highest probabilities of observing toxicant-induced effects would occur in these two embayments. The data also suggest that only a very small proportion of northern Puget Sound would be significantly contaminated and toxic.

All of the data from the historical research, collectively, served to identify those regions of Puget Sound in which the problems of chemical contamination were the worst and in which management actions of some kind were most needed. However, although these previous studies provided information on the degree and spatial patterns in chemical contamination and effects, none attempted to quantify or generate reliable estimates of the spatial scales of chemical contamination or measures of adverse effects.

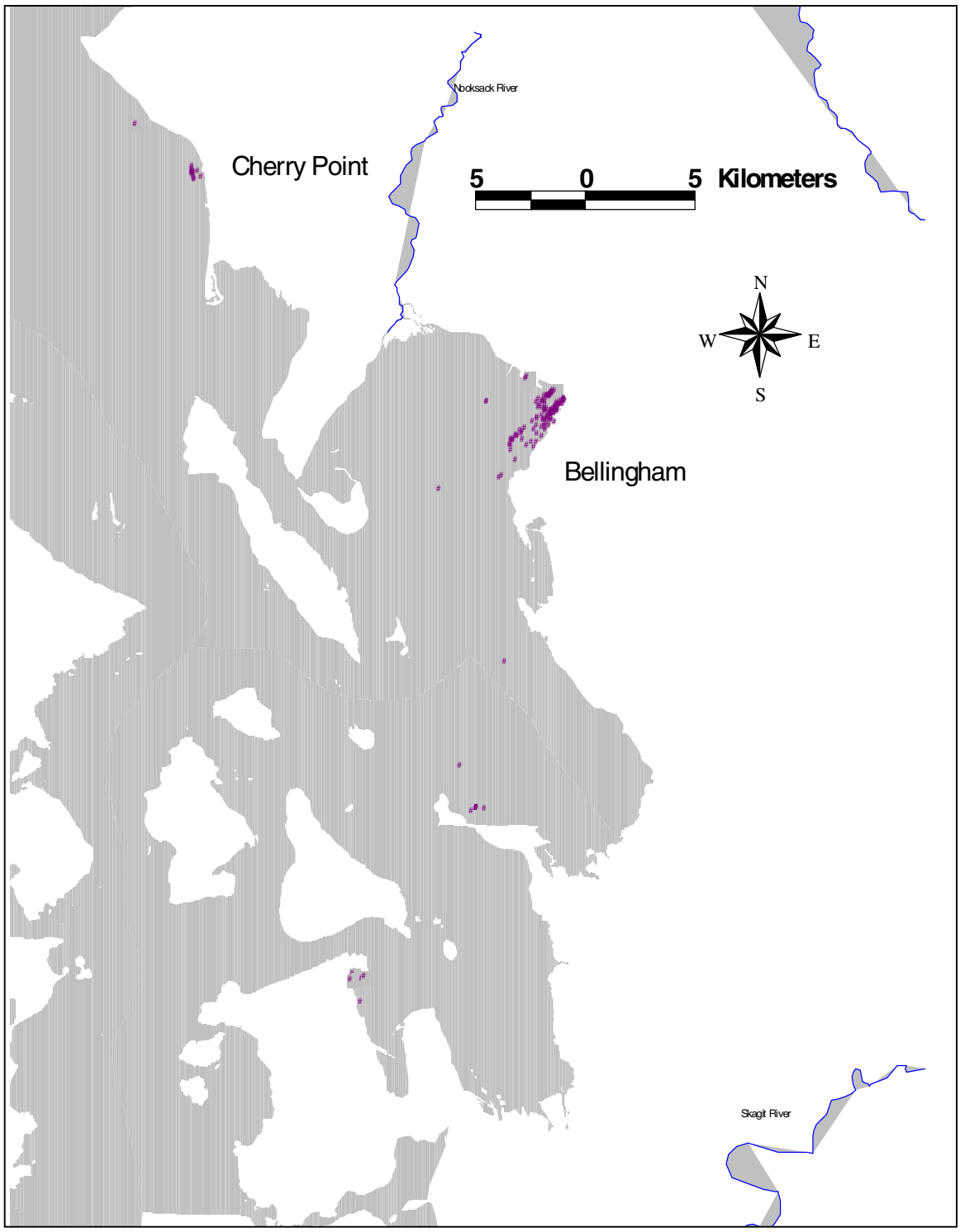

Figure 2a. Map of northern Puget Sound SEDQUAL stations where chemical contaminants in sediment samples exceeded Washington State Sediment Quality Standards (SQS) and Puget Sound Marine Sediment Cleanup Screening Levels (CSL). Bellingham area.

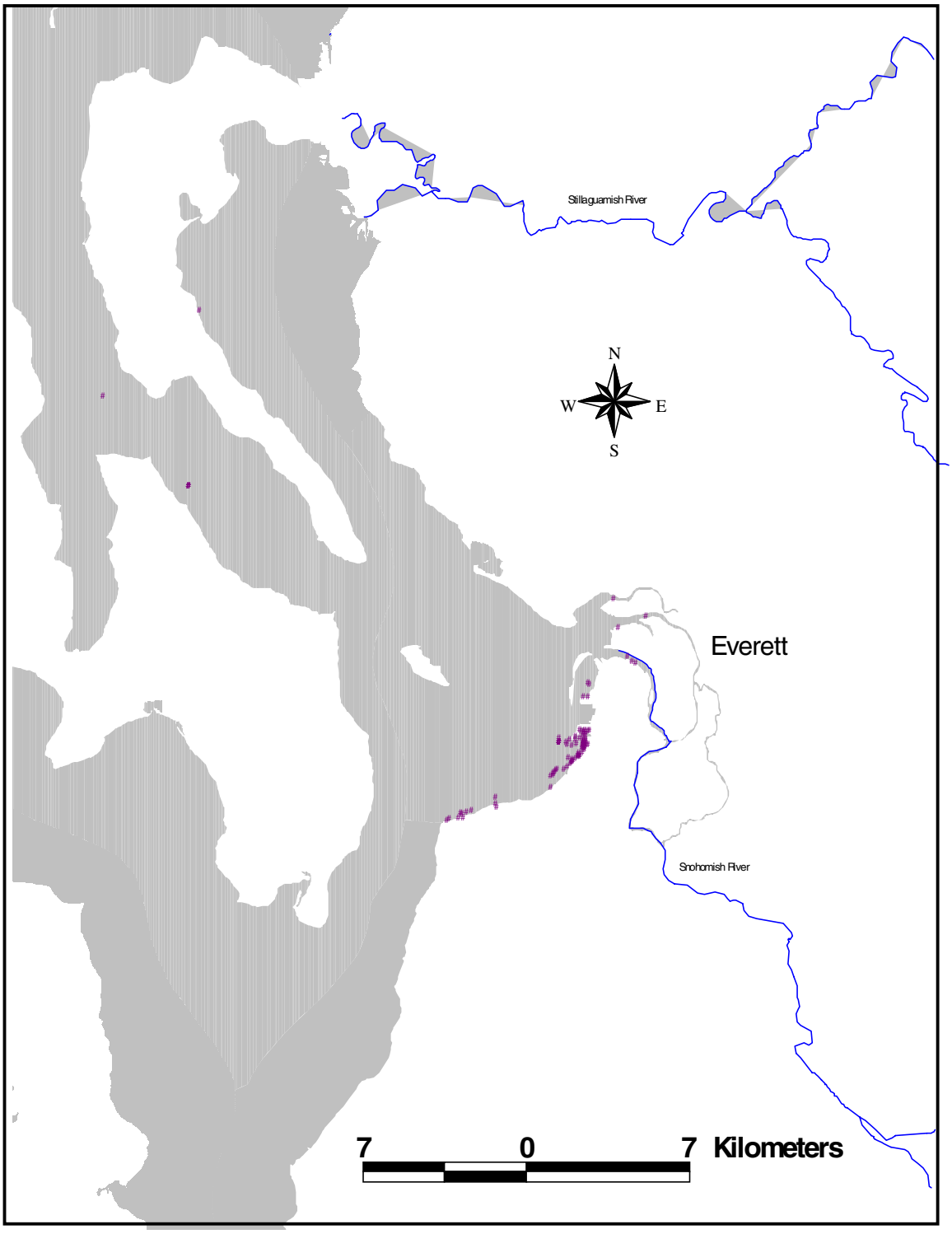

Figure 2b. Map of northern Puget Sound SEDQUAL stations where chemical contaminants in sediment samples exceeded Washington State Sediment Quality Standards (SQS) and Puget Sound Marine Sediment Cleanup Screening Levels (CSL). Everett area.

Goals and Objectives

The shared goal of this study for both the PSAMP Sediment Monitoring Component and NOAA's nationwide bioeffects assessment program was to characterize the ecotoxicological condition of sediments, as well as benthic infaunal assemblage structure, as a measure of adverse biological effects of toxic chemicals in northern Puget Sound. Based upon chemical analyses of sediments reported in previous studies, it appeared that there were relatively high probabilities that concentrations were sufficiently high in some regions of the study area to cause acute toxicity and infaunal assemblage alterations. Data from toxicity tests were intended to provide a means of determining whether toxic conditions, associated with high concentrations of chemical pollutants, actually occurred throughout any of the area. Examination of infaunal assemblages was intended to determine whether sediment chemistry and toxicity conditions are correlated with patterns in infaunal community structure. Underlying these goals was the intent to use a stratified-random sampling design that would allow the quantitation of the spatial extent of degraded sediment quality.

Based on the nature of sediment contamination issues in Puget Sound, and the respective mandates of NOAA and the state of Washington to address sediment contamination and associated effects in coastal waters, the objectives of the cooperative assessment of bioeffects in Puget Sound were to:

1. Determine the incidence and severity of sediment toxicity;

2. Identify spatial patterns and gradients in chemical concentrations and toxicity;

3. Estimate the spatial extent of chemical contamination and toxicity in surficial sediments;

4. Estimate the apparent relationships between toxicant concentrations, measures of sediment toxicity, and benthic infaunal assemblage indices; and

5. Compare the quality of sediment from northern, central, and southern Puget Sound measured in the three phases of this study.

This report includes a summary of the data collected and correlation analyses to examine chemistry, toxicity, and infaunal relationships. Results of further analyses relating chemistry, toxicity, and infaunal structure will be reported in a subsequent document.

Methods

Standardized methods taken from the Puget Sound Estuary Program (PSEP) protocols (PSEP, 1996a) were followed for the majority of this work. Any deviations from these protocols are noted below.

Sampling Design

By mutual agreement between Ecology and NOAA personnel, the study area was established in northern Puget Sound from the USA/Canadian border south to Everett Harbor, and east to either the 6-ft. isobath or the head of navigation. A stratified-random sampling design similar to those used in previous surveys conducted nationwide by NOAA (Long et al., 1996) was developed.

This stratified-random sampling approach combines the strengths of a stratified design with the random-probabilistic selection of sampling locations. Data generated within each stratum can be attributed to the dimensions of the stratum. Therefore, these data can be used to estimate the spatial extent of toxicity with a quantifiable degree of confidence (Heimbuch et al., 1995). Using best professional judgement, strata boundaries were established by project managers to coincide with the dimensions of major basins, bays, inlets, waterways, etc. in which hydrographic, bathymetric and sedimentological conditions were expected to be relatively homogeneous.

The study area was subdivided into 33 irregular-shaped strata (Table 1, Figure 3a). One hundred stations were sampled: three stations within each of 32 strata and four stations within one large stratum in the northern part of the study area (Figures 3b-3h).

Large strata were established in open waters where toxicant concentrations were expected to be uniformly low (e.g., Boundary Bay, Samish Bay, Saratoga Passage). This approach provided the least intense sampling effort in areas known or suspected to be relatively homogeneous in sediment type, water depth, and current conditions, and are distant from contaminant sources. In contrast, smaller strata were established in urban and industrial harbors nearer suspected sources in which conditions were expected to be heterogeneous or transitional (e.g., Bellingham Bay, Everett Harbor, Anacortes/March Point). As a result, sampling was more intense in the smaller strata than in the larger strata. The larger strata were roughly equivalent in size to each other, as were the smaller strata. With this sampling design, results from relatively small strata in which degraded or heterogeneous conditions were expected, had a relatively minor effect upon the estimates of the spatial extent of contamination and toxicity. This study was not designed to address small-scale contamination near problem sources, nor intertidal or shallow subtidal sediments.

Table 1. North Puget Sound sampling strata for the PSAMP/NOAA Cooperative Agreement Bioeffects Survey.

Stratum Number	Stratum Name	Area (km^2)	% of Total Area (773.9 km^2)
1	Drayton Harbor	16.68	2.16
2	Semiahmoo Bay - mouth of Drayton Harbor to west boundary of Semiahmoo Bay	32.91	4.25
3	Boundary Bay (west) - west of Semiahmoo Bay	26.46	3.42
4	Boundary Bay (south) - southern edge	97.09	12.55
5	Birch Bay - from Birch Point to Whitehorn Point	14.22	1.84
6	Cherry Point - Whitehorn Point to Sandy Point	18.57	2.40
7	Bellingham Bay (north)	9.51	1.23
8	Bellingham Bay - west downtown Bellingham, including waterways and marinas	3.81	0.49
9A	Bellingham Bay - east downtown Bellingham, including waterways and marinas	3.72	0.48
9B	Bellingham Bay - just south of stratum 9a	6.03	0.78
10	Bellingham Bay - just south of stratum 9b, along the south shoreline	7.41	0.96
11	Bellingham Bay (central)	25.77	3.33
12	Bellingham Bay - to south end of Lummi Island	56.88	7.35
13	Samish Bay/Bellingham Bay	64.11	8.28
14	Padilla Bay (inner) - shallow eastern boundary	13.14	1.70
15	Padilla Bay (outer)	21.69	2.80
16	March Point	2.07	0.27
17	Fidalgo Bay (inner) - 48°30'north down to trestle	2.52	0.33
18	Fidalgo Bay (outer) - to entrance of Anacortes	2.82	0.36
19	March Point - north of March Point to east end of Guemes Channel	3.72	0.48
20	Guemes Channel - this stratum was eliminated during the course of sampling due to the rocky nature of the substratum		
21	Skagit Bay	31.41	4.06
22	Saratoga Passage (north)	40.95	5.29
23	Oak Harbor	1.23	0.16
24	Penn Cove	9.18	1.19
25	Saratoga Passage (middle)	52.17	6.74
26	Saratoga Passage (south)	51.24	6.62
27	Port Susan	61.20	7.91
28	Possession Sound	60.63	7.83
29	Everett Harbor (inner)	0.15	0.02
30	Everett Harbor (middle)	0.18	0.02
31	Everett Harbor (outer)	0.36	0.05
32	Port Gardner	28.95	3.74
33	Snohomish River delta – including Steamboat and Ebey Sloughs	7.11	0.92

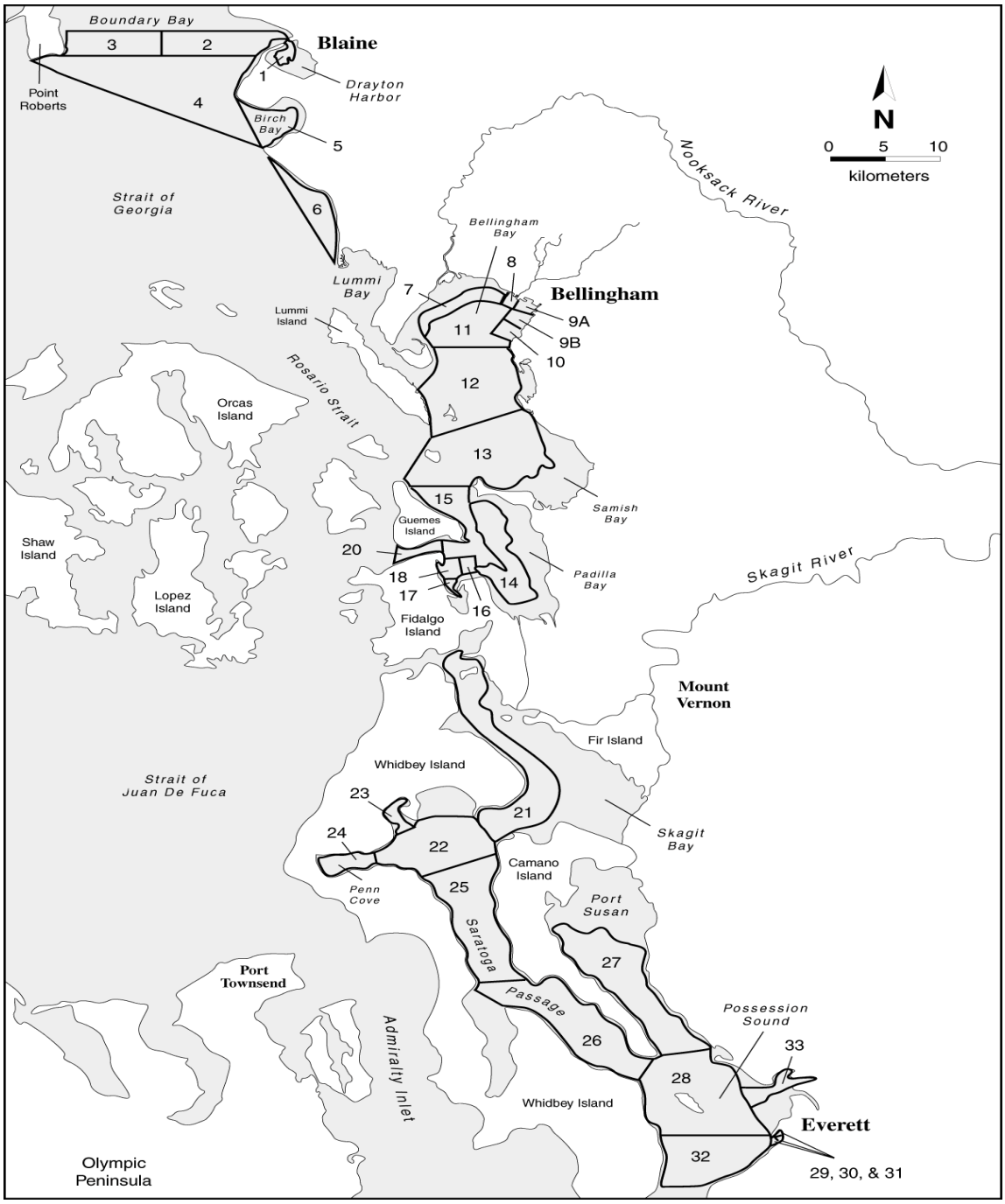

Figure 3a. Northern Puget Sound sampling strata for the PSAMP/NOAA Cooperative Agreement Bioeffects Survey, all strata.

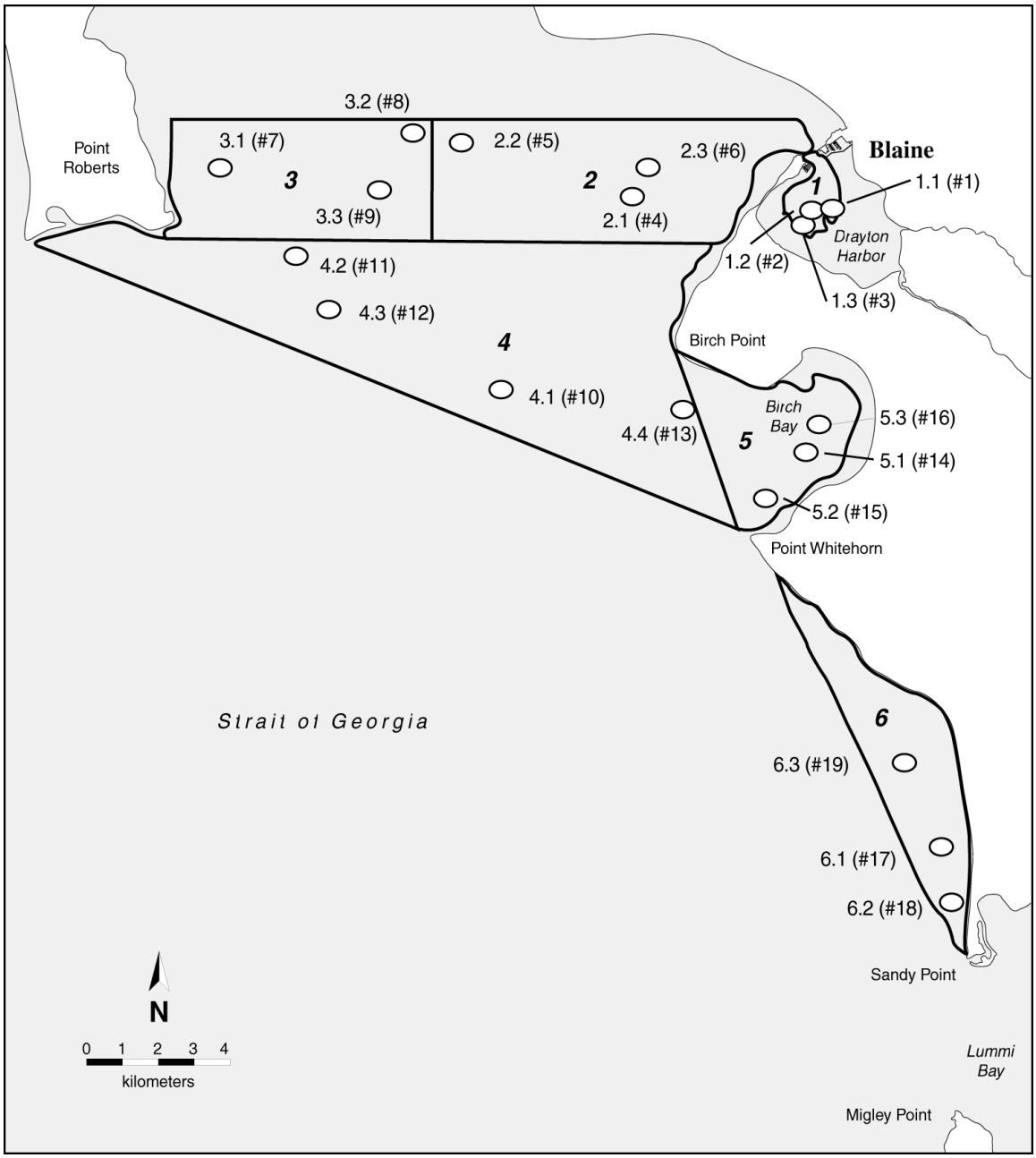

Figure 3b. Northern Puget Sound sampling strata for the PSAMP/NOAA Cooperative Agreement Bioeffects Survey, strata 1 through 6. (Strata numbers are shown in bold. Stations are identified as "stratum.station(sample)").

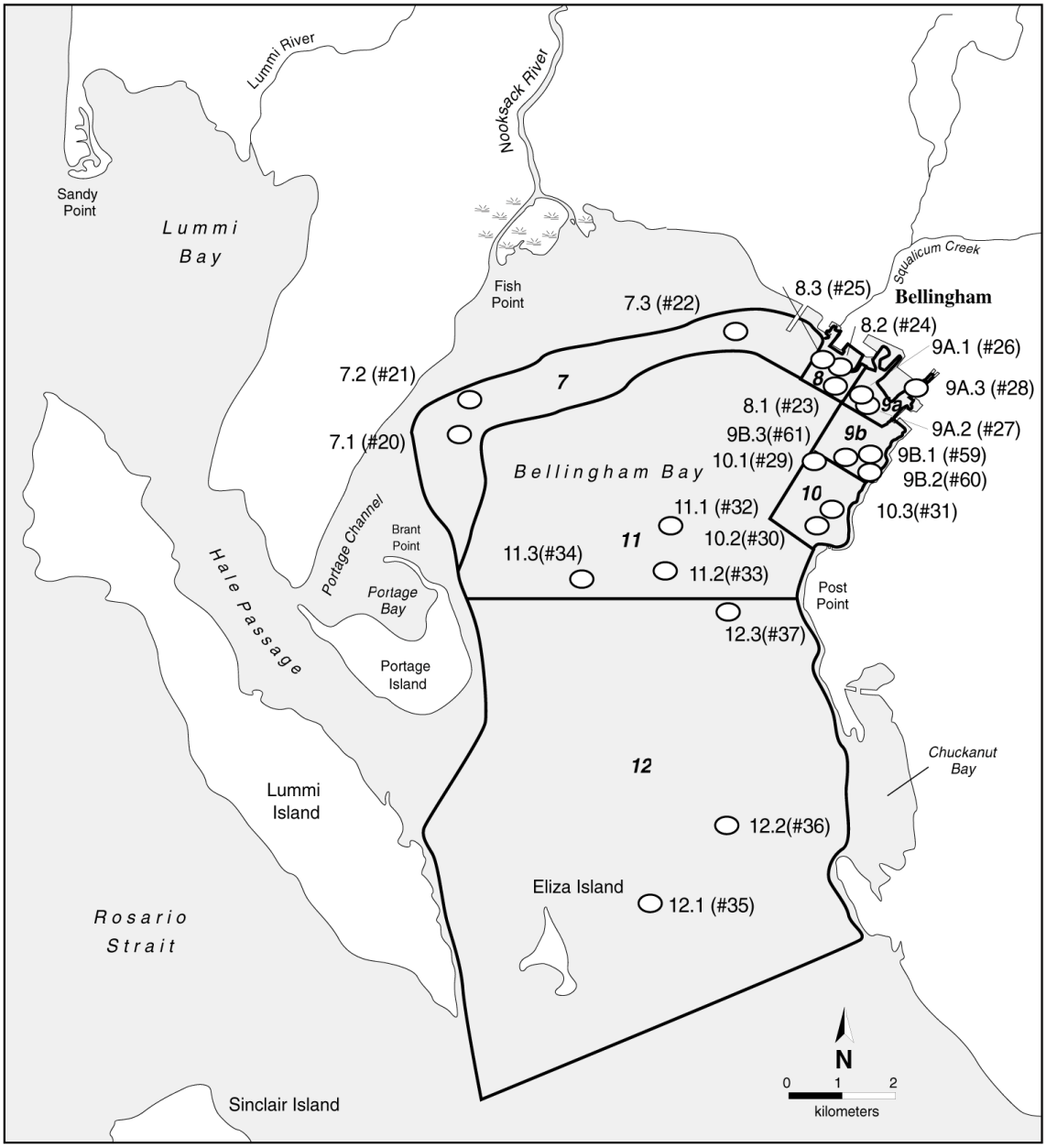

Figure 3c. Northern Puget Sound sampling strata for the PSAMP/NOAA Cooperative Agreement Bioeffects Survey, strata 7 through 12. (Strata numbers are shown in bold. Stations are identified as stratum.station(sample)").

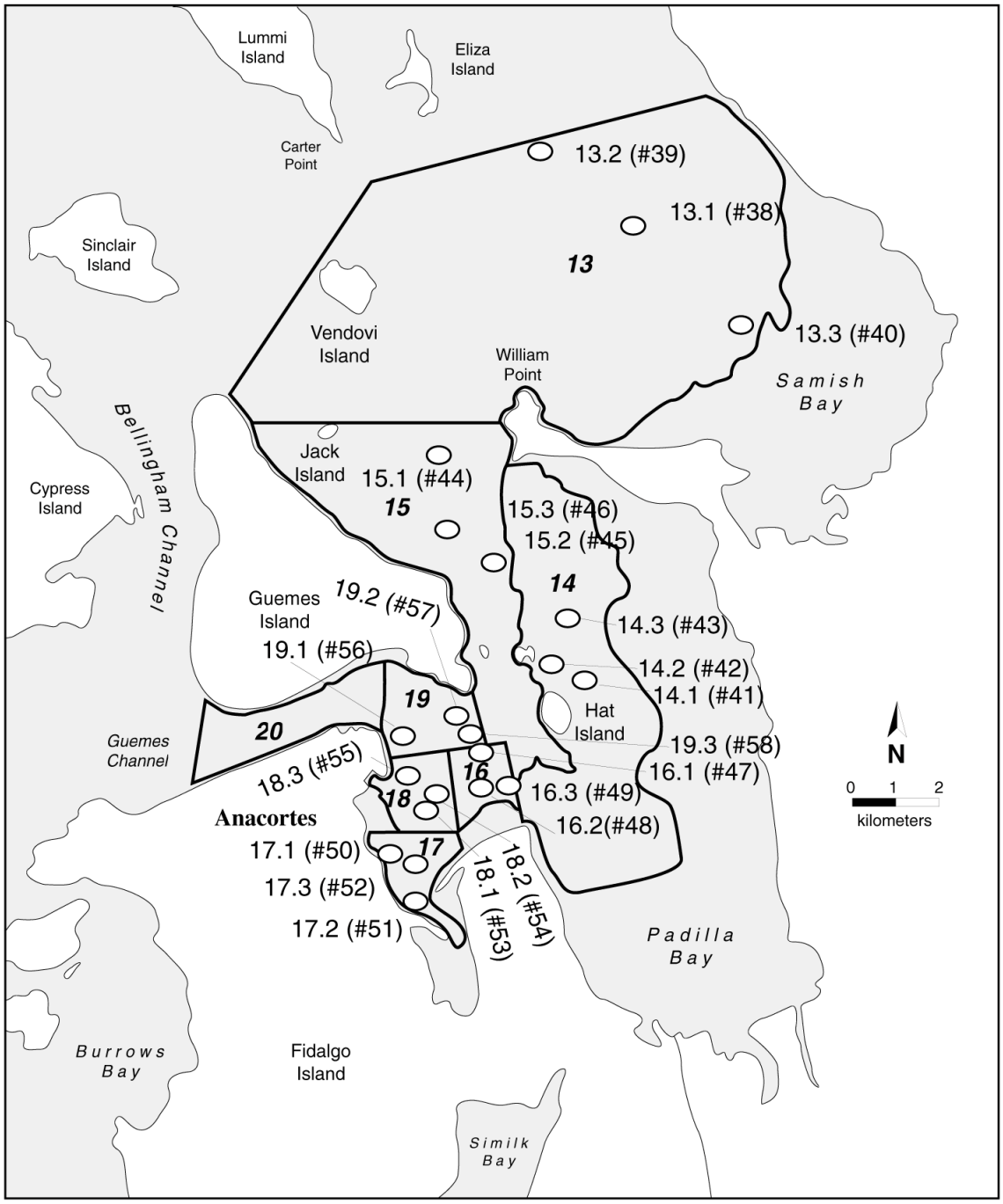

Figure 3d. Northern Puget Sound sampling strata for the PSAMP/NOAA Cooperative Agreement Bioeffects Survey, strata 13 through 20. (Strata numbers are shown in bold. Stations are identified as stratum.station(sample)").

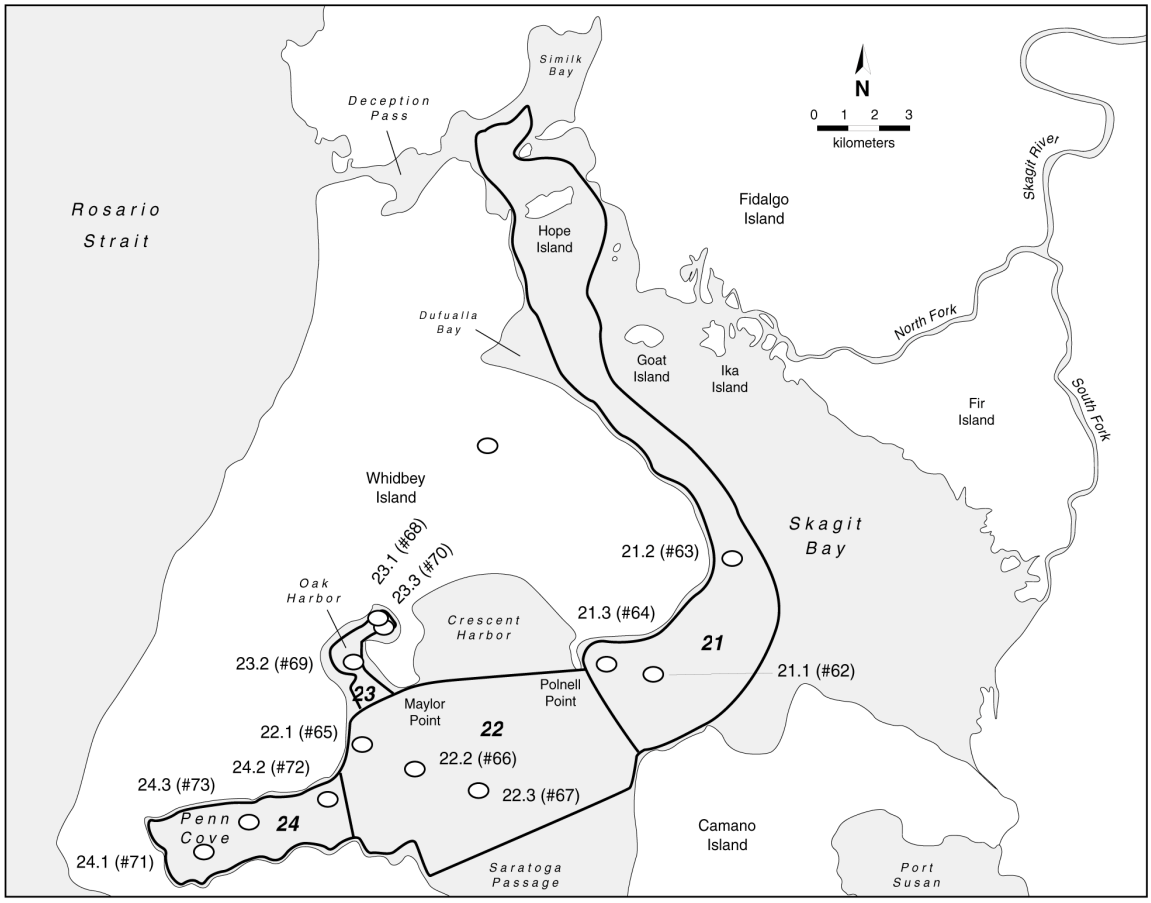

Figure 3e. Northern Puget Sound sampling strata for the PSAMP/NOAA Cooperative Agreement Bioeffects Survey, strata 21 through 24. (Strata numbers are shown in bold. Stations are identified as "stratum.station(sample)").

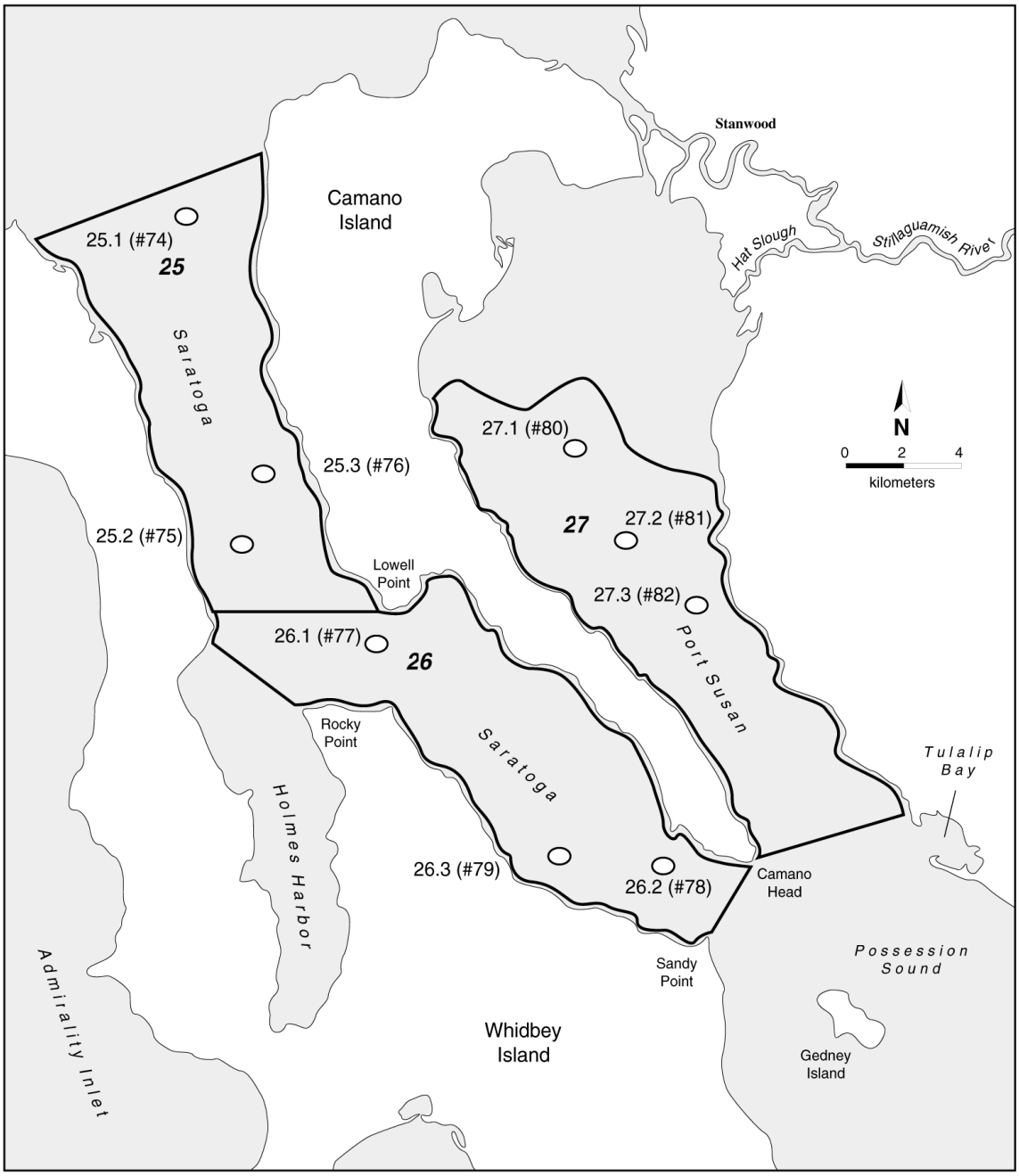

Figure 3f. Northern Puget Sound sampling strata for the PSAMP/NOAA Cooperative Agreement Bioeffects Survey, strata 25 through 27. (Strata numbers are shown in bold. Stations are identified as "stratum.station(sample)").

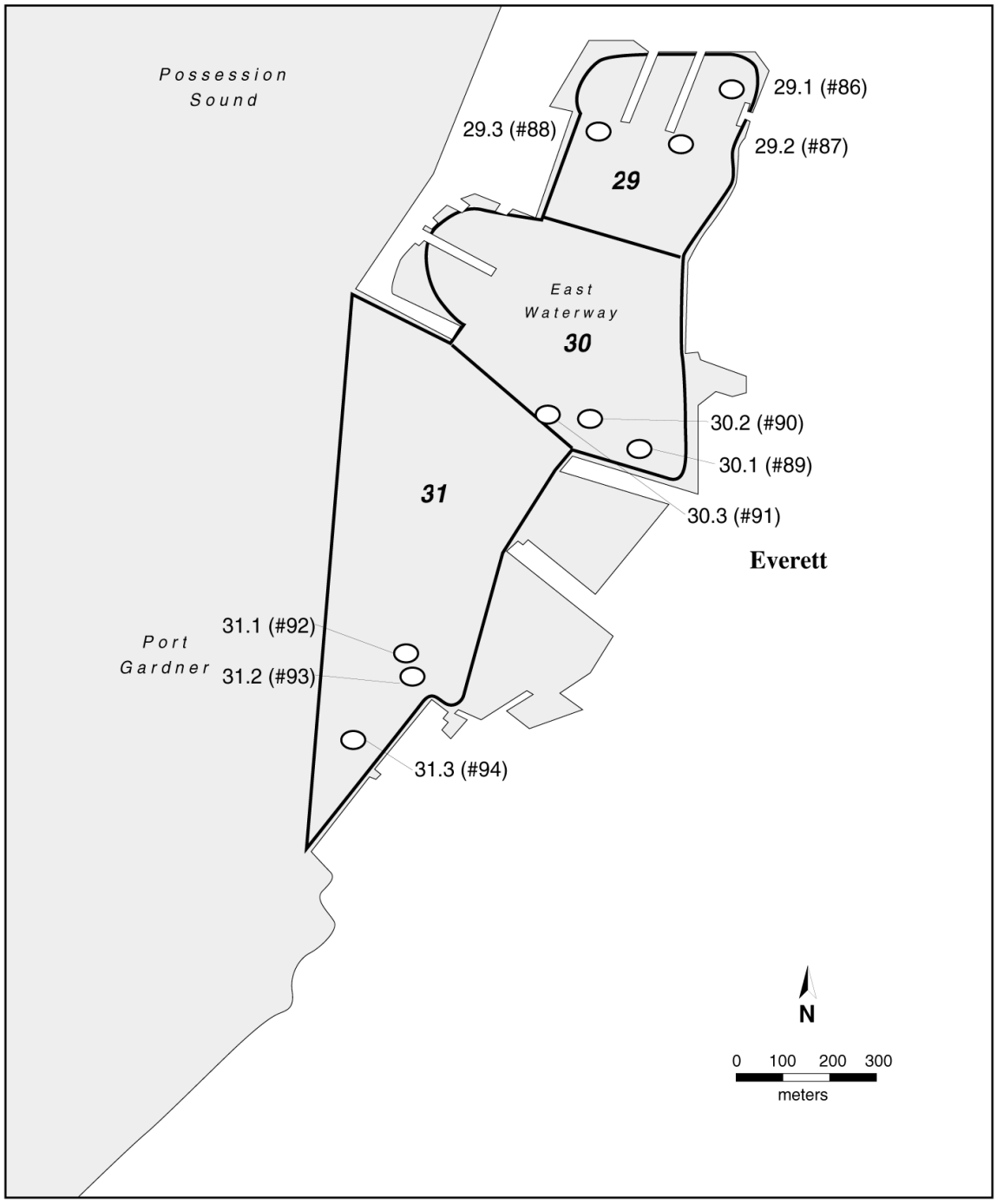

Figure 3g. Northern Puget Sound sampling strata for the PSAMP/NOAA Cooperative Agreement Bioeffects Survey, strata 29 through 31. (Strata numbers are shown in bold. Stations are identified as "stratum.station(sample)").

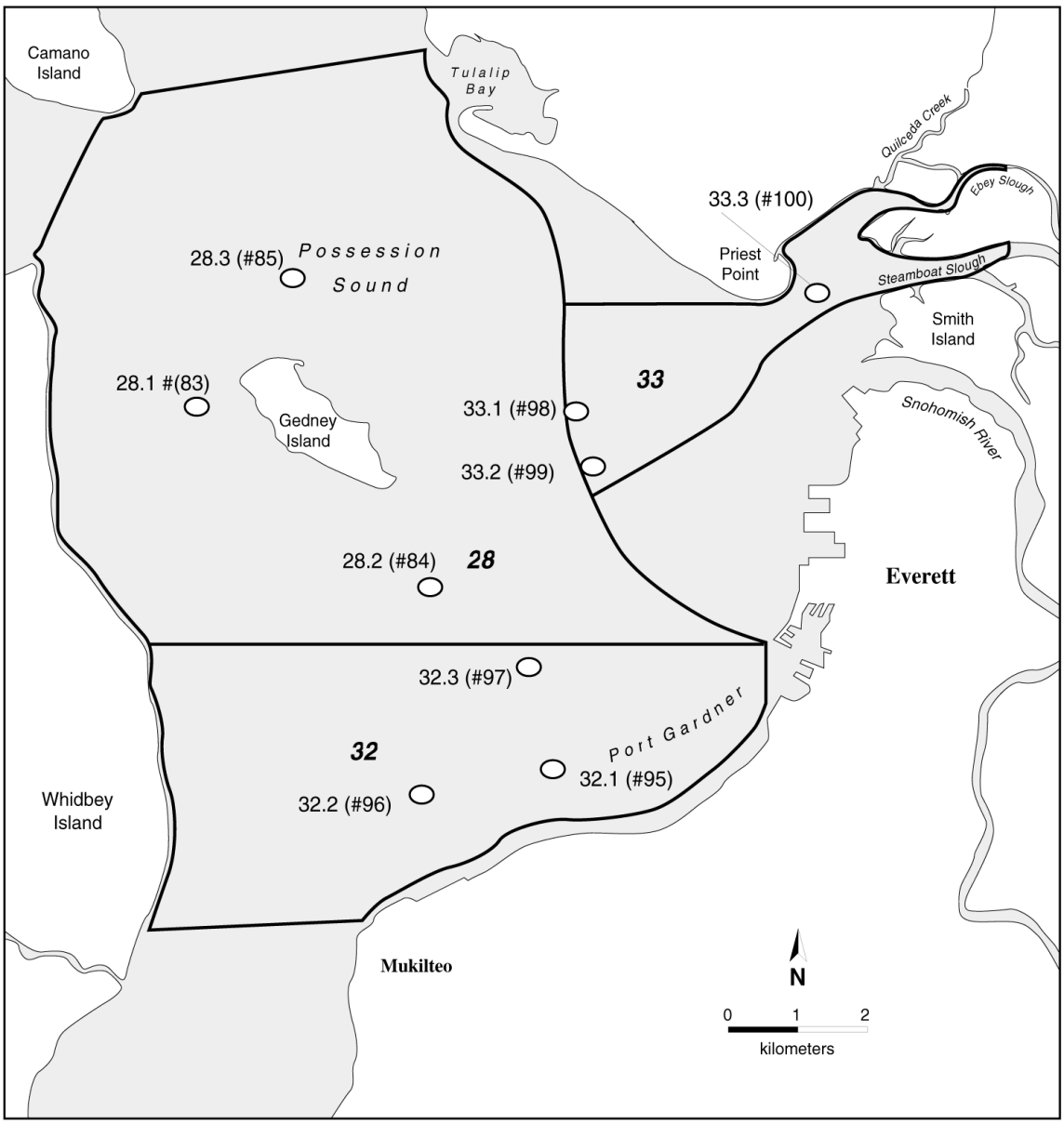

Figure 3h. Northern Puget Sound sampling strata for the PSAMP/NOAA Cooperative Agreement Bioeffects Survey, strata 28, 32, 33. (Strata numbers are shown in bold. Stations are identified as "stratum.station(sample)").

Within the boundaries of each stratum, all possible latitude/longitude intersections had equal probabilities of being selected as a sampling location. The locations of individual sampling stations within each stratum were chosen randomly using GINPRO software, developed by NOAA, applied to digitized navigation charts. Four alternate locations were provided for each station. The coordinates for each alternate were provided in tables and were plotted on the appropriate navigation chart. During June and July of 1997, sediment sampling at coordinates for each station was attempted until one sediment sample could be adequately obtained at each of the 100 stations. Because the station locations were chosen randomly, they were not uniformly distributed within the boundaries of each stratum (Figs. 3b-3h). In some cases the three locations were clustered near each other, while in other areas they were scattered more uniformly throughout the stratum. Final station coordinates are summarized in the navigation report (Appendix B).

Sample Collection

The 42' research vessel *Kittiwake* was used to collect the sediment samples. Differential Global Positioning System (DGPS) with an accuracy of better than 5 meters was used to position the vessel at the station coordinates. During the course of sampling, there were a few cases where the first set of station coordinates provided were inaccessible, or only rocks, cobble, shell hash, or woody debris were present at the station. In those cases, the first set of coordinates was rejected and the alternate station coordinates were sampled. In most cases, the first or second alternates were acceptable and were sampled. However, at Stratum 20, Guemes Channel, only rocks and cobble were encountered at all station alternates, and it was necessary to delete the entire stratum. As a replacement, stratum 9 was subdivided into 9a and 9b, and new random coordinates were generated for station locations within these two strata.

Prior to sampling each station, all sampling equipment was washed with seawater, Alconox soap and rinsed with seawater and acetone. Sediment samples were collected using a double 0.1 m^2 stainless steel modified van Veen grab sampler, allowing a chemistry/bioassay sediment sample to be collected simultaneously with a benthic infauna sediment sample. Upon collection by the grab, the sample was visually inspected to determine if the surface of the sample was undisturbed, and if there were enough fine-grained particles in the sediment. If the sample was accepted, station information and a number of visually descriptive assessments and measurements were recorded in field logs.

From one side of the sampler, one grab sample per station was collected for benthic infaunal analyses. All infaunal samples were rinsed through, and organisms retained from, nested 1.0 and 0.5-mm screens. Organisms were preserved in the field with a 10% aqueous solution of borax-buffered formalin.

From the other side of the sampler, sediment was removed for chemistry and toxicity analyses using a disposable high-density polyethylene (HDPE) scoop. The top two to three centimeters of the sediment was sampled to ensure the collection of recently deposited materials. The sampler was deployed three to six times until a sufficient volume of sediment was collected for all chemistry and toxicity analyses. Sediments were composited in a HDPE plastic bucket, and

homogenized by stirring until textural and color homogeneity were achieved. Homogenized sediment was then transferred to individual sample containers appropriate for each chemistry and toxicity analysis. Between grab deployments, the bucket was covered with an inner teflon lid placed on the sediment surface, as well as a top lid, to minimize contamination, oxidation, and photo-activation.

Field quality control sampling for chemistry and toxicity sediment samples included collection of split samples (a double volume sample, homogenized and split into two aliquots) at 5 stations, and one field blank collected (i.e., a jar containing "clean" sediments exposed to the atmosphere) and analyzed for PAH levels to assess whether diesel exhaust from the boat contributed any measurable contamination to the samples.

In the field, samples for chemical and bioassay analyses were stored in sealed containers placed in insulated chests filled with ice. Chemistry and toxicity samples were off-loaded from the research vessel and transferred to a walk-in refrigerator at Ecology's headquarters building in Olympia. There, they were held at 4^{o}C until they were transported to Ecology's Manchester Environmental Laboratory for chemistry analyses or to NOAA's bioassay contractors for toxicity testing. The formalin-fixed sediment samples collected for infaunal analyses were transported to the benthic laboratory at Ecology's headquarters building in Olympia to await rescreening. All appropriate sample-holding times were observed. Chain-of-custody procedures followed those recommended by the PSEP (1996c). These procedures were initiated when the first sample was collected and were followed until all samples were relinquished to the appropriate analytical laboratory.

Laboratory Analyses

Sediment analyses included three monitoring elements. Toxicity testing was conducted using four independent tests of sediment toxicity including: 10-day solid phase tests of amphipod survival (*Ampelisca abdita*); porewater tests of sea urchin egg fertilization (*Strongylocentrotus purpuratus*); microbial bioluminescence (Microtox™) tests of an organic solvent sediment extract; and Cytochrome P450 RGS tests of sediment extracts. Chemical analyses quantified 169 parameters and chemical compounds in the sediments. Taxonomic identification and enumeration of the benthic infaunal macroinvertebrates were used to determine the composition of assemblages present in the sediment samples collected. Laboratory methods used to analyze these monitoring elements are described below.

Toxicity Testing

Multiple toxicity tests were performed on aliquots of each sample to provide a weight of evidence. Tests were selected for which there were widely accepted protocols for each of three different phases (partitions) of the sediments, including amphipod survival (solid phase), sea urchin fertilization (pore water), and microbial bioluminescence and Cytochrome P450 RGS (organic solvent extract). Toxicological endpoints were selected that would represent a range in response from acute mortality to physiological impairment.

Amphipod Survival - Solid Phase

Amphipod survival tests are the most widely and frequently used assays in sediment evaluations performed in North America. They are performed with adult crustaceans exposed to relatively unaltered bulk sediments. In previous surveys performed by the NS&T Program (Long et al., 1996), *Ampelisca abdita* has shown relatively little sensitivity to "nuisance" factors such as grain size, ammonia, and organic carbon. This test has also provided wide ranges in responses among samples, strong statistical associations with elevated toxicant levels, and small within-sample variability.

Ampelisca abdita is a euryhaline benthic amphipod that ranges from Newfoundland to south central Florida, and along the eastern coast of the Gulf of Mexico. Along the Pacific coast it is abundant in San Francisco Bay. The *A. abdita* bulk sediment test has routinely been used for sediment toxicity tests in support of numerous EPA programs, including the Environmental Monitoring and Assessment Program (EMAP) in the Virginian, Louisianian, Californian, and Carolinian provinces (Schimmel et al., 1994).

Amphipod survival tests were conducted by Science Applications International Corporation, (SAIC) in Narragansett, R.I. All tests were initiated within 10 days of the date samples were collected. Samples were shipped by overnight courier in 4-liter high-density polyethylene jugs which had been washed, acid-stripped, and rinsed with de-ionized water. Sample jugs were packed in shipping coolers with blue ice. Each was inspected to ensure they were within acceptable temperature limits upon arrival and stored at 4°C until testing was initiated. Prior to testing, sediments were mixed with a stainless steel paddle and press-sieved through a 1.0-mm mesh sieve to remove debris, stones, resident biota, etc.

Amphipods were collected by SAIC from tidal flats in the Pettaquamscutt (Narrow) River, a small estuary flowing into Narragansett Bay, RI. Animals were held in the laboratory in pre-sieved uncontaminated ("home") sediments under static conditions. Fifty percent of the water in the holding containers was replaced every second day when the amphipods were fed. During holding, *A. abdita* were fed laboratory-cultured diatoms (*Phaeodactylum tricornutum*). Control sediments were collected by SAIC from the Central Long Island Sound (CLIS) reference station of the U.S Army Corps of Engineers, New England Division. These sediments have been tested repeatedly with the amphipod survival test and other assays and found to be non-toxic (amphipod survival has exceeding 90% in 85% of the tests) and uncontaminated (Long et al., 1996). Sub-samples of the CLIS sediments were tested along with each series of samples from northern Puget Sound.

Amphipod testing followed the procedures detailed in the Standard Guide for conducting 10-day Static Sediment Toxicity Tests with Marine and Estuarine Amphipods (ASTM, 1992). Briefly, amphipods were exposed to test and negative control sediments for 10 days with 5 replicates of 20 animals each under static conditions using filtered seawater. Aliquots of 200 mls of test or control sediments were placed in the bottom of the one-liter test chambers, and covered with approximately 600 mls of filtered seawater (28-30 ppt). Air was provided by air pumps and

delivered into the water column through a pipette to ensure acceptable oxygen concentrations, but suspended in a manner to ensure that the sediments would not be disturbed.

Temperature was maintained at approximately 20°C by a temperature-controlled water bath. Lighting was continuous during the 10-day exposure period to inhibit the swimming behavior of the amphipods. Constant light inhibits emergence of the organisms from the sediment, thereby maximizing the amphipod's exposure to the test sediments. Information on temperature, salinity, dissolved oxygen, pH and ammonia in test chambers was obtained during tests of each batch of samples to ensure compliance within acceptable ranges. Ammonia concentrations were determined in both pore waters (day 0 of the tests) and overlying waters (days 2 and 8 of the tests). Concentrations of the unionized form of ammonia were calculated, based upon measures of total ammonia, and concurrent measures of pH, salinity and temperature.

Twenty healthy, active animals were placed into each test chamber, and monitored to ensure they burrowed into sediments. Non-burrowing animals were replaced, and the test initiated. The jars were checked daily, and records kept for number of animals that were dead, floating on the water surface, emerged on the sediment surface, or in the water column. Those on the water surface were gently freed from the surface film to enable them to burrow. Dead amphipods were removed.

Tests were terminated after ten days. Contents of each of the test chambers were sieved through a 0.5 mm mesh screen and examined under a stereomicroscope for the presence of amphipods. Total amphipod mortality was recorded for each test replicate.

A positive control (reference toxicant) test was used to document the sensitivity of each batch of test organisms. The positive control consisted of 96 hr water-only exposures to sodium dodecyl sulfate (SDS). LC50 values were calculated for each test run with results from tests of five SDS concentrations. Control charts provided by SAIC showed consistent results in tests of both the positive and negative controls.

Sea Urchin Fertilization - Pore Water

Tests of sea urchin fertilization have been used in assessments of ambient water and effluents and in previous NS&T Program surveys of sediment toxicity (Long et al., 1996). Test results have shown wide ranges in responses among test samples, excellent within-sample homogeneity, and strong associations with the concentrations of toxicants in the sediments. This test combines the features of testing sediment pore waters (the phase of sediments in which dissolved toxicants are highly bioavailable) and exposures to early life stages of invertebrates (sperm cells) which often are more sensitive than adult forms. Tests of sediment porewater toxicity were conducted with the Pacific coast purple urchin *Strongylocentrotus purpuratus* by the U.S. Geological Survey laboratory in Corpus Christi, Texas.

Sediments from each sampling location were shipped by overnight courier in one-gallon high-density polyethylene jugs chilled in insulated coolers packed with blue ice. Upon arrival at the laboratory, samples were either refrigerated at 4°C or processed immediately. All samples were processed (i.e., pore waters extracted) within 10 days of the sampling date.

Pore water was extracted from sediments with a pressurized squeeze extraction device (Carr and Chapman, 1995). After extraction, porewater samples were centrifuged in polycarbonate bottles (@1200 G for 20 minutes) to remove any particulate matter. The supernatant was then frozen at -20°C. Two days before the start of a toxicity test, samples were moved from a freezer to a refrigerator at 4°C, and one day prior to testing, thawed in a tepid (20°C) water bath. Experiments performed by USGS have demonstrated no effects upon toxicity attributable to freezing and thawing of the porewater samples.

Tests followed the methods described previously (Carr and Chapman, 1995; Carr et al., 1996a; Carr, 1998) and USGS SOP F10.6, developed initially for *Arbacia punctulata*, but adapted for use with *S. purpuratus*. Unlike *A. punctulata*, adult *S. purpuratus* cannot be induced to spawn with electric stimulus. Therefore, spawning was induced by injecting 1-3 ml of 0.5 M potassium chloride into the coelomic cavity. Tests with *S. purpuratus* were conducted at 15°C; test temperatures were maintained by incubation of the pore waters, the dilution waters and the tests themselves in an environmental chamber. Adult *S. purpuratus* were obtained from Marinus Corporation, Long Beach, CA. Adult *A. punctulata*, used in inter-species comparisons on some samples were obtained from Gulf Specimen Co., Panacea, FL. Pore water from sediments collected in Redfish Bay, Texas, an area located near the testing facility, were used as negative controls. Sediment pore waters from this location have been determined to be non-toxic in this test in many repeated trials (Long et al., 1996). Each of the porewater samples was tested in a dilution series of 100%, 50%, and 25% of the water quality (salinity)-adjusted sample with 5 replicates per treatment. Dilutions were made with clean, filtered (0.45 µm), Port Aransas laboratory seawater, which has been shown in many previous trials to be non-toxic. A dilution series test with SDS was included as a positive control.

Sample temperatures were maintained at 15±1° C. Sample salinity was measured and adjusted to 30±1 ppt, if necessary, using purified deionized water or concentrated brine. Other water quality measurements were made for dissolved oxygen, pH, sulfide and total ammonia. Temperature and dissolved oxygen were measured with YSI meters; salinity was measured with Reichert or American Optical refractometers; pH, sulfide and total ammonia (expressed as total ammonia nitrogen, TAN) were measured with Orion meters and their respective probes. The concentrations of un-ionized ammonia (UAN) were calculated using respective TAN, salinity, temperature, and pH values.

For the sea urchin fertilization test, 50 µL of appropriately diluted sperm were added to each vial, and incubated at 15±1°C for 30 minutes. One milliliter of a well-mixed dilute egg suspension was added to each vial, and incubated an additional 30 minutes at 15± 1°C. Two milliliters of a 10% solution of buffered formalin was added to stop the test. Fertilization membranes were counted, and fertilization percentages calculated for each replicate test.

Because porewater toxicity tests had been performed with *Arbacia punctulata* in most areas NOAA has surveyed and *S. purpuratus* (native to Puget Sound) were selected for use in this survey, experiments were performed by the USGS to determine the relative sensitivity of the two species. Eleven samples (ten from Puget Sound plus the Redfish Bay control) were tested with

both species using appropriate protocols. Fertilization success was determined in all 11 samples at each of the porewater concentrations.

In addition to this comparative study, another was conducted to determine the relative sensitivities of *S. purpuratus* and *A. punctulata*. A series of five reference toxicant tests were performed with both species. Tests were conducted with copper sulfate, PCB Arohlor 1254, 2, 4'-DDD, phenanthrene, and naphthalene in seawater. In these tests, reference toxicant solutions were mixed using 0.45 µm filtered seawater to which a measured amount of toxicants was dissolved. Organic contaminants were first dissolved in HPLC grade methanol before addition to seawater to facilitate maximum solubility. Final concentrations of methanol in solution never exceeded 1%. A copper stock solution was prepared by measuring 2.94 mg of CuSO4:5H2O (1 mg Cu/mL) and diluting it in 1 liter of filtered seawater. A subsequent 1:50 dilution was prepared to arrive at an intial concentration of 20µg Cu/L. Nominal initial concentrations of the reference contaminants were: 20µg Cu/L as CuSO4:H2O; 5 µg Arohlor 1254/L; 20 µg 2, 4'-DDD/L; 5mg phenanthrene/L; and 20 mg naphthalene/L. Stock solutions were stirred for 25 h prior to serial dilution for testing. Each toxicant was tested at 9 separate 50% serial dilutions from the initial concentration. The phenanthrene stock solution was centrifuged and decanted prior to dilution to remove suspended undissolved material. Subsamples of the stock concentrations and/or the first and second dilutions were subsampled following testing. Organic contaminant samples were preserved with 10ml of HPLC grade hexane while Cu solutions were acidified to a pH of 2. Samples were sent on ice to the USGS analytical laboratory in Columbia, MO, for chemical analyses. Copper analyses were performed with a Perkin-Elmer Zeeman 3030 AA Spectrometer equipped with a graphite furnace. Organic toxicants were analyzed with gas chromatography following USGS SOPs C5.154 and C4.196.

Microbial Bioluminescence (Microtox™) - Organic Solvent Extract

This is a test of the relative toxicity of sediment extracts prepared with an organic solvent, and is immune to the effects of environmental factors such as grain size, ammonia and organic carbon. Organic toxicants and, to a lesser degree, trace metals that may or may not be readily bioavailable are extracted with the organic solvent. This test can therefore be considered as indicative of the potential toxicity of mixtures of substances bound to the sediment matrices. In previous NS&T Program surveys, the results of Microtox™ tests have shown extremely high correlations with the concentrations of mixtures of organic compounds. Microtox™ tests were run by the U.S. Geological Survey laboratory in Columbia, MO, on extracts prepared by Columbia Analytical Services (CAS) in Kelso, WA.

The Microtox™ assay was performed with dichloromethane (DCM) extracts of sediments following the basic procedures used in testing Puget Sound sediments (U.S. EPA, 1986, 1990, 1994) and Pensacola Bay sediments (Johnson and Long, 1998). All sediment samples were stored in the dark at 4°C for 5-10 days before processing was initiated. A 3-4 g sediment sample from each station was weighed, recorded, and placed into a DCM rinsed 50 mL centrifuge tube. A 15 g portion of sodium sulfate was added to each sample and mixed. Pesticide grade DCM (30 ml) was added and mixed. The mixture was shaken for 10 seconds, vented and tumbled overnight.

Sediment samples were allowed to warm to room temperature and the overlying water discarded. Samples were then homogenized with a stainless steel spatula, and 15-25 g of sediment were transferred to a centrifuge tube. The tubes were spun @ 1000 G for 5 min. and the pore water was removed using a Pasteur pipette. Three replicate 3-4 g sediment subsamples from each station were placed in mortars containing a 15 g portion of sodium sulfate and mixed. After 30 min, subsamples were ground with a pestle until dry. Subsamples were added to 50 mL centrifuge tubes, and 30 mL of DCM were added to each tube and shaken to dislodge sediments. Tubes were shaken overnight on an orbital shaker at a moderate speed, then centrifuged at 500 g for 5 min and the sediment extracts transferred to Turbovap™ tubes. Next, 20 mL of DCM was added to sediment, shaken by hand for 10 seconds, and spun @ 500 G for 5 min. The previous step was repeated once more and all three extracts were combined in the Turbovap™ tube. Sample extracts were then placed in the Turbovap™ and reduced to a volume of 0.5 mL. The sides of the Turbovap™ tubes were rinsed down with methylene chloride and again reduced to 0.5 mL. Then, 2.5 mL of dimethylsulfoxide (DMSO) were added to the tubes which were returned to the Turbovap™ for an additional 15 min. Sample extracts were then placed in clean vials and 2.5 mL of DMSO were added to obtain a final volume of 5 mL DMSO.

A suspension of luminescent bacteria, *Vibrio fischeri* (Azur Environmental, Inc.), was thawed and hydrated with toxicant-free distilled water, covered and stored in a 4°C well on the Microtox™ analyzer. An aliquot of 10 µL of the bacterial suspension was transferred to a test vial containing the standard dilutant (2% NaCl) and equilibrated to 15°C using a temperature-controlled photometer. The amount of light lost per sample was proportional to the toxicity of that test sample. To determine toxicity, each sample was diluted into four test concentrations. Percent decrease in luminescence of each cuvette relative to the reagent blank was calculated. Light loss was expressed as a gamma value and defined as the ratio of light lost to light remaining.

Because organic sediment extracts were obtained with DCM, a strong non-polar solvent, the final extract was evaporated and redissolved in DMSO. DMSO was compatible with the Microtox™ system because of its low test toxicity and good solubility with a broad spectrum of apolar chemicals (Johnson and Long, 1998). The log of gamma values from these four dilutions was plotted and compared with the log of the samples' concentrations. The concentrations of the extract that inhibited luminescence by 50% after a 5-minute exposure period, the EC50 value, was determined and expressed as mg equivalent sediment wet weight. Data were reduced using the Microtox™ Data Reduction software package. All EC50 values were average 5-min readings with 95% confidence intervals for three replicates.

A negative control (extraction blank) was prepared using DMSO, the test carrier solvent. A phenol standard (45 mg/L phenol) was run after re-constitution of each vial of freeze-dried *V. fischeri*. Tests of extracts of sediments from the Redfish Bay, Texas, site used in the urchin tests also were used as negative controls in the Microtox™ tests.

In addition to conducting the Microtox™ assay on sediment extracts prepared with an organic solvent, the solid-phase variant of the Microtox™ bioluminescence test was also run on 10 samples from northern Puget Sound plus the Redfish Bay control. This solid-phase test was conducted to facilitate comparison of the results with those from the solvent extract tests. This test was run with solid-phase sediments suspended in water.

Cytochrome P450 RGS - Organic Solvent Extract

This is an assay of the light produced by luciferase in a reporter gene system (RGS) of cultured human liver cells. These tests were run by the Columbia Analytical Services, Inc. laboratory in Carlsbad, CA on sediment extracts prepared by their laboratory in Kelso, WA. The assay has been highly responsive to the presence of mixed-function oxidase inducers such as dioxins, furans, high molecular weight PAHs, and co-planar PCBs in tissues and sediments (Anderson et al., 1995). Therefore, the RGS assay provides an estimate of the presence of contaminants bound to sediments that could produce chronic and/or carcinogenic effects in benthic biota and/or demersal fishes if they occupy the sediments (Anderson et al., in press; Jones et al., in press)

In these tests, standard protocols (Anderson et al., 1995, 1996; ASTM, 1997; APHA, 1996) were followed to ensure comparability with data derived for other areas. Approximately 20 g of sediment from each station were extracted using EPA method 3550 to produce 1mL of DCM/extract mixture. Extracts were exchanged into DMSO to produce sufficient amount of extracts for triplicate Microtox™ and RGS tests. Small portions of these samples (15 µL) were applied to approximately one million human liver cells contained in three replicate wells with 2 mL of culture medium. After 16 h of incubation, the cells were washed, then lysed, and the solution centrifuged. Fifty µL of the supernatant were transferred to a 96 well plate, luciferin was added, and luminescence in relative light units (RLU) was measured using a luminometer. Solvent blanks and the reference toxicants (2, 3, 7, 8 - dioxin and benzo[a]pyrene) were tested with each batch of samples.

Mean RLU, standard deviation, and coefficient of variation of three replicate analyses of each test solution were recorded. Enzyme induction was calculated as the mean RLU of the test solution divided by the mean RLU of the solvent blank. From a long-term control chart, the running average enzyme induction for 1 ng/mL dioxin was approximately 105, and the enzyme induction from 1 µg/mL of benzo[a]pyrene (B[a]P) was approximately 60. Data were converted to µg of B[a]P Equivalents per g of sediment. Because 15 µL of the 2mL extracts were used in these tests, the volume factor used in this survey was 133.3. Final division by the dry weight, which was calculated using percent solids of the 20 g samples, yielded b[a]p equivalents in µg/g. Also, by multiplying the enzyme induction produced by the sample by the volume factor (133.3), then dividing by 1000 to convert pg to ng and the dry weight of the sample, toxic equivalency quotients (TEQs) were calculated in ng/g. Tests were run with clean extracts spiked with tetrachlorodibenzo-p-dioxin (TCDD) and b[a]p to ensure compliance with results of previous tests. RGS assays were performed on the Redfish Bay extract as a negative control.

Chemical Analyses

Laboratory analyses were performed for 171 parameters and chemical compounds (Table 2), including 94 trace metals, pesticides, hydrocarbons and selected normalizers (i.e., grain size, total organic carbon) that are routinely quantified by the NS&T Program, plus simultaneously-extracted metals/acid volatile sulfides. An additional 27 compounds were required by Ecology to ensure comparability with previous PSAMP and enforcement studies. Fifty additional

Table 2. Chemical and physical analyses conducted on sediments collected from northern Puget Sound.

Related Parameters
Acid volatile sulfides/simultaneously extracted metals
Grain Size
Total organic carbon

Metals
Ancillary Metals
Aluminum
Barium
Calcium
Cobalt
Iron
Magnesium
Manganese
Potassium
Sodium
Vanadium

Priority Pollutant Metals
Antimony
Arsenic
Beryllium
Cadmium
Chromium
Copper
Lead
Mercury
Nickel
Selenium
Silver
Thallium
Zinc

Major Elements
Silicon

Trace Elements
Tin

Organics
Chlorinated Alkanes
Hexachlorobutadiene
Hexachlorocyclopentadiene
Hexachloroethane

Chlorinated and Nitro-Substituted Phenols
2,4,5-trichlorophenol
2,4,6-trichlorophenol
2,4-dichlorophenol
2,4-dinitrophenol
2-chlorophenol
2-nitrophenol
4,6-dinitro 2-methylphenol (=4,6-dinitro-o-cresol)
4-chloro 3-methylphenol
4-nitrophenol
Pentachlorophenol

Chlorinated Aromatic Compounds
1,2,4-trichlorobenzene
1,2-dichlorobenzene
1,3-dichlorobenzene
1,4-dichlorobenzene
2-chloronaphthalene
Hexachlorobenzene

Chlorinated Pesticides
2,4'-DDD
2,4'-DDE
2,4'-DDT
4,4'-DDD
4,4'-DDE
4-4'DDT
Aldrin
Alpha-chlordane
Alpha-HCH
Beta-HCH
Chlorpyrifos

Table 2 (cont.). Chemical and physical analyses conducted on sediments collected from northern Puget Sound.

Chlorinated Pesticides (cont.)
Cis-nonachlor
Delta-HCH
Diazinon
Dieldrin
Endosulfan I (Alpha-endosulfan)
Endosulfan II (Beta-endosulfan)
Endosulfan sulfate
Endrin
Endrin ketone
Endrin aldehyde
Gamma-chlordane
Gamma-HCH
Heptachlor
Heptachlor epoxide
Methoxychlor
Mirex
Oxychlordane
Toxaphene
Trans-nonachlor

Ethers
4-bromophenyl-phenyl ether
4-chlorophenyl-phenyl ether
Bis(2-chloroethyl)ether
Bis(2-chloroisopropyl)-ether

Polynuclear Aromatic Hydrocarbons
LPAHs
1,6,7-Trimethylnaphthalene
1-Methylnaphthalene
1-Methylphenanthrene
2,6-Dimethylnaphthalene
2-methylnapthalene
Acenaphthene
Acenaphtylene
Anthracene
Biphenyl
C1 - C2 Fluorenes
C1 - C3 Dibenzothiophenes
C1 - C4 naphthalenes
C1 - C4 Phenanthrenes
Dibenzothiophene
Fluorene
Naphthalene
Phenanthrene
Retene
calculated value:
LPAH

HPAHs
Benzo(a)anthracene
Benzo(a)pyrene
Benzo(b)fluoranthene
Benzo(e)pyrene
Benzo(g,h,i)perylene
Benzo(k)fluoranthene
C1 - C4 Chrysene
Chrysene
Dibenzo(a,h)anthracene
Fluoranthene
Indeno(1,2,3-c,d)pyrene
Perylene
Pyrene
calculated values:
total Benzofluoranthenes
HPAH

Miscellaneous Extractable Compounds
Benzoic acid
Benzyl alcohol
Beta-coprostanol
Dibenzofuran
Isophorone

Organonitrogen Compounds
2,4-dinitrotoluene
2,6-dinitrotoluene
2-nitroaniline
3,3'-dichlorobenzidine
3-nitroaniline
4-chloroaniline
4-nitroaniline
9(H) carbazol

Table 2 (cont.). Chemical and physical analyses conducted on sediments collected from northern Puget Sound.

Organonitrogen Compounds (cont.)
Caffeine
Nitrobenzene
N-nitroso-di-n-propylamine
N-nitrosodiphenylamine

Organotins
Butyl tins: Mono-, Di-, Tri-butyltin

Phenols
2,4-dimethylphenol
2-methylphenol
4-methylphenol
Bis(2-chloroethoxy)-methane
Phenol
P-nonylphenol

Phthalate Esters
Bis(2-ethylhexyl)phthalate
Butyl benzyl phthalate
Diethyl phthalate
Dimethyl phthalate
Di-n-butyl phthalate
Di-n-octyl phthalate

Polychlorinated Biphenyls
PCB Congeners
8
18
28
44
52
66
77
101
105
118
126
128
138
153
170
180
187
195
206
209

PCB Aroclors
1016
1221
1232
1242
1248
1254
1260

compounds were automatically quantified by Manchester during analysis for the required compounds. Analytical procedures provided performance equivalent to those of the NS&T Program and the PSEP Protocols, including those for analyses of blanks and standard reference materials. Information was reported on recovery of spiked blanks, analytical precision with standard reference materials, and duplicate analyses of every 20th sample.

The laboratory analytical methods and reporting limits for quantitation of the 171 chemistry parameters analyzed for are summarized in Table 3 and described in detail below. Methods and resolution levels for field collection of temperature and salinity are included in Table 4.

Grain Size

Analysis for grain size was performed according to the PSEP Protocols (PSEP, 1986b). The PSEP grain size method is a sieve-pipette method. In this method, the sample is passed through a series of progressively smaller sieves, with each fraction being weighed. After this separation, the very fine material remaining is placed into a column of water, and allowed to settle. Aliquots are removed at measured intervals, and the amount of material in each settling fraction is measured. This parameter was contracted by Manchester to Columbia Analytical Services, Inc., Kelso, WA.

Total Organic Carbon (TOC) in Sediment

Total organic carbon analysis was performed according to PSEP Protocols (PSEP, 1986b). The method involves drying sediment material, pretreatment and subsequent oxidation of the dried sediment, and determination of CO_2 by infra-red spectroscopy.

Simultaneously Extracted Metals (SEM)/Acid Volatile Sulfides (AVS)

Methodology for the determination of AVS follows EPA, 1991. Simultaneously extracted metals were determined by USEPA Method 200.7AV, the method for ultra-trace metals by inductively coupled plasma mass spectrometry.

Metals in Sediment - Preparation and Analysis

To maintain compatibility with previous PSAMP metals data, EPA Methods 3050/6010 were used for the determination of metals in sediment. Method 3050 is a strong acid (aqua regia) digest that has been used for the last several years by Ecology for the characterization of sediments for trace metal contamination. Method 3050 was also the recommended digestion technique for digestion of sediments in the recently revised PSEP protocols (PSEP, 1996d). This digestion does not yield geologic (total) recoveries for most analytes including silicon, iron, aluminum and manganese. It does, however, recover quantitatively most anthropogenic metals contamination and deposition.

For comparison with NOAA's national bioeffects survey's existing database, Manchester simultaneously performed a total (hydrofluoric acid-based) digestion (EPA method 3052) on portions of the same samples. Determination of metals values for both sets of samples were

Table 3. Chemistry Parameters: Laboratory analytical methods and reporting limits.

Parameter	Method	Reference	Reporting Limit
Grain Size	Sieve-pipette method	PSEP, 1986b	>2000 to <3.9 microns
Total Organic Carbon	Conversion to CO_2 measured by nondispersive infra-red spectroscopy	PSEP, 1986b	1 mg/L
Acid Volatile Sulfides/ Simult. Extracted Metals	AVS - EPA method SEM - ICP-MS	AVS - EPA, 1991 SEM - EPA 200.7AV	SEM - 1-10 ppm
Metals (Partial digestion)	Strong acid (aqua regia) digestion and analyzed via ICP, ICP-MS, or GFAA, depending upon the analyte	- digestion - EPA 3050 - analysis - PSEP, 1996d (EPA 200.7, 200.8, 206.2, 245.5, 270.2)	1-10 ppm
Metals (Total digestion)	Hydrofluoric acid-based digestion and analyzed via ICP or GFAA, depending upon the analyte	- digestion - EPA 3052 - analysis - PSEP, 1996d (EPA 200.7, 204.2, 206.2, 239.2, 270.2, 279.2, 282.2)	1-10 ppm
Mercury	Cold Vapor Atomic Absorption	PSEP, 1996d EPA 245.5	1-10 ppm
Butyl Tins	Solvent Extraction, Derivitization, Gas Chromatography/Mass Spectrometry in selected ion mode	Manchester Method (Manchester Environmental Laboratory, 1997)	40 µg/kg
Base/Neutral/Acid Organic Compounds	Capillary column Gas Chromatography/ Mass Spectrometry	PSEP 1996e, EPA 8270	100-200 ppb
Polynuclear Aromatic Hydrocarbons (PAH)	Capillary column Gas Chromatography/ Mass Spectrometry	PSEP 1996e, extraction following Manchester modification of EPA 8270	100-200 ppb
Chlorinated Pesticides and PCB (Aroclors)	Gas Chromatography Electron Capture Detection	PSEP 1996e, EPA 8081	1-5 ppb
PCB Congeners		NOAA, 1993a	1-5 ppb

Table 4. Chemistry Parameters: Field analytical methods and resolution.

Parameter	Method	Resolution
Temperature	Mercury Thermometer	1.0 °C
Surface salinity	Refractometer	1.0 ppt

made via ICP, ICP-MS, or GFAA, using a variety of EPA methods (see Table 3) depending upon the appropriateness of the technique for each analyte.

Mercury

Mercury was determined by USEPA Method 245.5, mercury in sediment by cold vapor atomic absorption (CVAA). The method consists of a strong acid sediment digestion, followed by reduction of ionic mercury to Hg^0, and analysis of mercury by cold vapor atomic absorption. This method is recommended by the PSEP Protocols (PSEP, 1996d) for the determination of mercury in Puget Sound sediment.

Butyl Tins

Butyl tins in sediments were analyzed by the Manchester Method (Manchester Environmental Laboratory, 1997). This method consists of solvent extraction of sediment, derivitization of the extract with the Grignard reagent hexylmagnesium bromide, cleanup with silica and alumina, and analysis by GC/MS in selected ion mode (SIM).

Base/Neutral/Acid (BNA) Organic Compounds and Polynuclear Aromatic Hydrocarbons (PAH) (extended list)

USEPA Method 8270, a recommended PSEP method (PSEP, 1996e), was used for semi-volatile analysis. This is a capillary column, GC/MS method. The extended analyte list was modified by the inclusion of additional PAH compounds on the NOAA target analyte list. At NOAA's request, PAH compounds were also run in a separate procedure, with sample extraction following the Manchester modification of USEPA Method 8270. The PAH data included in this report are from this second set of analyses.

Chlorinated Pesticides and Polychlorinated Biphenyls (PCB) Aroclors

EPA Method 8081 for chlorinated pesticides and PCB was used for the analysis of these compounds. This method is a GC method with dual dissimilar column confirmation. Electron capture detectors were used.

PCB Congeners

PCB methodology was based on the NOAA congener methods detailed in Volume IV of the NS&T Sampling and Analytical Methods documents (NOAA, 1993a). The concentration of the standard NOAA list of 20 congeners was determined.

Benthic Community Analyses

Sample Processing and Sorting

All methods, procedures, and documentation (chain-of-custody forms, tracking logs, and data sheets) were similar to those described for the PSEP (1987a) and in the PSAMP Marine Sediment Monitoring Component – Final Quality Assurance Project and Implementation Plan (Dutch et al., 1998).

Upon completion of field collection, benthic infaunal samples were checked into the benthic laboratory at Ecology's headquarters building. After a minimum fixation period of 24 hours (and maximum of 7 to 10 days), the samples were washed on sieves to remove the formalin (1.0 mm fraction on a 0.5 mm sieve, 0.5 mm fraction on a 0.25 mm sieve) and transferred to 70% ethanol. Sorting and taxonomic identification of the 0.5 mm fraction was completed outside of the scope of work of this effort. The results of these separate analyses will be reported elsewhere by NOAA. After staining with rose bengal, the 1.0 mm sample fractions were examined under dissection microscopes, and all macroinfaunal invertebrates and fragments were removed and sorted into the following major taxonomic groups: Annelida, Arthropoda, Mollusca, Echinodermata, and miscellaneous taxa. Meiofaunal organisms such as nematodes and foraminiferans were not removed from samples, although their presence and relative abundance were recorded. Representative samples of colonial organisms such as hydrozoans, sponges, and bryozoans were collected, and their relative abundance noted. Sorting QA/QC procedures consisted of resorting 20% of each sample by a second sorter to determine whether a sample sorting efficiency of 95% removal was met. If the 95% removal criterion was not met, the entire sample was resorted.

Taxonomic Identification

Upon completion of sorting and sorting QA/QC, all taxonomic work, with the exception of the primary polychaete taxonomy, was contracted to recognized specialists. Organisms were enumerated and identified to the lowest taxonomic level possible, generally to species. In general, anterior ends of organisms were counted, except for bivalves (hinges), gastropods (opercula), and ophiuroids (oral disks). When possible, at least two pieces of literature (preferably including original descriptions) were used for each species identification. A maximum of three representative organisms of each species or taxon were removed from the samples and placed in a voucher collection.

Taxonomic identification quality control for all taxonomists included re-identification of 5% of all samples identified by the primary taxonomist and verification of voucher specimens generated by another qualified taxonomist.

Data Summary, Display, and Statistical Analysis

Raw data files are too extensive to display in this report and will be made available on the Ecology Sediment Monitoring Program's web site. Quality assurance reports will also be posted to the web site upon completion (see inside front cover for address).

Toxicity Testing

Several statistical methods were used to identify the significance of the results of the toxicity tests, to identify relationships between measures of toxicity and contamination, to estimate spatial scales in toxicity and contamination, and to identify chemicals of greatest concern.

Amphipod Survival – Solid Phase

Data from each station in which mean percent survival was less than that of the control were compared to the CLIS control using a one-way, unpaired t-test (alpha < 0.05) assuming unequal variance. Data were not transformed since examination of data from previous tests has shown that *A. abdita* percentage survival data met the requirements for normality.

Significant toxicity for *A. abdita* is defined here as survival that is statistically less than that in the performance control (alpha < 0.05). In addition, samples in which survival was significantly less than controls and less than 80% of CLIS control values were regarded as "highly toxic". The 80% criterion is based upon statistical power curves created from SAIC's extensive testing database with *A. abdita* (Thursby et al., 1997). These curves show that the power to detect a 20% difference from the control is approximately 90%. The minimum significant difference (i.e., "MSD" of >20%, or <80%, of control response) also was used as the critical value in calculations of the spatial extent of toxicity (Long et al., 1996).

Sea Urchin Fertilization - Pore Water

For the sea urchin fertilizations, statistical comparisons among treatments were made using ANOVA and Dunnett's one-tailed t-test (which controls the experiment-wise error rate) on the arcsine square root transformed data with the aid of SAS (SAS, 1989). The trimmed Spearman-Karber method (Hamilton et al., 1977) with Abbott's correction (Morgan, 1992) was used to calculate EC50 (50% effective concentration) values for dilution series tests. Prior to statistical analyses, the transformed data sets were screened for outliers (Moser and Stevens, 1992). Outliers were detected by comparing the studentized residuals to a critical value from a t-distribution chosen using a Bonferroni-type adjustment. The adjustment is based on the number of observations (n) so that the overall probability of a type 1 error is at most 5%. The critical value (CV) is given by the following equation: cv= t(dfError, .05/[2 x n]). After omitting outliers, but prior to further analyses, the transformed data sets were tested for normality and for homogeneity of variance using SAS/LAB Software (SAS, 1992). Statistical comparisons were made with mean results from the Redfish Bay controls. Reference toxicant concentration results were compared to filtered seawater controls and each other using both Dunnett's t-test and Duncan's multiple range test to determine Lowest Observable Effects Concentrations (LOECs) and No Observable Effects Concentrations (NOECs).

In addition to the Dunnett's one-tailed t-tests, data from field-collected samples were treated with an analysis similar to the MSD analysis used in the amphipod tests. Power analyses of the sea urchin (*Arbacia punctulata*) fertilization data have shown MSDs of 15.5% for alpha < 0.05 and 19% for alpha < 0.01. However, to be consistent with the statistical methods used in previous surveys (Long et al., 1996), and to ensure that data from northern Puget Sound would be comparable to those from other areas around the country, we elected to use a critical value of <80% control response. This was the same critical value used for the amphipod tests; thus designating the samples as "highly toxic".

Microbial Bioluminescence (Microtox™) - Organic Solvent Extract

Microtox™ data were analyzed using the computer software package developed by Microbics Corporation to determine concentrations of the extract that inhibit luminescence by 50% (EC50). This value was then converted to mg dry wt using the calculated dry weight of sediment present in the original extract. To determine significant differences of samples from each station, pair-wise comparisons were made between survey samples and results from Redfish Bay control sediments using analysis of variance (ANOVA). Concentrations tested were expressed as mg dry wt based on the percent extract in the 1 ml exposure volume and the calculated dry weight of the extracted sediment. Statistical comparisons among treatments were made using ANOVA and Dunnett's one-tailed t-tests on the log transformed data with the aid of SAS (SAS, 1989).

Cytochrome P450 RGS - Organic Solvent Extract

Results of these tests were compiled on a Microsoft Excel spreadsheet. Mean RGS response and the 99% confidence interval (CI) were determined for all 100 samples as benzo[a]pyrene equivalents. Mean results from test samples were compared to the upper 99% CI for the data set to determine which samples had elevated responses. Comparisons with the Redfish Bay controls were not useful because of the extremely low response in the controls.

Incidence and Severity, Spatial Patterns and Gradients, and Spatial Extent of Sediment Toxicity

The incidence of sediment toxicity was determined for all samples tested by dividing the number of samples identified as significantly different from controls or "highly toxic" by the total number of samples (n=100) tested. Severity of toxicity was estimated as the range in response of the toxicity tests to the sediment samples.

Spatial patterns and gradients in sediment toxicity were illustrated by plotting toxicity data, for each of the four tests, on base maps of each major region in the northern Puget Sound study area.

Estimates of the spatial extent of sediment toxicity for each of the four tests performed in northern Puget Sound were determined with cumulative distribution functions, weighting the toxicity results from each station to the dimensions (km^2) of the sampling stratum in which the samples were collected (i.e., the sizes of the strata in which toxic results were recorded were summed) (Schimmel et al., 1994). The size of each stratum (km^2) was determined by use of an electronic planimeter applied to navigation charts, upon which the boundaries of each stratum

were outlined. Stratum size was calculated as the average of three trials, all of which were within 10% of each other.

A critical value of less than 80% of control response was used in the calculations of the spatial extent of toxicity for amphipod survival and urchin fertilization tests. That is, the sample-weighted sizes of each stratum in which toxicity test results were less than 80% of control responses were summed to estimate the spatial extent of toxicity. These critical values were derived following power analyses of data generated in many previous surveys and were the same critical values used in all previous NOAA surveys (Long et al., 1996).

Power analyses of existing data have not been performed thus far to determine empirically the critical statistical value for the Microtox™, and no critical values are described in the PSEP Protocols. Therefore, two new critical values intended to be more applicable to the northern Puget Sound data were generated for the Microtox™ test results, both based upon statistical analyses of the existing data from NOAA surveys conducted thus far (including the data from northern Puget Sound, n=1013). The two new critical values are <0.06 mg/ml and <0.51 mg/ml (Table 12). The first value (0.06 mg/ml) represents the 90% lower prediction limit (LPL) of the entire data set. The probability that a future observation from this data distribution would be more toxic (i.e., an EC50 < 0.06 mg/ml) would be 90%. Therefore, a sample with an EC50 less than 0.06 mg/ml would be extremely toxic in this test. The second value (0.51 mg/ml) represents the 80% LPL with the lowest (most toxic) 10% of the data values removed from the database to eliminate their influence on the distribution of the data. Samples with EC50 values <0.51 mg/ml or >0.06 mg/ml would be considered as moderately toxic in this test.

As with the Microtox™ tests, no critical values for the Cytochrome P450 RGS assays have been published. Therefore, as a part of this study, two critical values were calculated and used to estimate spatial extent of toxicity in northern Puget Sound. The first value, 37.1 µg/g benzo[a]pyrene equivalents, represented the upper 90% prediction limit (UPL) of the entire data set gathered thus far in all NOAA studies (n=530). This value agrees well with 32 µg/g, the RGS induction level equivalent to the ERL value (Long et al., 1995) for high molecular weight PAHs determined in regression analyses of the existing data for this test. Also, the upper 99% confidence interval for previous tests was 32.8 µg/g (n=527). Therefore, this value is viewed as a concentration above which toxicologically significant effects may begin in sediments. The second value, 11.1 µg/g, was the 80% UPL of the data distribution following elimination of the data above the 90th percentile from the entire database. The extremely toxic samples were deleted in this step to eliminate their effect upon the data distribution. This value (11.1 µg/g) is viewed as the upper limit of background RGS responses.

Concordance Among Toxicity Tests

Statistical concordance among test results was determined with a non-parametric test because the data were not normally distributed. Spearman-rank correlations were determined for combinations of different toxicity test results to quantify the degree to which these tests showed the same spatial patterns in toxicity.

Chemical Analyses

Results of the grain size analysis were reported in tabular and graphical form. Total organic carbon, temperature, and salinity measurements were also reported in tabular form for all stations. Summary statistics (i.e., mean, median, minimum, maximum, range, and number of non-detected and missing values) for all chemistry and organics data generated were calculated and reported in tabular form.

Spatial Patterns and Spatial Extent of Sediment Contamination

To identify spatial patterns in sediment contamination, sampling stations where chemical concentrations exceeded either the Sediment Quality Standards (SQS) or Cleanup Screening Levels (CSL) (as defined in Washington State's Sediment Management Standards – Ch. 173-204 WAC), or the Effects Range-Low (ERL) or Effects Range-Median (ERM) values of Long et al. (1995), were highlighted on strata maps. Chemical concentrations below ERL values are not expected to contribute to toxic effects. Sediments in which ERM, SQS, and CSL guideline concentrations were exceeded would have higher probabilities of being toxic than those in which they were not exceeded.

Two sets of maps were created to display patterns of metals contamination; one for the metals data generated with total digestion extractions, used for comparison with ERL and ERM values, and the other for the concentrations resulting from partial digestion extractions, used for comparison with state SQS and CSL criteria. In all comparisons, samples were ignored when concentrations were reported as below quantitation limits (bql) and the quantitation limits equaled or exceeded the guidelines. For classes of compounds (PAHs, PCBs, DDTs) in which concentrations of individual compounds were summed, concentrations reported with quantitation limit qualifiers were treated as one-half the quantitation limit.

The spatial extent of contamination was determined with cumulative distribution functions in which the sizes of strata with samples exceeding the ERM, SQS, and CSL effects-based, numerical guidelines were summed.

Chemistry/Toxicity Relationships

Chemistry/toxicity relationships were determined in a multi-step sequence. First, non-parametric, Spearman-rank correlations were used to determine if there were relationships between the four measures of toxicity and the concentrations of classes of toxicants (i.e., 4 groups of chemicals) normalized to their respective ERM values (Long et al., 1995) and Washington State SQS and CSL values (Washington State Sediment Management Standards – Ch. 173-204 WAC). ERM, SQS, and CSL quotients were generated. These chemical index values, derived by summing the quotients formed when the chemical concentrations in the samples are divided by their respective ERM, SQS, and CSL values, were calculated for suites of compounds and correlated with toxicity results.

Second, Spearman-rank correlations were also used to determine relationships between each toxicity test and each physical/chemical variable. The correlation coefficients and their statistical significance (p values) were recorded and compared among chemicals to identify which chemicals co-varied with toxicity and which did not. For many of the different semivolatile organic substances in the sediments, correlations were conducted for all 100 samples, using the limits of quantitation for values reported as undetected. If the majority of concentrations were qualified as either estimates or below quantitation limits, the correlations were run again after eliminating those samples. No analyses were performed for the numerous chemicals whose concentrations were below the limits of quantitation in all samples. All correlations were also run separately for the 15 samples collected from the vicinity of Everett Harbor (samples from stations 86-100).

Third, for those chemicals in which a significant correlation was observed, the data were examined in scatterplots to determine whether there was a reasonable pattern of increasing toxicity with increasing chemical concentration. Also, chemical concentrations in the scatterplots were compared with the SQS, CSL, and ERM values to determine which samples, if any, were both toxic and had elevated chemical concentrations. The concentrations of un-ionized ammonia were compared to Lowest Observable Effects Concentrations (LOEC) determined for the sea urchin tests by the USGS (Carr et al., 1996b) and No Observable Effects Concentrations (NOEC) determined for amphipod survival tests (Kohn et al., 1994).

The objectives of this study did not include a determination of the cause(s) of toxicity or benthic alterations. Such determinations would require the performance of toxicity identification evaluations and other similar research. The purpose of the multi-step approach used in the study was to identify which chemicals, if any, showed the strongest concordance with the measures of toxicity and benthic infaunal structure.

Correlations were determined for all the substances that were quantified, including trace metals (both total and partial digestion), metalloids, simultaneously-extracted metals (SEM)/acid volatile sulfides (AVS), un-ionized ammonia (UAN), percent fines, total organic carbon (TOC), chlorinated organic hydrocarbons (COHs), and polynuclear aromatic hydrocarbons (PAHs). Concentrations were normalized to TOC where required for SQS and CSL values.

Those substances that showed significant correlations with measures of toxicity were indicated with asterisks (*= $p<0.05$, ** = $p<0.01$, ***= $p<0.001$, and ****= $p<0.0001$) depending upon the level of probability. In correlation analyses involving a large number of variables such as in this survey, some correlations could appear to be significant by random chance alone. Adjustments (such as Bonferroni's adjustment) often are needed to account for this possibility. Therefore, note that in the correlation tables only those coefficients shown with four asterisks would remain significant if the number of variables (171) were taken into account in these analyses (i.e., $p=0.0001 \times 171=0.017$).

Benthic Community Analyses

All benthic infaunal data were reviewed and standardized for any taxonomic nomenclatural inconsistencies by Ecology personnel using an internally developed standardization process. With assistance from the taxonomists, the final species list was also reexamined for identification and removal of taxa that were non-countable infauna. This included (1) organisms recorded with presence/absence data, such as colonial species, (2) meiofaunal organisms, and (3) incidental taxa which were caught by the grab, but are not a part of the infauna (e.g., planktonic forms). Following these criteria, a total of 48 taxa were removed from the data files (Appendix C).

A series of benthic infaunal indices were then calculated to summarize the raw data and characterize the infaunal invertebrate assemblages identified from each station. Indices were based upon all countable taxa, excluding colonial forms. Five indices were calculated, including total abundance, major taxa abundance, taxa richness, Pielou's evenness (J'), and Swartz's dominance. These indices are defined in Table 5.

Nonparametric Spearman-rank correlation analyses were conducted among all benthic indices, chemistry, and toxicity data. The correlation coefficients and their statistical significance (p values) were recorded and examined to identify which benthic indices co-varied with toxicity results and chemistry concentrations. Comparisons were made to determine similarities between these correlation results and those generated for the chemistry/toxicity correlation analyses.

The benthic data analyses and interpretations presented in this report are intended to be preliminary and general. Estimates of the spatial extent of benthic alterations are not made due to absence of a widely accepted critical value at this time. A more thorough examination of the benthic infauna communities in northern Puget Sound and their relationship to sediment characteristics, toxicity, and chemistry will be presented in future reports.

Table 5. Benthic infaunal indices calculated to characterize the infaunal invertebrate assemblages identified from each PSAMP/NOAA monitoring station.

Infaunal Index	Definition	Calculation
Total Abundance	A measure of density equal to the total number of organisms per sample area	Sum of all organisms counted in each sample
Major Taxa Abundance	A measure of density equal to the total number of organisms in each major taxa group (Annelida, Mollusca, Echinodermata, Arthropoda, Miscellaneous Taxa) per sample area	Sum of all organisms counted in each major taxa group per sample
Taxa Richness	Total number of taxa (taxa = lowest level of identification for each organism) per sample area	Sum of all taxa identified in each sample
Pielou's Evenness (J') (Pielou, 1966, 1974)	Relates the observed diversity in benthic assemblages as a proportion of the maximum possible diversity for the data set (the equitability (evenness) of the distribution of individuals among taxa)	$J' = H'/\log s$ Where: $H' = -\sum_{i=I}^{s} p_i \log p_i$ where p_i = the proportion of the assemblage that belongs to the ith species ($p=n_i/N$, where n_i=the number of individuals in the i species and N= total number of individuals), and where s = the total number of taxa
Swartz's Dominance Index (SDI) (Swartz et al., 1985)	The minimum number of taxa whose combined abundance account for 75% of the total abundance in each sample	Sum of the minimum number of taxa whose combined abundance account for 75% of the total abundance in each sample

Results

Toxicity Testing

Incidence and Severity of Toxicity

Amphipod Survival - Solid Phase

Amphipod survival tests were performed in 11 batches corresponding to the numbers of samples received from the field crew. Sample holding times from date of collection to initiation of the tests ranged from 4 to 10 days. Test temperatures ranged from 19.5°C to 20.5°C. All other water quality parameters (D.O., pH, salinity, ammonia) were also within acceptable ranges for *Ampelisca abdita*. Test animals ranged in sizes from >0.5 mm to <1.18 mm. Mean survival in CLIS controls ranged from 93% to 99%, well within the acceptable range. LC50 concentrations from 11 96-hr tests of SDS in water ranged from 2.16 mg/L to 7.86 mg/L, only one of which (2.16 mg/L in batch 4) was outside the acceptable control chart range (4.6 mg/L to 10.3 mg/L). Because the data from the negative controls and Puget Sound samples in batch 4 did not indicate elevated sensitivity of these test animals, the data were accepted.

Mean percent survival in samples from 13 stations was statistically significant ($p<0.05$) relative to the CLIS controls (Table 6). Thus, the incidence of significantly toxic responses was 13%. These 13 samples were collected in stratum 2 (Semiahmoo Bay), stratum 4 (southern Boundary Bay), strata 9A and 9B (inner Bellingham Bay), stratum 13 (Samish/Bellingham Bay), stratum 14 (inner Padilla Bay), stratum 21 (Skagit Bay), stratum 23 (Oak Harbor), stratum 24 (Penn Cove), strata 29 and 30 (inner and middle Everett Harbor), and stratum 33 (Snohomish River delta). Mean survival as percent of the CLIS controls ranged from 82% to 105%, indicating a relatively narrow range in response to the samples. Mean percent survival exceeded 80% of controls in all samples; therefore, none of the samples was "highly toxic" as defined in Methods. Thus, the incidence of highly significant toxicity was 0% in this test.

Sea Urchin Fertilization – Pore Water

Tests of sea urchin fertilization were performed on samples of 100%, 50%, and 25% pore waters from each of the 100 samples plus the Redfish Bay, TX controls. All samples were processed within 10 days of the date of collection, usually within one or two days of the date of arrival. All tests were performed at salinities of 30 ± 1 ppt. Sulfide concentrations were below the detection limit of 0.01 mg/L in 96 of the samples. In samples 86-89 sulfide concentrations ranged from 1.98 mg/L to 5.00 mg/L in 100% pore waters and could have contributed to toxicity in those samples. Porewater dissolved oxygen concentrations ranged from 5.94 mg/L to 8.99 mg/L (81.4 to 104% saturation). Stirring was required for nine samples which initially had DO concentrations below 80% saturation. Test sample pH values ranged from 6.8 to 8.03 while pH in controls ranged from 8.09 to 8.34. Total ammonia concentrations ranged from 0.08 to 13.3 mg/L and un-ionized ammonia concentrations ranged from 2.0 to 95.7 µg/L, well below the

Table 6. Results of amphipod survival tests in 100 sediment samples from northern Puget Sound.

Stratum	Sample	Mean amphipod survival (%)	Mean survival in control (%)	Mean amphipod survival as % of control	Statistical significance
1	1	97	99	98	
Drayton	2	94	96	98	
Harbor	3	99	96	103	
2	4	95	99	96	*
Semiahmoo	5	90	99	91	*
Bay	6	95	96	99	
3	7	92	96	96	
W. Boundary	8	96	96	100	
Bay	9	95	96	99	
4	10	95	96	99	
S. Boundary	11	92	99	93	
Bay	12	100	99	101	
	13	94	99	95	*
5	14	95	99	96	
Birch	15	96	99	97	
Bay	16	98	99	99	
6	17	95	96	99	
Cherry	18	96	96	100	
Point	19	94	96	98	
7	20	95	97	98	
Bellingham	21	93	97	96	
Bay	22	94	97	97	
8	23	96	97	99	
Bellingham	24	97	93	104	
Bay	25	96	97	99	

Table 6 (cont.). Results of amphipod survival tests in 100 sediment samples from northern Puget Sound.

Stratum	Sample	Mean amphipod survival (%)	Mean survival in control (%)	Mean amphipod survival as % of control	Statistical significance
9A	26	97	96	101	
Bellingham	27	95	96	99	
Bay	28	89	96	93	*
9B	59	92	96	96	
Bellingham	60	90	96	94	*
Bay	61	94	96	98	
10	29	95	97	98	
Bellingham	30	88	97	91	
Bay	31	93	97	96	
11	32	95	93	102	
Bellingham	33	95	93	102	
Bay	34	88	93	94	
12	35	93	93	100	
Bellingham	36	95	93	102	
Bay	37	89	93	95	
13	38	92	93	99	
Samish/	39	97	93	104	
Belling. Bay	40	91	97	94	*
14	41	95	94	101	
Padilla	42	86	94	91	*
Bay (inner)	43	94	94	100	
15	44	86	94	91	
Padilla	45	89	94	95	
Bay (outer)	46	87	94	93	
16	47	86	94	91	
March	48	88	94	94	
Point	49	94	94	100	

Table 6 (cont.). Results of amphipod survival tests in 100 sediment samples from northern Puget Sound.

Stratum	Sample	Mean amphipod survival (%)	Mean survival in control (%)	Mean amphipod survival as % of control	Statistical significance
17	50	85	94	90	
Fidalgo	51	90	94	96	
Bay (inner)	52	87	94	93	
18	53	86	94	91	
Fidalgo	54	92	94	98	
Bay (outer)	55	92	94	98	
19	56	89	94	95	
March	57	95	94	101	
Point	58	94	94	100	
21	62	93	99	94	*
Skagit	63	96	99	97	
Bay	64	100	99	101	
22	65	96	99	97	
Saratoga	66	97	99	98	
Passage (no.)	67	95	99	96	
23	68	97	99	98	
Oak	69	93	99	94	*
Harbor	70	98	99	99	
24	71	79	96	82	*
Penn	72	93	99	94	
Cove	73	97	99	98	
25	74	90	96	94	
Saratoga	75	94	96	97	
Passage (mid.)	76	90	96	94	

Table 6 (cont.). Results of amphipod survival tests in 100 sediment samples from northern Puget Sound.

Stratum	Sample	Mean amphipod survival (%)	Mean survival in control (%)	Mean amphipod survival as % of control	Statistical significance
26	77	98	96	102	
Saratoga	78	92	97	95	
Passage (so.)	79	93	96	97	
27	80	95	97	98	
Port	81	96	97	99	
Susan	82	93	97	96	
28	83	98	97	101	
Possession	84	96	97	99	
Sound	85	96	97	99	
29	86	94	98	96	
Everett	87	83	98	84	*
Harbor (inner)	88	88	98	90	
30	89	88	98	89	
Everett	90	88	96	92	*
Harbor (mid.)	91	93	96	97	
31	92	90	98	92	
Everett	93	95	98	97	
Harbor (outer)	94	98	98	100	
32	95	91	98	93	
Port	96	97	97	100	
Gardner	97	93	97	96	
33	98	95	96	99	
Snohomish	99	91	98	93	
River delta	100	86	96	90	*

* Mean survival significantly less than CLIS controls ($p<0.05$)

** Mean survival significantly less than CLIS controls and less than 80% of CLIS controls

lowest observable effects concentrations (LOEC=800 µg/L for *Arbacia punctulata*). An equivalent LOEC is not yet available for *S. purpuratus*. All of these data indicate that testing conditions were within acceptable limits for these tests.

Tests were run in three batches of samples plus the Redfish Bay controls. The EC50 concentrations for the SDS positive controls were 2.41, 3.23, and 3.51 mg/L for batches 1, 2, and 3, respectively.

Mean responses for each sample and each porewater concentration are shown in Table 7, along with mean responses normalized to control responses. Four measures of statistical significance are indicated. If percent fertilization was significantly reduced relative to controls (Dunnett's t-test), but fertilization was less than the minimum significant difference (MSD) calculated for *A. punctulata*, significance is shown as + for alpha <0.05 and shown as ++ for alpha <0.01. If percent fertilization was significantly reduced relative to controls (Dunnett's t-test) and percent fertilization exceeded the minimum significant difference (i.e., <80% of control response), significance is shown as * for alpha <0.05 and ** for alpha <0.01. The MSD value for *A. punctulata* was used, because none is available thus far for *S. purpuratus*.

Among the 100 samples tested with 100%, 50%, and 25% porewater concentrations, 15, 8 and 6 samples, respectively were highly toxic (i.e., different from controls at alpha <0.01 and exceeded the MSD)(Table 7). As percent of Redfish Bay controls, mean fertilization success among all samples ranged from 0.0% in two samples from inner Everett Harbor and one sample collected off Point Roberts, to 121% in several samples scattered throughout the area.

Toxic conditions were indicated in samples from several different areas. Samples from stations 89 - 93 collected in Everett Harbor were highly toxic in both the 100% and 50% porewater concentrations and those from stations 90-93 were also highly toxic in 25% pore water. These five samples along with the sample from station 3 collected in Drayton Harbor were the most toxic of the 100 samples tested with this test. Other samples that were highly toxic in at least the 100% porewater concentrations included those from station 2 (Drayton Harbor), station 22 (northern Bellingham Bay), station 43 (inner Padilla Bay), station 51 (inner Fidalgo Bay), station 82 (Port Susan), stations 86 and 87 (inner Everett Harbor, station 94 (outer Everett Harbor), and station 100 (Snohomish River delta).

The relative sensitivities of both *S. purpuratus* and *A. punctulata* to 11 of the samples were compared (Table 8). Tests with both species identified the same samples as either non-toxic or toxic, indicating very similar sensitivities to the samples. Three samples were highly toxic in 100% pore waters in both tests, two of which were also highly toxic in tests of 50% and 25% pore waters. Among those samples in which toxicity was observed, fertilization success was invariably lower among *S. purpuratus* than *A. punctulata*, indicating higher sensitivity for *S. purpuratus*. Also, the EC50 concentrations for tests of SDS were 5.23 mg/L and 2.91 mg/L for *A. punctulata* and *S. purpuratus*, respectively. Again, these data suggest that *S. purpuratus* is slightly more sensitive than *A. punctulata*.

Table 7. Results of sea urchin fertilization tests on pore waters from 100 sediment samples from northern Puget Sound. Tests performed with *S. purpuratus*.

Stratum	Sample	*100% pore water*			*50% pore water*			*25% pore water*		
		Mean % fertilization	**% of control**	**Statistical significance**	**Mean % fertilization**	**% of control**	**Statistical significance**	**Mean % fertilization**	**% of control**	**Statistical significance**
1	1	98.6	117		99.8	104		99.0	101	
Drayton	2	24.6	29	**	69.8	73	**	89.0	91	++
Harbor	3	0.4	0	**	16.6	17	**	68.2	69	**
2	4	99.6	118		99.4	104		99.0	101	
Semiahmoo	5	99.6	118		99.2	104		99.8	102	
Bay	6	99.2	117		98.2	103		99.6	101	
3	7	98.8	117		98.8	103		99.0	101	
West	8	98.8	117		99.6	104		98.6	100	
Boundary Bay	9	99.8	118		99.4	104		99.6	101	
4	10	99.8	118		99.4	104		99.2	101	
South	11	99.0	117		99.6	104		98.6	100	
Boundary	12	98.4	116		99.8	104		99.2	101	
Bay	13	98.2	116		99.2	104		97.8	100	
5	14	99.4	117		99.4	104		99.6	101	
Birch	15	99.8	118		98.4	103		98.6	100	
Bay	16	99.6	118		99.0	103		99.0	101	
6	17	97.0	115		97.2	101		95.4	97	
Cherry	18	95.0	112		96.6	101		95.6	97	
Point	19	97.0	115		98.6	103		96.0	98	
7	20	95.8	113		93.8	98		94.8	97	
Bellingham	21	95.6	113		96.4	101		97.6	99	
Bay	22	38.6	46	**	84.2	88	++	97.0	99	
8	23	96.6	114		96.8	101		96.6	98	
Bellingham	24	97.4	115		97.2	101		97.4	99	
Bay	25	96.2	114		98.4	103		98.8	101	
9A	26	96.2	119		96.2	103		97.8	100	
Bellingham	27	96.2	119		96.2	103		97.4	100	
Bay	28	94.0	117		96.0	103		98.0	101	

Table 7 (cont.). Results of sea urchin fertilization tests on pore waters from 100 sediment samples from northern Puget Sound. Tests performed with *S. purpuratus*.

Stratum	Sample	*100% pore water*			*50% pore water*			*25% pore water*		
		Mean % fertilization	% of control	Statistical significance	Mean % fertilization	% of control	Statistical significance	Mean % fertilization	% of control	Statistical significance
9B	59	98.0	103		96.4	103		97.6	109	
Bellingham	60	98.8	104		98.6	105		98.4	110	
Bay	61	93.0	98		97.0	103		97.4	109	
10	29	96.8	120		96.8	104		97.0	100	
Bellingham	30	97.2	121		94.8	102		96.6	99	
Bay	31	95.4	118		96.2	103		97.2	100	
11	32	75.8	94		89.8	96		93.6	96	
Bellingham	33	94.0	117		95.4	102		95.2	98	
Bay	34	83.0	103		92.8	100		90.8	93	++
12	35	94.6	117		96.2	103		95.2	98	
Bellingham	36	88.2	109		91.2	98		96.6	99	
Bay	37	92.0	114		94.4	101		94.0	97	
13	38	93.4	116		94.2	101		90.6	93	++
Samish/	39	94.4	117		92.8	100		93.8	96	
Belling. Bay	40	93.0	115		94.8	102		95.0	98	
14	41	83.4	103		90.4	97		91.4	94	++
Padilla	42	90.0	112		90.4	97		93.0	95	+
Bay (inner)	43	40.8	51	**	81.4	87	++	86.0	88	++
15	44	93.6	116		92.2	99		94.6	97	
Padilla	45	96.4	120		94.0	101		93.0	95	+
Bay (outer)	46	95.0	118		93.6	100		88.6	91	++
16	47	91.8	114		94.2	101		91.4	94	++
March	48	92.0	114		93.2	100		93.2	96	
Point	49	90.0	112		90.2	97		91.0	93	++
17	50	92.6	115		92.6	99		88.4	91	++
Fidalgo	51	41.4	51	**	80.6	86	++	89.4	92	++
Bay (inner)	52	81.8	101		91.2	98		89.8	92	++

Table 7 (cont.). Results of sea urchin fertilization tests on pore waters from 100 sediment samples from northern Puget Sound. Tests performed with *S. purpuratus*.

Stratum	Sample	*100% pore water*			*50% pore water*			*25% pore water*		
		Mean % fertilization	**% of control**	**Statistical significance**	**Mean % fertilization**	**% of control**	**Statistical significance**	**Mean % fertilization**	**% of control**	**Statistical significance**
18	53	90.8	113		89.0	95		89.0	91	++
Fidalgo	54	89.2	111		87.4	94		87.8	90	++
Bay (outer)	55	93.0	115		96.4	103		96.6	99	
19	56	95.6	119		96.8	104		97.6	100	
March	57	97.6	121		98.8	106		99.0	102	
Point	58	96.6	120		99.4	107		97.6	100	
21	62	97.0	102		97.0	103		99.0	110	
Skagit	63	95.0	100		95.8	102		93.8	105	
Bay	64	90.6	95		96.4	103		96.6	108	
22	65	85.4	90	++	85.0	90	++	91.4	102	
Saratoga	66	84.0	88	++	87.6	93		87.8	98	
Passage (n)	67	91.0	96		89.2	95		89.2	99	
23	68	98.2	103		97.0	103		97.4	109	
Oak	69	97.8	103		96.2	102		96.0	107	
Harbor	70	97.8	103		98.4	105		98.0	109	
24	71	98.8	104		97.6	104		98.0	109	
Penn	72	95.0	100		95.0	101		96.8	108	
Cove	73	97.0	102		95.8	102		92.6	103	
25	74	92.0	97		96.4	103		95.6	107	
Saratoga	75	87.2	92	+	94.0	100		94.4	105	
Passage (m)	76	89.6	94		93.2	99		93.4	104	
26	77	96.6	101		95.8	102		95.4	106	
Saratoga	78	97.0	102		97.4	104		95.8	107	
Passage (s)	79	95.8	101		96.2	102		93.6	104	
27	80	93.2	98		94.6	101		90.6	101	
Port	81	90.2	95		92.8	99		92.6	103	
Susan	82	72.4	76	**	89.8	96		91.4	102	

Table 7 (cont.). Results of sea urchin fertilization tests on pore waters from 100 sediment samples from northern Puget Sound. Tests performed with *S. purpuratus*.

Stratum	Sample	*100% pore water*			*50% pore water*			*25% pore water*		
		Mean % fertilization	**% of control**	**Statistical significance**	**Mean % fertilization**	**% of control**	**Statistical significance**	**Mean % fertilization**	**% of control**	**Statistical significance**
28	83	97.6	121		98.4	106		97.2	100	
Possession	84	96.4	120		97.4	105		97.4	100	
Sound	85	96.2	119		97.0	104		94.4	97	
29	86	18.4	23	**	93.8	101		98.2	101	
Everett	87	9.6	12	**	89.5	96		96.8	99	
Harbor (in)	88	40.0	50	**	94.0	101		95.8	98	
30	89	0.0	0	**	24.6	26	**	82.6	85	++
Everett	90	0.8	1	**	1.0	1	**	1.8	2	**
Harbor (m)	91	0.4	0	**	1.4	2	**	2.8	3	**
31	92	3.8	5	**	9.0	10	**	56.4	58	**
Everett	93	1.8	2	**	12.0	13	**	63.2	65	**
Harbor (o)	94	54.6	68	**	92.6	99		93.4	96	
32	95	96.8	120		98.6	106		96.2	99	
Port	96	95.6	119		96.4	103		95.0	98	
Gardner	97	91.4	113		94.4	101		95.4	98	
33	98	97.2	121		97.8	105		94.2	97	
Snohomish	99	95.8	119		92.8	100		87.4	90	++
River delta	100	75.8	94		75.4	81	**	78.0	80	**

• Mean response significantly different from controls
(Dunnett's t-test: +=alpha<0.05 or ++=alpha< 0.01)
• Mean response significantly different from controls (Dunnett's t-test) and exceeds minimum significant difference
(*=alpha<0.05 or **=alpha< 0.01)

Table 8. Comparison between mean percent fertilization in *A. punctulata* and *S. purpuratus* in ten samples from northern Puget Sound plus the control (means ± std. dev.).

Stratum	Sample	Percent pore water	Percent fertilization			
			A. punctulata	Statisicial significance	*S. purpuratus*	Statistical significance
	Control	100	76±6		81±8	
		50	93±3		93±2	
		25	94±4		97±2	
9A Bellingham Bay	26	100	96±3		96±2	
		50	98±1		96±2	
		25	96±1		98±1	
9A Bellingham Bay	27	100	97±2		96±2	
		50	98±1		96±1	
		25	97±2		97±2	
10 Bellingham Bay	30	100	96±3		97±2	
		50	94±3		95±2	
		25	94±3		97±2	
10 Bellingham Bay	31	100	96±1		95±3	
		50	98±1		96±4	
		25	97±1		97±1	
12 Bellingham Bay	36	100	93±5		88±7	
		50	97±1		91±3	
		25	96±2		97±3	
28 Possession Sound	85	100	97±3		96±3	
		50	97±1		97±2	
		25	91±6		94±2	
29 Everett Harbor (inner)	86	100	60±14	**	18±7	**
		50	96±3		94±3	
		25	98±1		98±2	

Table 8 (cont.). Comparison between mean percent fertilization in *A. punctulata* and *S. purpuratus* in ten samples from northern Puget Sound plus the control (means ± std. dev.).

Stratum	Sample	Percent pore water	Percent fertilization			
			A. punctulata	Statisicial significance	*S. purpuratus*	Statistical significance
30	90	100	27±8	**	1±1	**
Everett		50	48±11	**	1±1	**
Harbor (mid.)		25	43±13	**	2±1	**
30	91	100	44±6	**	0.4±0.6	**
Everett		50	47±7	**	1±1	**
Harbor (mid.)		25	53±5	**	3±3	**
32	96	100	96±3		96±3	
Port		50	96±2		96±2	
Gardner		25	95±2		95±2	

• Mean response significantly different from controls
(Dunnett's t-test: +=alpha<0.05 or ++=alpha< 0.01)
• Mean response significantly different from controls (Dunnett's t-test) and exceeds minimum significant difference
(*=alpha<0.05 or **=alpha< 0.01)

Results of the inter-species comparisons conducted by performing a series of dilution tests, with five reference toxicants, on both species are provided in Table 9. In these experiments clean seawater was spiked with known amounts of chemicals and tested in dilution series to determine if the two species were similarly insensitive to the same substances. Data are listed for copper, PCB Aroclor 1254, 2, 4'-DDD, phenanthrene, and naphthalene. No Observable Effects Concentrations (NOEC) and Lowest Observable Effects Concentrations (LOEC) were determined by the USGS laboratory. No dose response was observed in either of the tests of the PCB mixture. The NOEC is shown as >4.5 µg PCB/L, the highest concentration used in the experiments, which was near the maximum solubility for this mixture in seawater. Because the PCBs were not toxic at the highest concentration, no dose-response curve could be calculated and, therefore, the LOEC could not be estimated (Table 9). Similarly no values could be calculated for *S. purpuratus* in tests of DDD. *A. punctulata* were slightly more sensitive than *S. purpuratus* to copper, DDD, and naphthalene and similar in sensitivity to phenanthrene.

In summary, although *A. punctulata* was slightly less sensitive than *S. purpuratus* to the pore waters extracted from the sediments, it was slightly more sensitive to three of the five individual reference toxicants. Therefore, it appears that tests performed with either species are roughly equivalent in sensitivity.

Table 9. No Observable Effect Concentrations (NOEC) and Lowest Observable Effect Concentrations (LOEC) determined in spiked water bioassays performed with *Arbacia punctulata* and *Strongylocentrotus purpuratus*.

	NOEC		*LOEC*	
Chemical	***A. punctulata***	***S. purpuratus***	***A. punctulata***	***S. purpuratus***
copper	0.52 µg/L	8.2 µg/L	1.05 µg/L	19.0 µg/L
PCB Arohlor 1254	>4.5 µg/L	>4.5 µg/L	na	na
2,4'-DDD	0.07 µg/L	>16.8 µg/L	0.14 µg/L	na
phenanthrene	0.33 mg/L	0.33 mg/L	0.68 mg/L	0.68 mg/L
naphthalene	4.4 mg/L	8.7 mg/L	8.7 mg/L	16.8 mg/L

na = not available

Microbial Bioluminescence (Microtox™) and Cytochrome P450 RGS – Organic Solvent Extract

Microtox™ tests and Cytochrome P450 RGS assays were performed on portions of the same organic solvent extracts prepared for all 100 samples. Results of these two bioassays performed on the sediment extracts are provided in Table 10.

Examination of the results of the Microtox™ organic solvent bioluminescence test indicated that the mean EC50 (50% effective concentration) for the Redfish Bay control was 102.9 mg/mL. In previous tests of the sediments from this location, mean EC50s were 30.7, 36.0, and 48.9 mg/mL, indicating that the material tested with this survey was less toxic than that tested in previous surveys of other areas. Tests of the phenol-spiked blank provided a mean EC50 concentration of 15.2 mg/mL.

Statistical comparisons of the data indicated 97 of the 100 samples were significantly different from controls. Thus, the incidence of significantly toxic responses was 97%. The three stations where EC50 values were not significantly different from controls included Port Susan (station 80), Port Gardner (station 95), and Steamboat Slough at the mouth of the Snohomish River (station 100). In addition, 87 of the EC50 values were less than 80% of the phenol-spiked blank EC50 value of 15.23 mg/mL. To examine the relative degree of toxicity of the samples, the Microtox™ test results were expressed as percentages of Redfish Bay controls. Results ranged from 0.2% to 141%. EC50s less than 1.0%, indicating toxicity in these samples was >100 times that in the controls, were recorded for 17 samples. EC50s for all nine stations located within Everett Harbor (stations 86-94) were less than 1.0% of controls, indicating these were consistently the most toxic samples in this test. Other samples that displayed the highest toxicity (mean EC50 < 1% of control) were collected from stations in Boundary Bay, inner and outer Bellingham Bay, Padilla Bay, Fidalgo Bay, Oak Harbor, and Penn Cove.

Table 10. Results of Microtox™ tests (as mean mg/mL and percent of Redfish Bay control) and Cytochrome P450 RGS bioassays (as benzo[a]pyrene equivalents (µg/g)) of 100 sediment samples from northern Puget Sound.

		Microtox™ EC50		*Statistical*	*P450 RGS*
Stratum	**Sample**	**Mean (mg/mL)**	**% of ctrl**	**Significance**	**b[a]p eq (µg/g)**
Redfish Bay	negative control	102.90	100	na	0.20
phenol-spiked blank		15.23	na	na	na
1	1	2.37	2.30	**	6.46
Drayton	2	1.80	1.75	**	8.51
Harbor	3	1.33	1.30	**	10.51
2	4	2.73	2.66	**	2.72
Semiahmoo	5	1.06	1.03	**	2.51
Bay	6	2.50	2.43	**	8.71
3	7	6.83	6.64	**	0.27
W. Boundary	8	1.02	0.99	**	2.17
Bay	9	1.67	1.62	**	2.32
4	10	9.37	9.10	**	5.83
S. Boundary	11	1.57	1.52	**	3.03
Bay	12	2.23	2.17	**	2.57
	13	4.37	4.24	**	3.95
5	14	1.46	1.42	**	2.01
Birch	15	2.90	2.82	**	2.40
Bay	16	2.63	2.56	**	2.67
6	17	4.90	4.76	**	3.01
Cherry	18	2.40	2.33	**	2.83
Point	19	12.17	11.82	**	3.04
7	20	7.33	7.13	**	1.49
Bellingham	21	5.43	5.28	**	1.72
Bay	22	1.57	1.52	**	1.63

Table 10 (cont.).

Stratum	Sample	*Microtox™ EC50* Mean (mg/mL)	*Microtox™ EC50* % of ctrl	*Statistical* Significance	*P450 RGS* b[a]p eq (µg/g)
8	23	8.23	8.00	**	2.63
Bellingham	24	5.93	5.77	**	2.98
Bay	25	4.00	3.89	**	2.06
9A	26	12.87	12.50	**	4.70
Bellingham	27	12.00	11.66	**	3.31
Bay	28	0.63	0.62	**	19.09
9B	59	4.13	4.02	**	3.08
Bellingham	60	3.47	3.37	**	8.64
Bay	61	2.73	2.66	**	2.41
10	29	2.13	2.07	**	3.00
Bellingham	30	1.93	1.88	**	16.08
Bay	31	3.07	2.98	**	2.92
11	32	0.47	0.46	**	3.31
Bellingham	33	2.17	2.11	**	4.09
Bay	34	0.51	0.50	**	2.76
12	35	2.90	2.82	**	3.12
Bellingham	36	20.97	20.38	**	3.01
Bay	37	2.67	2.59	**	4.50
13	38	21.03	20.44	**	9.23
Samish/	39	5.17	5.02	**	3.80
Belling. Bay	40	0.98	0.95	**	2.99
14	41	0.54	0.52	**	12.41
Padilla	42	2.80	2.72	**	7.64
Bay (inner)	43	1.83	1.78	**	1.78
15	44	6.47	6.28	**	6.32
Padilla	45	2.67	2.59	**	1.50
Bay (outer)	46	4.73	4.60	**	2.68

Table 10 (cont.).

Stratum	Sample	*Microtox™ EC50*		*Statistical*	*P450 RGS*
		Mean (mg/mL)	**% of ctrl**	**Significance**	**b[a]p eq (µg/g)**
16	47	3.70	3.60	**	11.10
March	48	6.47	6.28	**	12.19
Point	49	1.23	1.20	**	9.79
17	50	1.10	1.07	**	1.89
Fidalgo	51	3.83	3.73	**	3.70
Bay (inner)	52	0.89	0.86	**	3.72
18	53	2.80	2.72	**	10.79
Fidalgo	54	3.27	3.17	**	12.11
Bay (outer)	55	11.33	11.01	**	6.60
19	56	15.73	15.29	**	4.88
March	57	19.00	18.46	**	8.91
Point	58	9.80	9.52	**	5.12
21	62	6.30	6.12	**	0.62
Skagit	63	8.90	8.65	**	0.36
Bay	64	3.97	3.85	**	0.87
22	65	1.50	1.46	**	1.10
Saratoga	66	2.13	2.07	**	2.43
Passage (north)	67	2.43	2.36	**	3.04
23	68	1.16	1.13	**	4.72
Oak	69	1.11	1.08	**	4.54
Harbor	70	0.61	0.59	**	3.50
24	71	2.13	2.07	**	2.28
Penn	72	13.77	13.38	**	3.63
Cove	73	0.94	0.91	**	2.74
25	74	4.20	4.08	**	2.61
Saratoga	75	4.10	3.98	**	2.83
Passage (middle)	76	3.80	3.69	**	4.66

Table 10 (cont.).

Stratum	Sample	*Microtox™ EC50* Mean (mg/mL)	*Microtox™ EC50* % of ctrl	*Statistical* Significance	*P450 RGS* b[a]p eq (µg/g)
26	77	45.50	44.22	**	1.06
Saratoga	78	11.13	10.82	**	4.15
Passage (south)	79	9.67	9.39	**	3.78
27	80	77.73	75.54		3.72
Port	81	12.60	12.24	**	2.79
Susan	82	6.70	6.51	**	5.76
28	83	7.07	6.87	**	7.05
Possession	84	8.13	7.90	**	4.83
Sound	85	9.67	9.39	**	5.46
29	86	0.51	0.50	**	202.2
Everett	87	0.69	0.67	**	33.1
Harbor (inner)	88	0.94	0.91	**	115.8
30	89	0.20	0.20	**	25.8
Everett	90	0.71	0.69	**	129.2
Harbor (middle)	91	0.58	0.57	**	86.4
31	92	0.40	0.39	**	28.8
Everett	93	0.42	0.41	**	29.2
Harbor (outer)	94	0.44	0.43	**	28.7
32	95	145.00	140.91		3.2
Port	96	4.63	4.50	**	7.7
Gardner	97	9.17	8.91	**	22.9
33	98	2.50	2.43	**	4.2
Snohomish	99	57.57	55.94	**	0.3
River delta	100	120.63	117.23		0.3

* indicates significant difference from controls ($p<0.05$)
** indicates significant difference from controls ($p<0.05$) and <80% of controls

Results of the solid-phase variant of the Microtox™ bioluminescence test run on 10 samples from northern Puget Sound plus the Redfish Bay control are displayed in Table 11 and compared with results from the solvent extract tests. EC50 values in the solid-phase tests were much lower than those in the solvent extract tests for the Redfish Bay control and several Puget Sound samples (e.g., stations 26, 27, and 36), but provided similar results in most of the other samples. In the only sample that was not significantly different from controls (station 86), toxicity was less severe in the solid-phase test than in the organic solvent test.

Table 11. Comparison of results of Microtox™ solid-phase and solvent extract tests on samples from 10 selected northern Puget Sound stations and controls.

		Solid-phase test		*Solvent extract test*	
Stratum	**Sample**	**Mean EC50 (mg/mL)**	**Statistical significance**	**Mean EC50 (mg/mL)**	**Statistical significance**
Redfish Bay	Negative control	10	na	102.9	na
9A Bellingham Bay	26	1.8	**	12.9	**
	27	1.9	**	12.0	**
10 Bellingham Bay	30	1.5	**	1.9	**
	31	0.3	**	3.1	**
12 Bellingham Bay	36	2.3	**	21.0	**
28 Possession Sound	85	1.4	**	9.7	**
29 Everett Harbor (inner)	86	8.1	ns	0.5	**
30 Everett Harbor (middle)	90	1.7	**	0.7	**
	91	2.3	**	0.6	**
32 Port Gardner	96	3.3	**	4.6	**

na = not applicable
ns = not significant

The Cytochrome P450 RGS assays were run in 16 batches, with each sample tested in triplicate. If coefficients of variation (cv) exceeded 20%, the sample was re-tested and the averages of the results were then used in calculating the final values. If enzyme induction exceeded 100, the

sample was diluted 1:10 in DMSO and retested. This was necessary in only four samples. Results were reported as benzo[a]pyrene equivalents (B[a]Peq) in µg/gram for each sample.

The Redfish Bay control sediments caused an extremely low level of enzyme induction, equivalent to 0.2 µgB[a]PEq (ug/g) (Table 9). Among the northern Puget Sound samples, enzyme induction ranged from 0.3 µg/g in three samples to over 202 µg/g in the sample from station 86. The mean of results for all 100 samples was 11.1 µB[a]PEq (ug/g) with a standard deviation of 27.3 and a 99% confidence interval of 4.0-18.1. There were three samples in which enzyme induction exceeded 100 µg/g (all from Everett Harbor) and 11 in which it exceeded 18.1 µg/g. As in the Microtox™ tests, the nine samples from Everett Harbor (stations 86-94) consistently showed the highest induction, and, therefore, the highest toxicant contamination. Almost all of the other samples had very low induction (<23 µg/g), many with values of less than 10 µg/g, indicating non-contaminated conditions.

Spatial Patterns and Gradients in Toxicity

Spatial patterns in toxicity were illustrated in the accompanying figures: one set of maps for the amphipod and urchin test results (Figures 4-10), and one set each for the Microtox™ and Cytochrome P450 RGS test results (Figures 11-25). Amphipod and urchin test results are displayed as symbols keyed to the statistical significance of the responses. Stations are shown in which amphipod survival was

- not significantly different from CLIS controls ($p>0.05$) (i.e., not toxic); or
- significantly different from controls ($p<0.05$).

There were no stations in which amphipod survival was less than 80% of controls (i.e., "highly" toxic).

Also, stations are shown on the same figures in which urchin fertilization was:

- not significantly different from Redfish Bay controls ($p>0.05$) (i.e., not toxic in 100% pore water); or significantly different from controls ($p<0.01$) and less than 80% of controls in 100% pore water only (i.e., toxic in only 100% pore water); or
- significantly different from controls ($p<0.01$) and less than 80% of controls in 100% + 50% porewater concentrations (i.e., toxic in 100% + 50% pore water); or
- significantly different from controls ($p<0.01$) and less than 80% of controls in 100% + 50% + 25% porewater concentrations (i.e., toxic in 100% + 50% + 25% pore water). Samples in which significant results were observed in all three porewater concentrations were considered the most toxic.

Microtox™ and Cytochrome P450 RGS data are shown as histograms for each station. Microtox™ results are expressed as effective concentrations that caused 50% reductions in bioluminescence activity (EC50s) in units of mg of sediment/mL of solvent. In this test, high values indicate lower levels of contamination, while low values indicate higher levels of contamination. In contrast, data from the P450 RGS assays are expressed as benzo[a]pyrene equivalents (µg /g) of sediment and high values indicate the presence of toxic chemicals.

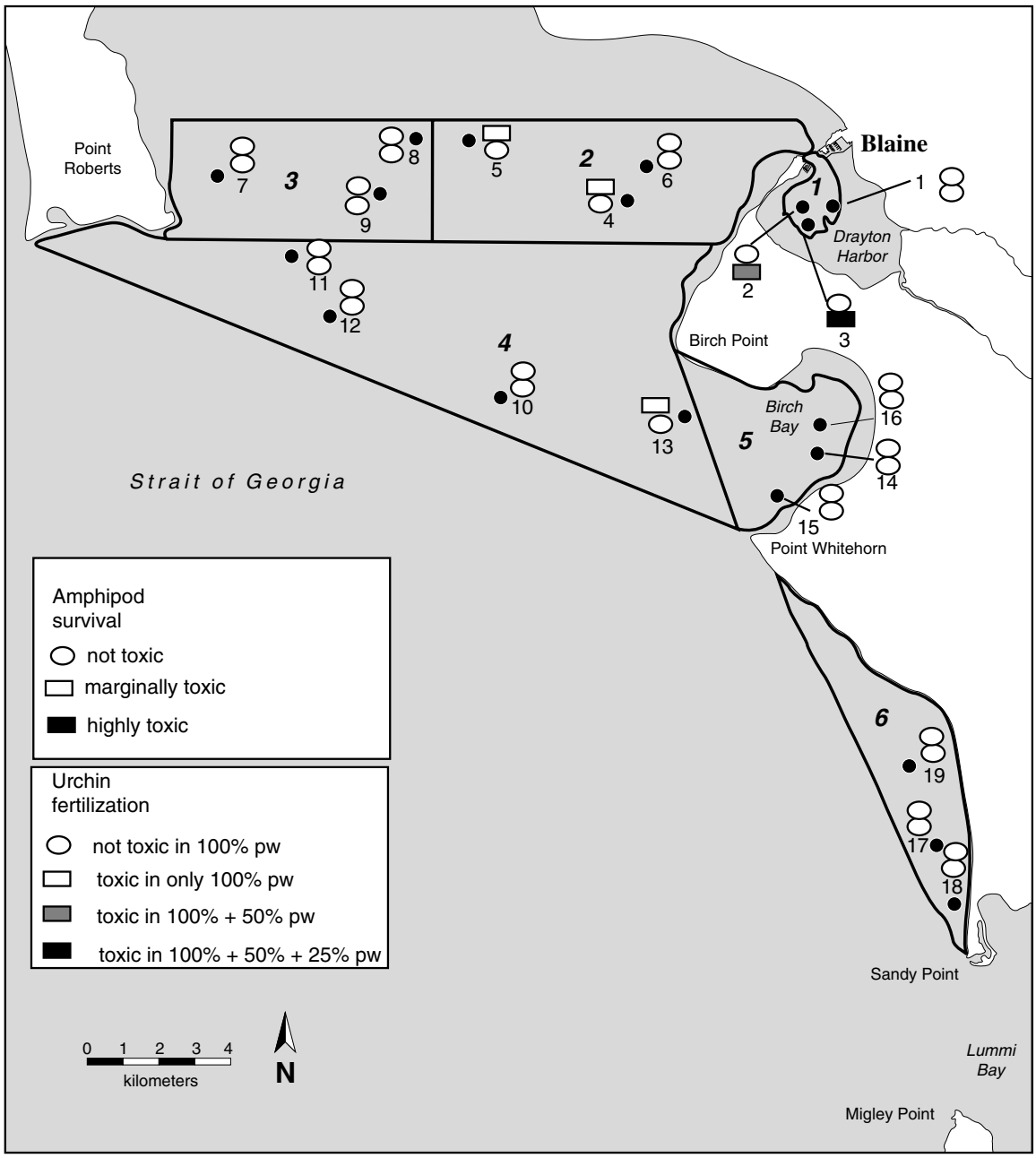

Figure 4. Results of amphipod survival tests (top symbols) and sea urchin fertilization tests (in three porewater concentrations, bottom symbols) for 19 stations distributed among six sampling strata in southern Strait of Georgia and vicinity.

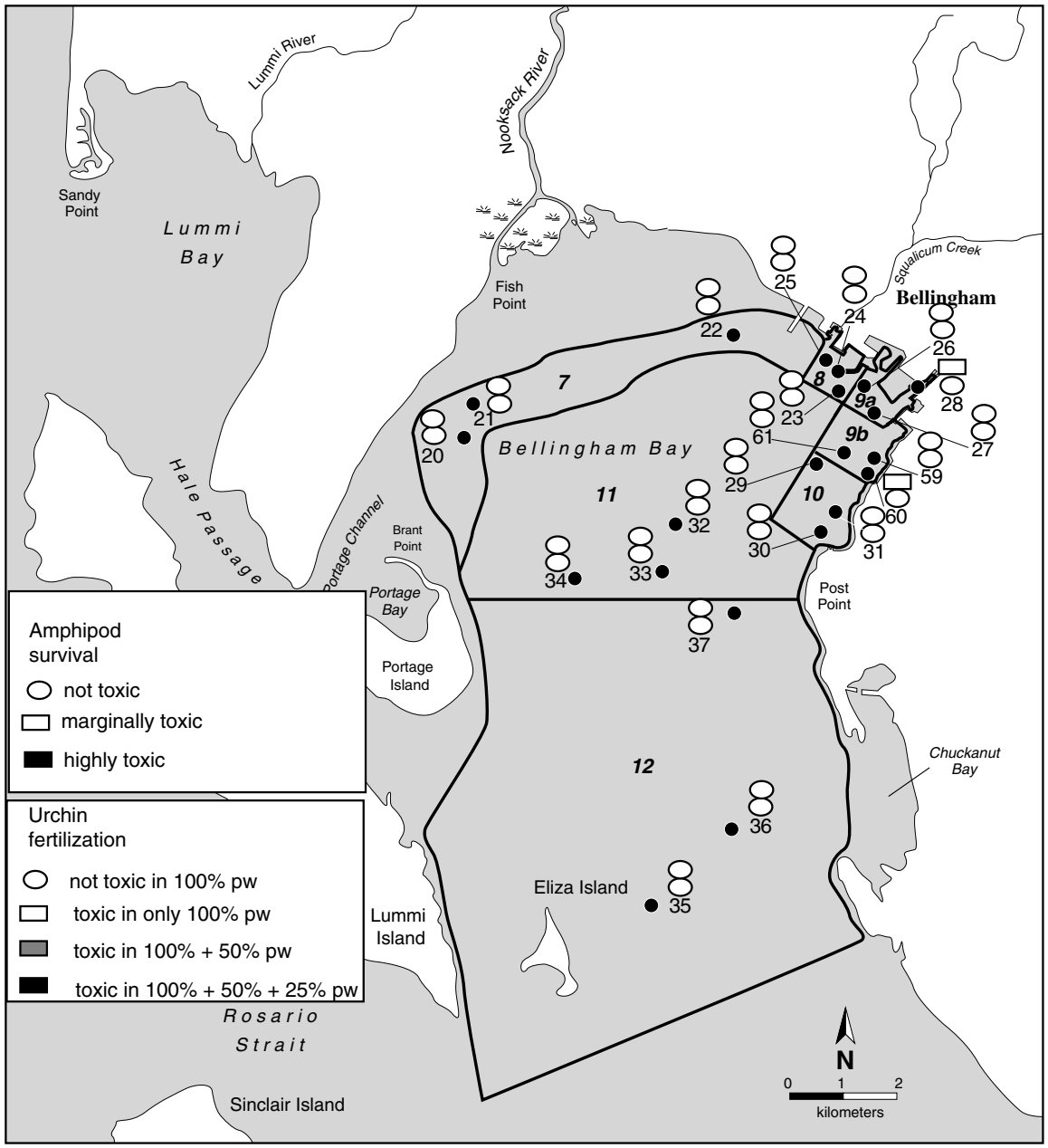

Figure 5. Results of amphipod survival tests (top symbols) and sea urchin fertilization tests (in three porewater concentrations, bottom symbols) for 21 stations distributed among seven sampling strata in Bellingham Bay and vicinity.

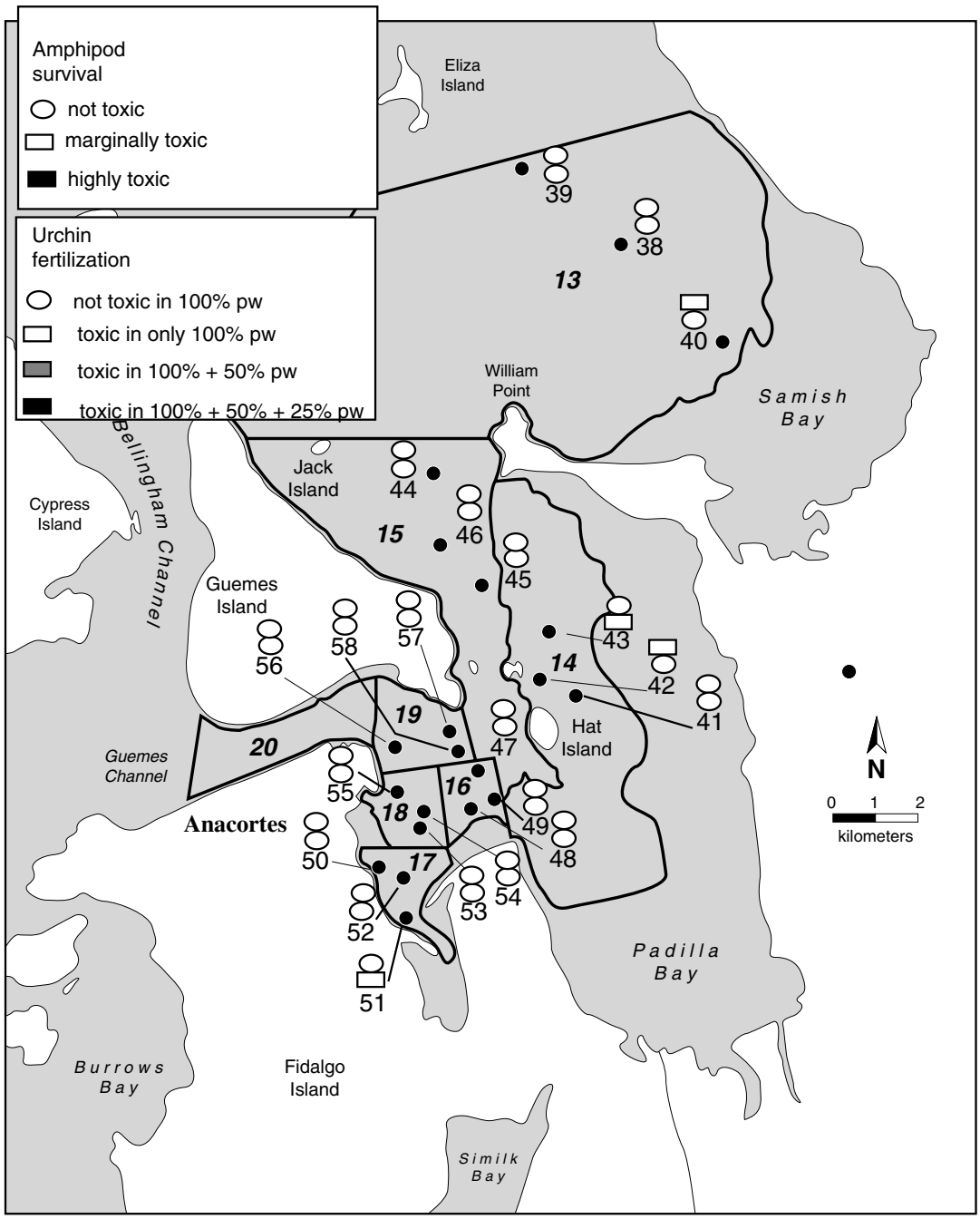

Figure 6. Results of amphipod survival tests (top symbols) and sea urchin fertilization tests (in three porewater concentrations, bottom symbols) for 18 stations distributed among six sampling strata in the vicinity of Anacortes.

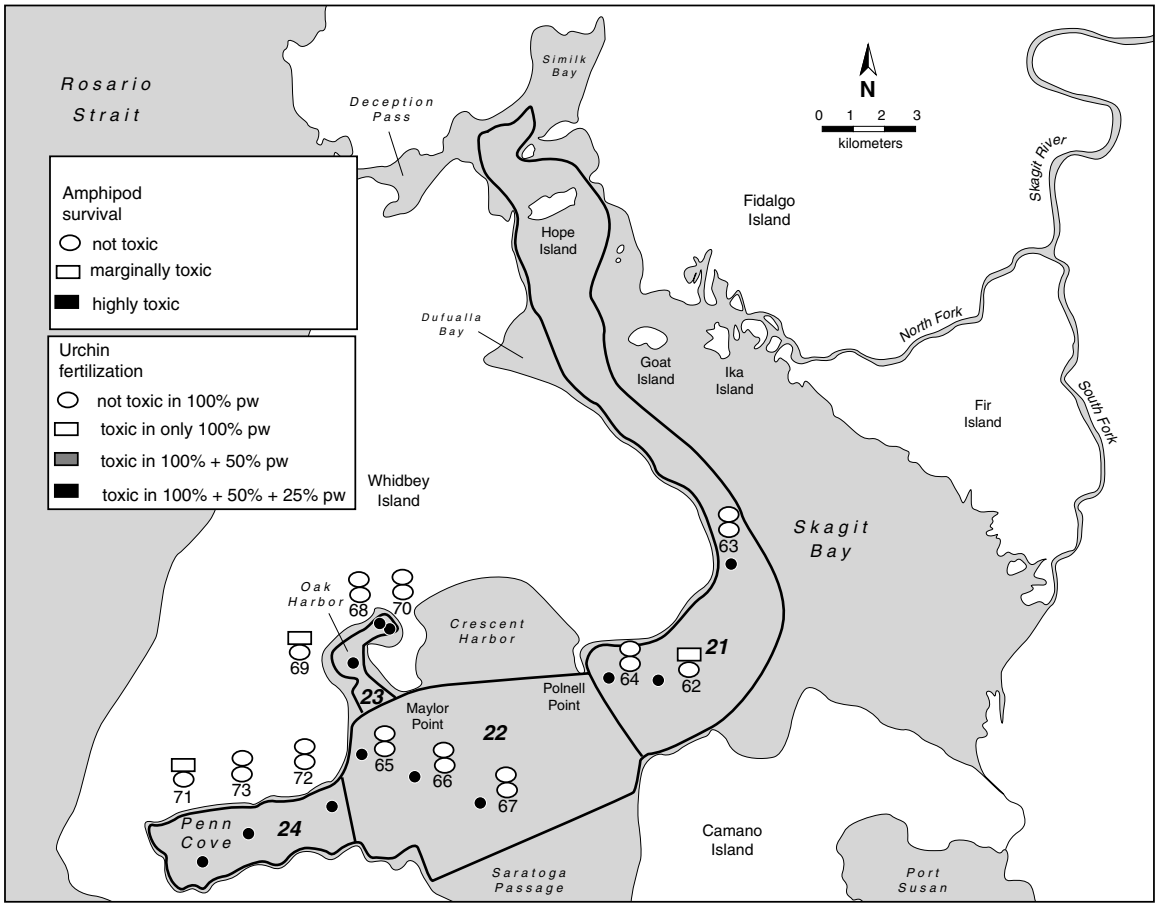

Figure 7. Results of amphipod survival tests (top symbols) and sea urchin fertilization tests (in three porewater concentrations, bottom symbols) for 12 stations distributed among four sampling strata in the vicinity of Oak Harbor.

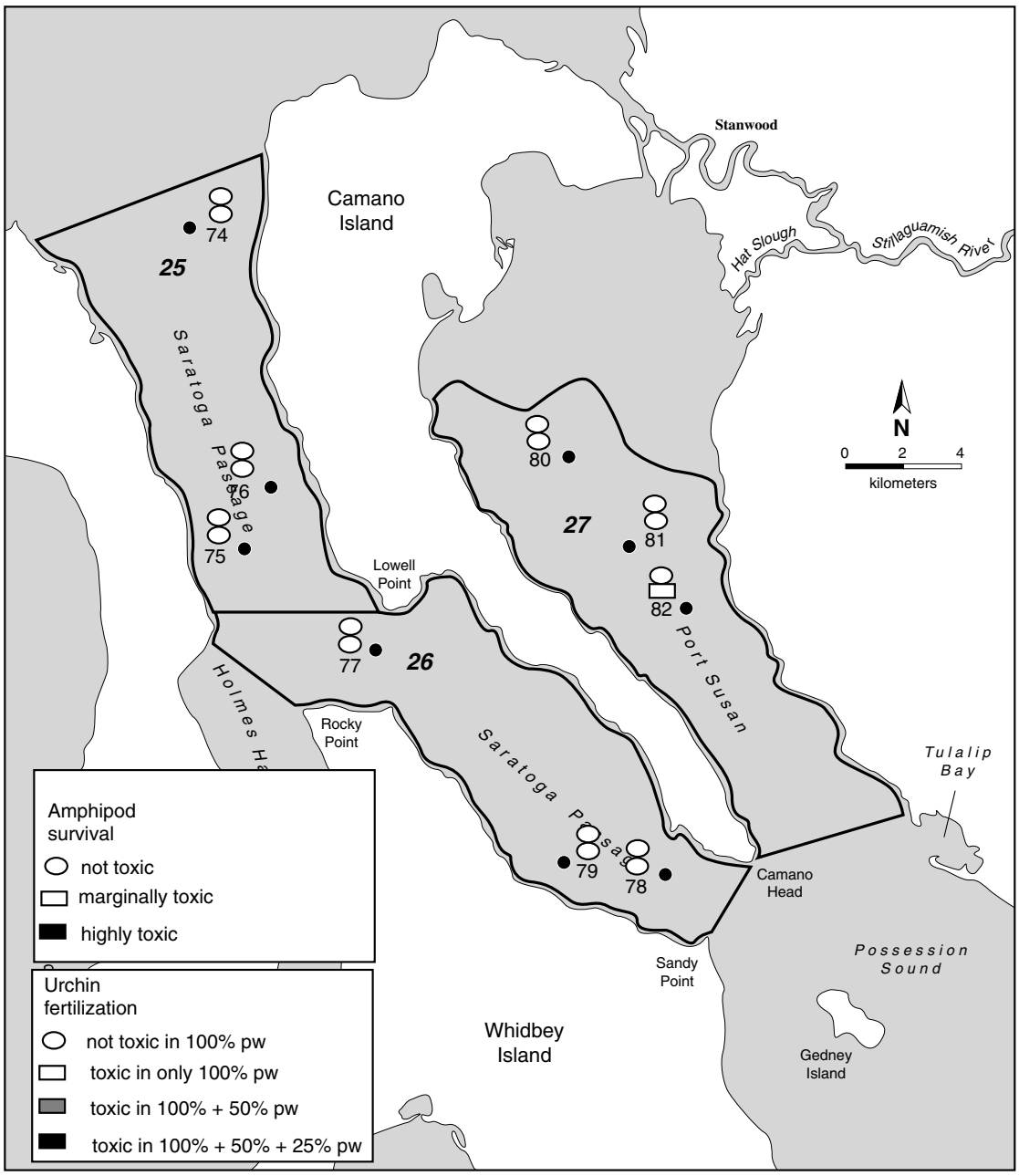

Figure 8. Results of amphipod survival tests (top symbols) and sea urchin fertilization tests (in three porewater concentrations, bottom symbols) for 9 stations distributed among three sampling strata in Saratoga Passage and Port Susan.

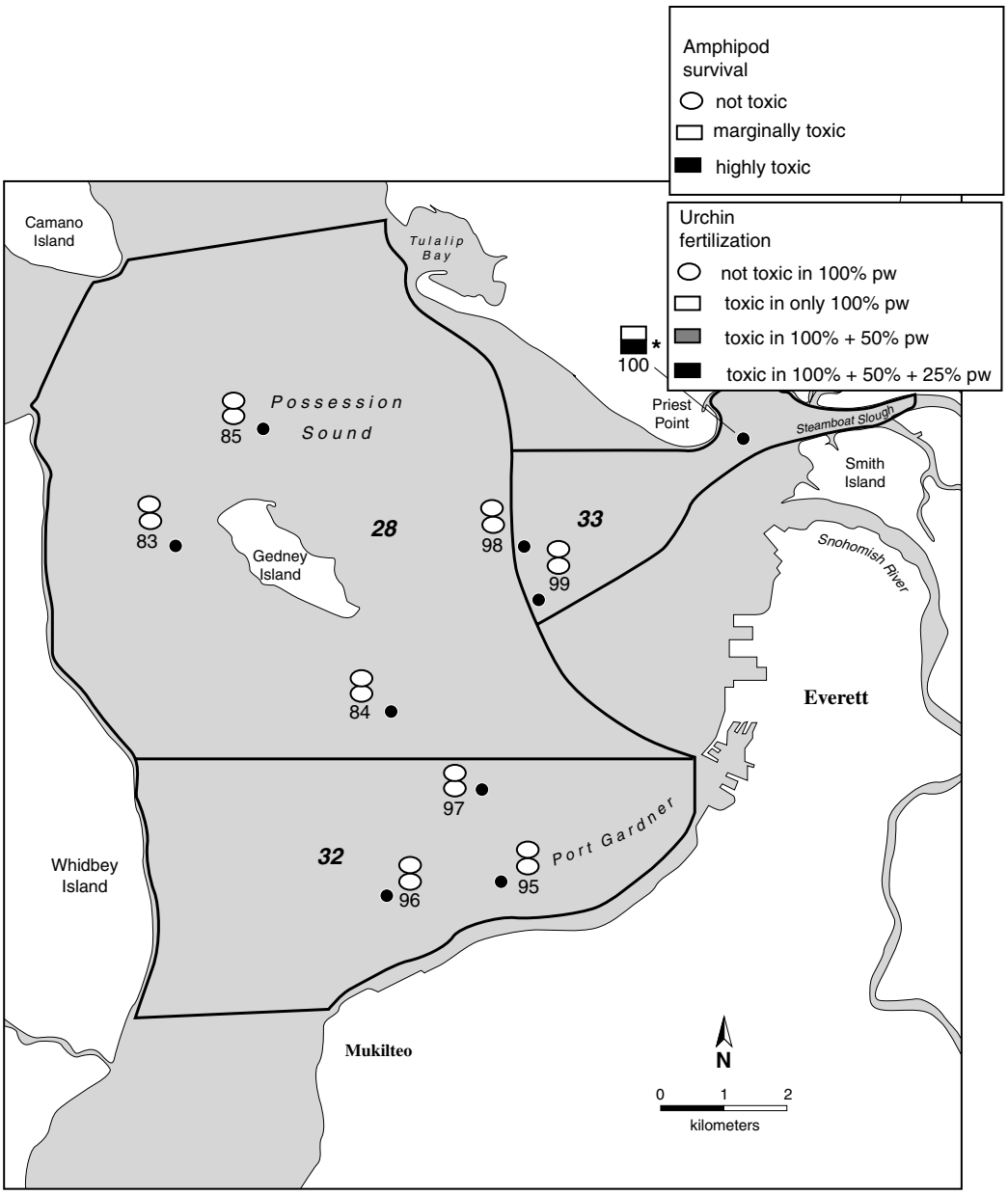

Figure 9. Results of amphipod survival tests (top symbols) and sea urchin fertilization tests (in three porewater concentrations, bottom symbols) for 9 stations distributed among three sampling strata in Port Gardner bay and the Snohomish River. (*Results were significant in both 50% and 25% pore water, but not in 100% pore water).

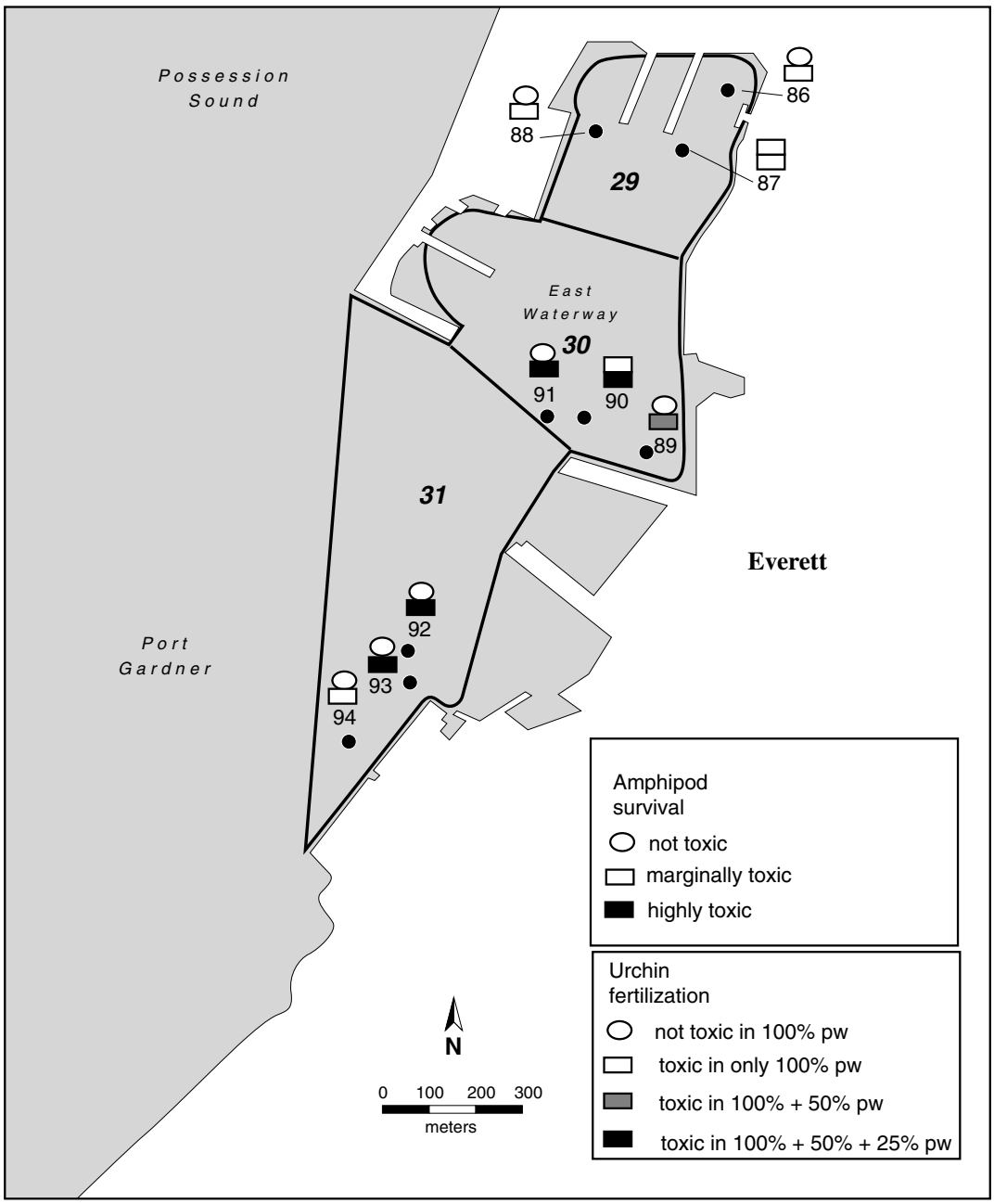

Figure 10. Results of amphipod survival tests (top symbols) and sea urchin fertilization tests (in three porewater concentrations, bottom symbols) for 9 stations distributed among three sampling strata in Everett Harbor.

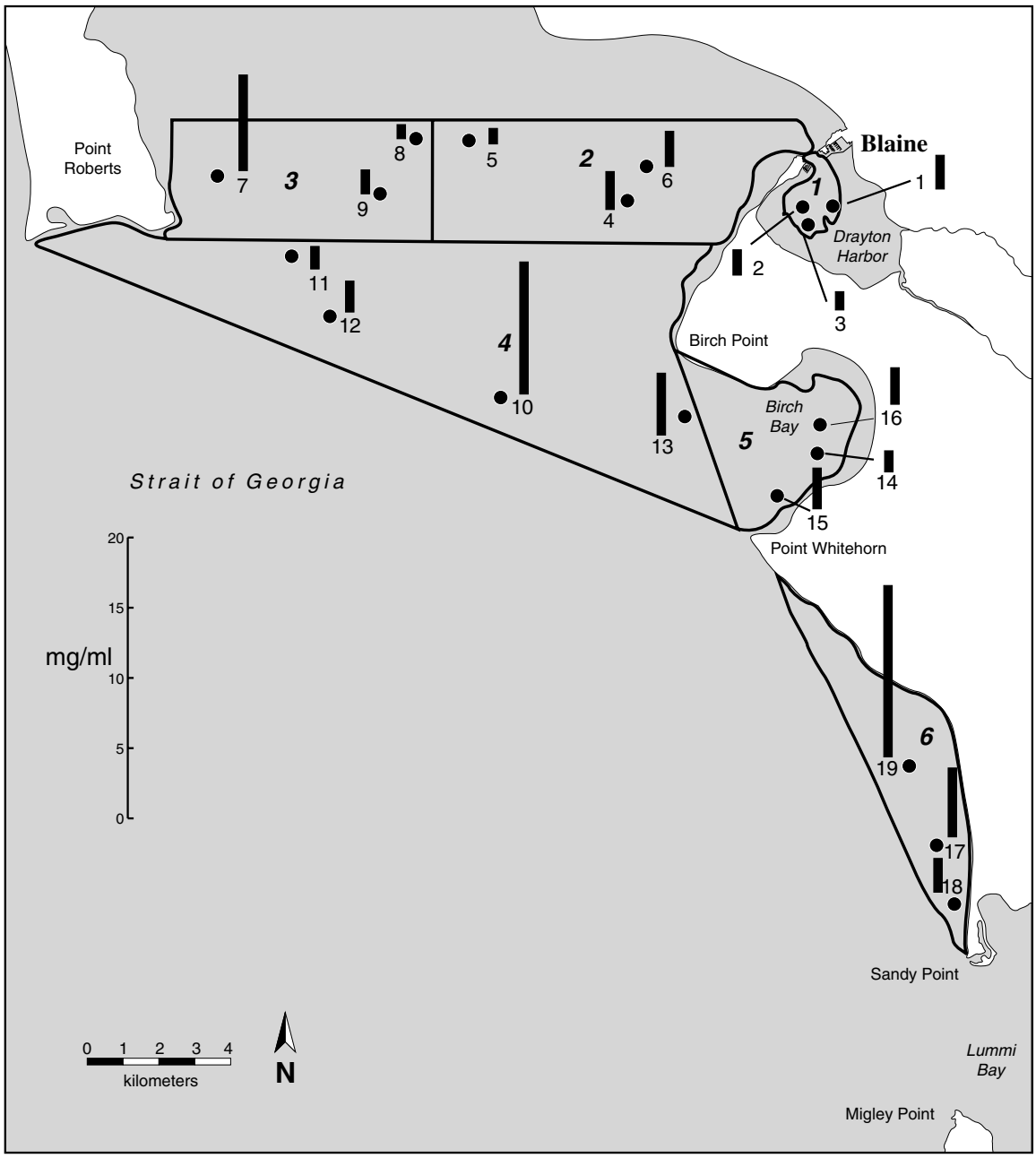

Figure 11. Results of Microtox™ bioluminescence tests for 19 stations distributed among six sampling strata in southern strait of Georgia and vicinity.

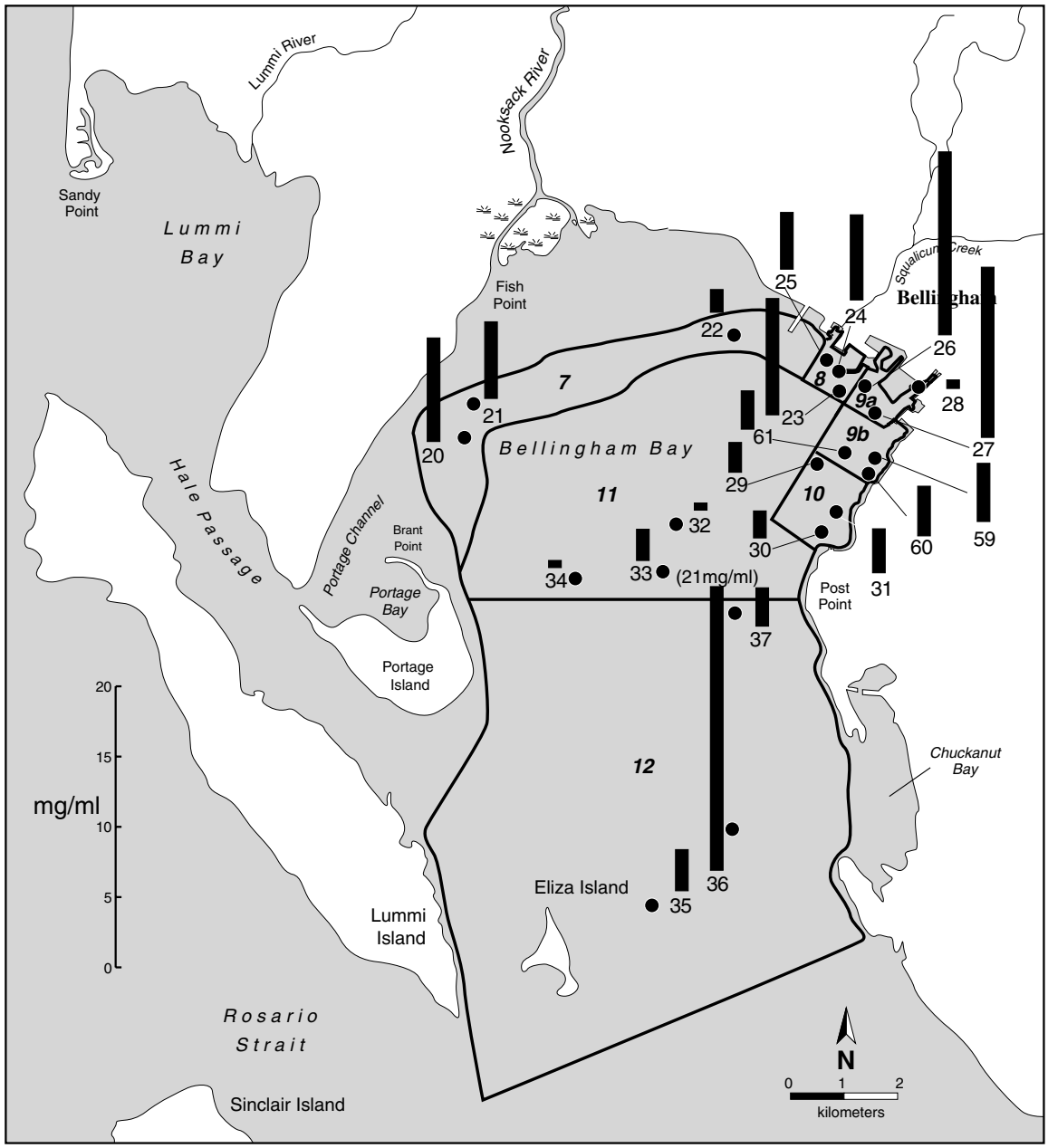

Figure 12. Results of Microtox™ bioluminescence tests for 21 stations distributed among seven sampling strata in Bellingham Bay and vicinity.

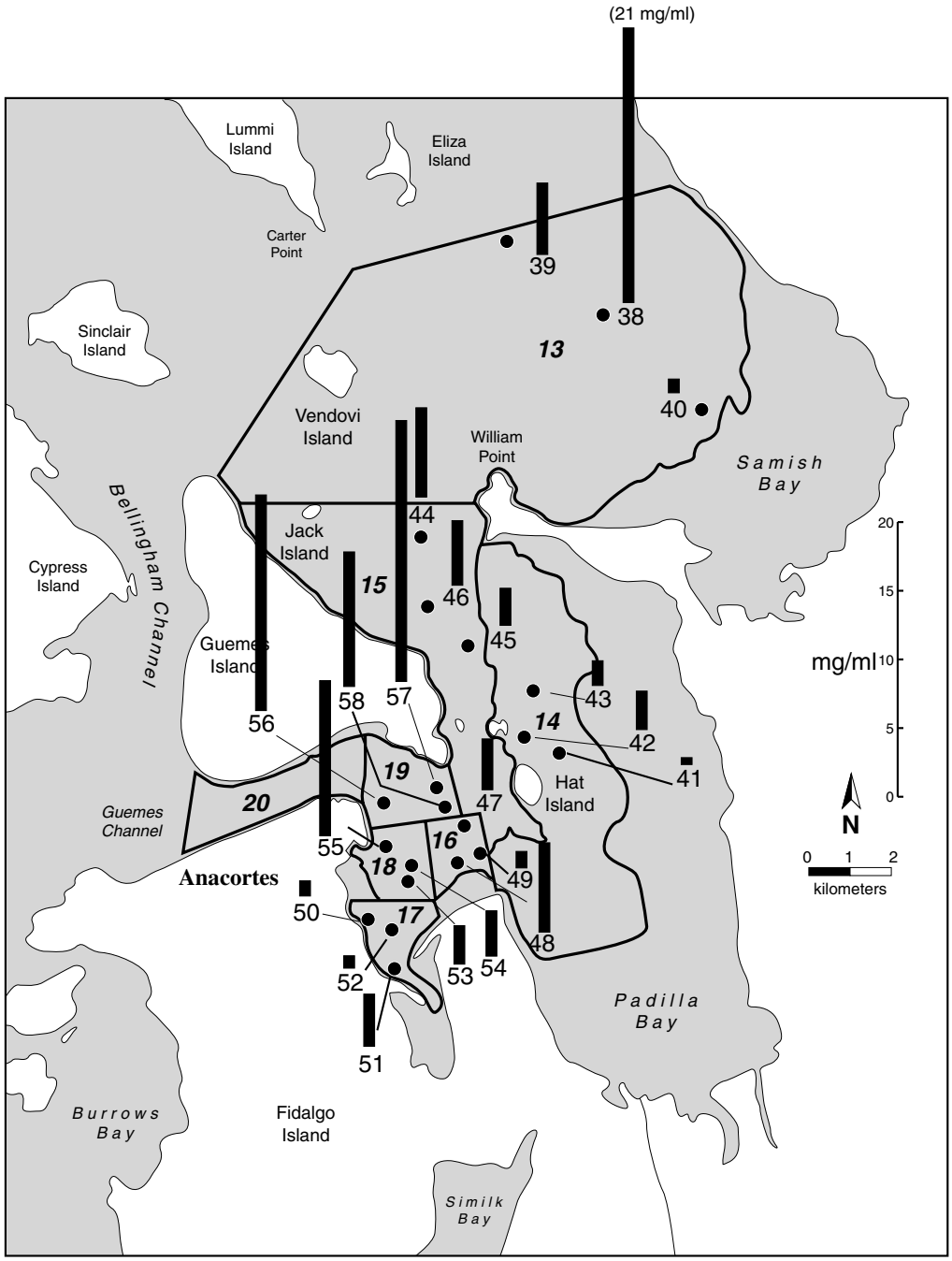

Figure 13. Results of Microtox™ bioluminescence tests for 18 stations distributed among six sampling strata in the vicinity of Anacortes.

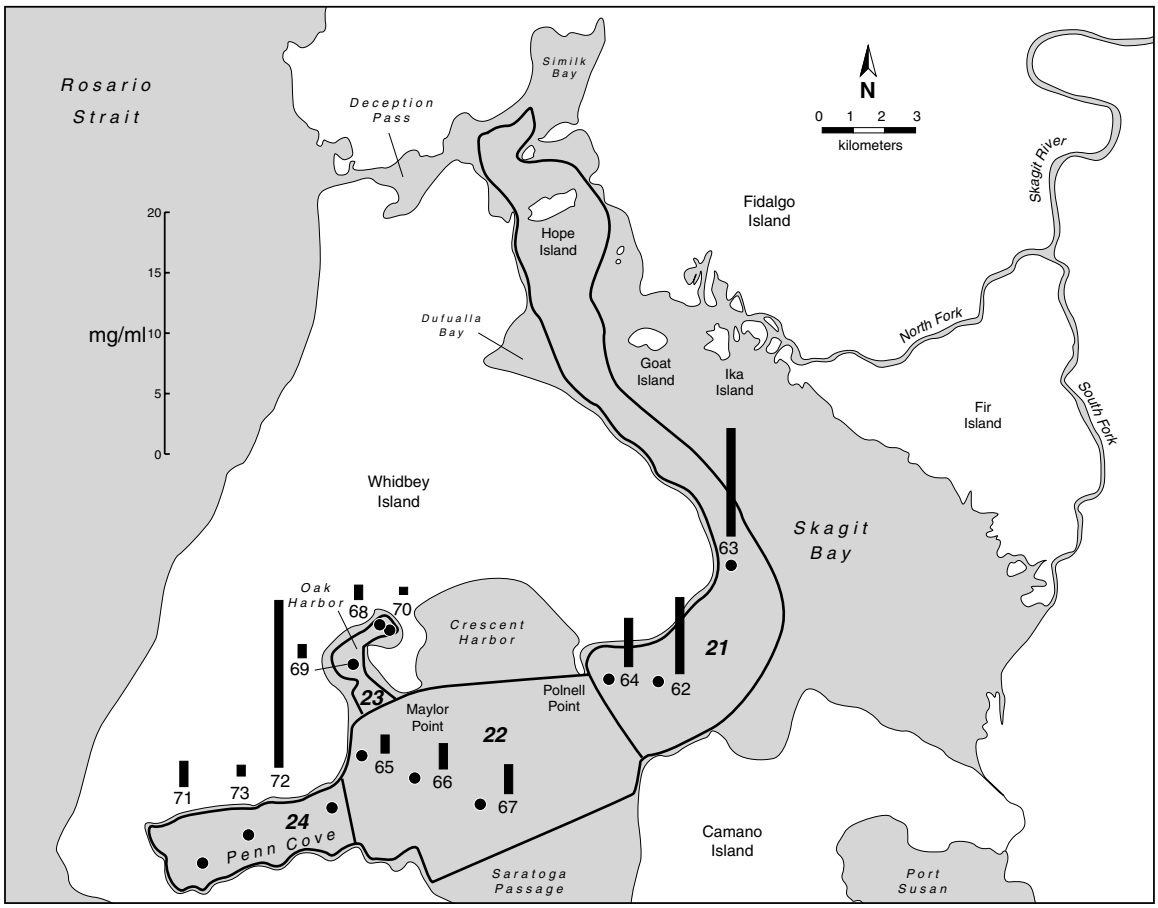

Figure 14. Results of Microtox™ bioluminescence tests for 12 stations distributed among four sampling strata in the vicinity of Oak Harbor.

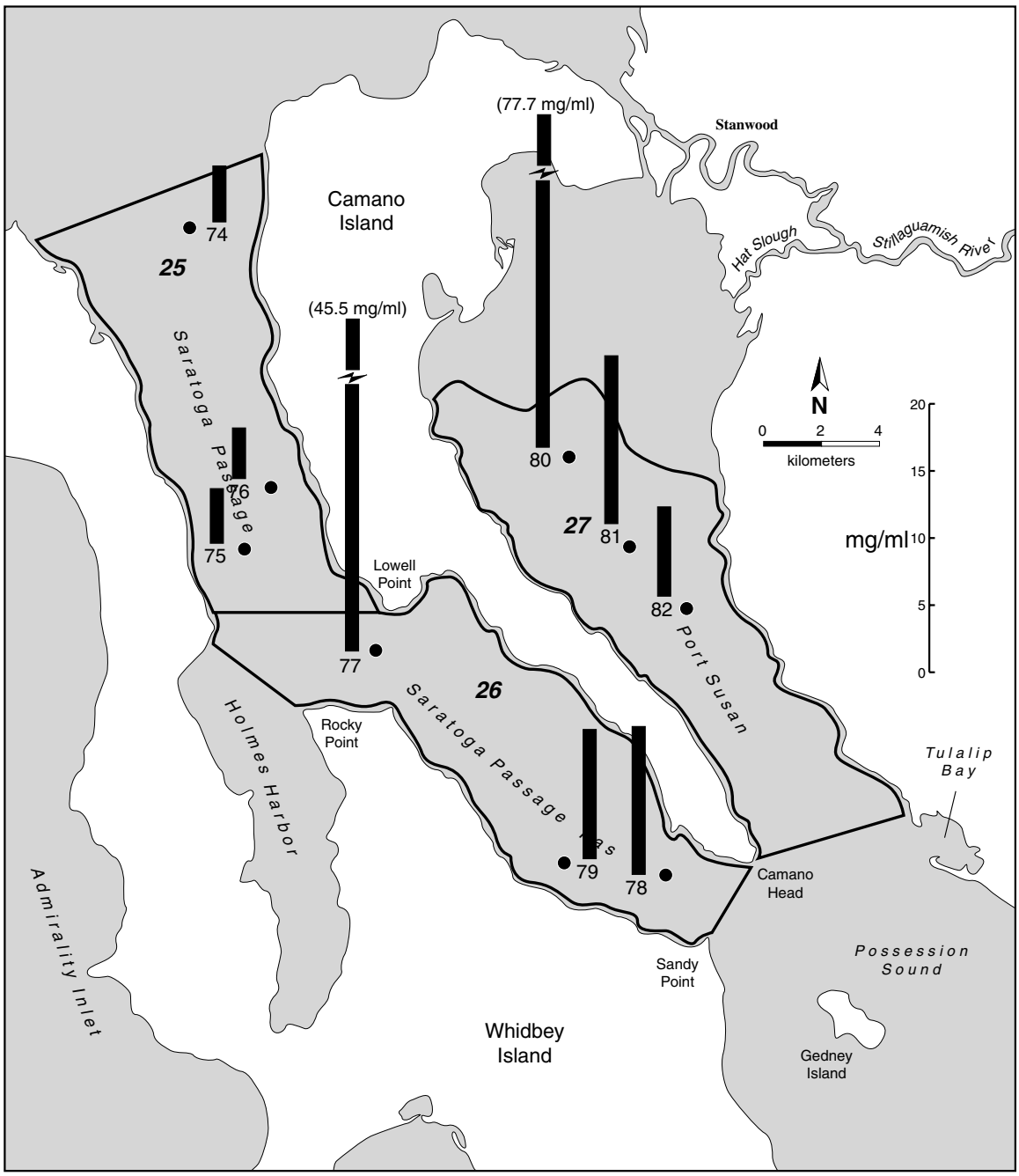

Figure 15. Results of Microtox™ bioluminescence tests for 9 stations distributed among three sampling strata in Saratoga Passage and Port Susan.

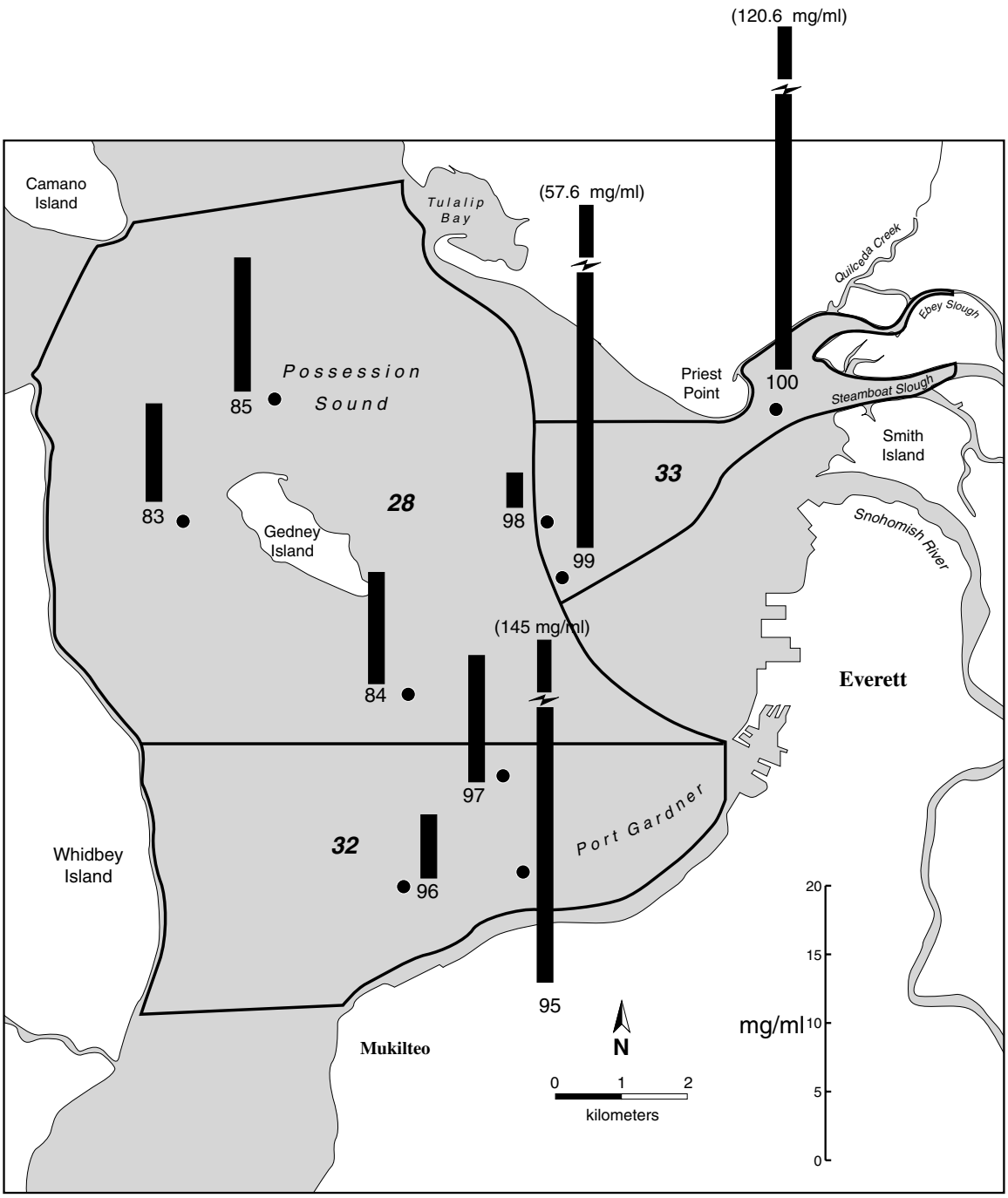

Figure 16. Results of Microtox™ bioluminescence tests for 9 stations distributed among three sampling strata in Port Gardner Bay and the Snohomish River.

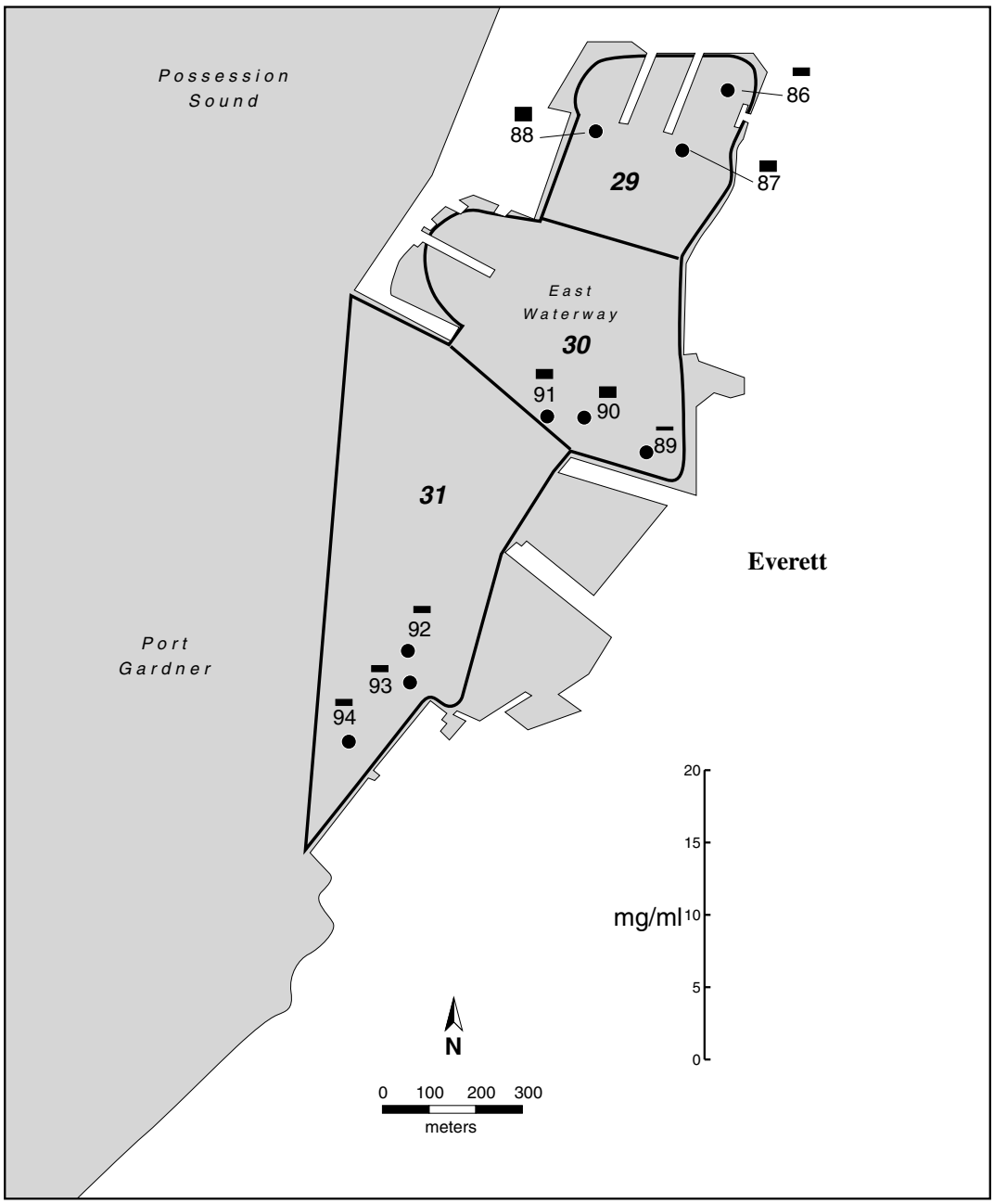

Figure 17. Results of Microtox™ bioluminescence tests for 9 stations distributed among three sampling strata in Everett Harbor.

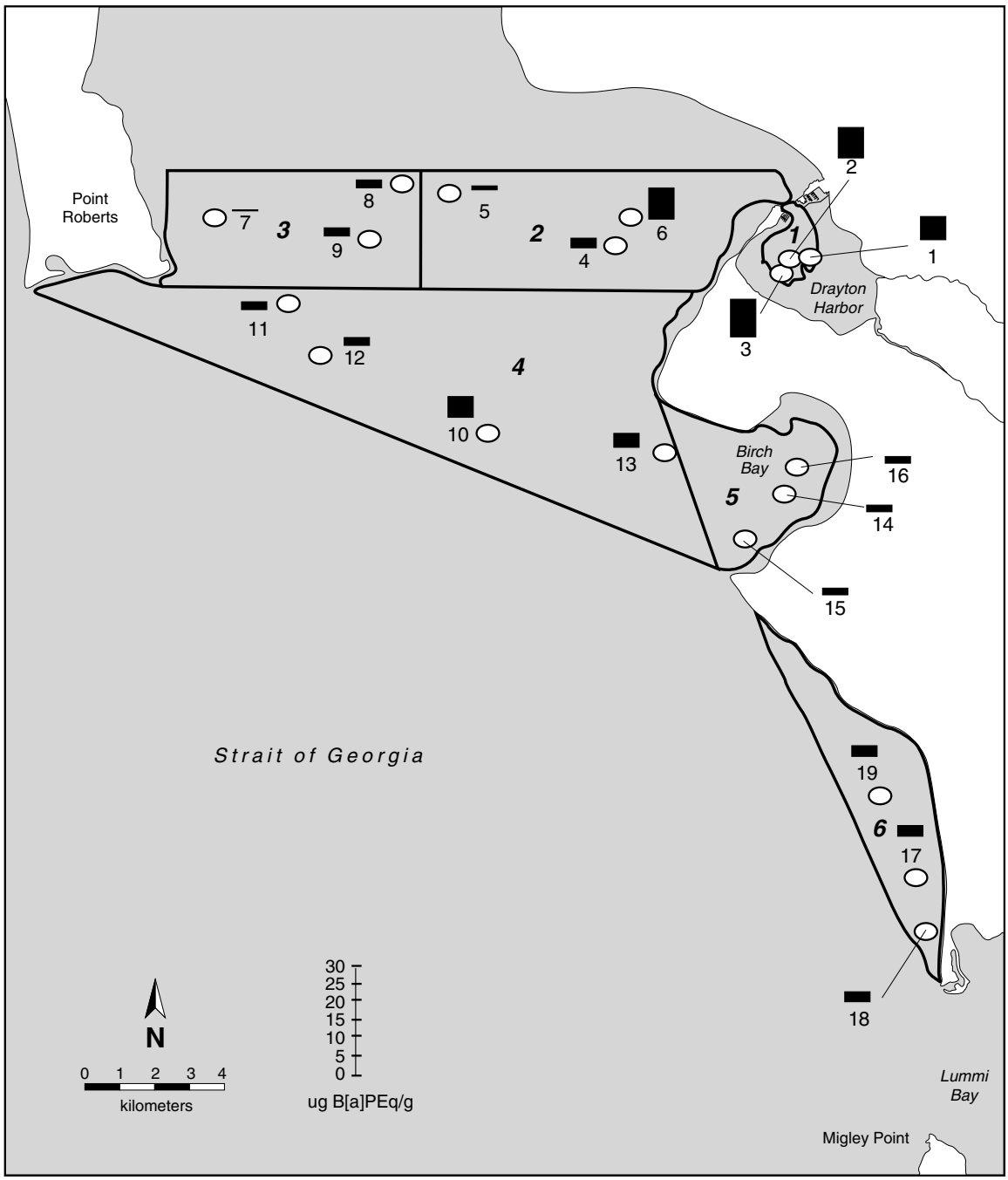

Figure 18. Results of Cytochrome P-450 RGS assays on 19 samples distributed among six strata in the southern Strait of Georgia and vicinity.

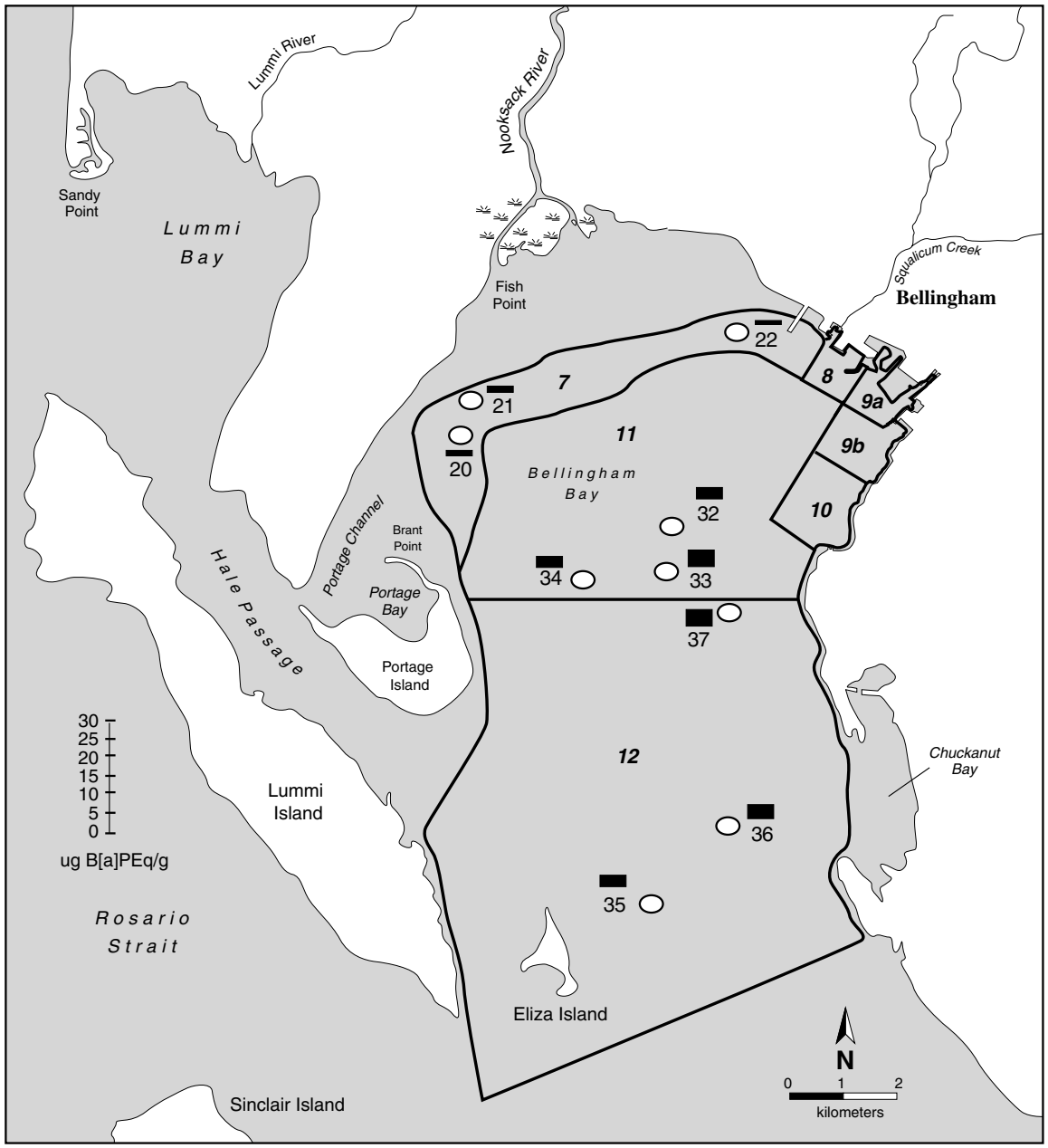

Figure 19. Results of Cytochrome P-450 RGS assays on 9 samples distributed among three strata in outer Bellingham Bay.

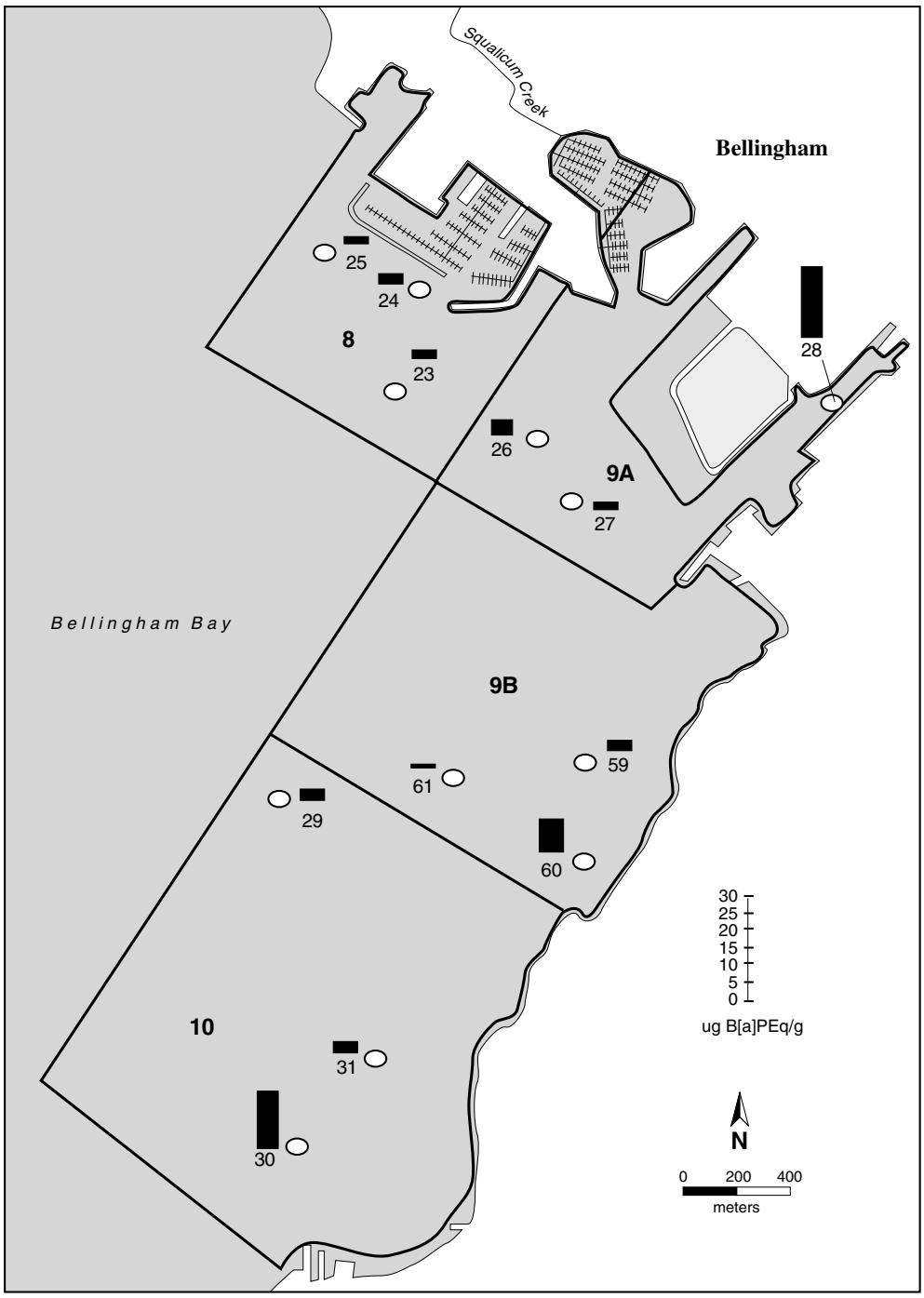

Figure 20. Results of Cytochrome P-450 RGS assays on 12 samples distributed among four strata in inner Bellingham Bay.

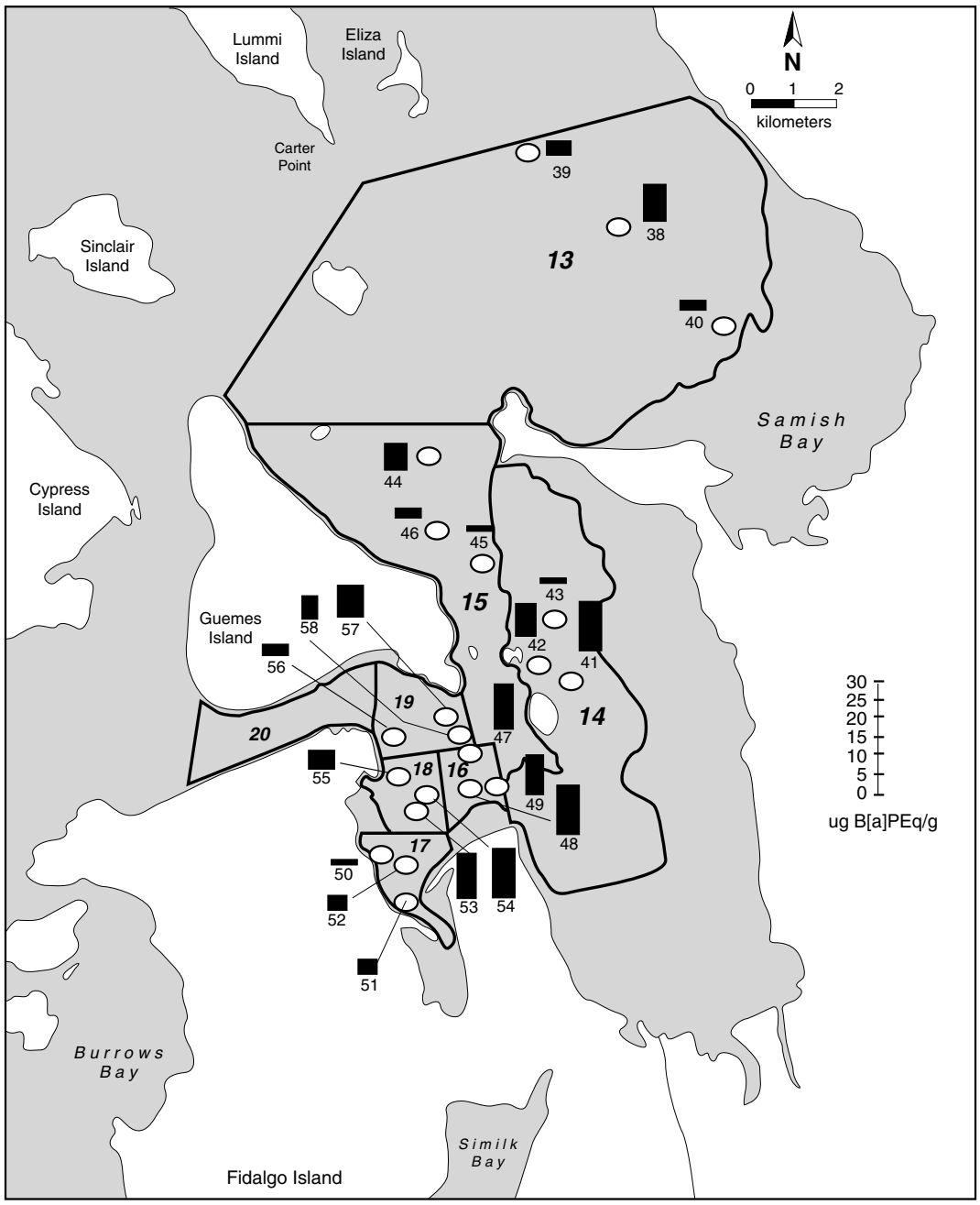

Figure 21. Results of Cytochrome P-450 RGS assays on 18 samples distributed among six strata in the vicinity of Anacortes.

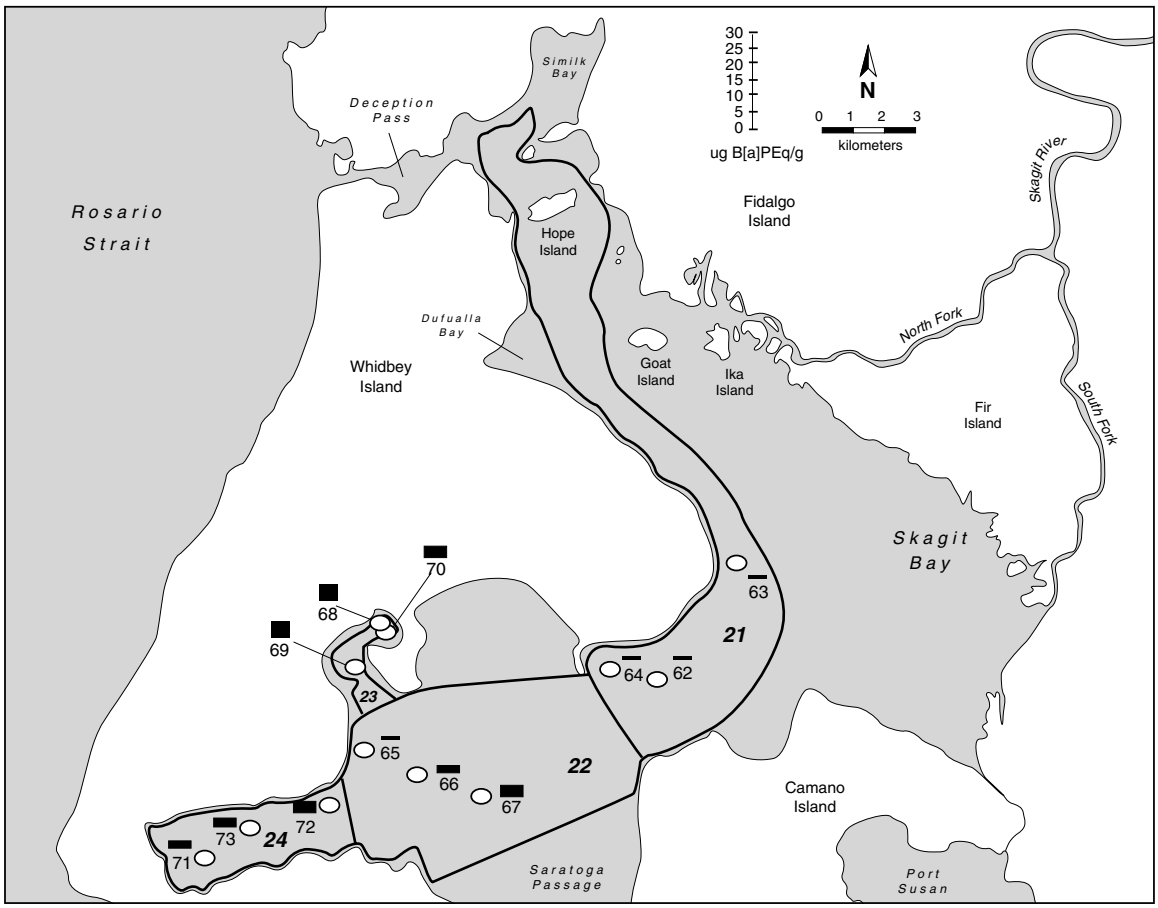

Figure 22. Results of Cytochrome P-450 RGS assays on 12 samples distributed among four strata in the vicinity of Oak Harbor.

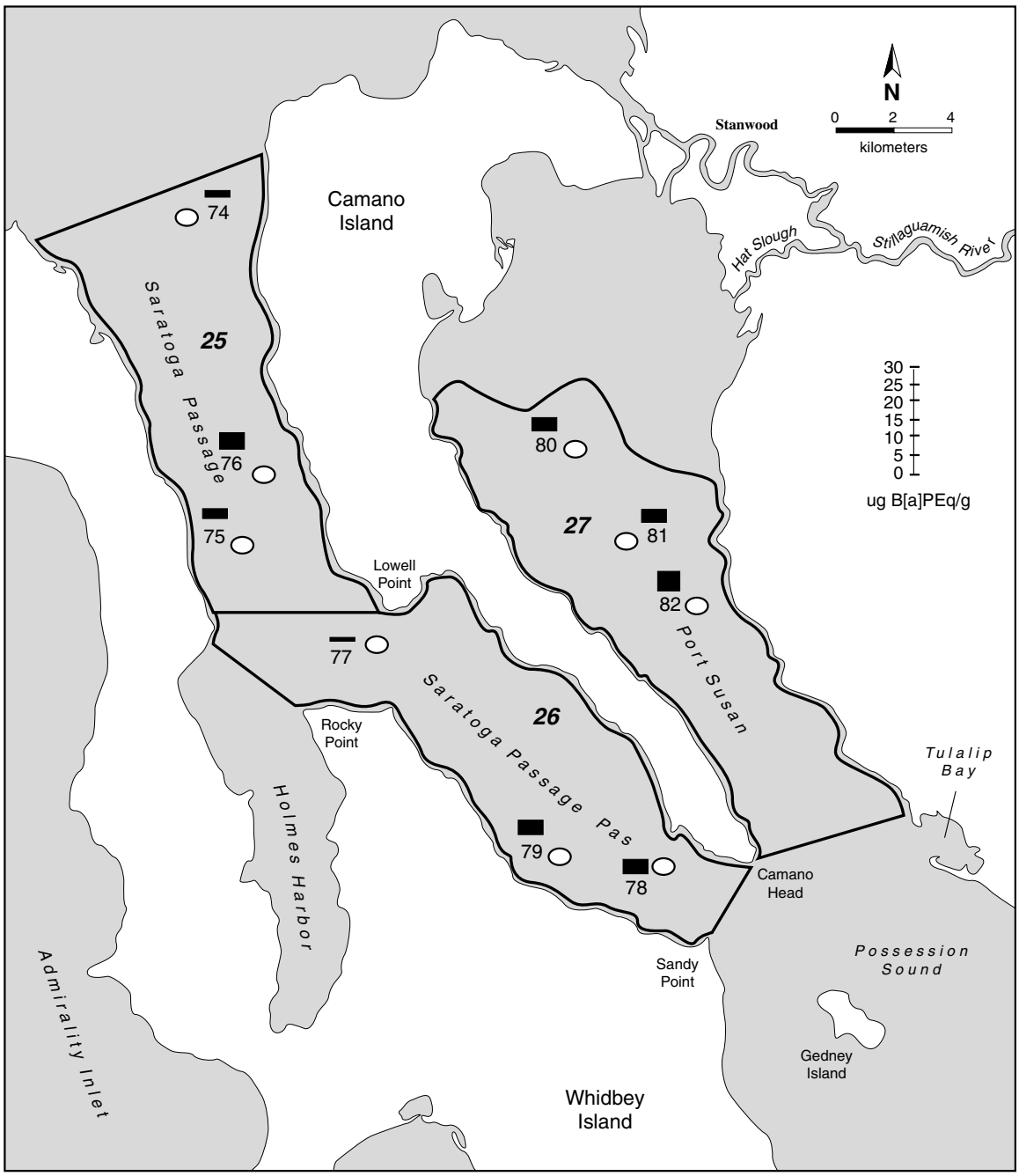

Figure 23. Results of Cytochrome P-450 RGS assays on 9 samples distributed among three strata in Saratoga Passage and Port Susan.

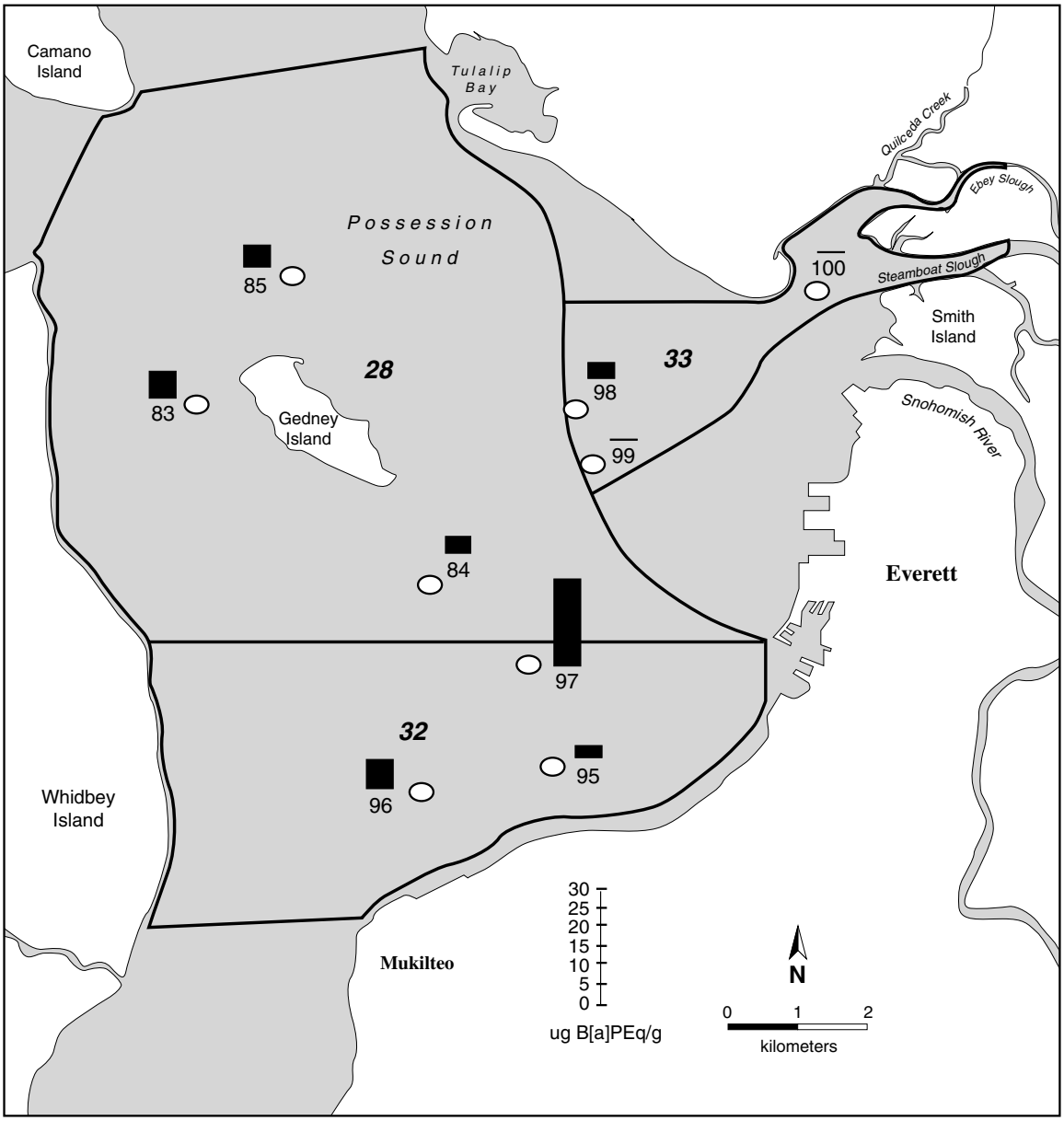

Figure 24. Results of Cytochrome P-450 RGS assays on 9 samples distributed among three strata in Port Gardner Bay and Snohomish River.

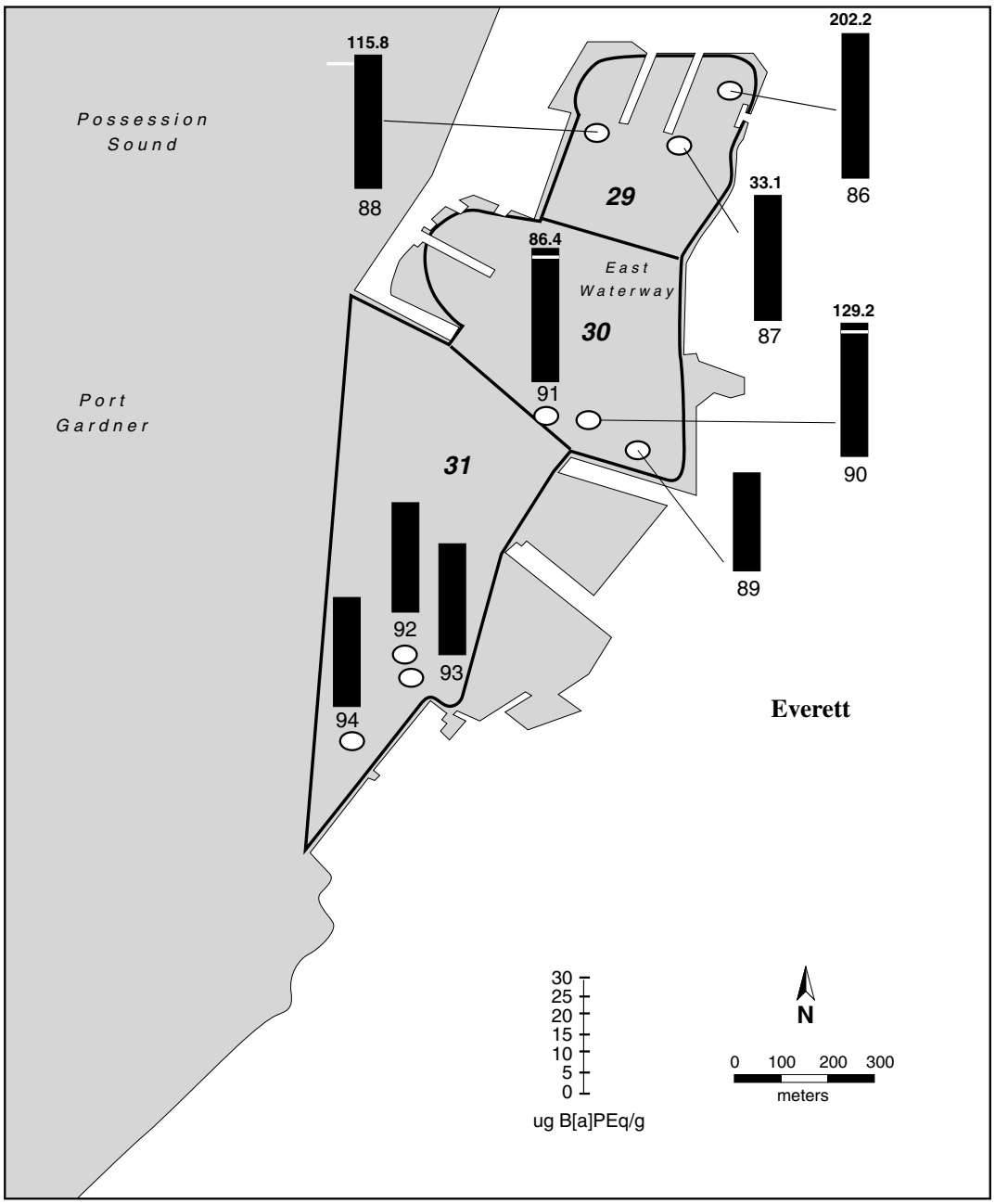

Figure 25. Results of Cytochrome P-450 RGS assays on 9 samples distributed among three strata in Everett harbor and vicinity.

Amphipod Survival and Sea Urchin Fertilization

In the northernmost region of the study area, most samples did not indicate significant results in either the amphipod survival or urchin fertilization tests (Figure 4). However, there were two samples from stratum 2 (stations 4 and 5) in Semiahmoo Bay and one sample (station 13) west of Birch Bay in which mean survival was significantly lower than in the controls. Also, there were two stations within Drayton Harbor in which urchin fertilization was significantly reduced in both 100% and 50% porewater concentrations (station 2) or in all three porewater concentrations (station 3).

In the Bellingham Bay area, there were two samples (from stations 28 and 60) in which amphipod survival was significantly reduced (Figure 5). There was no significant toxicity apparent in the urchin fertilization tests in this region. In the Samish Bay/Anacortes area (Figure 6), amphipod survival was significantly reduced in two samples (stations 40 in Samish Bay and 42 in inner Padilla Bay) and there were two stations in which urchin fertilization was significantly reduced in only the 100% pore water (stations 43 in inner Padilla Bay and 51 in inner Fidalgo Bay).

Amphipod survival was significantly reduced in samples from three stations in the Oak Harbor area (Figure 7); one each in Skagit Bay (station 62), Oak Harbor (station 69), and Penn Cove (station 71). However, none of these samples was toxic in the urchin fertilization tests.

All but one sample (station 82, Port Susan) were non-toxic in the Saratoga Passage/Port Susan area (Figure 8). Non-toxic conditions continued southward into Port Gardner Bay (Figure 9). One sample collected in the lower Snohomish River (station 100) showed reduced urchin fertilization in the tests of 50% and 25% pore water, but, curiously, not in the test of 100% pore waters.

Two of the samples from inner and mid-Everett harbor (stations 87 and 90) displayed significantly reduced toxicity in the amphipod survival tests (Figure 10). All nine samples from the Everett Harbor/East Waterway vicinity were toxic in at least the tests of 100% pore water; one was toxic in both 100% and 50% pore water (station 89), and four showed high toxicity in tests of all porewater concentrations (stations 90, 91, 92, 93). Collectively, these samples were the most toxic in the urchin fertilization tests. However, as shown in Figure 9, toxicity diminished rapidly beyond the mouth of the harbor into Port Gardner Bay.

Microbial Bioluminescence (Microtox™)

In this test the amount of sediment extract needed to induce a 50% reduction in bioluminescence was calculated as the endpoint. Results of this test are illustrated as histograms for each station. EC50 concentrations often were lowest within or near urban harbors of the study area.

Samples from Drayton Harbor and the lower reaches of Boundary Bay provided relatively low EC50s (generally less than 5.0 mg/ml, Figure 11). Most of the samples from the Birch Bay area and stations 10 and 13 west of Birch Bay had considerably lower EC50s than those collected further north. Two of the three samples collected in stratum 6 near Cherry Point had relatively high EC50s.

A wider range in response was apparent among the samples from Bellingham Bay (Figure 12). The EC50s for samples from stations 28, 32, and 34 were 0.6, 0.5, and 0.5 mg/ml, respectively, the highest measures of toxicity in these seven strata. Station 28 was located in the highly urbanized Whatcom Waterway, whereas stations 32 and 34 were located toward the outer reaches of the bay and, therefore, farther from potential sources. All three stations in stratum 11, the outer bay, showed relatively high toxicity. Other strata in which Microtox™ tests showed relatively low

EC50 values (i.e., higher toxicity) were strata 9b, 10, and 12 (with the exception of station 36, which had the highest EC50 value for these seven strata). Two stations (26 and 27) within stratum 9a were among the least toxic and two stations (35 and 37) within stratum 12 were among the most toxic.

An equally wide range in response was apparent in the Anacortes area (Figure 13). EC50s ranged from 0.5 mg/ml in station 41, to 21 mg/ml in station 38. Samples from station 40 in Samish Bay and stations 41-43 in Padilla Bay were among the most toxic. Also, samples from stations 49-54 collected near March Point and Anacortes were relatively toxic. As expected, samples from stations 56-58 collected in Guemes Channel were among the least toxic.

All three samples from stratum 23 (Oak Harbor), all three samples from stratum 22 (northern Saratoga Passage), and two samples from Penn Cove were among those that were either moderately or highly toxic (EC50s< 2.5mg/ml) in the Oak Harbor/Skagit Bay area (Figure 14). In central Saratoga Passage, EC50s ranged from 3.8 to 4.2 mg/ml (indicative of a moderate response), whereas in southern Saratoga Passage and Port Susan, EC50s were 6.7 to 77.7 mg/ml - among the least toxic (Figure 15). Continuing southward, most samples from Port Gardner and the Snohomish River provided EC50s of about 10 mg/ml or greater - indicative of a relatively low response (Figure 16).

All nine of the samples from strata 29-31 in Everett Harbor and vicinity provided EC50s of less than 1.0 mg/ml, indicative of the most toxic conditions (Figure 17). No strong spatial gradient in the data was apparent, the results ranging from 0.4 to 0.9 mg/ml. Among all regions included in the survey, these samples had consistently the lowest EC50 concentrations.

Cytochrome P450 RGS

Results of this test are illustrated as histograms for each station. High values are indicative of the response to the presence of organic compounds, such as dioxins, furans, and PAHs in the sediment extracts. Data are shown as benzo[a]pyrene equivalents. Concentrations greater than 15.7 µg/g exceed the upper 95% confidence interval of historical data from previous surveys (n=451).

Data from the Drayton Harbor/southern Strait of Georgia area indicated P450 induction was highest in samples from the three stations in Drayton Harbor and one station (station 6) west of Drayton Harbor (Figure 18). All samples from Bellingham Bay provided relatively low RGS assay responses, with the exception of two samples collected within inner Bellingham Bay (stations 28 and 30) which indicated the presence of relatively high concentrations of organic compounds (Figures 19 and 20).

In the Anacortes area, samples collected from the vicinity of March Point (stations 47-49 and 53-54) were more contaminated than those collected in most other stations (Figure 21). There appeared to be a pattern of relatively high RGS assay responses in the vicinity of March Point heading northeastward into Padilla Bay. Samples from Fidalgo Bay (stations 50-52) and Guemes Channel (stations 56-58) were among the least contaminated. However, none of the assay responses exceeded 15 µg/g.

All samples collected in strata 21-24 near Oak Harbor and strata 25-27 in Saratoga Passage/ Port Susan provided very low RGS assay responses, indicative of relatively non-contaminated conditions (Figures 22 and 23). This pattern of relatively low contamination continued southward (Figure 24) into Possession Sound and Port Gardner Bay. However, the RGS assay response in the sample from station 97, west of Everett Harbor, was 22.9 µg/g- a relatively high value.

Samples from Everett Harbor provided RGS assay responses distinctly different from those seen in all other stations. RGS responses in all nine samples exceeded 16 µg/g (Figure 25). The sample from station 86 had the highest response (202.2 µg/g). This is the second highest response observed thus far in the NOAA studies performed nationwide (n=530). Follow-up chemical analyses on this sample indicated it contained elevated levels of dioxins. Although all nine stations within strata 29-31 had very high RGS assay responses, concentrations generally decreased southward into stratum 31. The results were very similar, ranging from 28.7 µg/g to 29.2 µg/g among the three samples from stratum 31. RGS responses quickly decreased to background levels in Port Gardner Bay.

Summary

Overall, the data from the Microtox™, Cytochrome P450 RGS, and sea urchin fertilization tests indicated that samples from Everett Harbor were clearly the most toxic relative to those from other locations. Urchin fertilization success was lowest, microbial bioluminescence was reduced to the greatest degree, and RGS assay responses were highest in samples from strata 29-31 in the Everett Harbor area. However, none of the amphipod survival tests was significant in these samples.

Less severe toxicity was observed in at least one toxicity test in other stations scattered throughout the survey area, notably in some stations in Drayton Harbor, in southern Boundary Bay, in Whatcom Waterway and other regions of Bellingham Bay, near March Point, and in Oak Harbor. Samples from Saratoga Passage, Possession Sound, and most of Port Gardner Bay were among the least degraded in these tests.

Spatial Extent of Toxicity

Estimates of the spatial extent of toxicity for the four tests performed on sediments from the northern Puget Sound stations were calculated and are displayed in Table 12.

For amphipod survival, the mean percent survival in all 100 samples exceeded 80% of the CLIS controls; therefore, the spatial extent of toxicity was 0%. In the sea urchin fertilization tests, mean fertilization success was less than 80% of Redfish Bay controls in samples that represented 40.6 km^2 (equivalent to 5.2% of the total area sampled) in tests of 100% pore water. The spatial extent of toxicity was 1.5% and 0.8% in tests of 50% and 25% pore water, respectively.

Four spatial extent values were generated for microbial bioluminescence, including comparison of results to the critical value of 80% of the Redfish Bay and the phenol-spiked control, and comparison to the two new critical values generated representing the 80% and 90% lower

Table 12. Estimates of the spatial extent of toxicity in four independent tests performed on 100 sediment samples from northern Puget Sound.

Toxicity test	"Toxic" area (km^2)	Percent of total (773.9 km^2) area
Amphipod survival [A]	0.0	0.0
Urchin fertilization [A]		
• 100% porewater	40.6	5.24
• 50% porewater	11.5	1.49
• 25% porewater	5.9	0.76
Microbial bioluminescence		
• relative to control [B]	761.9	98.45
• relative to control + phenol [C]	648.3	83.76
• relative to 80% LPL of 0.51mg/ml [D]	17.7	2.29
• relative to 90% LPL of 0.06mg/ml [E]	0.0	0.0
Cytochrome P450 RGS		
• relative to 80% UPL of 11.1µg/g [F]	20.10	2.60
• relative to 90% UPL of 37.1µg/g [G]	0.22	0.03

[A] Critical value: mean survival or fertilization success < 80% of control

[B] Critical value: mean EC50 < 80% of control

[C] Critical value: mean EC50 < EC50 for control spiked with phenol (15.2 mg/ml)

[D] Critical value: mean EC50 < 0.51 mg/ml (80% LPL with the lowest, i.e., most toxic, samples removed)

[E] Critical value: mean EC50 < 0.06 mg/ml (90% lower prediction limit (LPL) of the entire data set – NOAA surveys + northern Puget Sound data, n=1013)

[F] Critical value: > 11.1µg/g benzo[a]pyrene equivalents/g sediment determined as the 80% upper prediction limit (UPL) following removal of 10% of the most toxic (highest) values from a database composed of NOAA data from many surveys nationwide (n=530)

[G] Critical value: > 37.1µg/g benzo[a]pyrene equivalents/g sediment determined as the 90% upper prediction limit (UPL) of the entire NOAA data set (n=530)

prediction limits of the existing NOAA data sets (Table 12). Using the critical value of <80% of the Redfish Bay controls, the spatial extent of toxicity in northern Puget Sound was calculated as 98.5%. Relative to the phenol-adjusted response in the Redfish Bay control, the estimated spatial extent of significant toxicity in the Microtox™ tests was 83.8%. These data suggested that toxicity in northern Puget Sound as measured with the Microtox™ tests was very widespread. However, the Microtox™ test results for the control samples from Redfish Bay (EC50=102.9 mg/ml) in this study differed considerably from those from previous tests of sediments from the Redfish Bay site (typically EC50s 20-30 mg/ml) and they differed from those obtained in tests of other control sites (typically EC50s 1-10 mg/ml) tested in previous NOAA surveys (Long et al., 1996). Estimates of the spatial extent of toxicity based upon the two new 80% and 90% LPL critical values were 2.3% and 0.0%, respectively, and suggested that relatively severe toxicity in this test was much more restricted in scope than estimated with the critical value of <80% of control.

Calculations of values of the spatial extent of toxicity for the northern Puget Sound Cytrochrome P450 RGS sediment data, using the 80% and 90% upper prediction limits calculated for the NOAA data set, indicated that strata in which responses were greater than 37.1 µg/g or 11.1 µg/g represented 0.2 km^2 (0.03% of the total) and 20.1 km^2 (2.6% of the total), respectively (Table 12). These results suggest that, as observed in the Microtox™ tests, relatively severe toxicity was restricted in scope.

Concordance among Toxicity Tests

Non-parametric, Spearman-rank correlations (rho) were determined for combinations of different toxicity test results to quantify the degree to which these tests showed the same spatial patterns in toxicity response (Table 13). In this analysis, it is critical to identify whether the correlation coefficients are positive or negative. With the amphipod, urchin and Microtox™ tests, sediment quality improves as the test results (expressed as either survival, fertilization success, or EC50s) increase; however, sediment quality deteriorates with increases in the numerical results of the Cytochrome P450 assay results. Therefore, with the former three tests, positive correlation coefficients suggest the tests co-varied with each other. In contrast, co-variance with results of the Cytochrome P450 test would be indicated with a negative sign.

Probably because results of the amphipod survival test covered a very small range, none of the other toxicity test results showed a significant correlation with data from this test (Table 13). Microtox™ test results, on the other hand, were significantly correlated with results from the Cytochrome P450 RGS assay and the urchin fertilization test. The strongest correlation was between results of the Microtox test and the urchin fertilization test (rho=0.360, p=0.0003, n=100); indicating these two tests identified similar patterns in toxicity among the sampling stations. The degree of concordance among toxicity tests was similar to that observed by NOAA in New York Harbor, Boston Harbor, Biscayne Bay, Tampa Bay, and other survey areas. Generally, with the exception of the amphipod survival test, the different tests indicated overlapping, but not duplicative patterns in toxicity.

Table 13. Spearman-rank correlation coefficients for combinations of different toxicity tests performed with 100 sediment samples from northern Puget Sound.

	Amphipod survival	Signifi-cance (p)	Microtox™ Biolumine-scence	Signifi-cance (p)	Cytochrome P450 RGS assay	Signifi-cance (p)
Amphipod survival [A]						
Microtox™ [A]	0.160	ns				
Cytochrome P450	-0.081	ns	-0.214	0.03*		
Urchin fertilization [A]	0.162	ns	0.360	0.003***	-0.119	ns

[A] Data expressed as percent of control
*p<0.05
**p<0.01
***p<0.001
ns = not significant (p>0.05)

Chemical Analyses

Results of the sediment chemistry analyses conducted for this survey are presented in the following sections. Due to the large volume of data generated, brief summaries of the results are included below, while either raw or summary data tables are included in the Appendices. As stated earlier, all raw data can be obtained from the Ecology Sediment Monitoring Team's web site. The web site address is located on the inside cover of this report.

Grain Size

The grain size data are reported in Appendix D, Table 1, and frequency distributions of the four particle size classes, % gravel, % sand, % silt, and % clay, are depicted for all stations in Appendix D, Figure 1. From these data, sediment from the 100 stations can be characterized into four groups (sand, silty sand, mixed sediments, and silt-clay) based on their relative proportion of % sand to % fines (silt + clay)(Table 14). Gravel content was less than 1.0% in 86 of the stations, with the highest values (ranging from 11.0-16.5%) occurring at four of the mixed sediment stations.

Table 14. Sediment types characterizing the 100 samples collected in 1997 from northern Puget Sound strata.

Sediment type	% sand	% silt-clay	% gravel (range of data for each station type)	No. of stations with this sediment type
Sand	>80	<20	0.0 - 3.7	8
Silty sand	60 - 80	20 - <40	0.0 - 6.5	12
Mixed	20 - <60	40 - 80	0.0 – 16.5	25
Silt-clay	<20	>80	0.0 – 5.2	55

Over one-half (55%) of the stations sampled were comprised of sediments with a predominance (>80%) of silt-clay particles, while the remaining 45% of the samples had sediments comprised primarily of sand, silty sand, or mixed particles (8, 12, and 25% of the samples, respectively).

Total Organic Carbon (TOC), Temperature, and Salinity

Total organic carbon (TOC) and temperature measurements taken from the sediment samples, and salinity measurements collected from water in the grab, are displayed in Appendix D, Table 2. Values for TOC ranged between 0.13 – 9.91%, with a mean of 1.90%. Temperature ranged between 10 – 15 °C, with a mean of 11.42°C. Salinity values ranged between 14 – 32 ppt, with a mean of 25.22 ppt.

Simultaneously Extracted Metals (SEM)/Acid Volatile Sulfides (AVS)

All acid volatile sulfide data were qualified by the laboratory as estimated, due to the erratic, unreproducible results generated from the procedure and instrumentation. Although the data quality for the simultaneously extracted metals (SEM) samples was very good, all SEM/AVS data were discarded, because SEM/AVS ratios could not be generated.

Metals and Organics

Appendix D, Table 3 contains a summary of metal and organic compounds data, including mean, median, minimum, maximum, range, total number of values, number of undetected values, and the number of missing values. Compounds which, at some or all stations, were undetected at the quantitation limits reported by the laboratory included 8 of 24 metals (strong acid digestion method), 6 of 24 metals (hydrofluoric acid digestion method), 3 of 4 organotins, 50 of 52 organic compounds quantified through BNA analyses, 14 of 27 low and high molecular weight polynuclear aromatic hydrocarbons, and all 55 chlorinated pesticide and polychlorinated biphenyl (PCB) compounds.

Spatial Patterns in Chemical Contamination

Stations where chemical concentrations exceeded either the SQS, CSL, ERL, or ERM sediment guideline concentrations were highlighted on strata maps (Figures 26-46). There were five stations among the 100 sampled in which at least one trace metal concentration equaled or exceeded an SQS value (Figure 26). In the sample from station 94 (stratum 31, mouth of Everett Harbor), the concentration of zinc (776 ppm) exceeded only the SQS value (410 ppm). The concentrations of arsenic (205 ppm) and copper (464 ppm) exceeded both the SQS (57 and 390, respectively) and CSL (93 and 390, respectively) values. The concentrations of mercury (0.43 to 0.81 ppm) exceeded the SQS value (0.41 ppm) in the samples from station 9 (stratum 3, West Boundary Bay), and stations 27 and 28 (stratum 9A) and station 60 (stratum 9B) in Bellingham Bay. The mercury concentration in the sample from station 9 also exceeded the CSL of 0.59 ppm. One or more trace metals exceeded ERM concentrations at two stations; one in southern Boundary Bay and one in Everett Harbor (Figure 27).

Concentrations of one or more individual LPAHs exceeded respective ERL values in samples from strata 9A, 9B, 10, 11, and 12 in Bellingham Bay (Figure 28); stratum 17 near Anacortes (Figure 29); strata 29, 30, and 31 in Everett Harbor (Figure 30); and strata 28, 32, and 33 in Port Gardner Bay (Figure 31). In addition, the concentrations of one or more individual LPAHs exceeded ERM values in samples from stations 86, 89, 92, 93, and 94 - all in Everett Harbor (Figure 30). Concentrations of the sum of 7 LPAHs exceeded the ERM value in eight samples: those from stations 86-90 and 92-94 in Everett Harbor.

Concentrations of high molecular weight PAHs (HPAHs) followed a pattern similar to that for the LPAHs. One or more HPAHs exceeded the ERL values in samples from strata 9A and 9B in Bellingham Bay (Figure 32); stratum 17 near Anacortes (Figure 33); and strata 29, 30, and 31 in Everett Harbor (Figure 34). ERM concentrations were exceeded in samples 86, 89, 90 and 92 only from Everett Harbor stations (Figure 34), but, unlike the LPAHs, not in Port Gardner Bay. The concentration of the sum of 6 HPAHs exceeded the ERM value (9600 ppb) in the sample from station 86 (15,727 ppb).

Chlorinated pesticides and PCB values exceeded ERLs at 4 stations from Bellingham Bay, all stations except station 86 from Everett Harbor (strata 29, 30, and 31) and one station in Port Gardner Bay. The ERM values were exceeded at station 86 (Figures 35 and 36). The SQS criteria were also exceeded at station 86 (not displayed).

Benzoic acid concentrations were elevated relative to state CSL values in samples from southern Boundary Bay, Oak Harbor, and Penn Cove (Figure 37). Samples from inner Everett Harbor (Figure 38) also had high benzoic acid concentrations.

The concentrations of individual phenol compounds were elevated in many samples scattered throughout the survey area. Concentrations exceeded the CSL value in sediments from Drayton Harbor, southern Boundary Bay, parts of Bellingham Bay, Padilla Bay, Samish Bay, Fidalgo Bay, Oak Harbor, Penn Cove, Saratoga Passage, inner Everett Harbor, and Port Gardner Bay (Figures 39-45). Many other stations had phenol concentrations that exceeded the SQS values, but not the CSL values.

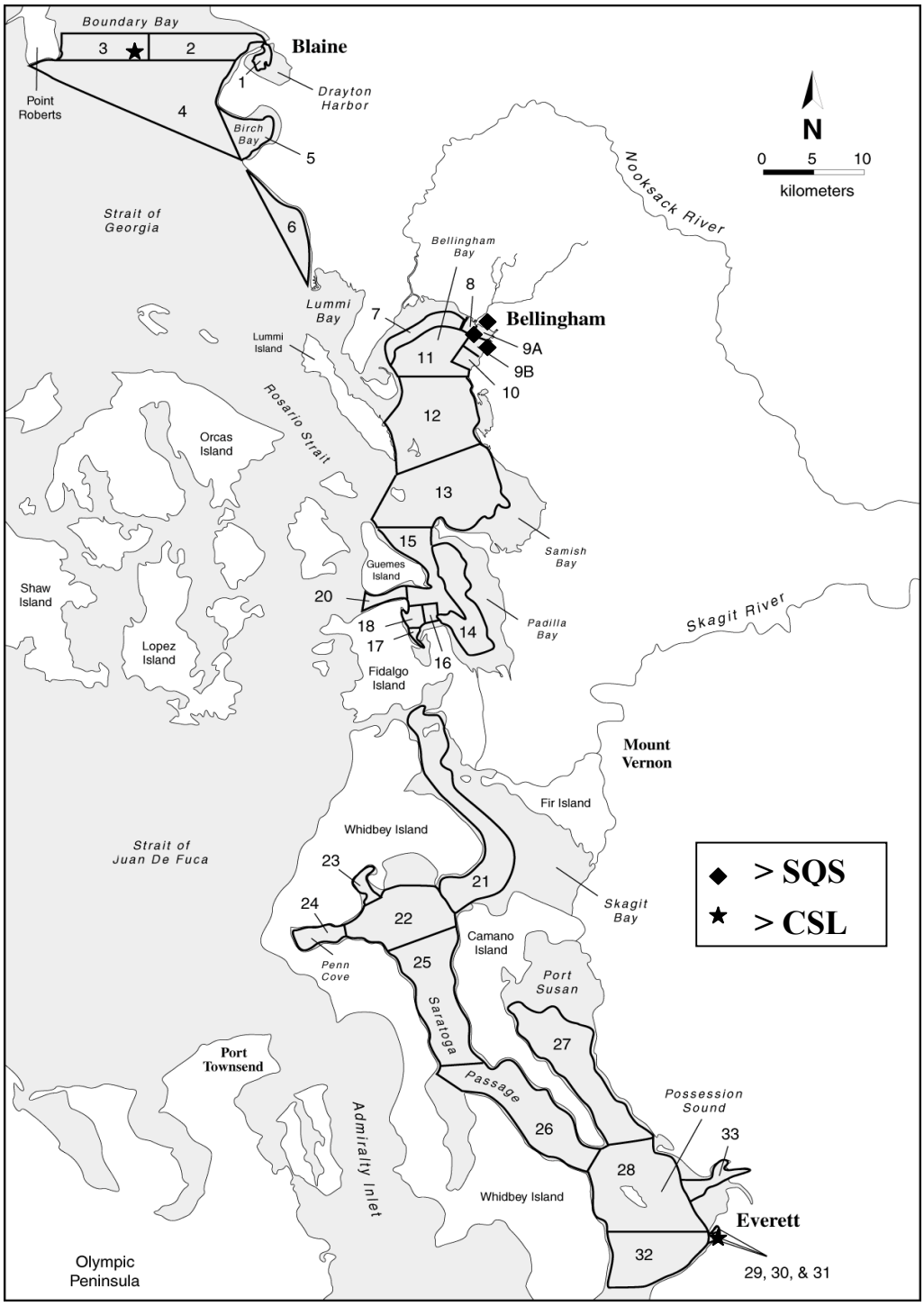

Figure 26. Sampling stations in northern Puget Sound with trace metal concentrations exceeding Washington State criteria.

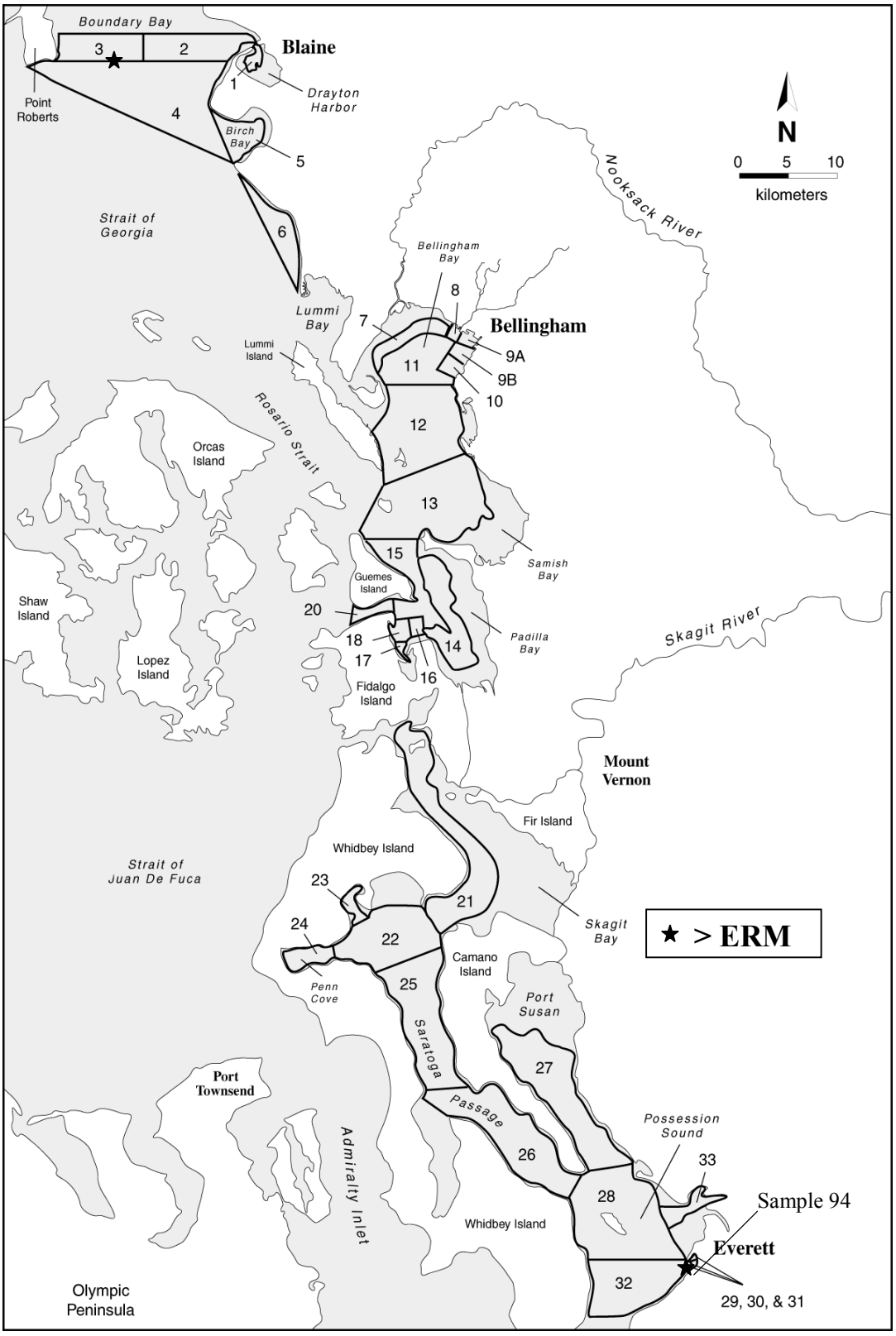

Figure 27. Sampling stations in northern Puget Sound with trace metal concentrations exceeding numerical guidelines from Long et al. (1995).

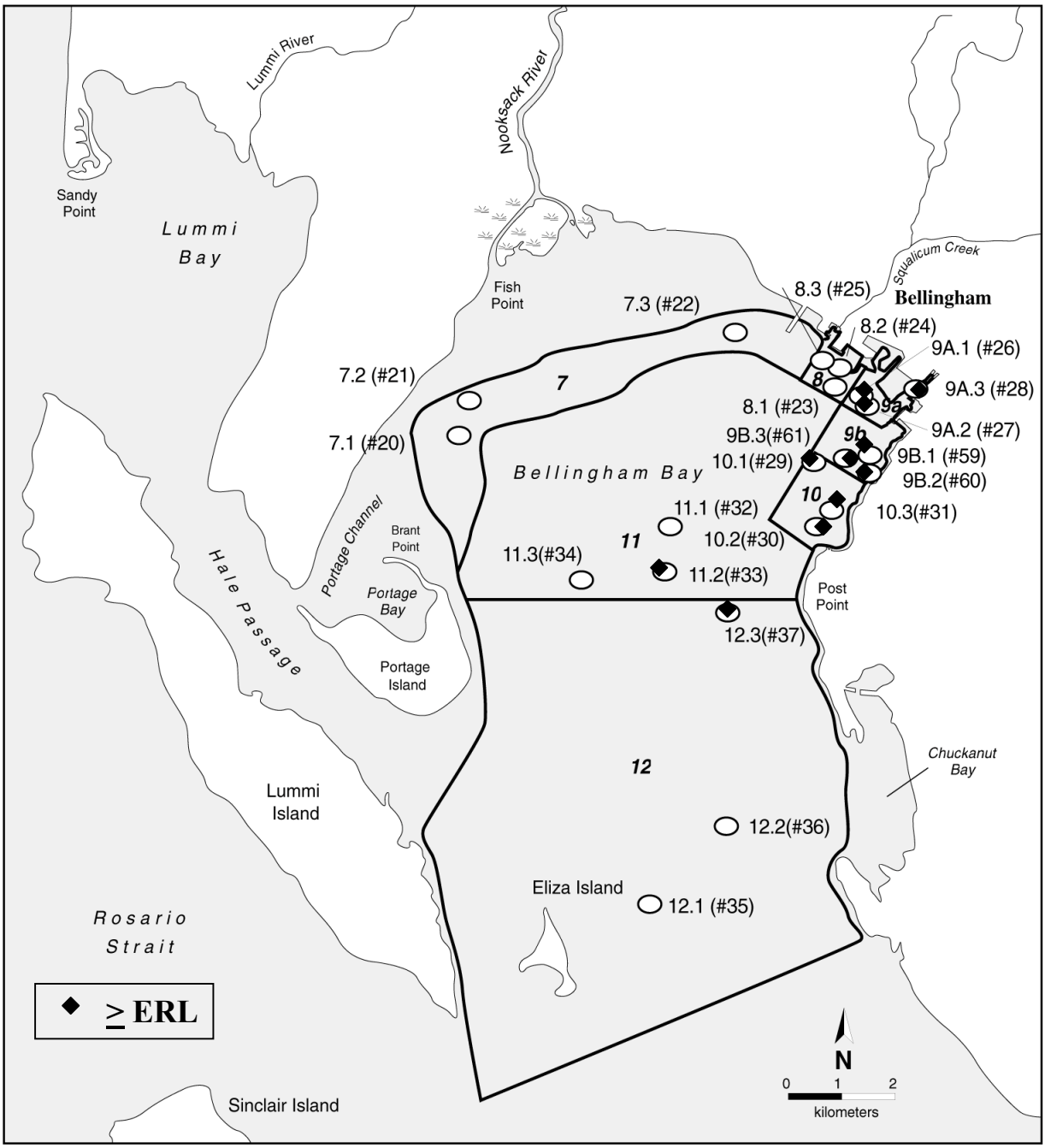

Figure 28. Sampling stations in Bellingham Bay with individual low molecular weight polynuclear aromatic hydrocarbon concentrations exceeding numerical guidelines from Long et al. (1995).

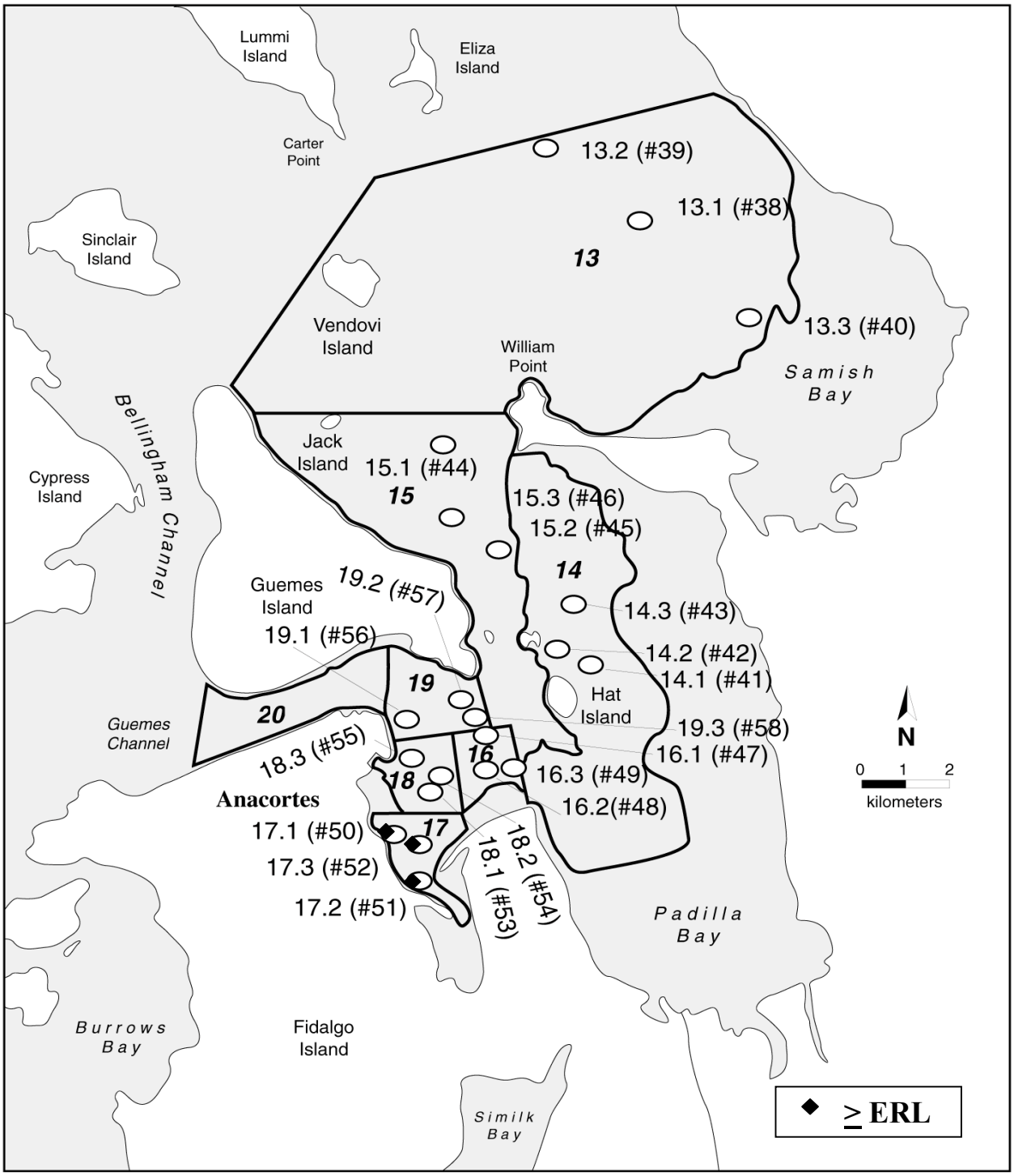

Figure 29. Sampling stations in near Anacortes with individual low molecular weight polynuclear aromatic hydrocarbon concentrations exceeding numerical guidelines from Long et al. (1995).

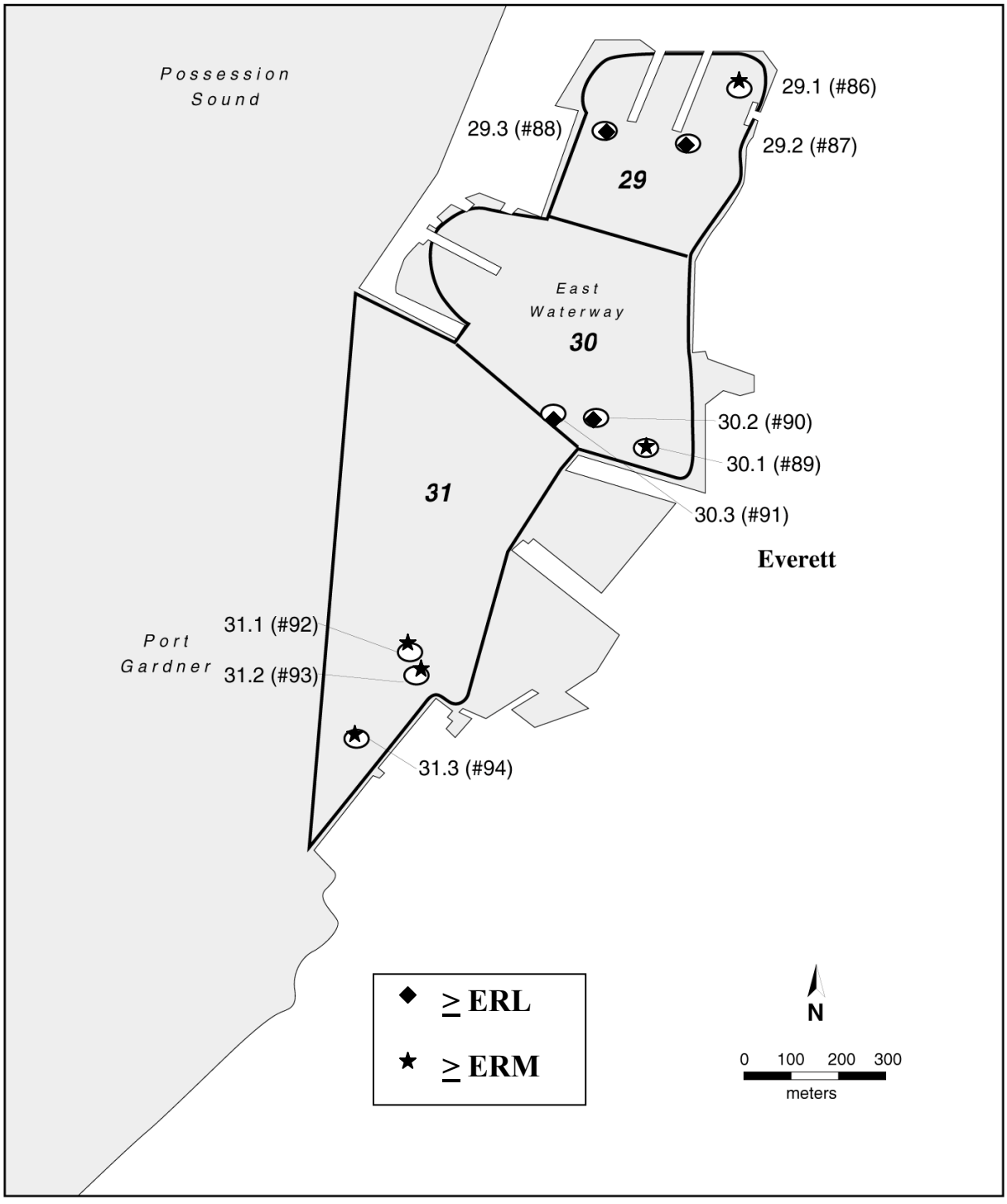

Figure 30. Sampling stations in Everett Harbor with individual low molecular weight polynuclear aromatic hydrocarbon concentrations exceeding numerical guidelines from Long et al. (1995).

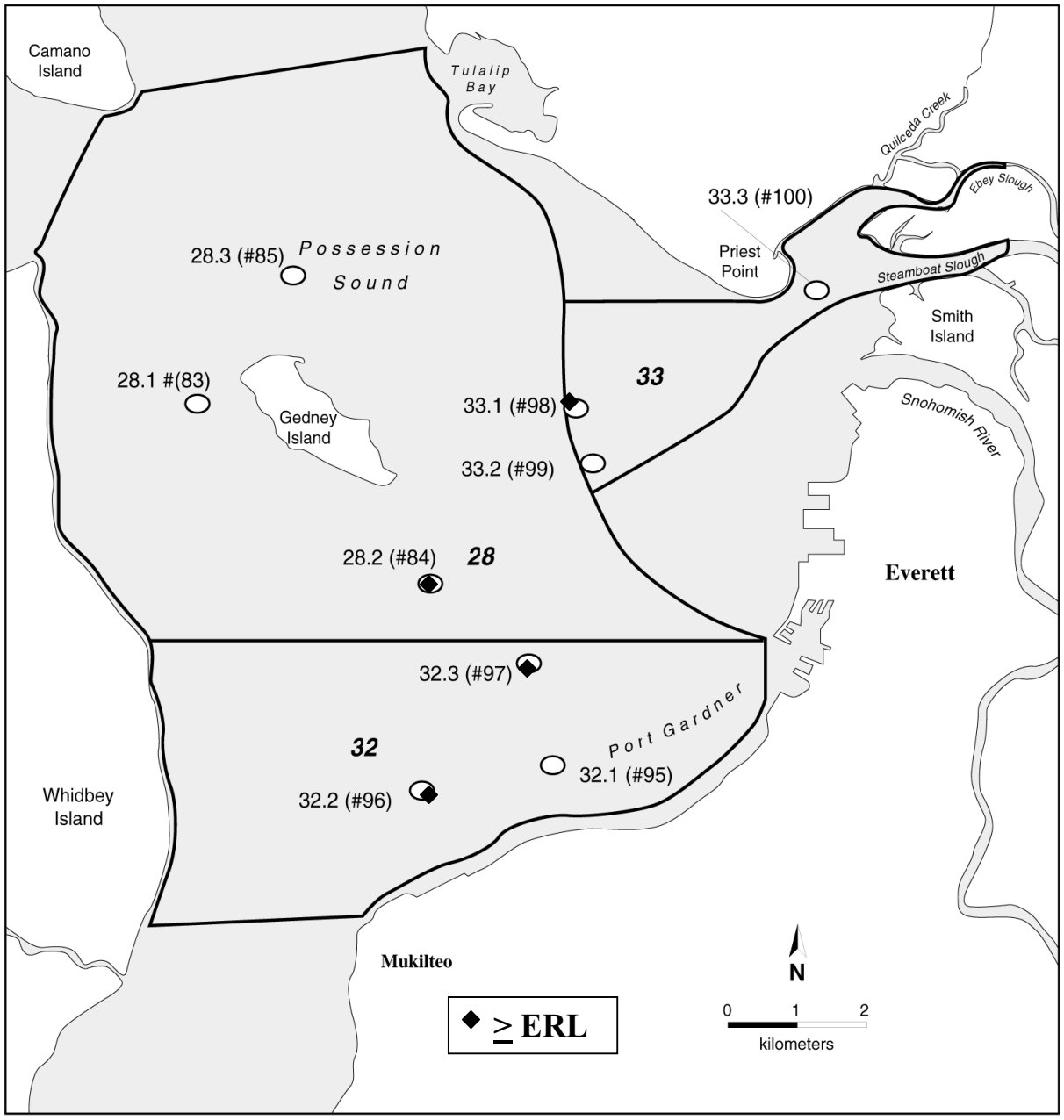

Figure 31. Sampling stations in Port Gardner Bay with individual low molecular weight polynuclear aromatic hydrocarbon concentrations exceeding numerical guidelines from Long et al. (1995).

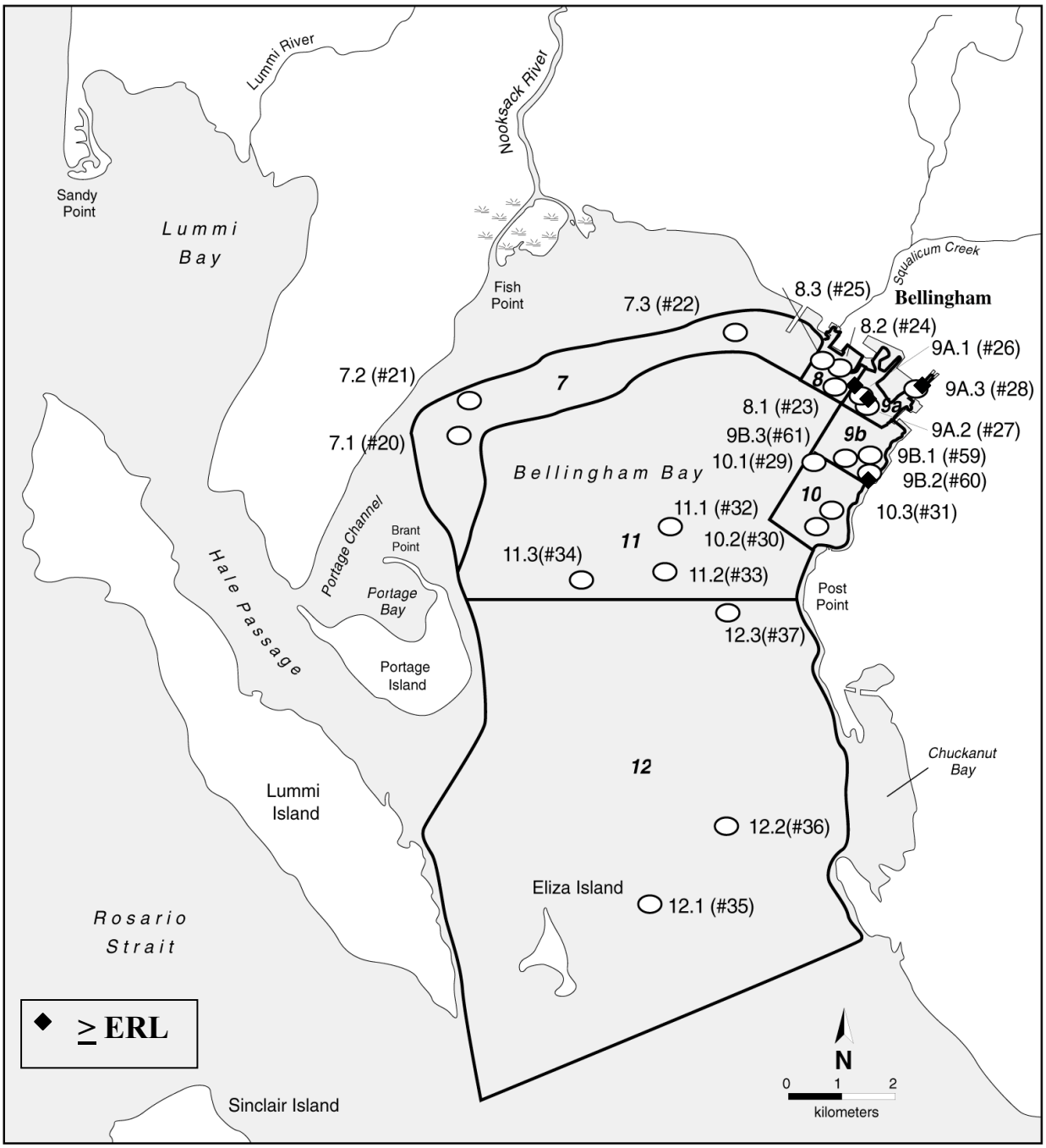

Figure 32. Sampling stations in Bellingham Bay with individual high molecular weight polynuclear aromatic hydrocarbon concentrations exceeding numerical guidelines from Long et al. (1995).

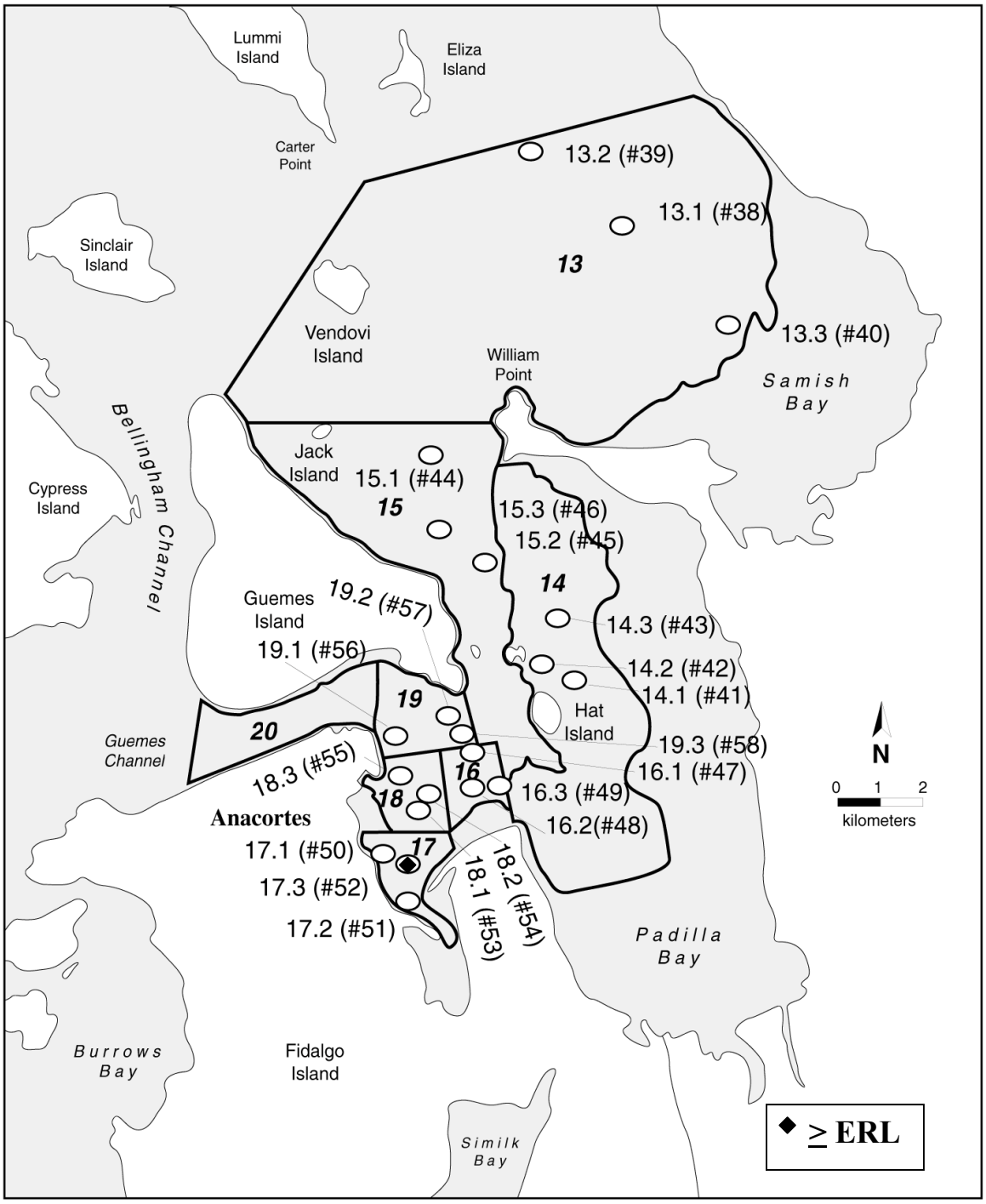

Figure 33. Sampling stations near Anacortes with individual high molecular weight polynuclear aromatic hydrocarbon concentrations exceeding numerical guidelines from Long et al. (1995).

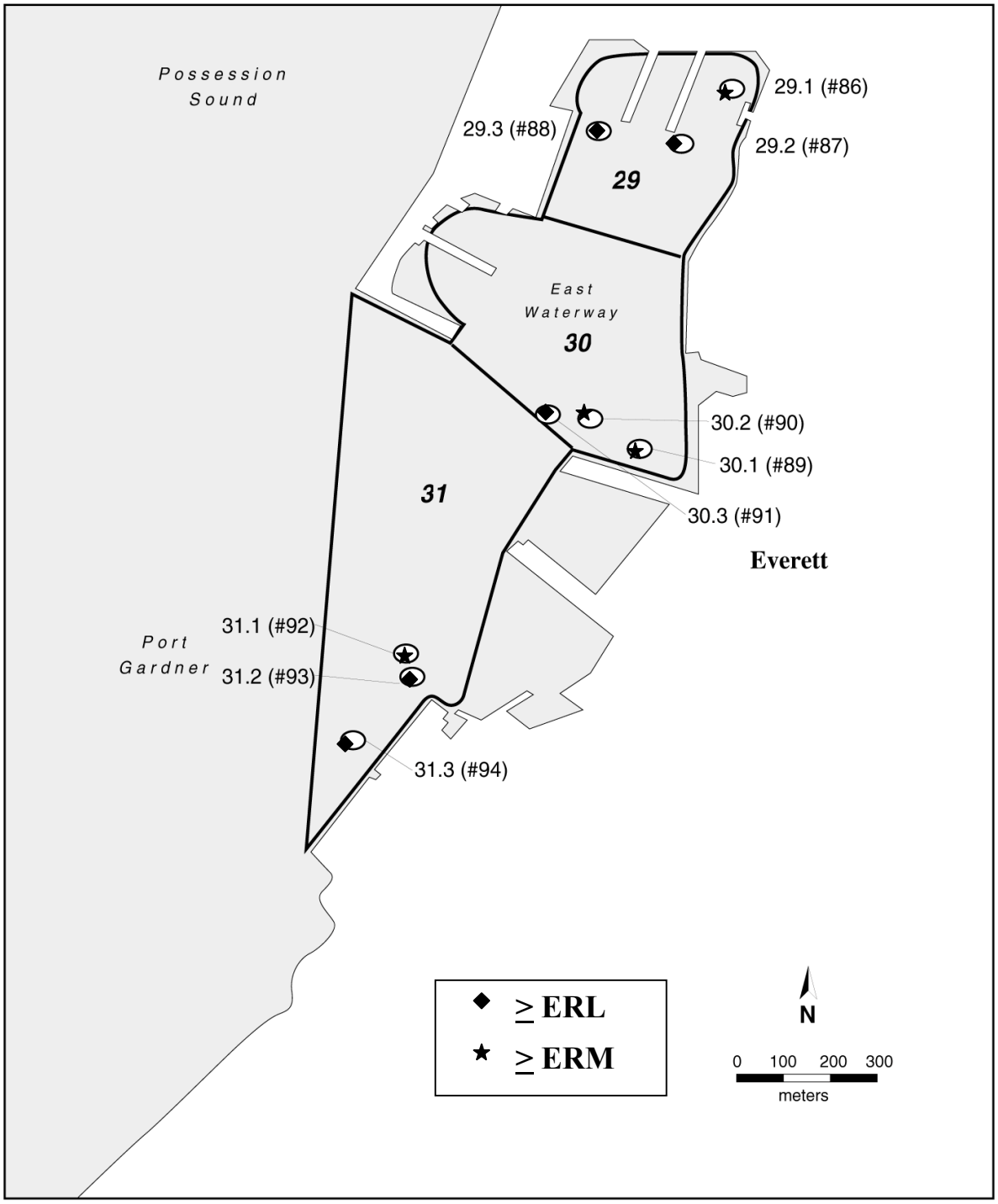

Figure 34. Sampling stations in Everett Harbor with individual high molecular weight polynuclear aromatic hydrocarbon concentrations exceeding numerical guidelines from Long et al. (1995).

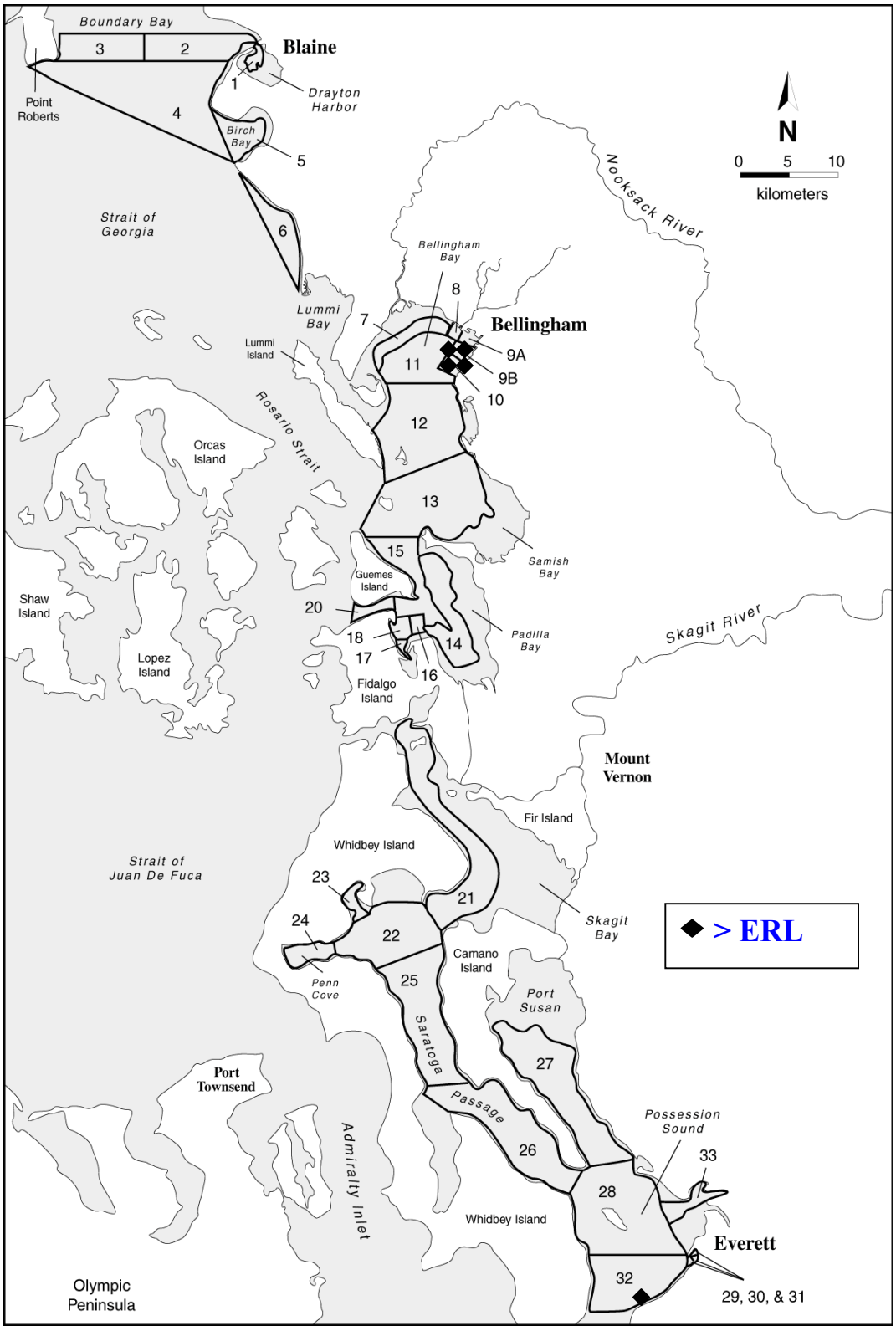

Figure 35. Sampling stations in northern Puget Sound with chlorinated pesticides and PCB concentrations exceeding numerical guidelines from Long et al. (1995).

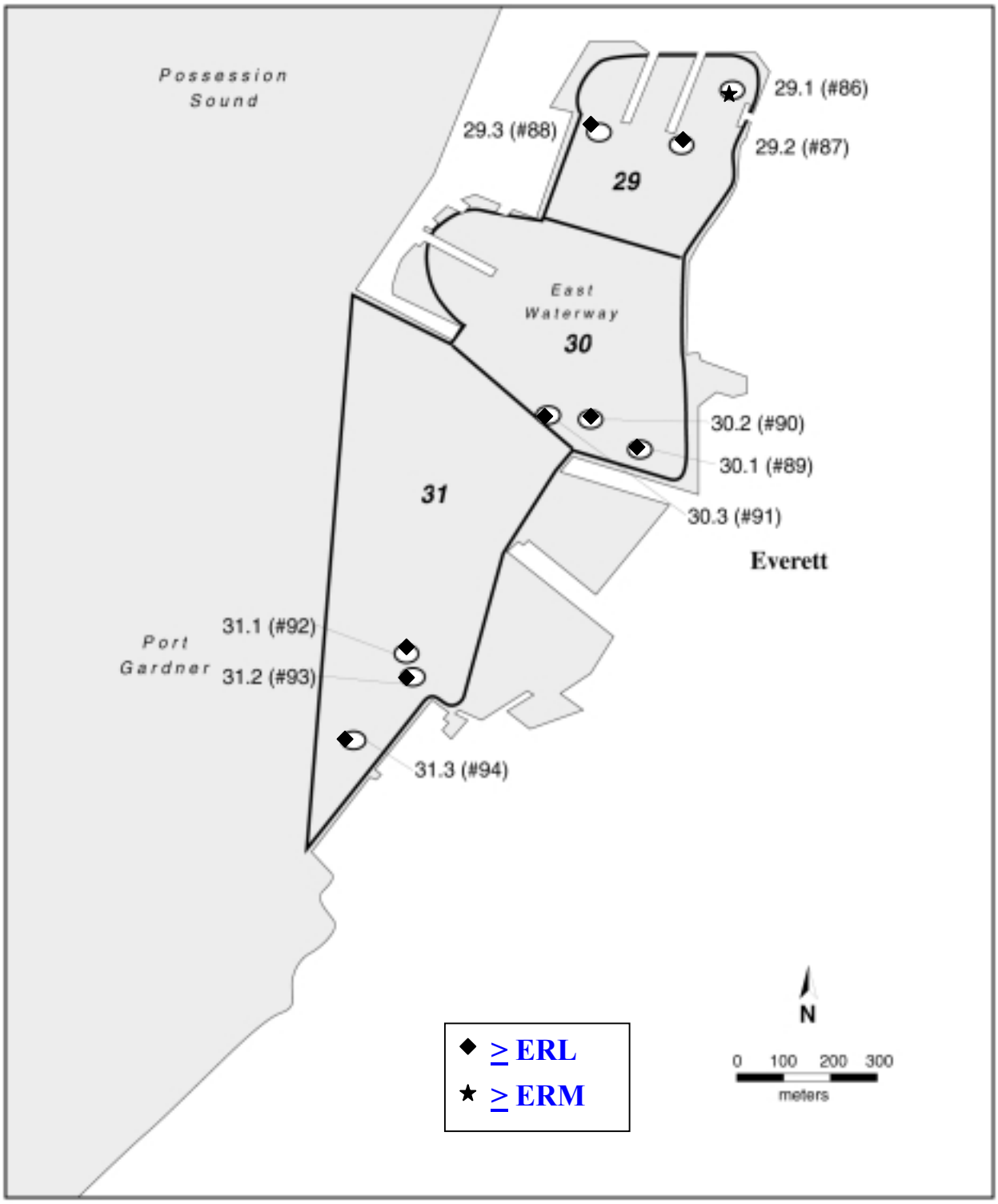

Figure 36. Sampling stations in Everett Harbor with chlorinated pesticides and PCB concentrations exceeding numerical guidelines from Long et al. (1995).

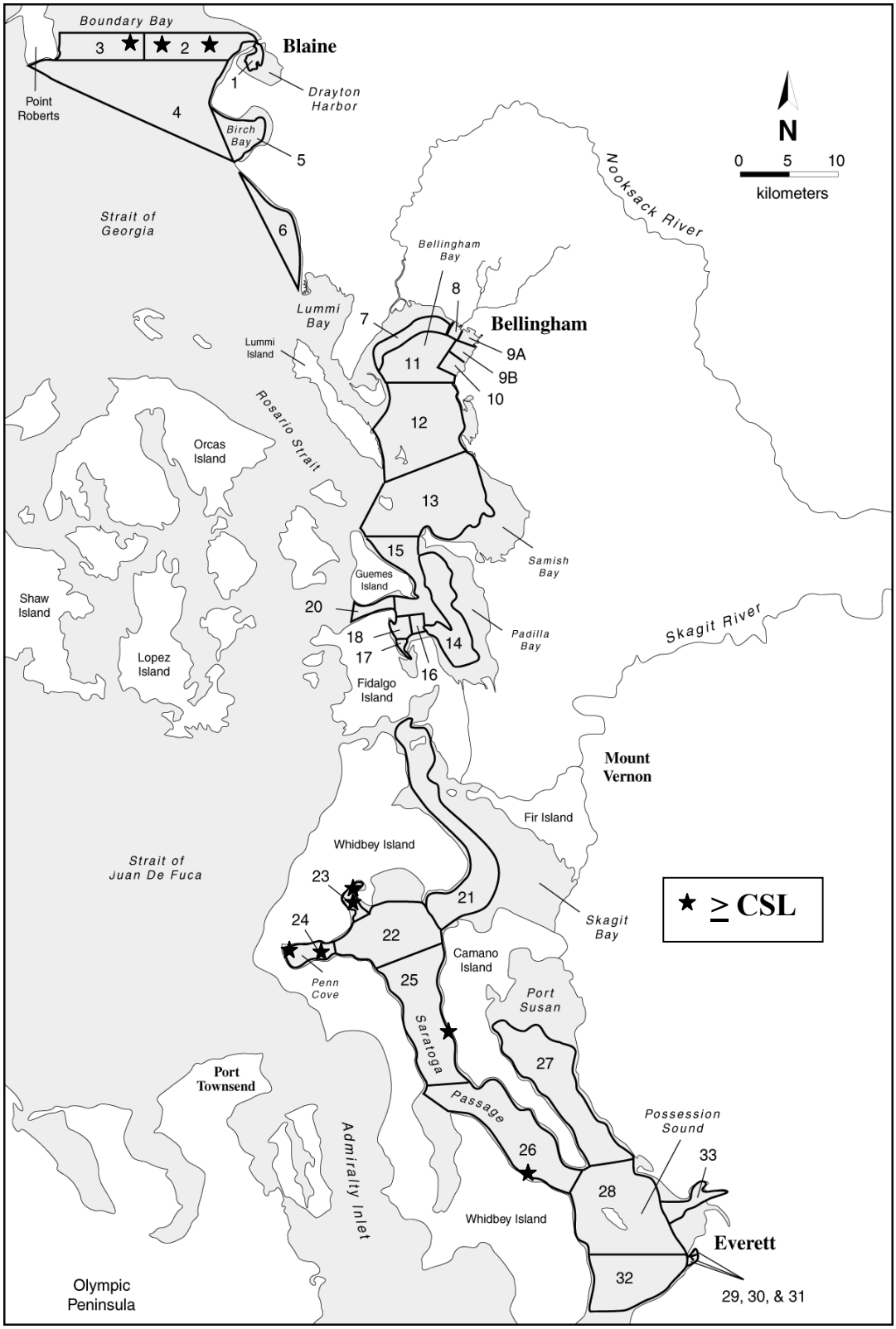

Figure 37. Sampling stations in northern Puget Sound with benzoic acid concentrations exceeding Washington State criteria.

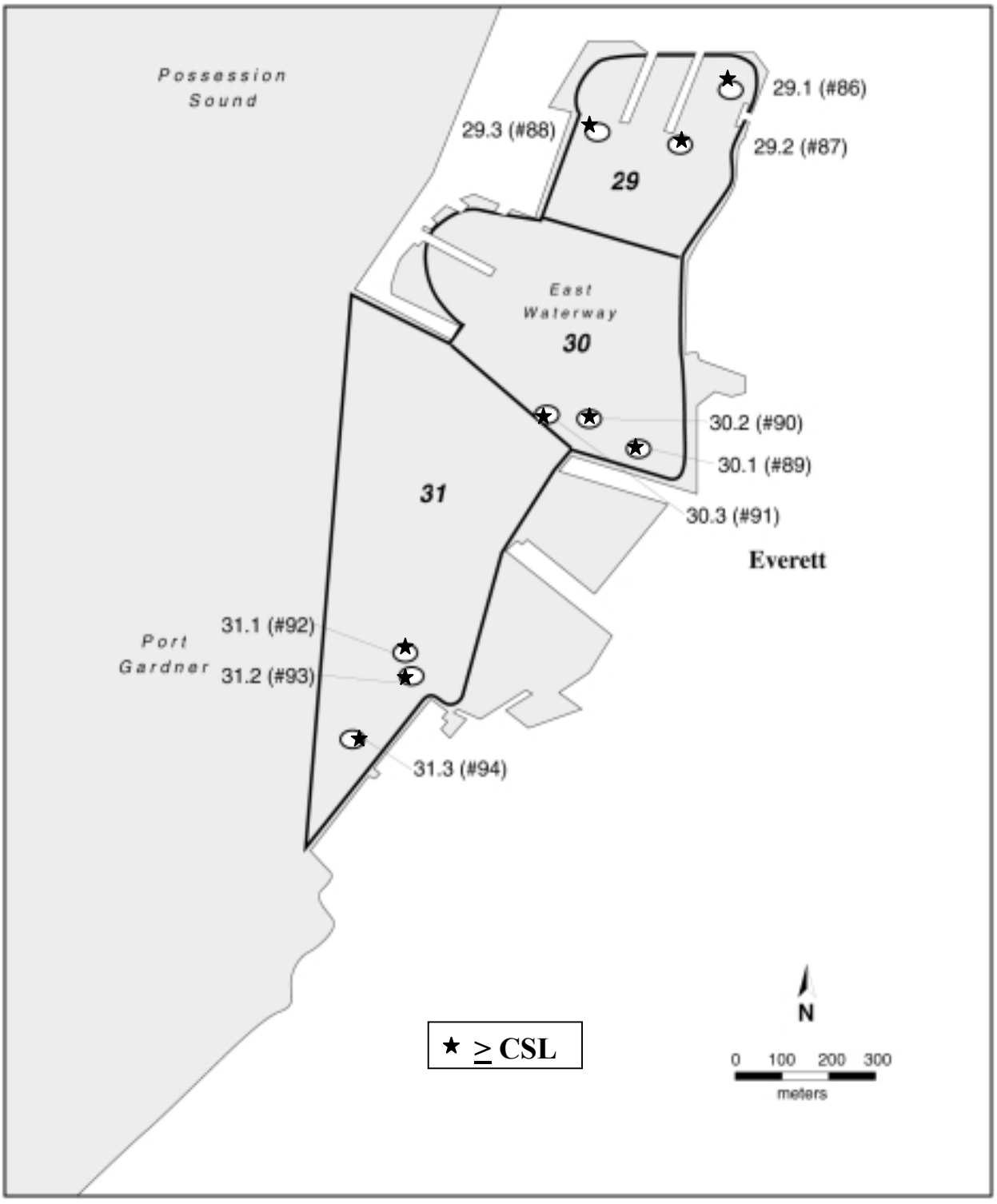

Figure 38. Sampling stations in Everett Harbor with benzoic acid concentrations exceeding Washington State criteria.

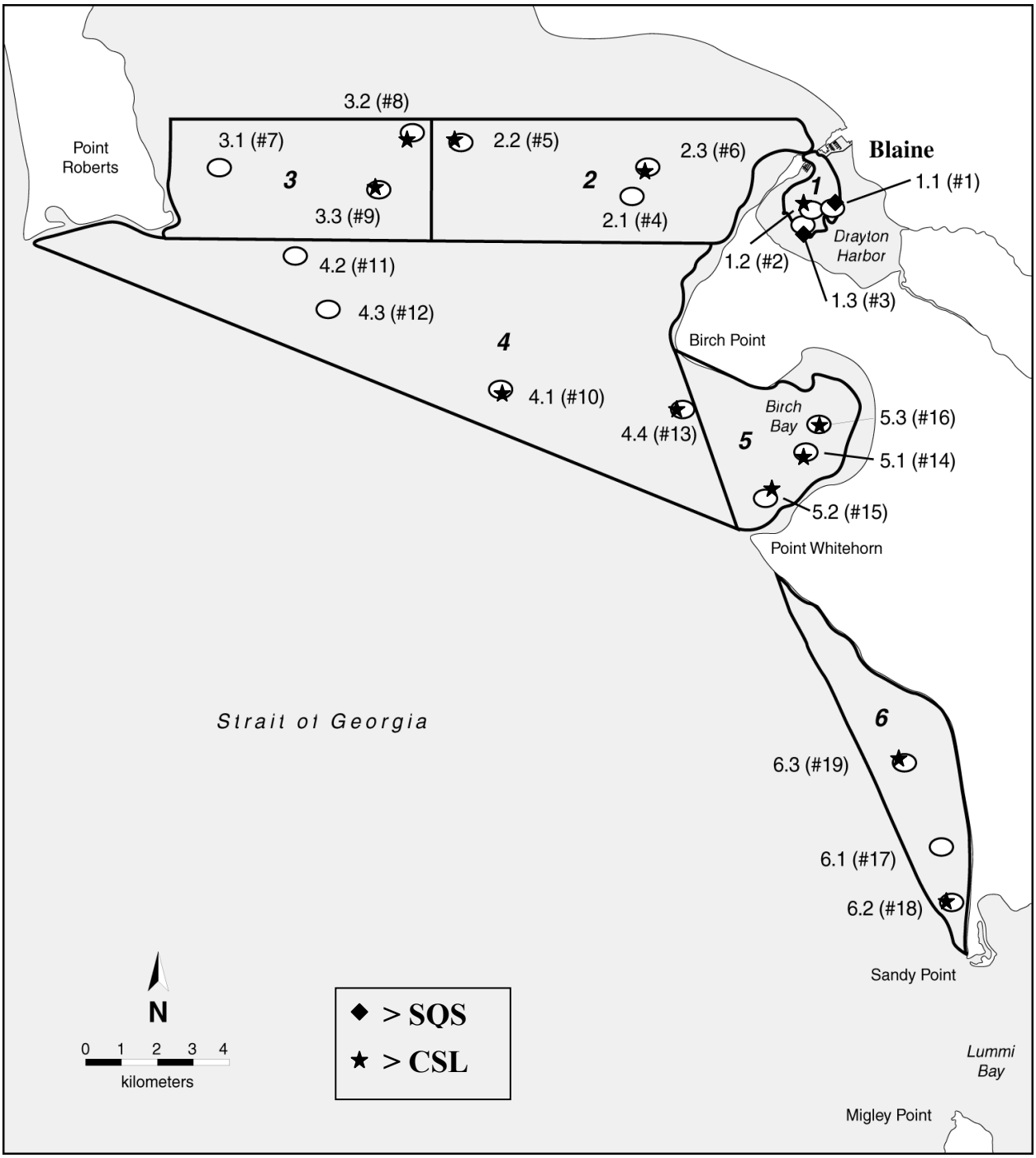

Figure 39. Individual phenol compounds at sampling stations in the Strait of Georgia with concentrations exceeding Washington State criteria.

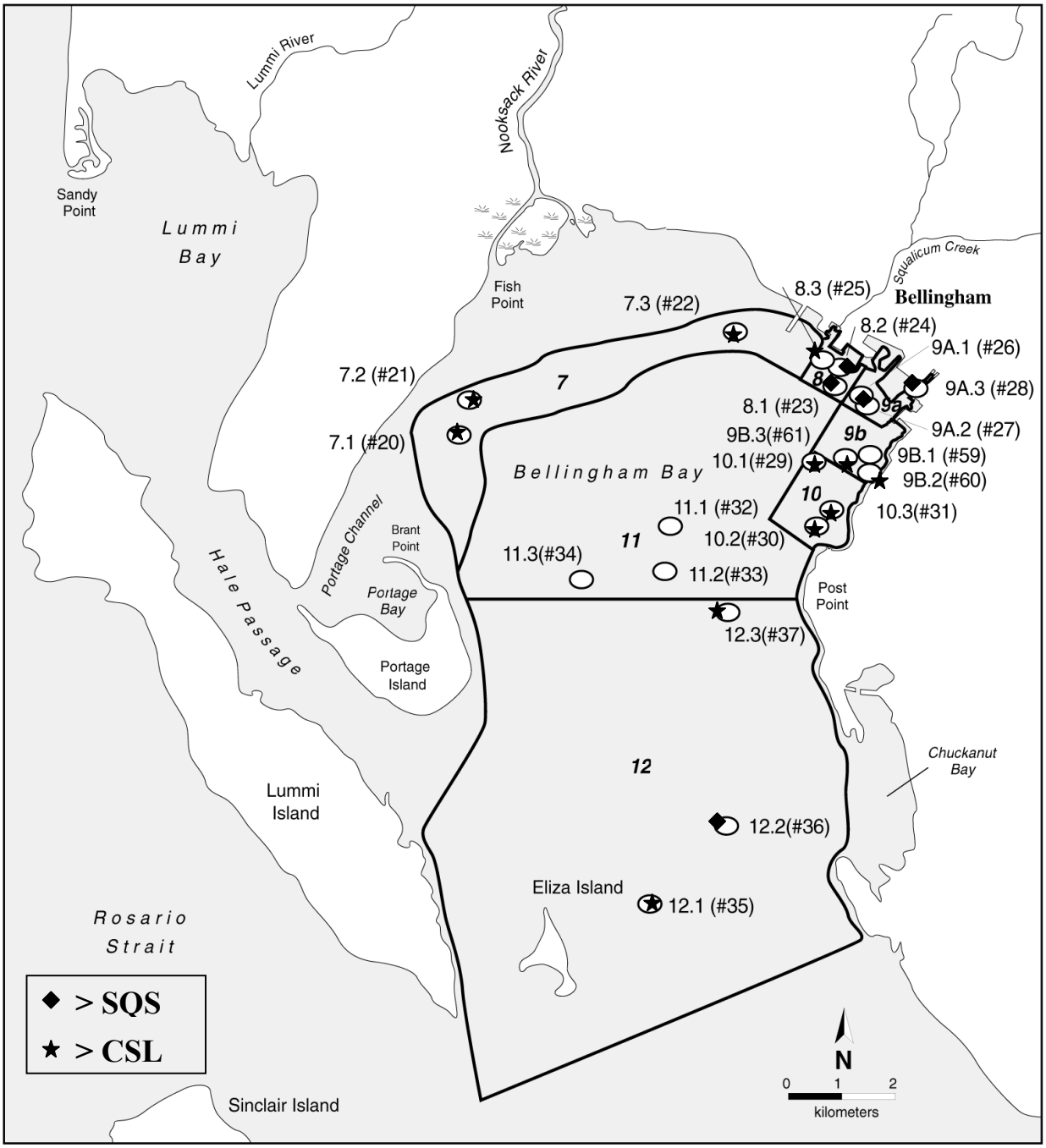

Figure 40. Individual phenol compounds at sampling stations in Bellingham Bay with concentrations exceeding Washington State criteria.

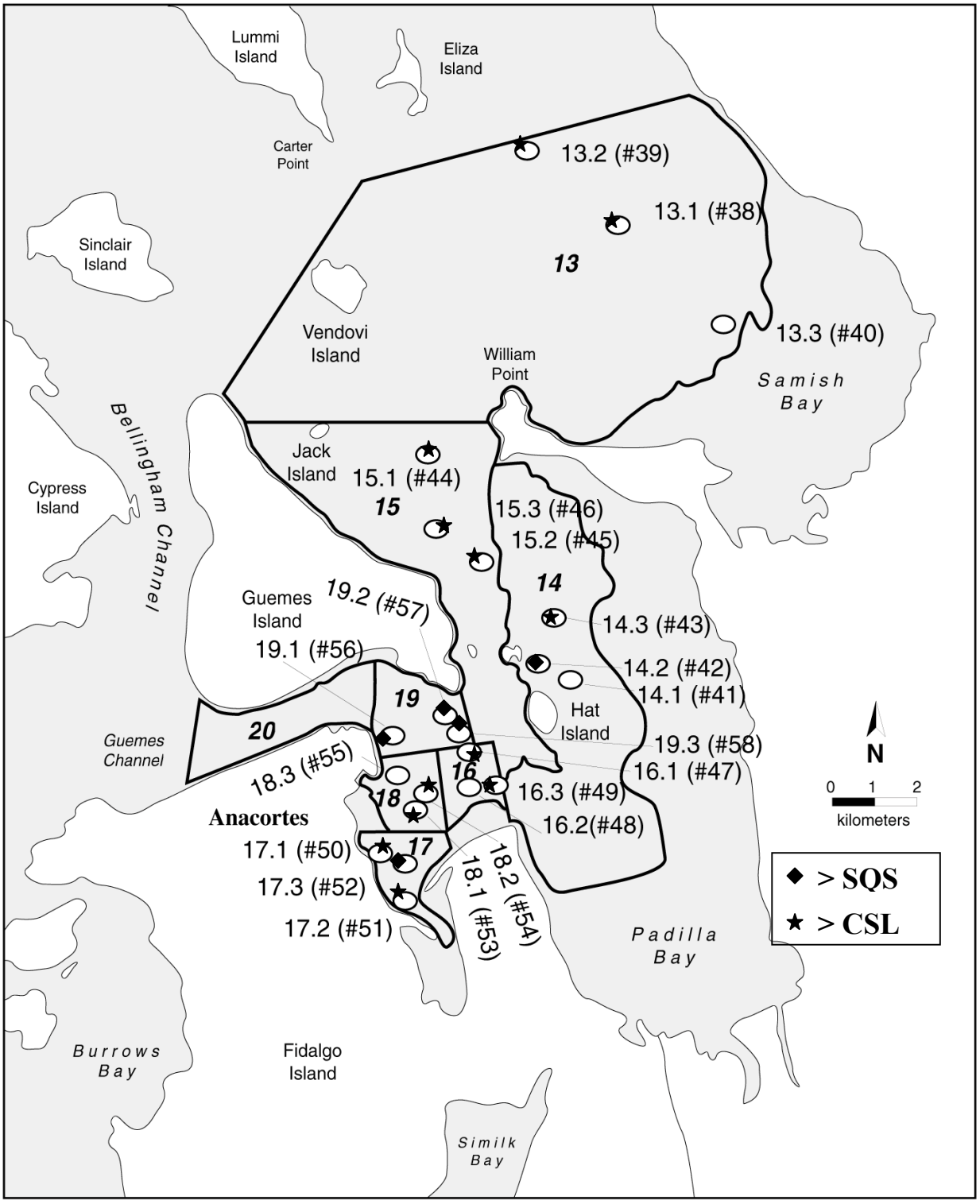

Figure 41. Individual phenol compounds at sampling stations near Anacortes with concentrations exceeding Washington State criteria.

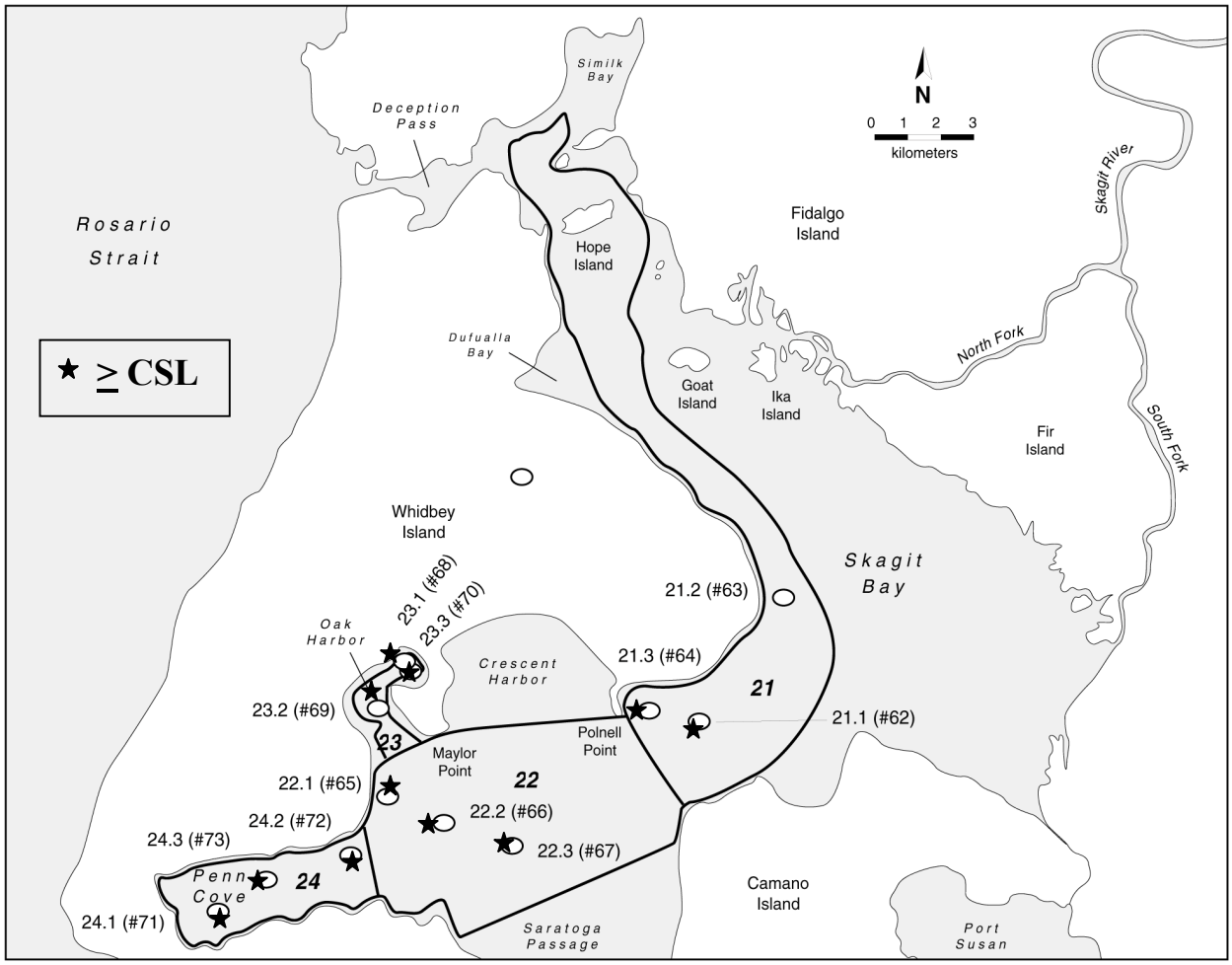

Figure 42. Individual phenol compounds at sampling stations west of Whidbey Island with concentrations exceeding Washington State criteria.

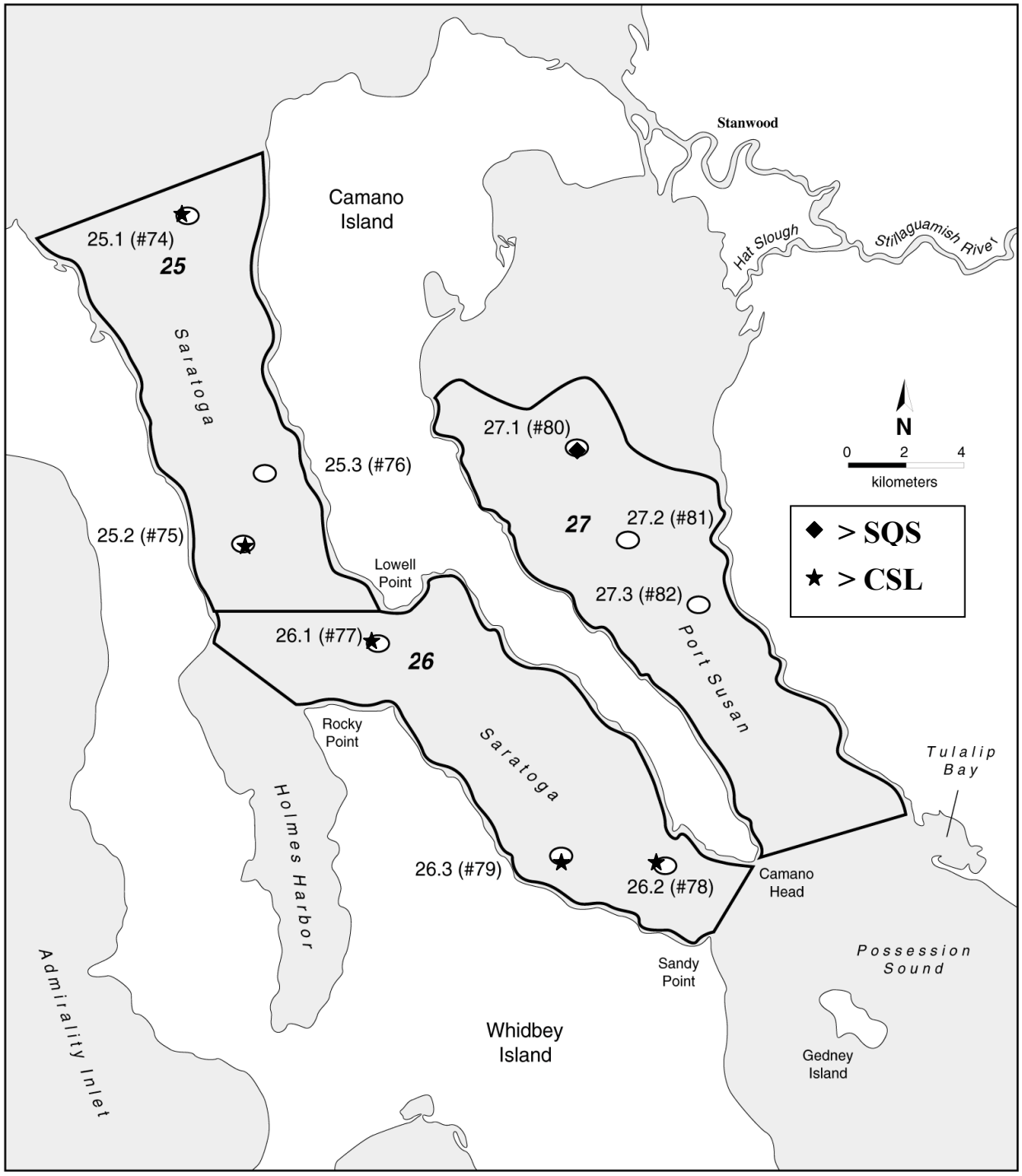

Figure 43. Individual phenol compounds at sampling stations surrounding Camano Island with concentrations exceeding Washington State criteria.

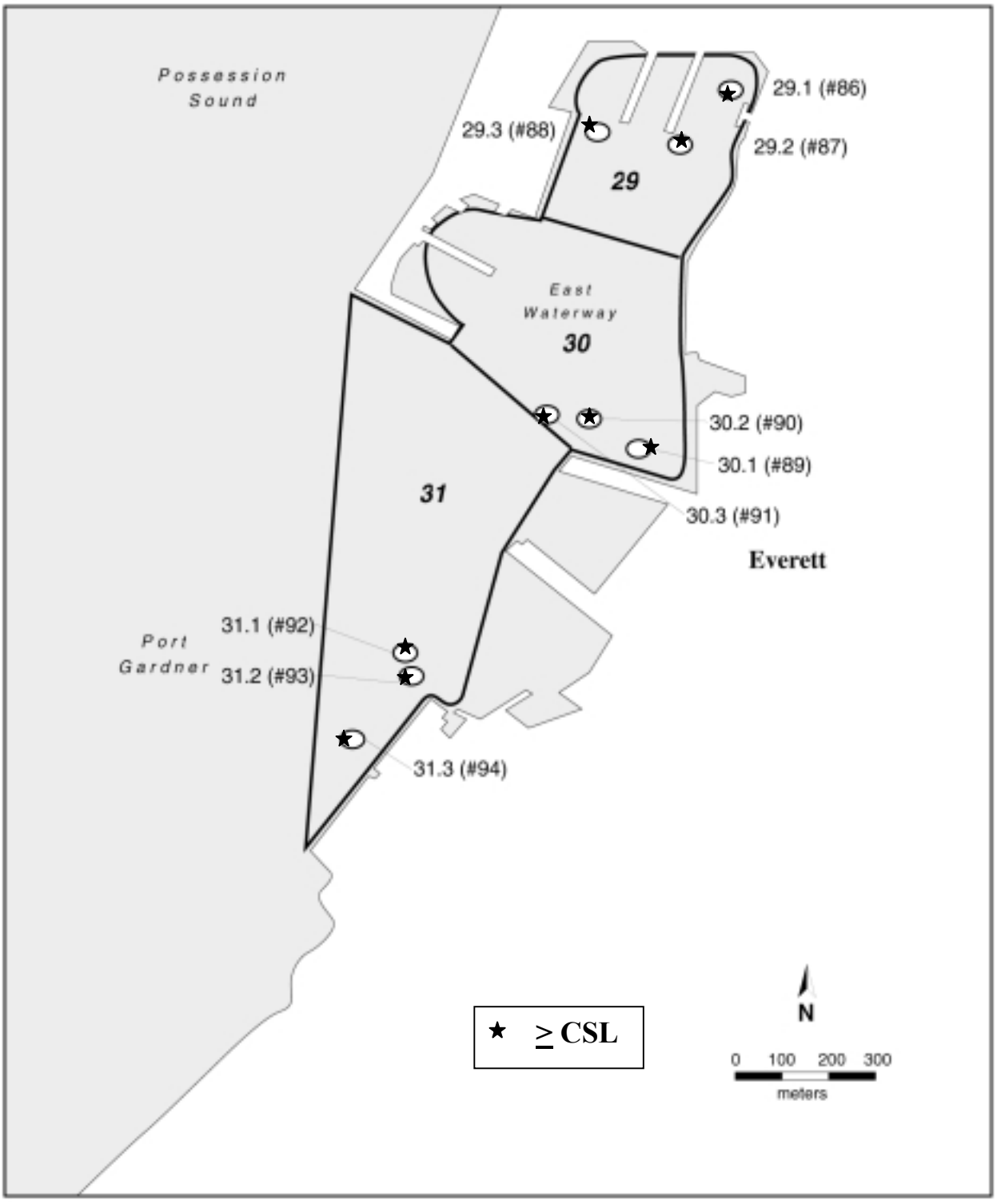

Figure 44. Individual phenol compounds at sampling stations in inner Everett Harbor with concentrations exceeding Washington State criteria.

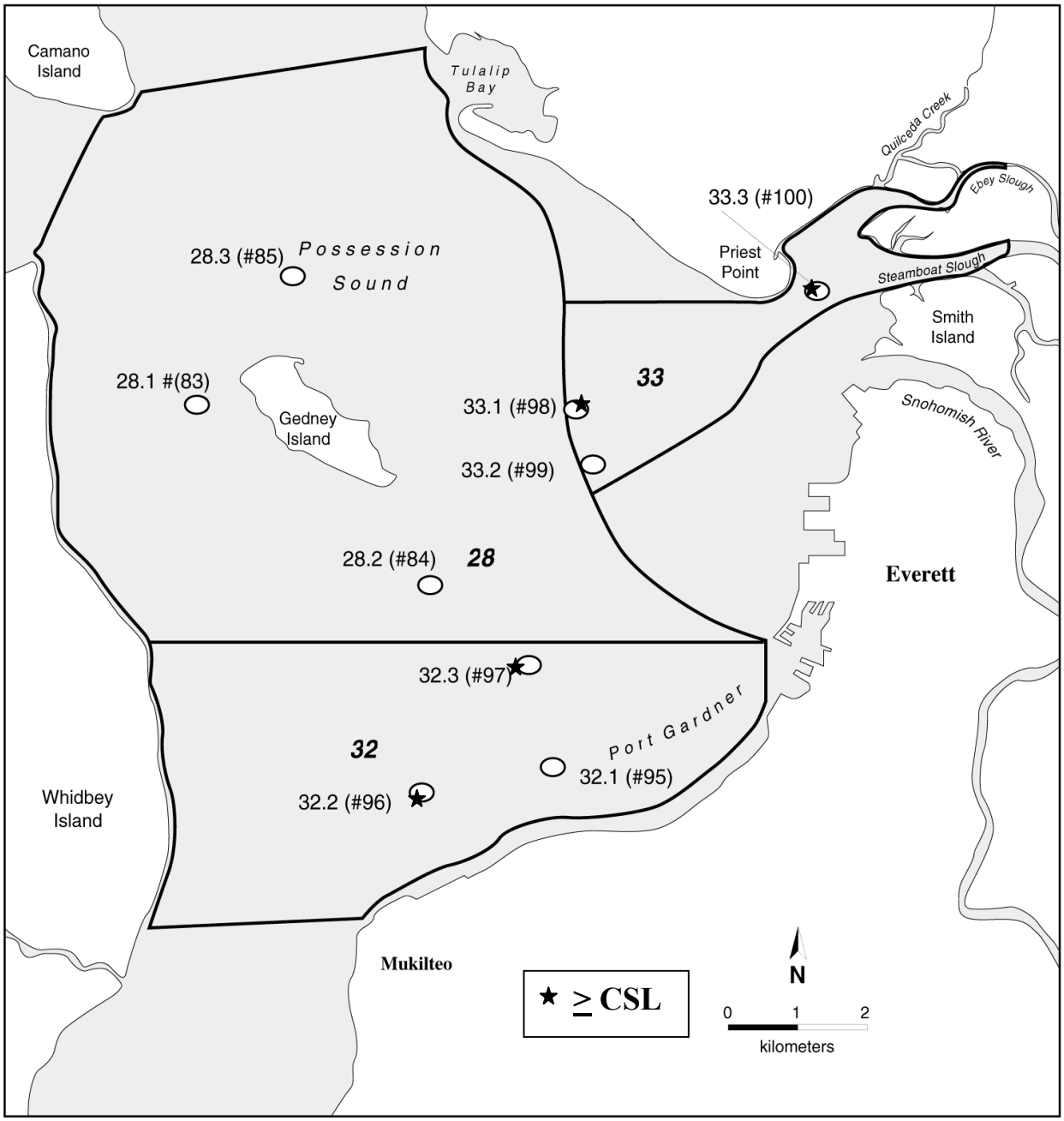

Figure 45. Individual phenol compounds at sampling stations in Port Gardener Bay with concentrations exceeding Washington State criteria.

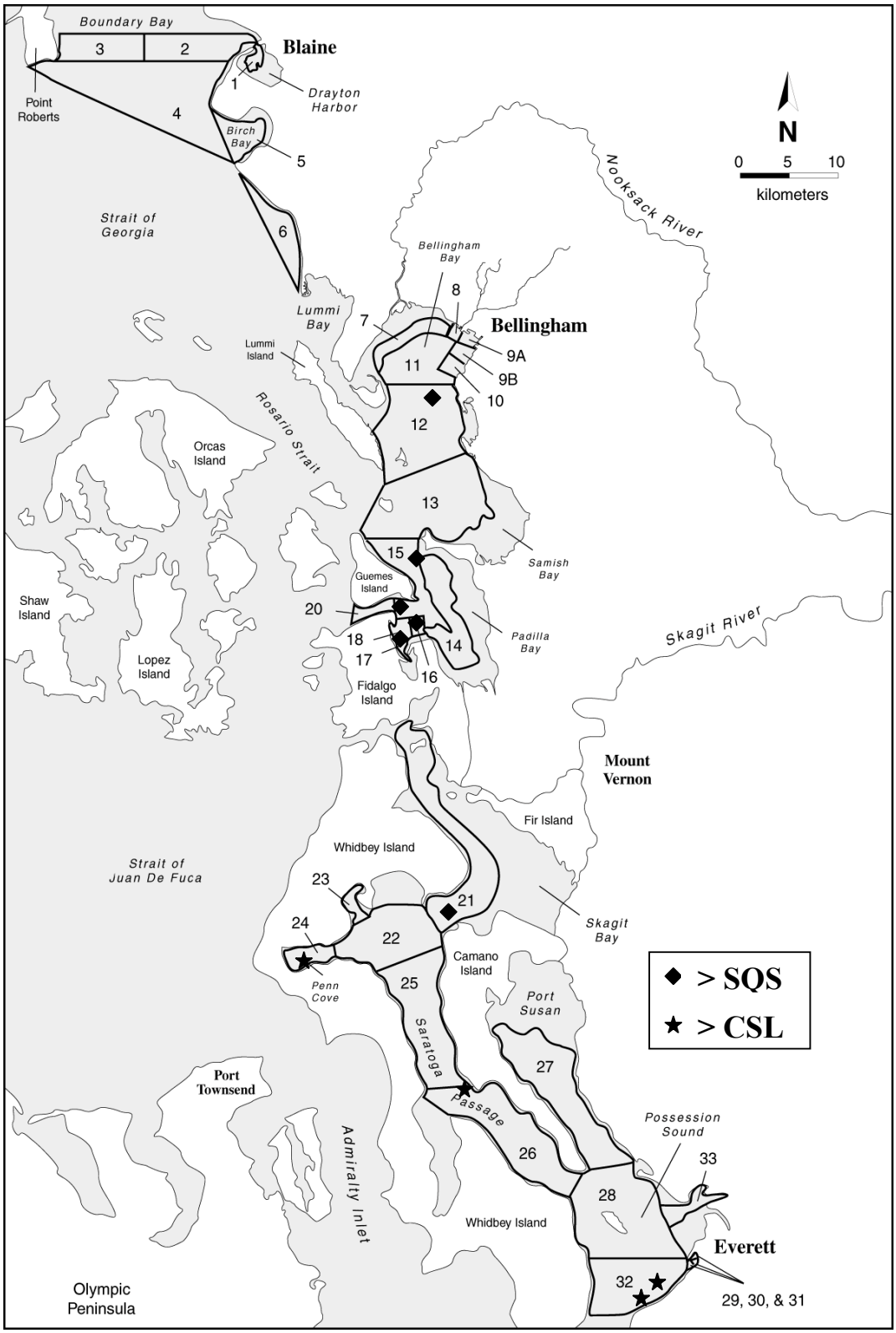

Figure 46. Sampling stations in Northern Puget Sound with individual phthalate esters exceeding state numerical guidelines.

Phthalate esters occurred in concentrations above the SQS values in samples from outer Bellingham Bay, near Anacortes, in Skagit Bay, in Penn Cove, and in Port Gardner Bay (Figure 46).

Summary

Overall, chemical concentrations were most elevated in sediments from the most urbanized/industrialized embayments, i.e., Everett Harbor and Bellingham Bay. The concentrations of several trace metals and two classes of PAHs followed this pattern. PAH concentrations were moderate in a few samples collected near another urban center - Anacortes. Some chemical groups, notably the phenols and phthalate esters, were elevated in concentrations at stations scattered throughout the entire area. In contrast, mercury occurred at high concentrations in only one sample collected from southern Boundary Bay.

Generally, chemical concentrations were lowest in samples collected in Samish Bay, Padilla Bay, Saratoga Passage, Port Susan, and the southern Strait of Georgia. These are areas of least urban/industrial development.

Spatial Extent of Chemical Contamination

Using the same approach as used in the calculations of the spatial extent of toxicity, estimates were made of the spatial extent of chemical contamination for those compounds for which sediment guidelines and standards exist. The numbers of samples that exceeded applicable sediment quality guidelines (ERM values) (Long et al., 1995) and Washington State Sediment Management Standards (SQS and CSL values) (Ch. 173-201 WAC) were determined and the percent of the total strata area these samples represented was calculated (Table 15). The ERM, SQS, and CSL values were intended to represent concentrations above which adverse biological effects would be expected. Spatial extent values were not calculated for ERL guidelines, as they are not predictive of deleterious effects.

For most trace metals, the samples in which the ERM, SQS, or CSL values were exceeded represented a very small proportion (0.0 to 1.7%) of the overall study area. The sample from station 94 (Everett Harbor), represented <0.1% of the study area. In that sample, the concentrations of arsenic and copper exceeded all three guideline values, the concentration of zinc exceeded the ERM and SQS values, and the lead concentration exceeded the ERM. In the sample from station 9 (Boundary Bay), the mercury concentration exceeded all three values. The mercury concentrations in the samples from three stations in Bellingham Bay (stations 27, 28, and 60) also exceeded the SQS.

The data for nickel were exceptional. The ERM value for nickel was exceeded in 51 samples, representing approximately 51% of the study area. The ERM value for nickel was identified by Long et al. (1995) as a value with relatively poor reliability and therefore a guideline for which there was limited confidence. Therefore, the nickel concentrations were probably of limited toxicological significance.

Table 15. Number of samples (stations) exceeding individual numerical guidelines (ERM, SQS, and CSL values) and estimated spatial extent of chemical contamination, (expressed as percent of total area (773.9 km^2), relative to each guideline.

Compound	≥ ERM [a]			≥ SQS [b]			≥ CSL [b]		
	No.	% of Total Area	Station No.	No.	% of Total Area	Station No.	No.	% of Total Area	Station No.
Trace metals [c]									
Arsenic	1	<0.1	94	1	<0.1	94	1	<0.1	94
Cadmium	0	0.0		0	0.0		0	0.0	
Chromium	0	0.0		0	0.0		0	0.0	
Copper	1	<0.1	94	1	<0.1	94	1	<0.1	94
Lead	1	<0.1	94	0	0.0		0	0.0	
Mercury	1	1.1	9	4	1.7	9, 27, 28, 60	1	1.1	9
Nickel	51	50.8		n/a	n/a		n/a	n/a	
Silver	0	0.0		0	0.0		0	0.0	
Zinc	1	<0.1	94	1	<0.1	94	0	0.0	
Total for any individual trace metals (excluding nickel)	2	1.2	9, 94	5	1.7	9, 27, 28, 60, 94	2	1.2	9, 94
Organic Compounds									
LPAH									
2-Methylnaphthalene	0	0.0		0	0.0		0	0.0	
Acenaphthene	4	<0.1	86, 89, 92, 93	0	0.0		0	0.0	
Acenaphthylene	0	0.0		0	0.0		0	0.0	
Anthracene	1	0.0	86	0	0.0		0	0.0	
Fluorene	4	<0.1	86, 89, 92, 93	0	0.0		0	0.0	
Naphthalene	0	0.0		0	0.0		0	0.0	
Phenanthrene	5	<0.1	86, 89, 92, 93, 94	0	0.0		0	0.0	
Total for any individual LPAH	5	<0.1	86, 89, 92, 93, 94	0	0.0		0	0.0	
Sum of LPAH									
Sum of 6 LPAH [d], (Ch 173-204 WSDOE Sediment Management Standards)	n/a	n/a		0	0.0		0	0.0	
Sum of 7 LPAH, (Long et al., 1995)	8	<0.1	86, 87, 88, 89, 90, 82, 93, 94	n/a	n/a		n/a	n/a	
HPAH									
Benzo(a)anthracene	0	0.0		0	0.0		0	0.0	
Benzo(a)pyrene	0	0.0		0	0.0		0	0.0	
Benzo(g,h,i)perylene	n/a	n/a		0	0.0		0	0.0	
Chrysene	0	0.0		0	0.0		0	0.0	

Table 15 (cont.).

Compound	≥ ERM [a]			≥ SQS [b]			≥ CSL [b]		
	No.	% of Total Area	Station No.	No.	% of Total Area	Station No.	No.	% of Total Area	Station No.
Dibenzo(a,h)anthracene	0	0.0		0	0.0		0	0.0	
Fluoranthene	1	<0.1	86	0	0.0		0	0.0	
Indeno(1,2,3-c,d)pyrene	n/a	n/a		0	0.0		0	0.0	
Pyrene	4	<0.1	86, 89, 90, 92	0	0.0		0	0.0	
Total benzofluoranthenes	n/a	n/a		0	0.0		0	0.0	
Total for any individual HPAH	4	<0.1		0	0.0		0	0.0	
Sum of HPAH									
Sum of 9 HPAH, (Ch 173-204 WSDOE Sediment Management Standards)	n/a	n/a		0	0.0		0	0.0	
Sum of 6 HPAH, (Long et al., 1995)	1	<0.1	86	n/a	n/a		n/a	n/a	
Total for any individual PAH	6	<0.1	86, 89, 90, 92, 93, 94	0	0.0		0	0.0	
Total PAH (Sum of 13 PAH)	0	0.0		n/a	n/a		n/a	n/a	
Phenols [e]									
4-Methylphenol	n/a	n/a		46	34.9		46	34.9	
*Phenol	n/a	n/a		51	51.2		22	24.9	
>QL only				45	44.6				
***Total for any individual phenols**	n/a	n/a		79	68.7		64	56.5	
>QL only				77	64.8				
Phthalate Esters [e]									
*Bis (2-Ethylhexyl) Phthalate	n/a	n/a		10	11.3	36, 37, 41, 57, 71, 77, 95, 96, 99, 100	5	5.4	71, 77, 95, 96, 100
>QL only				5	7.5	37, 71, 77, 95, 96	4	5.1	71, 77, 95, 96
Di-N-Butylphthalate	n/a	n/a		5	2.7	46, 49, 53, 56, 62	0	0.0	
***Total for any individual phthalate esters**	n/a	n/a		15	14.0	36, 37, 41, 46, 49, 53, 56, 57, 62, 71, 77, 95, 96, 99, 100	5	5.4	71, 77, 95, 96, 100

Table 15 (cont.).

Compound	≥ ERM [a]			≥ SQS [b]			≥ CSL [b]		
	No.	% of Total Area	Station No.	No.	% of Total Area	Station No.	No.	% of Total Area	Station No.
>QL only				10	10.2	37, 46, 49, 53, 56, 62, 71, 77, 95, 96	4	5.1	71, 77, 95, 96
Chlorinated Pesticide and PCBs									
*p,p'-DDE	0	0.0		n/a	n/a		n/a	n/a	
*Total DDT	0	0.0		n/a	n/a		n/a	n/a	
*Total PCB:									
*Total Aroclors (Ch 173-204 WSDOE Sediment Management Standards)	n/a	n/a		5	4.4	57, 86, 96, 99, 100	0	0.0	
>QL only				1	<0.1	86			
*Total congeners, (Long et al., 1995)	1	<0.1	86	n/a	n/a		n/a	n/a	
Miscellaneous Compounds [e]									
*Benzoic Acid	n/a	n/a		56	38.4		56	38.4	
>QL only				18	9.4		18	9.4	
Dibenzofuran	n/a	n/a		0	0.0		0	0.0	
***Total for all individual compounds (excluding nickel)** [e]	9	1.2	9, 86, 87, 88, 89, 90, 92, 93, 94	90	79.6		82	73.4	
>QL only				80	68.5		66	60.0	

[a] ERM = effects range median (Long et al., 1995)

[b] SQS = sediment quality standard, CSL = cleanup screening levels (Washington State Sediment Management Standards – Ch. 173-204 WAC)

[c] Trace metal data derived with strong acid digestion were used for comparison to ERM values while those derived with hydrofluoric acid digestion were used for comparison to SQS and CSL values

[d] The LPAH criterion represents the sum of the Naphthalene, Acenaphthylene, Acenaphthene, Fluorene, Phenanthrene, and Anthracene

[e] Numerous compounds have been omitted from this table because all sample values exceeding guideline/standards were qualified as undetected (i.e., measured at or below quantitation limits)

n/a = no guideline or standard available

* = calculation includes all values which exceed SQS and CSLs, **including** those that were at or below the quantitation limits reported by Manchester Environmental Lab

>QL only = calculation includes all values which exceed SQS and CSLs, **excluding** those that were at or below the quantitation limits reported by Manchester Environmental Lab

There were two samples in which one or more numerical guidelines were exceeded for any trace metal (excluding nickel). One or more of the ERMs or CSLs for metals were exceeded in the samples from stations 9 (Boundary Bay) and 94 (Everett Harbor), representing about 1.2% of the area. Five stations (number 9 in Boundary Bay); 27, 28, and 60 in Bellingham Bay; and 94 in Everett Harbor had at least one metal concentration that exceeded the SQS values, representing 1.7% of the study area (Table 15, Figures 26 and 27).

Comparisons of the organic compound data with their respective guidelines also are included in Table 15. The number of samples in which ERM values (expressed on a dry weight basis) for individual low molecular weight polynuclear aromatic hydrocarbons (LPAHs) were exceeded ranged from none to 5, representing <0.1% of the study area. The total number of samples with any individual LPAH exceeding an ERM value was 5 (Everett Harbor stations 86, 89, 92, 93, and 94), representing <0.1% of the study area (Figure 30). The sum total of seven LPAHs exceeded the ERM value for that class of compounds in 8 stations (86-90, 92-94, all in Everett Harbor), representing <0.1% of the study area. None of the concentrations of LPAHs (expressed in organic carbon normalized units) exceeded the respective Washington SQS or CSL values.

The number of samples in which concentrations of individual high molecular weight polynuclear aromatic hydrocarbons (HPAHs) exceeded numerical guidelines and the areas they represented were much lower than for the LPAHs (Table 15). The numbers of samples in which ERM values for HPAHs were exceeded ranged from none to 4, representing <0.1% of the study area. The total number of samples with any individual HPAH exceeding an ERM value was 4 (Everett Harbor stations 86, 89, 90, 92), representing <0.1% of the study area (Figure 34). The sum total of six HPAHs exceeded the ERM value for that class of compounds in only one sample (station 86, Everett Harbor), representing <0.1% of the total study area. None of the concentrations of HPAHs (expressed in organic carbon normalized units) exceeded the respective Washington SQS or CSL values.

There were six samples in which one or more of 13 individual PAHs exceeded an ERM value. These six samples were collected in the Everett Harbor area (stations 86,89,90,92,93, and 94) and represented <0.1% of the total study area. No samples had total PAH concentrations (sum of 13 compounds) that exceeded the ERM value for that class of compounds.

Concentrations of many organic compounds, especially the phenols, phthalate esters, chlorinated pesticides, PCBs, and other miscellaneous substances were reported either at or below the laboratory quantitation limit (QL). Data for these substances, therefore, were qualified as "undetected". However, in many samples the QL exceeded the state SQS and/or CSL concentrations, making comparisons with the state standards meaningless. Compounds in which this situation occurred are shown in Table 15 with asterisks to highlight the qualified nature of the data. To account for this situation, the numbers of samples exceeding the standards and the spatial extent estimates were calculated twice and both sets of results entered into Table 15. The first set of results for these substances consider all samples exceeding the standards regardless of the numbers of qualified results, while the second set (shown as ">QL only") were calculated only with detected and quantified concentrations that exceeded the state standards. For example, there were 51 samples in which the concentrations of phenol exceeded the SQS value, 45 of which were detected, quantifiable concentrations. The stations in which these concentrations

exceeded the SQS value represented approximately 51 and 45% of the total study area, respectively. Compounds in which all values exceeding state standards were qualified as "undetected" were eliminated from Table 15.

There are no ERM values for phenols or phthalate esters (Table 15). There were 46 samples in which the SQS and CSL values were exceeded for 4-methylphenol. These samples represented approximately 35% of the study area. Similarly, the SQS and CSL values for phenol were exceeded in 51 and 22 samples (51 and 25% of the study area), respectively. However, six of the samples exceeding the SQS value had concentrations reported as below the limits of quantitation, leaving a balance of 45 samples (45% of the study area) in which the SQS was exceeded. Results for the total concentrations of any individual phenols indicated 77 samples (>QL only) exceeding SQS values and 64 exceeding CSL values (representing 65 and 56% of the study area, respectively) (Figures 39-45). Guidelines were exceeded considerably less frequently for the phthalate esters (Table 15, Figure 46).

None of the DDE or total DDT concentrations exceeded the ERM value. Only one sample (station 86, inner Everett Harbor) had a total PCB concentration that exceeded the ERM for the sum of congeners or the SQS for the sum of Aroclors, representing, in both cases, <0.1% of the total study area.

The concentrations of benzoic acid exceeded the SQS and CSL values in 56 samples, including 18 (approximately 9% of the study area) in which the results were above the limits of quantitation. These 18 stations were located in Boundary Bay, Oak Harbor, Penn Cove, Saratoga Passage, and Everett Harbor (Table 15, Figures 37 and 38). The guidelines for dibenzofuran were not exceeded in any samples.

Finally, Table 15 includes the number of samples in which one or more chemicals exceeded any of the respective ERM (excluding nickel), SQS, or CSL values. Based upon quantifiable results, eight samples (station 9, Boundary Bay), and stations 86-90 and 92-94 (Everett Harbor), representing approximately 1.2% of the total study area had one or more chemical concentrations above the ERM values. Because of the influence of the phenols, phthalate esters, and benzoic acid data, much higher numbers of samples exceeded the SQS and CSL values, with 80 and 66 samples (>QL only) representing approximately 68 and 60% of the study area, respectively.

Summary

With a few exceptions, most chemical concentrations in the northern Puget Sound samples were below concentrations that might cause toxicity. Relative to the ERM, SQS, and/or CSL guidelines, chemical concentrations were elevated in two to five samples for trace metals and six samples for PAHs. For those semi-volatile organic compounds with the quantitation limit problems described above, concentrations were elevated above the SQS and CSL values in at least 77 and 64 samples for total phenols, ten and four samples for phthalate esters, 18 samples for benzoic acid, one sample for total PCB Aroclors, one sample for total PCB congeners, and none for DDE and total DDT. Some of these chemicals (e.g., phenols) may be of significant toxicological concern throughout much of the area.

Relationships between Measures of Toxicity and Chemical Concentrations

The associations between the results of the toxicity tests and the concentrations of potentially toxic substances in the samples were determined in several steps, beginning with simple, non-parametric Spearman-rank correlation analyses. This step provided a quantitative method to identify which chemicals or chemical groups, if any, showed the strongest statistical relationships with the different measures of toxicity.

Toxicity vs. Classes of Compounds

First, to determine if there were relationships between the four measures of toxicity and the concentrations of classes of toxicants, correlation analyses were conducted with four groups of chemicals normalized to (i.e., divided by) their respective ERM and Washington State SQS and CSL values (Table 16). All ERM, SQS, and CSL values, with the exception of the SQS and CSL organics, were reported on a dry weight basis. The SQS and CSL organics values were reported on an organic carbon normalized basis, as required by the Washington State Sediment Management Standards – Ch. 173-204 WAC. Mean ERM quotients were derived for the compounds listed in Table 15, including nine trace metals (using the total digestion metals data), three chlorinated hydrocarbon values/or sums (p,p'-DDE, total DDT, and total PCB), 13 polynuclear aromatic hydrocarbons (PAH), and all 25 compounds. Similar methods were used to conduct correlation analysis between toxicity results and mean SQS and CSL quotients. These mean quotients were derived for the chemical concentrations of eight trace metals, excluding nickel (using the partial digestion metals data), six LPAHs (excluding 2-methylnaphthalene), nine HPAHs, and all 15 PAHs normalized to the SQS and CLS values.

Results of the amphipod survival tests were not significantly correlated with any of the four classes of substances (Table 16). Due to the very small range in response in the amphipod tests among the samples, highly significant correlations with chemical concentrations were not expected. Significant correlations were apparent in the other three tests, however. Sea urchin fertilization success diminished with increasing concentrations of trace metals, chlorinated organics, and all 25 substances for which ERM values were reported. Urchin fertilization was also correlated with the sum of 8 metals normalized to their SQS and CSL values, but not with the PAHs.

Microbial bioluminescence (Microtox™) results showed a strong negative correlation with ERM-normalized concentrations of all classes of substances except the trace metals (Table 16). Correlations between microbial bioluminescence and the SQS and CSL quotients were, with the exception of the LPAH concentration, significant, but weaker than with the ERM quotients.

In the Cytochrome P450 RGS assays, enzyme induction increased with increasing concentrations of all classes of organic substances, especially the PAHs (Table 16). These statistical correlations ($p<0.0001$) were very similar (rho = 0.509 to 0.564), whether the concentrations were normalized to ERMs reported on a dry weight basis or SQS and CSL values reported on an organic carbon basis. Because the P450 RGS assay is intended to be responsive to the presence of PAHs and certain chlorinated organics in the samples, it is not surprising to see these strong correlations. Cytochrome P450 RGS assays are not expected to respond to trace metals and, accordingly, the correlation with these substances were either not significant or very weak.

Table 16. Spearman-rank correlation coefficients (rho, corrected for ties) and significant levels (p) for results of four toxicity tests and concentrations of trace metals, chlorinated organic hydrocarbons, and total PAHs normalized to their respective ERM, SQS, CSL values for all sites (n=100).

Chemical	Amphipod survival (p)	Urchin fertilization (p)	Microbial bioluminescence (p)	Cytochrome P-450 (p)
ERM values				
mean ERM quotients for 9 trace metals	0.043 ns	-0.197 *	-0.056 ns	0.025 ns
mean ERM quotients for 3 chlorinated organic hydrocarbons	-0.186 ns	-0.307 **	-0.412 ****	0.245 *
mean ERM quotients for 13 polynuclear aromatic hydrocarbons	-0.079 ns	-0.019 ns	-0.359 ***	0.554 ****
mean ERM quotients for 25 substances	-0.067 ns	-0.294 **	-0.251 *	0.23 *
SQS values				
mean SQS quotients for 8 trace metals	-0.06 ns	-0.244 *	-0.241 *	0.2 *
mean SQS quotients for 6 low molecular weight polynuclear aromatic hydrocarbons	-0.112 ns	0.115 ns	-0.174 ns	0.554 ****
mean SQS quotients for 9 high molecular weight polynuclear aromatic hydrocarbons	-0.089 ns	0.044 ns	-0.213 *	0.522 ****
mean SQS quotients for 15 polynuclear aromatic hydrocarbons	-0.11 ns	0.087 ns	-0.213 *	0.558 ****
CSL values				
mean CSL quotients for 8 trace metals	-0.057 ns	-0.244 *	-0.232 *	0.188 ns
mean CSL quotients for 6 low molecular weight polynuclear aromatic hydrocarbons	-0.106 ns	0.101 ns	-0.158 ns	0.564 ****
mean CSL quotients for 9 high molecular weight polynuclear aromatic hydrocarbons	-0.082 ns	0.045 ns	-0.204 *	0.509 ****
mean CSL quotients for 15 polynuclear aromatic hydrocarbons	-0.116 ns	0.085 ns	-0.213 *	0.562 ****

ns=p>0.05
* p<0.05
** p<0.01
*** p<0.001
**** p<0.0001

To further identify chemistry/toxicity relationships, correlation coefficients were calculated for the 15 samples collected in strata 28-32 (stations 86-100) in the vicinity of Everett Harbor, the region in which toxicity was most pronounced (Table 17). In this limited data set, the number of significant correlations increased, and the correlation coefficients increased remarkably relative to those calculated for the entire data set.

Correlations between the mean ERM quotients for the 13 PAHs and all 25 substances, and the urchin, Microtox™, and Cytochrome P450 tests, were highly significant (i.e., rho=0.7 or greater, $p<0.01$) in the Everett Harbor area. Microbial bioluminescence and the mean ERM quotients for the 25 substances showed the single highest correlation coefficient (rho = -0.854). Amphipod survival also showed a weak, but significant, association with the mean ERM quotient for the 13 PAHs in Everett Harbor. All correlation coefficients between the mean SQS and CSL quotients for LPAH, HPAH, and total PAH values and tests of toxicity increased and became significant in the Everett Harbor samples relative to those from the entire study area.

These results suggest that the tests of pore waters and solvent extracts were highly associated with concentrations of numerous substances in complex mixtures, but were influenced, in large part, by the presence of PAHs in the sediments from Everett Harbor.

Toxicity vs. Individual Compounds

In the second set of analyses, correlations were determined between concentrations of individual substances and measures of toxicity. In the tables and discussion that follow, some apparently significant correlations could have occurred by chance alone, given the large number of chemical variables (>170). If the number of independent variables (chemicals) were taken into account (e.g., in a Bonferroni-type of adjustment), correlations would remain statistically significant only with p values of 0.0001 (i.e., those listed with four asterisks). Thus, correlation coefficients with significance (p) values of 0.0001 are regarded as "highly significant" in the text.

The correlation coefficients (rho) and significance levels (p) for individual trace metals and each toxicity test are listed in Table 18 (trace metals concentrations determined with total digestions) and Table 19 (concentrations determined with partial digestions). As expected, based upon the results of the correlations performed with the classes of chemicals, amphipod survival was not highly correlated (i.e., $p<0.0001$) with any of the metals concentrations determined with partial digestions. Amphipod survival also was not correlated with ammonia concentrations. Cadmium, selenium and titanium concentrations indicated concordance with amphipod survival; however, none of these correlations were highly significant ($p<0.001$). The weak correspondence between metals concentrations and amphipod survival probably was a result of the narrow range in response in the toxicity tests.

Table 17. Spearman-rank correlation coefficients (rho, corrected for ties) and significance levels (p) for results of four toxicity tests and concentrations of trace metals, chlorinated organic hydrocarbons, and total PAHs normalized to their respective ERM, SQS, CSL values for Everett Harbor sites (n=15).

Chemical	Amphipod survival (p)	Urchin fertilization (p)	Microbial bioluminescence (p)	Cytochrome P-450 (p)
ERM values				
mean ERM quotients for 9 trace metals	-0.056 ns	-0.12 ns	-0.382 ns	0.257 ns
mean ERM quotients for 3 chlorinated organic hydrocarbons	-0.375 ns	-0.462 ns	-0.546 *	0.661 *
mean ERM quotients for 13 polynuclear aromatic hydrocarbons	-0.57 *	-0.791 **	-0.839 **	0.739 **
mean ERM quotients for 25 substances	-0.285 ns	-0.688 **	-0.875 **	0.7 **
SQS values				
mean SQS quotients for 8 trace metals	-0.391 ns	-0.557 *	-0.668 **	0.693 **
mean SQS quotients for 6 low molecular weight polynuclear aromatic hydrocarbons	-0.475 ns	-0.825 ***	-0.846 ****	0.707 **
mean SQS quotients for 9 high molecular weight polynuclear aromatic hydrocarbons	-0.429 ns	-0.553 *	-0.757 **	0.589 *
mean SQS quotients for 15 polynuclear aromatic hydrocarbons	-0.468 ns	-0.788 ***	-0.821 ***	0.761 ***
CSL values				
mean CSL quotients for 8 trace metals	-0.391 ns	-0.557 *	-0.668 **	0.693 **
mean CSL quotients for 6 low molecular weight polynuclear aromatic hydrocarbons	-0.463 ns	-0.845 ****	-0.832 ***	0.725 **
mean CSL quotients for 9 high molecular weight polynuclear aromatic hydrocarbons	-0.396 ns	-0.517 *	-0.718 **	0.604 *
mean CSL quotients for 15 polynuclear aromatic hydrocarbons	-0.486 ns	-0.784 ***	-0.825 ***	0.757 **

ns=p>0.05
* p<0.05
** p<0.01
*** p<0.001
**** p<0.0001

Table 18. Spearman-rank correlations (rho, corrected for ties) and significance levels (p) for results of four toxicity tests and concentrations of total digestion trace metals and metalloids in sediments.

Chemical	Amphipod (p) survival	Urchin (p) fertilization	Microbial (p) bioluminescence	Cytochrome (p) P450
Aluminum	-0.006 ns	-0.054 ns	0.151 ns	-0.107 ns
Antimony	0.071 ns	-0.353 ***	-0.08 ns	0.229 *
Arsenic	-0.042 ns	-0.189 ns	-0.053 ns	0.152 ns
Barium	0.148 ns	0.107 ns	0.138 ns	-0.265 **
Beryllium	-0.093 ns	0.019 ns	0.398 ****	-0.181 ns
Cadmium	-0.327 ***	-0.373 ***	-0.364 ***	0.334 ***
Calcium	-0.094 ns	0.038 ns	-0.031 ns	0.02 ns
Chromium	0.068 ns	-0.148 ns	0.022 ns	-0.068 ns
Cobalt	0.113 ns	-0.157 ns	0.185 ns	-0.023 ns
Copper	-0.1 ns	-0.338 ***	-0.25 *	0.254 *
Iron	0.113 ns	-0.068 ns	0.11 ns	-0.061 ns
Lead	-0.127 ns	-0.231 *	-0.231 *	0.373 ***
Magnesium	0.035 ns	-0.141 ns	0.052 ns	-0.1 ns
Manganese	0.103 ns	-0.125 ns	0.301 **	0.051 ns
Mercury	-0.036 ns	-0.158 ns	-0.176 ns	0.219 *
Nickel	0.099 ns	-0.15 ns	0.087 ns	-0.105 ns
Potassium	0.1 ns	0.116 ns	0.17 ns	-0.252 *
Selenium	-0.215 *	-0.225 *	-0.215 *	0.399 ****
Silver	0.008 ns	-0.012 ns	-0.062 ns	0.053 ns
Sodium	-0.137 ns	-0.208 *	-0.234 *	0.157 ns
Thallium	-0.026 ns	-0.254 *	-0.237 *	0.157 ns
Tin	-0.049 ns	-0.297 **	-0.333 **	0.633 ***
Titanium	0.257 **	0.223 *	0.211 *	-0.213 *
Vanadium	0.115 ns	-0.046 ns	0.146 ns	-0.107 ns
Zinc	-0.08 ns	-0.277 **	-0.231 *	0.279 **

ns= $p>0.05$
* $p<0.05$
** $p<0.01$
*** $p<0.001$
**** $p<0.0001$

Table 19. Spearman-rank correlations (rho, corrected for ties) and significance levels (p) for results of four toxicity tests and concentrations of partial digestion trace metals, ammonia, and metalloids in sediments.

Chemical	Amphipod survival (p)	Urchin fertilization (p)	Microbial bioluminescence (p)	Cytochrome P450 (p)
Un-ionized ammonia	-0.031 ns	-0.185 ns		
Aluminum	0.048 ns	-0.146 ns	-0.013 ns	-0.04 ns
Antimony	-0.048 ns	-0.259 **	-0.284 **	0.271 **
Arsenic	-0.094 ns	-0.299 **	-0.118 ns	0.102 ns
Barium	0.051 ns	-0.174 ns	-0.146 ns	0.071 ns
Beryllium	0.078 ns	0.036 ns	0.038 ns	-0.06 ns
Cadmium	-0.214 *	-0.438 ****	-0.563 ****	0.36 ***
Calcium	-0.127 ns	0.052 ns	-0.128 ns	0.129 ns
Chromium	0.02 ns	-0.226 *	-0.003 ns	-0.055 ns
Cobalt	0.131 ns	-0.169 ns	0.12 ns	-0.053 ns
Copper	-0.103 ns	-0.366 ***	-0.259 **	0.232 *
Iron	0.092 ns	-0.145 ns	0.039 ns	-0.069 ns
Lead	-0.152 ns	-0.198 *	-0.252 *	0.399 ****
Magnesium	0.08 ns	-0.158 ns	0.034 ns	0.083 ns
Manganese	0.116 ns	-0.118 ns	0.232 ns	-0.083 ns
Mercury	-0.036 ns	-0.158 ns	-0.176 ns	0.219 *
Nickel	0.106 ns	-0.157 ns	0.078 ns	-0.118 ns
Potassium	-0.025 ns	-0.153 ns	-0.141 ns	0.036 ns
Selenium	-0.104 ns	-0.202 *	-0.365 ***	0.324 **
Silver	0.12 ns	0.253 ns	-0.168 ns	0.031 ns
Sodium	-0.132 ns	-0.266 **	-0.276 **	0.178 ns
Thallium	bql	bql	bql	bql
Tin	-0.181 ns	-0.52 ****	-0.438 ****	0.507 ****
Titanium	0.157 ns	-0.018 ns	0.033 ns	-0.117 ns
Vanadium	0.035 ns	-0.219 *	-0.002 ns	-0.039 ns
Zinc	-0.077 ns	-0.347 ***	-0.265 **	0.245 *

ns = p>0.05
bql = concentrations below quantitation limits in all samples
* p<0.05
** p<0.01
*** p<0.001
**** p<0.0001

In contrast, a larger number of the correlations with trace metal concentrations were either significant or highly significant in the three other toxicity tests. In the urchin fertilization tests, the correlations were significant at $p<0.05$ for the concentrations of 11 metals determined with partial digestions (Table 19) and 10 metals determined with total digestions (Table 18). However, only the correlations with cadmium and tin determined with partial digestions were significant at $p<0.0001$.

The tests of microbial bioluminescence and Cytochrome P450 RGS induction are not known to be sensitive to trace metals, and because the tests are performed with exposures to organic solvent extracts, trace metals were not expected in the extracts. In the previous section, correlations between trace metals normalized to sediment guideline standards vs. measures of toxicity in Microtox™ and Cytochrome P450 RGS tests either were weak or not significant. Nevertheless, significant correlations were apparent, although probably spurious, for the concentrations of many individual metals determined in both the partial and total digestions. These data suggest that trace metal concentrations co-varied with the concentrations of organic compounds, the substances to which these two bioassays are known to respond.

The correlations and significance levels differed between the results of the two digestions. Some correlations improved with the results from the total digestions relative to those determined with partial digestions, and others showed an opposite trend. The differences may have been attributable to the higher recovery levels that would be expected in the total digestions or different quantification levels attained by the laboratory. Either or both of these factors could have changed the slopes of the chemical concentration-to-toxicity regressions and the variances around the slopes.

Results of correlation analyses for toxicity tests and concentrations of low molecular weight PAHs are shown in Table 20. None of the individual compounds or summed concentrations were significantly correlated with either amphipod survival or urchin fertilization. However, results of both the Microtox™ tests and Cytochrome P450 assays showed strong correlations with all but two compounds (biphenyl and retene).

Correlation coefficients for high molecular weight PAHs were very similar to those for low molecular weight compounds (Table 21). That is, the associations were not significant for most substances in the amphipod and urchin tests, whereas they were significant at $p<0.001$ or $p<0.0001$ for nearly all compounds in the two tests performed with organic solvent extracts. The correlations between the concentrations of HPAH and Cytochrome P450 RGS assay results were predictable, because this test is known to be highly responsive to the presence of these compounds. In addition, Cytochrome P-450 RGS induction was very strongly correlated with the summed concentrations of low-, high-, and total PAHs. These associations were less significant with the Microtox™ test.

Correlations determined for the PCBs and DDTs (Table 22) were not significant for most substances in the amphipod tests, significant for all substances in the urchin fertilization tests, highly significant for most substances in the Microtox™ tests, and either not significant or weak in the Cytochrome P450 tests. It is noteworthy that the correlation coefficients indicated a strong association between decreased microbial bioluminescence and the summed concentrations

Table 20. Spearman-rank correlations (rho, corrected for ties) and significant levels (p) for results of four toxicity tests and concentrations of Low Molecular Weight PAHs (LPAH) in sediments.

Chemical	Amphipod survival (p)	Urchin fertilization (p)	Microbial bioluminescence (p)	Cytochrome P-450 (p)
Acenaphthene	-0.083 ns	0.012 ns	-0.348 ***	0.588 ****
Acenaphthylene	-0.114 ns	-0.001 ns	-0.271 ***	0.582 ****
Anthracene	-0.098 ns	-0.014 ns	-0.354 ***	0.576 ****
Biphenyl	-0.001 ns	0.164 ns	-0.02 ns	0.16 ns
Flourene	-0.078 ns	0.012 ns	-0.315 **	0.559 ****
2,6 Dimethylnaphthalene	-0.142 ns	-0.186 ns	-0.315 ****	0.263 **
1-Methylnaphthalene	-0.058 ns	0.015 ns	-0.683 ***	0.395 ****
2-Methylnaphthalene	-0.068 ns	-0.001 ns	-0.308 **	0.409 ****
Naphthalene	-0.087 ns	-0.37 ns	-0.278 **	0.5 ****
1-Methylphenanthrene	-0.058 ns	-0.012 ns	-0.316 **	0.477 ****
Phenanthrene	-0.068 ns	0.001 ns	-0.316 **	0.54 ****
1,6,7 Trimethylnaphthalene	-0.045 ns	0.008 ns	-0.233 *	0.452 ****
2-Methylphenanthrene	-0.057 ns	-0.015 ns	-0.32 **	0.422 ****
Dibenzothiophene	-0.065 ns	-0.019 ns	-0.384 ****	0.502 ****
Retene	-0.085 ns	-0.093 ns	-0.182 ns	0.359 ***
Sum 7 LPAH^	-0.059 ns	0.001 ns	-0.299 **	0.546 ****
Sum 6 LPAH^^	-0.084 ns	0.108 ns	-0.178 ns	0.549 ****
Total LPAH	-0.112 ns	0.017 ns	-0.299 **	0.456 ****

^7LPAH = Naphthalene, 2-Methylnaphthalene, Acenaphthene, Acenaphthylene, Fluorene, Phenanthrene, Anthracene
^^6LPAH = Naphthalene, Acenaphthene, Acenaphthylene, Fluorene, Phenanthrene, Anthracene
ns=$p>0.05$
* $p<0.05$
** $p<0.01$
*** $p<0.001$
**** $p<0.0001$

Table 21. Spearman-rank correlations (rho, corrected for ties) and significance levels (p) for results of four toxicity tests and concentrations of High Molecular Weight PAHs (HPAH) in sediments.

Chemical	Amphipod survival (p)	Urchin fertilization (p)	Microbial bioluminescence (p)	Cytochrome P-450 (p)
Benzo(a)anthracene	-0.083 ns	-0.03 ns	-0.344 ***	0.559 ****
Benzo(a)pyrene	-0.061 ns	-0.034 ns	-0.339 ***	0.542 ****
Benzo(e)pyrene	-0.084 ns	-0.109 ns	-0.384 ****	0.521 ****
Chrysene	-0.089 ns	-0.056 ns	-0.354 ***	0.555 ****
Dibenzo(a,h)anthracene	-0.098 ns	-0.041 ns	-0.383 ****	0.53 ****
Fluoranthene	-0.098 ns	-0.047 ns	-0.381 ***	0.556 ****
Perylene	-0.101 ns	-0.251 *	-0.23 *	0.41 ****
Pyrene	-0.11 ns	-0.07 ns	-0.376 ***	0.563 ****
Benzo(b)fluoranthene	-0.08 ns	-0.107 ns	-0.391 ****	0.534 ****
Benzo(k)fluoranthene	-0.071 ns	-0.101 ns	-0.385 ****	0.546 ****
Benzo(ghi)perylene	-0.072 ns	-0.122 ns	-0.388 ****	0.447 ****
Indeno(1,2,3)pyrene	-0.05 ns	-0.086 ns	-0.376 ***	0.502 ****
Sum of 6 HPAH^	-0.1 ns	-0.052 ns	-0.385 ****	0.546 ****
Sum of 9 HPAH^^	-0.081 ns	0.037 ns	-0.256 *	0.565 ****
Total HPAH	-0.104 ns	-0.09 ns	-0.385 ****	0.543 ****
Sum 13 PAH^^^	-0.091 ns	-0.029 ns	-0.364 ***	0.556 ****
Sum 15 PAH^^^^	-0.079 ns	0.064 ns	-0.243 *	0.575 ****
Total all PAH	-0.101 ns	-0.049 ns	-0.396 ***	0.529 ****

^6HPAH = Fluoranthene, Pyrene, Benzo(a)anthracene, Chrysene, Benzo(a)pyrene, and Dibenzo(a,h)anthracene
^^9HPAH = Fluoranthene, Pyrene, Benzo(a)anthracene, Chrysene, Total Benzofluoranthenes, Benzo(a)pyrene, Indeno(1,2,3,-c,d)pyrene, Dibenzo(a,h)anthracene and Benzo(g,h,i)perylene
^^^13PAH = 7LPAH and 6HPAH
^^^^15PAH = 6LPAH and 9HPAH
ns=p>0.05
* p<0.05
** p<0.01
*** p<0.001
**** p<0.0001

Table 22. Spearman-rank correlations (rho, corrected for ties) for results of four toxicity tests and concentrations of PCBs and DDTs in sediments.

Chemical	Amphipod (p) survival	Urchin (p) fertilization	Microbial (p) bioluminescence	Cytochrome (p) P-450
Aroclor 1254	-0.149 ns	-0.355 ***	-0.518 ****	0.216 *
no bqls	-0.562 *	-0.826 ****	-0.67 **	0.815 ****
Everett Harbor	-0.673 *	-0.755 **	-0.643 *	0.846 ***
Aroclor 1260	-0.095 ns	0.253 *	-0.367 ***	0.231 ns
no bqls	-0.288 ns	0 ns	0.357 ns	0.464 ns
Everett Harbor	-0.288 ns	0 ns	0.357 ns	0.464 ns
Total Aroclors	-0.128 ns	-0.311 **	-0.409 ****	0.248 *
Everett Harbor	-0.368 ns	-0.483 ns	-0.565 *	0.672 **
4,4'-DDE	-0.177 ns	-0.276 **	-0.33 **	0.194 ns
no bqls	-0.633 *	0.162 ns	-0.092 ns	0.448 ns
Everett Harbor	-0.949 ns	0.8 ns	0.8 ns	0.6 ns
Total DDTs	-0.159 ns	-0.265 **	-0.353 ***	0.249 *
Everett Harbor	-0.18 ns	-0.464 ns	-0.52 *	0.584 *
PCB Congeners 28	-0.153 ns	-0.279 **	-0.367 ***	0.164 ns
no bqls	-0.523 ns	-0.256 ns	-0.301 ns	0.683 *
Everett Harbor	-0.466 ns	-0.076 ns	-0.017 ns	0.753 *
PCB Congener 44	-0.174 ns	-0.279 **	-0.339 ****	0.199 *
no bqls	0.882 *	0.319 ns	0.029 ns	0.638 ns
Everett Harbor	0.882 *	0.319 ns	0.029 ns	0.638 ns
PCB Congener 52	-0.192 ns	-0.351 ***	-0.406 ****	0.261 **
no bqls	-0.481 ns	-0.197 ns	-0.092 ns	0.718 *
Everett Harbor	-0.481 ns	-0.197 ns	-0.092 ns	0.718 *
PCB Congener 66	-0.197 *	-0.377 ***	-0.459 ****	0.123 ns
no bqls	-0.365 ns	-0.636 **	-0.713 **	0.748 ***
Everett Harbor	-0.36 ns	-0.504 ns	-0.613 *	0.746 **
PCB Congener 77	-0.149 ns	-0.3 **	-0.428 ****	0.086 ns
no bqls	0.08 ns	-0.263 ns	-0.103 ns	0.6 ns
Everett Harbor	0.018 ns	-0.673 ns	-0.571 ns	0.714 ns
PCB Congener 101	-0.184 ns	-0.406 ****	-0.519 ****	0.18 ns
no bqls	-0.523 *	-0.79 ****	-0.749 ***	0.878 ****
Everett Harbor	-0.626 *	-0.729 **	-0.745 **	0.853 ****
PCB Congener 105	-0.184 ns	-0.296 **	-0.373 ***	0.203 *
no bqls	-0.493 ns	-0.086 ns	-0.314 ns	0.486 ns
Everett Harbor	-0.493 ns	-0.086 ns	-0.314 ns	0.486 ns

Table 22 (cont.). Spearman-rank correlations (rho, corrected for ties) for results of four toxicity tests and concentrations of PCBs and DDTs in sediments.

Chemical	Amphipod (p) survival	Urchin (p) fertilization	Microbial (p) bioluminescence	Cytochrome (p) P-450
PCB Congener 118	-0.201 *	-0.396 ****	-0.455 ****	0.227 *
no bqls	-0.718 **	-0.579 *	-0.596 *	0.755 **
Everett Harbor	0.712 **	-0.464 ns	-0.516 ns	0.73 **
PCB Congener 128	-0.17 ns	-0.274 **	-0.35 ***	0.174 ns
no bqls	-0.206 ns	-0.143 ns	-0.257 ns	0.714 ns
Everett Harbor	-0.206 ns	-0.143 ns	-0.257 ns	0.174 ns
PCB Congener 138	-0.19 ns	-0.388 ****	-0.494 ****	0.211 *
no bqls	-0.555 *	-0.759 ***	-0.694 **	0.815 ****
Everett Harbor	-0.698 **	-0.661 *	-0.649 *	0.816 ***
PCB Congener 153	-0.182 ns	-0.4 ****	-0.523 ****	0.18 ns
no bqls	-0.489 *	-0.759 ***	-0.694 **	0.845 ****
Everett Harbor	-0.591 *	-0.688 **	-0.692 **	0.886 ****
PCB Congener 170	-0.154 ns	-0.248 *	-0.329 ***	0.148 ns
no bqls	-0.36 ns	-0.214 ns	-0.179 ns	0.571 ns
Everett Harbor	-0.36 ns	-0.214 ns	-0.179 ns	0.571 ns
PCB Congener 180	-0.176 ns	-0.336 ***	-0.41 ****	0.249 *
no bqls	-0.538 ns	-0.127 ns	-0.025 ns	0.679 *
Everett Harbor	-0.538 ns	-0.127 ns	-0.025 ns	0.679 *
PCB Congener 187	-0.123 ns	-0.217 *	-0.304 **	0.117 ns
no bqls	-0.277 ns	0.024 ns	-0.333 ns	0.619 ns
Everett Harbor	-0.277 ns	0.024 ns	-0.333 ns	0.619 ns
Total 19 PCB congeners	-0.181 ns	-0.371 ***	-0.448 ****	0.226 *
Everett Harbor	-0.38 ns	-0.469 ns	-0.557 *	0.664 **
Total chlordanes	-0.174 ns	-0.24 *	-0.334 ***	0.186 ns
Everett Harbor	-0.238 ns	-0.208 ns	-0.291 ns	0.422 ns
Total HCHs	-0.253 ns	-0.085 ns	-0.199 *	0.227 *
Everett Harbor	-0.016 ns	0.374 ns	0.373 ns	-0.072 ns

ns=P> 0.05
* p<0.05
** p<0.01
*** p<0.001
**** p<0.0001
no bqls = values below the quantitation limit were eliminated from the analysis
Everett Harbor, n = 15, values below the quantitation limit were eliminated from the analysis

of all Aroclor mixtures and all 19 PCB congeners, indicating the presence of mixtures of these compounds. The effects of removing the qualified (i.e., at or below quantitation limit) data and calculating correlations only for Everett Harbor samples were highly variable, increasing the correlations in some cases and decreasing them in others.

Correlation analyses were also performed for butyl tins and many different semivolatile organic substances in the sediments (Table 23). Correlation coefficients are shown first for all 100 samples, using the limits of quantitation for values reported as undetected. If the majority of concentrations were qualified as either estimates or below quantitation limits, the correlations were run again after eliminating those samples. No analyses were performed for the numerous chemicals whose concentrations were below the limits of quantitation in all samples. All correlations were also run separately for the 15 samples collected from the vicinity of Everett Harbor (samples from stations 86-100).

A number of substances, including total phenols, carbazole, and benzoic acid showed weak correlations with amphipod survival (Table 23). These correlations were most significant when undetected data (qualified data measuring at or below the quantitation limit) were eliminated or when data from Everett Harbor only were used in the calculations. The significance of the correlations often improved when the samples with qualified results were eliminated. For example, the correlation between amphipod survival and carbazole improved from rho = -0.118 to rho = -0.523. The correlations with the butyl tin compounds often improved markedly with elimination of the samples for which there were qualified data (i.e., no bqls). Often, the samples that remained in the data set following removal of qualified results were the samples from Everett Harbor. Therefore, the correlations with chemical concentrations in the 15 Everett Harbor samples were similar to those in the samples with quantifiable results.

In the full data set, many substances were significantly correlated with urchin fertilization, notably carbazole, 4-methylphenol, and total phenols. In many cases (but not all) the correlations improved when qualified data were eliminated or correlations were performed with only the Everett Harbor samples. The strongest correlations were apparent in the Microtox™ tests. Some correlation coefficients exceeded 0.700 in the data from Everett Harbor. Correlations were very significant between Microtox™ and concentrations of dibenzofuran, dibenzothiophene, and retene, exceeding 0.8 in the samples from Everett Harbor.

Scatterplots

In the third step in the analyses of toxicity/chemistry relationships, scatterplots were prepared to illustrate the actual distribution of data for relationships with highly significant correlation coefficients. In these diagrams, results of toxicity tests were either (1) plotted against chemical concentrations and, where applicable, either the ERL/ERM values or SQS/CSL values were shown to add perspective; or (2) chemical data were shown as mean ERM-, SQS-, or CSL-quotients. In this step, it was anticipated that those chemicals or chemical classes that most likely contributed to toxicity were those in which (1) there was a highly significant correlation coefficient, (2) there was a reasonable and visual pattern of increasing toxicity with increasing concentrations of the substance(s), and (3) samples in which toxicity was greatest had the highest

Table 23. Spearman-rank correlations (rho, corrected for ties) for results of four toxicity tests and concentrations of unqualified butyl tins and semivolatile organics in sediments.

Chemical	Amphipod (p) survival	Urchin (p) fertilization	Microbial (p) bioluminescence	Cytochrome (p) P-450
Benzoic acid	-0.182 ns	-0.052 ns	-0.333 ***	0.259 **
no bqls	-0.513 ***	-0.424 **	-0.552 ****	0.564 ****
Everett Harbor	-0.667 **	-0.646 *	-0.552 *	0.783 ***
Bis(2-ethylhexyl)-phthalate	0.031 ns	-0.139 ns	0.018 ns	0.109 ns
no bqls	-0.118 ns	0.483 ns	0.245 ns	-0.027 ns
Everett Harbor	0.359 ns	0.6 ns	-0.6 ns	-0.7 ns
Carbazole	-0.118 ns	-0.405 ****	-0.271 **	0.12 ns
no bqls	-0.523 **	-0.665 ***	-0.786 ****	0.754 ****
Everett Harbor	0.468 ns	0.672 *	-0.393 ns	-0.192 ns
Dibenzofuran	-0.066 ns	-0.074 ns	-0.294 **	0.515 ****
no bqls	-0.086 ns	-0.056 ns	-0.275 **	0.501 ****
Everett Harbor	-0.475 ns	-0.781 ***	-0.857 ****	0.736 **
Dibenzothiophene	-0.065 ns	-0.019 ns	-0.384 ****	0.502 ****
no bqls	-0.078 ns	-0.016 ns	-0.403 ****	0.502 ***
Everett Harbor	-0.461 ns	-0.729 **	-0.875 ****	0.682 **
Retene	-0.085 ns	-0.093 ns	-0.182 ns	0.359 ***
no bqls	-0.085 ns	-0.093 ns	-0.182 ns	0.359 ***
Everett Harbor	-0.377 ns	-0.67 **	-0.839 ****	0.689 **
Organotins				
Dibutyl tin	-0.178 ns	-0.247 *	-0.392 ****	0.246 *
no bqls	-0.359 *	-0.32 *	-0.529 ***	0.493 ***
Everett Harbor	-0.367 ns	-0.207 ns	-0.345 ns	0.455 ns
Monobutyl tin	-0.001 ns	-0.254 *	-0.316 **	0.057 ns
no bqls	-0.068 ns	-0.124 ns	-0.537 *	0.398 ns
Everett Harbor	-0.5 ns	-0.5 ns	-0.5 ns	0.5 ns
Tributyl tin	-0.222 *	-0.219 *	-0.214 *	0.341 ***
no bqls	-0.326 *	-0.362 *	-0.426 **	0.599 ****
Everett Harbor	-0.5 ns	-0.547 ns	-0.382 ns	0.618 *

Table 23 (cont.). Spearman-rank correlations (rho, corrected for ties) for results of four toxicity tests and concentrations of unqualified butyl tins and semivolatile organics in sediments.

Chemical	Amphipod (p) survival	Urchin (p) fertilization	Microbial (p) bioluminescence	Cytochrome (p) P-450
Phenols				
4-Methylphenol	-0.266 **	-0.301 **	-0.392 ****	0.239 *
no bqls	-0.351 ***	-0.291 **	-0.357 ***	0.162 ns
Everett Harbor	-0.761 ***	-0.722 **	-0.614 *	0.832 ***
Phenol	0.179 ns	0.051 ns	0.147 ns	-0.072 ns
no bqls	0.241 ns	0.258 ns	-0.028 ns	-0.191 ns
Everett Harbor	0.8 ns	0.4 ns	0.2 ns	-1 ns
Total phenols	-0.271 **	-0.337 ***	-0.421 ****	0.213 *
Everett Harbor	-0.687 **	-0.763 ***	-0.632 *	0.864 ****

ns=p> 0.05
* p<0.05
** p<0.01
*** p<0.001
**** p<0.0001
no bqls = values below the quantitation limit were eliminated from the analysis
Everett Harbor, n = 15, values below the quantitation limit were eliminated from the analysis

chemical concentrations that exceeded an effects-based guideline or standard. Because none of the chemicals were highly correlated with amphipod survival, the scatter plots were restricted to the data from the urchin fertilization, Microtox™, and Cytochrome P450 RGS bioassays. To further clarify the apparent relationships between bioassay results and chemical concentrations, scatterplots also were prepared for the 15 samples collected from contiguous stations 86-100 in Everett Harbor and Port Gardner Bay. Several of these scatterplots are discussed below, and all scatterplots are displayed at the end of this section.

Percent sea urchin fertilization in tests performed with 100% pore water was highly correlated with the concentrations of PAHs in the sediments. This association was especially apparent in the samples from Everett Harbor (Figures 47, 48). In these scatterplots, PAH concentrations were expressed as mean SQS or CSL quotients for 15 parent compounds. Sea urchin fertilization was highest among 6 samples with lowest PAH concentrations, gradually decreased with increases in PAH concentrations, and was lowest among three samples with the highest concentrations of PAHs. A very similar pattern was apparent with the sums of LPAHs, whether normalized to the SQS or CSL values (Figures 49, 50).

Urchin fertilization showed strong correlations with several trace metals in the sediments, especially with cadmium, copper, tin, and zinc. The data shown in Figure 51 for cadmium concentrations based upon partial digestions indicated highest percent fertilization in a cluster of samples with lowest cadmium concentrations and lowest fertilization success among four samples from Everett Harbor with the highest cadmium concentrations (2.6 to 2.8 ppm). The correlation between percent urchin fertilization and the concentrations of cadmium in partial digestions was very significant (rho = -0.438, $p<0.0001$). The association between fertilization success and cadmium concentrations in total digestions (shown in Figure 52) was less significant (rho = -0.373, $p<0.001$), possibly as a result of higher method detection limits. Three samples collected in Everett Harbor with the highest cadmium concentrations (>2.5 ppm) were toxic in this test (Figure 52); however, the large majority of samples had unquantifiable or undetectable concentrations of cadmium.

The associations between fertilization success and the concentrations of both copper and zinc determined with either partial digestions or total digestions were somewhat weaker than with cadmium (Figures 53-56). In the majority of the samples, percent fertilization was very high (>80% relative to controls) when copper and zinc concentrations were lowest. Also, there were some samples with slightly elevated copper and zinc concentrations in which fertilization success was relatively low (<60%). All six of the samples with zinc concentrations that exceeded the ERL value were toxic and fertilization success was less than 60% (Figure 56); however, there were many samples with low zinc concentrations in which fertilization success was equally low. A pattern similar to those observed for cadmium, copper, and zinc also was apparent for tin (Figure 57). There were many samples with unquantifiable or undetectable tin concentrations in which percent fertilization was very high and a few samples with slightly elevated concentrations in which fertilization success was very low or zero. There are no sediment quality guidelines or criteria for tin.

The concentrations of some of the potentially toxic trace metals (e.g., copper, lead, tin, zinc) were highest in the sample from station 94. Although fertilization success in this sample was significantly lower than in the controls, mean percent fertilization (68%) was not the lowest among the samples tested. Therefore, the statistical correlations between metals concentrations and percent fertilization would have improved without the data from station 94.

In Figure 58, results of the Microtox™ tests expressed as EC50s normalized to the Redfish Bay control response are plotted against the mean ERM quotients for the 13 PAHs for which ERMs were derived. This diagram indicates a considerable amount of scatter in the bioassay data at the lowest chemical concentrations (mean ERM quotients for PAHs <0.1) and the highest toxicity (EC50s <20% of controls) among samples with higher PAH concentrations (quotients >0.1). The data show the same pattern when expressed on a dry weight basis (Figure 59). All the samples in which the ERL value for total PAHs was exceeded were highly toxic. The sample from station 86 in Everett Harbor was the most contaminated and it was highly toxic in this test, therefore, undoubtedly contributing to the high correlations between the concentrations of PAHs and toxicity in the Microtox™ tests. Microtox™ test results from the 15 Everett Harbor samples showed a strong association between bioluminescence activity and the concentrations of PAHs for which SQS and CSL criteria were derived (Figures 60, 61). However, it was apparent that the

strong correlations were driven by one non-toxic sample with very low PAH concentrations. The least toxic sample (from station 95) had a relatively low concentration of total PAH. Microtox™ results were more strongly correlated with high molecular weight PAHs than with low molecular weight compounds (Figures 62, 63). However, the scatterplots looked very similar and all samples were highly toxic in which the ERL value for either HPAHs or LPAHs were exceeded.

Although the correlations between Microtox™ results and concentrations of LPAHs in Everett Harbor were highly significant, the scatterplots showed a relatively weak association (Figures 64, 65). The sample from station 95 was least toxic (EC50 >140% of control) and had among the lowest concentrations of LPAHs. The significant correlation would probably become non-significant if data from station 95 were eliminated.

Microtox™ results are plotted against the mean ERM quotients for three chlorinated organics (4, 4' - DDE, total DDTs, total PCBs) in Figure 66. Although the correlation coefficient was highly significant, the scatterplot showed considerable variability in toxicity among the least contaminated samples. A similar pattern (Figure 67) was apparent for Microtox™ test results and dibutyl tin, the form of butyl tin for which the correlation with Microtox™ results was most significant (Table 22). The concentrations of chlorinated hydrocarbons and dibutyl tin were the highest in the sample from station 86 in Everett Harbor, and this sample was very toxic in the Microtox tests, thereby contributing to the strong statistical correlations.

Because the Cytochrome P450 RGS assay results showed significant correlations with the PAHs, scatterplots were prepared for several different classes of PAHs either compared to or normalized to either ERM, SQS, or CSL values. In all cases the diagrams for total PAHs demonstrate similar patterns: highly significant correlation coefficients; a large cluster of samples with lowest chemical concentrations and lowest enzyme induction responses; and gradually increasing bioassay responses with increasing chemical concentrations (Figures 68-73). The sample from station 86, which had the highest concentrations of 13 PAHs (expressed as either total PAH [in units of dry weight] or mean ERM quotients), also was the sample in which the enzyme induction response was highest (Figures 68, 69). However, the significance of the sample from station 86 became less clear when the PAH concentrations were plotted as mean SQS or CSL quotients expressed in units of organic carbon (Figures 70-73).

All of these plots with Cytochrome P450 RGS assay results show lowest responses among many samples with low PAH concentrations in the lower left hand corner of the plots, and a relatively large degree of scatter in the data among samples with intermediate and high PAH concentrations. In all cases three samples appear in the center of the diagrams with higher Cytochrome P450 RGS responses than five or six other samples within the same range in PAH concentrations. The three samples were collected from stations 88, 90, and 91 in Everett Harbor. Enzyme induction in these samples may have been accelerated by exposures to other chemicals (e.g., dioxins as in sample 86) in addition to the PAHs, resulting in the unusually high responses.

Analysis of the extract from sample 86, in which the RGS response was greatest, indicated the concentration of total dioxins and furans was 30ppb, producing a total dioxin equivalency of 110 pptr. It is likely that dioxins also occurred in the samples from stations 88, 90, and 91,

thereby contributing to the elevated RGS responses shown in Figure 68 and others. The correlation between RGS response and total PAHs was 0.99 in four samples (86, 88, 90, and 91).

Cytochrome P450 RGS assay responses showed a strong pattern of concordance with the concentrations of LPAH; most of the highest responses occurred in samples in which LPAH concentrations exceeded the ERM value of 3160 ppb (Figure 74). Although none of the LPAH concentrations exceeded the SQS value of 370 mg/kg (organic carbon normalized) (Figure 75), there was comparable concordance with Cytochrome P450 RGS results when the LPAH data were normalized to organic carbon as expressed as mean SQS quotients (Figure 76) or mean CSL quotients (Figure 77). Whether shown as total HPAHs on a dry weight basis or total HPAHs on an organic carbon basis or as mean SQS or mean CSL quotients, Cytochrome P450 RGS assay results showed an equally strong association with the concentrations of this class of PAHs (Figures 78-81). In the last scatterplot, Cytochrome P450 RGS induction increased with increasing concentrations of dibenzofuran, largely driven, again, by the sample from station 86 (Figure 82).

In all of the scatterplots of the Cytochrome P450 RGS data, the highest induction levels (>80µg/g) occurred in four samples (86, 88, 90, and 91) from Everett Harbor. The highest induction level occurred in the sample from station 86, which also had the highest PAH concentrations. However, the samples from stations 88, 90, and 91, often indicated higher induction levels than other samples from Puget Sound in which PAH concentrations were comparable. The unusually high P-450 induction responses in these samples probably were attributable to the presence of dioxins and PCBs in the samples.

Summary

Data from statistical tests and scatterplots suggest that responses in toxicity tests were strongly associated with the presence of complex mixtures of chemicals. Classes of PAHs, pesticides, phenols, other organic compounds, and several trace metals were elevated in samples that were toxic, showed strong statistical correlations with measures of toxicity, and chemical concentrations in the most toxic samples often exceeded effects-based numerical guidelines or standards.

Associations between measures of toxicity and concentrations of toxicants were most significant in samples from Everett Harbor and vicinity. It was apparent that the statistical associations observed between toxicity and chemical data were driven, in large part, by the data from the Everett Harbor samples. Samples from this region often were highly toxic in the urchin, Microtox™ and P450 RGS bioassays and were most contaminated with PAHs, other organic compounds, and several trace metals. The chemicals with the strongest associations with toxicity differed somewhat among the different tests. This observation was expected, because of the differences in sensitivities to toxicants among the tests.

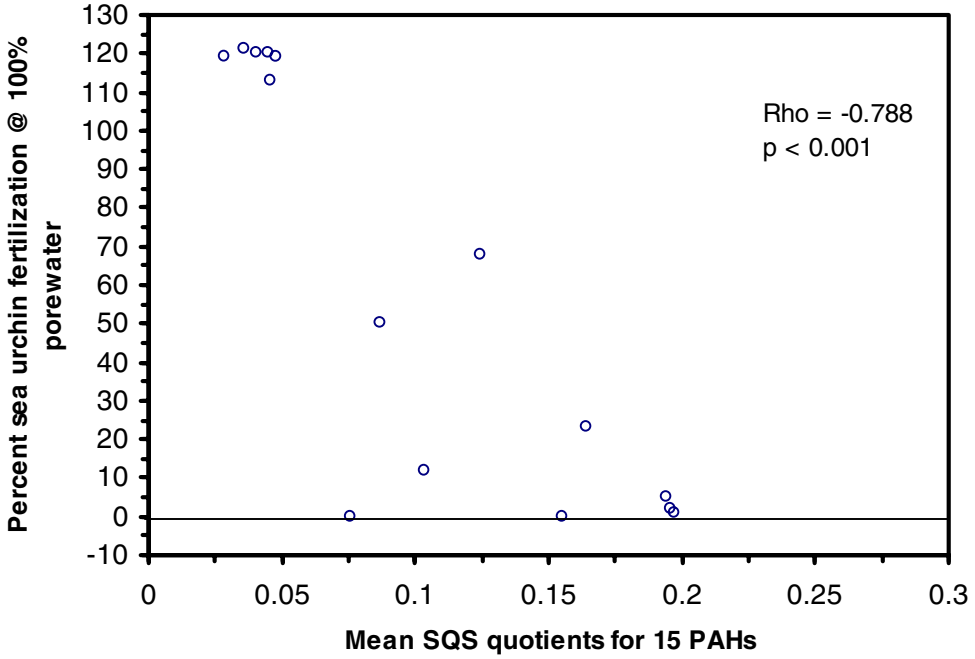

Figure 47. Relationship between sea urchin fertilization in pore water and the mean SQS quotients for 15 polynuclear aromatic hydrocarbons for Everett Harbor.

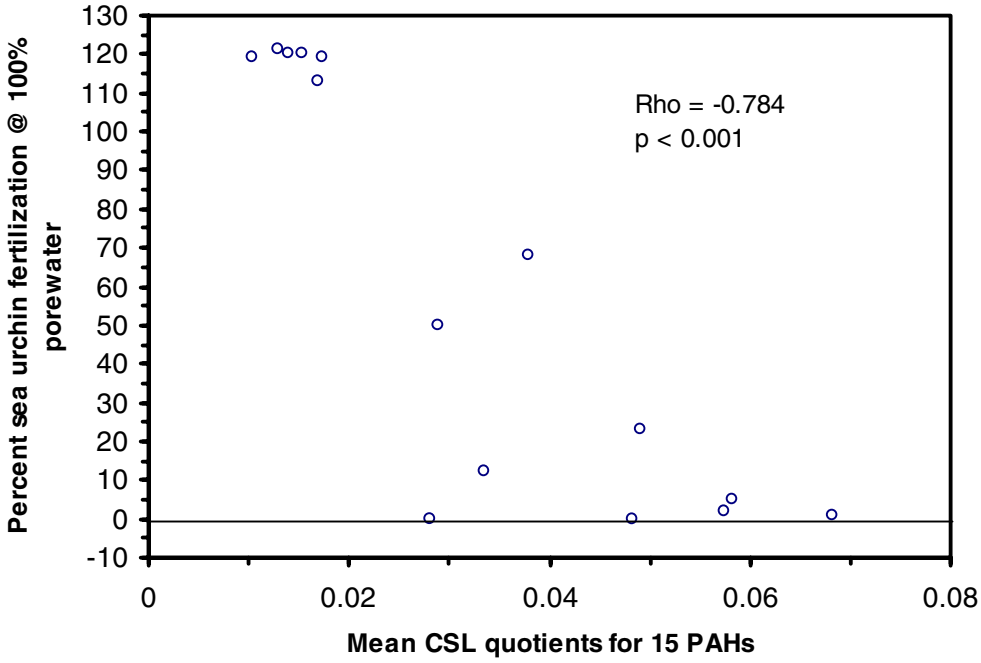

Figure 48. Relationship between sea urchin fertilization in pore water and the mean CSL quotients for 15 polynuclear aromatic hydrocarbons for Everett Harbor.

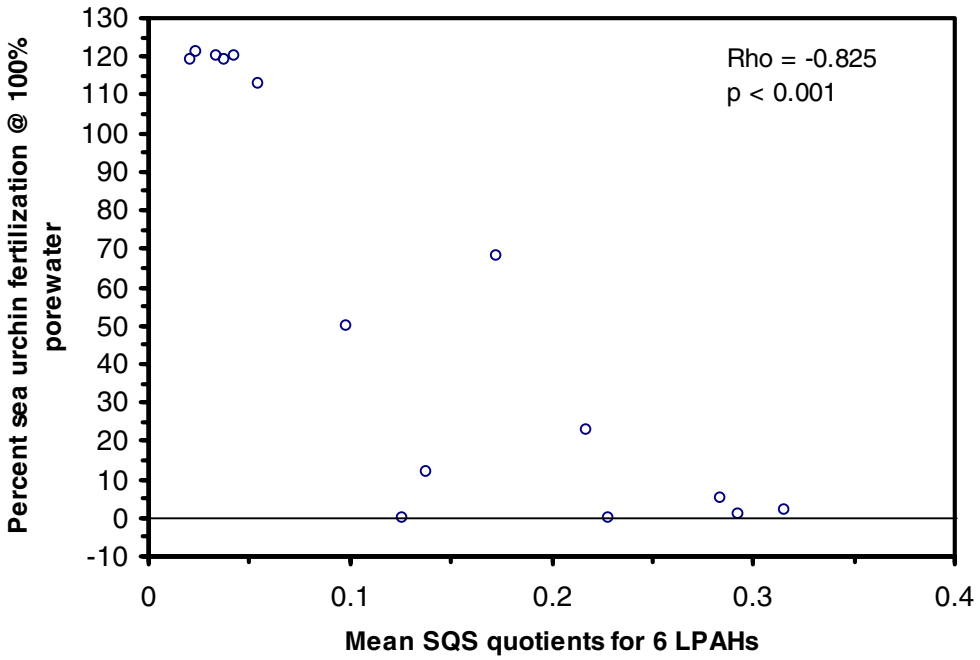

Figure 49. Relationship between sea urchin fertilization in pore water and the mean SQS quotients for 6 low molecular weight polynuclear aromatic hydrocarbons for Everett Harbor.

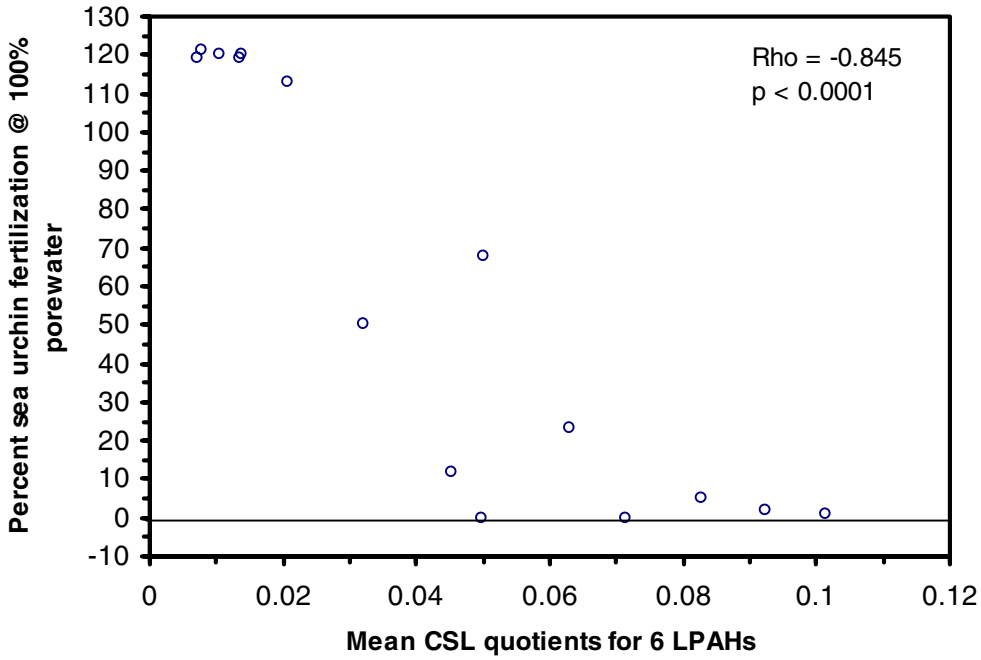

Figure 50. Relationship between sea urchin fertilization in pore water and the mean CSL quotients for 6 low molecular weight polynuclear aromatic hydrocarbons for Everett Harbor.

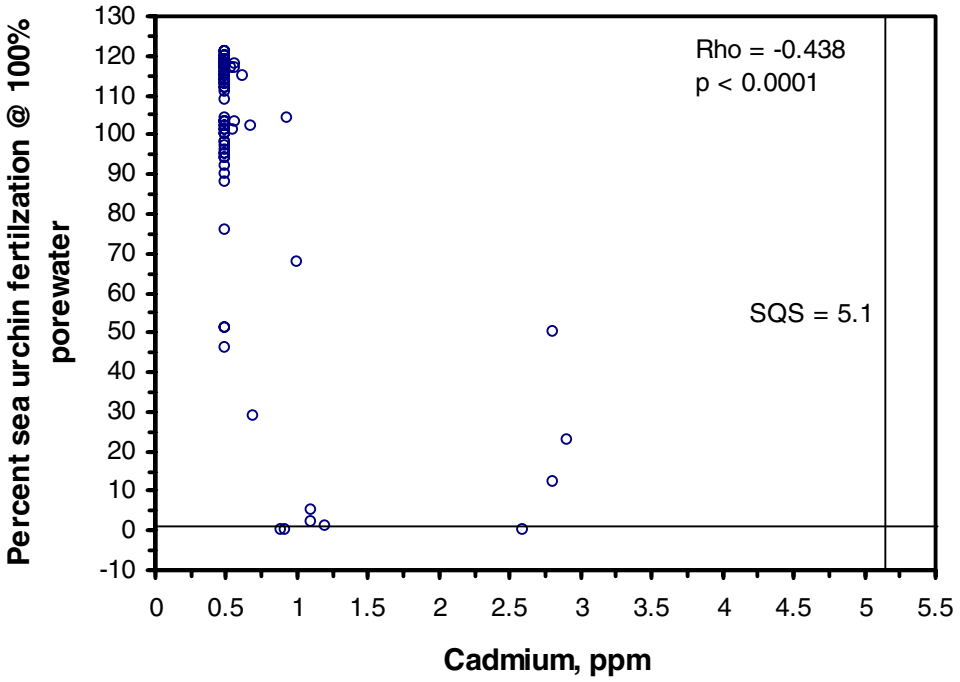

Figure 51. Relationship between sea urchin fertilization in pore water and the concentrations of cadmium in partially digested sediments from Northern Puget Sound.

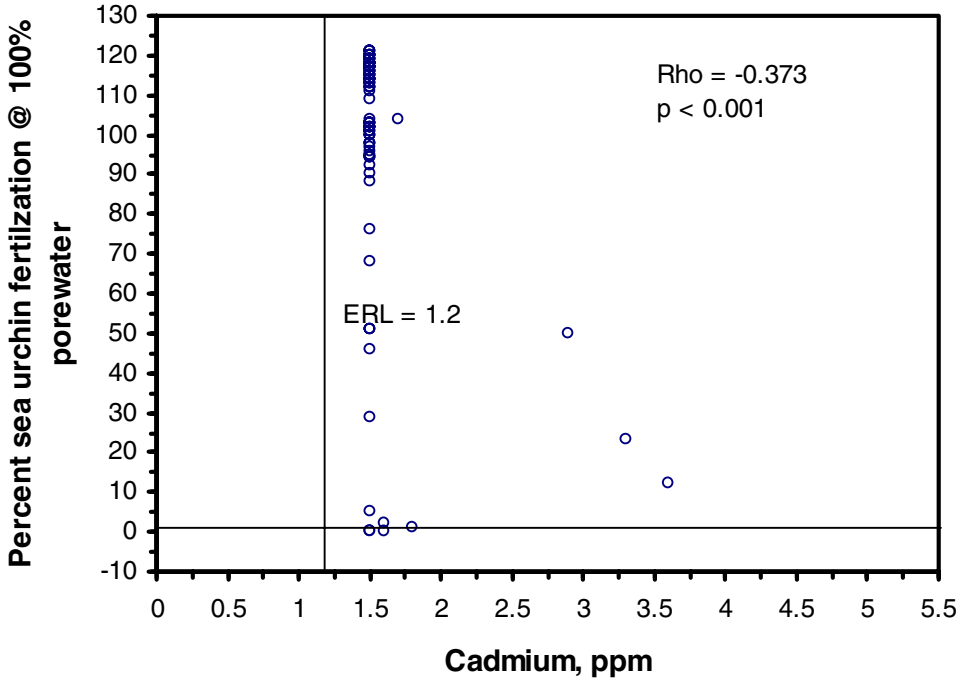

Figure 52. Relationship between sea urchin fertilization in pore water and concentrations of cadmium in totally digested sediments from Northern Puget Sound.

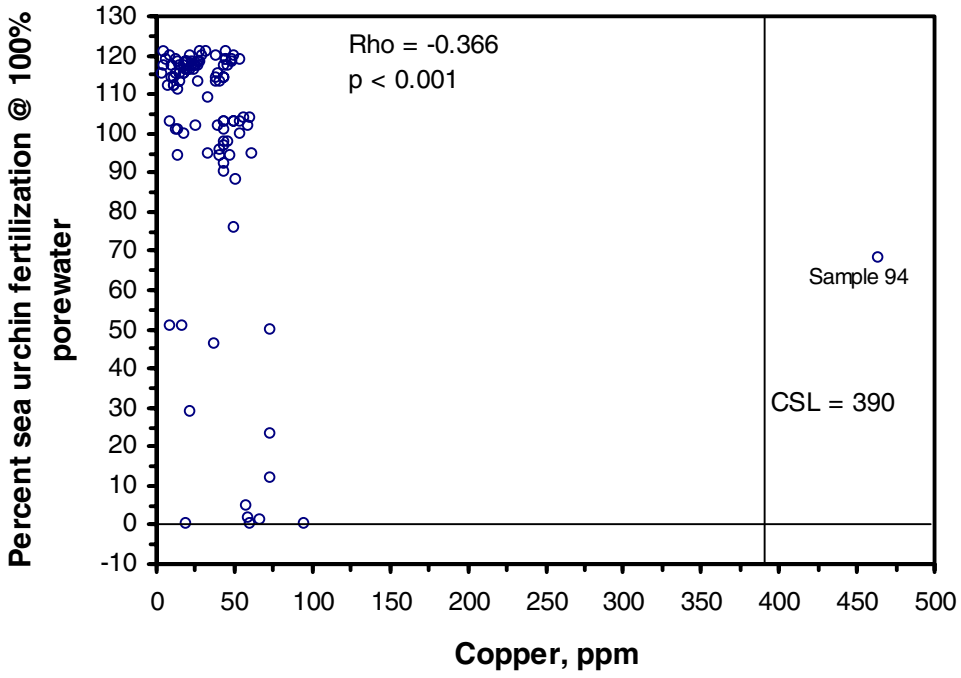

Figure 53. Relationship between sea urchin fertilization in pore water and the concentrations of copper in partially digested sediments from Northern Puget Sound.

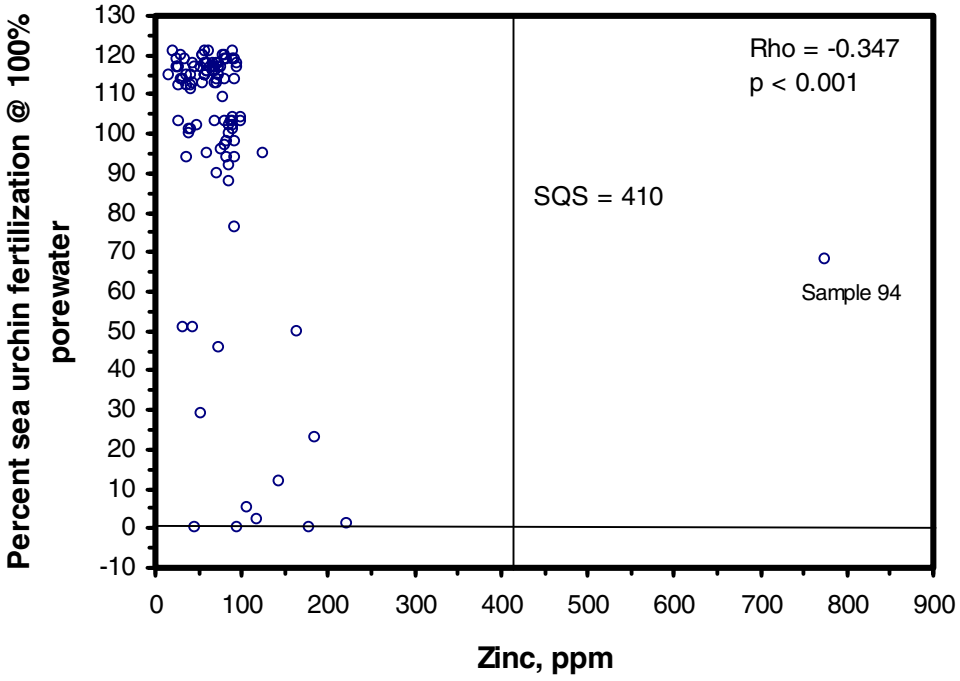

Figure 54. Relationship between sea urchin fertilization in pore water and the concentrations of zinc in partially digested sediments from Northern Puget Sound.

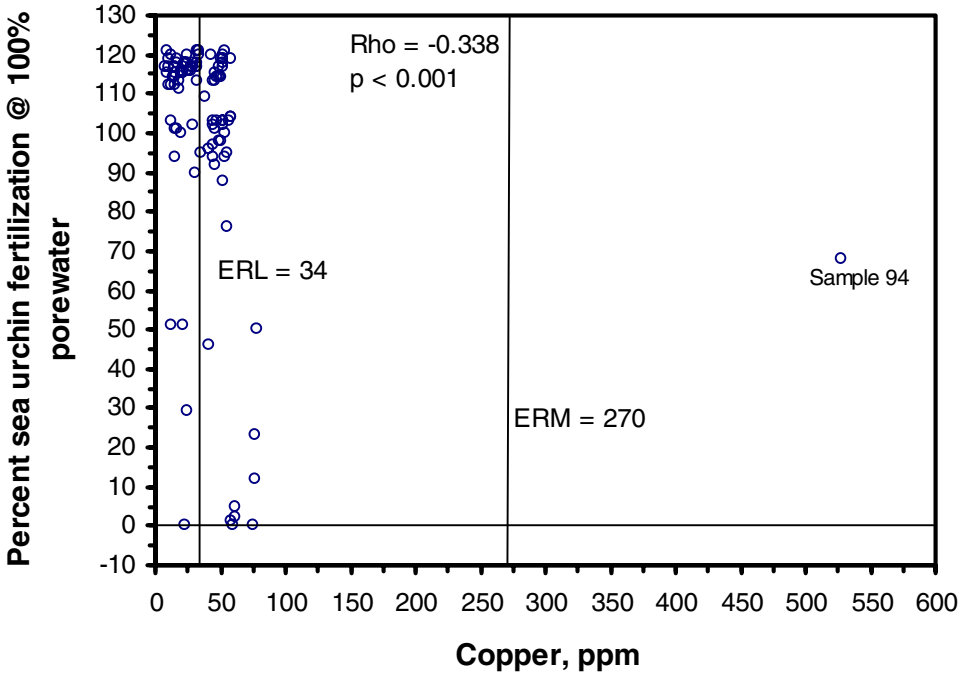

Figure 55. Relationship between sea urchin fertilization in pore water and the concentrations of copper in totally digested sediments from Northern Puget Sound.

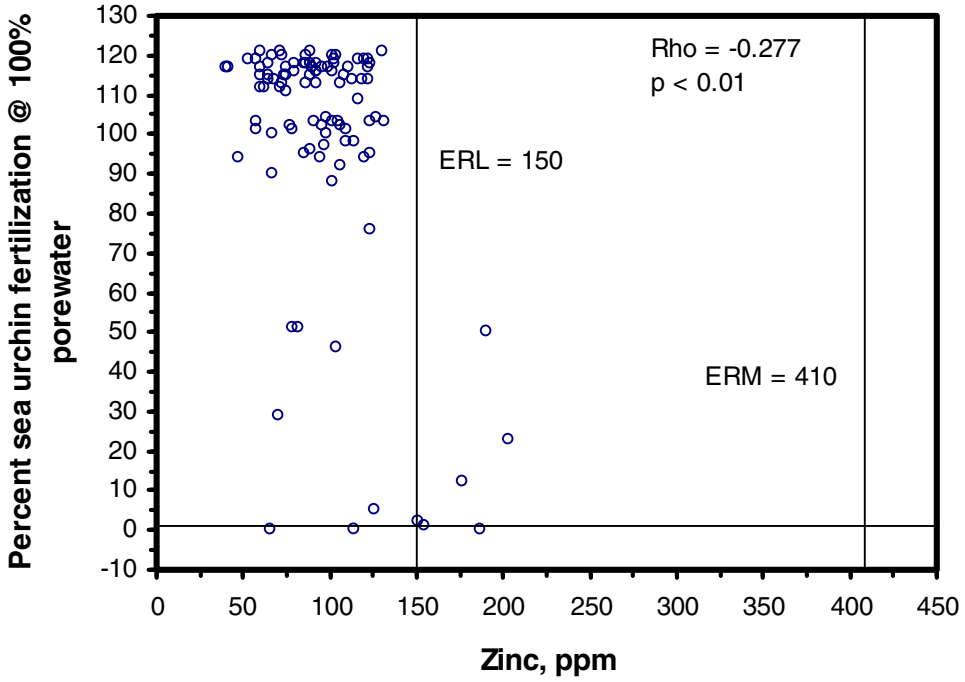

Figure 56. Relationship between sea urchin fertilization in pore water and the concentrations of zinc in totally digested sediments from Northern Puget Sound.

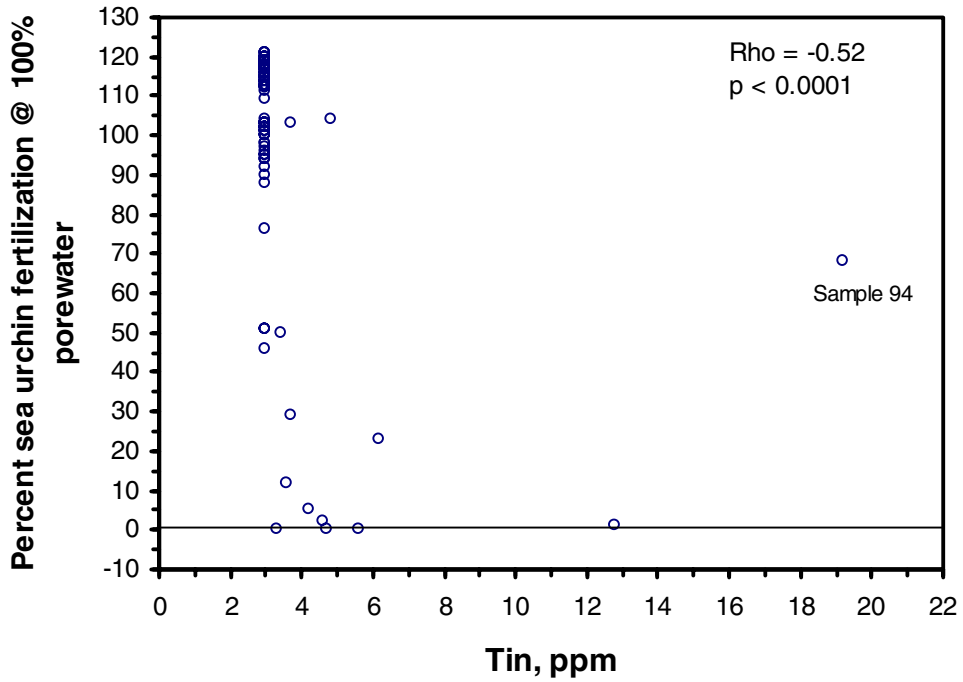

Figure 57. Relationship between sea urchin fertilization in pore water and the concentrations of tin in sediments from Northern Puget Sound.

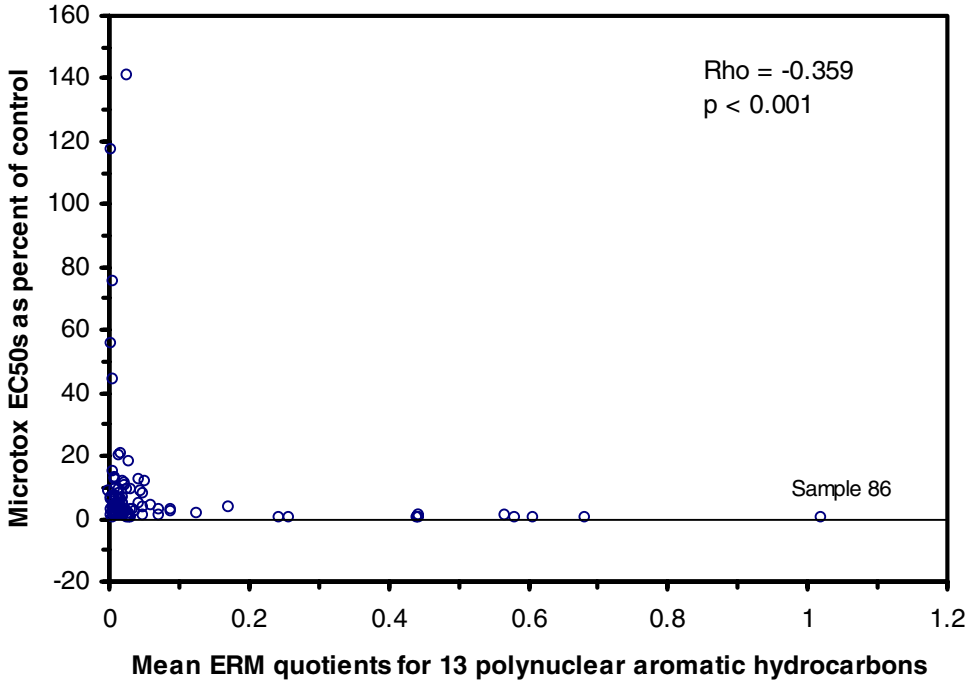

Figure 58. Relationship between microbial bioluminescence (Microtox™ EC50s) and the mean ERM quotients for 13 polynuclear aromatic hydrocarbons in Northern Puget Sound.

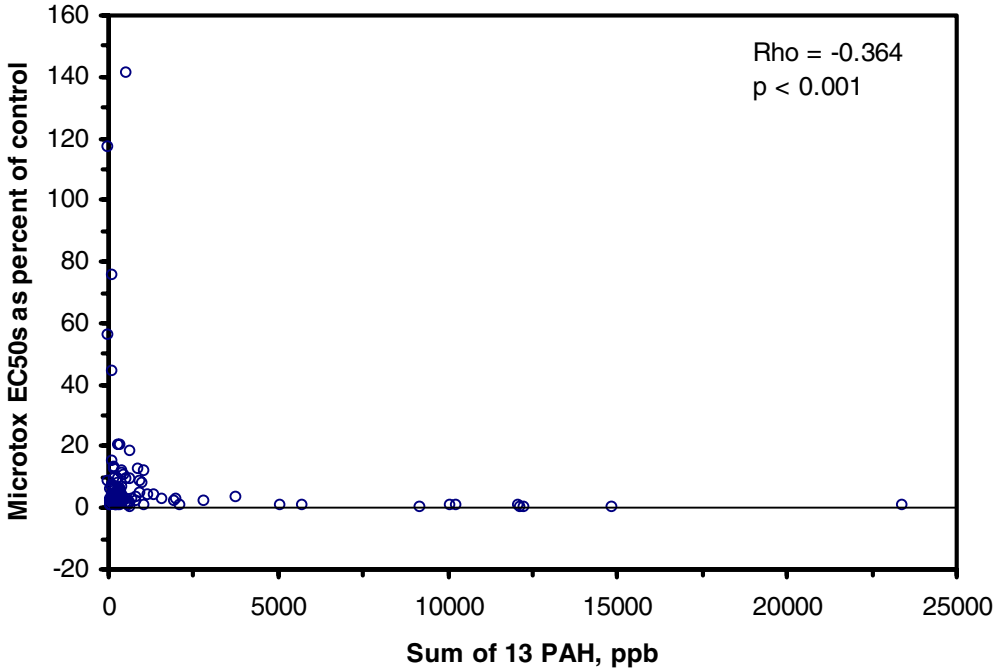

Figure 59. Relationship between microbial bioluminescence and the sum of 13 polynuclear aromatic hydrocarbons in Northern Puget Sound sediments

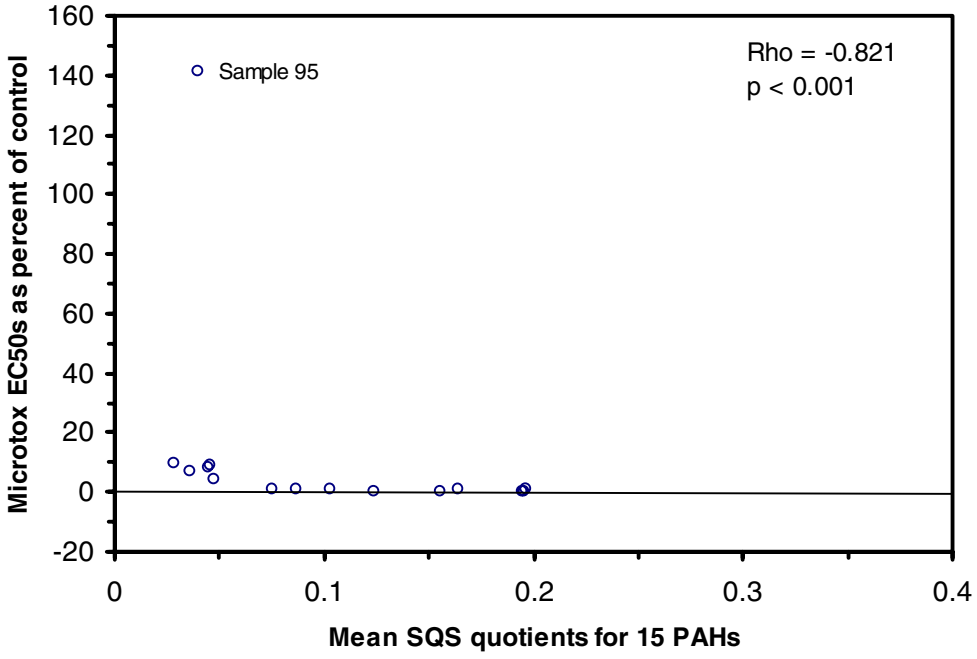

Figure 60. Relationship between microbial bioluminescence and the mean SQS quotients for 15 polynuclear aromatic hydrocarbons for Everett Harbor.

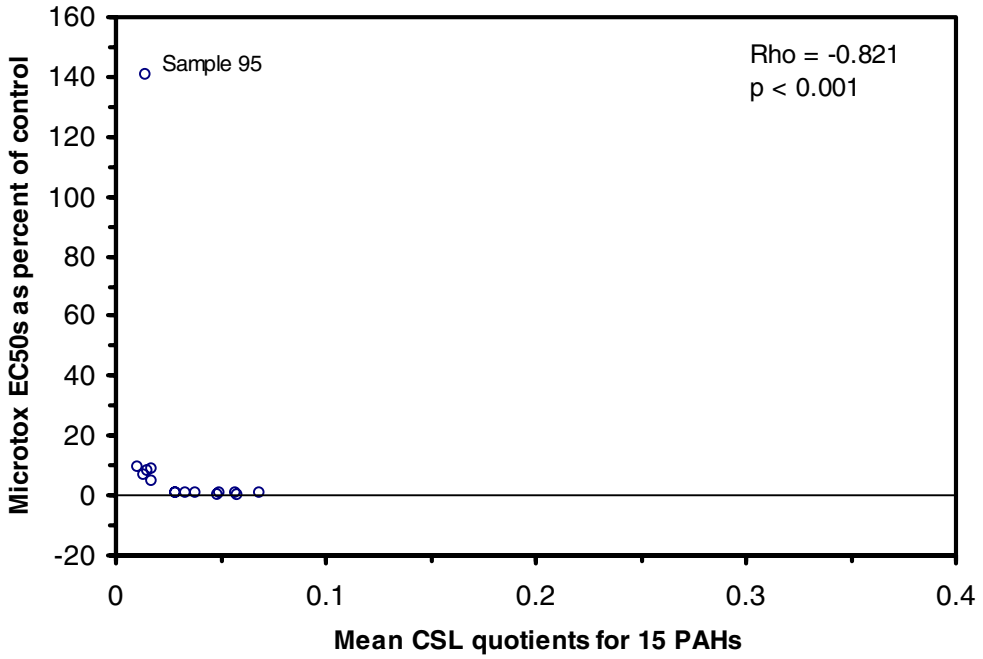

Figure 61. Relationship between microbial bioluminescence and the mean CSL quotients for 15 polynuclear aromatic hydrocarbons for Everett Harbor.

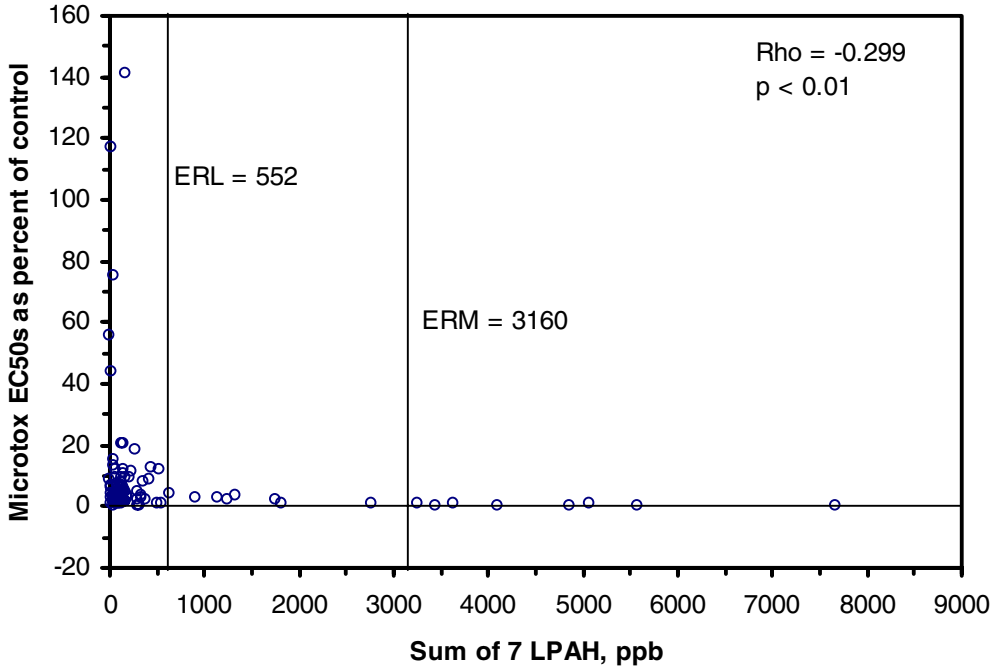

Figure 62. Relationship between microbial bioluminescence and 7 low molecular weight polynuclear aromatic hydrocarbons in Northern Puget Sound.

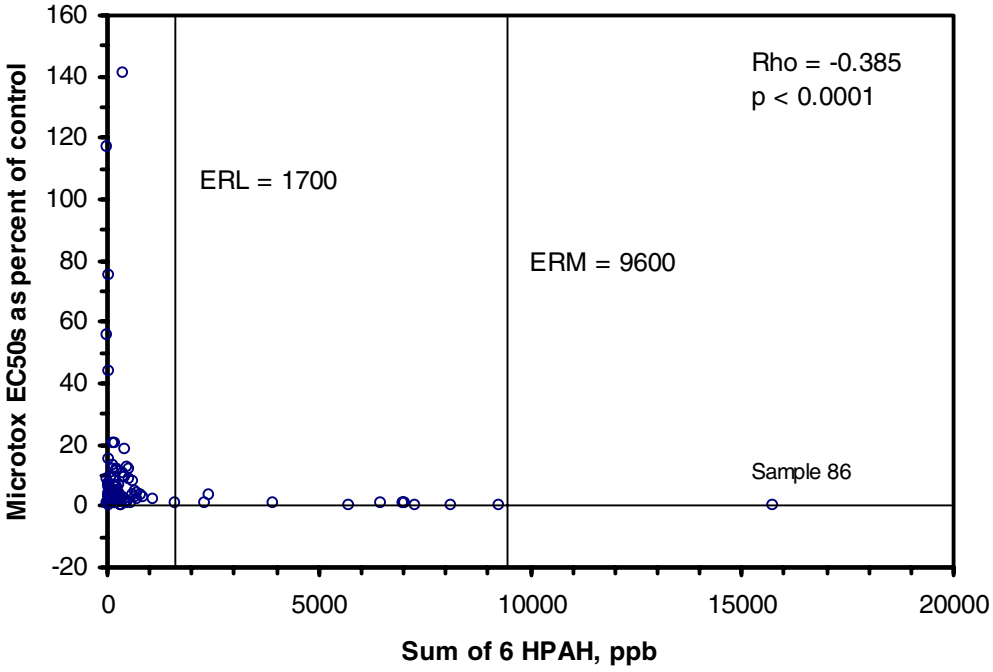

Figure 63. Relationship between microbial bioluminescence and 6 high molecular weight polynuclear aromatic hydrocarbons in Northern Puget Sound sediments.

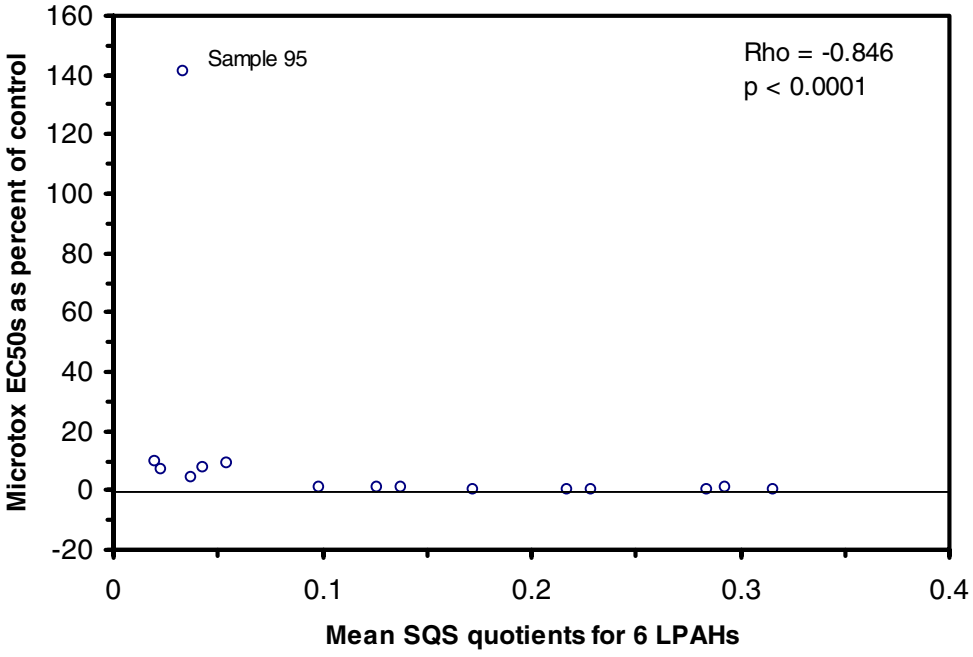

Figure 64. Relationship between microbial bioluminescence and the mean SQS quotients for 6 low molecular weight polynuclear aromatic hydrocarbons for Everett Harbor.

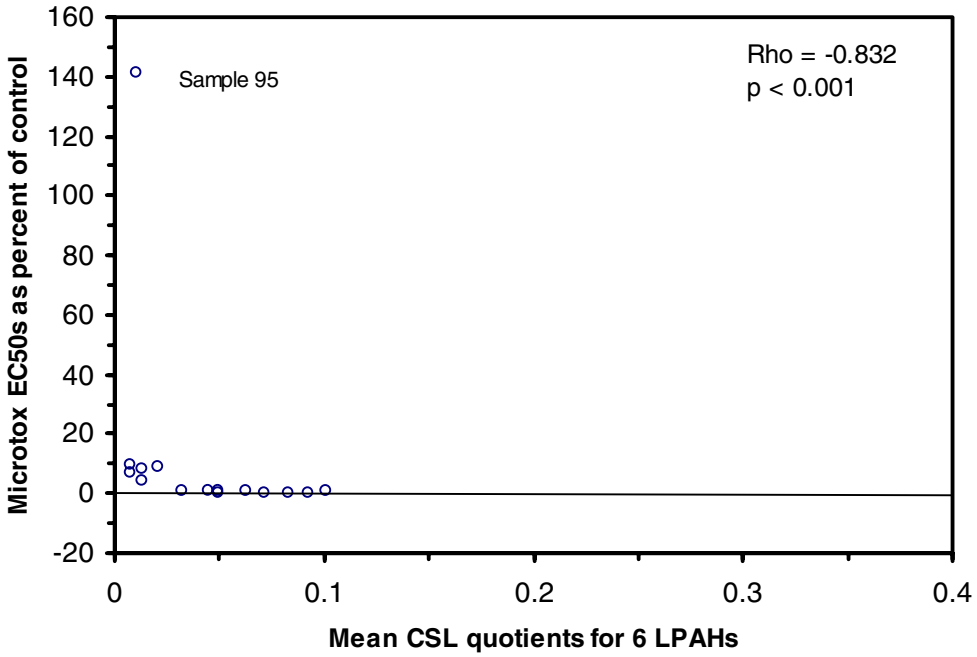

Figure 65. Relationship between microbial bioluminescence and the mean CSL quotients for 6 low molecular weight polynuclear aromatic hydrocarbons for Everett Harbor.

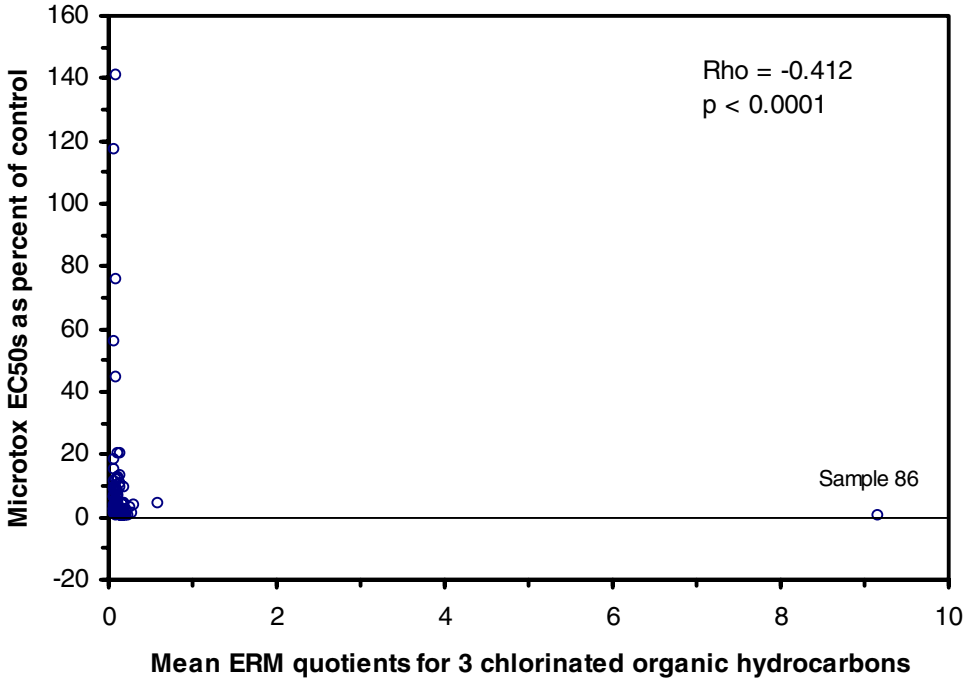

Figure 66. Relationship between microbial bioluminescence (Microtox™ EC50s) and the mean ERM quotients for 3 chlorinated organic hydrocarbons in Northern Puget Sound.

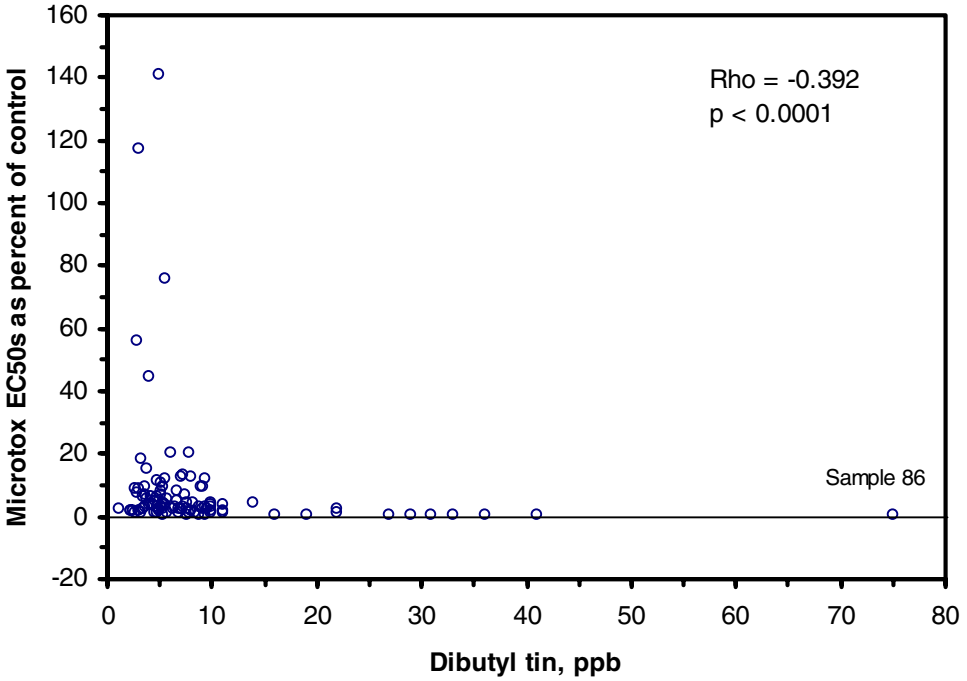

Figure 67. Relationship between microbial bioluminescence and concentrations of dibutyl tin in Northern Puget Sound sediments.

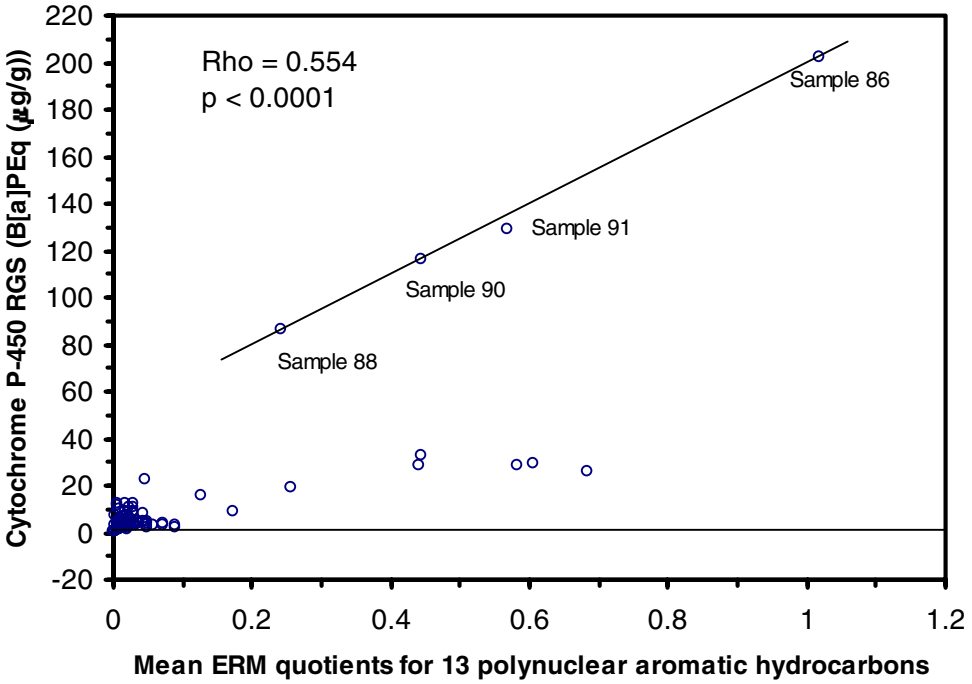

Figure 68. Relationship between Cytochrome P450 RGS and the mean ERM quotients for 13 polynuclear aromatic hydrocarbons in Northern Puget Sound Sediments.

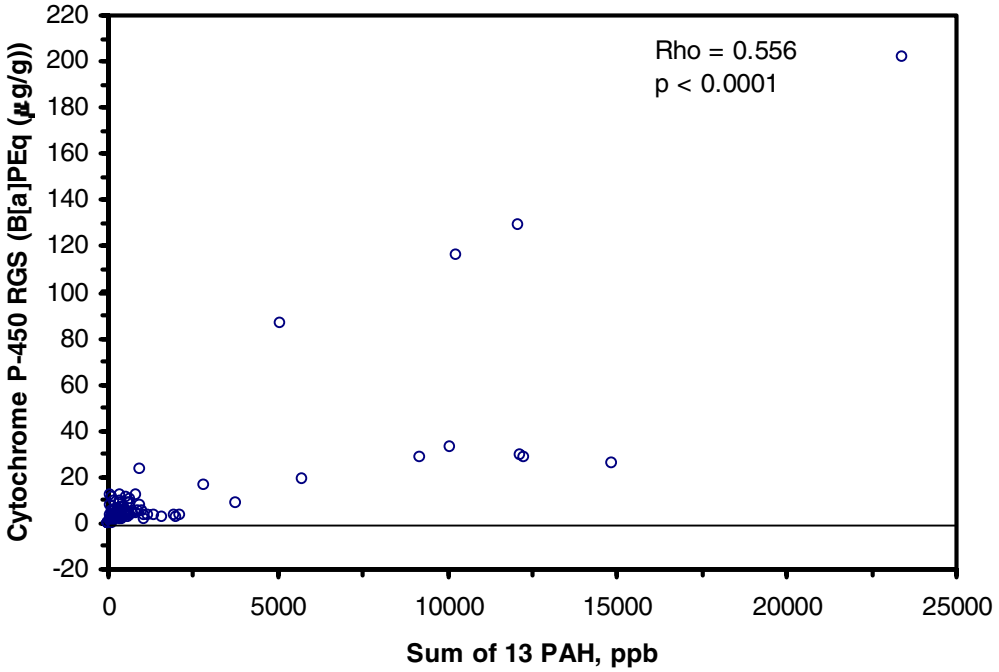

Figure 69. Relationship between Cytochrome P450 RGS and the sum of 13 polynuclear aromatic hydrocarbons in Northern Puget Sound.

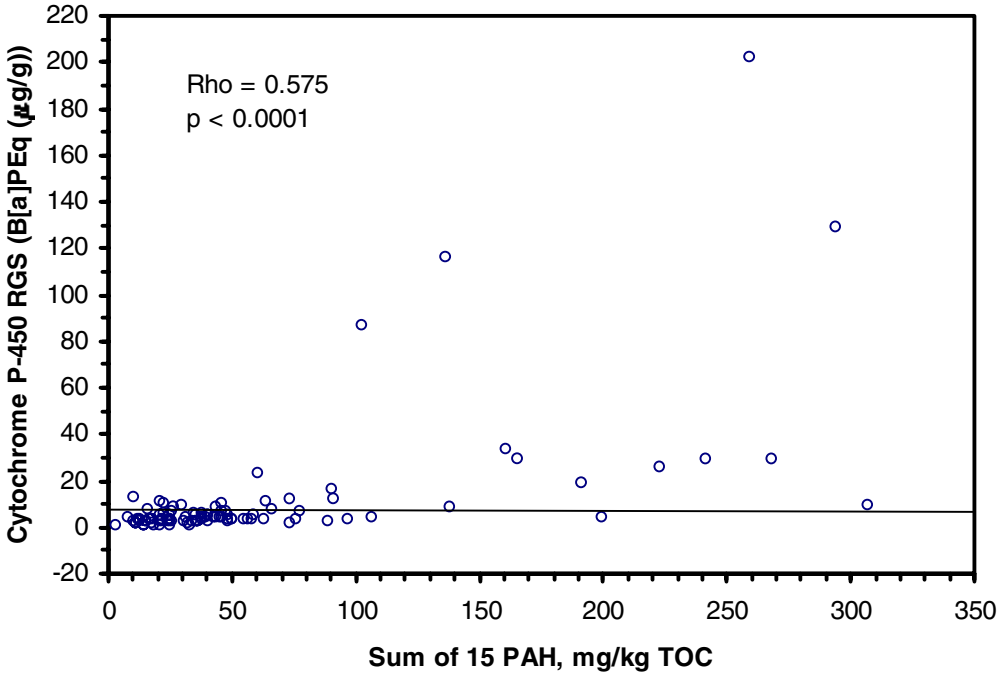

Figure 70. Relationship between Cytochrome P450 RGS and the sum of 15 polynuclear aromatic hydrocarbons in Northern Puget Sound.

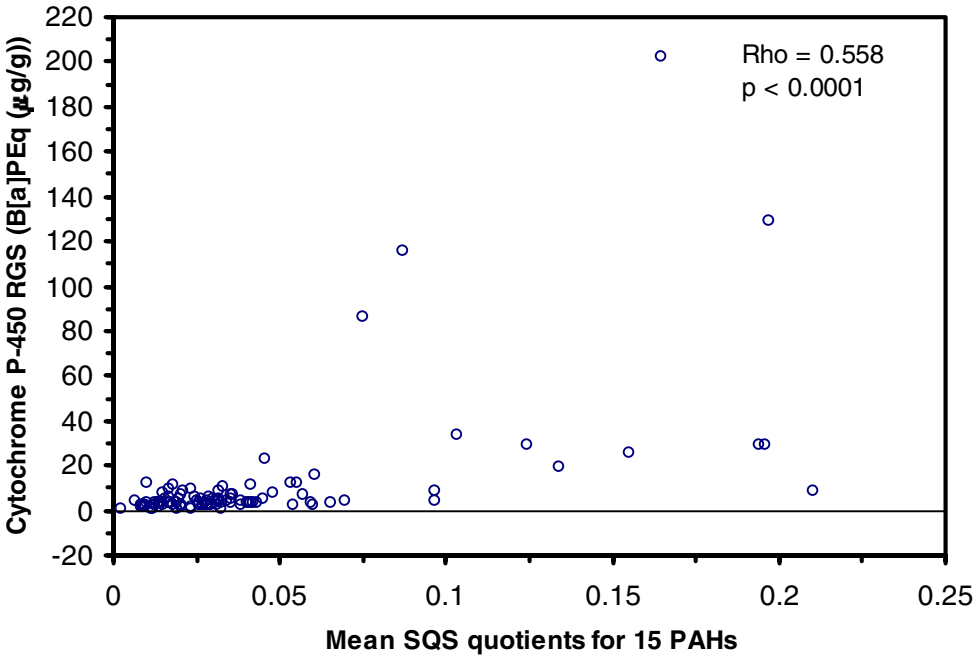

Figure 71. Relationship between Cytochrome P450 RGS and the mean SQS quotients for 15 polynuclear aromatic hydrocarbons in Northern Puget Sound Sediments.

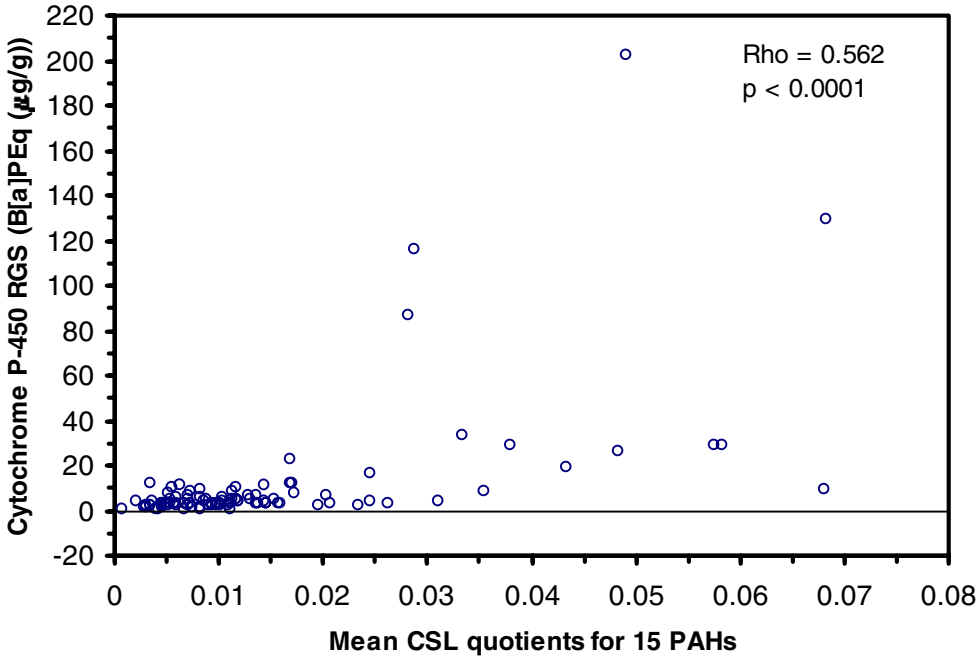

Figure 72. Relationship between Cytochrome P450 RGS and the mean CSL quotients for 15 polynuclear aromatic hydrocarbons in Northern Puget Sound Sediments.

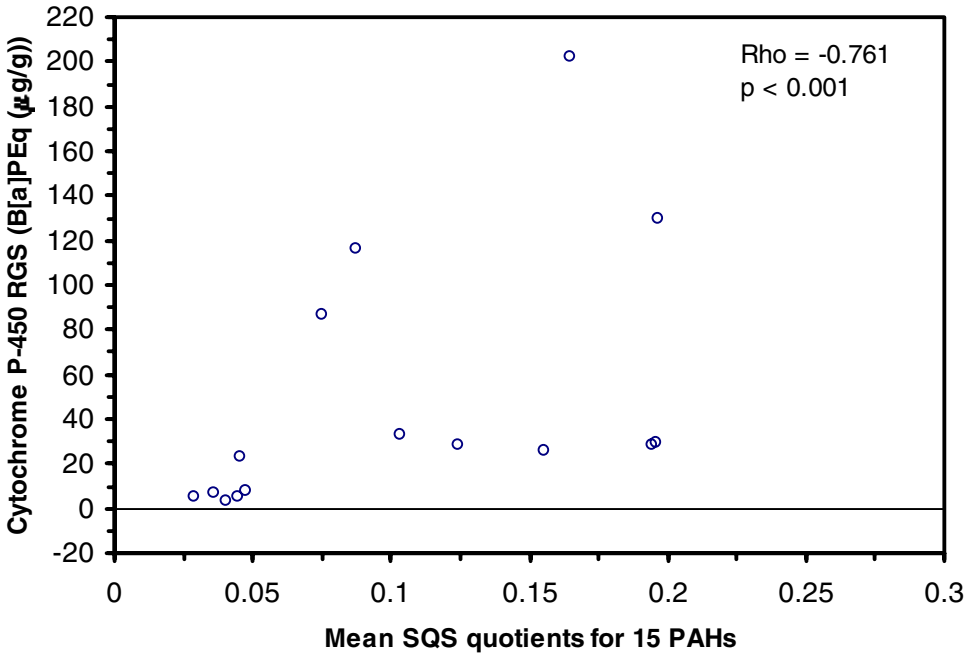

Figure 73. Relationship between Cytochrome P450 RGS and the mean SQS quotients for 15 polynuclear aromatic hydrocarbons for Everett Harbor.

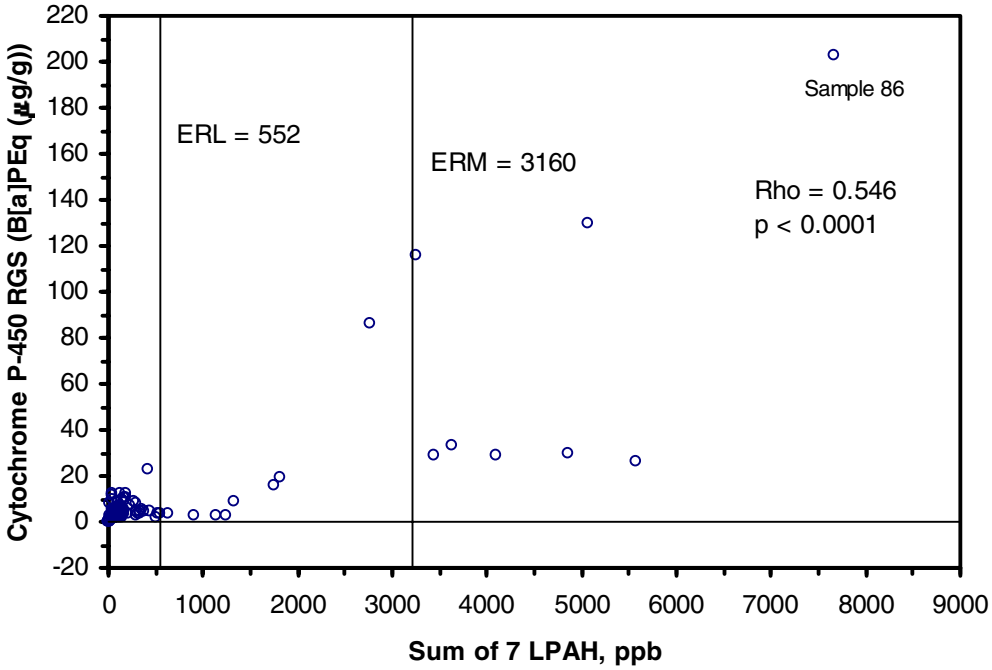

Figure 74. Relationship between Cytochrome P450 RGS and 7 low molecular weight aromatic hydrocarbons in Northern Puget Sound.

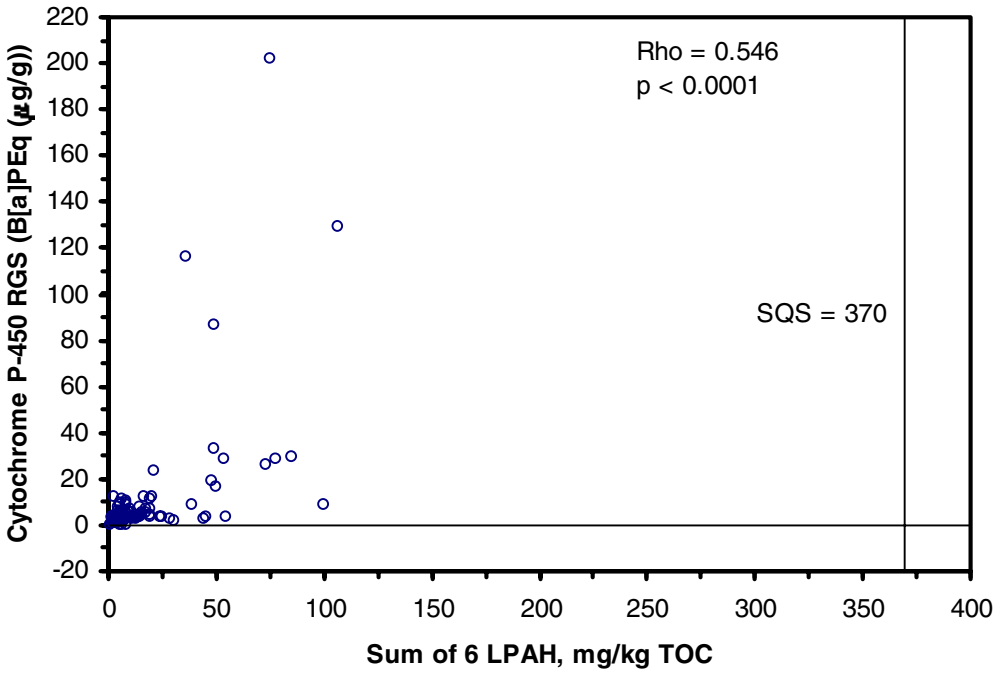

Figure 75. Relationship between Cytochrome P450 RGS and 6 low molecular weight aromatic hydrocarbons in Northern Puget Sound.

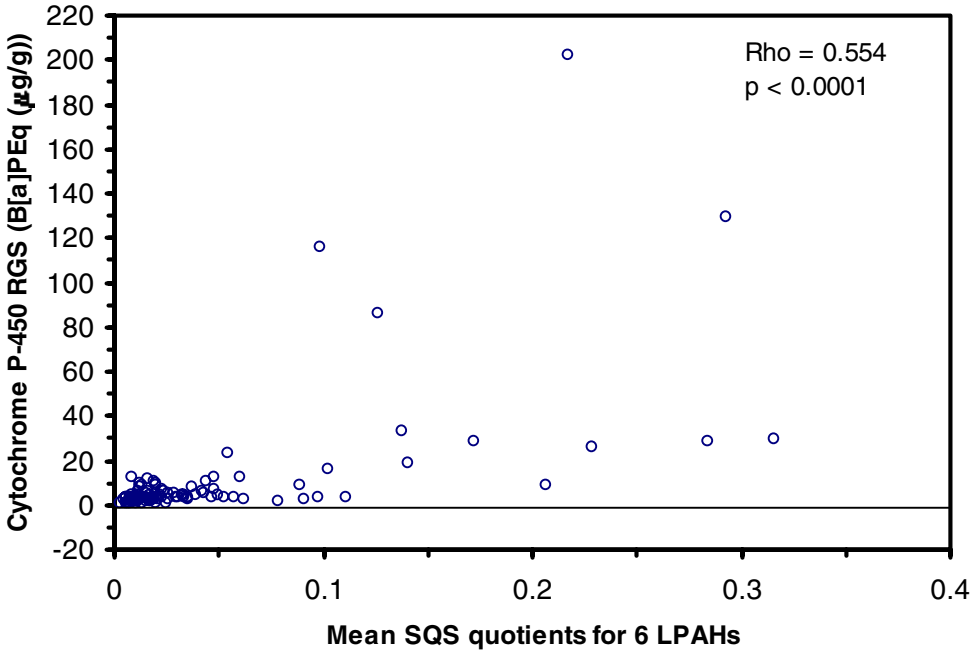

Figure 76. Relationship between Cytochrome P450 RGS and the mean SQS quotients for 6 low molecular weight polynuclear aromatic hydrocarbons in Northern Puget Sound Sediments.

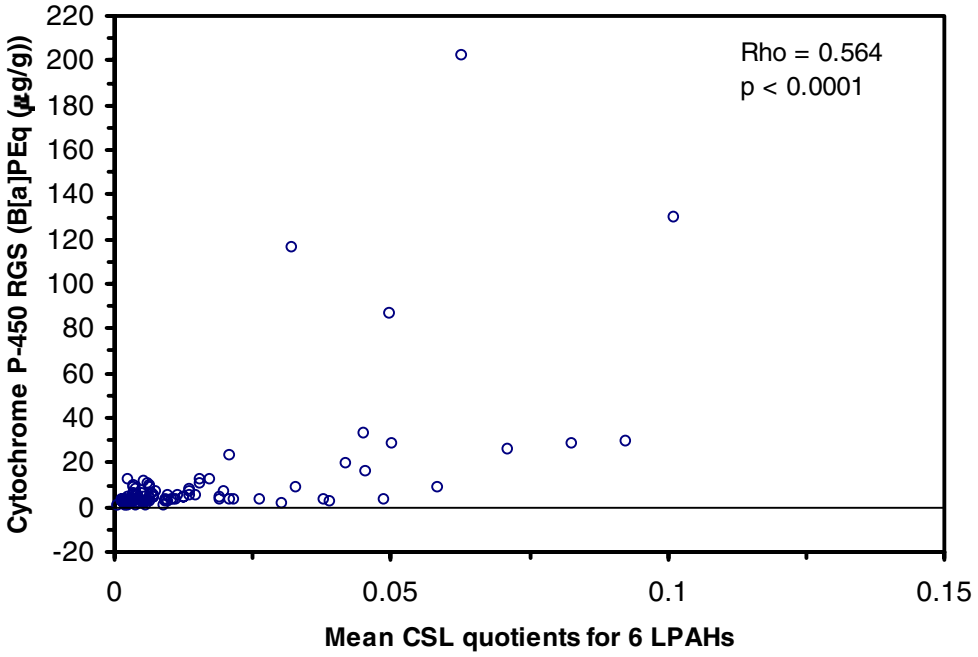

Figure 77. Relationship between Cytochrome P450 RGS and the mean CSL quotients for 6 low molecular weight polynuclear aromatic hydrocarbons in Northern Puget Sound Sediments.

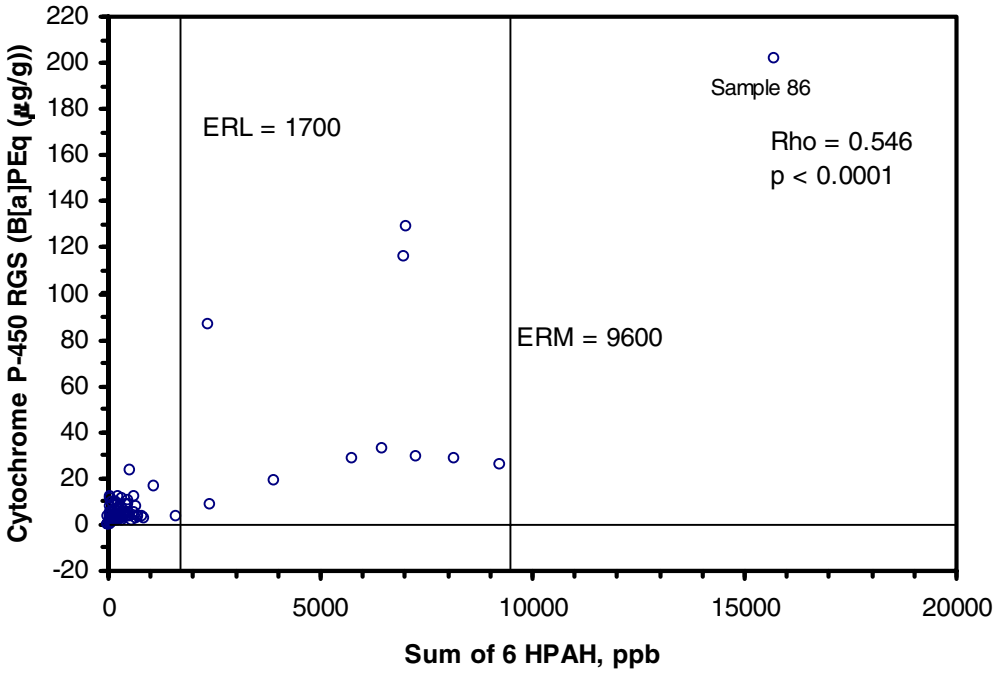

Figure 78. Relationship between Cytochrome P450 RGS and 6 high molecular weight aromatic hydrocarbons in Northern Puget Sound.

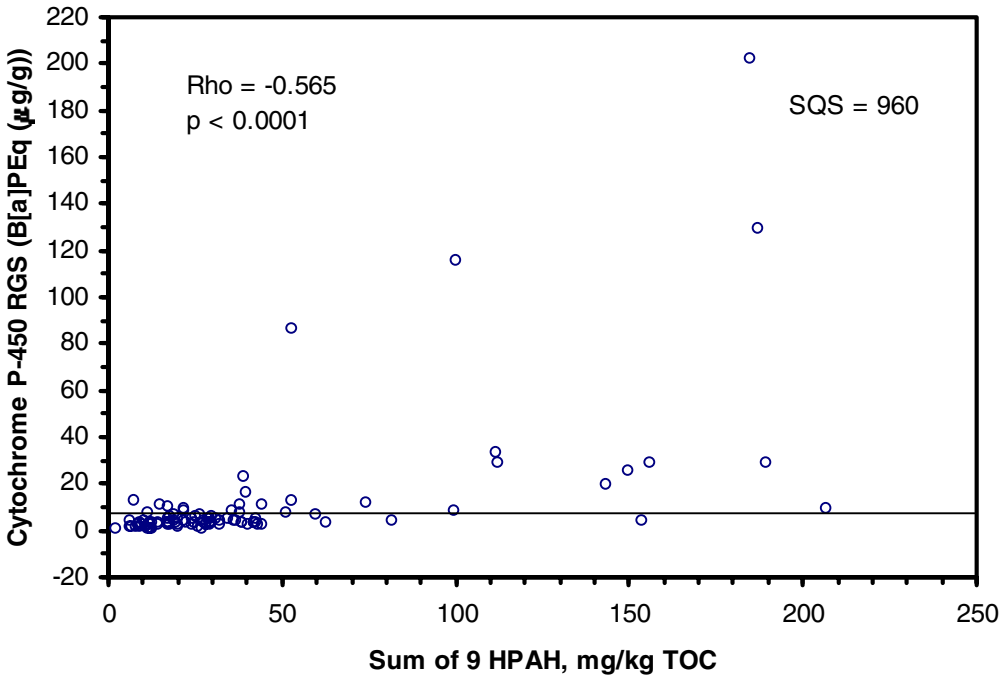

Figure 79. Relationship between Cytochrome P450 RGS and 9 high molecular weight aromatic hydrocarbons in Northern Puget Sound.

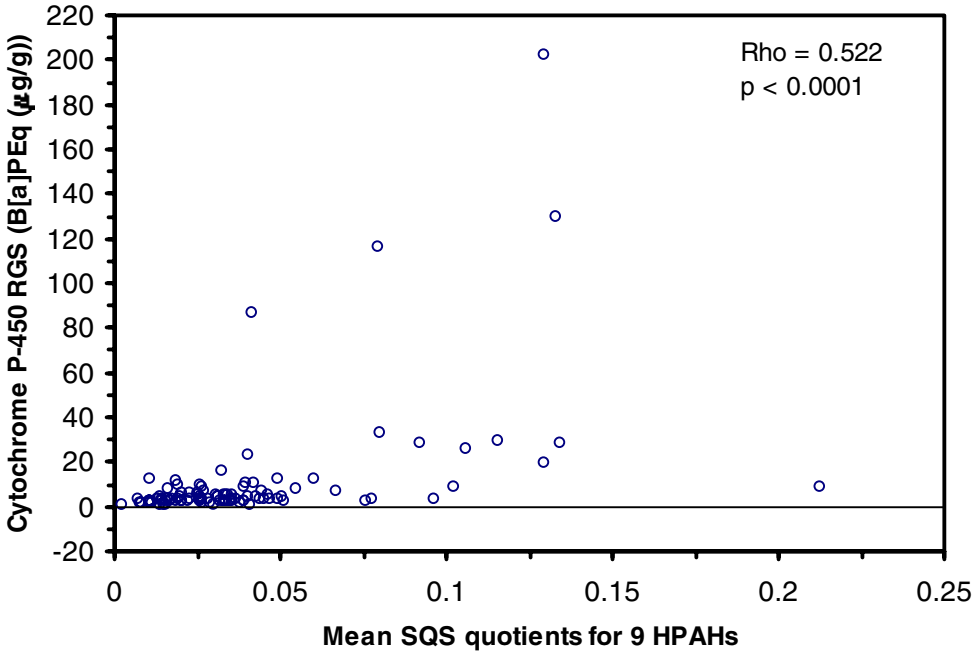

Figure 80. Relationship between Cytochrome P450 RGS and the mean SQS quotients for 9 high molecular weight polynuclear aromatic hydrocarbons in Northern Puget Sound Sediments.

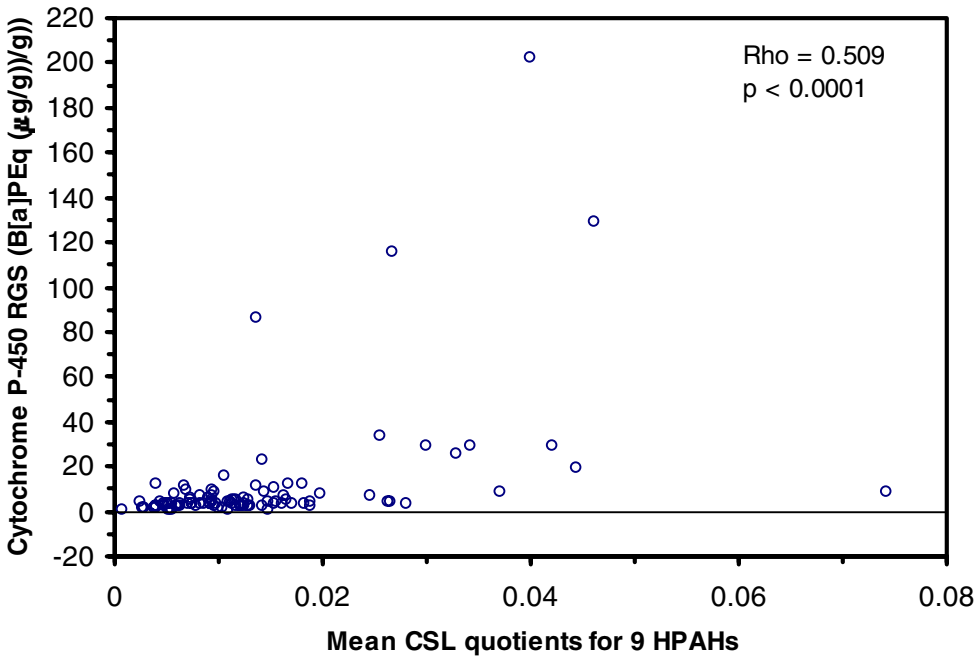

Figure 81. Relationship between Cytochrome P450 RGS and the mean CSL quotients for 9 high molecular weight polynuclear aromatic hydrocarbons in Northern Puget Sound Sediments.

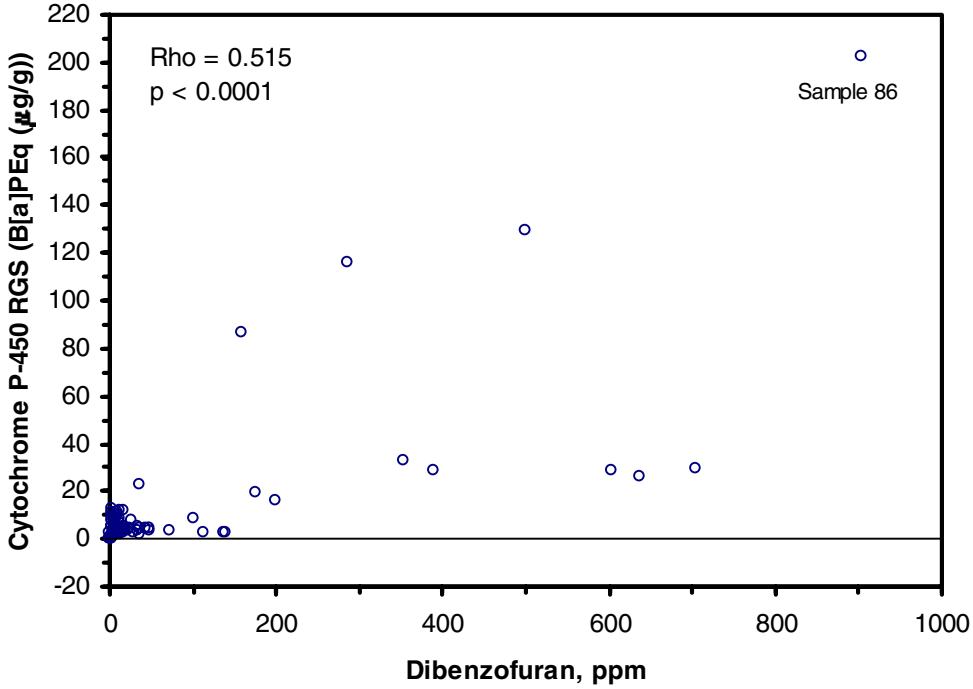

Figure 82. Relationship between Cytochrome P450 RGS and dibenzofuran in Northern Puget Sound Sediments.

Benthic Community Analyses

Community Composition and Benthic Indices

The benthic invertebrate taxa found in the 100 northern Puget Sound infauna samples are listed in Appendix E. Five hundred-nine taxa were recognized, of which 387 (76%) were identified to the species level. These taxa included 183 polychaete species (representing 47% of the 387 taxa identified to species level); 111 arthropod species (representing 29% of the total); 68 mollusc species (18% of the total); and 25 echinoderm species and miscellaneous taxa (i.e., Cnidaria, Platyhelminthes, Nemertina, Sipuncula, Phoronidae, Enteropneusta, and Ascidiacea) that accounted for 6% of the total number of species. The animals found in the study included several possibly undescribed species.

As described in the Methods section, nine benthic infaunal indices were calculated to aid in the examination of the community structure at each station. These indices included total abundance, major taxa abundance (calculated for Annelida, Arthropoda, Mollusca, Echinodermata, miscellaneous taxa), taxa richness, Pielou's evenness, and Swartz's Dominance Index, and were calculated based on the abundance data collected for the 509 taxa found (Tables 24 and 25). Total abundance is displayed in both tables, to facilitate comparisons among indices.

Total Abundance

Total abundance (number of individuals per 0.1 m^2) of benthic invertebrates at each station (Table 24) ranged from 7,671 organisms at station 43 (Padilla Bay) to 24 organisms at station 100 (Snohomish River delta). Additional stations with high total abundance (>1500 organisms) included stations in Bellingham Bay (stations 20-24, 26, 27, 29, 30, 60 and 61), Boundary Bay (station 7), Samish Bay (station 40), Padilla Bay (station 41), and March Point (station 49). Stations in which total abundance was relatively low (<200 organisms) included several in Everett Harbor (stations 86-89 and 91), Drayton Harbor (stations 2 and 3), Port Susan (stations 81 and 82), Saratoga Passage off Camano Island (station 78), Whatcom Waterway in Bellingham Bay (station 28), Oak Harbor (station 69), and Boundary Bay (station 9).

Major Taxa Abundance

Total abundance and percent total abundance of five major taxonomic groups (Annelida, Arthropoda, Echinodermata, Mollusca, and miscellaneous taxa) are listed in Table 24. Results also are compared among stations in stacked histograms (Appendix F).

The total abundance of annelids ranged from 5,084 animals (station 43, Padilla Bay) to 2 animals (station 100, Snohomish River delta). Annelid abundance calculated as the percentage of total abundance ranged from 93% (station 89, Everett Harbor) to 4% (station 15, Birch Bay). In 39% of the 100 stations sampled, 50% or more of the total benthic infaunal animals were annelids.

Table 24. Total abundance, major taxa abundance, and major taxa percent abundance for the 1997 northern Puget Sound sampling stations.

Stratum	Sample	Total Abundance	Major Taxa Abundance									
			Anne-lida	Annelida % of total abundance	Arthro-poda	Arthropoda % of total abundance	Echino-derm	Echinoderm % of total abundance	Mollusc	Mollusc % of total abundance	Misc. Taxa	Misc.Taxa % of total abundance
1	1	487	272	56%	109	22%	19	4%	68	14%	19	4%
Drayton	2	122	59	48%	24	20%	0	0%	35	29%	4	3%
Harbor	3	54	37	69%	0	0%	0	0%	17	31%	0	0%
2	4	864	74	9%	572	66%	51	6%	160	19%	7	1%
Semiahmoo	5	1118	411	37%	653	58%	41	4%	13	1%	0	0%
Bay	6	1100	85	8%	925	84%	24	2%	66	6%	0	0%
3	7	5055	358	7%	2062	41%	46	1%	2581	51%	8	0%
W. Boundary	8	783	555	71%	106	14%	65	8%	57	7%	0	0%
Bay	9	197	128	65%	6	3%	25	13%	37	19%	1	1%
4	10	521	150	29%	165	32%	18	3%	123	24%	65	12%
S. Boundary	11	1083	141	13%	653	60%	28	3%	261	24%	0	0%
Bay	12	856	77	9%	615	72%	54	6%	94	11%	16	2%
	13	554	124	22%	240	43%	80	14%	105	19%	5	1%
5	14	965	89	9%	455	47%	24	2%	392	41%	5	1%
Birch	15	1235	48	4%	554	45%	103	8%	527	43%	3	0%
Bay	16	746	90	12%	434	58%	21	3%	199	27%	2	0%
6	17	1454	227	16%	223	15%	14	1%	956	66%	34	2%
Cherry	18	1092	98	9%	268	25%	25	2%	689	63%	12	1%
Point	19	792	263	33%	68	9%	20	3%	362	46%	79	10%
7	20	1860	1270	68%	503	27%	70	4%	7	0%	10	1%
Bellingham	21	2672	1794	67%	748	28%	93	3%	25	1%	12	0%
Bay	22	1846	1661	90%	36	2%	20	1%	4	0%	125	7%
8	23	5125	4228	82%	712	14%	170	3%	7	0%	8	0%
Bellingham	24	2786	1843	66%	759	27%	173	6%	4	0%	7	0%
Bay	25	984	58	6%	802	82%	116	12%	1	0%	7	1%

Table 24 (cont.).

Stratum	Sample	Total Abundance	Major Taxa Abundance									
			Anne-lida	Annelida % of total abundance	Arthro-poda	Arthropoda % of total abundance	Echino-derm	Echinoderm % of total abundance	Mollusc	Mollusc % of total abundance	Misc. Taxa	Misc.Taxa % of total abundance
9A	26	1602	186	12%	1135	71%	266	17%	0	0%	15	1%
Bellingham	27	1908	549	29%	1118	59%	221	12%	4	0%	16	1%
Bay	28	143	102	71%	9	6%	14	10%	16	11%	2	1%
9B	59	1232	326	26%	720	58%	180	15%	4	0%	2	0%
Bellingham	60	3444	2380	69%	595	17%	437	13%	16	0%	16	0%
Bay	61	2672	702	26%	1294	48%	650	24%	15	1%	11	0%
10	29	5783	4129	71%	1194	21%	420	7%	27	0%	13	0%
Bellingham	30	1908	773	41%	444	23%	595	31%	93	5%	3	0%
Bay	31	280	108	39%	20	7%	95	34%	55	20%	2	1%
11	32	403	287	71%	5	1%	13	3%	96	24%	2	0%
Bellingham	33	379	272	72%	24	6%	19	5%	62	16%	2	1%
Bay	34	1303	1139	87%	11	1%	10	1%	141	11%	2	0%
12	35	520	261	50%	34	7%	163	31%	58	11%	4	1%
Bellingham	36	409	129	32%	26	6%	191	47%	62	15%	1	0%
Bay	37	232	157	68%	26	11%	7	3%	37	16%	5	2%
13	38	1202	397	33%	173	14%	564	47%	63	5%	5	0%
Samish/Bell.	39	509	121	24%	65	13%	24	5%	240	47%	59	12%
Bay	40	2529	511	20%	928	37%	347	14%	722	29%	21	1%
14	41	2651	1989	75%	185	7%	124	5%	349	13%	4	0%
Padilla	42	1189	370	31%	385	32%	93	8%	332	28%	9	1%
Bay (inner)	43	7671	5084	66%	2016	26%	66	1%	430	6%	75	1%
15	44	498	121	24%	176	35%	63	13%	136	27%	2	0%
Padilla	45	634	85	13%	143	23%	11	2%	389	61%	6	1%
Bay (outer)	46	398	61	15%	88	22%	23	6%	222	56%	4	1%

Table 24 (cont.).

Stratum	Sample	Total Abundance	Major Taxa Abundance									
			Anne-lida	Annelida % of total abundance	Arthro-poda	Arthropoda % of total abundance	Echino-derm	Echinoderm % of total abundance	Mollusc	Mollusc % of total abundance	Misc. Taxa	Misc.Taxa % of total abundance
16	47	633	333	53%	19	3%	1	0%	271	43%	9	1%
March	48	582	349	60%	47	8%	14	2%	151	26%	21	4%
Point	49	1555	755	49%	396	25%	78	5%	309	20%	17	1%
17	50	623	358	57%	78	13%	16	3%	165	26%	6	1%
Inner Fidalgo	51	1358	613	45%	43	3%	15	1%	675	50%	12	1%
Bay (inner)	52	339	166	49%	72	21%	11	3%	85	25%	5	1%
18	53	748	308	41%	181	24%	72	10%	167	22%	20	3%
Fidalgo	54	707	276	39%	140	20%	9	1%	275	39%	7	1%
Bay (outer)	55	633	305	48%	51	8%	63	10%	204	32%	10	2%
19	56	495	85	17%	35	7%	8	2%	365	74%	2	0%
March	57	203	45	22%	18	9%	11	5%	128	63%	1	0%
Point	58	646	319	49%	21	3%	10	2%	290	45%	6	1%
21	62	900	206	23%	85	9%	1	0%	588	65%	20	2%
Skagit	63	408	231	57%	93	23%	0	0%	80	20%	4	1%
Bay	64	796	254	32%	19	2%	3	0%	513	64%	7	1%
22	65	603	373	62%	39	6%	1	0%	177	29%	13	2%
Saratoga	66	600	404	67%	13	2%	0	0%	177	30%	6	1%
Passage (no.)	67	272	179	66%	27	10%	0	0%	61	22%	5	2%
23	68	1110	966	87%	5	0%	0	0%	134	12%	5	0%
Oak	69	194	95	49%	6	3%	0	0%	90	46%	3	2%
Harbor	70	1159	980	85%	4	0%	0	0%	163	14%	12	1%
24	71	650	577	89%	3	0%	1	0%	65	10%	4	1%
Penn	72	697	533	76%	14	2%	3	0%	139	20%	8	1%
Cove	73	318	215	68%	2	1%	1	0%	90	28%	10	3%

Table 24 (cont.).

Stratum	Sample	Total Abundance	Major Taxa Abundance									
			Anne-lida	Annelida % of total abundance	Arthro-poda	Arthropoda % of total abundance	Echino-derm	Echinoderm % of total abundance	Mollusc	Mollusc % of total abundance	Misc. Taxa	Misc.Taxa % of total abundance
25	74	223	141	63%	15	7%	0	0%	64	29%	3	1%
Saratoga	75	254	81	32%	38	15%	1	0%	128	50%	6	2%
Passage (mid.)	76	225	81	36%	25	11%	1	0%	117	52%	1	0%
26	77	429	203	47%	37	9%	1	0%	179	42%	9	2%
Saratoga	78	137	93	68%	19	14%	4	3%	7	5%	14	10%
Passage (so.)	79	203	153	75%	24	12%	3	1%	11	5%	12	6%
27	80	312	238	76%	30	10%	0	0%	42	13%	2	1%
Port	81	128	48	38%	13	10%	2	2%	62	48%	3	2%
Susan	82	148	39	26%	57	39%	3	2%	45	30%	4	3%
28	83	269	147	55%	43	16%	2	1%	59	22%	18	7%
Possession	84	332	158	48%	26	8%	4	1%	131	39%	13	4%
Sound	85	322	98	30%	43	13%	1	0%	174	54%	6	2%
29	86	54	12	22%	42	78%	0	0%	0	0%	0	0%
Everett	87	109	57	52%	52	48%	0	0%	0	0%	0	0%
Harbor (inner)	88	40	19	48%	21	53%	0	0%	0	0%	0	0%
30	89	74	69	93%	3	4%	0	0%	2	3%	0	0%
Everett	90	663	354	53%	290	44%	0	0%	18	3%	1	0%
Harbor (mid.)	91	92	36	39%	48	52%	0	0%	4	4%	4	4%
31	92	226	111	49%	73	32%	0	0%	42	19%	0	0%
Everett	93	574	280	49%	70	12%	1	0%	217	38%	6	1%
Harbor (out.)	94	813	337	41%	211	26%	8	1%	250	31%	7	1%
32	95	583	169	29%	37	6%	0	0%	364	62%	13	2%
Port	96	259	111	43%	36	14%	5	2%	96	37%	11	4%
Gardner	97	855	273	32%	40	5%	1	0%	539	63%	2	0%
33	98	579	270	47%	170	29%	0	0%	126	22%	13	2%
Snohomish	99	537	29	5%	44	8%	1	0%	463	86%	0	0%
River delta	100	24	2	8%	16	67%	0	0%	4	17%	2	8%

Table 25. Total abundance, taxa richness, Pielou's evenness, and Swartz's Dominance Index for the 1997 northern Puget Sound sampling stations.

Stratum	Sample	Abundance	Taxa Richness	Pielou's Evenness (J')	Swartz's Dominance Index
1	1	487	53	0.853	16
Drayton	2	122	24	0.882	10
Harbor	3	54	11	0.886	5
2	4	864	49	0.557	5
Semiahmoo	5	1118	29	0.437	2
Bay	6	1100	37	0.438	2
3	7	5055	66	0.481	3
W. Boundary	8	783	43	0.610	5
Bay	9	197	34	0.734	8
4	10	521	56	0.755	11
S. Boundary	11	1083	39	0.563	4
Bay	12	856	51	0.583	5
	13	554	60	0.762	13
5	14	965	41	0.631	5
Birch	15	1235	43	0.563	4
Bay	16	746	38	0.584	5
6	17	1454	74	0.623	9
Cherry	18	1092	53	0.524	4
Point	19	792	63	0.767	13
7	20	1860	49	0.390	2
Bellingham	21	2672	55	0.390	2
Bay	22	1846	41	0.508	5
8	23	5125	32	0.247	1
Bellingham	24	2786	36	0.402	3
Bay	25	984	37	0.493	3
9A	26	1602	30	0.553	3
Bellingham	27	1908	40	0.568	4
Bay	28	143	35	0.794	11
9B	59	1232	32	0.623	4
Bellingham	60	3444	39	0.422	3
Bay	61	2672	38	0.567	4
10	29	5783	41	0.352	2
Bellingham	30	1908	37	0.590	4
Bay	31	280	33	0.787	9

Table 25 (cont.). Total abundance, taxa richness, Pielou's evenness, and Swartz's Dominance Index for the 1997 northern Puget Sound sampling stations.

Stratum	Sample	Abundance	Taxa Richness	Pielou's Evenness (J')	Swartz's Dominance Index
11	32	403	33	0.614	5
Bellingham	33	379	47	0.707	10
Bay	34	1303	30	0.281	1
12	35	520	41	0.678	7
Bellingham	36	409	34	0.676	5
Bay	37	232	44	0.835	14
13	38	1202	41	0.549	4
Samish/Bell.	39	509	49	0.754	12
Bay	40	2529	83	0.578	5
14	41	2651	78	0.563	7
Padilla	42	1189	73	0.693	11
Bay (inner)	43	7671	110	0.484	4
15	44	498	52	0.796	12
Padilla	45	634	49	0.742	10
Bay (outer)	46	398	54	0.805	14
16	47	633	92	0.804	22
March	48	582	88	0.798	19
Point	49	1555	65	0.647	8
17	50	623	50	0.681	9
Fidalgo	51	1358	74	0.511	5
Bay (inner)	52	339	41	0.743	8
18	53	748	63	0.777	14
Fidalgo	54	707	50	0.709	9
Bay (outer)	55	633	103	0.817	25
19	56	495	71	0.666	17
March	57	203	45	0.849	14
Point	58	646	96	0.816	24
21	62	900	51	0.486	4
Skagit	63	408	64	0.755	13
Bay	64	796	71	0.513	6
22	65	603	61	0.644	7
Saratoga	66	600	36	0.591	3
Passage (no.)	67	272	40	0.774	9

Table 25 (cont.). Total abundance, taxa richness, Pielou's evenness, and Swartz's Dominance Index for the 1997 northern Puget Sound sampling stations.

Stratum	Sample	Abundance	Taxa Richness	Pielou's Evenness (J')	Swartz's Dominance Index
23	68	1110	43	0.572	5
Oak	69	194	33	0.806	10
Harbor	70	1159	41	0.491	4
24	71	650	23	0.550	3
Penn	72	697	51	0.570	4
Cove	73	318	36	0.709	6
25	74	223	32	0.809	10
Saratoga	75	254	32	0.628	6
Passage (mid.)	76	225	36	0.600	5
26	77	429	71	0.729	15
Saratoga	78	137	44	0.879	16
Passage (so.)	79	203	44	0.764	10
27	80	312	44	0.705	10
Port	81	128	33	0.719	10
Susan	82	148	18	0.724	4
28	83	269	70	0.867	25
Possession	84	332	44	0.730	10
Sound	85	322	31	0.623	5
29	86	54	7	0.725	3
Everett	87	109	9	0.572	2
Harbor (inner)	88	40	4	0.642	2
30	89	74	7	0.246	1
Everett	90	663	46	0.672	6
Harbor (mid.)	91	92	21	0.817	8
31	92	226	34	0.749	9
Everett	93	574	50	0.743	10
Harbor (out.)	94	813	78	0.777	16
32	95	583	63	0.661	10
Port	96	259	51	0.801	14
Gardner	97	855	60	0.535	6
33	98	579	57	0.797	14
Snohomish	99	537	23	0.514	2
River delta	100	24	6	0.877	3

Total abundance of arthropods ranged from 2,062 animals (station 7, Boundary Bay) to none (station 3, Drayton Harbor). Percent total abundance of arthropods ranged from 84% in East Boundary Bay (station 6) to 0% in Drayton Harbor (station 3). Only 14% of the 100 sampled stations were dominated by arthropods.

Total abundance of molluscs ranged from 2,581 animals at station 7 (Boundary Bay) to none at three stations in Everett Harbor (stations 86-88) and station 26 in Bellingham Bay. Percent total abundance of molluscs ranged from 86% (station 99, Snohomish River delta) to 0% at Everett Harbor (stations 86-88) and Bellingham Bay (station 26). Molluscs dominated 16% of the stations sampled.

Total abundance of echinoderms ranged from 650 at station 61 (Bellingham Bay) to 0 at several stations, primarily in Everett Harbor (stations 86-92), Drayton Harbor (stations 2 and 3), and Oak Harbor (stations 68-70). Percent total abundance ranged from 47% (Bellingham Bay, stations 36 and 38) to 0% at the previously mentioned stations in Everett Harbor, Drayton Harbor, and Oak Harbor. None of the samples were dominated by echinoderms.

Total abundance of miscellaneous taxa (i.e., Cnidaria, Platyhelminthes, Nemertina, Sipuncula, Phoronidae, Enteropneusta, and Ascidiacea) ranged from 125 organisms at station 22 (Bellingham Bay, northern tideflats) to none at ten stations (stations 86-89 and 93 in Everett Harbor; station 5 in Central Boundary Bay; station 3 in Drayton Harbor; stations 6, 8 and 11 in Boundary Bay; and station 99 in the Snohomish River delta). Percent total abundance of miscellaneous taxa ranged from 12% at stations 10 (Boundary Bay) and station 39 (Samish Bay/Bellingham Bay) to 0% at the stations indicated above in which miscellaneous taxa were absent.

Taxa Richness

The total number of recognizable species (taxa richness, Table 25) ranged from 110 in Padilla Bay (station 43) to 4 taxa in Everett Harbor (station 88). Stations with highest taxa richness (>70 taxa) were those in outer Fidalgo Bay and March Point (stations 47, 48, 55, 56, and 58); inner Fidalgo Bay (station 51); Padilla Bay (stations 41-43); Samish Bay (station 40); Skagit Bay (station 64); Cherry Point (station 17); Saratoga Passage (station 77); Possession Sound (station 70); and outer Everett Harbor (station 94). Stations with low taxa richness (< 25 taxa) included Everett Harbor (stations 86-89 and 91); Drayton Harbor (stations 2 and 3); Snohomish River delta (stations 99 and 100); Port Susan (station 82); and Penn Cove (station 71).

Evenness

Pielou's index of evenness (Table 25) ranged from 0.866 (high homogeneity or good evenness) in Drayton Harbor (station 3) to 0.246 (low homogeneity or poor evenness) in Everett Harbor (station 89). Relatively high evenness values (J'>0.80) were observed in Drayton Harbor (stations 1,2, and 3); Saratoga Passage (stations 74 and 78); Snohomish River delta (station 100); Possession Sound (station 83); outer Fidalgo Bay and March Point (stations 47, 55, 57, and 58); Everett Harbor (station 91); Oak Harbor (station 69); and Padilla Bay (station 46). Low

evenness values (J'<0.50) were found in Bellingham Bay (stations 20, 21, 23-25, 29, 34, and 60); Semiahmoo and Boundary Bay (stations 5-7); Padilla Bay (station 43); Skagit Bay (station 62); and Oak Harbor (station 70).

Swartz's Dominance Index (SDI)

Swartz's Dominance Index (SDI) values (Table 25) ranged from 25 dominant taxa at outer Fidalgo Bay (station 55) and Possession Sound (station 83) to 1 dominant taxon being dominant at Bellingham Bay (stations 23 and 34) and Everett Harbor (station 89). SDI values generally followed the same pattern as the evenness index values.

Summary

Most of the indices of benthic community structure followed similar patterns among the 100 stations, indicating both abundant and diverse assemblages at some stations and depauperate conditions at other stations. For example, samples from southern Strait of Georgia, outer Bellingham Bay, Padilla Bay, March Point, and Fidalgo Bay often had the most abundant and diverse infauna. In contrast, two or more of the calculated indices indicated relatively depauperate communities existed at some locations sampled in Drayton Harbor, Semiahmoo Bay, inner Bellingham Bay, Port Susan, and Everett Harbor.

Relationships between Benthic Indices and Sediment Characteristics, Toxicity, and Chemical Concentrations

Spearman rank correlations were calculated to quantify the relationships between benthic infaunal indices and many sediment characteristics. Because benthic infaunal structure can be a function of many naturally occurring factors, correlations were calculated for sedimentological variables (Table 26), as well as measures of toxicity (Table 27) and chemical concentrations (Tables 28-35).

Benthic Infauna Indices vs. Grain Size and Total Organic Carbon

The concentrations of many toxicants in sediments would be expected to increase with increasing concentrations of both fine-grained particles and total organic carbon. Therefore, many indices of benthic structure were expected to be negatively correlated with both parameters, although the abundance of some taxa could increase with increasing carbon content as a source of food. As expected, a number of the benthic infaunal indices were correlated with percent fines and total organic carbon in the sediments (Table 26). Indices of taxa richness, dominance, and Mollusca abundance decreased with increasing concentrations of fines or organic carbon or both. The abundance of miscellaneous taxa also decreased with increasing organic carbon content, and evenness decreased with increasing concentrations of fines. None of the correlation coefficients with positive signs were statistically significant.

Table 26. Spearman rank correlations between benthic infaunal indices, grain size (% fines), and % TOC.

Benthic Index	% fines (p)	% TOC (p)
Total Abundance	0.094 ns	-0.19 ns
Taxa Richness	-0.532 ****	-0.6 ****
Pielou's Evenness (J')	-0.331 ***	-0.105 ns
Swartz's Dominance Index	-0.398 ****	-0.311 **
Annelid Abundance	0.109 ns	-0.048 ns
Arthropod Abundance	-0.049 ns	-0.137 ns
Echinoderm Abundance	0.175 ns	-0.102 ns
Mollusca Abundance	-0.431 ****	-0.562 ****
Miscellaneous Taxa Abundance	-0.129 ns	-0.327 ***

ns = p>0.05
* p<0.05
** p<0.01
*** p<0.001
**** p<0.0001

Table 27. Spearman rank correlations between benthic infaunal indices and the results of four toxicity tests for all stations.

Benthic Index	Amphipod survival (p)	Urchin fertilization (p)	Microbial biolumin-escence (p)	Cytochrome P450 (p)
Total Abundance	0.143 ns	0.248 *	0.007 ns	-0.291 **
Taxa Richness	0.163 ns	0.238 *	0.225 *	-0.015 ns
Pielou's Evenness (J')	-0.016 ns	0.012 ns	0.096 ns	0.350 ***
Swartz's Dominance Index	0.104 ns	0.181 ns	0.198 *	0.281 **
Annelid Abundance	0.096 ns	0.003 ns	-0.101 ns	-0.124 ns
Arthropod Abundance	0.059 ns	0.295 **	0.044 ns	-0.128 ns
Echinoderm Abundance	0.220 *	0.465 ****	0.131 ns	-0.178 ns
Mollusca Abundance	0.041 ns	0.229 *	0.098 ns	-0.155 ns
Miscellaneous Taxa Abundance	0.247 *	0.152 ns	0.243 *	-0.157 ns

ns = p>0.05
* p<0.05
** p<0.01
*** p<0.001
**** p<0.0001

Table 28. Spearman-rank correlations (rho, corrected for ties) and significance levels (p) for results of five benthic infaunal indices and concentrations of trace metals (total digestion), chlorinated organic hydrocarbons, and total PAHs, normalized to their respective ERM, SQS and CSL values for all sites (n=100).

Chemical	Total Abundance	(p)	Taxa Richness	(p)	Pielou's Evenness (J')	(p)	Swartz's Dominance	(p)	Annelida Abundance	(p)	Arthropod Abundance	(p)	Echinoderm Abundance	(p)	Mollusca Abundance	(p)	Misc. Taxa Abundance	(p)
ERM values																		
mean ERM quotients for 9 trace metals:	-0.01	ns	-0.498	****	-0.277	**	-0.36	***	0.107	ns	-0.085	ns	-0.008	ns	-0.575	****	-0.066	ns
mean ERM quotients for 3 chlorinated organic hydrocarbons:	-0.259	**	-0.59	****	-0.056	ns	-0.275	**	-0.119	ns	-0.205	*	-0.166	ns	-0.491	****	-0.324	**
mean ERM quotients for 13 polynuclear aromatic hydrocarbons:	-0.168	ns	-0.294	**	0.111	ns	-0.013	ns	-0.104	ns	0.004	ns	-0.025	ns	-0.358	***	-0.15	ns
mean ERM quotients for 25 substances:	-0.13	ns	-0.533	****	-0.198	*	-0.33	***	0.012	ns	-0.107	ns	-0.119	ns	-0.607	****	-0.181	ns
SQS values																		
mean SQS quotients for 8 trace metals:	-0.183	ns	-0.602	****	-0.156	ns	-0.331	***	-0.007	ns	-0.171	ns	-0.093	ns	-0.629	****	-0.248	*
mean SQS quotients for 6 low molecular weight polynuclear aromatic hydrocarbons:	-0.109	ns	-0.072	ns	0.185	ns	0.101	ns	-0.117	ns	0.117	ns	0.052	ns	-0.196	ns	-0.071	ns
mean SQS quotients for 9 high molecular weight polynuclear aromatic hydrocarbons:	-0.217	*	-0.058	ns	0.205	*	0.143	ns	-0.273	**	-0.009	ns	-0.13	ns	-0.041	ns	-0.099	ns
mean SQS quotients for 15 polynuclear aromatic hydrocarbons:	-0.164	ns	-0.074	ns	0.203	*	0.125	ns	-0.193	ns	0.06	ns	-0.041	ns	-0.122	ns	-0.095	ns

Table 28 (cont.). Spearman-rank correlations (rho, corrected for ties) and significance levels (p) for results of five benthic infaunal indices and concentrations of trace metals (total digestion), chlorinated organic hydrocarbons, and total PAHs, normalized to their respective ERM, SQS and CSL values for all sites (n=100).

Chemical	Total Abundance	(p)	Taxa Richness	(p)	Pielou's Evenness (J')	(p)	Swartz's Dominance	(p)	Annelida Abundance	(p)	Arthropod Abundance	(p)	Echinoderm Abundance	(p)	Mollusca Abundance	(p)	Misc. Taxa Abundance	(p)
CSL values																		
mean CSL quotients for 8 trace metals:	-0.174	ns	-0.603	****	-0.167	ns	-0.34	***	-0.001	ns	-0.164	ns	-0.081	ns	-0.633	****	-0.25	*
mean CSL quotients for 6 low molecular weight polynuclear aromatic hydrocarbons:	-0.127	ns	-0.079	ns	0.203	*	0.117	ns	-0.106	ns	0.094	ns	0.046	ns	-0.214	*	-0.084	ns
mean CSL quotients for 9 high molecular weight polynuclear aromatic hydrocarbons:	-0.221	*	-0.047	ns	0.202	*	0.148	ns	-0.287	**	-0.02	ns	-0.14	ns	-0.024	ns	-0.101	ns
mean CSL quotients for 15 polynuclear aromatic hydrocarbons:	-0.174	ns	-0.074	ns	0.211	*	0.134	ns	-0.191	ns	0.05	ns	-0.041	ns	-0.124	ns	-0.102	ns

ns= p>0.05
* p<0.05
** p<0.01
*** p<0.001
**** p<0.0001

Table 29. Spearman-rank correlations (rho, corrected for ties) and significance levels (p) for results of five benthic infaunal indices and concentrations of trace metals (total digestion), chlorinated organic hydrocarbons, and total PAHs, normalized to their respective ERM, SQS and CSL values for Everett Harbor sites (n=15).

Chemical	Total Abundance	(p)	Taxa Richness	(p)	Pielou's Evenness (J')	(p)	Swartz's Dominance	(p)	Annelida Abundance	(p)	Arthropod Abundance	(p)	Echinoderm Abundance	(p)	Mollusca Abundance	(p)	Misc. Taxa Abundance	(p)
ERM values																		
mean ERM quotients for 9 trace metals:	-0.346	ns	-0.388	ns	-0.168	ns	-0.311	ns	-0.331	ns	0.077	ns	0.117	ns	-0.319	ns	-0.361	ns
mean ERM quotients for 3 chlorinated organic hydrocarbons:	-0.657	**	-0.608	*	-0.05	ns	-0.438	ns	-0.509	ns	-0.046	ns	-0.311	ns	-0.746	**	-0.621	*
mean ERM quotients for 13 polynuclear aromatic hydrocarbons:	-0.389	ns	-0.574	*	-0.225	ns	-0.522	*	-0.218	ns	0.193	ns	-0.482	ns	-0.541	*	-0.772	***
mean ERM quotients for 25 substances:	-0.321	ns	-0.4	ns	-0.018	ns	-0.32	ns	-0.159	ns	0.306	ns	-0.222	ns	-0.437	ns	-0.619	*
SQS values																		
mean SQS quotients for 8 trace metals:	-0.371	ns	-0.52	*	-0.221	ns	-0.492	ns	-0.254	ns	0.195	ns	-0.243	ns	-0.534	*	-0.66	**
mean SQS quotients for 6 low molecular weight polynuclear aromatic hydrocarbons:	-0.086	ns	-0.263	ns	-0.05	ns	-0.262	ns	0.146	ns	0.459	ns	-0.383	ns	-0.315	ns	-0.605	*
mean SQS quotients for 9 high molecular weight polynuclear aromatic hydrocarbons:	-0.186	ns	-0.229	ns	0.036	ns	-0.153	ns	0.089	ns	0.363	ns	-0.331	ns	-0.401	ns	-0.525	*
mean SQS quotients for 15 polynuclear aromatic hydrocarbons:	-0.132	ns	-0.273	ns	-0.014	ns	-0.257	ns	0.107	ns	0.459	ns	-0.385	ns	-0.38	ns	-0.623	*

Table 29 (cont.). Spearman-rank correlations (rho, corrected for ties) and significance levels (p) for results of five benthic infaunal indices and concentrations of trace metals (total digestion), chlorinated organic hydrocarbons, and total PAHs, normalized to their respective ERM, SQS and CSL values for Everett Harbor sites (n=15).

Chemical	Total Abundance	(p)	Taxa Richness	(p)	Pielou's Evenness (J')	(p)	Swartz's Dominance	(p)	Annelida Abundance	(p)	Arthropod Abundance	(p)	Echinoderm Abundance	(p)	Mollusca Abundance	(p)	Misc. Taxa Abundance	(p)
CSL values																		
mean CSL quotients for 8 trace metals:	-0.371	ns	-0.52	*	-0.221	ns	-0.492	ns	-0.254	ns	0.195	ns	-0.243	ns	-0.534	*	-0.66	**
mean CSL quotients for 6 low molecular weight polynuclear aromatic hydrocarbons:	-0.082	ns	-0.263	ns	-0.021	ns	-0.259	ns	0.15	ns	0.466	ns	-0.405	ns	-0.326	ns	-0.599	*
mean CSL quotients for 9 high molecular weight polynuclear aromatic hydrocarbons:	-0.15	ns	-0.204	ns	0.018	ns	-0.153	ns	0.132	ns	0.336	ns	-0.28	ns	-0.391	ns	-0.512	ns
mean CSL quotients for 15 polynuclear aromatic hydrocarbons:	-0.15	ns	-0.284	ns	-0.011	ns	-0.264	ns	0.089	ns	0.463	ns	-0.407	ns	-0.398	ns	-0.647	**

ns= p>0.05
* p<0.05
** p<0.01
*** p<0.001
**** p<0.0001

Table 30. Spearman-rank correlations (rho, corrected for ties) and significance levels (p) for results of five benthic infaunal indices and concentrations of trace metals (total digestion).

Chemical	Total Abundance	(p)	Taxa Richness	(p)	Pielou's Evenness (J')	(p)	Swartz's Dominance	(p)	Annelida Abundance	(p)	Arthropoda Mollusca	(p)	Echinoderm Abundance	(p)	Mollusca Abundance	(p)	Misc. Taxa Abundance	(p)
Aluminum	0.157	ns	-0.258	**	-0.274	**	-0.232	*	0.252	*	-0.064	ns	0.126	ns	-0.323	**	0.106	ns
Antimony	-0.166	ns	-0.151	ns	0.165	ns	0.039	ns	-0.127	ns	-0.008	ns	-0.105	ns	-0.178	ns	-0.113	ns
Arsenic	0.027	ns	-0.379	***	-0.235	*	-0.301	**	0.151	ns	0.032	ns	-0	ns	-0.413	****	-0.042	ns
Barium	0.326	***	-0.147	ns	-0.289	**	-0.228	*	0.242	*	0.089	ns	0.294	**	-0.176	ns	0.133	ns
Beryllium	-0.13	ns	-0.155	ns	-0.05	ns	-0.061	ns	-0.093	ns	-0.101	ns	-0.005	ns	-0.039	ns	-0.014	ns
Cadmium	-0.246	*	-0.289	**	-0.087	ns	-0.254	*	-0.147	ns	-0.137	ns	-0.34	***	-0.282	**	-0.311	**
Calcium	0.289	**	0.323	**	-0.018	ns	0.13	ns	0.199	*	0.212	*	0.109	ns	0.184	ns	0.23	*
Chromium	0.05	ns	-0.48	****	-0.328	***	-0.379	***	0.147	ns	-0.087	ns	-0.001	ns	-0.511	****	-0.057	ns
Cobalt	-0.031	ns	-0.359	***	-0.229	*	-0.243	*	0.06	ns	-0.084	ns	-0.094	ns	-0.458	****	0.048	ns
Copper	-0.225	*	-0.581	****	-0.142	ns	-0.317	**	-0.037	ns	-0.245	*	-0.28	**	-0.543	****	-0.24	*
Iron	0.08	ns	-0.404	****	-0.274	**	-0.289	**	0.151	ns	-0.044	ns	0.12	ns	-0.448	****	-0.002	ns
lead	-0.348	***	-0.515	****	0.016	ns	-0.148	ns	-0.208	*	-0.202	*	-0.205	*	-0.467	****	-0.293	**
Magnesium	0.09	ns	-0.431	****	-0.353	***	-0.38	****	0.187	ns	-0.097	ns	0.076	ns	-0.467	****	0.01	ns
Manganese	-0.013	ns	-0.149	ns	-0.136	ns	-0.065	ns	0.139	ns	-0.145	ns	-0.087	ns	-0.3	**	0.161	ns
Mercury	-0.171	ns	-0.555	****	-0.119	ns	-0.277	**	0.013	ns	-0.147	ns	-0.03	ns	-0.603	****	-0.203	*
Nickel	0.035	ns	-0.426	****	-0.293	**	-0.333	***	0.135	ns	-0.119	ns	-0.016	ns	-0.5	****	0.035	ns
Potassium	0.142	ns	-0.276	**	-0.225	*	-0.218	*	0.12	ns	-0.031	ns	0.268	**	-0.147	ns	0.035	ns
Selenium	-0.365	***	-0.271	**	0.075	ns	-0.05	ns	-0.144	ns	-0.36	***	-0.436	****	-0.205	*	-0.291	**
Silver	-0.005	ns	-0.071	ns	-0.018	ns	-0.007	ns	0.061	ns	-0.07	ns	-0.113	ns	0.069	ns	-0.008	ns
Sodium	-0.27	**	-0.549	****	-0.07	ns	-0.285	**	-0.181	ns	-0.254	*	-0.096	ns	-0.331	***	-0.278	**
Thallium	-0.299	**	-0.283	**	0.054	ns	-0.171	ns	-0.282	**	-0.091	ns	-0.282	**	-0.254	*	-0.276	**
Tin	-0.369	***	-0.351	**	0.194	ns	0.01	ns	-0.206	**	-0.181	ns	-0.23	ns	-0.342	*	-0.293	**
Titanium	0.318	**	-0.183	ns	-0.328	***	-0.25	*	0.12	ns	0.258	**	0.438	****	-0.228	*	0.063	ns
Vanadium	0.025	ns	-0.472	****	-0.294	**	-0.335	***	0.089	ns	-0.114	ns	0.063	ns	-0.459	****	-0.051	ns
Zinc	-0.12	ns	-0.55	****	-0.184	ns	-0.325	***	-0.001	ns	-0.082	ns	-0.029	ns	-0.585	****	-0.239	*

ns= p>0.05
* p<0.05
** p<0.01
*** p<0.001

Table 31. Spearman-rank correlations (rho, corrected for ties) and significance levels (p) for results of five benthic infaunal indices and concentrations of trace metals (partial digestion).

Chemical	Total Abund-ance	(p)	Taxa Richness	(p)	Pielou's Evenness (J')	(p)	Swartz's Dominance	(p)	Annelida Abundance	(p)	Arthropoda Abundance	(p)	Echinoderm Abundance	(p)	Mollusca Abundance	(p)	Misc. Taxa Abundance	(p)
Aluminum	-0.129	ns	-0.544	****	-0.188	ns	-0.295	**	0.047	ns	-0.262	**	-0.071	ns	-0.477	****	-0.106	ns
Antimony	-0.156	ns	-0.1	ns	-0.014	ns	-0.079	ns	-0.129	ns	-0.068	ns	-0.176	ns	-0.131	ns	-0.163	ns
Arsenic	-0.131	ns	-0.538	****	-0.234	*	-0.374	***	0.013	ns	-0.133	ns	-0.246	*	-0.499	****	-0.154	ns
Barium	-0.059	ns	-0.575	****	-0.222	*	-0.338	***	0.062	ns	-0.12	ns	0.045	ns	-0.568	****	-0.151	ns
Beryllium	-0.08	ns	-0.525	****	-0.174	ns	-0.284	**	-0.048	ns	-0.12	ns	0.153	ns	-0.418	****	-0.159	ns
Cadmium	-0.347	***	-0.322	**	0.157	ns	-0.079	ns	-0.159	ns	-0.213	*	-0.39	****	-0.306	**	-0.34	***
Calcium	0.023	ns	-0.119	ns	0.025	ns	0.053	ns	0.068	ns	-0.141	ns	0.07	ns	-0.085	ns	-0.122	ns
Chromium	-0.076	ns	-0.513	****	-0.234	*	-0.326	***	0.112	ns	-0.228	*	-0.115	ns	-0.494	****	-0.075	ns
Cobalt	-0.05	ns	-0.416	****	-0.21	*	-0.256	*	0.084	ns	-0.132	ns	-0.055	ns	-0.512	****	0.021	ns
Copper	-0.26	**	-0.576	****	-0.114	ns	-0.293	**	-0.044	ns	-0.295	**	-0.327	***	-0.536	****	-0.237	*
Iron	-0.02	ns	-0.486	****	-0.237	*	-0.306	**	0.113	ns	-0.154	ns	0.024	ns	-0.476	****	-0.066	ns
Lead	-0.313	**	-0.519	****	0.012	ns	-0.172	ns	-0.191	ns	-0.195	ns	-0.171	ns	-0.484	****	-0.3	**
Magnesium	-0.001	ns	-0.518	****	-0.296	**	-0.382	****	0.112	ns	-0.136	ns	0.029	ns	-0.559	****	-0.053	ns
Manganese	-0.132	ns	-0.434	****	-0.154	ns	-0.227	*	0.025	ns	-0.202	*	-0.093	ns	-0.52	****	0.019	ns
Mercury	-0.171	ns	-0.555	****	-0.119	ns	-0.277	**	0.013	ns	-0.147	ns	-0.03	ns	-0.603	****	-0.203	*
Nickel	0.035	ns	-0.436	****	-0.298	**	-0.345	***	0.144	ns	-0.13	ns	-0.001	ns	-0.516	****	0.017	ns
Potassium	-0.321	**	-0.507	****	-0.025	ns	-0.156	ns	-0.164	ns	-0.387	****	-0.172	ns	-0.307	**	-0.263	**
Selenium	-0.008	ns	-0.27	**	-0.104	ns	-0.208	*	0.109	ns	-0.028	ns	0.121	ns	-0.275	**	-0.13	ns
Silver	0.268	**	-0.313	**	-0.281	**	-0.345	***	0.13	ns	0.302	**	0.605	****	-0.349	***	-0.194	ns
Sodium	-0.358	***	-0.605	****	-0.041	ns	-0.247	*	-0.187	ns	-0.34	***	-0.197	*	-0.438	****	-0.36	***
Thallium	bql		bql		bql		bql		bql		bql		bql		bql		bql	
Tin	-0.254	*	-0.316	**	0.095	ns	-0.132	ns	-0.191	ns	-0.025	ns	-0.31	**	-0.359	***	-0.313	**
Titanium	0.041	ns	-0.41	****	-0.203	*	-0.236	*	0.09	ns	-0.107	ns	0.098	ns	-0.314	**	-0.043	ns
Vanadium	-0.149	ns	-0.541	****	-0.196	ns	-0.305	**	0.03	ns	-0.273	**	-0.132	ns	-0.458	****	-0.11	ns
Zinc	-0.242	*	-0.598	****	-0.114	ns	-0.295	**	-0.066	ns	-0.219	*	-0.196	ns	-0.572	****	-0.271	**

bql= below quantitation limit
ns= $p>0.05$
* $p<0.05$
** $p<0.01$
*** $p<0.001$
**** $p<0.0001$

Table 32. Spearman-rank correlations (rho, corrected for ties) and significance levels (p) for results of five benthic infaunal indices and concentrations of low molecular polynuclear aromatic hydrocarbons.

Chemical	Total Abundance	(p)	Taxa Richness	(p)	Pielou's Evenness (J')	(p)	Swartz's Dominance	(p)	Annelida Abundance	(p)	Arthropoda Abundance	(p)	Echinoderm Abundance	(p)	Mollusca Abundance	(p)	Misc. Taxa Abundance	(p)
Acenaphthene	-0.097	ns	-0.23	*	0.084	ns	-0.002	ns	-0.052	ns	0.058	ns	0.004	ns	-0.294	**	-0.094	ns
Acenaphthylene	-0.239	*	-0.264	**	0.202	*	0.074	ns	-0.119	ns	-0.034	ns	-0.053	ns	-0.322	**	-0.197	*
Anthracene	-0.191	ns	-0.26	**	0.141	ns	0.02	ns	-0.127	ns	-0.027	ns	-0.093	ns	-0.302	**	-0.125	ns
Biphenyl	0.005	ns	0.022	ns	0.095	ns	0.048	ns	-0.084	ns	0.096	ns	0.135	ns	0.052	ns	-0.141	ns
Fluorene	-0.161	ns	-0.269	**	0.117	ns	0.006	ns	-0.086	ns	0.023	ns	0.004	ns	-0.358	***	-0.118	ns
2,6-Dimethylnaphthalene	-0.09	ns	-0.405	****	-0.092	ns	-0.245	*	0.033	ns	-0.134	ns	-0.043	ns	-0.317	**	-0.271	**
1-Methylnaphthalene	-0.027	ns	-0.314	**	-0.038	ns	-0.147	ns	-0.054	ns	0.175	ns	0.198	*	-0.399	****	-0.183	ns
2-Methylnaphthalene	-0.012	ns	-0.306	**	-0.063	ns	-0.154	ns	-0.031	ns	0.179	ns	0.176	ns	-0.413	****	-0.147	ns
Naphthalene	-0.119	ns	-0.29	**	0.065	ns	-0.052	ns	-0.02	ns	0.063	ns	0.075	ns	-0.394	****	-0.152	ns
1-Methylphenanthrene	-0.093	ns	-0.322	**	0.003	ns	-0.113	ns	-0.129	ns	0.142	ns	0.134	ns	-0.401	****	-0.149	ns
Phenanthrene	-0.149	ns	-0.285	**	0.105	ns	-0.017	ns	-0.103	ns	0.071	ns	0.042	ns	-0.41	****	-0.123	ns
1,6,7-Trimethylnaphthalene	-0.098	ns	-0.316	**	0.02	ns	-0.082	ns	-0.09	ns	0.126	ns	0.18	ns	-0.437	****	-0.131	ns
2-Methylphenanthrene	-0.101	ns	-0.335	***	-0.011	ns	-0.12	ns	-0.129	ns	0.119	ns	0.158	ns	-0.45	****	-0.17	ns
Dibenzothiophene	-0.14	ns	-0.316	**	0.071	ns	-0.059	ns	-0.1	ns	0.028	ns	0.008	ns	-0.363	***	-0.149	ns
Retene	-0.106	ns	-0.332	***	-0.085	ns	-0.155	ns	-0.047	ns	0.064	ns	-0.011	ns	-0.518	****	-0.097	ns
sum 7 LPAH	-0.14	ns	-0.283	**	0.099	ns	-0.02	ns	-0.083	ns	0.063	ns	0.051	ns	-0.396	****	-0.129	ns
sum 6 LPAH	-0.109	ns	-0.08	ns	0.189	ns	0.102	ns	-0.104	ns	0.116	ns	0.062	ns	-0.229	*	-0.068	ns
Total LPAH	-0.152	ns	-0.35	***	0.046	ns	-0.107	ns	-0.091	ns	-0.013	ns	0.004	ns	-0.346	***	-0.196	ns

ns= p>0.05 ** p<0.01 **** p<0.0001
* p<0.05 *** p<0.001

Table 33. Spearman-rank correlations (rho, corrected for ties) and significance levels (p) for results of five benthic infaunal indices and concentrations of high molecular weight aromatic hydorcarbons.

Chemical	Total Abundance	(p)	Taxa Richness	(p)	Pielou's Evenness (J')	(p)	Swartz's Dominance	(p)	Annelida Abundance	(p)	Arthropoda Abundance	(p)	Echinoderm Abundance	(p)	Mollusca Abundance	(p)	Misc. Taxa Abundance	(p)
Benzo(a)anthracene	-0.232	*	-0.289	**	0.148	ns	0.008	ns	-0.24	*	-0.02	ns	-0.102	ns	-0.28	**	-0.202	*
Benzo(a)pyrene	-0.246	*	-0.306	**	0.139	ns	-0.006	ns	-0.252	*	-0.049	ns	-0.105	ns	-0.285	**	-0.214	*
Benzo(b)fluoranthene	-0.236	*	-0.376	***	0.071	ns	-0.075	ns	-0.193	ns	-0.093	ns	-0.129	ns	-0.351	***	-0.232	*
Benzo(e)pyrene	-0.244	*	-0.386	****	0.082	ns	-0.071	ns	-0.189	ns	-0.095	ns	-0.114	ns	-0.367	***	-0.235	*
Benzo(g,h,i)perylene	-0.241	*	-0.431	****	0.039	ns	-0.126	ns	-0.197	*	-0.11	ns	-0.125	ns	-0.389	****	-0.235	*
Benzo(k)fluoranthene	-0.272	**	-0.346	***	0.126	ns	-0.027	ns	-0.203	*	-0.126	ns	-0.173	ns	-0.315	**	-0.208	*
Chrysene	-0.178	ns	-0.316	**	0.088	ns	-0.041	ns	-0.14	ns	-0.018	ns	-0.059	ns	-0.346	***	-0.161	ns
Dibenz(a,h)-anthracene	-0.244	*	-0.263	**	0.105	ns	-0.005	ns	-0.304	**	-0.066	ns	-0.118	ns	-0.175	ns	-0.262	**
Fluoranthene	-0.188	ns	-0.321	**	0.105	ns	-0.032	ns	-0.113	ns	-0.023	ns	-0.075	ns	-0.353	***	-0.177	ns
Indeno(1,2,3-c,d)-pyrene	-0.259	**	-0.372	***	0.092	ns	-0.066	ns	-0.243	*	-0.093	ns	-0.125	ns	-0.336	***	-0.246	*
Perylene	-0.441	****	-0.32	**	0.123	ns	0.021	ns	-0.277	**	-0.335	***	-0.434	***	-0.263	**	-0.171	ns
Pyrene	-0.2	*	-0.315	**	0.119	ns	-0.024	ns	-0.13	ns	-0.024	ns	-0.09	ns	-0.342	***	-0.173	ns
sum 6 HPAH	-0.187	ns	-0.321	**	0.097	ns	-0.041	ns	-0.139	ns	-0.016	ns	-0.071	ns	-0.335	***	-0.184	ns
sum of 9 HPAH	-0.176	ns	-0.072	ns	0.206	*	0.136	ns	-0.189	ns	0.026	ns	-0.081	ns	-0.11	ns	-0.073	ns
Total HPAH	-0.242	*	-0.344	***	0.114	ns	-0.03	ns	-0.164	ns	-0.072	ns	-0.129	ns	-0.348	***	-0.18	ns
sum 13 PAH	-0.181	ns	-0.303	**	0.115	ns	-0.016	ns	-0.112	ns	-0.008	ns	-0.046	ns	-0.355	***	-0.166	ns
sum 15 PAH	-0.146	ns	-0.078	ns	0.198	*	0.123	ns	-0.154	ns	0.065	ns	-0.029	ns	-0.155	ns	-0.075	ns
Total HPAH	-0.242	*	-0.344	***	0.114	ns	-0.03	ns	-0.164	ns	-0.072	ns	-0.129	ns	-0.348	***	-0.18	ns
Total PAH	-0.213	*	-0.346	***	0.103	ns	-0.042	ns	-0.125	ns	-0.07	ns	-0.092	ns	-0.353	***	-0.179	ns

ns= p>0.05 ** p<0.01 **** p<0.0001
* p<0.05 *** p<0.001

Table 34. Spearman-rank correlations (rho, corrected for ties) and significance levels (p) for results of five benthic infaunal indices and concentrations of DDT and PCB compounds.

Chemical	Total Abundance	(p)	Taxa Richness	(p)	Pielou's Evenness (J')	(p)	Swartz's Dominance	(p)	Annelida Abundance	(p)	Arthropoda Abundance	(p)	Echinoderm Abundance	(p)	Mollusca Abundance	(p)	Misc. Taxa Abundance	(p)
Aroclor 1254	-0.223	*	-0.554	****	-0.082	ns	-0.271	**	-0.087	ns	-0.224	*	-0.169	ns	-0.422	****	-0.416	****
no bqls	-0.352	ns	-0.504	*	-0.316	ns	-0.525	*	-0.172	ns	0.051	ns	-0.389	ns	-0.551	*	-0.788	***
Everett Harbor	-0.478	ns	-0.643	*	-0.132	ns	-0.554	*	-0.286	ns	0.190	ns	-0.571	*	-0.743	**	-0.835	***
Aroclor 1260	-0.254	*	-0.505	****	-0.038	ns	-0.218	*	-0.088	ns	-0.228	*	-0.184	ns	-0.431	****	-0.291	**
no bqls	-0.750	ns	-0.685	ns	-0.643	ns	-0.679	ns	-0.750	ns	-0.714	ns	-0.356	ns	-0.811	*	-0.453	ns
Everett Harbor	-0.750	ns	-0.685	ns	-0.643	ns	-0.679	ns	-0.750	ns	-0.714	ns	-0.356	ns	-0.811	*	-0.453	ns
Total Aroclors	-0.303	**	-0.572	****	-0.038	ns	-0.244	*	-0.132	ns	-0.262	**	-0.219	*	-0.466	****	-0.351	***
no bqls	-0.303	**	-0.572	****	-0.038	ns	-0.244	*	-0.132	ns	-0.262	**	-0.219	*	-0.466	****	-0.351	***
Everett Harbor	-0.651	**	-0.614	*	-0.068	ns	-0.457	ns	-0.504	ns	-0.061	ns	-0.290	ns	-0.739	**	-0.646	**
4,4' DDE	-0.079	ns	0.245	ns	-0.171	ns	-0.307	ns	0.023	ns	-0.310	ns	-0.175	ns	0.030	ns	-0.166	ns
no bqls	0.866	ns	0.943	ns	0.029	*	0.165	ns	0.864	ns	0.659	ns	ND		0.699	ns	0.251	ns
Everett Harbor	ND		ND		ND		ND		ND		ND		ND		ND		ND	
Total DDTs	-0.251	*	-0.567	****	-0.037	ns	-0.243	*	-0.118	ns	-0.186	ns	-0.149	ns	-0.476	****	-0.288	**
no bqls	-0.251	*	-0.567	****	-0.037	ns	-0.243	*	-0.118	ns	-0.186	ns	-0.149	ns	-0.476	****	-0.288	**
Everett Harbor	-0.470	ns	-0.422	ns	0.050	ns	-0.314	ns	-0.391	ns	0.120	ns	-0.133	ns	-0.626	*	-0.479	ns
PCB Congener 28	-0.302	**	-0.581	****	-0.062	ns	-0.280	**	-0.185	ns	-0.265	**	-0.212	*	-0.427	****	-0.307	**
no bqls	-0.528	ns	-0.689	*	-0.278	ns	-0.641	*	-0.401	ns	0.018	ns	-0.587	ns	-0.699	*	-0.640	*
Everett Harbor	-0.452	ns	-0.580	ns	-0.126	ns	-0.489	ns	-0.318	ns	0.100	ns	-0.624	ns	-0.715	*	-0.623	ns
PCB Congener 44	-0.309	**	-0.580	****	-0.017	ns	-0.227	*	-0.145	ns	-0.287	**	-0.238	*	-0.430	****	-0.325	***
no bqls	0.174	ns	0.324	ns	0.928	**	0.824	*	-0.116	ns	0.551	ns	ND		0.154	ns	0.133	ns
Everett Harbor	0.174	ns	0.324	ns	0.928	**	0.824	*	-0.116	ns	0.551	ns	ND		0.154	ns	0.133	ns
PCB Congener 52	-0.329	***	-0.592	****	-0.009	ns	-0.235	*	-0.178	ns	-0.264	**	-0.269	**	-0.456	****	-0.355	***
no bqls	-0.448	ns	-0.455	ns	-0.092	ns	-0.407	ns	-0.546	ns	0.141	ns	-0.747	*	-0.615	ns	-0.740	*
Everett Harbor	-0.448	ns	-0.455	ns	-0.092	ns	-0.407	ns	-0.546	ns	0.141	ns	-0.747	*	-0.615	ns	-0.740	*
PCB Congener 66	-0.206	*	-0.573	****	-0.103	ns	-0.327	***	-0.089	ns	-0.203	*	-0.130	ns	-0.431	****	-0.404	****
no bqls	-0.513	*	-0.708	**	-0.297	ns	-0.637	**	-0.527	*	0.017	ns	-0.297	ns	-0.597	*	-0.812	****
Everett Harbor	-0.597	*	-0.618	*	-0.074	ns	-0.486	ns	-0.574	*	0.083	ns	-0.283	ns	-0.716	**	-0.697	**

Table 34 (cont.). Spearman-rank correlations (rho, corrected for ties) and significance levels (p) for results of five benthic infaunal indices and concentrations of DDT and PCB compounds.

Chemical	Total Abund-ance	(p)	Taxa Rich-ness	(p)	Pielou's Evenness (J')	(p)	Swartz's Dominance	(p)	Annelida Abundance	(p)	Arthropoda Abundance	(p)	Echinoderm Abundance	(p)	Mollusca Abundance	(p)	Misc. Taxa Abundance	(p)
PCB Congener 77	-0.166	ns	-0.536	****	-0.132	ns	-0.309	**	-0.065	ns	-0.230	*	-0.085	ns	-0.376	***	-0.355	***
no bqls	0.273	ns	0.067	ns	-0.164	ns	0.000	ns	0.321	ns	-0.310	ns	0.296	ns	0.164	ns	-0.374	ns
Everett Harbor	0.036	ns	-0.286	ns	-0.036	ns	-0.109	ns	0.107	ns	-0.162	ns	0.418	ns	-0.107	ns	-0.595	ns
PCB Congener 101	-0.185	ns	-0.523	****	-0.089	ns	-0.282	**	-0.072	ns	-0.182	ns	-0.149	ns	-0.410	****	-0.388	****
no bqls	-0.498	*	-0.609	**	-0.295	ns	-0.581	*	-0.331	ns	-0.010	ns	-0.415	ns	-0.614	**	-0.845	****
Everett Harbor	-0.615	*	-0.712	**	-0.186	ns	-0.611	*	-0.462	ns	0.095	ns	-0.572	*	-0.746	**	-0.890	****
PCB Congener 105	-0.325	***	-0.591	****	-0.014	ns	-0.235	*	-0.160	ns	-0.280	**	-0.239	*	-0.458	****	-0.319	**
no bqls	-0.600	ns	-0.714	ns	0.486	ns	-0.058	ns	-0.371	ns	0.257	ns	-0.828	*	-0.600	ns	-0.759	ns
Everett Harbor	-0.600	ns	-0.714	ns	0.486	ns	-0.058	ns	-0.371	ns	0.257	ns	-0.828	*	-0.600	ns	-0.759	ns
PCB Congener 118	-0.290	**	-0.542	****	0.003	ns	-0.222	*	-0.147	ns	-0.234	*	-0.223	*	-0.473	****	-0.338	***
no bqls	-0.675	*	-0.634	*	-0.127	ns	-0.526	ns	-0.573	*	-0.019	ns	-0.748	**	-0.742	**	-0.826	***
Everett Harbor	-0.719	**	-0.670	*	-0.088	ns	-0.527	ns	-0.600	*	-0.112	ns	-0.742	**	-0.792	**	-0.838	***
PCB Congener 128	-0.323	**	-0.600	****	-0.024	ns	-0.249	*	-0.161	ns	-0.298	**	-0.221	*	-0.457	****	-0.306	**
no bqls	-0.886	*	-0.841	*	0.086	ns	-0.667	ns	-0.829	*	-0.257	ns	-0.655	ns	-0.986	***	-0.676	ns
Everett Harbor	-0.886	*	-0.841	*	0.086	ns	-0.667	ns	-0.829	*	-0.257	ns	-0.655	ns	-0.986	***	-0.676	ns
PCB Congener 138	-0.215	*	-0.532	****	-0.076	ns	-0.267	**	-0.092	ns	-0.215	*	-0.175	ns	-0.416	****	-0.389	****
no bqls	-0.526	*	-0.587	*	-0.368	ns	-0.596	**	-0.376	ns	-0.113	ns	-0.419	ns	-0.653	**	-0.807	****
Everett Harbor	-0.680	**	-0.770	**	-0.374	ns	-0.733	**	-0.568	*	-0.046	ns	-0.578	*	-0.829	***	-0.922	****
PCB Congener 153	-0.182	ns	-0.521	****	-0.087	ns	-0.280	**	-0.070	ns	-0.180	ns	-0.147	ns	-0.405	****	-0.388	****
no bqls	-0.436	ns	-0.510	*	-0.239	ns	-0.490	*	-0.277	ns	0.025	ns	-0.401	ns	-0.566	*	-0.774	***
Everett Harbor	-0.574	*	-0.671	**	-0.125	ns	-0.551	*	-0.436	ns	0.190	ns	-0.543	*	-0.722	**	-0.853	****
PCB Congener 170	-0.319	**	-0.607	****	-0.024	ns	-0.251	*	-0.165	ns	-0.302	**	-0.200	*	-0.454	****	-0.294	**
no bqls	-0.821	*	-0.721	ns	0.000	ns	-0.577	ns	-0.679	ns	-0.321	ns	-0.598	ns	-0.883	**	-0.704	ns
Everett Harbor	-0.821	*	-0.721	ns	0.000	ns	-0.577	ns	-0.679	ns	-0.321	ns	-0.598	ns	-0.883	**	-0.704	ns
PCB Congener 180	-0.341	***	-0.587	****	0.010	ns	-0.221	*	-0.179	ns	-0.268	**	-0.262	**	-0.464	****	-0.321	**
no bqls	-0.747	*	-0.799	**	-0.327	ns	-0.652	*	-0.512	ns	-0.247	ns	-0.652	*	-0.850	**	-0.731	*
Everett Harbor	-0.747	*	-0.799	**	-0.327	ns	-0.652	*	-0.512	ns	-0.247	ns	-0.652	*	-0.850	**	-0.731	*

Table 34 (cont.). Spearman-rank correlations (rho, corrected for ties) and significance levels (p) for results of five benthic infaunal indices and concentrations of DDT and PCB compounds.

Chemical	Total Abund-ance	(p)	Taxa Rich-ness	(p)	Pielou's Evenness (J')	(p)	Swartz's Dominance	(p)	Annelida Abundance	(p)	Arthropoda Abundance	(p)	Echinoderm Abundance	(p)	Mollusca Abundance	(p)	Misc. Taxa Abundance	(p)
PCB Congener 187	-0.289	**	-0.583	****	-0.011	ns	-0.226	*	-0.137	ns	-0.299	**	-0.171	ns	-0.425	****	-0.269	**
no bqls	-0.738	*	-0.766	*	0.000	ns	-0.482	ns	-0.429	ns	-0.262	ns	-0.504	ns	-0.634	ns	-0.634	ns
Everett Harbor	-0.738	*	-0.766	*	0.000	ns	-0.482	ns	-0.429	ns	-0.262	ns	-0.504	ns	-0.634	ns	-0.634	ns
2x total PCB	-0.297	**	-0.595	****	-0.032	ns	-0.259	**	-0.154	ns	-0.247	*	-0.217	*	-0.469	****	-0.355	***
Everett Harbor	-0.707	**	-0.634	*	0.007	ns	-0.420	ns	-0.567	*	-0.025	ns	-0.352	ns	-0.760	**	-0.643	**
Total 19 PCB Congeners	-0.297	**	-0.595	****	-0.032	ns	-0.259	**	-0.154	ns	-0.247	*	-0.217	*	-0.469	****	-0.355	***
no bqls	-0.297	**	-0.595	****	-0.032	ns	-0.259	**	-0.154	ns	-0.247	*	-0.217	*	-0.469	****	-0.355	***
Everett Harbor	-0.707	**	-0.634	*	0.007	ns	-0.422	ns	-0.567	*	-0.025	ns	-0.352	ns	-0.760	**	-0.643	**
Total chlordanes	-0.258	**	-0.584	****	-0.061	ns	-0.269	**	-0.111	ns	-0.241	*	-0.166	ns	-0.458	****	-0.298	**
no bqls	-0.258	**	-0.584	****	-0.061	ns	-0.269	**	-0.111	ns	-0.241	*	-0.166	ns	-0.458	****	-0.298	**
Everett Harbor	-0.569	*	-0.576	*	-0.190	ns	-0.456	ns	-0.487	ns	-0.185	ns	-0.098	ns	-0.643	**	-0.482	ns
Total HCHs	-0.242	*	-0.541	****	-0.053	ns	-0.215	*	-0.079	ns	-0.215	*	-0.077	ns	-0.504	****	-0.252	*
no bqls	-0.242	*	-0.541	****	-0.053	ns	-0.215	*	-0.079	ns	-0.215	*	-0.077	ns	-0.504	****	-0.252	*
Everett Harbor	-0.326	ns	-0.354	ns	-0.370	ns	-0.364	ns	-0.445	ns	-0.533	*	0.113	ns	-0.281	ns	-0.134	ns

ND=no data
ns= p>0.05
* p<0.05
** p<0.01
*** p<0.001
**** p<0.0001

Table 35. Spearman-rank correlations (rho, corrected for ties) and significance levels (p) for results of five benthic infaunal indices and concentrations of organotin and organic compounds.

Chemical	Total Abundance	(p)	Taxa Richness	(p)	Pielou's Evenness (J')	(p)	Swartz's Dominance	(p)	Annelida Abundance	(p)	Arthropoda Abundance	(p)	Echinoderm Abundance	(p)	Mollusca Abundance	(p)	Misc. Taxa Abundance	(p)
Benzoic acid	0.167	ns	-0.166	ns	-0.208	*	-0.251	*	0.202	*	0.177	ns	0.321	**	-0.281	**	-0.086	ns
no bqls	-0.313	*	-0.493	***	-0.058	ns	-0.347	*	-0.286	ns	-0.107	ns	-0.158	ns	-0.426	**	-0.375	*
Everett Harbor	-0.649	*	-0.808	***	-0.414	ns	-0.762	**	-0.515	ns	-0.015	ns	-0.65	*	-0.8	***	-0.797	***
Bis(2-ethylhexyl) phthalate	-0.275	**	0.048	ns	0.21	*	0.184	ns	-0.139	ns	-0.241	*	-0.252	*	0.022	ns	0	ns
no bqls	-0.267	ns	0.041	ns	0.345	ns	0.406	ns	-0.292	ns	-0.356	ns	0.026	ns	0.054	ns	-0.13	ns
Everett Harbor	0.1	ns	0	ns	0.5	ns	0.2	ns	0.1	ns	-0.9	*	0.154	ns	0.5	ns	0.6	ns
Carbazole	-0.318	**	-0.365	***	-0.043	ns	-0.186	ns	-0.111	ns	-0.312	**	-0.39	****	-0.303	**	-0.258	**
no bqls	-0.383	*	-0.449	*	-0.015	ns	-0.297	ns	-0.142	ns	-0.248	ns	-0.593	**	-0.587	**	-0.543	**
Everett Harbor	0.176	ns	0.261	ns	0.234	ns	0.458	ns	0.092	ns	0.134	ns	0.642	ns	0.357	ns	0.193	ns
Dibenzofuran	-0.137	ns	-0.342	***	0.033	ns	-0.086	ns	-0.023	ns	-0.001	ns	-0.014	ns	-0.449	****	-0.115	ns
no bqls	-0.143	ns	-0.374	***	0.015	ns	-0.113	ns	-0.05	ns	-0.003	ns	-0.028	ns	-0.436	****	-0.144	ns
Everett Harbor	-0.264	ns	-0.443	ns	-0.161	ns	-0.42	ns	-0.089	ns	0.297	ns	-0.391	ns	-0.416	ns	-0.714	**
Dibenzothiophene	-0.14	ns	-0.316	**	0.071	ns	-0.059	ns	-0.1	ns	0.028	ns	0.008	ns	-0.363	***	-0.149	ns
no bqls	-0.123	ns	-0.3	**	0.064	ns	-0.066	ns	-0.088	ns	0.05	ns	0.027	ns	-0.347	***	-0.133	ns
Everett Harbor	-0.296	ns	-0.429	ns	-0.125	ns	-0.37	ns	-0.121	ns	0.256	ns	-0.36	ns	-0.412	ns	-0.669	**
Retene	-0.106	ns	-0.332	***	-0.085	ns	-0.155	ns	-0.047	ns	0.064	ns	-0.011	ns	-0.518	****	-0.097	ns
no bqls	-0.106	ns	-0.332	***	-0.085	ns	-0.155	ns	-0.047	ns	0.064	ns	-0.011	ns	-0.518	****	-0.097	ns
Everett Harbor	-0.236	ns	-0.336	ns	-0.039	ns	-0.271	ns	-0.1	ns	0.349	ns	-0.268	ns	-0.319	ns	-0.614	*
Phenols																		
4-Methylphenol	-0.124	ns	-0.122	ns	0.052	ns	-0.028	ns	0.041	ns	-0.205	*	-0.263	**	-0.003	ns	-0.08	ns
no bqls	-0.134	ns	-0.159	ns	0.025	ns	-0.11	ns	-0.021	ns	-0.198	ns	-0.297	**	0.037	ns	-0.118	ns
Everett Harbor	-0.564	*	-0.692	**	-0.325	ns	-0.686	**	-0.429	ns	0.014	ns	-0.733	**	-0.742	**	-0.838	****

Table 35 (cont.). Spearman-rank correlations (rho, corrected for ties) and significance levels (p) for results of five benthic infaunal indices and concentrations of organotin and organic compounds.

Chemical	Total Abundance	(p)	Taxa Richness	(p)	Pielou's Evenness (J')	(p)	Swartz's Dominance	(p)	Annelida Abundance	(p)	Arthropoda Abundance	(p)	Echinoderm Abundance	(p)	Mollusca Abundance	(p)	Misc. Taxa Abundance	(p)
Phenol	-0.045	ns	0.126	ns	0.194	ns	0.184	ns	0.026	ns	0.003	ns	0.03	ns	-0.039	ns	0.086	ns
no bqls	-0.002	ns	-0.073	ns	0.045	ns	-0.044	ns	-0.122	ns	0.208	ns	0.203	ns	-0.176	ns	-0.023	ns
Everett Harbor	0.4	ns	0.8	ns	1		0.8	ns	0.2	ns	0.4	ns	0.632	ns	0.4	ns	0.632	ns
total phenols	-0.231	*	-0.294	**	0.027	ns	-0.103	ns	-0.052	ns	-0.288	**	-0.316	**	-0.107	ns	-0.185	ns
no bqls	-0.231	*	-0.294	**	0.027	ns	-0.103	ns	-0.052	ns	-0.288	**	-0.316	**	-0.107	ns	-0.185	ns
Everett Harbor	-0.611	*	-0.803	***	-0.361	ns	-0.779	***	-0.507	ns	0.048	ns	-0.64	*	-0.781	***	-0.907	****
Organotins																		
Dibutyl tin	-0.228	*	-0.478	****	-0.06	ns	-0.212	*	-0.072	ns	-0.158	ns	-0.122	ns	-0.406	****	-0.317	**
no bqls	-0.356	*	-0.372	*	0.149	ns	-0.036	ns	-0.231	ns	-0.184	ns	-0.3	*	-0.238	ns	-0.39	**
Everett Harbor	-0.285	ns	-0.34	ns	-0.055	ns	-0.25	ns	-0.067	ns	0.261	ns	-0.517	ns	-0.436	ns	-0.562	ns
Monobutyl tin	-0.216	*	-0.341	***	0.005	ns	-0.075	ns	0.02	ns	-0.353	***	-0.238	*	-0.125	ns	-0.15	ns
no bqls	-0.054	ns	-0.524	*	-0.135	ns	-0.333	ns	0.144	ns	-0.552	**	-0.22	ns	-0.172	ns	-0.276	ns
Everett Harbor	1		0.5	ns	-0.5	ns	-0.5	ns	1		1		0.5	ns	1		-0.5	ns
Tributyl tin	-0.231	*	-0.245	*	0.087	ns	-0.021	ns	-0.106	ns	-0.12	ns	-0.207	*	-0.219	*	-0.114	ns
no bqls	-0.287	ns	-0.238	ns	0.151	ns	-0.025	ns	-0.151	ns	-0.081	ns	-0.337	*	-0.33	*	-0.152	ns
Everett Harbor	-0.682	*	-0.743	**	-0.236	ns	-0.644	*	-0.555	ns	-0.1	ns	-0.708	*	-0.826	**	-0.61	*

ns= p>0.05
* p<0.05
** p<0.01
*** p<0.001
**** p<0.0001

Benthic Infauna Indices vs. Toxicity

Indices of benthic abundance and diversity (i.e., richness and evenness) would be expected to decrease with decreasing amphipod survival, urchin fertilization success, and microbial bioluminescence EC50's. Correlations calculated between the benthic infauna indices and the four measures of toxicity showed little or no correspondence, with some notable exceptions (Table 27). The strongest correlation (rho=0.465, $p<0.0001$) between toxicity and benthic infauna indices occurred between mean percent sea urchin fertilization success and abundance of echinoderms in the benthic samples. That is, as urchin fertilization success decreased in the laboratory tests, the number of echinoderms in the benthic samples also decreased. There was also a slight positive correlation between urchin fertilization success and arthropod abundance (rho=0.295, $p<0.01$).

Indices of benthic abundance and diversity would be expected to decrease with increasing Cytochrome P450 RGS induction. Accordingly, total abundance decreased as P-450 induction increase (rho=0.291, $p<0.01$). However, contrary to expectations, the indices of evenness and dominance increased significantly with increasing P-450 induction. Benthic Infauna Indices vs. Classes of Chemicals

The associations between the benthic infaunal indices and the concentrations of potentially toxic substances in the samples were examined with correlation analyses. Indices of benthic abundance, evenness, dominance, and diversity would be expected to decrease as measures of toxicity increased. Similar to the procedures followed to correlate toxicity test results with chemical concentrations, relationships were first determined between various benthic indices and the concentrations of classes of toxicants. Correlations were first performed with the concentrations of four groups of chemicals normalized to (i.e., divided by) their respective ERM values and Washington State SQS and CSL values. Correlation coefficients were calculated with the data from all 100 stations and then with only 15 Everett Harbor/Port Gardner stations (Tables 28 and 29, respectively). All significant correlations for these parameters were inverse (negative) in direction.

Highly significant negative correlations ($p<0.001$) were observed between mean ERM quotients for all three chemical groups and the indices of both taxa richness and Mollusca abundance. Both of these benthic indices also had highly significant negative correlations with mean ERM quotients for all 25 substances. The dominance index had significant negative correlation with the concentrations of metals and all 25 substances. The correlations between the above three infaunal indices and trace metals concentrations normalized to the SQS and CSL values for trace metals were equally significant. Fewer (with higher p values) or no significant correlations were observed between the remaining infaunal indices (i.e., total abundance, Pielou's Evenness, and the abundance of Annelida, Arthropoda, Echinodermata, and miscellaneous taxa) vs. the ERM, SQS, and CSL quotients (Table 28).

None of these correlations remained highly significant ($p<0.001$) for the data from the 15 Everett Harbor/Port Gardner stations alone. The abundance of miscellaneous taxa was highly correlated with the mean ERM quotients for 13 PAHs. Correlations with other substances were much weaker (Table 29).

Benthic Infauna Indices vs. Individual Chemical Compounds

In the next set of analyses, correlations between concentrations of individual substances and infaunal indices were determined. As with the toxicity vs. individual chemical compound correlation analyses, some apparently significant correlations in the tables and discussion that follow could have occurred by chance alone, given the large number of chemical variables (>170). If the number of independent variables (chemicals) were taken into account (e.g., in a Bonferroni-type of adjustment), correlations would remain statistically significant only with p values of 0.0001 or less (i.e., four asterisks).

The correlation coefficients (rho) and significance levels (p) for the concentrations of individual trace metals determined with total digestions vs. infaunal indices are listed in Table 30. The results were highly variable among both the different metals and different benthic indices. However, all of the benthic indices indicated at least weak ($p<0.05$) to highly significant ($p<0.0001$) correlations (both positive and negative) with several or more trace metals. Of the nine benthic indices calculated, indices of taxa richness and Mollusca abundance were most frequently negatively correlated at the $p<0.0001$ level with concentrations of trace metals determined with the total digestion method (Table 30). Among the metals that were measured, the concentrations of chromium, lead, magnesium, nickel, vanadium, and zinc often were highly correlated ($p<0.001$ or <0.0001) with the benthic indices.

Similar data are shown in Table 31 for metals concentrations determined with partial digestions. Measures of taxa richness and Mollusca abundance most frequently indicated significant negative correlations with concentrations of trace metals determined with the partial digestion process (Table 31). Both indices were very highly correlated with the majority of the metals. The dominance index also was negatively correlated with many of the metals concentrations. None of the individual metals was clearly more correlated with the benthic indices than the others.

Results of correlation analyses between the infaunal indices and concentrations of LPAH and HPAH are listed in Tables 32 and 33, respectively. In both cases, taxa richness and Mollusca abundance decreased significantly with increasing chemical concentrations. Taxa richness, however, was significantly negatively correlated at the $p<0.0001$ level of significance with only one individual LPAH and two HPAH compounds. In contrast, Mollusca abundance was significantly negatively correlated with nine LPAH compounds. Total abundance was strongly negatively correlated with one HPAH compound, perylene, and indicated a weak association with many other compounds. None of the remaining infaunal indices (Pielou's Evenness, Swartz's Dominance, and abundance of Annelida, Arthropoda, Echinodermata, and miscellaneous taxa) were significantly correlated (i.e., $p<0.0001$) with any of the polynuclear aromatic hydrocarbon compounds.

Correlation analyses were also performed for infaunal indices and concentrations of DDT and PCB compounds (Table 34), and concentrations of organotins and many different semivolatile organic substances in the sediments (Table 35). In these two tables, correlation coefficients are first shown for all 100 samples, using the quantitation limits for values reported as undetected (i.e., at or below quantitation limits). As in previous sections of this report, if the majority of concentrations were qualified as either estimates or undetected the correlations were run again

after eliminating those samples. No analyses were performed for the numerous chemicals whose concentrations were at or below the limits of quantitation in all samples. Correlations are also shown for the 15 samples collected from the vicinity of Everett Harbor (samples from stations 86-100).

Taxa richness, Mollusca abundance, and miscellaneous taxa abundance were most significantly correlated with the concentrations of DDT, PCB, organotin, and other organic compounds (Tables 34, 35). When data from all 100 samples were considered, including those qualified as estimates or undetected, taxa richness was very significantly negatively correlated ($p<0.0001$) with all except one of the DDT and PCB compounds and with one organotin, i.e., dibutyl tin. Similarly, Mollusca abundance was significantly negatively correlated with most of the DDT and PCB compounds, but the coefficients often were smaller than those for taxa richness. The abundance of miscellaneous taxa was significantly correlated with five DDT and PCB compounds at the $p<0.0001$ level.

Many of the correlation coefficients increased when either the qualified data were eliminated or only the Everett Harbor data were used in the analyses (Tables 34, 35). For example, the correlation between the concentrations of aroclor 1254 and the abundance of other taxa increased from 0.416 to 0.788 and 0.835, respectively. However, the significance levels for the correlations calculated without qualified data and with only Everett Harbor samples often were much lower because of the smaller sample sizes. When only unqualified data were considered in the analyses, taxa richness and Mollusca abundance retained significant correlations with total aroclors, total DDTs, total PCB congeners, total chlordanes, and total HCHs. Mollusca abundance also retained significant negative correlations with dibenzofuran and retene. Miscellaneous taxa abundance retained its significant correlations with PCB congeners 66, 101, and 138. The concentrations of PCB Congeners 101, 138, and 153, 4-methylphenol and total phenols displayed significant negative correlations with miscellaneous taxa abundance at the Everett Harbor stations.

Summary

Analyses of the correlations between measures of benthic community diversity and abundance and the concentrations of potentially toxic chemicals indicated that several of the benthic community indices co-varied with complex mixtures of chemicals. Indices of taxa richness and abundance of molluscs and miscellaneous taxa indicated the strongest associations with chemical concentrations. There was no single group of chemicals nor any individual substance that was uniquely correlated with the benthic indices. Rather, the concentrations of many trace metals, PAHs, PCBs, and other organics appeared to co-vary with each other and with the benthic indices. These observations were similar to those made with the correlations between measures of toxicity and chemical concentrations; that is, indicative of the presence of complex mixtures of chemicals in samples that were toxic.

Triad Synthesis: Chemistry, Toxicity, and Infaunal Parameters at all Stations

The relationships among the data from the chemical analyses, toxicity tests, and benthic community analyses were examined to determine concordance in results. Stations are identified below in which the chemical, toxicity, and benthic data appeared to suggest either degraded or non-degraded conditions.

To simultaneously examine all three "triad" parameters measured in this study, selected results from the toxicity, chemistry, and infaunal community analyses from all stations were combined into one table (Appendix G). Triad parameters for the 18 stations which indicated both significant toxicity (i.e., significant results for any of the urchin fertilization (100% porewater), Microtox™, or Cytochrome P450 RGS toxicity tests), chemical contamination (i.e., measurements exceeding ERM, SQS, or CSL values), and potentially impacted infaunal communities, are listed in Table 36. Sixteen stations with no indications of significantly toxic sediments or chemical contamination, and with relatively abundant and diverse infaunal communities are listed in Table 37. Both sets of stations are displayed in Figures 83 through 89. The remaining 66 stations display either signs of significant chemical contamination but no toxicity, or significant toxicity, but no chemical contamination, and possess a wide range of infaunal community parameters.

The 18 stations in Table 36 display significant results for both chemistry and toxicity parameters as well as potentially impacted infaunal communities. These stations are located in five different regions of northern Puget Sound, and portray differing suites of triad results. These areas and their triad data are described below.

Stations 2 and 3 are located in the southern end of Drayton Harbor (Figure 83). These stations were shallow (3.5m); composed of silt, clay, and shell fragments with a strong hydrogen sulfide smell; and displayed lowered salinity (25ppt) and elevated sediment temperature (14-15°C). The surrounding land base is primarily rural/residential, with a marina present. The chemical exceeding SQS and CSL values was phenol, which exceeded state regulatory criteria at 45 of the 100 stations sampled in this study. Urchin fertilization results were significant in 100% porewater. Infaunal indices of total abundance, taxa richness, and dominance were relatively low, and the invertebrate communities in both stations were dominated, in part, by the polychaete *Nephyts cornuta* and the bivalve *Macoma nasuta*. Examination of the triad parameters for these two stations along with station 3 in strata 1 (Appendix G) indicates a clear gradient of response from southwestern station 3 to eastern station 1 (i.e., increasing urchin fertilization success and Microtox values, decreasing P-450 response) and in all infaunal indices (i.e., abundance, richness and dominance values increased, while evenness values decreased slightly). The dominant species composition also changed along a gradient from station 3 to 1. *Macoma nasuta* was present only in stations 3 and 2, while *Protomedeia grandimana* was present only in stations 2 and 1. *Nephtys cornuta* was the top dominant species in all three stations, but its numbers increased from southwest station 3 to eastern station 1. While phenol exceeded SQS criteria at all three stations, it is possible that this shallow bay experiences naturally occurring phenomena including restricted water circulation, episodes of low dissolved oxygen in bottom waters and the sediments, or periods of freshwater input, which could impact the composition of the infaunal community.

Table 36. Triad results for Northern Puget Sound stations with significant results for both chemistry and toxicity parameters

	Chemistry						Toxicity			Infauna											
Statum, Sample, Location	Number of ERMs exceeded	Compounds Exceeding ERM	Number of SQSs exceeded	Compounds Exceeding SQS	Number of CSLs exceeded	Compounds Exceeding CSL	Mean Urchin Fertilization in 100% pore water as % of Control (and statistical significance)	Microtox EC50 (mg/ml) (and statistical significance)	P-450 induction (ug/g) (and statistical significance)	Total Abundance	Species Richness	Annelid Abundance	Arthropod Abundance	Echinoderm Abundance	Mollusca Abundance	Misc. Abundance	Pielou's Evenness (J')	Swartz's Dominance Index (SDI)	Dominant Species	Count
1, 2, Drayton Harbor		none	1	Phenol	1	Phenol	29**	1.8ns	8.51ns	122	24	59	24	0	35	4	0.88	10	Nephtys cornuta Protomedeia grandimana Glycinde polygnatha Macoma nasuta	17 15 13 13
1, 3, Drayton Harbor		none	1	Phenol		none	0**	1.33ns	10.51ns	54	11	37	0	0	17	0	0.89	5	Nephtys cornuta Prionospio (Minuspio) lighti Terebellides californica Macoma nasuta	14 8 8 7
7, 22, Bellingham Bay		none	1	Phenol	1	Phenol	46**	1.57ns	1.63ns	1846	41	1661	36	20	4	125	0.51	5	Aphelochaeta monilaris Nephtys cornuta Scoletoma luti Heteromastus filobranchus	1059 124 107 71
9A, 28, Bellingham Bay		none	2	Mercury, Phenol		none	117ns	0.63ns	19.09++	143	35	102	9	14	16	2	0.79	11	Nephtys cornuta Aphelochaeta monilaris Amphiuridae Glycinde polygnatha	40 14 13 8
10, 30, Bellingham Bay		none	1	4-Methylphenol	1	4-Methylphenol	121ns	1.93ns	16.08++	1908	37	773	444	595	93	3	0.59	4	Amphiodia urtica/periercta complex Owenia fusiformis Pholoe sp. Euphilomedes carcharodonta	516 392 319 252
14, 43, Inner Padilla Bay		none	2	4-Methylphenol, Phenol	1	4-Methylphenol	51**	1.83ns	1.78ns	7671	110	5084	2016	66	430	75	0.48	4	Owenia fusiformis Leptochelia savignyi Exogone (E.) lourei Exogone dwisula	2996 1680 910 192
17, 51, Inner Fidalgo Bay		none	1	4-Methylphenol	1	4-Methylphenol	51**	3.83ns	3.7ns	1358	74	613	43	15	675	12	0.51	5	Psephidia lordi Owenia fusiformis Aricidea (Acmira) lopezi Terebellides nr. kobei	569 386 26 24

Table 36. Triad results for Northern Puget Sound stations with significant results for both chemistry and toxicity parameters

	Chemistry						Toxicity			Infauna											
Statum, Sample, Location	Number of ERMs exceeded	Compounds Exceeding ERM	Number of SQSs exceeded	Compounds Exceeding SQS	Number of CSLs exceeded	Compounds Exceeding CSL	Mean Urchin Fertilization in 100% pore water as % of Control (and statistical significance)	Microtox EC50 (mg/ml) (and statistical significance)	P-450 induction (ug/g) (and statistical significance)	Total Abundance	Species Richness	Annelid Abundance	Arthropod Abundance	Echinoderm Abundance	Mollusca Abundance	Misc. Abundance	Pielou's Evenness (J')	Swartz's Dominance Index (SDI)	Dominant Species	Count
18, 54, Outer Fidalgo Bay		none	2	4-Methylphenol, Phenol	1	4-Methylphenol	111ns	3.27ns	12.11++	707	50	276	140	9	275	7	0.71	9	Rochefortia tumida Protomedeia grandimana Aphelochaeta monilaris Owenia fusiformis	204 90 75 41
29, 86, Inner Everett Harbor	9	Acenaphthene, Anthracene, Fluorene, Phenanthrene, Total 7 LPAH, Fluroanthene, Pyrene, Total 6 HPAH, Total PCB	3	Total Arochlors, 4-Methylphenol, Benzoic acid	2	Benzoic acid, 4-Methylphenol	23**	0.51ns	202.2+++	54	7	12	42	0	0	0	0.73	3	Nebalia pugettensis Aoroides spinosus Capitella capitata hyperspecies Eteone sp.	22 18 7 4
29, 87, Inner Everett Harbor	1	Total 7 LPAH	2	Benzoic acid, 4-Methylphenol	2	Benzoic acid, 4-Methylphenol	12**	0.69ns	33.1++	109	9	57	52	0	0	0	0.57	2	Capitella capitata hyperspecies Aoroides spinosus Nebalia pugettensis Desdimelita desdichada	52 40 8 3
29, 88, Inner Everett Harbor	1	Total 7 LPAH	3	Benzoic acid, 4-Methylphenol	2	Benzoic acid, 4-Methylphenol	50**	0.94ns	115.8+++	40	4	19	21	0	0	0	0.64	2	Nebalia pugettensis Capitella capitata hyperspecies Aoroides sp. Eteone sp.	20 18 1 1
30, 89, Middle Everett Harbor	5	Phenanthrene, Acenaphthene, Fluorene, Total 7 LPAH, Pyrene	2	Benzoic acid, 4-Methylphenol	2	Benzoic acid, 4-Methylphenol	0**	0.2ns	25.8++	74	7	69	3	0	2	0	0.25	1	Capitella capitata hyperspecies Macoma carlottensis Aoroides sp. Eteone sp.	67 2 1 1
30, 90, Middle Everett Harbor	2	Total 7 LPAH, Pyrene	2	Benzoic acid, 4-Methylphenol	2	Benzoic acid, 4-Methylphenol	1**	0.71ns	129.2+++	663	46	354	290	0	18	1	0.67	6	Leptochelia savignyi Capitella capitata hyperspecies Prionospio (Minuspio) lighti Nebalia pugettensis	146 106 102 88

Table 36. Triad results for Northern Puget Sound stations with significant results for both chemistry and toxicity parameters

	Chemistry						Toxicity			Infauna											
Statum, Sample, Location	Number of ERMs exceeded	Compounds Exceeding ERM	Number of SQSs exceeded	Compounds Exceeding SQS	Number of CSLs exceeded	Compounds Exceeding CSL	Mean Urchin Fertilization in 100% pore water as % of Control (and statistical significance)	Microtox EC50 (mg/ml) (and statistical significance)	P-450 induction (ug/g) (and statistical significance)	Total Abundance	Species Richness	Annelid Abundance	Arthropod Abundance	Echinoderm Abundance	Mollusca Abundance	Misc. Abundance	Pielou's Evenness (J')	Swartz's Dominance Index (SDI)	Dominant Species	Count
30, 91, Middle Everett Harbor		none	2	Benzoic acid, 4-Methylphenol	2	4-Methylphenol	0**	0.58ns	86.4+++	92	21	36	48	0	4	4	0.82	8	Euphilomedes carcharodonta Capitella capitata hyperspecies Americhelidium variabilum Nebalia pugettensis	28 9 8 7
31, 92, Outer Everett Harbor	5	Phenanthrene, Acenaphthene, Fluorene, Total 7 LPAH, Pyrene	3	Benzoic acid, 4-Methylphenol, Phenol	2	Benzoic acid, 4-Methylphenol	5**	0.4^	28.8++	226	34	111	73	0	42	0	0.75	9	Capitella capitata hyperspecies Euphilomedes carcharodonta Macoma carlottensis Pleusymtes coquilla	69 32 15 14
31, 93, Outer Everett Harbor	4	Acenaphthene, Phenanthrene, Fluorene, Total 7 LPAH	2	Benzoic acid, 4-Methylphenol	2	Benzoic acid, 4-Methylphenol	2**	0.42^	29.2++	574	50	280	70	1	217	6	0.74	10	Capitella capitata hyperspecies Rochefortia tumida Axinopsida serricata Euphilomedes carcharodonta	134 65 62 48
31, 94, Outer Everett Harbor	6	Lead, Copper, Arsenic, Zinc, Phenanthrene, Toal 7 LPAH	5	Arsenic, Copper, Zinc, Benzoic acid, 4-Methylphenol	3	Copper, Benzoic acid, 4-Methylphenol	68**	0.44^	28.7++	813	78	337	211	8	250	7	0.78	16	Euphilomedes carcharodonta Axinopsida serricata Rochefortia tumida Capitella capitata hyperspecies	136 67 63 59
32, 97, Port Gardner		none	1	4-Methylphenol	1	4-Methylphenol	113ns	9.17ns	22.9++	855	60	273	40	1	539	2	0.53	6	Axinopsida serricata Prionospio (Minuspio) lighti Heteromastus filiformis Macoma carlottensis	462 64 39 33

ns=not significant

**=p<0.01

^ = mean EC50<0.51 mg/ml determined as the 80% lower prediction limit (LPL) with the lowest (i.e., most toxic) samples removed, but ≥0.06 mg/ml determined as the 90% lower prediction limit (LPL) earlier in this report.

++ = value > 11.1 benzo[a]pyrene equivalents (ug/g sediment) determined as the 80% upper prediction limit (UPL), but ≤37.1 benzo[a]pyrene equivalents (ug/g sediment) determined as the 90% upper prediction limit (UPL) earlier in this report.

+++ = value > 37.1 benzo[a]pyrene equivalents (ug/g sediment) determined as the 90% upper prediction limit (UPL) earlier in this report.

Table 37. Triad results for Northern Puget Sound stations with no significant results for both chemistry and toxicity parameters

	Chemistry						Toxicity			Infauna											
Statum, Sample, Location	Number of ERMs exceeded	Compounds Exceeding ERM	Number of SQSs exceeded	Compounds Exceeding SQS	Number of CSLs exceeded	Compounds Exceeding CSL	Mean Urchin Fertilization in 100% pore water as % of Control (and statistical significance)	Microtox EC50 (mg/ml) (and statistical significance)	P-450 induction (ug/g) (and statistical significance)	Total Abundance	Species Richness	Annelid Abundance	Arthropod Abundance	Echinoderm Abundance	Mollusca Abundance	Misc. Abundance	Pielou's Evenness (J')	Swartz's Dominance Index (SDI)	Dominant Species	Count
2, 4, Semiahmoo Bay		none		none		none	118ns	2.73ns	2.72ns	864	49	74	572	51	160	7	0.56	5	Eudorella (tridentata) pacifica Psephidia lordi Protomedeia grandimana Amphiodia urtica/periercta complex	388 109 103 43
3, 7, West Boundary Bay		none		none		none	117ns	6.83ns	0.27ns	5055	66	358	2062	46	2581	8	0.48	3	Rochefortia tumida Ampelisca agassizi Psephidia lordi Euphilomedes carcharodonta	1635 1299 885 373
4, 11, South Boundary Bay		none		none		none	117ns	1.57ns	3.03ns	1083	39	141	653	28	261	0	0.56	4	Protomedeia grandimana Eudorella (tridentata) pacifica Psephidia lordi Lumbrineris cruzensis	447 170 162 48
4, 12, South Boundary Bay		none		none		none	116ns	2.23ns	2.57ns	856	51	77	615	54	94	16	0.58	5	Eudorella (tridentata) pacifica Protomedeia grandimana Amphiodia urtica/periercta complex Psephidia lordi	304 238 50 30
6, 17, Cherry Point		none		none		none	115ns	4.9ns	3.01ns	1454	74	227	223	14	956	34	0.62	9	Psephidia lordi Axinopsida serricata Eudorella (tridentata) pacifica Levinsenia gracilis	586 112 85 71

Table 37. Triad results for Northern Puget Sound stations with no significant results for both chemistry and toxicity parameters

	Chemistry						Toxicity			Infauna											
Statum, Sample, Location	Number of ERMs exceeded	Compounds Exceeding ERM	Number of SQSs exceeded	Compounds Exceeding SQS	Number of CSLs exceeded	Compounds Exceeding CSL	Mean Urchin Fertilization in 100% pore water as % of Control (and statistical significance)	Microtox EC50 (mg/ml) (and statistical significance)	P-450 induction (ug/g) (and statistical significance)	Total Abundance	Species Richness	Annelid Abundance	Arthropod Abundance	Echinoderm Abundance	Mollusca Abundance	Misc. Abundance	Pielou's Evenness (J')	Swartz's Dominance Index (SDI)	Dominant Species	Count
9B, 59, Bellingham Bay		none		none		none	103ns	4.13ns	3.08ns	1232	32	326	720	180	4	2	0.62	4	Euphilomedes carcharodonta Protomedeia prudens/Cheirimedeia zotea Owenia fusiformis Amphiodia urtica/periercta complex	321 264 189 170
11, 33, Bellingham Bay		none		none		none	117ns	2.17ns	4.09ns	379	47	272	24	19	62	2	0.71	10	Aphelochaeta monilaris Axinopsida serricata Heteromastus filobranchus Lumbrineris cruzensis	119 51 42 15
11, 34, Bellingham Bay		none		none		none	103ns	0.51ns	2.76ns	1303	30	1139	11	10	141	2	0.28	1	Aphelochaeta monilaris Axinopsida serricata Heteromastus filiformis Lumbrineris cruzensis	1037 127 24 20
13, 40, Samish / Bellingham Bay		none		none		none	115ns	0.98ns	2.99ns	2529	83	511	928	347	722	21	0.58	5	Rochefortia tumida Ampelisca agassizi Amphiodia urtica/periercta complex Owenia fusiformis	598 597 334 334
18, 55, Outer Fidalgo Bay		none		none		none	115ns	11.33ns	6.6ns	633	103	305	51	63	204	10	0.82	25	Psephidia lordi Amphiodia urtica/periercta complex Scoletoma luti Nephtys cornuta	75 59 41 36

Table 37. Triad results for Northern Puget Sound stations with no significant results for both chemistry and toxicity parameters

	Chemistry						Toxicity			Infauna											
Statum, Sample, Location	Number of ERMs exceeded	Compounds Exceeding ERM	Number of SQSs exceeded	Compounds Exceeding SQS	Number of CSLs exceeded	Compounds Exceeding CSL	Mean Urchin Fertilization in 100% pore water as % of Control (and statistical significance)	Microtox EC50 (mg/ml) (and statistical significance)	P-450 induction (ug/g) (and statistical significance)	Total Abundance	Species Richness	Annelid Abundance	Arthropod Abundance	Echinoderm Abundance	Mollusca Abundance	Misc. Abundance	Pielou's Evenness (J')	Swartz's Dominance Index (SDI)	Dominant Species	Count
21, 63, Skagit Bay		none		none		none	100ns	8.9ns	0.36ns	408	64	231	93	0	80	4	0.76	13	Scalibregma inflatum Scoletoma luti Astyris gausapata Rhepoxynius boreovariatus	93 46 36 27
27, 81, Port Susan		none		none		none	95ns	12.6ns	2.79ns	128	33	48	13	2	62	3	0.72	10	Axinopsida serricata Levinsenia gracilis Onuphis elegans Chaetozone spp.	54 9 7 6
28, 83, Possession Sound		none		none		none	121ns	7.07ns	7.05ns	269	70	147	43	2	59	18	0.87	25	Adontorhina cyclia Scoletoma luti Leitoscoloplos pugettensis Sternaspis scutata	36 24 14 14
28, 84, Possession Sound		none		none		none	120ns	8.13ns	4.83ns	332	44	158	26	4	131	13	0.73	10	Axinopsida serricata Heteromastus filobranchus Microclymene caudata Prionospio (Minuspio) lighti	102 40 22 20
28, 85, Possession Sound		none		none		none	119ns	9.67ns	5.46ns	322	31	98	43	1	174	6	0.62	5	Axinopsida serricata Eudorella (tridentata) pacifica Chaetozone commonalis Prionospio jubata	154 31 22 21
33, 99, Snohomish River Delta		none		none		none	119ns	57.57ns	0.3ns	537	23	29	44	1	463	0	0.51	2	Tellina nuculoides Psephidia lordi Rochefortia tumida Lamprops quadriplicata	231 174 52 18

ns=not significant

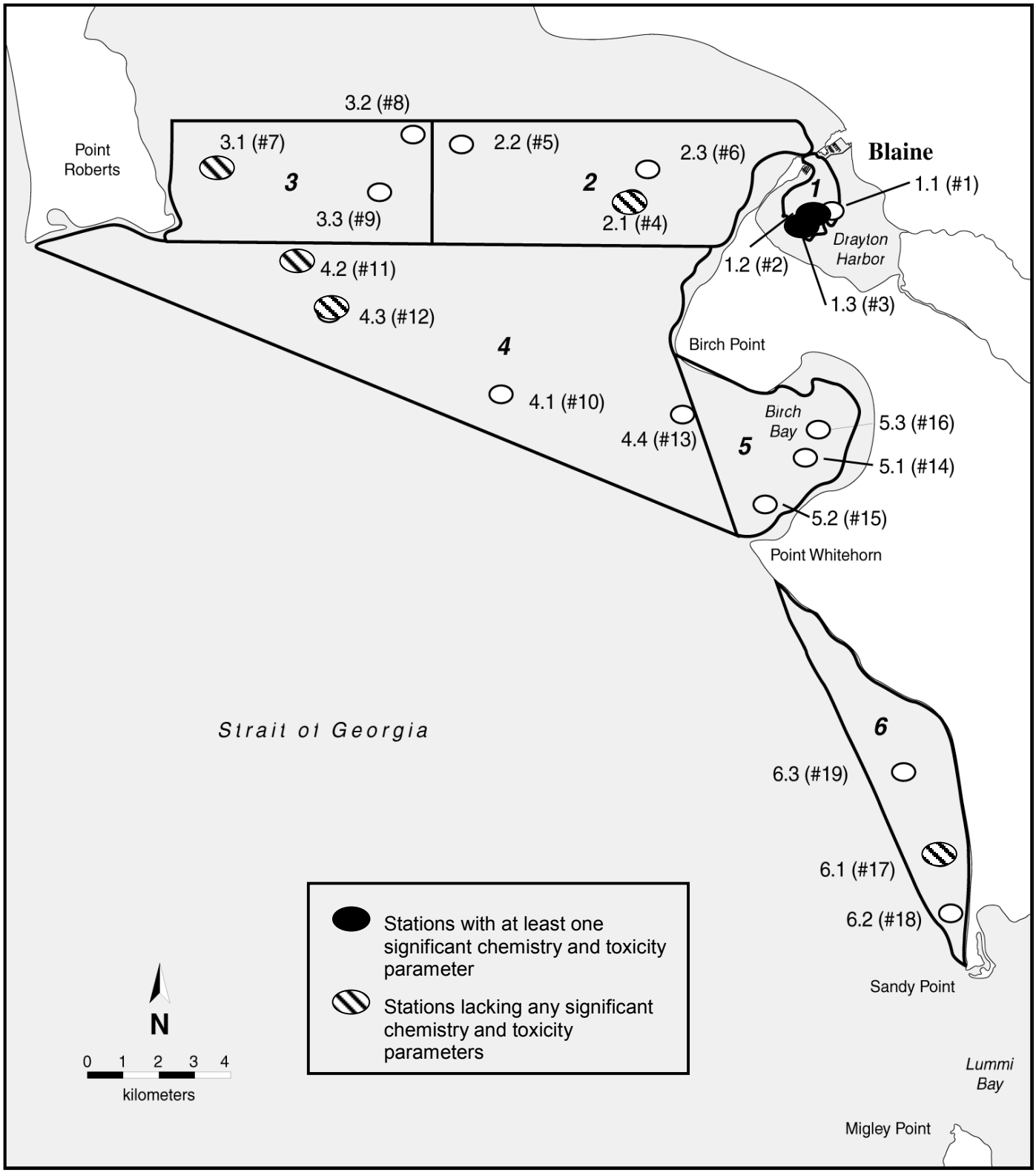

Figure 83. Northern Puget Sound stations with significant results and stations with non-significant results for chemistry and toxicity tests in southern Strait of Georgia and vicinity.

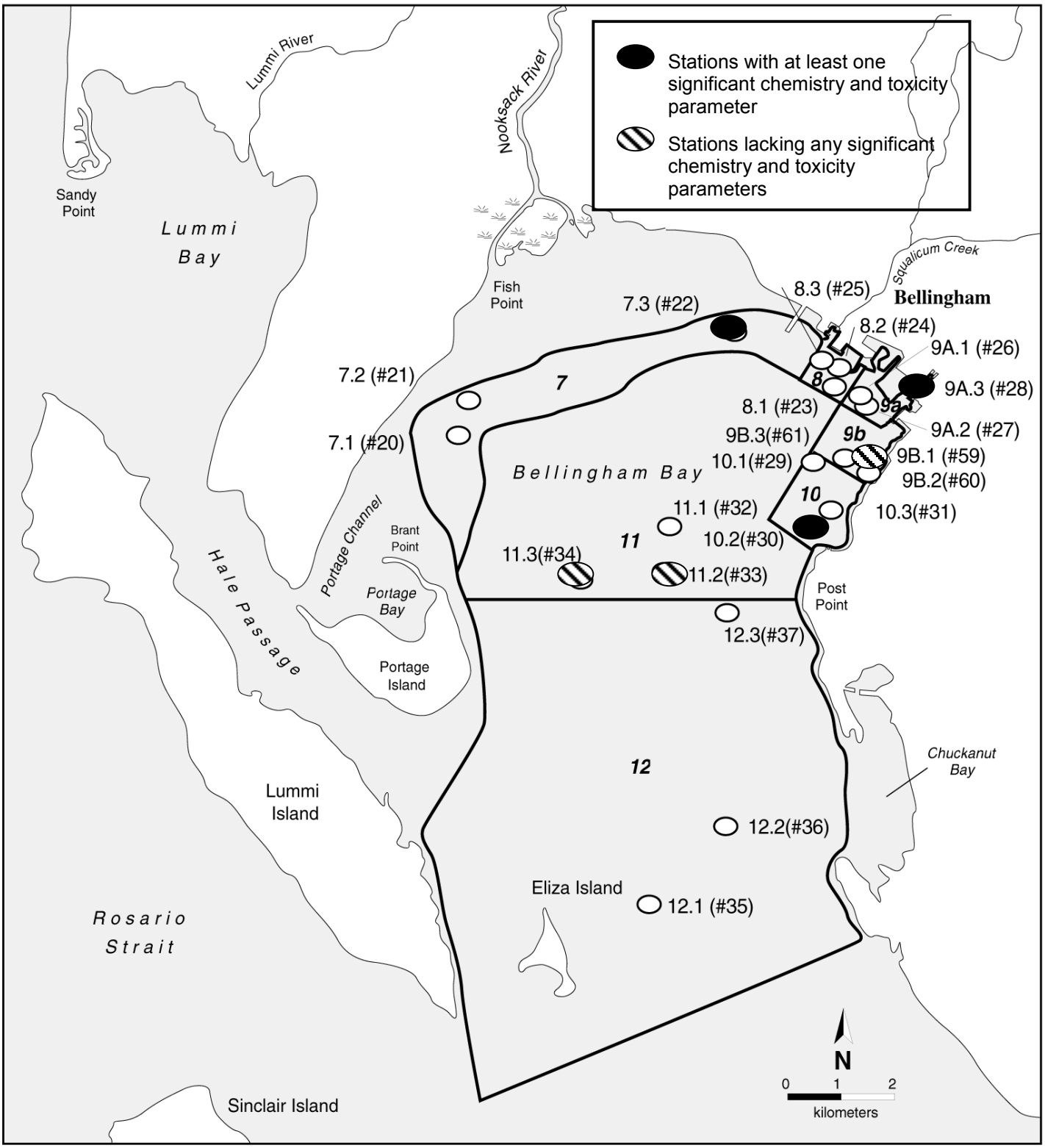

Figure 84. Northern Puget Sound stations with significant results and stations with non-significant results for chemistry and toxicity tests in Bellingham Bay and vicinity.

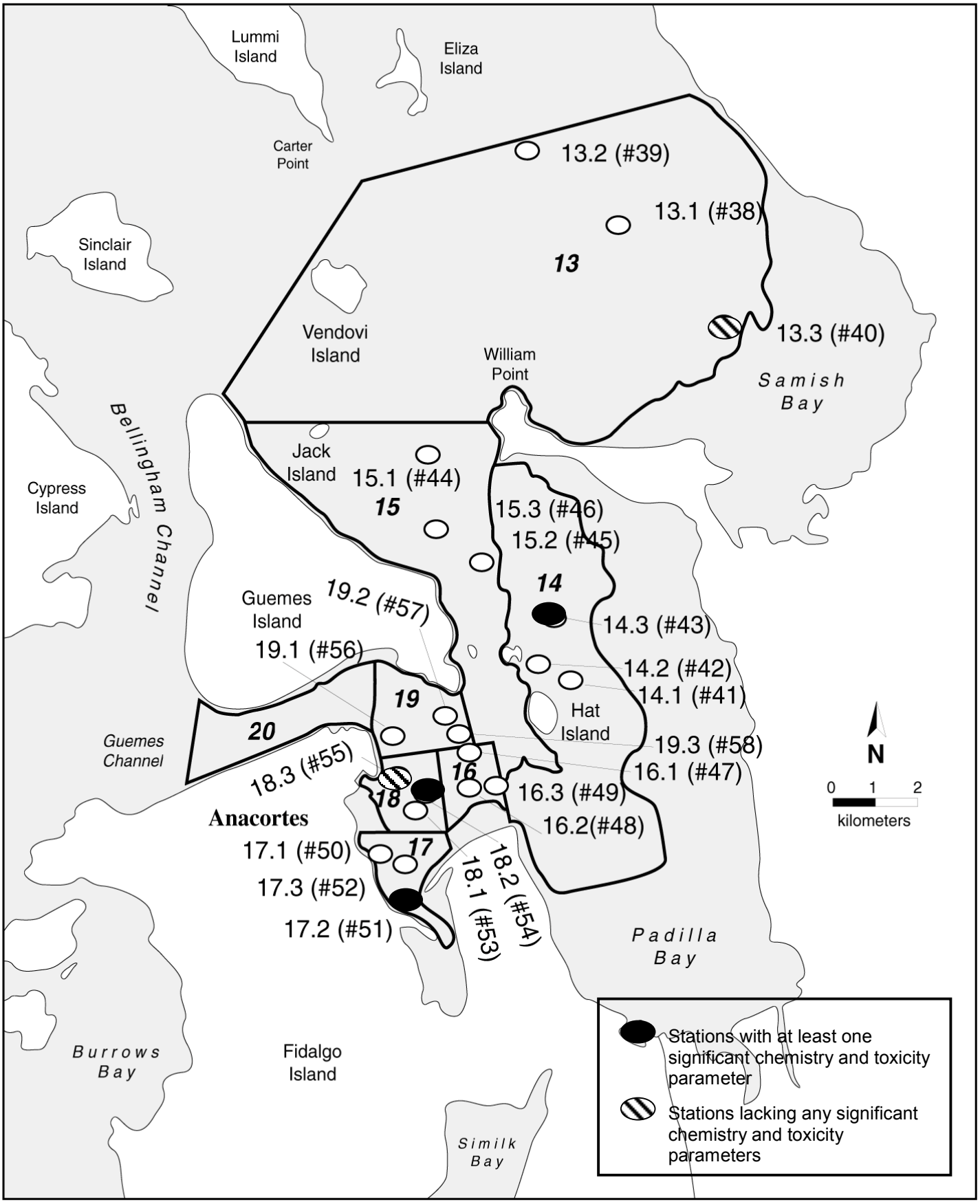

Figure 85. Northern Puget Sound stations with significant results and stations with non-significant results for chemistry and toxicity tests in the vicinity of Anacortes.

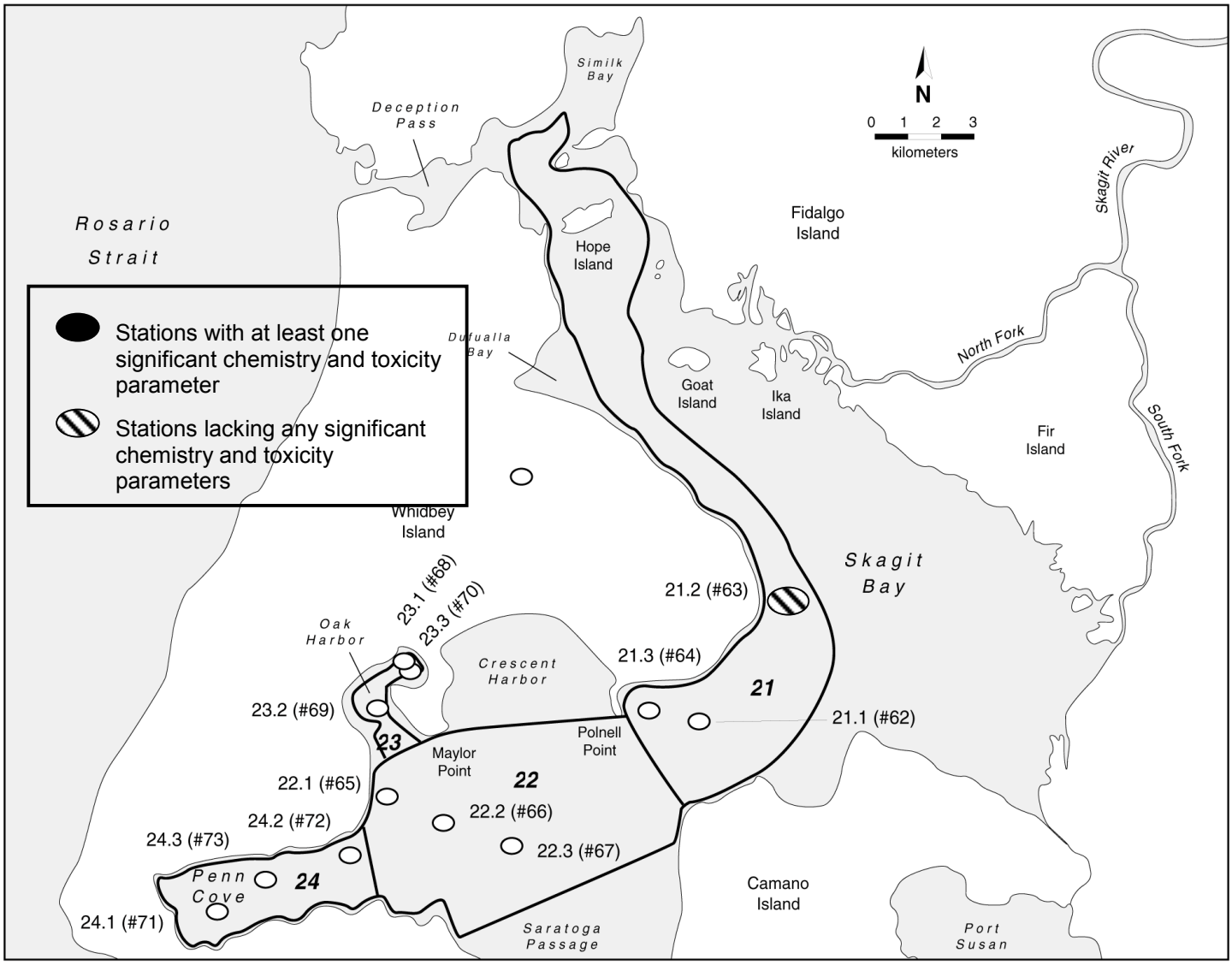

Figure 86. Northern Puget Sound stations with significant results and stations with non-significant results for chemistry and toxicity tests in the vicinity of Oak Harbor.

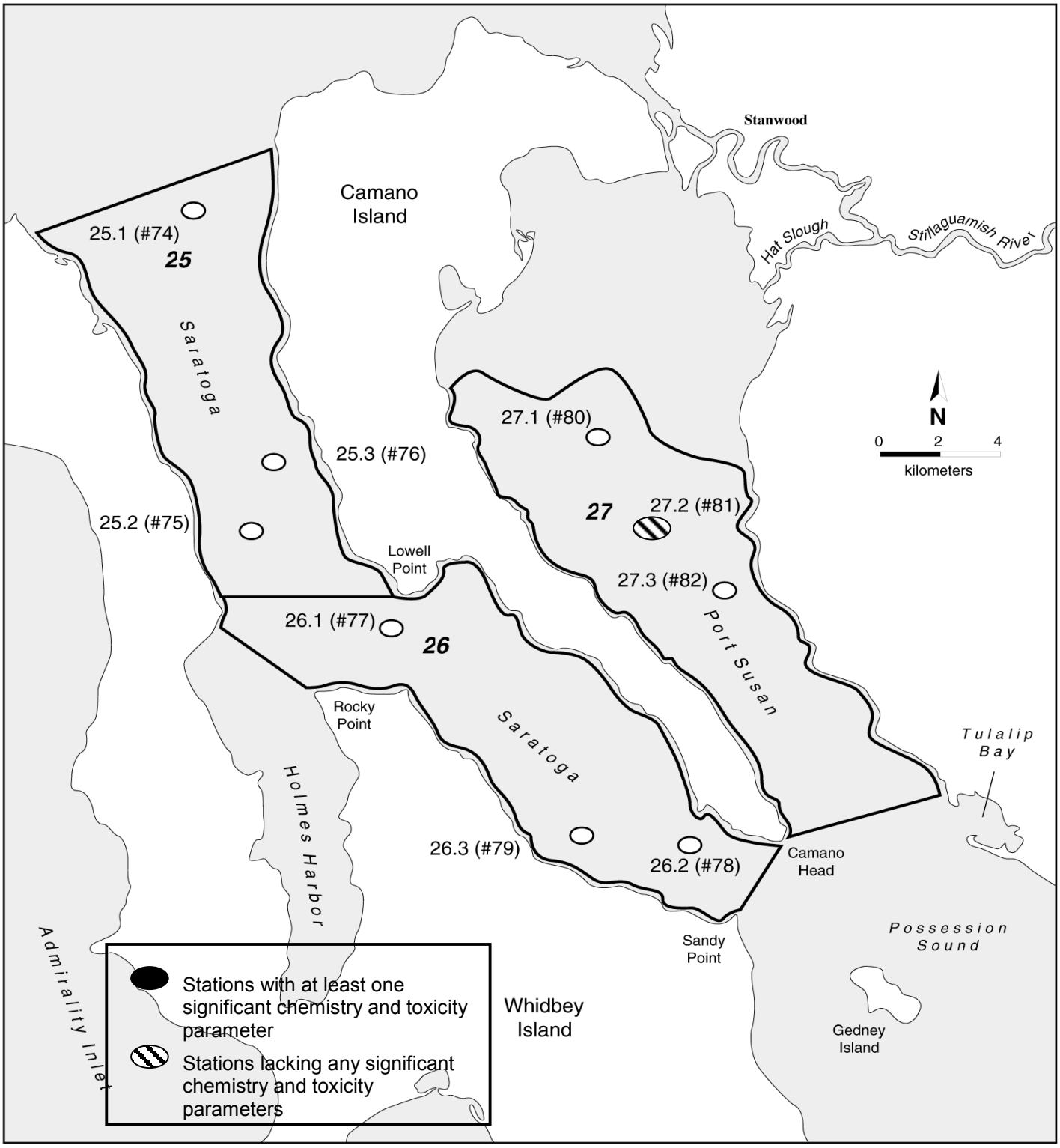

Figure 87. Northern Puget Sound stations with significant results and stations with non-significant results for chemistry and toxicity test in Port Susan.

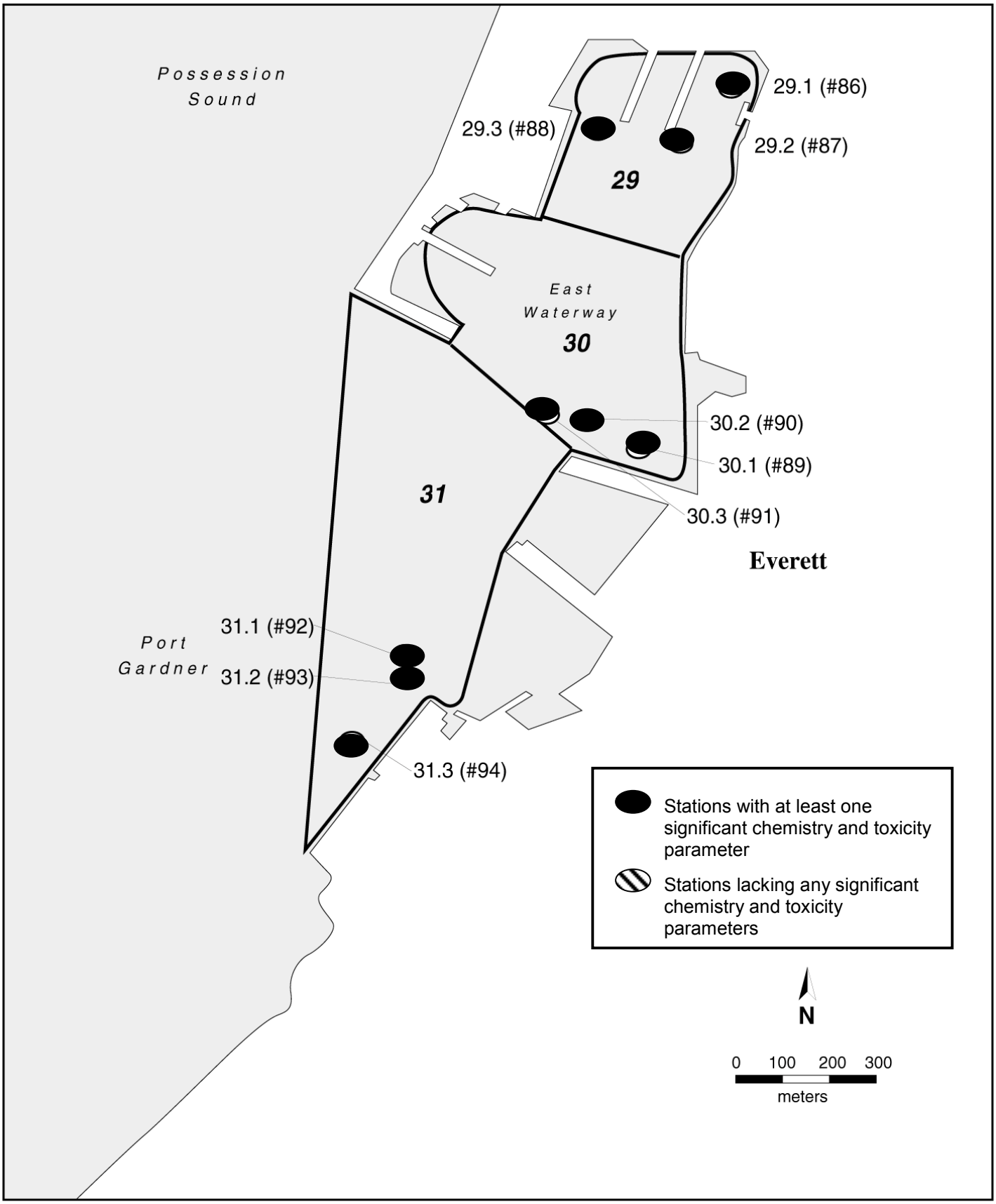

Figure 88. Northern Puget Sound stations with significant results and stations with non-significant results for chemistry and toxicity tests in Everett Harbor.

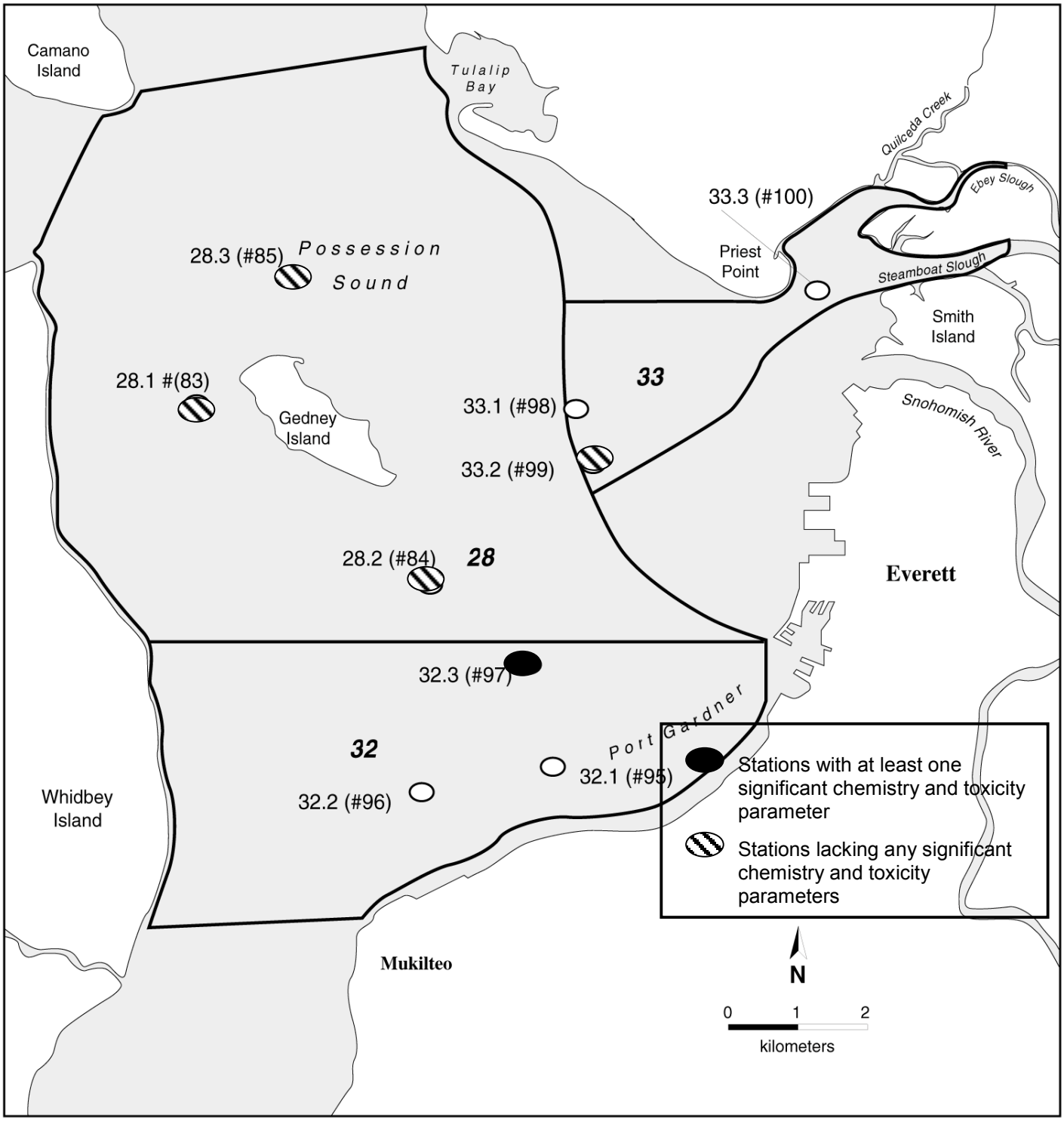

Figure 89. Northern Puget Sound stations with significant results and stations with non-significant results for chemistry and toxicity test in Possession Sound, Port Gardner Bay, and the Snohomish River delta.

Of the remaining stations in this localized area (strata 1 through 6), five display no significant chemistry or bioassay results (stations 4, 7, 11, and 12 in Semiahmoo and Boundary Bay, and station 17 in the Cherry Point area). Twelve have at least one significant chemistry result (including benzoic acid, phenol, and/or 4-methylphenol; and mercury (station 9 only)) or toxicity result. Infaunal communities at these stations appear, for the most part, to be relatively abundant and diverse. Station 9, however, which displayed levels of mercury, benzoic acid, and phenol above both state and NOAA criteria displayed the lowest total and specific taxa abundance values, with only 6 arthropods (known to be sensitive to environmental contaminants) represented in this sample.

Stations 22, 28, and 30 were located in different strata in Bellingham Bay (Figure 84). Physical characteristics at these three stations differed, as did the suite of triad results for each of these stations.

Station 22 was located in the shallow (7m) region of northern Bellingham Bay. Sediments were comprised of silt and clay. Salinity values were low (24ppt) and sediment temperature was elevated (13.5°C). Phenol values exceeded both SQS and CSL guidelines, and the urchin fertilization results were significant in tests of 100% porewater. Total abundance was high (1846 individuals), while dominance values were low (5 taxa). The infaunal community was dominated by the polychaetes *Aphelochaeta monilaris*, *Nephtys cornuta*, *Scoletoma luti,* and *Heteromastus filobranchus*, differing from the dominant organisms (*Owenia fusiformis*, *Euphilomedes carcharodonta*, *Protomedeia prudens/Cheirimedeia zotea*, and *Amphiodia urtica/periercta* complex) shared by stations 20 and 21, which were located at the western end of stratum 7 and displayed a different suite of physical parameters.

Sediments from station 30, in southern Bellingham, Bay, were composed of black silt/clay with a brown surface film. The station was at 16m, with a salinity of 27ppt and a sediment temperature of 12.5°C. Four-methylphenol levels were elevated above state guidelines, and Cytochrome P450 RGS results were significant. Total abundance (1908 individuals) and dominance (4 taxa) values were similar to that in station 22, but the species composition for station 30 was very different, being dominated by the ophiuroid *Amphiodia urtica/periercta* complex, the polychaetes *Owenia fusiformis* and *Pholoe* sp., and the ostracod *Euphilomedes carcharodonta*. The other two stations (29 and 31) in strata 10 also display elevated 4-methylphenol levels, but no other pattern of similarity or difference could be discerned for the toxicity or chemistry values measured in this strata (Appendix G).

Sediments from station 28, located near the pulp and paper mill in Whatcom Waterway, were different from those in stations 22 and 30, being comprised primarily of sand and wood, and were black with a strong hydrogen sulfide odor. The station depth here was 12m, and the salinity and sediment temperature were 23ppt and 13°C, respectively. Both mercury and phenol values were above SQS guidelines, and as with station 30, there were elevated Cytochrome P450 RGS results. The infaunal indices, in contrast to both stations 22 and 30, displayed low total abundance (143 individuals) and higher evenness (J'=0.79) and dominance (11 species) values. Similar to station 22, however, this inner urban station was again dominated by polychaetes, and shared the same top two dominant species, *Aphelochaeta monilaris* and *Nephtys cornuta*. In

comparison with the other two stations (26 and 27) in strata 9A (Appendix G), station 28 had a total abundance level that was lower by an order of magnitude (1602, 1908, and 143 individuals, respectively), and arthropod abundance values that were lower by two orders of magnitude (1135, 1118, and 9 individuals, respectively). In contrast, evenness and dominance values were higher at station 28 than at stations 26 and 27 (J'=0.79, 0.55, and 0.57 and SDI=11, 3, and 4, respectively), probably due to the absence of the arthropods *Protomedeia prudens/Cheirimedeia zotea* and *Euphilomedes charcharodonta* which dominate stations 26 and 27.

The other stations sampled from the 7 strata (7 through 12) in the Bellingham area include three that indicated no significant chemistry or bioassay results (stations 33, and 34 in central Bellingham Bay, and station 59, close to the south Bellingham shoreline). The 15 other stations had at least one significant chemistry (in many cases the phenol compounds) or toxicity result, and varying indices of community structure.

Figure 85 depicts three stations (station 43 – inner Padilla Bay, station 51-inner Fidalgo Bay, and 54-outer Fidalgo Bay) in the Anacortes area which indicated significant results for both the sediment chemistry and toxicity analyses. Chemicals exceeding guidelines at these three stations again included 4-methylphenol and phenol. Urchin fertilization results were significant in 100% porewater at the Padilla Bay and inner Fidalgo Bay stations, while the Cytochrome P450 results were elevated at the outer Fidalgo Bay. All three stations were located in similar depths (4-6.5m), and had similar salinity and sediment temperature values (30-32ppt and 11-12°C). Both Fidalgo Bay stations were in the vicinity of Anacortes/March Point oil refineries.

Total abundance and taxa richness were highest from the Padilla Bay station sediments (7671 individuals, 110 taxa), which were comprised of sand, silt, and clay, and an abundance of decomposing eelgrass, displaying an oily sheen (possibly due to the decomposition of the eelgrass). These values were lower for the inner Fidalgo Bay station sediments (1358 individuals, 74 taxa) which were comprised of silt and clay, and lowest (707 individuals, 50 taxa) in the outer Fidalgo Bay station sediments, which were comprised of sand, silt, and clay, with some eel grass and woody debris. The evenness values and dominance index displayed the opposite relationship. Although all three stations shared the dominant polychaete *Owenia fusiformis*, the infaunal species composition at the three stations differed from one another. The inner Padilla Bay station was dominated primarily by the polychaetes *Owenia fusiformis*, *Exogone lourei* and *Exogone dwisula*, and the tanaid *Leptochelia savignyi*. The inner Fidalgo Bay station was dominated by the bivalve *Psephidia lordi* and the polychaetes *Owenia fusiformis*, *Aricidea lopezi*, and *Terebellides nr. kobei*. The outer Fidalgo Bay station had the most even distribution of organisms, with high abundances of molluscs (*Rochefortia tumida*), arthropods (the amphipod *Protomedeia grandimana*) and polychaetes (*Aphelochaeta monilaris* and *Owenia fusiformis*).

The other stations sampled from the 7 strata (13 through 19) in the Anacortes area include two which display no significant chemistry or bioassay results, station 40 in Samish Bay and station 55 in outer Fidalgo Bay off March Point. The 16 other stations have at least one significant chemistry (in all cases the phenol compounds) or toxicity result and varying indices of

community structure based on location. No noticeable patterns were observed in any of the measured parameters when comparing stations within strata in this region (Appendix G).

There were no stations sampled in the vicinity of Whidbey Island and Skagit Bay (Figure 86) or Saratoga Passage and Port Susan (Figure 87), that indicated both significant chemistry and toxicity results. Only two stations (station 63 - Skagit Bay and station 81 - Port Susan) indicated no significant results for either parameter.

Sediments from the nine Everett Harbor stations (86-94) exhibited a number of similar observable characteristics. All stations were comprised of sediments that were black silt, clay, and wood chips. Sediments from stations 86 through 91 were all of similar depth (11-14m), salinity (20-25ppt), and temperature (11-12°C) ranges, had a strong petroleum smell and exhibited sheens. Stations 86 through 89 had a white gelatinous diatom film growing on the sediment surface that was seen at no other stations sampled in this study. Sediments from stations 92-94 were deeper (22m), but had salinity and temperatures similar to the other six stations. Sediments from stations 92 through 94 also exhibited sheens and had a strong hydrogen sulfide smell.

As expected and presented earlier, sediments from these nine Everett Harbor stations (86-94) had both significant toxicity and elevated levels of chemical contamination (Figure 88). Urchin fertilization was severely reduced and Cytochrome P450 RGS results were elevated and significant at all nine stations relative to critical values established in this study. Also, results of the Microtox™ tests were significant for the three outer harbor stations (92-94). Contaminant levels exceeded from 1 to 9 ERM, SQS, and CSL values at all nine Everett Harbor stations, and included high levels of trace metals, LPAHs, HPAHs, benzoic acid, 4-methylphenol, and phenol.

The benthic infaunal indices at Everett Harbor all appeared to be relatively low in comparison with the majority of the 100 stations examined in this study. Total abundance, major taxa abundance, taxa richness, and dominance were extremely low at the inner Everett Harbor stations (86-88), and indicated a rough gradient of increase from the head to the mouth of the Harbor. Annelids and arthropods were present at all nine stations, while molluscs were absent from the three inner harbor stations (86-88). Miscellaneous taxa and echinoderms also appeared to display a pattern. Miscellaneous taxa were absent from all but two mid-harbor stations (90 and 91) and two outer harbor station (93 and 94), while echinoderms were absent from all but outer harbor stations 93 and 94. The polychaete *Capitella capitata*, widely recognized as pollution-tolerant, was one of the dominant species present at all nine stations. The arthropods *Nebalia pugettensis* and *Aoroides spinosus/*sp. were two dominant species present at all three inner harbor stations, while the polychaete *Eteone* sp. was dominant at two of these stations (86 and 88). *Nebalia pugettensis* was dominant in two of the three mid-Everett Harbor stations (90 and 91). The ostracod *Euphilomedes carcharodonta* was dominant in all three outer harbor stations (92-94).

The last station which displayed both significant chemistry and toxicity results was station 97 in outer Port Gardner/Possession Sound (Figure 89). The significant chemistry result was due to

the presence of 4-methylphenol, found in concentrations above both SQS and CSL guidelines, while the significant toxicity result was due to elevated Cytochrome P450 RGS results.

Station 97 was located in moderately deep water (122m), with low salinity (20ppt) and temperature (10°C). The sediments were comprised of sand, silt, and clay. Total species abundance and taxa richness at this station was similar to station 94 in outer Everett Harbor (855 vs. 813 individuals, and 60 vs. 78 taxa, respectively), but the evenness and dominance values were much lower for the station in Possession Sound. Both stations shared the dominant bivalve *Axinopsida serricata*, but station 97 was dominated by these, the bivalve *Macoma carlottensis*, and the polychaetes *Prionospio lighti* and *Heteromastus filiformis*. Station 94 was dominated by the ostracod *Euphilomedes carcharodonta*, and had lower numbers and more evenly distributed suites of bivalves, polychaetes, and arthropods.

The other stations sampled from the 3 strata (28, 32, and 33) in Possession Sound, Port Gardner, and the Snohomish River delta area included four which indicated no significant chemistry or bioassay results (stations 83, 84, 85, and 99). The four other stations had at least one significant chemistry (including bis(2-ethylhexyl)phthalate, 4-methylphenol, and/or phenol) or toxicity result, and varying indices of community structure. Station 100 displays extremely low abundance, taxa richness and dominance values, most certainly due to the freshwater influence of the Snohomish River.

Discussion

Spatial Extent of Toxicity

The survey of sediment toxicity in northern Puget Sound was similar in intent and design to those performed elsewhere by NOAA in many different bays and estuaries in the U.S. using comparable methods. Data have been generated for areas along the Atlantic, Gulf of Mexico, and Pacific coasts to determine the presence, severity, regional patterns and spatial scales of toxicity (Long et al., 1996). Spatial extent of toxicity in other regions ranged from 0.0% of the area to 100% of the area, depending upon the toxicity test.

The intent of this survey of northern Puget Sound was to provide information on toxicity throughout all regions of the study area, including a number of urbanized/industrialized regions. The survey area, therefore, was very large and complex. The primary objectives were to estimate the severity, spatial patterns, and spatial extent of toxicity, chemical contamination and relationships to benthic community structure. A stratified-random design was followed to ensure that unbiased sampling was conducted and, therefore, the data could be attributed to the strata within which samples were collected. This survey was not intended to focus upon any potential discharger or other source of toxicants. The survey was designed neither to provide evidence to be used to regulate or identify any sources of pollution nor to determine the causes of toxicity. Rather, the data from the laboratory bioassays were intended to represent the toxicological condition of the survey area, using a battery of complimentary tests.

Four different toxicity tests were performed on all 100 sediment samples. Additional tests were performed on a selected subset of the samples. As expected, all tests showed some degree of differences in results among the samples and with the negative controls. All showed spatial patterns in toxicity that were unique to each test, but, also overlapped to varying degrees with results of other tests. No two tests showed duplicative results.

Amphipod Survival – Solid Phase

These tests of relatively unaltered, bulk sediments were performed with adult crustaceans exposed to the sediments for 10 days. The endpoint was survival. Data from several field surveys conducted along portions of the Pacific, Atlantic, and Gulf of Mexico coasts have shown that significantly diminished survival of these animals often is coincident with decreases in total abundance of benthos, abundance of crustaceans including amphipods, total species richness, and other metrics of benthic community structure (Long et al., 1996). Therefore, this test often is viewed as having relatively high ecological relevance. In addition, it is the most frequently used test nationwide in dredging material and hazardous waste site assessments.

The amphipod tests proved to be the least sensitive of those performed in northern Puget Sound. Of the 100 samples tested, survival was significantly different from controls in only 13 samples. Samples in which test results were significant were collected at stations widely scattered throughout the study area. The data showed no consistent spatial pattern or gradient in response

among contiguous stations or strata. There were no samples in which survival was both statistically significant and mean survival was less than 80% of controls; the response level determined empirically to be highly significant (Thursby et al., 1997).

The distribution of the results in the amphipod tests performed in Puget Sound was very different relative to the distribution of results from studies with *Ampelisca abdita* compiled in the NOAA/EMAP national database (Table 38). Whereas amphipod survival was less than 80% of controls in 12.4% of samples from studies performed elsewhere, none of the samples from northern Puget Sound showed survival that low. In the national database only 47% of samples indicated survival of 90-99.9%. In northern Puget Sound, 76% of samples showed comparable survival.

Table 38. Incidence of toxicity in amphipod survival tests performed with *Ampelisca abdita*.

	National database (n = 2630)		*Northern Puget Sound (n = 100)*	
Percent control-adjusted amphipod survival	**Number of samples**	**Percent**	**Number of samples**	**Percent**
>=100	734	27.90	21	21.00
90-99.9	1237	47.00	76	76.00
80-89.9	330	12.50	3	3.00
70-79.9	112	4.30	0	0.00
60-69.9	55	2.10	0	0.00
50-59.9	30	1.10	0	0.00
40-49.9	24	0.90	0	0.00
30-39.9	27	1.00	0	0.00
20-29.9	19	0.70	0	0.00
10-19.9	25	1.00	0	0.00
0.0-9.9	35	1.30	0	0.00

With the results of the amphipod tests weighted to the sizes of the sampling strata within which samples were collected, the spatial scales of toxicity could be estimated. A critical value of <80% of control response was used to estimate the spatial extent of toxicity in this test. However, because none of the test samples indicated less than 80% survival relative to controls, the spatial extent of toxicity was estimated as zero (Table 12).

To add perspective to these data, the results from northern Puget Sound were compared to those from other regions surveyed by NOAA in the U.S. (Long et al., 1996). In surveys of 24 U.S. regions, estimates of the spatial extent of toxicity ranged from 0.0% in many areas to 85% in Newark Bay, New Jersey (Table 39). Northern Puget Sound was among the many regions in which an estimate of 0% was calculated. With the data generated in studies conducted through 1995, the overall "national average" was calculated as 10.9%. With the addition of data generated through 1996, the "national average" was recalculated to be 6.9%. The data for northern Puget Sound fell well below these national averages. These data suggest that acute toxicity as measured in the amphipod survival tests was neither severe nor widespread in this region.

Sea Urchin Fertilization – Pore Water

Sea urchin fertilization success was determined as a measure of the survival and viability of sperm exposed to the pore waters of the sediments. Gametes and larval stages of invertebrates often are more sensitive, and have developed fewer defense mechanisms to toxicants, than adults. The test endpoint – fertilization success – is a sublethal response expected to be more sensitive than an acute mortality response. The gametes were exposed to the pore waters extracted from the samples; the phase in which toxicants were expected to be highly bioavailable. This test was adapted from protocols for bioassays originally performed to test wastewater effluents and has had wide application throughout North America in tests of both effluents and sediment pore waters. The combined effects of these features was to develop a relatively sensitive test, much more sensitive than that performed with the adult amphipods.

In northern Puget Sound, 15% of the samples were significantly toxic relative to controls in tests of 100% (undiluted) pore waters. The strata in which sediments were highly toxic (i.e., percent fertilization <80% of controls) totaled about 5%, 1.4% and 0.7% of the survey area in tests with 100%, 50%, and 25% porewater concentrations, respectively (Table 12). Many of the samples from Everett Harbor were among the most toxic in the urchin fertilization tests. Other samples in which toxicity was relatively high were collected in Drayton Harbor, Bellingham Bay, Padilla Bay, Fidalgo Bay, and Port Susan.

NOAA estimated the spatial extent of toxicity in urchin fertilization or equivalent tests performed with pore water in many other regions of the U.S. (Long et al., 1996). These estimates ranged from 98% in San Pedro Bay, California to 0.0% in Leadenwah Creek, South Carolina (Table 40). As in the amphipod tests, northern Puget Sound ranked near the bottom of this range, well below the "national averages" of 43% and 39% calculated with data generated through 1995 and 1996, respectively. Equivalent results in this test were reported in areas such as Sabine Lake, Texas; Pensacola Bay, Florida; and St. Simons Sound, Georgia; in which urbanization and industrialization were restricted to relatively small portions of the estuaries.

Table 39. Spatial extent of toxicity (km^2 and percentage of total area) in amphipod survival tests performed with solid-phase sediments from 24 U.S. bays and estuaries.

Survey Areas	Year sampled	No. of samples	Total area (km^2)	Amphipod survival toxic area (km^2)	Percent of total area
Newark Bay	93	57	13	10.8	85.0%
San Diego Bay	93	117	40.2	26.3	65.8%
California coastal lagoons	94	30	5	2.9	57.9%
Tijuana River	93	6	0.3	0.18	56.2%
Long Island Sound	91	60	71.86	36.3	50.5%
Hudson-Raritan Estuary	91	117	350	133.3	38.1%
San Pedro Bay	92	105	53.8	7.8	14.5%
Biscayne Bay	95/96	226	484.2	62.3	12.9%
National average: 1995		**1274**	**2532.6**	**277.00**	**10.9%**
Boston Harbor	93	55	56.1	5.7	10.0%
National average: 1996		**1470**	**4158.1**	**286.40**	**6.9%**
Savannah River	94	60	13.12	0.16	1.2%
St. Simons Sound	94	20	24.6	0.10	0.4%
Tampa Bay	92/93	165	550	0.5	0.1%
Galveston Bay	96	75	1351.1	0.0	0.0%
Northern Puget Sound	**97**	**100**	**773.9**	**0.0**	**0.0%**
Pensacola Bay	93	40	273	0.04	0.0%
Choctawhatchee Bay	94	37	254.47	0.0	0.0%
Sabine Lake	95	66	245.9	0.0	0.0%
Apalachicola Bay	94	9	187.58	0.0	0.0%
St. Andrew Bay	93	31	127.2	0.0	0.0%
Charleston Harbor	93	63	41.1	0.0	0.0%
Winyah Bay	93	9	7.3	0.0	0.0%
Mission Bay	93	11	6.1	0.0	0.0%
Leadenwah Creek	93	9	1.69	0.0	0.0%
San Diego River	93	2	0.5	0.0	0.0%

Table 40. Spatial extent of toxicity (km^2 and percentages of total area) in sea urchin fertilization tests performed with 100% sediment porewaters from 21 U.S. bays and estuaries.

Survey areas	Year sampled	No. of samples	Total area (km^2)	Urchin fertilization (100% porewater) toxic area (km^2)	Percent of total area
San Pedro Bay	92	105	53.8	52.6	97.7%
Tampa Bay	92/93	165	550	463.6	84.3%
San Diego Bay	93	117	40.2	25.6	76.0%
Mission Bay	93	11	6.1	4.0	65.9%
Tijuana River	93	6	0.3	0.18	56.2%
San Diego River	93	2	0.5	0.26	52.0%
Biscayne Bay	95/96	226	484.2	229.5	47.4%
Choctawhatchee Bay	94	37	254.47	113.14	44.4%
California coastal lagoons	94	30	5	2.1	42.7%
National average: 1995		**940**	**2082.6**	**886.3**	**42.6%**
Winyah Bay	93	9	7.3	3.1	42.2%
National average: 1996		**1136**	**3723.26**	**1439.73**	**38.7%**
Apalachicola Bay	94	9	187.58	63.6	33.9%
Galveston Bay	96	75	1351.1	432.0	32.0%
Charleston Harbor	93	63	41.1	12.5	30.4%
Savannah River	94	60	13.12	2.42	18.4%
Boston Harbor	93	55	56.1	3.8	6.6%
Sabine Lake	95	66	245.9	14.0	5.7%
Pensacola Bay	93	40	273	14.4	5.3%
Northern Puget Sound	**97**	**100**	**773.9**	**40.6**	**5.2%**
St. Simons Sound	94	20	24.6	0.65	2.6%
St. Andrew Bay	93	31	127.2	2.28	1.8%
Leadenwah Creek	93	9	1.69	0.0	0.0%

Microbial Bioluminescence (Microtox™) - Organic Solvent Extract

The Microtox™ tests were performed with organic solvent extracts of the sediments. These extracts were intended to elute all potentially toxic organic substances associated with sediment particles regardless of their bioavailability. The tests, therefore, provide an estimate of the potential for toxicity attributable to complex mixtures of toxicants associated with the sediment. This test is not sensitive to the presence of ammonia, hydrogen sulfide, fine-grained particles or other features of sediments that may confound results of other tests. The test endpoint is a measure of metabolic activity, not acute mortality. These features combined to provide a relatively sensitive test - usually the most sensitive test performed nationwide in the NOAA surveys (Long et al., 1996).

In northern Puget Sound, the data were difficult to interpret because of the unusual result in the negative control sample from Redfish Bay, Texas. Test results for the control showed the sample to be considerably less toxic relative to previous tests of sediments from that site and to tests of negative control sediments from other sites used in previous surveys. Therefore, new analytical procedures were used with the compiled NOAA data to provide more suitable values for evaluating the northern Puget Sound data.

Using a critical value of <0.51 mg/ml, it was estimated that the spatial extent of toxicity in the Microtox™ tests represented approximately 2.2% of the survey area (Table 12). This estimate ranked northern Puget Sound near the bottom of the distribution for data generated from 17 bays and estuaries surveyed by NOAA (Table 41). Roughly equivalent results were reported for Tampa Bay, Florida. The estimate for northern Puget Sound was well below the "national averages" of 61% and 66% calculated for data generated through 1995 and 1996, respectively.

Cytochrome P450 RGS - Organic Solvent Extract

This test is intended to identify samples in which there were elevated concentrations of mixed-function oxygenase-inducing organic compounds, notably the dioxins and high molecular weight PAHs. It is performed with a cultured cell line that provides very reliable and consistent results. As with the Microtox™ tests, these assays are conducted with an organic solvent extract of the sediment. High Cytochrome P450 RGS induction may signify the presence of substances that could cause or contribute to the induction of mutagenic and/or carcinogenic responses in local resident biota.

In northern Puget Sound, the Cytochrome P450 RGS assay indicated that samples in which results exceeded 11.1 and 37.1 B[a]P equivalents (µg/g) (i.e., the 80 and 90% upper prediction limits calculated for the Cytochrome P450 RGS assays from the entire NOAA bioeffects database) represented 2.6% and 0.03% of the study area, respectively (Table 12). Results from northern Puget Sound are compared to those for five other regions in Table 42. Cytochrome P450 RGS responses greater than 37.1 B[a]P equivalents (µg/g) were most pervasive in Delaware Bay, Delaware, followed by Sabine Lake, Texas, and northern Puget Sound. Examination of the Cytochrome P450 RGS responses greater than 11.1 B[a]P equivalents (µg/g) indicated that for the six estuarine areas examined, Puget Sound had the lowest response for the percent of total area.

Table 41. Spatial extent of toxicity (km^2 and percentages of total area) in microbial bioluminescence tests performed with solvent extracts of sediments from 17 U.S. bays and estuaries.

Survey areas	Year sampled	No. of samples	Total area (km^2)	Microbial bioluminescence toxic area (km^2)	Percent of total area
Choctawhatchee Bay	94	37	254.47	254.47	100.0%
St. Andrew Bay	93	31	127.2	127	100.0%
Apalachicola Bay	94	9	187.58	186.84	99.6%
Pensacola Bay	93	40	273	262.8	96.4%
Galveston Bay	96	75	1351.1	1143.7	84.6%
Sabine Lake	95	66	245.9	194.2	79.0%
Winyah Bay	93	9	7.3	5.13	70.0%
Long Island Sound	91	60	71.86	48.8	67.9%
National average: 1996		**1042**	**4039.22**	**2670.69**	**66.1%**
National average: 1995		**846**	**2416.2**	**1482.3**	**61.3%**
Savannah River	94	60	13.12	7.49	57.1%
Biscayne Bay	95/96	226	484.2	248.4	51.3%
St. Simons Sound	94	20	24.6	11.42	46.4%
Boston Harbor	93	55	56.1	25.8	44.9%
Charleston Harbor	93	63	41.1	17.6	42.9%
Hudson-Raritan Estuary	91	117	350	136.1	38.9%
Leadenwah Creek	93	9	1.69	0.34	20.1%
Northern Puget Sound*	**97**	**100**	**773.9**	**17.7**	**2.2%**
Tampa Bay	92/93	165	550	0.6	0.1%

* Critical value of <0.51 mg/L

Table 42. Spatial extent of Cytochrome P450 RGS responses >11.1 and >37.1 B[a]P equivalents (µg/g) in six U.S. bays and estuaries (km² and percentages of total area).

				Cytochrome P450 RGS responses			
				(>11.1 B[a]P equivalents (µg/g))		*(>37.1 B[a]P equivalents (µg/g))*	
Survey areas	**Year sampled**	**No. of samples**	**Total area (km²)**	**(km²)**	**Percent of total area**	**(km²)**	**Percent of total area**
Delaware Bay	97	73	2346.8	145.2	6.2	80.5	3.4
Sabine Lake	95	65	245.9	6.7	2.7	1.7	0.7
Northern Puget Sound	**97**	**100**	**773.9**	20.1	2.6	0.2	0.03
California coastal lagoons	94	30	5.0	2.3	46.0	0.0	0.0
Biscayne Bay	96	121	271.4	8.8	3.2	0.0	0.0
Galveston Bay	96	75	1351.5	56.7	4.2	0.0	0.0

Severity of Chemical Contamination

The severity of chemical contamination in northern Puget Sound can be compared with comparable data from other areas also sampled with equivalent probabilistic stratified-random study designs. In the northern Puget Sound study, none of the mean ERM quotients for 100 samples exceeded 1.0. In comparison, 6 of 226 samples (3%) from Biscayne Bay, Florida had mean ERM quotients of 1.0 or greater (Long et al., in press). Among 1068 samples collected by NOAA and EPA in many estuaries nationwide, 51 (5%) had mean ERM quotients of 1.0 or greater (Long et al., 1998).

In northern Puget Sound, there were 8 samples (8%) representing about 9.5 km^2 (or 1.2% of the total area) in which one or more ERMs were exceeded from urban bays. In Biscayne Bay, 33 of 226 samples (15%) representing about 0.7% of the study area had equivalent chemical concentrations (Long et al., in press). In selected small bays of southern California, 18 of 30 randomly chosen station, representing 67% of the study area, had chemical concentrations that exceeded one or more Probable Effects Level (PEL) guidelines (Anderson et al., 1997). In the nationwide, combined NOAA/EPA database, 27% of samples had at least one chemical concentration greater than the ERM (Long et al., 1998). In the Carolinian estuarine province, Hyland et al. (1996) estimated that the surficial extent of chemical contamination in sediments was about 16% relative to the ERMs. In data compiled from three years of study in the Carolinian Province, however, the size of the area with elevated chemical contamination decreased to about 5% (Dr. Jeff Hyland, NOAA, personal communication). In data compiled by

Dr. Hyland from stratified-random sampling in the Carolinian Province, Virginian Province, Louisianian Province, northern Chesapeake Bay, Delaware Bay, and DelMarVa estuaries, the estimates of the spatial extent of contamination in which one or more ERM values were exceeded ranged from about 2% to about 8%. Therefore, the data for northern Puget Sound (8%) were comparable to those from many other regions sampled and tested with equivalent methods.

Comparisons between the chemical data generated in this 1997 NOAA/Ecology study versus those assembled from previous studies in Puget Sound (data compiled in the SEDQUAL data base), and those from the NOAA/EPA estuarine database and reported by Long et al. (1998), are summarized in Appendix H. The median and maximum concentrations for the majority of substances quantified in the 1997 study were lower than those reported either in previous Puget Sound surveys or by Long et al. (1998). For some of these chemicals, however, the minimum concentrations exceeded previous minima, probably reflecting differences in the reporting limits between studies.

There were some chemicals in which the concentrations reported in the 1997 study were relatively high, exceeding median concentrations in previous studies by at least a factor of 2.0 (Appendix H). These chemicals included hexachlorobutadiene, hexachlorobenzene, benzoic acid, phenol, several substituted phenols, most phthalate esters, antimony, thallium, cadmium, silver, dibenzo(a,h)anthracene, 4,4'-DDT, 4,4'-DDE, and many other chlorinated pesticides.

Collectively, the chemical data indicated that most of the northern Puget Sound sediment samples were not highly contaminated. Relative to effects-based guidelines or standards, relative to previous Puget Sound studies, and relative to data from other areas in the U.S.; the concentrations of most trace metals, most PAHs, total PCBs, and most chlorinated pesticides were not very high in the majority of the samples. However, the concentrations of phenols, benzoic acid, DDT isomers, some chlorinated pesticides, and some phthalate esters were relatively high in many samples.

The highest concentrations of mixtures of substances often occurred in samples from Everett Harbor, especially in the inner reaches of the east waterway. Samples from Everett Harbor had elevated concentrations of PAHs, many chlorinated pesticides, benzoic acid, phenols, semivolatiles, phthalate esters, and a few trace metals. The samples with the highest chemical levels also were among those that were most toxic in the RGS, Microtox™, and urchin fertilization tests. Concentrations of most substances decreased remarkably in adjoining Port Gardner Bay.

Other samples with relatively high chemical concentrations were collected from sites scattered throughout the study area. Some samples collected near the urban centers of Blaine, Bellingham, and Anacortes had elevated concentrations of some substances. Mercury occurred at a high concentration in one sample from southern Boundary Bay. Mercury also was elevated in concentration in samples collected in Bellingham Bay. Arsenic, copper, and zinc occurred at high concentrations in inner Everett Harbor. High phenol concentrations (exceeding Washington State standards) occurred in many samples throughout the study area, notably in samples collected in Everett, Bellingham Bay, and near Anacortes. Samples collected near Blaine and Oak Harbor had high benzoic acid concentrations. The PAH concentrations were moderate in

samples collected near Anacortes and in Bellingham Bay. One or more semivolatile organic compounds occurred at high concentrations throughout the area. Curiously, PAH concentrations were not particularly elevated in samples collected near the petroleum refineries at March Point or Cherry Point.

Toxicity/Chemistry Relationships

The chemicals for which analyses were performed may have been the sole cause of toxicity or contributed substantially to the toxic responses. However, it is important to understand that other substances for which no analyses were conducted also may have contributed. The chemical and toxicity data were analyzed to determine their correlative relationships. It was not possible to identify and confirm which chemicals caused toxic responses in the urchin fertilization, Microtox™, and Cytochrome P450 RGS tests in the samples from northern Puget Sound. Determinations of causality require extensive toxicity identification evaluations and spiked sediment bioassays.

Typically in surveys of sediment quality nationwide, NOAA has determined that complex mixtures of trace metals, organic compounds, and occasionally ammonia have shown strong statistical associations with one or more measures of toxicity (Long et al., 1996). Frequently, as a result of the toxicity/chemistry correlation analyses, some number of chemicals will show the strongest associations leading to the hypothesis that these chemicals may have caused or contributed to the toxicity that was observed. However, the strength of these correlations can vary considerably among study areas and among the toxicity tests performed.

In northern Puget Sound, the data were similar to those collected in several other regions (e.g., western Florida panhandle, Boston Harbor, South Carolina/Georgia estuaries). Severe toxicity in the amphipod tests was not observed in any samples or only in very limited numbers of samples and, therefore, correlations with toxicity were not significant or were weak. However, correlations with chemical concentrations were more readily apparent in the results of the sublethal tests, notably urchin fertilization and microbial bioluminescence.

As observed in the studies of Tampa Bay and Biscayne Bay, Florida, and Hudson-Raritan Estuary, in New York and New Jersey, chemistry/toxicity correlations determined estuary-wide improved considerably when correlations were performed with data from the specific regions in which toxicity was most severe. The strong statistical associations between the results of the sea urchin, Microtox™, and RGS tests and the mean ERM quotients for 25 substances provided evidence that mixtures of organic substances and trace metals could have contributed to these measures of toxicity. Furthermore, the highly significant correlations between the two measures of toxicity in the solvent extracts and the concentrations of PAHs normalized to effects-based guidelines or criteria suggest that these substances occurred at sufficiently high concentrations to contribute to the sublethal toxic responses. The observation that these correlations with PAHs increased considerably among the samples from Everett Harbor suggests that the chemical/toxicological relationships were driven in large part by the data from that area.

The sea urchin tests performed on pore waters extracted from the sediments and the Microtox™ and Cytochrome P450 RGS tests performed on solvent extracts showed overlapping, but

different, spatial patterns in toxicity. Because of the nature of these tests, it is reasonable to assume that they responded to different substances in the sediments. The data showed that urchin fertilization was statistically associated with several trace metals (notably cadmium, copper, tin and zinc) some of which occurred at concentrations above their respective ERL levels as well as the PAHs. Because the solvent extracts would not be expected to elute trace metals, Microtox™ and Cytochrome P450 RGS results should show strong associations with concentrations of PAHs and other organic compounds. Indeed, the correlation analyses and scatterplots showed this to be the case. Microbial bioluminescence decreased and Cytochrome P450 RGS enzyme induction increased with increases in the concentrations of many organic compounds, notably including the PAHs, phenols, benzoic acid, and some pesticides.

To aid in the interpretation of the relationships between Cytochrome P450 RGS induction and chemical concentrations, seven samples selected from the Everett Harbor area and Bellingham Bay area were tested at two exposure time periods (6 and 16 hours). The maximal response of the Cytochrome P450 RGS assay to PAHs occurs in 6 hours exposure, whereas that for chlorinated substances occurs in 16 hours exposure. In all seven samples, the response at 6 hours exposure was greater than at 16 hours, indicating the presence of PAHs in the sediments. However, the 6:16 hour ratios were relatively small (1.1 to 3.0), indicating the presence of chlorinated compounds along with the PAHs. Chemical analyses for dioxins and furans in the sample from station 86 in which induction was greatest (202 B[a]PEq (ug/g)) revealed that, indeed, the sample had detectable concentrations of dioxins and furans. The concentration of 2378-tcdd in sample 86 was 3.6 pg/g and the concentration of all substances (expressed as 2378-tcdd equivalents) was 110 pg/g. Other, non-quantified substances may have been present at toxicologically significant concentrations.

Benthic Community Structure, the "Triad" Synthesis, and the Weight-of-Evidence Approach

The abundance, diversity, and species composition of marine infaunal communities vary considerably from place to place and over both short and long time scales as a result of many natural and anthropogenic factors (Reish, 1955; Nichols, 1970; McCauley et al., 1976; Pearson and Rosenberg, 1978; Dauer et al., 1979; James and Gibson, 1979; Bellan-Santini, 1980; Dauer and Conner, 1980; Gray, 1982; Becker et al., 1990; Ferraro et al., 1991; Llansó et al., 1998b). Major differences in benthic communities can result from wide ranges in water depths, oxygen concentrations at the sediment-water interface, the texture (grain size) and geochemical (i.e., minerological) composition of the sediment particles, water salinity as a function of proximity to a river or stream, bottom water current velocity or physical disturbance as a result of natural factors or maritime traffic, and the effects of large predators. In addition, the composition of benthic communities at any single location can be a function of seasonal or inter-annual changes in larval recruitment, availability of food, proximity to adult brood stock, predation, and seasonal differences in temperature, freshwater runoff, current velocity and physical disturbances.

In the northern Puget Sound study, sampling stations ranged in depths from 3 to 171 meters, reflecting the differences among locations sampled in shallow bays and locations sampled in

deeper basins. Among the 100 stations, sediment texture ranged from <1.0% fine-grained particles at a few locations to 100% fines at other stations, suggesting major differences in the sedimentological environments within the study area. The salinities of water samples collected with the benthic sampler ranged from 25 ppt to 32 ppt, reflecting the effects of freshwater runoff at locations sampled near river mouths. As a result of these and other natural environmental factors, the benthic communities near the mouths of the Skagit and Snohomish rivers, for example, would be expected to be very different from those in the deep water of Possession Sound. Also, dominant infauna in the sediments in the relatively protected inner Everett Harbor would be expected to differ considerably from those in, for example, the open waters of southern Strait of Georgia or the seagrass-dominated shallows of Padilla Bay.

Chapman (1996) provided recommendations for graphical and tabular presentations of data from the Sediment Quality Triad (i.e., measures of chemical contamination, toxicity, and benthic community structure). He suggested that locations with elevated chemical concentrations (for example, with respect to effects-based guidelines or criteria), and evidence of acute toxicity in laboratory tests (such as with the amphipod survival bioassays), and alterations to resident infaunal communities constituted "strong evidence of pollution – induced degradation" in his "weight-of-evidence" approach. In contrast, he suggested that there was "strong evidence against pollution-induced degradation" at sites lacking contamination, toxicity, and benthic alterations. Several other permutations were described in which sediments appeared to be contaminated, but not toxic, either with or without alterations to the benthos or in which sediments were not contaminated with measured substances, but, nevertheless, were toxic, either with or without benthic alterations. Plausible explanations were offered of benthic "alterations" at non-contaminated and/or non-toxic locations possibly attributable to natural factors, such as those identified above.

In the northern Puget Sound samples, indices of taxa richness, evenness, dominance and abundance of molluscs were significantly correlated with measures of organic carbon content and/or percent fine-grained particles. Therefore, as expected, the composition, abundance, and diversity of benthic assemblages appeared to relate to differences in the sediment properties among locations. Also, several indices of benthic structure were highly correlated with many of the chemicals for which analyses were performed, including indices of the presence of complex mixtures of contaminants. Notably, the abundance of echinoderms, arthropods, and all taxa were highly correlated with indices of chemical mixtures that included a number of phenols, substituted (i.e., chlorinated) phenols, chlorinated benzenes, halogenated ethers, and organo-nitrogen compounds. These data do not mean that the benthos was altered or changed at some sites as a result of exposure to these substances. Rather, the data simply indicate that several indices of the abundance and diversity of the infauna co-varied with the concentrations of many chemicals; some or none of which may have contributed to the apparent changes in the benthos.

Generally, the benthic community indices were not highly correlated with the data from the four toxicity tests, suggesting that the measures of the benthic community structure and measures of toxicity co-varied with different chemical and/or physical variables in the sediments. However, there were a few notable exceptions. The abundance of echinoderm taxa in the benthos decreased with decreases in fertilization success in the porewater toxicity tests. Echinoderm

abundance was noticeably lower in the strata sampled south of the Deception Pass/Skagit River area as compared to the more northerly strata. Urchin fertilization often was relatively low in some of these samples, most notably those from Everett Harbor. These data do not mean there was a causative relationship between the losses of echinoderms in the benthos and the toxicity of the pore waters in the urchin tests. Echinoderm abundance may have decreased significantly because of a variety of factors either related or not to the factors that caused the toxicity to urchin sperm in the bioassays.

Determinations of the concordance in the quantification of the spatial extent of contamination, toxicity, and benthic alterations were hindered by the lack of critical numerical values for the benthic indices applicable to Puget Sound. Therefore, it was not possible to quantify the spatial extent of strong evidence either for or against "pollution – induced degradation" with the full triad of data as per Chapman (1996). However, it was possible to simultaneously examine the results of all three "triad" parameters (i.e., selected results from the toxicity, chemistry, and infaunal community analyses measured) (Appendix G) to look for patterns that either support or oppose evidence of "pollution-induced degredation" for the 100 stations sampled in this study.

Examination of all three "triad" parameters, including selected results from the toxicity, chemistry, and infaunal community analyses measured in this study, indicate that only a small portion (18 out of 100) of the stations monitored indicated significant results from both the toxicity and chemistry analyses (Table 36). Of these 18 stations, the nine Everett Harbor stations and possibly station 97 in Port Gardner, also indicated infaunal community characteristics that suggest a pattern possibly attributed to a decreasing gradient of chemical contamination and toxicity from the head to the mouth of Everett Harbor and into Port Gardner, rather than being the result of other natural environmental factors (e.g., grain size, depth, salinity, temperature, restricted water circulation, etc.). Together, the data from these 10 stations would suffice as "strong evidence for pollution-induced degradation". In contrast, 16 of the 100 stations indicated no significant toxicity or elevated chemistry concentrations, and had a wide range of infaunal parameters that could have been attributed to a number of variables, including naturally occurring environmental phenomenon. These stations were found in locations through the northern Puget Sound study area, and with few exceptions (e.g., station 59, Bellingham Bay), were not in immediate proximity to urban/industrial centers.

In the 66 remaining stations, there was relatively poor correspondence among the data from the three components of the triad. Often, one or more substances exceeded a guideline concentration, but the sample was not toxic, and the benthos varied considerably in structure, presumably as a result of many factors, including natural environmental variables. In other instances, the sample displayed toxic results in one of the tests, but no significant chemistry concentrations were measured, and no real correspondence with the benthos could be discerned. Additional statistical analyses are required to fully describe the multivariate relationships among the different types of sediment quality data.

Conclusions

- One hundred sediment samples were collected from northern Puget Sound and analyzed for toxicity, chemical constituents, and benthic infauna during 1997. The different tests indicated overlapping patterns or gradients in toxicity. Overall, however, the data indicated that sediments from inner Everett Harbor were the most toxic.

- Tests of the induction of CYP1A activity in the Cytochrome P450 RGS assay indicated a clear pattern of highest chemical concentrations in sediments from Everett Harbor. Enzyme induction was highly correlated with the presence of mixtures of organic substances, primarily PAHs. However, there was evidence in samples from Everett Harbor of the presence of dioxins and furans.

- The spatial extent of toxicity was estimated by weighting the results of each test to the sizes of the sampling strata. The total study area was estimated to represent about 773.9 square kilometers. The area in which highly significant toxicity occurred totaled 0% of the total area in the amphipod survival tests; 5% of the area in urchin fertilization tests; 2% of the area in microbial bioluminescence tests; and 0.03% of the area in the Cytochrome P450 RGS assays. Toxic conditions were observed mainly in samples collected near urban/industrial areas.

- The estimates of the spatial extent of toxicity measured in these four tests in northern Puget Sound generally were lower than the "national average" estimates compiled from many other surveys previously conducted by NOAA, suggesting that northern Puget Sound sediments were less toxic relative to sediments from other estuarine regions of the United States.

- The surficial area in which chemical concentrations exceeded numerical guidelines (Long et al., 1995) or Washington State standards was very small for most substances, typically representing less than 1 km^2. Both the percentages of samples that exceeded numerical guidelines and the surficial extent of contamination as compared to the guidelines were lower than observed elsewhere in comparable studies of other urban/industrial estuaries and bays conducted nationwide. However, many samples exceeded the state of Washington standards for 4-methylphenol, phenol, and benzoic acid. Also, many samples had chemical concentrations (e.g., DDT, PCB, and several trace metals) that exceeded low-range chemical guidelines (Long et al., 1995), suggesting slight or intermediate levels of contamination occurred in those samples.

- Statistical analyses and scatterplots of the data indicated that complex mixtures of substances were associated with and possibly contributed to the toxicity observed in the tests. Some substances (notably the PAHs) were statistically correlated with measures of toxicity, showed increasing toxicity with increasing concentrations, and were most toxic in samples in which chemical concentrations exceeded effects-based, numerical guidelines or standards. The nature of these chemical mixtures differed among sampling locations. Also, the mixtures showing statistical associations with toxicity differed among the tests performed.

- Benthic infaunal indices calculated for all stations throughout northern Puget Sound displayed a wide range of results from one strata to the next, and in many cases, within a strata. Correlation analyses between infaunal indices and sediment toxicity and chemistry indicated strong inverse relationships between both taxa richness and Mollusca abundance in the benthos, and percent fines, percent TOC, and the concentrations of the majority of potentially toxic chemicals.

- Examination of all three "triad" parameters, following Chapman (1996) indicated that only a small portion (18 out of 100) of the stations monitored displayed significant results from both the toxicity and chemistry analyses, and of these, only the nine Everett Harbor stations and possibly station 97 in Port Gardner, also displayed infaunal community characteristics that suggest "strong evidence for pollution-induced degradation".

- In contrast, 16 of the 100 stations, scattered throughout the study area, had both no significant toxicity and no elevated chemical concentrations. All of these stations had a wide range of infaunal parameters that could be attributed to naturally occurring environmental variables, suggesting "strong evidence against pollution-induced degradation" at these stations.

- The 66 other stations in the study area indicated relatively poor correspondence among the data from the three components of the triad. Additional statistical analyses are required to fully describe the multivariate relationships among the different types of sediment quality data.

- The causes of toxicity were not determined in this study. However, the weight of evidence strongly suggests that the samples from Everett Harbor had the highest chemical concentrations and the highest degree of toxicity, and, therefore, contributed substantially to the overall chemical/toxicological associations that were observed. Some samples from stations in Drayton Harbor, southern Boundary Bay, Bellingham Bay, Padilla Bay, Fidalgo Bay, and Port Gardner also had slight or moderate degrees of contamination and/or toxicity.

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Appendix A

Detected chemicals from northern Puget Sound SEDQUAL sediment samples exceeding Washington State Sediment Quality Standards (SQS) and Cleanup Screening Levels (CSL)

Appendix A. Detected chemicals from northern Puget Sound SEDQUAL sediment samples exceeding Washington State Sediment Quality Standards (SQS) and Cleanup Screening Levels (CSL).

Chemical contaminant	SQS Sample location (No. of samples)	SQS exceeded	CSL Sample location (No. of samples)	CSL exceeded
1,4-Dichlorobenzene	Bellingham Bay (1)	3.1	Bellingham Bay (1)	9
2,4-Dimethylphenol	Inner Bellingham Bay (1), Bellingham Bay (6), East Waterway Everett Harbor (2), Inner Everett Harbor (5) Everett Harbor (1),	29	Inner Harbor Bellingham Bay (1), Bellingham Bay (6), East Waterway Everett Harbor (2), Everett Harbor (1), Inner Harbor Everett Harbor (5)	29
2-Methylnaphthalene	Bellingham Bay (1), East Waterway Everett Harbor (3), North Port Gardner Everett Harbor (1)	38	East Waterway Everett Harbor (2)	64
2-Methylphenol	Bellingham Bay (2), East Waterway Everett Harbor (2), Inner Harbor Everett Harbor (4), Everett Harbor (1)	63	Bellingham Bay (2), East Waterway Everett Harbor (2), Inner Harbor Everett Harbor (4), Everett Harbor (1)	63
4-Methylphenol	Bellingham Bay (26), East Waterway Everett Harbor (9), Ebey Slough Everett Harbor (1), Inner Harbor Everett Harbor (4), Everett Harbor (8), North Port Gardner Everett Harbor (9), Outer Port Gardner Everett Harbor (6), Samish Bay (2), Snohomish River Delta Everett Harbor (2), Steamboat Slough Everett Harbor (1)	670	Bellingham Bay (26), East waterway Everett Harbor (9), Ebey Slough Everet Harbor (1), Everett Harbor (8), Inner Harbor Everett Harbor (4), North Port Gardner Everett Harbor (9), Outer Port Gardner Everett Harbor (6), Samish Bay (2), Snohomish River Delta Everett Harbor (3), Steamboat Slough Everett Harbor (1)	670
Acenaphthene	Bellingham Bay (7), East Waterway Everett Harbor (5), Everett Harbor (3), Inner Harbor Everett Harbor (1), North Port Gardner Everett Harbor (1)	16	Bellingham Bay (2), East Waterway Everett Harbor (3), Everett Harbor (1), North Port Gardner Everett Harbor (1)	57
Anthracene	Bellingam Bay (1)	220		

Appendix A. Continued

Arsenic	Inner Harbor Bellingham Bay (1), Bellingham Bay (1), East Waterway Everett Harbor (1)	57	Inner Bellingham Bay (2), Bellingham Bay (1), East Waterway Everett Harbor, Everett Harbor (1)	93
Benzo(a)anthracene	Inner Harbor Bellingham Bay(2), Bellingham Bay (1), Capsante Fidalgo Bay (1), North Port Gardner Everett Harbor (1)	110	Inner Harbor Bellingham Bay (2)	270
Benzo(a)pyrene	Inner Harbor Bellingham Bay (2), Bellingham Bay (1), East Waterway Everett Harbor (2), Everett Harbor (1), North Port Gardner Everett Harbor	99	Inner Harbor Bellingham Bay (1), East Waterway Everett Harbor (1), Everett Harbor (1)	210
Benzo(g,h,i)perylene	Inner Harbor Bellingham Bay (1), Bellingham Bay (1), Capsante Fidalgo Bay (1), East Waterway Everett Harbor (6), North Port Gardner Everett Harbor (1)	31	East Waterway Everett Harbor (5), Inner Harbor Bellingham Bay (1)	78
Benzoic acid	Bellingham Bay (1), East Waterway Everett Harbor (1), Ebey Slough Everett Harbor (1), Everett Harbor (3), North Port Gardner Everett Harbor (3), Samish Bay (1), Snohomish River Delta Everett Harbor (2)	650	Bellingham Bay (1), East Waterway Everett Harbor (1), Ebey Slough Everett Harbor (1), Everett Harbor (3), North Port Gardner Everett Harbor (3), Samish Bay (1), Snohomish River Delta Everett Harbor (2)	650
Benzyl alcohol	Bellingham Bay (1), East Waterway Everett Harbor (2), Everett Harbor (2), Snohomish River Delta Everett Harbor (1)	57	Bellingham Bay (1), East Waterway Everett Harbor (1), Everett Harbor (1), Snohomish River Delta Everett Harbor (1)	73
Bis(2-ethylhexyl) phthalate	Inner Harbor Bellingahm Bay (2), Bellingham Bay (8), Everett Harbor (8), Mukilteo offshore Everett Harbor (2), Samish Bay (2), Swinomish Channel Skagit Bay (1)	47	Inner Bellingham Bay (2), Bellingham Bay (4), Everett Harbor (3), Mukilteo offshore Everett Harbor (1), Samish Bay (1)	78
Butyl benzyl phthalate	Bellingham Bay (5), North Port Gardner Everett Harbor (1), Samish Bay (1), Snohomish River Everett Harbor (1)	4.9	Bellingham Bay (1)	64

Appendix A. Continued

Cadmium	Bellingham Bay (2), East Waterway Everett Harbor (2)	5.1	Bellingham Bay (1), East Waterway Everett Harbor (1)	6.7
Chromium	Bellingham Bay (1), North Port Gardner Everett Harbor (1)	260	Bellingham Bay (1), North Port Gardner Everett Harbor (1)	270
Chrysene	Inner Harbor Bellingham Bay (2), Bellingham Bay (5), Capsante Fidalgo Bay (4), East Waterway Everett Harbor (3), North Port Gardner Everett Harbor (1)	110	Inner Bellingham Bay (1), Bellingham Bay (1)	460
Copper	Inner Harbor Bellingham Bay (1), Bellingham Bay (2), East Waterway Everett Harbor (1)	390	Inner Harbor Bellingham Bay (1), Bellingham Bay (2), East Waterway Everett Harbor (1)	390
Dibenz(a,h)anthracene	Bellingham Bay (8), Capsante Fidalgo Bay (1), Everett Harbor (1), North Port Gardner Everett Harbor (1), Snohomish River Everett Harbor (1)	12	Bellingham Bay (1)	33
Dibenzofuran	Bellingham Bay (4), East Waterway Everett Harbor (2), Everett Harbor (2), North Port Gardner Everett Harbor (3)	15	Bellingham Bay (2), East Waterway Everett Harbor (1), Everett Harbor (1), North Port Gardner Everett Harbor (1)	58
Di-n-butyl phthalate	Snohomish River Everett Harbor (1)	220		
Di-n-octyl phthalate	Everett Harbor (1)	58		
Fluoranthene	Inner Harbor Bellingham Bay (2), Bellingham Bay (5), Capsante Fidalgo Bay (4), East waterway Everett Harbor (1), Everett Harbor (2), North Port Gardner Everett Harbor (1), Oak Harbor (1), Swinomish Channel Skagit Bay (1)	160	Inner Harbor Bellingham Bay (1), Bellingham Bay (2)	1200

Appendix A. Continued

Fluorene	Bellingham Bay (3), East Waterway Everett Harbor (5), Everett Harbor (1), North Port Gardner Everett Harbor (1)	23	Bellingham Bay (3), East Waterway Everett Harbor (2), North Port Gardner Everett Harbor (1)	79
Hexachlorobenzene	Bellingham Bay (4), Everett Harbor (2)	0.38		
High Molecular Weight PAH	Bellingham Bay (1), North Port Gardner Everett Harbor (1), Oak Harbor (1)	960		
Indeno (1,2,3-cd) pyrene	Inner Harbor Bellingham Bay (1) Bellingham Bay (5), North Port Gardner Everett Harbor (1)	34	Inner Harbor Bellingham Bay (1)	88
Lead	East Waterway Everett Harbor (1)	450		
Low Molecular Weight PAH	Bellingham Bay (1), East Waterway Everett Harbor (1), North Port Gardner Everett Harbor (1)	370	Bellingham Bay (1)	780
Mercury	Inner Harbor Bellingham Bay (24), Bellingham Bay (104), East Waterway Everett Harbor (7), Everett Harbor (2), Oak Harbor (1), Port Susan Everett Harbor (1) Possession Sound Everett Harbor (1), Snohomish River Delta Everett Harbor (3)	0.41	Inner Harbor Bellingham Bay (19), Bellingham Bay (80), East Waterway Everett Harbor (3), Oak Harbor (1), Snohomish River Delta Everett Harbor (2)	0.59
Naphthalene	East Waterway Everett Harbor (7), Everett Harbor (1)	99	East Waterway Everett Harbor (3)	170
N-Nitroso diphenylamine	Steamboat Slough Everett Harbor (1)	11	Steamboat Slough Everett Harbor (1)	11
Pentachlorophenol	Bellingham Bay (4), East Waterway Everett Harbor (1)	360		

Appendix A. Continued

Phenanthrene	Inner Bellingham Bay (1), Bellingham Bay (4), East Waterway Everett Harbor (3), Everet Harbor (1), North Port Gardner Everett habor (2)	100	Bellingham Bay (2)	480
Phenol	Bellingham Bay (21), East Waterway Everett Harbor (9), Everett Harbor (4), North Port Gardner Everett Harbor (6), Saratoga Passage E. Whidbey Island (1)	420	Bellingham Bay (7), East Waterway Everett Harbor (6), Ebey Slough Everett Harbor (1), Everett Harbor (2), North Port Gardner Everett Harbor (2)	1200
Pyrene	Inner Harbor Bellingham Bay (1), Bellingham Bay (1)	1000	Inner Harbor Bellingham Bay (1)	1400
Total benzofluoranthenes (b+k (+j))	Inner Harbor Bellingham Bay (2), Bellingham Bay (4), Everett Harbor (1)	230	Inner Harbor Bellingham Bay (1), Bellingham Bay (1), North Port Gardner Everett Harbor, Everett Harbor (1)	450
Total Polychlorinated Biphenyls	East Waterway Everett Harbor (2), Inner Harbor Everett Harbor (1), Mukilteo offshore Everett Harbor (1), North Port Gardner Everett Harbor (1)	12	North Port Gardner Everett Harbor (1)	65
Zinc	Inner Harbor Bellingham Bay (1), Bellingham Bay (6), East waterway Everett Harbor (6), Everett Harbor (2)	410	Bellingham Bay (1), East Waterway Everett Harbor (2), Everett Harbor (2)	960

Appendix B

Navigation report for the 1997 northern Puget Sound sampling stations

Appendix B. Navigation report for the 1997 northern Puget Sound sampling stations - includes station positioning and sample collection information.

Stratum No.	Sample No.	Station No.	Deploy-ment No.	Location	Date	GPS Time	Meter Wheel Depth m.	Predicted Tide (m.): Nearest Station	Predicted Mudline Depth, m. (MLLW)	Sample Location LORAN-C Yankee	Sample Location LORAN-C Zulu	Sample Location DGPS (Trimble NT300D) NAD 83, Decimal Minutes Latitude	Sample Location DGPS (Trimble NT300D) NAD 83, Decimal Minutes Longitude	Station Target NAD 1983 Decimal Minutes Latitude	Station Target NAD 1983 Decimal Minutes Longitude	Comments
1	**1**	1	1	Drayton Harbor	18-Jun-97	0856	4.0	0.1	-3.9	28847.5	42410.5?	48 58.584	122 45.837	48 58.583	122 45.833	heavy VV
			2			0912	3.5	0.0	-3.5	28847.8	42410.9	48 58.584	122 45.833			
			3			0925	3.5	-0.1	-3.6	28847.5	42411.0	48 58.584	122 45.833			
1	**2**	2	1	Drayton Harbor	19-Jun-97	1029	3.5	-0.4	-3.9	28849.4	42409.4	48 58.650	122 46.234	48 58.650	122 46.233	light VV
			2			1042	3.5	-0.4	-3.9	28849.3	42409.5	48 58.649	122 46.235			
			3			1056	3.5	-0.5	-4.0	28849.3	42409.4	48 58.649	122 46.233			
1	**3**	3	1	Drayton Harbor	19-Jun-97	0927	3.5	0.0	-3.5	28847.8	42408.4	48 58.468	122 46.366	48 58.467	122 46.367	light VV
			2			0942	3.5	-0.1	-3.6	28847.9	42408.5	48 58.464	122 46.365			
			3			0956	3.5	-0.2	-3.7	28847.8	42408.4	48 58.462	122 46.366			
2	**4**	1	1	Eastern Boundary Bay	16-Jun-97	1809	18.5	2.0	-16.5	28860.0	42389.4	48 58.399	122 51.200	48 58.400	122 51.200	light VV
			2			1827	18.5	1.9	-16.6	28860.0	42389.5	48 58.401	122 51.201			
			3			1843	18.5	1.9	-16.6	28860.1	42389.5	48 58.401	122 51.197			
2	**5**	2	1	Central Boundary Bay	16-Jun-97	1547	33.0	2.0	-31.0	28878.7	42379.0	48 59.348	122 54.602	48 59.350	122 54.600	light VV
			2			1610	33.0	2.1	-30.9	28878.6	42378.9	48 59.349	122 54.601			
			3			1640	33.0	2.1	-30.9	28878.8	42379.0	48 59.349	122 54.602			
			4			1711	33.0	2.1	-30.9	28878.6	42379.0	48 59.350	122 54.604			
			5			1726	33.0	2.1	-30.9	28878.6	42379.0	48 59.349	122 54.602			
2	**6**	3	1	Eastern Boundary Bay	19-Jun-97	1222	17.5	-0.3	-17.8	28866.9	42392.8	48 59.150	122 50.903	48 59.150	122 50.900	light VV
			2			1236	17.5	-0.2	-17.7	28867.0	42392.8	48 59.151	122 50.901			
			3			1250	18.0	-0.1	-18.1	28866.8	42392.8	48 59.149	122 50.900			
3	**7**	1	1	Boundary Bay, Pt. Roberts	16-Jun-97	0937	9.5	0.2	-9.3	28888.3	42358.3	48 59.049	122 59.599	48 59.050	122 59.600	heavy VV
			2			0957	9.5	0.3	-9.2	28888.4	42358.3	48 59.051	122 59.602			
			3			1016	10.0	0.3	-9.7	28888.3	42358.3	48 59.048	122 59.600			
			4			1038	10.0	0.4	-9.6	28888.4	42358.3	48 59.052	122 59.599			
3	**8**	2	1	Boundary Bay	16-Jun-97	1403	34.0	1.6	-32.4	28884.5	42376.4	48 59.699	122 55.503	48 59.700	122 55.500	light VV
			2			1424	33.0	1.7	-31.3	28884.6	42376.5	48 59.699	122 55.503			
			3			1453	33.0	1.8	-31.2	28884.6	42376.5	48 59.699	122 55.501			
3	**9**	3	1	Boundary Bay	16-Jun-97	1149	31.0	0.7	-30.3	28876.8	42371.4	48 58.797	122 56.101	48 58.800	122 56.100	light VV
			2			1210	31.5	0.8	-30.7	28876.9	42371.6	48 58.803	122 56.095			
			3			1233	31.5	1.0	-30.5	28876.8	42371.5	48 58.800	122 56.099			
4	**10**	1	1	Boundary Bay, southern edge	19-Jun-97	1333	28.0	0.2	-27.8	28840.7	42375.3	48 56.034	122 53.064	48 56.033	122 53.067	light VV
			2			1350	28.0	0.4	-27.6	28840.7	42375.3	48 56.034	122 53.064			
			3			1407	28.5	0.6	-27.9	28840.7	42375.3	48 56.032	122 53.067			
			4			1421	28.5	0.7	-27.8	28840.8	42375.3	48 56.036	122 53.064			
4	**11**	2.2	1	Boundary Bay, southern edge	17-Jun-97	1720	29.0	2.3	-26.7	28874.7	42364.5	48 58.249	122 57.467	48 58.250	122 57.467	light VV
			2			1735	29.0	2.3	-26.7	28874.8	42364.4	48 58.251	122 57.467			
			3			1749	29.0	2.3	-26.7	28874.8	42364.4	48 58.251	122 57.466			
4	**12**	3	1	Boundary Bay, southern edge	17-Jun-97	1507	29.0	1.8	-27.2	28863.8	42363.5	48 57.281	122 56.985	48 57.283	122 56.983	light VV
			2			1527	29.0	1.9	-27.1	28863.7	42363.5	48 57.284	122 56.983			
			3			1542	29.0	2.0	-27.0	28863.7	42363.6	48 57.283	122 56.982			
			4			1556	29.0	2.1	-26.9	28863.7	42363.5	48 57.281	122 56.983			
4	**13**	4	1	Outer Birch Bay	18-Jun-97	1024	13.5	-0.3	-13.8	28825.9	42388.0	48 55.547	122 49.369	48 55.550	122 49.367	light VV
			2			1041	13.5	-0.3	-13.8	28825.8	42388.0	48 55.547	122 49.366			
			3			1055	13.5	-0.3	-13.8	28826.0	42388.2	48 55.548	122 49.369			
5	**14**	1.2	1	Birch Bay	17-Jun-97	1124	7.5	0.2	-7.3	28813.0	42399.0	48 55.118	122 46.215	48 55.117	122 46.217	light VV
			2			1144	7.5	0.3	-7.2	28813.0	42399.0	48 55.118	122 46.219			
			3			1159	7.5	0.4	-7.1	28813.0	42399.0	48 55.119	122 46.219			
5	**15**	2	1	Birch Bay	17-Jun-97	1016	10.0	0.0	-10.0	28807.9	42393.8	48 54.401	122 47.002	48 54.400	122 47.000	light VV
			2			1033	9.5	0.0	-9.5	28807.9	42393.9	48 54.398	122 46.998			
			3			1049	9.5	0.0	-9.5	28807.9	42393.9	48 54.403	122 46.997			

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Stratum No.	Sample No.	Station No.	Deploy-ment No.	Location	Date	GPS Time	Meter Wheel Depth m.	Predicted Tide (m.): Nearest Station	Predicted Mudline Depth, m. (MLLW)	Sample Location LORAN-C Yankee	Sample Location LORAN-C Zulu	Sample Location DGPS (Trimble NT300D) NAD 83, Decimal Minutes Latitude	Sample Location DGPS (Trimble NT300D) NAD 83, Decimal Minutes Longitude	Station Target NAD 1983 Decimal Minutes Latitude	Station Target NAD 1983 Decimal Minutes Longitude	Comments
5	**16**	3	1	Birch Bay	17-Jun-97	1310	7.0	0.9	-6.1	28815.6	42400.7	48 55.416	122 46.000	48 55.417	122 46.000	light VV
			2			1330	7.5	1.0	-6.5	28815.5	42400.7	48 55.417	122 46.000			
			3			1347	7.5	1.2	-6.3	28815.6	42400.7	48 55.417	122 46.000			
6	**17**	1	1	S.E. Strait of Georgia	18-Jun-97	1353	10.5	0.8	-9.7	28741.2	42392.6	48 48.917	122 43.133	48 48.917	122 43.133	light VV
			2			1412	11.0	1.0	-10.0	28741.3	42392.6	48 48.915	122 43.130			
			3			1432	11.0	1.2	-9.8	28741.2	42392.6	48 48.919	122 43.135			
6	**18**	2	1	S.E. Strait of Georgia	18-Jun-97	1220	4.0	0.1	-3.9	28729.8	42391.1	48 47.884	122 42.817	48 47.883	122 42.817	heavy VV
			2			1231	4.0	0.2	-3.8	28729.6	42390.8	48 47.884	122 42.816			
			3			1244	4.0	0.3	-3.7	28729.6	42390.7	48 47.883	122 42.816			
			4			1256	4.0	0.4	-3.6	28729.6	42390.9	48 47.884	122 42.814			
6	**19**	3	1	S.E. Strait of Georgia	18-Jun-97	1512	23.0	1.5	-21.5	28759.2	42392.3	48 50.349	122 44.317	48 50.350	122 44.317	light VV
			2			1529	23.0	1.7	-21.3	28759.1	42392.2	48 50.350	122 44.321			
			3			1544	23.0	1.8	-21.2	28759.1	42392.3	48 50.350	122 44.316			
			4			1558	23.0	1.9	-21.1	28759.1	42392.2	48 50.352	122 44.320			
7	**20**	1	1	Northern Bellingham Bay	10-Jun-97	0903	9.5	1.7	-7.8	NA	NA	48 44.267	122 36.434	48 44.267	122 36.433	light VV
			2			0919	9.5	1.6	-7.9	NA	NA	48 44.265	122 36.435			
			3			0933	9.5	1.6	-7.9	28674.6	42404.3	48 44.267	122 36.433			
7	**21**	2	1	Northern Bellingham Bay	10-Jun-97	1005	8.0	1.5	-6.5	28678.1	42404.8	48 44.583	122 36.534	48 44.583	122 36.533	light VV
			2			1021	7.5	1.4	-6.1	28678.1	42404.8	48 44.582	122 36.534			
			3			1034	7.5	1.3	-6.2	28678.2	42404.8	48 44.586	122 36.533			
7	**22**	3	1	Northern Bellingham Bay	11-Jun-97	0826	7.0	1.6	-5.4	28675.6	42422.2	48 45.500	122 32.417	48 45.500	122 32.417	heavy VV
			2			0852	7.0	1.6	-5.4	28675.6	42422.2	48 45.501	122 32.422			
			3			0906	7.0	1.6	-5.4	28675.6	42422.2	48 45.499	122 32.419			
8	**23**	1	1	Bellingham Bay, off Squalicum Hbr.	10-Jun-97	1246	7.5	0.5	-7.0	NA	NA	48 45.085	122 30.767	48 45.083	122 30.767	light VV
			2			1341	7.0	0.2	-6.8	28666.5	42426.9	48 45.082	122 30.768			
			3			1351	7.0	0.2	-6.8	28666.5	42426.9	48 45.082	122 30.768			
8	**24**	2	1	Bellingham Bay, off Squalicum Hbr.	10-Jun-97	1430	5.5	0.0	-5.5	28666.9	42427.6	48 45.168	122 30.650	48 45.167	122 30.650	light VV
			2			1443	6.0	0.0	-6.0	28667.0	42427.5	48 45.166	122 30.651			
			3			1458	5.5	0.0	-5.5	28666.9	42427.5	48 45.166	122 30.654			
8	**25**	3	1	Bellingham Bay, off Squalicum Hbr.	10-Jun-97	1535	5.0	0.0	-5.0	28668.2	42427.2	48 45.249	122 30.799	48 45.250	122 30.800	light VV
			2			1550	5.0	0.1	-4.9	28668.2	42427.2	48 45.249	122 30.798			
			3			1602	5.0	0.1	-4.9	28668.3	42427.2	48 45.250	122 30.801			
9A	**26**	1	1	Bellingham Bay, off Squalicum Hbr.	12-Jun-97	0939	7.5	1.4	-6.1	28662.8	42428.3	48 44.883	122 30.233	48 44.883	122 30.233	light VV
			2			0958	7.5	1.5	-6.0	28662.8	42428.2	48 44.883	122 30.235			
			3			1012	7.5	1.5	-6.0	28662.9	42428.2	48 44.886	122 30.232			
9A	**27**	2	1	Bellingham Bay, off Squalicum Hbr.	12-Jun-97	1047	7.0	1.4	-5.6	28661.9	42428.6	48 44.834	122 30.083	48 44.833	122 30.083	light VV
			2			1104	7.0	1.4	-5.6	28661.9	42428.7	48 44.833	122 30.086			
			3			1117	7.5	1.4	-6.1	28661.8	42428.6	48 44.832	122 30.081			
9A	**28**	3	1	Bellingham Bay, Whatcom Wty.	12-Jun-97	1237	7.0	1.2	-5.8	28661.4	42431.4	48 44.979	122 29.413	48 44.983	122 29.417	light VV
			2			1302	7.0	1.1	-5.9	28661.4	42431.5	48 44.980	122 29.411			4 rejects
			3			1332	6.0	1.0	-5.0	28661.4	42431.5	48 44.985	122 29.407			
							Moved station 9A ten meters east. Center of station on shoreline rock fill.									
9B	**59**	1	1	Bellingham Bay, South Bellingham	11-Jun-97	1553	8.5	0.3	-8.2	28656.2	42427.4	48 44.283	122 29.968	48 44.283	122 29.967	light VV
			2			1610	8.5	0.3	-8.2	28656.2	42427.4	48 44.282	122 29.968			
			3			1623	8.5	0.3	-8.2	28656.2	42427.4	48 44.284	122 29.965			
9B	**60**	2	1	Bellingham Bay, South Bellingham	11-Jun-97	1655	7.0	0.3	-6.7	28654.3	42426.9	48 44.099	122 29.953	48 44.100	122 29.950	light VV
			2			1712	7.0	0.4	-6.6	28654.2	42426.9	48 44.100	122 29.953			
			3			1728	6.5	0.5	-6.0	28654.2	42426.9	48 44.096	122 29.949			
9B	**61**	3	1	Bellingham Bay, South Bellingham	12-Jun-97	0823	12.0	1.3	-10.7	28656.0	42426.1	48 44.181	122 30.282	48 44.183	122 30.283	light VV
			2			0839	12.0	1.3	-10.7	28656.0	42426.1	48 44.182	122 30.285			
			3			0854	12.0	1.3	-10.7	28656.1	42426.1	48 44.182	122 30.284			

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10	**29**	1	1	Bellingham Bay, South Bellingham	10-Jun-97	1637	14.0	0.2	-13.8	28659.2	42424.2	48 44.317	122 30.917	48 44.317	122 30.917	light VV
			2			1650	14.0	0.3	-13.7	28659.2	42424.2	48 44.318	122 30.920			
			3			1704	14.0	0.4	-13.6	28659.1	42424.2	48 44.318	122 30.920			
10	**30**	2	1	Bellingham Bay, South Bellingham	11-Jun-97	1010	16.0	1.5	-14.5	28655.3	42424.2	48 43.997	122 30.668	48 44.000	122 30.667	light VV
			2			1031	16.0	1.5	-14.5	28655.4	42424.3	48 44.000	122 30.669			
			3			1044	16.0	1.4	-14.6	28655.3	42424.2	48 44.000	122 30.672			
			4			1055	16.0	1.4	-14.6	28655.3	42424.2	48 44.001	122 30.670			
10	**31**	3	1	Bellingham Bay, South Bellingham	11-Jun-97	1149	18.5	1.2	-17.3	28652.2	42422.1	48 43.616	122 30.949	48 43.617	122 30.950	light VV
			2			1215	18.5	1.0	-17.5	28652.2	42422.1	48 43.615	122 30.950			
			3			1230	18.5	1.0	-17.5	28652.3	42422.1	48 43.615	122 30.950			
11	**32**	1	1	Bellingham Bay	9-Jun-97	1226	28.0	0.1	-27.9	28656.1	42415.5	48 43.500	122 32.715	48 43.500	122 32.717	light VV
			2			1241	27.5	0.0	-27.5	28656.0	42415.5	48 43.500	122 32.714			
			3			1257	27.5	0.0	-27.5	28656.1	42415.5	48 43.501	122 32.722			
			4			1312	27.5	-0.1	-27.6	28656.0	42415.5	48 43.502	122 32.720			
11	**33**	2	1	Bellingham Bay	9-Jun-97	1355	30.0	-0.2	-30.2	28651.2	42414.1	48 43.016	122 32.729	48 43.017	122 32.733	light VV
			2			1411	30.0	-0.2	-30.2	28651.3	42414.1	48 43.019	122 32.732			1 reject
			3			1424	30.0	-0.2	-30.2	28651.1	42414.0	48 43.017	122 32.734			
			4			1443	30.0	-0.2	-30.2	28651.3	42414.1	48 43.017	122 32.738			
11	**34**	3	1	Bellingham Bay	9-Jun-97	1520	29.0	-0.1	-29.1	28653.4	42409.2	48 42.884	122 33.987	48 42.883	122 33.983	light VV
			2			1543	29.0	0.0	-29.0	28653.4	42409.2	48 42.883	122 33.984			
			3			1558	29.0	0.1	-28.9	28653.5	42409.2	48 42.880	122 33.983			
			4			1612	29.5	0.2	-29.3	28653.5	42409.3	48 42.883	122 33.982			
			5			1624	29.5	0.3	-29.2	28653.5	42409.2	48 42.883	122 33.982			
			6			1635	29.5	0.4	-29.1	28653.5	42409.2	48 42.885	122 33.981			
12	**35**	1	1	Bellingham Bay	6-Jun-97	1619	20.0	1.1	-18.9	28617.4	42404.0	48 39.618	122 32.983	48 39.617	122 32.983	light VV
			2			1638	19.5	1.3	-18.2	28617.4	42403.9	48 39.616	122 32.984			
			3			1657	20.0	1.5	-18.5	28617.5	42403.9	48 39.617	122 32.985			
12	**36**	2	1	Bellingham Bay	9-Jun-97	0902	24.0	1.6	-22.4	28625.7	42409.3	48 40.649	122 32.216	48 40.650	122 32.217	light VV
			2			0918	23.5	1.5	-22.0	28625.7	42409.3	48 40.648	122 32.220			
			3			0931	23.5	1.5	-22.0	28625.7	42409.3	48 40.652	122 32.219			
			4			0944	23.5	1.4	-22.1	28625.7	42409.3	48 40.651	122 32.214			
12	**37**	3	1	Bellingham Bay	9-Jun-97	1026	31.5	1.1	-30.4	28644.2	42415.6	48 42.534	122 31.949	48 42.533	122 31.950	light VV
			2			1041	31.5	0.9	-30.6	28644.1	42415.5	48 42.530	122 31.947			
			3			1051	31.5	0.9	-30.6	28644.2	42415.6	48 42.533	122 31.946			
			4			1104	31.5	0.8	-30.7	28644.2	42415.6	48 42.533	122 31.950			
13	**38**	1	1	Samish Bay/ Bellingham Bay	6-Jun-97	1106	14.0	-0.4	-14.4	28591.8	42403.4	48 37.518	122 31.549	48 37.517	122 31.550	light VV
			2			1130	13.5	-0.5	-14.0	28591.7	42403.4	48 37.515	122 31.554			1 reject
			3			1153	13.5	-0.6	-14.1	28591.7	42403.4	48 37.516	122 31.548			
			4			1211	13.5	-0.6	-14.1	28591.8	42403.4	48 37.520	122 31.551			
13	**39**	2	1	Samish Bay/ Bellingham Bay	6-Jun-97	1339	15.0	-0.3	-15.3	28606.5	42401.3	48 38.547	122 32.971	48 38.550	122 32.967	light VV
			2			1359	15.0	-0.2	-15.2	28606.6	42401.3	48 38.551	122 32.970			
			3			1416	15.0	-0.1	-15.1	28606.5	42401.3	48 38.550	122 32.970			
			4			1432	15.0	0.0	-15.0	28606.6	42401.3	48 38.552	122 32.967			
			5			1448	15.0	0.2	-14.8	28606.6	42401.3	48 38.549	122 32.972			
13	**40**	3	1	Samish Bay	11-Jun-97	1355	5.0	0.5	-4.5	28571.1	42407.0	48 36.166	122 29.366	48 36.167	122 29.367	heavy VV
			2			1414	5.0	0.5	-4.5	28571.1	42406.9	48 36.168	122 29.371			
			3			1429	5.0	0.4	-4.6	28571.1	42407.0	48 36.167	122 29.369			
			4			1441	5.0	0.4	-4.6	28571.2	42407.0	48 36.169	122 29.370			
14	**41**	1	1	Padilla Bay	3-Jun-97	1538	4.0	1.9	-2.1	28535.6	42386.5	48 31.701	122 32.167	48 31.700	122 32.167	heavy VV
			2			1555	4.0	2.0	-2.0	28535.6	42386.5	48 31.699	122 32.167			
			3			1611	4.0	2.1	-1.9	28535.6	42386.6	48 31.699	122 32.164			

Appendix B. Navigation report for the 1997 northern Puget Sound sampling stations - includes station positioning and sample collection information.

Stratum No.	Sample No.	Station No.	Deploy-ment No.	Location	Date	GPS Time	Meter Wheel Depth m.	Predicted Tide (m.): Nearest Station	Predicted Mudline Depth, m. (MLLW)	Sample Location LORAN-C Yankee	Sample Location LORAN-C Zulu	Sample Location DGPS (Trimble NT300D) NAD 83, Decimal Minutes Latitude	Sample Location DGPS (Trimble NT300D) NAD 83, Decimal Minutes Longitude	Station Target NAD 1983 Decimal Minutes Latitude	Station Target NAD 1983 Decimal Minutes Longitude	Comments
14	**42**	2	1	Padilla Bay	3-Jun-97	1650	3.5	2.3	-1.2	28540.4	42384.6	48 31.917	122 32.933	48 31.917	122 32.933	heavy VV
			2			1702	3.5	2.3	-1.2	28540.4	42384.6	48 31.919	122 32.930			
			3			1711	4.0	2.3	-1.7	28540.4	42384.6	48 31.920	122 32.934			
			4			1723	3.5	2.3	-1.2	28540.4	42384.6	48 31.919	122 32.927			
			5			1735	4.5	2.3	-2.2	28540.5	42384.6	48 31.934	122 32.933	Moved 30 m. north, eel grass		
14	**43**	3	1	Padilla Bay	3-Jun-97	1431	4.0	1.3	-2.7	28545.1	42386.7	48 32.501	122 32.663	48 32.500	122 32.667	heavy VV
			2			1448	4.0	1.5	-2.5			48 32.502	122 32.668			
			3			1504	5.0	1.6	-3.4	28545.2	42386.8	48 32.498	122 32.665			
15	**44**	1	1	Padilla Bay	5-Jun-97	1352	29.0	0.2	-28.8	28573.8	42385.2	48 34.749	122 34.735	48 34.750	122 34.733	light VV
			2			1413	29.0	0.4	-28.6	28574.0	42385.1	48 34.754	122 34.736			
			3			1435	29.0	0.6	-28.4	28573.9	42385.1	48 34.750	122 34.733			
			4			1459	29.0	0.8	-28.2	28573.9	42385.1	48 34.751	122 34.733			
			5			1513	29.0	1.0	-28.0	28573.9	42385.1	48 34.753	122 34.735			
15	**45**	2	1	Padilla Bay	5-Jun-97	1549	19.0	1.3	-17.7	28556.9	42383.9	48 33.266	122 34.018	48 33.267	122 34.017	light VV
			2			1605	19.5	1.5	-18.0	28556.9	42383.9	48 33.267	122 34.018			
			3			1618	19.5	1.6	-17.9	28556.9	42383.9	48 33.267	122 34.016			
			4			1634	20.0	1.7	-18.3	28556.9	42383.9	48 33.263	122 34.016			
15	**46**	3.2	1	Padilla Bay	5-Jun-97	1118	26.0	-0.6	-26.6	28565.9	42382.4	48 33.833	122 34.831	48 33.833	122 34.833	light VV
			2			1138	26.0	-0.5	-26.5	28565.9	42382.4	48 33.833	122 34.829			
			3			1156	26.0	-0.5	-26.5	28565.9	42382.4	48 33.835	122 34.831			
			4			1216	26.0	-0.4	-26.4	28565.9	42382.5	48 33.832	122 34.828			
			5			1235	26.0	-0.3	-26.3	28565.9	42352.4	48 33.831	122 34.833			
16	**47**	1	1	Outer Fidalgo Bay, March Pt.	4-Jun-97	0930	29.0	-0.3	-29.3	28534.8	42377.7	48 30.969	122 34.216	48 30.967	122 34.217	heavy VV
			2			0948	29.0	-0.4	-29.4	28534.7	42377.7	48 30.966	122 34.211			
			3			1001	29.0	-0.4	-29.4	28534.8	42377.7	48 30.965	122 34.215			
16	**48**	2	1	Outer Fidalgo Bay, March Pt.	4-Jun-97	1037	8.0	-0.5	-8.5	28529.2	42376.4	48 30.416	122 34.183	48 30.417	122 34.183	heavy VV
			2			1052	8.0	-0.5	-8.5	28529.3	42376.4	48 30.416	122 34.179			
			3			1105	8.0	-0.4	-8.4	28529.3	42376.4	48 30.418	122 34.185			
16	**49**	3	1	Outer Fidalgo Bay, March Pt.	4-Jun-97	1420	2.5	0.8	-1.7	28527.0	42378.3	48 30.366	122 33.597	48 30.367	122 33.600	heavy VV
			2			1439	3.0	1.0	-2.0	28526.9	42378.3	48 30.362	122 33.600			
			3			1454	3.0	1.2	-1.8	28527.0	42378.3	48 30.369	122 33.602			
17	**50**	1	1	Inner Fidalgo Bay	4-Jun-97	1542	4.0	1.6	-2.4	28529.7	42368.6	48 29.898	122 35.981	48 29.900	122 35.983	heavy VV
			2			1609	4.5	1.9	-2.6	28529.8	42368.6	48 29.900	122 35.984			light VV
			3			1625	4.0	2.0	-2.0	28529.7	42368.6	48 29.901	122 35.981			light VV
17	**51**	2	1	Inner Fidalgo Bay	4-Jun-97	1245	6.5	0.0	-6.5	28520.5	42369.7	48 29.198	122 35.200	48 29.200	122 35.200	heavy VV
			2			1308	7.0	0.2	-6.8	28520.5	42369.7	48 29.200	122 35.199			
			3			1323	7.0	0.3	-6.7	28520.5	42369.7	48 29.199	122 35.199			
			4			1341	7.0	0.5	-6.5	28520.5	42369.7	48 29.199	122 35.198			
17	**52**	3	1	Inner Fidalgo Bay	5-Jun-97	1723	5.0	2.1	-2.9	28527.1	42369.5	48 29.733	122 35.632	48 29.733	122 35.633	light VV
			2			1744	5.0	2.3	-2.7	28527.0	42369.5	48 29.735	122 35.630			
			3			1808	5.0	2.4	-2.6	28527.0	42369.4	48 29.736	122 35.637			
			4			1824	5.0	2.5	-2.5	28527.0	42369.5	48 29.732	122 35.634			
18	**53**	1	1	Outer Fidalgo Bay, March Pt.	2-Jun-97	1050	3.2	0.2	-3.0	28530.6	42372.7	48 30.268	122 35.116	48 30.267	122 35.117	light VV
			2			1117	3.2	0.3	-2.9	28530.7	42372.6	48 30.265	122 35.118			
			3			1134	3.4	0.4	-3.0	28530.7	42372.7	48 30.265	122 35.119			
18	**54**	2	1	Outer Fidalgo Bay, March Pt.	2-Jun-97	1321	4.1	1.2	-2.9	28530.7	42373.9	48 30.366	122 34.813	48 30.367	122 34.817	light VV
			2			1340	4.0	1.3	-2.7	28530.6	42374.0	48 30.367	122 34.818			
			3			1401	4.0	1.5	-2.5	28530.7	42373.9	48 30.365	122 34.817			
			4			1416	5.5	1.6	-3.9	28530.7	42373.9	48 30.368	122 34.822			

Appendix B. Navigation report for the 1997 northern Puget Sound sampling stations - includes station positioning and sample collection information.

Stratum No.	Sample No.	Station No.	Deploy-ment No.	Location	Date	GPS Time	Meter Wheel Depth m.	Predicted Tide (m.): Nearest Station	Predicted Mudline Depth, m. (MLLW)	Sample Location LORAN-C Yankee	Sample Location LORAN-C Zulu	Sample Location DGPS (Trimble NT300D) NAD 83, Decimal Minutes Latitude	Sample Location DGPS (Trimble NT300D) NAD 83, Decimal Minutes Longitude	Station Target NAD 1983 Decimal Minutes Latitude	Station Target NAD 1983 Decimal Minutes Longitude	Comments
18	**55**	3	1	Outer Fidalgo Bay, Cap Sante	2-Jun-97	1500	15.0	1.9	-13.1	28538.1	42372.4	48 30.850	122 35.667	48 30.850	122 35.667	heavy VV
			2			1527	15.0	2.0	-13.0			48 30.849	122 35.668			
			3			1548	15.0	2.1	-12.9	28538.0	42372.4	48 30.850	122 35.669			
			4			1606	15.0	2.1	-12.9			48 30.848	122 35.665			
19	**56**	1	1	Outer Fidalgo Bay, Cap Sante	3-Jun-97	0841	19.0	-0.1	-19.1	28540.1	42372.3	48 31.049	122 35.734	48 31.050	122 35.733	heavy VV
			2			0914	19.5	-0.2	-19.7	28540.1	42372.4	48 31.051	122 35.732			5 rejects
			3			0930	19.0	-0.3	-19.3	28540.1	42372.4	48 31.054	122 35.733			cobble
			4			0941	19.0	-0.3	-19.3	28540.1	42372.4	48 31.049	122 35.731			
			5			0950	19.0	-0.3	-19.3	28540.1	42372.4	48 31.050	122 35.737			
19	**57**	2.4	1	Outer Fidalgo Bay, March Pt.	3-Jun-97	1107	19.5	-0.1	-19.6	28537.8	42376.5	48 31.134	122 34.682	48 31.133	122 34.683	Missed
			2			1121	19.5	-0.1	-19.6	28537.8	42376.6	48 31.132	122 34.684			first
			3			1140	20.0	0.0	-20.0	28537.8	42376.6	48 31.133	122 34.684			alternate
			4			1156	20.0	0.1	-19.9	28537.8	42376.5	48 31.130	122 35.679			
19	**58**	3	1	Outer Fidalgo Bay, March Pt.	3-Jun-97	1320	24.0	0.7	-23.3	28536.4	42377.0	48 31.050	122 34.484	48 31.050	122 34.483	heavy VV
			2			1333	24.0	0.8	-23.2	28536.4	42377.0	48 31.048	122 34.484			
			3			1348	24.5	1.0	-23.5	28536.4	42377.1	48 31.049	122 34.484			
21	**62**	1	1	Skagit Bay	2-Jul-97	1104	22.0	-0.3	-22.3	28380.3	42352.2	48 16.048	122 31.005	48 16.050	122 31.000	heavy VV
			2			1118	22.0	-0.2	-22.2	28380.3	42352.2	48 16.049	122 31.001			
			3			1131	22.0	-0.1	-22.1	28380.3	42352.2	48 16.052	122 30.997			
			4			1146	23.0	0.1	-22.9	28380.3	42352.2	48 16.049	122 31.003			
21	**63**	2	1	Skagit Bay	2-Jul-97	0954	19.0	-0.5	-19.5	28398.4	42363.1	48 18.500	122 29.498	48 18.500	122 29.500	heavy VV
			2			1004	19.0	-0.5	-19.5	28398.4	42362.9	48 18.500	122 29.506			1 reject
			3			1024	20.0	-0.4	-20.4	28398.4	42363.0	48 18.499	122 29.501			
			4			1033	20.0	-0.4	-20.4	28398.5	42363.0	48 18.502	122 29.502			
21	**64**	3	1	Skagit Bay	2-Jul-97	1251	23.0	0.8	-22.2	28388.1	42346.6	48 16.251	122 32.752	48 16.250	122 32.750	heavy VV
			2			1305	23.5	1.0	-22.5	28388.1	42346.6	48 16.250	122 32.748			
			3			1317	23.5	1.2	-22.3	28388.1	42346.7	48 16.248	122 32.751			
22	**65**	1	1	South of Oak Harbor	2-Jul-97	1410	15.0	2.0	-13.0	28400.0	42324.2	48 15.348	122 38.786	48 15.350	122 38.783	light VV
			2			1431	15.5	2.2	-13.3	28400.0	42324.2	48 15.350	122 38.786			
			3			1445	16.0	2.4	-13.6	28399.9	42324.2	48 15.350	122 38.782			
			4			1455	16.0	2.5	-13.5	28399.9	42324.2	48 15.348	122 38.784			
22	**66**	2	1	Mouth of Penn Cove	1-Jul-97	1514	34.0	3.0	-31.0	28387.9	42327.4	48 14.570	122 37.331	48 14.567	122 37.333	light VV
			2			1528	34.0	3.0	-31.0	28387.9	42327.4	48 14.567	122 37.333			
			3			1540	34.0	3.1	-30.9	28387.8	42327.4	48 14.566	122 37.329			
22	**67**	3	1	Northern Saratoga Passage	1-Jul-97	1408	44.0	2.4	-41.6	28377.9	42333.5	48 14.230	122 35.288	48 14.233	122 35.283	light VV
			2			1426	44.0	2.6	-41.4	28377.9	42333.6	48 14.233	122 35.280			
			3			1439	44.5	2.7	-41.8	28377.9	42333.5	48 14.233	122 35.286			
23	**68**	1	1	Oak Harbor	3-Jul-97	0912	3.5	0.0	-3.5	28414.4	42330.1	48 17.117	122 38.232	48 17.117	122 38.233	light VV
			2			0920	3.5	-0.2	-3.7	28414.5	42330.1	48 17.115	122 38.233			(heavy ok)
			3			0940	3.0	-0.3	-3.3	28414.4	42330.1	48 17.117	122 38.230			
23	**69**	2	1	Oak Harbor	2-Jul-97	1548	7.5	3.0	-4.5	28411.5	42325.6	48 16.467	122 39.119	48 16.467	122 39.117	light VV
			2			1603	7.5	3.1	-4.4	28411.5	42325.6	48 16.468	122 39.122			
			3			1614	7.5	3.2	-4.3	28411.5	42325.6	48 16.467	122 39.117			
23	**70**	3	1	Oak Harbor	3-Jul-97	1010	3.0	-0.5	-3.5	28413.5	42330.0	48 17.034	122 38.199	48 17.033	122 38.200	light VV
			2			1024	2.5	-0.5	-3.0	28413.6	42330.0	48 17.034	122 38.198			(heavy ok)
			3			1035	2.5	-0.5	-3.0	28413.6	42330.0	48 17.033	122 38.198			
			4			1047	2.5	-0.5	-3.0	28413.5	42330.0	48 17.033	122 38.201			
24	**71**	1	1	Penn Cove	1-Jul-97	0935	14.5	-0.3	-14.8	28395.8	42306.7	48 13.483	122 42.631	48 13.483	122 42.633	light VV
			2			0954	14.5	-0.2	-14.7	28395.8	42306.7	48 13.482	122 42.636			
			3			1006	14.5	-0.2	-14.7	28395.8	42306.7	48 13.482	122 42.633			

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Stratum No.	Sample No.	Station No.	Deploy-ment No.	Location	Date	GPS Time	Meter Wheel Depth m.	Predicted Tide (m.): Nearest Station	Predicted Mudline Depth, m. (MLLW)	Sample Location LORAN-C Yankee	Sample Location LORAN-C Zulu	Sample Location DGPS (Trimble NT300D) NAD 83, Decimal Minutes Latitude	Sample Location DGPS (Trimble NT300D) NAD 83, Decimal Minutes Longitude	Station Target NAD 1983 Decimal Minutes Latitude	Station Target NAD 1983 Decimal Minutes Longitude	Comments
24	**72**	2	1	Penn Cove	1-Jul-97	1253	24.0	1.5	-22.5	28393.0	42317.5	48 14.169	122 39.948	48 14.167	122 39.950	light VV
			2			1307	24.5	1.7	-22.8	28393.0	42317.5	48 14.169	122 39.948			
			3			1319	25.0	1.9	-23.1	28393.0	42317.5	48 14.167	122 39.954			
24	**73**	3	1	Penn Cove	1-Jul-97	1057	22.0	0.2	-21.8	28396.1	42311.1	48 13.901	122 41.614	48 13.900	122 41.617	light VV
			2			1116	23.0	0.3	-22.7	28396.2	42311.2	48 13.898	122 41.619			
			3			1135	23.0	0.6	-22.4	28396.2	42311.2	48 13.900	122 41.619			
25	**74**	1.2	1	Saratoga Passage	30-Jun-97	1750	57.0	2.3	-54.7	28367.4	42334.1	48 13.368	122 33.549	48 13.367	122 33.550	light VV
			2			1809	57.0	2.2	-54.8	28367.4	42334.0	48 13.367	122 33.547			
			3			1821	57.0	2.1	-54.9	28367.3	42333.9	48 13.365	122 33.548			
25	**75**	2	1	Saratoga Passage	30-Jun-97	1406	90.0	2.6	-87.4	28314.1	42329.2	48 08.333	122 32.616	48 08.333	122 32.617	light VV
			2			1428	90.0	2.7	-87.3	28314.0	42329.2	48 08.334	122 32.618			
			3			1442	90.0	2.8	-87.2	28314.0	42329.2	48 08.333	122 32.617			
			4			1457	90.5	2.8	-87.7	28314.0	42329.2	48 08.330	122 32.616			
25	**76**	3	1	Saratoga Passage	30-Jun-97	1526	90.0	2.9	-87.1	28321.6	42332.9	48 09.350	122 32.114	48 09.350	122 32.117	light VV
			2			1545	90.0	2.9	-87.1	28321.6	42333.0	48 09.347	122 32.116			
			3			1600	90.0	2.8	-87.2	28321.6	42332.9	48 09.348	122 32.121			
			4			1614	90.0	2.8	-87.2	28321.6	42333.0	48 09.352	122 32.117			
26	**77**	1.2	1	Saratoga Passage	30-Jun-97	1209	140.0	1.6	-138.4	28288.1	42335.4	48 06.698	122 29.554	48 06.700	122 29.550	light VV
			2			1227	140.0	1.8	-138.2	28288.0	42335.4	48 06.700	122 29.549			
			3			1243	140.0	2.0	-138.0	28288.1	42335.4	48 06.701	122 29.550			
26	**78**	2	1	Saratoga Passage	24-Jun-97	1054	162.0	1.3	-160.7	28236.6	42348.0	48 03.467	122 23.415	48 03.467	122 23.417	light VV
			2			1111	162.0	1.1	-160.9	28236.6	42348.0	48 03.467	122 23.416			
			3			1137	161.5	0.7	-160.8	28236.7	42348.0	48 03.470	122 23.411			
26	**79**	3	1	Saratoga Passage	30-Jun-97	1014	113.0	0.4	-112.6	28246.4	42341.7	48 03.683	122 25.551	48 03.683	122 25.550	light VV
			2			1038	114.0	0.6	-113.4	28246.5	42341.7	48 03.685	122 25.550			
			3			1055	114.0	0.8	-113.2	28246.5	42341.7	48 03.685	122 25.548			
27	**80**	1	1	Port Susan	23-Jun-97	1419	15.0	-0.5	-15.5	28304.9	42358.2	48 10.178	122 25.068	48 10.183	122 25.067	light VV
			2			1438	15.0	-0.3	-15.3	28304.9	42358.2	48 10.179	122 25.067			
			3			1454	15.5	-0.2	-15.7	28304.9	42358.1	48 10.184	122 25.068			
			4			1505	15.5	-0.1	-15.6	28305.0	42358.2	48 10.185	122 25.069			
27	**81**	2	1	Port Susan	23-Jun-97	1247	107.0	-0.6	-107.6	28288.8	42357.5	48 08.764	122 24.262	48 08.767	122 24.267	light VV
			2			1308	107.0	-0.7	-107.7	28288.7	42357.5	48 08.765	122 24.260			
			3			1341	107.5	-0.7	-108.2	28288.9	42357.5	48 08.767	122 24.268			
27	**82**	3	1	Port Susan	23-Jun-97	1047	119.0	0.7	-118.3	28269.9	42360.0	48 07.416	122 22.483	48 07.417	122 22.483	light VV
			2			1112	119.0	0.3	-118.7	28270.0	42360.1	48 07.419	122 22.486			
			3			1136	118.5	0.0	-118.5	28270.0	42360.0	48 07.419	122 22.485			
28	**83**	1	1	Possession Sound, Gedney Is.	24-Jun-97	0910	171.0	2.4	-168.6	28204.7	42351.5	48 01.083	122 20.635	48 01.083	122 20.633	light VV
			2			0931	170.0	2.3	-167.7	28204.8	42351.6	48 01.081	122 20.635			
			3			0955	170.0	2.0	-168.0	28204.7	42351.6	48 01.080	122 20.632			
28	**84**	2	1	Possession Sound, Gedney Is.	24-Jun-97	1256	133.5	-0.1	-133.6	28174.6	42358.7	47 59.233	122 17.001	47 59.233	122 17.000	light VV
			2			1314	133.0	-0.3	-133.3	28174.7	42358.7	47 59.237	122 17.006			
			3			1331	133.0	-0.4	-133.4	28174.6	42358.8	47 59.235	122 16.997			
28	**85**	3	1	Possession Sound, Gedney Is.	23-Jun-97	1630	115.5	1.1	-114.4	28209.8	42359.4	48 02.319	122 18.986	48 02.317	122 18.983	light VV
			2			1652	116.0	1.4	-114.6	28209.8	42359.4	48 02.318	122 18.983			
			3			1709	116.0	1.7	-114.3	28209.7	42359.4	48 02.316	122 18.984			
29	**86**	1	1	Port of Everett, East Waterway	26-Jun-97	0855	10.0	2.5	-7.5	28160.4	42370.9	47 59.281	122 13.098	47 59.283	122 13.100	heavy VV
			2			0934	10.5	2.5	-8.0	28160.4	42370.8	47 59.281	122 13.105			5 rejects
			3			0947	11.0	2.5	-8.5	28160.4	42370.8	47 59.285	122 13.101			
			4			1005	11.0	2.5	-8.5	28160.4	42370.8	47 59.287	122 13.100			

Appendix B. Navigation report for the 1997 northern Puget Sound sampling stations - includes station positioning and sample collection information.

Stratum No.	Sample No.	Station No.	Deploy-ment No.	Location	Date	GPS Time	Meter Wheel Depth m.	Predicted Tide (m.): Nearest Station	Predicted Mudline Depth, m. (MLLW)	Sample Location LORAN-C Yankee	Sample Location LORAN-C Zulu	Sample Location DGPS (Trimble NT300D) NAD 83, Decimal Minutes Latitude	Sample Location DGPS (Trimble NT300D) NAD 83, Decimal Minutes Longitude	Station Target NAD 1983 Decimal Minutes Latitude	Station Target NAD 1983 Decimal Minutes Longitude	Comments
29	**87**	2	1	Port of Everett, East Waterway	26-Jun-97	1056	14.0	2.4	-11.6	28160.2	42370.5	47 59.233	122 13.200	47 59.233	122 13.200	light VV
			2			1113	14.5	2.3	-12.2	28160.3	42370.4	47 59.235	122 13.201			1 reject
			3			1125	14.0	2.2	-11.8	28160.3	42370.4	47 59.234	122 13.203			
29	**88**	3	1	Port of Everett, East Waterway	26-Jun-97	1303	14.0	1.4	-12.6	28160.9	42370.1	47 59.251	122 13.321	47 59.250	122 13.317	light VV
			2			1319	12.0	1.2	-10.8	28160.8	42370.1	47 59.252	122 13.319			5 rejects
			3			1329	13.0	1.1	-11.9	28160.8	42370.1	47 59.250	122 13.321			
			4			1338	13.5	1.0	-12.5	28160.8	42370.1	47 59.250	122 13.318			
			5			1354	12.0	0.9	-11.1	28160.8	42370.1	47 59.249	122 13.320			
30	**89**	1.3	1	Port of Everett, East Waterway	26-Jun-97	1450	13.0	0.5	-12.5	28157.2	42369.5	47 58.883	122 13.235	47 58.883	122 13.233	light VV
			2			1505	13.0	0.4	-12.6	28157.3	42369.6	47 58.886	122 13.230			dredged
			3			1516	13.0	0.4	-12.6	28157.4	42369.6	47 58.885	122 13.232			
30	**90**	2	1	Port of Everett, East Waterway	27-Jun-97	1211	13.5	2.3	-11.2	28158.0	42369.4	47 58.934	122 13.331	47 58.933	122 13.333	heavy VV
			2			1226	13.0	2.2	-10.8	28158.1	42369.4	47 58.932	122 13.333			1 reject
			3			1242	13.0	2.1	-10.9	28158.1	42369.3	47 58.932	122 13.332			
			4			1253	13.5	2.1	-11.4	28158.1	42369.4	47 58.932	122 13.332			
30	**91**	3.2	1	Port of Everett, East Waterway	27-Jun-97	1335	13.0	1.8	-11.2	28158.5	42369.0	47 58.933	122 13.435	47 58.933	122 13.433	heavy VV
			2			1351	13.5	1.7	-11.8	28158.4	42369.0	47 58.931	122 13.434			1 reject
			3			1404	13.0	1.6	-11.4	28158.5	42369.0	47 58.933	122 13.435			
			4			1416	13.0	1.5	-11.5	28158.5	42369.1	47 58.934	122 13.432			
			5			1431	13.0	1.4	-11.6	28158.4	42369.1	47 58.931	122 13.434			
31	**92**	1	1	Port of Everett, East Waterway	25-Jun-97	1116	21.5	1.7	-19.8	28156.7	42367.8	47 58.649	122 13.633	47 58.650	122 13.633	heavy VV
			2			1142	20.5	1.4	-19.1	28156.7	42367.8	47 58.648	122 13.635			2 rejects
			3			1200	20.0	1.2	-18.8	28156.6	42367.8	47 58.647	122 13.633			
31	**93**	2	1	Port of Everett, East Waterway	25-Jun-97	1323	18.5	0.4	-18.1	28156.5	42367.7	47 58.617	122 13.632	47 58.617	122 13.633	heavy VV
			2			1339	18.5	0.2	-18.3	28156.5	42367.7	47 58.617	122 13.635			
			3			1352	19.0	0.1	-18.9	28156.4	42367.7	47 58.618	122 13.631			
			4			1405	19.0	0.0	-19.0	28156.5	42367.7	47 58.618	122 13.636			
31	**94**	3	1	Port of Everett, East Waterway	25-Jun-97	1453	22.0	-0.1	-22.1	28156.3	42367.3	47 58.549	122 13.734	47 58.550	122 13.733	heavy VV
			2			1510	21.5	-0.1	-21.6	28156.2	42367.3	47 58.551	122 13.733			4 rejects
			3			1531	21.5	-0.1	-21.6	28156.2	42367.3	47 58.548	122 13.732			
			4			1540	23.0	0.0	-23.0	28156.3	42367.2	47 58.551	122 13.737			
32	**95**	1	1	Port Gardner	25-Jun-97	0954	124.0	2.4	-121.6	28160.5	42360.2	47 58.181	122 15.768	47 58.183	122 15.767	light VV
			2			1018	124.0	2.3	-121.7	28160.5	42360.2	47 58.183	122 15.767			
			3			1035	124.0	2.1	-121.9	28160.5	42360.2	47 58.183	122 15.770			
32	**96**	2	1	Outer Port Gradner	24-Jun-97	1410	144.0	-0.5	-144.5	28164.7	42356.3	47 58.117	122 17.001	47 58.117	122 17.000	light VV
			2			1439	144.5	-0.4	-144.9	28164.7	42356.3	47 58.117	122 17.002			
			3			1454	144.5	-0.4	-144.9	28164.7	42356.3	47 58.118	122 17.004			
32	**97**	3	1	Outer Port Gradner	24-Jun-97	1538	121.5	0.0	-121.5	28164.8	42360.8	47 58.616	122 15.865	47 58.617	122 15.867	light VV
			2			1601	122.0	0.2	-121.8	28164.8	42360.8	47 58.619	122 15.868			
			3			1618	122.0	0.4	-121.6	28164.8	42360.8	47 58.619	122 15.866			
33	**98**	1	1	Snohomish River delta	27-Jun-97	0852	18.0	1.9	-16.1	28187.3	42364.4	48 00.933	122 16.331	48 00.933	122 16.333	heavy VV
			2			0906	16.0	2.0	-14.0	28187.4	42364.5	48 00.936	122 16.329			
			3			0918	16.0	2.1	-13.9	28187.2	42364.5	48 00.932	122 16.327			
33	**99**	2	1	Snohomish River delta	25-Jun-97	0859	4.5	2.7	-1.8	28180.9	42364.9	48 00.432	122 15.817	48 00.433	122 15.817	heavy VV
			2			0912	4.5	2.7	-1.8	28180.9	42364.9	48 00.434	122 15.819			
			3			0923	4.5	2.6	-1.9	28180.8	42364.9	48 00.433	122 15.818			
33	**100**	3	1	Snohomish River delta	27-Jun-97	0956	4.0	2.3	-1.7	28184.0	42375.6	48 01.784	122 13.404	48 01.783	122 13.400	heavy VV
			2			1005	4.0	2.3	-1.7	28183.9	42375.6	48 01.783	122 13.400			
			3			1015	4.0	2.3	-1.7	28184.0	42375.6	48 01.783	122 13.404			
			4			1025	4.0	2.4	-1.6	28184.0	42375.6	48 01.782	122 13.398			

Appendix C

Infaunal taxa removed from the final 1997 species list

Appendix C. Species eliminated from the 1997 benthic infaunal data base

Elimination Criteria	Phylum	Class	Family	Taxon
incidental[1]	Arthropoda	Cirripedia		Cirripedia
				Balanomorpha
			Balanidae	Balanus crenatus
				Balanus glandula
		Malacostraca	Hyperiidae	Parathemisto pacifica
				Megalops (Caridea)
				Megalops (Brachyura
				Crustacean eggs
				Zoea (anomuran)
				Zoea (brachyuran)
				Zoea larva
	Mollusca	Gastropoda		Gastropod egg capsules
				Fish egg
meiofauna[2]	Protozoa	Rotaliina	Elphidiidae	Elphidiella hannai
			Nonionidae	Nonionidae
	Nematoda			Nematoda
	Foraminifera			Foraminifera
	Arthropoda	Copepoda		Calanoida
				Harpacticoida
				Harpacticoida sp.A
				Harpacticoida sp. B
				Harpacticoida sp. C
presence/absence[3]	Cnidaria	Hydrozoa	Hydromedusae	Hydromedusa indet.
				Athecate hydroid
			Bougainvilliidae	Bougainvilliidae
			Corymorphidae	Euphysa sp.
			Corynidae	cf. Sarsia
			Eudendriidae	cf. Eudendrium sp. indet.
				Thecatae sp. indet.
			Campanulariidae	Campanulariidae
				Campanularia sp. indet.
				Campanulariidae sp. 2

Appendix C. Species eliminated from the 1997 benthic infaunal data base

Elimination Criteria	Phylum	Class	Family	Taxon
				cf. Obelia sp.
				Obelia sp. indet.
				Obelia dichotoma
				Clytia sp. indet.
			Lafoeidae	Lafoea sp. indet
			Eirenidae	Eutonina indicans
			Sertulariidae	Sertularella sp. indet.
				Sertularella tenella
				Abietinaria sp.
				Abietinaria sp. indet.
				Thuiaria sp. indet
			Plumulariidae	Plumularia sp.
	Bryozoa	Gymnolaemata	Membraniporidae	Membranipora membranacea
			Celleporidae	Celleporina hyalina
			Alcyonidiidae	Alcyonidium sp. indet
	Entoprocta		Barentsiidae	Barentsia sp.

incidental[1]: organisms caught which are not soft sediment infaunal invertebrates - e.g., hard substrate dwellers, larval species, etc.
meiofauna[2]: organisms which are smaller than the infaunal fraction but accidentally caught by the 1mm screen
presence/absence[3]: organisms, such as colonial species, for which a count of individuals cannot be made

Appendix D

Chemistry data summary

Table 1. Grain size distribution for the 1997 northern Puget Sound sampling stations (tabular form)

Table 2. Total Organic Carbon, Temperature, and Salinity measurements for the 1997 northern Puget Sound sampling stations

Table 3. Summary Statistics for Metals and Organics Data

Figure 1. Grain size distribution for the 1997 northern Puget Sound sampling stations (frequency distribution)

Appendix D, Table 1 - Grain size distribution for the 1997 northern Puget Sound sampling stations (grain size in fractional percent) [1,2]

Stratum	Sample	% Water Content[3]	% Solids[4]	% Gravel	% Very Coarse Sand	% Coarse Sand	% Medium Sand	% Fine Sand	% Very Fine Sand	Total % Sand	% Silt	% Clay	% Fines (Silt + Clay)
				> 2000 um	2000-1000 um	1000-500 um	500-250 um	250-125 um	125-62.5 um	2000-62.5 um	62.5-3.9 um	< 3.9 um	<62.5 um
1	**1**	40.8	71.0	**0.0**	0.0	0.1	0.5	43.5	34.7	**78.8**	**16.3**	**4.5**	**20.7**
Drayton	**2**	121.7	45.1	**0.0**	0.0	0.1	0.8	7.9	29.5	**38.3**	**46.4**	**6.1**	**52.5**
Harbor	**3**	102.8	49.3	**0.0**	0.0	0.1	2.2	10.4	30.5	**43.1**	**47.5**	**6.8**	**54.3**
2	**4**	140.4	41.6	**0.0**	0.0	0.1	0.6	0.7	7.3	**8.7**	**72.4**	**14.8**	**87.3**
Semiahmoo	**5**	171.7	36.8	**0.0**	0.0	0.0	0.1	0.8	2.2	**3.1**	**78.4**	**17.7**	**96.1**
Bay	**6**	200.3	33.3	**0.0**	0.0	0.0	0.0	1.1	3.6	**4.8**	**79.2**	**13.0**	**92.2**
3	**7**	33.2	75.1	**0.0**	0.0	0.3	2.1	67.6	28.8	**98.8**	**1.4**	**0.4**	**1.7**
W. Boundary	**8**	66.1	60.2	**0.0**	0.0	0.0	0.3	28.9	45.1	**74.3**	**21.9**	**8.4**	**30.4**
Bay	**9**	160.4	38.4	**0.0**	0.0	0.0	0.2	1.5	2.2	**3.8**	**70.3**	**18.1**	**88.4**
4	**10**	90.1	52.6	**0.5**	0.0	0.2	0.3	0.6	24.9	**25.9**	**57.5**	**11.8**	**69.3**
S. Boundary	**11**	191.5	34.3	**0.0**	0.0	0.0	0.5	1.3	4.6	**6.4**	**74.8**	**14.2**	**89.0**
Bay	**12**	102	49.5	**0.1**	0.1	0.1	0.2	0.5	7.8	**8.7**	**68.0**	**19.9**	**87.9**
	13	95.7	51.1	**0.0**	0.0	0.1	1.0	2.2	30.6	**33.9**	**51.7**	**13.4**	**65.1**
	13	96	51.1	**0.0**	0.0	0.1	1.1	2.1	29.8	**33.1**	**52.5**	**14.7**	**67.3**
	13**	96	51	**0**	0	0	1	2	30	**34**	**52**	**14**	**66.2**
5	**14**	79.5	55.7	**0.0**	0.0	0.1	0.7	1.6	9.8	**12.2**	**75.6**	**7.8**	**83.4**
Birch	**15**	108.8	47.9	**0.0**	0.0	0.0	0.3	0.9	12.9	**14.0**	**74.7**	**11.7**	**86.4**
Bay	**16**	81.2	55.2	**0.0**	0.0	0.0	0.2	2.7	17.8	**20.8**	**67.8**	**6.9**	**74.8**
6	**17**	58	63.2	**0.0**	0.0	0.1	0.2	2.1	38.9	**41.3**	**45.1**	**12.5**	**57.7**
Cherry	**18**	31	76.3	**0.0**	0.0	0.1	0.7	18.9	56.4	**76.1**	**21.2**	**3.3**	**24.5**
Point	**19**	62.3	61.6	**0.0**	0.0	0.1	0.1	1.0	38.7	**39.9**	**47.8**	**14.9**	**62.7**
7	**20**	66.1	60.2	**0.0**	0.0	0.4	5.7	19.8	6.5	**32.4**	**54.7**	**11.1**	**65.9**
Bellingham	**21**	61.8	61.8	**0.0**	0.0	0.1	0.2	0.3	2.9	**3.5**	**78.5**	**12.4**	**90.9**
Bay	**22**	65.6	60.4	**0.0**	0.0	0.0	0.1	0.5	6.1	**6.8**	**78.4**	**12.6**	**91.1**
8	**23**	101.6	49.6	**0.0**	0.0	0.0	0.1	0.2	0.8	**1.2**	**84.8**	**13.0**	**97.7**
Bellingham	**24**	75.1	57.1	**0.0**	0.0	0.0	0.1	0.3	0.8	**1.3**	**82.9**	**13.2**	**96.1**
Bay	**25**	76.1	56.8	**0.0**	0.0	0.0	0.1	0.2	1.0	**1.3**	**86.3**	**9.8**	**96.2**

Appendix D, Table 1 - Grain size distribution for the 1997 northern Puget Sound sampling stations (grain size in fractional percent) [1,2]

Stratum	Sample	% Water Content[3]	% Solids[4]	% Gravel	% Very Coarse Sand	% Coarse Sand	% Medium Sand	% Fine Sand	% Very Fine Sand	Total % Sand	% Silt	% Clay	% Fines (Silt + Clay)
				> 2000 um	2000-1000 um	1000-500 um	500-250 um	250-125 um	125-62.5 um	2000-62.5 um	62.5-3.9 um	< 3.9 um	<62.5 um
9A	**26**	146.9	40.5	**0.0**	0.0	0.0	0.0	0.1	0.3	**0.6**	**86.1**	**16.3**	**102.4**
Bellingham	**27**	132	43.1	**0.0**	0.0	0.1	0.4	1.1	2.0	**3.6**	**76.1**	**18.4**	**94.5**
Bay	**28**	99	50.2	**16.5**	5.9	5.1	12.4	8.5	4.4	**36.3**	**42.2**	**9.0**	**51.3**
9B	**59**	167	37.5	**0.0**	0.0	0.0	0.0	0.3	0.7	**1.1**	**74.0**	**21.3**	**95.2**
Bellingham	**60**	154	39.4	**0.0**	0.0	0.1	0.5	1.2	1.9	**3.6**	**68.4**	**20.0**	**88.4**
Bay	**61**	181.7	35.5	**0.0**	0.0	0.0	0.1	0.7	1.6	**2.5**	**79.8**	**21.8**	**101.7**
10	**29**	137.0	42.2	**0.0**	0.0	0.5	1.8	4.5	5.4	**12.3**	**70.0**	**18.8**	**88.8**
Bellingham	**30**	191.5	34.3	**0.0**	0.0	0.1	0.3	0.6	1.3	**2.4**	**78.9**	**13.9**	**92.8**
Bay	**31**	185.7	35.0	**0.0**	0.0	0.1	0.3	0.6	0.6	**1.7**	**65.0**	**25.3**	**90.3**
11	**32**	148.8	40.2	**0.0**	0.0	0.1	0.3	0.9	0.9	**2.3**	**57.3**	**36.5**	**93.9**
Bellingham	**32**	148.8	40.2	**0.0**	0.0	0.1	0.3	0.4	0.5	**1.2**	**57.9**	**38.4**	**96.4**
Bay	**32**	148.8	40.2	**0.0**	0.0	0.1	0.2	0.6	0.7	**1.7**	**55.8**	**40.8**	**96.6**
	32*	148.8	40.2	**0.0**	0.0	0.1	0.3	0.6	0.7	**1.7**	**57.0**	**38.6**	**95.6**
	33	138.1	42.0	**0.0**	0.0	0.1	0.2	0.5	0.7	**1.6**	**55.7**	**38.9**	**94.6**
	34	241.3	29.3	**0.0**	0.0	0.0	0.1	0.3	0.5	**1.0**	**78.9**	**28.3**	**107.2**
12	**35**	157	38.9	**0.0**	0.0	0.1	0.1	0.8	4.6	**5.7**	**72.1**	**16.8**	**88.9**
Bellingham	**36**	150.0	40.0	**0.0**	0.0	0.1	0.1	0.5	1.1	**1.8**	**68.2**	**26.0**	**94.2**
Bay	**37**	174.0	36.5	**0.0**	0.0	0.2	0.7	1.1	1.1	**3.2**	**67.2**	**27.3**	**94.5**
13	**38**	121	45.3	**0.0**	0.2	0.0	0.3	1.3	10.7	**12.6**	**66.8**	**20.1**	**87.0**
Samish/Bell.	**39**	95	51.2	**0.2**	0.2	0.1	0.2	1.0	15.3	**16.9**	**57.4**	**22.2**	**79.6**
Bay	**40**	29	77.5	**0.0**	0.0	4.2	48.2	36.4	4.4	**93.2**	**5.2**	**2.4**	**7.5**
14	**41**	48.4	67.4	**0.3**	0.2	1.2	6.6	21.7	35.2	**64.9**	**26.5**	**5.4**	**31.9**
Inner Padilla	**42**	32.3	75.6	**0.1**	0.2	6.9	29.0	36.5	13.6	**86.2**	**10.9**	**3.5**	**14.4**
Bay	**43**	56.0	64.1	**3.9**	0.2	28.0	35.7	7.7	6.5	**78.2**	**13.5**	**4.5**	**18.0**
15	**44**	80.2	55.5	**2.2**	0.2	0.1	0.3	0.7	13.9	**15.2**	**60.1**	**18.5**	**78.7**
Outer Padilla	**45**	86.9	53.5	**0.0**	0.2	0.3	0.6	2.0	13.7	**16.8**	**61.6**	**18.4**	**80.0**
Bay	**46**	80.8	55.3	**0.0**	0.2	0.2	0.5	1.0	14.0	**16.0**	**64.1**	**17.9**	**82.0**
16	**47**	38.3	72.3	**6.5**	0.2	3.4	8.3	35.5	20.3	**67.7**	**18.1**	**6.3**	**24.4**
March	**48**	32.6	75.4	**3.7**	0.2	2.9	23.4	37.4	9.2	**73.1**	**13.0**	**6.5**	**19.5**
Point	**49**	44.3	69.3	**0.0**	0.2	0.2	0.7	27.2	35.3	**63.7**	**26.4**	**7.0**	**33.4**

Appendix D, Table 1 - Grain size distribution for the 1997 northern Puget Sound sampling stations (grain size in fractional percent) [1,2]

Stratum	Sample	% Water Content[3]	% Solids[4]	% Gravel	% Very Coarse Sand	% Coarse Sand	% Medium Sand	% Fine Sand	% Very Fine Sand	Total % Sand	% Silt	% Clay	% Fines (Silt + Clay)
				> 2000 um	2000-1000 um	1000-500 um	500-250 um	250-125 um	125-62.5 um	2000-62.5 um	62.5-3.9 um	< 3.9 um	<62.5 um
17	**50**	71.8	58.2	**0.6**	0.2	0.6	1.2	1.3	10.2	**13.5**	**73.0**	**10.0**	**83.0**
Inner	**51**	68.1	59.5	**0.1**	0.2	0.7	1.7	4.6	16.1	**23.3**	**59.9**	**12.8**	**72.7**
Fidalgo Bay	**52**	68.6	59.3	**0.6**	0.2	0.3	0.5	0.6	16.1	**17.8**	**75.0**	**6.2**	**81.2**
18	**53**	78.9	55.9	**0.0**	0.2	0.2	0.3	6.4	44.2	**51.3**	**46.2**	**9.5**	**55.7**
Outer	**54**	64.7	60.7	**0.5**	0.2	0.4	0.8	22.6	35.3	**59.3**	**38.4**	**7.5**	**45.9**
Fidalgo Bay	**55**	44.3	69.3	**1.1**	0.2	0.7	1.8	33.3	30.2	**66.2**	**21.8**	**7.6**	**29.4**
19	**56**	29.5	77.2	**3.7**	0.2	1.5	6.4	67.0	13.2	**88.3**	**5.3**	**2.8**	**8.0**
March	**57**	33.9	74.7	**0.0**	0.2	1.0	21.6	67.9	4.4	**95.2**	**1.9**	**1.1**	**2.9**
Point	**58**	28.0	78.1	**0.7**	0.2	3.1	23.7	48.4	7.0	**82.4**	**8.6**	**4.4**	**13.0**
21	**62**	59	62.9	**0.0**	0.0	0.1	0.1	1.9	36.1	**38.2**	**39.9**	**15.4**	**55.4**
Skagit	**63**	30	77.0	**0.2**	0.1	0.1	0.3	29.0	43.3	**72.8**	**21.2**	**4.8**	**26.0**
Bay	**64**	70	58.8	**0.0**	0.0	0.0	0.1	0.4	13.8	**14.4**	**66.8**	**15.9**	**82.7**
22	**65**	153.8	39.4	**0.3**	0.0	1.8	13.3	6.9	2.3	**24.3**	**54.4**	**12.2**	**66.6**
North Saratoga	**66**	179.3	35.8	**0.1**	0.0	0.0	0.3	1.7	3.7	**5.7**	**74.4**	**15.7**	**90.1**
Passage	**67**	168	37.3	**0.0**	0.0	0.0	0.1	0.5	1.3	**1.9**	**74.6**	**21.2**	**95.8**
23	**68**	151.9	39.7	**5.2**	0.0	0.1	0.3	0.7	3.1	**4.2**	**71.1**	**19.7**	**90.7**
Oak	**69**	139.2	41.8	**0.1**	0.0	0.1	0.4	1.6	6.9	**9.0**	**75.7**	**11.9**	**87.5**
Harbor	**70**	131.5	43.2	**0.6**	0.0	0.0	0.1	0.4	2.6	**3.2**	**73.6**	**20.5**	**94.1**
24	**71**	190.7	34.4	**0.0**	0.0	0.0	0.2	0.9	2.4	**3.6**	**67.6**	**26.7**	**94.3**
Penn	**72**	151.3	39.8	**0.0**	0.0	0.2	0.6	1.4	2.7	**4.9**	**74.0**	**16.2**	**90.2**
Cove	**73**	194.1	34.0	**0.0**	0.0	0.2	0.6	0.9	1.3	**3.0**	**70.2**	**23.6**	**93.8**
25	**74**	180.9	35.6	**0.0**	0.0	0.2	0.4	0.7	1.1	**2.4**	**76.1**	**19.7**	**95.8**
Mid-Saratoga	**75**	278.8	26.4	**0.0**	0.0	0.0	0.2	0.8	2.0	**3.0**	**66.0**	**21.0**	**87.0**
Passage	**76**	281.7	26.2	**0.0**	0.0	0.1	0.4	0.8	2.3	**3.5**	**66.3**	**25.0**	**91.3**
26	**77**	45.6	68.7	**0.7**	0.0	16.8	36.1	14.5	6.2	**73.6**	**9.3**	**9.3**	**18.6**
South Saratoga	**78**	206.7	32.6	**0.0**	0.0	0.2	1.2	4.0	8.1	**13.6**	**48.1**	**35.3**	**83.4**
Passage	**79**	206.7	32.6	**0.0**	0.0	0.2	0.4	1.2	3.2	**5.1**	**46.1**	**39.5**	**85.6**
	79	206.7	32.6	**0.0**	0.0	0.0	0.7	1.9	3.7	**6.4**	**46.6**	**39.5**	**86.1**
	79	243.6	29.1	**0.0**	0.0	0.1	0.2	1.4	4.0	**5.7**	**47.9**	**43.6**	**91.5**
	79*	219.0	31.4	**0.0**	0.0	0.1	0.4	1.5	3.7	**5.8**	**46.9**	**40.9**	**87.8**

Appendix D, Table 1 - Grain size distribution for the 1997 northern Puget Sound sampling stations (grain size in fractional percent) [1,2]

Stratum	Sample	% Water Content[3]	% Solids[4]	% Gravel	% Very Coarse Sand	% Coarse Sand	% Medium Sand	% Fine Sand	% Very Fine Sand	Total % Sand	% Silt	% Clay	% Fines (Silt + Clay)
				> 2000 um	2000-1000 um	1000-500 um	500-250 um	250-125 um	125-62.5 um	2000-62.5 um	62.5-3.9 um	< 3.9 um	<62.5 um
27	**80**	94.6	51.4	**0.0**	0.0	0.0	0.0	0.2	1.8	**2.0**	**71.8**	**16.7**	**88.5**
Port	**81**	173.2	36.6	**0.0**	0.0	0.0	0.2	0.7	0.7	**1.7**	**61.8**	**31.9**	**93.7**
Susan	**82**	192.4	34.2	**0.0**	0.0	0.0	0.3	1.1	2.0	**3.4**	**65.5**	**31.1**	**96.6**
28	**83**	104.9	48.8	**0.3**	0.0	2.5	12.0	24.4	9.5	**48.5**	**28.4**	**20.1**	**48.5**
Possession	**84**	144.5	40.9	**0.0**	0.0	0.0	0.1	1.1	6.7	**8.0**	**65.5**	**20.8**	**86.3**
Sound	**85**	204.0	32.9	**0.1**	0.0	0.0	0.0	0.3	2.3	**2.7**	**68.7**	**25.4**	**94.0**
29	**86**	259.7	27.8	**0.9**	0.0	2.9	4.8	8.5	11.8	**28.1**	**56.1**	**6.0**	**62.1**
Inner Everett	**87**	187.4	34.8	**0.2**	0.0	1.6	2.7	3.3	7.4	**14.9**	**68.2**	**10.2**	**78.4**
Harbor	**88**	230.0	30.3	**4.8**	0.0	2.4	3.4	3.8	4.2	**13.8**	**64.0**	**8.5**	**72.5**
30	**89**	197.6	33.6	**0.4**	0.0	0.6	1.1	2.6	8.2	**12.6**	**71.9**	**6.9**	**78.8**
Middle Everett	**90**	127.3	44.0	**16.3**	0.0	4.2	6.9	7.2	11.5	**29.8**	**47.6**	**4.3**	**51.9**
Harbor	**91**	132.6	43.0	**10.6**	0.0	4.5	7.2	6.0	14.8	**32.5**	**43.0**	**7.3**	**50.3**
31	**92**	127.8	43.9	**2.2**	0.0	1.6	2.8	5.4	14.0	**23.7**	**65.6**	**7.5**	**73.1**
Outer Everett	**93**	135.8	42.4	**2.8**	0.0	1.5	2.6	5.2	12.7	**21.9**	**68.9**	**2.9**	**71.8**
Harbor	**94**	114.6	46.6	**11.0**	0.0	6.1	5.0	5.7	12.9	**29.7**	**49.4**	**7.6**	**57.0**
32	**95**	80.8	55.3	**0.0**	0.0	0.7	11.4	24.0	9.6	**45.7**	**39.7**	**14.9**	**54.6**
Port	**96**	164.6	37.8	**0.0**	0.0	0.0	0.2	1.2	5.3	**6.7**	**71.7**	**20.5**	**92.2**
Gardner	**97**	112.8	47.0	**0.3**	0.0	0.6	3.0	5.6	15.9	**25.1**	**61.3**	**13.5**	**74.7**
33	**98**	40.3	71.3	**0.0**	0.0	1.0	4.9	27.8	34.5	**68.3**	**23.8**	**5.6**	**29.4**
Snohomish	**99**	24	80.6	**0.0**	0.0	8.0	58.5	28.7	1.2	**96.5**	**1.1**	**0.4**	**1.5**
River Delta	**100**	22.7	81.5	**0.1**	0.0	22.8	52.4	21.5	1.1	**97.8**	**0.4**	**0.0**	**0.4**

Appendix D, Table 1 - Grain size distribution for the 1997 northern Puget Sound sampling stations (grain size in fractional percent) [1,2]

Stratum	Sample	% Water Content[3]	% Solids[4]	% Gravel	% Very Coarse Sand	% Coarse Sand	% Medium Sand	% Fine Sand	% Very Fine Sand	Total % Sand	% Silt	% Clay	% Fines (Silt + Clay)
				> 2000 um	2000-1000 um	1000-500 um	500-250 um	250-125 um	125-62.5 um	2000-62.5 um	62.5-3.9 um	< 3.9 um	<62.5 um
Quality Control Samples													
Stratum-Sample													
2-5	**101**	212.5	32.0	**0.0**	0.0	0.0	0.1	0.6	2.3	**3.0**	**80.6**	**17.2**	**97.9**
6-19	**102**	72.7	57.9	**0.0**	0.0	0.1	0.3	1.0	36.6	**38.0**	**48.0**	**11.1**	**59.0**
11-34	**103**	216.5	31.6	**0.0**	0.0	0.1	0.2	0.5	0.1	**0.9**	**62.7**	**32.0**	**94.7**
23-68	**104**	125.7	44.3	**0.0**	0.0	0.1	0.2	0.5	2.5	**3.4**	**77.6**	**16.7**	**94.2**
27-80	**105**	97.6	50.6	**0.0**	0.0	0.0	0.0	0.2	1.7	**2.0**	**73.9**	**16.2**	**90.1**

[1] Organics included. Corrected for dissolved solids.

[2] Particle size intervals based on US Army Corps of Engineers and Wentworth Soil Classification Systems.

[3] Gravimetric water content following ASTM D2216 methodology.

[4] Percent Solids measured according to Plumb, 1981. EPA/CE-81-1.

*** Mean of three lab replicates.**

**** Mean of two lab replicates (not enough sample for three replicates).**

Appendix D, Table 2 - Total Organic Carbon, Temperature, and Salinity measurements for the 1997 northern Puget Sound sampling stations

Stratum	Sample	% TOC	Temperature °C	Salinity (ppt)
1	1	0.78	14.00	25.00
Drayton	2	1.82	14.00	25.00
Harbor	3	1.77	15.00	25.00
2	4	1.43	11.00	25.00
Semiahmoo	5	2.03	11.00	24.00
Bay	6	1.8	11.00	27.00
3	7	0.35	15.00	20.00
W. Boundary	8	0.89	11.00	25.00
Bay	9	1.79	12.00	20.00
4	10	1.02	11.00	30.00
S. Boundary	11	1.85	11.00	30.00
Bay	12	1.39	11.00	27.00
5	13*	1.09	11.00	27.00
Birch	14	1.24	12.00	25.00
Bay	15	1.33	12.00	30.00
	16	1.04	13.00	30.00
6	17	0.88	11.00	27.00
Cherry	18	0.53	13.00	30.00
Point	19	0.88	10.00	30.00
7	20	0.84	11.00	27.00
Bellingham	21	1.56	11.50	27.00
Bay	22	1.35	13.50	24.00
8	23	1.66	12.00	25.00
Bellingham	24	1.63	12.50	26.00
Bay	25	1.55	13.00	24.00
9A	26	2.15	13.00	23.00
Bellingham	27	2.38	14.00	23.00
Bay	28	3.52	14.00	14.00
9B	59	2.42	13.50	23.00
Bellingham	60	3.19	13.50	20.00
Bay	61	2.43	13.00	23.00
10	29	2.14	11.50	27.00
Bellingham	30	3.33	12.50	27.00
Bay	31	2.91	10.50	28.00
11	32	2.05	11.00	30.00
Bellingham	33	2.22	10.00	30.00
Bay	34	2.09	10.00	30.00
12	35	1.66	11.00	28.00

Appendix D, Table 2 - Total Organic Carbon, Temperature, and Salinity measurements for the 1997 northern Puget Sound sampling stations

Stratum	Sample	% TOC	Temperature °C	Salinity (ppt)
Bellingham	36	1.92	11.00	30.00
Bay	37	1.98	10.00	30.00
13	38	1.36	11.00	29.00
Samish/Bell.	39	1.31	10.00	30.00
Bay	40	0.34	13.00	27.00
14	41	0.93	12.00	31.00
Inner Padilla	42	0.55	11.00	31.00
Bay	43	1	12.00	31.00
15	44	1.3	11.00	30.00
Outer Padilla	45	1.67	10.50	29.00
Bay	46	1.26	10.50	31.00
16	47	0.57	10.50	30.00
March	48	0.58	10.50	32.00
Point	49	0.83	11.00	30.00
17	50	1.47	11.00	31.00
Inner	51	1.3	11.50	30.00
Fidalgo Bay	52	1.14	12.00	29.00
18	53	0.96	11.50	32.00
Outer	54	1	11.00	32.00
Fidalgo Bay	55	1.08	11.00	31.00
19	56	0.36	11.00	31.00
March	57	0.26	11.00	30.00
Point	58	0.48	11.00	31.00
21	62	0.71	11.00	25.00
Skagit	63	0.41	11.00	16.00
Bay	64	0.84	10.00	21.00
22	65	1.46	10.00	22.00
North Saratog	66	1.68	10.00	20.00
Passage	67	1.37	10.00	17.00
23	68	1.72	12.00	23.00
Oak	69	1.65	12.00	17.00
Harbor	70	1.7	12.00	21.00
24	71	2.02	10.00	25.00
Penn	72	1.87	11.00	15.00
Cove	73	2.03	10.00	20.00
25	74	1.54	10.00	15.00
Mid-Saratoga	75	1.98	10.00	20.00
Passage	76	1.98	10.00	18.00

Appendix D, Table 2 - Total Organic Carbon, Temperature, and Salinity measurements for the 1997 northern Puget Sound sampling stations

Stratum	Sample	% TOC	Temperature °C	Salinity (ppt)
26	77	0.55	10.00	20.00
South Saratog	78	1.77	10.00	25.00
Passage	79*	2.03	10.00	20.00
27	80	1.26	11.00	20.00
Port	81	1.25	11.00	20.00
Susan	82	1.5	10.00	20.00
28	83	1.16	10.00	25.00
Possession	84	2.05	10.00	25.00
Sound	85	1.88	10.00	20.00
29	86	9.91	12.00	30.00
Inner Everett	87	6.93	12.00	23.00
Harbor	88	8.56	12.00	25.00
30	89	7.2	11.00	25.00
Middle Everet	90	4.48	12.00	25.00
Harbor	91	5.27	12.00	20.00
31	92	4.94	11.00	25.00
Outer Everett	93	5.35	12.00	25.00
Harbor	94	6.15	12.00	25.00
32	95	1.21	10.00	30.00
Port	96	1.83	11.00	20.00
Gardner	97	1.73	10.00	20.00
33	98	1.33	11.00	25.00
Snohomish	99	0.14	14.00	20.00
River Delta	100	0.13	14.00	15.00
	mean	1.90	11.42	25.22
	min	0.13	10.00	14.00
	max	9.91	15.00	32.00

Appendix D, Table 3 - Summary Statistics for Metals and Organics Data

COMPOUND (unit of measure)	MEAN	MEDIAN	MINIMUM	MAXIMUM	RANGE	N	NO. OF NONDETECTED VALUES	NO. OF MISSING VALUES
METALS (ppm, mg/kg dry wt)								
Ancillary Metals								
Aluminum*	15,559.14	16,000.00	4,460.00	29,000.00	24,540.00	105	0	0
Aluminum**	67,958.10	69,300.00	32,800.00	88,900.00	56,100.00	105	0	0
Barium*	37.75	40.30	9.12	101.00	91.88	105	0	0
Barium**	400.96	408.00	233.00	518.00	285.00	105	0	0
Calcium*	7,094.10	5,440.00	1,940.00	36,100.00	34,160.00	105	0	0
Calcium**	19,203.33	17,900.00	5,010.00	62,800.00	57,790.00	105	0	0
Cobalt*	9.98	9.67	2.00	26.80	24.80	105	0	0
Cobalt**	14.73	14.00	5.30	44.20	38.90	105	0	0
Iron*	25,298.48	25,300.00	5,540.00	51,700.00	46,160.00	105	0	0
Iron**	35,889.52	36,300.00	14,400.00	62,300.00	47,900.00	105	0	0
Magnesium*	11,354.67	10,600.00	2,060.00	24,000.00	21,940.00	105	0	0
Magnesium**	16,150.00	15,000.00	3,520.00	29,600.00	26,080.00	105	0	0
Manganese*	303.00	268.00	56.30	930.00	873.70	105	0	0
Manganese**	534.25	507.00	268.00	1,060.00	792.00	105	0	0
Potassium*	2,265.38	2,250.00	543.00	3,810.00	3,267.00	105	0	0
Potassium**	12,614.67	12,800.00	9,530.00	16,200.00	6,670.00	105	0	0
Sodium*	12,660.67	12,300.00	1,070.00	27,500.00	26,430.00	105	0	0
Sodium**	29,254.29	29,400.00	17,600.00	38,500.00	20,900.00	105	0	0
Vanadium*	48.45	49.80	12.90	93.10	80.20	105	0	0
Vanadium**	112.41	110.00	57.80	176.00	118.20	105	0	0
Priority Pollutant Metals								
Antimony*	22.91	0.63	0.21	67.90	67.69	3	102	0
Antimony**	34.15	1.00	0.87	365.00	364.13	11	94	0
Arsenic*	9.50	7.56	2.91	205.00	202.09	105	0	0
Arsenic**	15.32	9.60	5.30	537.00	531.70	105	0	0
Beryllium*	0.34	0.36	0.10	0.54	0.44	104	1	0
Beryllium**	1.21	1.20	0.77	1.80	1.03	105	0	0
Cadmium*	1.21	0.91	0.54	2.90	2.36	19	86	0
Cadmium**	2.25	1.75	1.50	3.60	2.10	8	97	0

Appendix D, Table 3 - Summary Statistics for Metals and Organics Data

COMPOUND (unit of measure)	MEAN	MEDIAN	MINIMUM	MAXIMUM	RANGE	N	NO. OF NONDETECTED VALUES	NO. OF MISSING VALUES
Chromium*	44.86	39.30	7.74	135.00	127.26	105	0	0
Chromium**	93.78	81.70	23.20	196.00	172.80	105	0	0
Copper*	37.78	32.90	4.40	464.00	459.60	105	0	0
Copper**	41.23	33.20	7.10	527.00	519.90	105	0	0
Lead*	11.87	6.70	3.00	190.00	187.00	77	28	0
Lead**	17.41	13.30	6.80	313.00	306.20	105	0	0
Mercury	0.12	0.08	0.01	0.81	0.80	105	0	0
Nickel*	49.87	41.30	7.60	140.00	132.40	105	0	0
Nickel**	61.18	53.00	15.00	147.00	132.00	105	0	0
Selenium*	0.49	0.47	0.30	0.97	0.67	82	23	0
Selenium**	0.78	0.73	0.50	1.50	1.00	34	71	0
Silver*	0.68	0.65	0.31	1.20	0.89	72	33	0
Silver**	1.70	1.60	1.50	2.10	0.60	6	99	0
Thallium*						0	105	0
Thallium**	0.55	0.49	0.40	1.10	0.70	19	86	0
Zinc*	78.52	71.20	15.20	776.00	760.80	105	0	0
Zinc**	107.08	94.00	40.00	1,220.00	1,180.00	105	0	0
*Titanium**	*770.68*	*792.00*	*343.00*	*1,250.00*	*907.00*	*105*	*0*	*0*
*Titanium***	*3,865.05*	*3,950.00*	*2,220.00*	*5,210.00*	*2,990.00*	*105*	*0*	*0*
Major Elements								
Silicon**	235,827.18	259,000.00	12,500.00	359,000.00	346,500.00	103	2	0
Trace Elements								
Tin*	5.72	4.20	3.00	19.20	16.20	15	90	0
Tin**	2.24	1.55	1.00	22.60	21.60	86	19	0
* strong acid digestion								
** hydrofluoric acid digestion								
Italics - compound not from original project list								

Appendix D, Table 3 - Summary Statistics for Metals and Organics Data

COMPOUND (unit of measure)	MEAN	MEDIAN	MINIMUM	MAXIMUM	RANGE	N	NO. OF NONDETECTED VALUES	NO. OF MISSING VALUES
Organotins (ug/kg dry wt)								
Monobutyltin	24.30	19.00	6.90	64.00	57.10	25	78	0
Dibutyltin C	12.83	8.80	1.10	75.00	73.90	51	54	0
Tributyltin	48.79	6.90	0.00	417.00	417.00	47	56	0
Tripentyltin	90.99	91.00	42.00	125.00	83.00	105	0	0
ORGANICS (ug/kg dry wt)								
Chlorinated Aromatic Compounds								
1,2,4-trichlorobenzene						0	105	0
1,2-dichlorobenzene						0	105	0
1,3-dichlorobenzene						0	105	0
1,4-dichlorobenzene	4.50	4.50	3.60	5.40	1.80	2	103	0
2-chloronaphthalene						0	105	0
Hexachlorobenzene						0	105	0
Chlorinated Alkanes								
Hexachlorobutadien						0	105	0
Hexachlorocyclopentadiene						0	0	105
Hexachloroethane						0	105	0
Chlorinated and Nitro-Substituted Phenols								
2,4,5-trichlorophenol						0	105	0
2,4,6-trichlorophenol	46.69	24.00	7.70	209.00	201.30	14	91	0
2,4-dichlorophenol	69.63	31.00	13.00	292.00	279.00	8	97	0
2,4-dinitrophenol						0	105	0
2-chlorophenol						0	105	0
2-nitrophenol						0	105	0
4,6-dinitro 2-methylphenol						0	105	0
4-chloro 3-methylphenol						0	105	0
4-nitrophenol						0	105	0
Pentachlorophenol	165.14	155.00	85.00	331.00	246.00	7	98	0

Appendix D, Table 3 - Summary Statistics for Metals and Organics Data

COMPOUND (unit of measure)	MEAN	MEDIAN	MINIMUM	MAXIMUM	RANGE	N	NO. OF NONDETECTED VALUES	NO. OF MISSING VALUES
Ethers								
4-bromophenyl-phenyl ether						0	105	0
4-chlorophenyl-phenyl ether						0	105	0
Bis(2-chloroethyl)ether						0	105	0
Bis(2-chloroisopropyl)-ether						0	105	0
HPAHs								
Benzo(a)anthracene	88.38	29.00	0.85	1,250.00	1,249.15	105	0	0
Benzo(a)pyrene	58.60	29.00	0.27	597.00	596.73	105	0	0
Benzo(b)fluoranthene	111.70	48.00	1.60	1,380.00	1,378.40	105	0	0
Benzo(g,h,i)perylene	41.64	27.00	0.59	261.00	260.41	105	0	0
Benzo(k)fluoranthene	38.47	18.00	0.39	408.00	407.61	105	0	0
Chrysene	112.73	40.00	1.50	1,610.00	1,608.50	105	0	0
Dibenzo(a,h)anthracene	10.60	5.00	0.82	79.00	78.18	84	21	0
Fluoranthene	325.56	78.00	3.00	4,550.00	4,547.00	105	0	0
Indeno(1,2,3-c,d)pyrene	40.78	27.50	0.39	278.00	277.61	102	3	0
Pyrene	284.26	71.00	2.20	3,790.00	3,787.80	105	0	0
Benzo(e)pyrene	52.14	24.00	0.68	580.00	579.32	105	0	0
Perylene	92.70	70.00	7.90	350.00	342.10	105	0	0
C1-Chrysenes	70.02	33.00	5.40	661.00	655.60	81	23	1
C2-Chrysenes	26.87	21.00	1.40	99.00	97.60	43	61	1
C3-Chrysenes	17.76	8.60	0.34	64.00	63.66	8	96	1
C4-Chrysenes						0	104	1
C1 Fluoranthenes	202.14	70.00	6.00	2,460.00	2,454.00	97	7	1
LPAHs								
2-methylnapthalene	39.55	20.00	0.93	304.00	303.07	104	1	0
Acenaphthene	44.58	3.90	0.32	672.00	671.68	89	16	0
Acenaphtylene	17.88	4.05	0.13	112.00	111.87	104	1	0
Anthracene	71.89	12.00	0.46	1,190.00	1,189.54	105	0	0
Fluorene	62.37	12.00	0.98	986.00	985.02	101	4	0
Naphthalene	117.76	15.00	1.10	1,360.00	1,358.90	103	2	0
Phenanthrene	206.01	63.00	4.80	2,270.00	2,265.20	103	2	0
Retene	325.26	39.00	2.70	8,930.00	8,927.30	105	0	0

Appendix D, Table 3 - Summary Statistics for Metals and Organics Data

COMPOUND (unit of measure)	MEAN	MEDIAN	MINIMUM	MAXIMUM	RANGE	N	NO. OF NONDETECTED VALUES	NO. OF MISSING VALUES
Biphenyl	22.94	7.65	0.68	270.00	269.32	100	5	0
1-Methylnaphthalene	23.31	13.00	0.60	170.00	169.40	103	2	0
2,6-Dimethylnaphthalene	49.64	29.00	1.40	263.00	261.60	103	2	0
1,6,7-Trimethylnaphthalene	16.52	11.50	0.90	100.00	99.10	104	1	0
1-Methylphenanthrene	26.99	15.00	1.00	310.00	309.00	101	4	0
Dibenzothiophene	16.13	3.85	0.26	258.00	257.74	104	1	0
C1 naphthalenes	83.24	37.00	2.50	1,370.00	1,367.50	103	1	1
C2 naphthalenes	68.66	49.00	1.00	422.00	421.00	102	2	1
C3 naphthalenes	100.83	67.00	4.00	690.00	686.00	84	20	1
C4 naphthalenes	65.16	65.00	1.30	214.00	212.70	17	87	1
C1 Fluorenes	2.45	2.45	1.90	3.00	1.10	2	102	1
C2 Fluorenes	3.73	4.80	1.50	4.90	3.40	3	101	1
C3 Fluorenes						0	104	1
C1 Phenanthrenes	133.12	59.00	1.20	960.00	958.80	102	2	1
C2 Phenanthrenes	65.51	38.00	1.70	376.00	374.30	75	29	1
C3 Phenanthrenes	28.52	19.00	3.30	223.00	219.70	67	37	1
C4 Phenanthrenes	67.94	12.00	0.51	1,390.00	1,389.49	76	28	1
C1 Dibenzothiophenes	49.58	56.00	4.10	112.00	107.90	15	89	1
C2 Dibenzothiophenes	80.50	83.00	45.00	111.00	66.00	4	100	1
C3 Dibenzothiophenes						0	104	1
Miscellaneous Extractable Compounds								
Benzoic acid	788.11	561.00	324.00	4,300.00	3,976.00	47	58	0
Benzyl alcohol	26.27	22.00	13.00	56.00	43.00	15	90	0
Beta-coprostanol	427.72	257.00	54.00	1,520.00	1,466.00	47	58	0
Isophorone	8.53	8.35	4.40	13.00	8.60	8	97	0
Dibenzofuran	69.51	9.80	1.40	1,350.00	1,348.60	87	18	0
Organonitrogen Compounds								
2,4-dinitrotoluene						0	105	0
2,6-dinitrotoluene	212.00	212.00	212.00	212.00	0.00	1	104	0
2-nitroaniline						0	105	0
3,3'-dichlorobenzidine						0	105	0
3-nitroaniline						0	105	0

Appendix D, Table 3 - Summary Statistics for Metals and Organics Data

COMPOUND (unit of measure)	MEAN	MEDIAN	MINIMUM	MAXIMUM	RANGE	N	NO. OF NONDETECTED VALUES	NO. OF MISSING VALUES
4-chloroaniline						0	105	0
4-nitroaniline						0	105	0
9(H)carbazol	62.60	15.00	1.90	430.00	428.10	28	77	0
Caffeine	18.50	18.50	18.00	19.00	1.00	2	103	0
N-nitroso-di-n-propylamine						0	105	0
Nitrobenzene						0	105	0
N-nitrosodiphenylamine						0	105	0
Phenols								
2,4-dimethylphenol						0	105	0
2-methylphenol						0	13	0
4-methylphenol	1,242.51	620.00	8.50	12,000.00		101	105	0
Bis(2-chloroethoxy)-methane						0	105	0
Phenol	1,317.10	766.00	107.00	6,260.00	6,153.00	60	45	0
P-nonylphenol	11.30	11.30	9.60	13.00	3.40	2	103	0
Phthalate Esters								
Bis(2-ethylhexyl)phthalate	3,565.64	398.00	113.00	37,800.00	37,687.00	14	91	0
Butyl benzyl phthalte	28.67	28.00	16.00	42.00	26.00	3	102	0
Di-n-butyl phthalate	1,017.62	407.00	128.00	5,630.00	5,502.00	26	79	0
Di-n-octyl phthalate	23.00	23.00	23.00	23.00	0.00	1	104	0
Diethyl phthalate	49.00	49.00	45.00	53.00	8.00	2	103	0
Dimethyl phthalate	103.00	103.00	31.00	175.00	144.00	2	103	0
Chlorinated Pesticides								
Aldrin						0	105	0
Alpha-chlordane						0	105	0
Alpha-HCH (Alpha BHC)						0	105	0
Beta-HCH (Beta BHC)						0	105	0
Delta-HCH (Delta BHC)						0	105	0
Dieldrin						0	105	0
Endo-sulfansulfate						0	105	0
Endrin						0	105	0
Endrin ketone						0	105	0

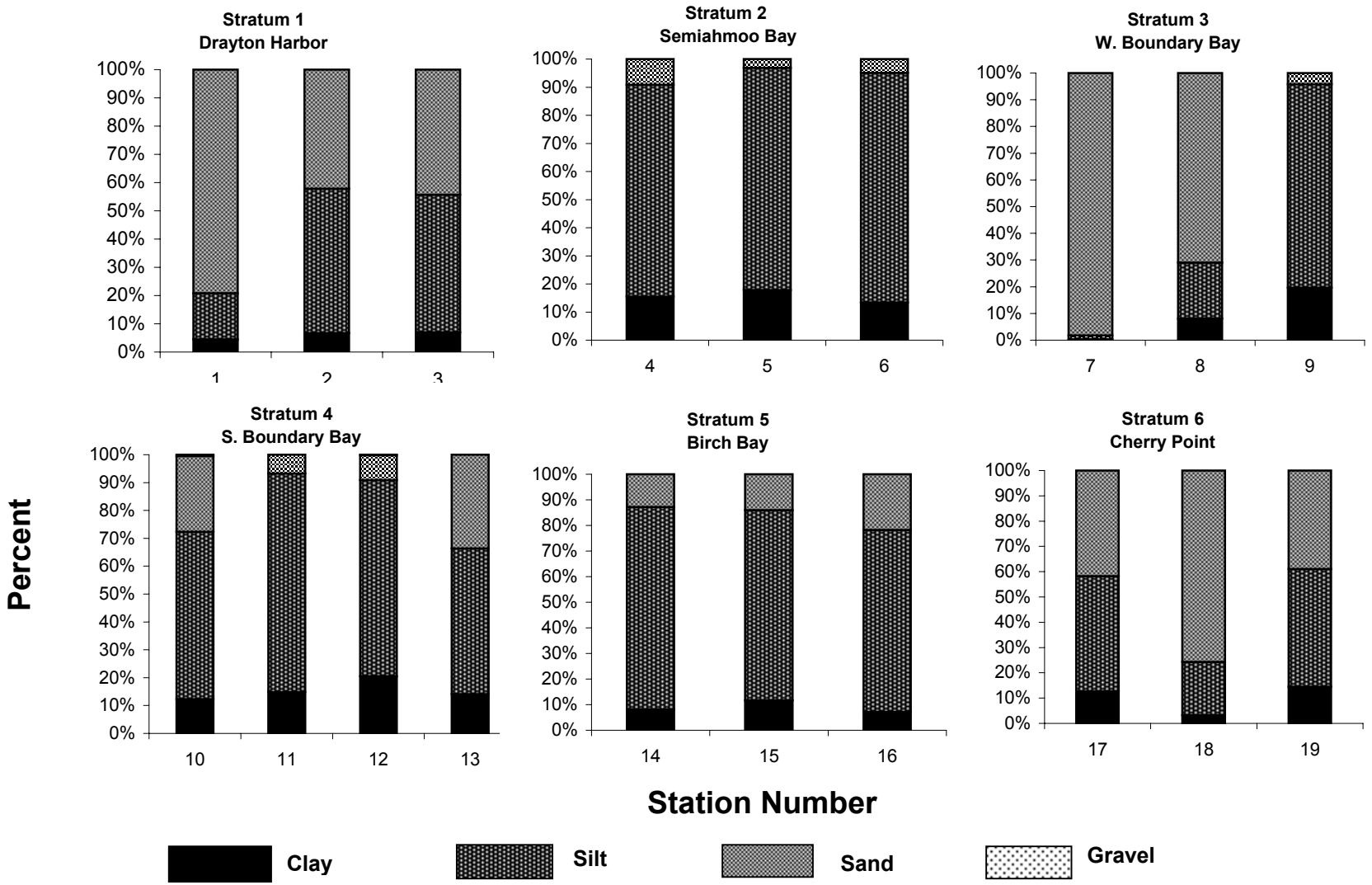
Appendix D, Table 3 - Summary Statistics for Metals and Organics Data

COMPOUND (unit of measure)	MEAN	MEDIAN	MINIMUM	MAXIMUM	RANGE	N	NO. OF NONDETECTED VALUES	NO. OF MISSING VALUES
Endrin-aldehyde						0	94	11
Gamma-chlordane (Trans-Chlordane)						0		
Gamma-HCH (Gamma BHC) (Lindane)						0	105	0
Heptachlor						0	103	2
Heptachlor epoxide						0	103	2
Methoxychlor						0	105	0
2,4'-DDD	1.18	1.18	0.25	2.10	1.85	2	103	0
4,4'-DDD	3.87	1.30	0.86	14.00	13.14	5	100	0
2,4'-DDE						0	105	0
4,4'-DDE	1.35	1.30	1.10	1.90	0.80	11	94	0
2,4'-DDT						0	104	1
4,4'-DDT	2.90	2.90	2.90	2.90	0.00	1	103	1
Cis-nonachlor						0	105	0
Trans-nonachlor						0	105	0
Oxychlordane						0	105	0
Mirex						0	105	0
Endosulfan I (Alpha-endosulfan)						0	105	0
Endosulfan II (Beta-endosulfan)						0	105	0
Chlorpyrifos						0	105	0
Toxaphene						0	105	0
Polycyclic Chlorinated Biphenyls								
PCB Arochlors:								
1016						0	105	0
1221						0	105	0
1232						0	105	0
1242	9.17	9.60	6.90	11.00	4.10	3	102	0
1248	5.57	4.90	3.70	8.10	4.40	3	102	0
1254	19.80	9.70	3.30	50.00	46.70	17	88	0
1260	509.57	23.00	19.00	3,400.00	3,381.00	7	98	0
PCB Congeners:								
8						0	105	0
18	1.43		0.27	2.00	1.73	6	99	0

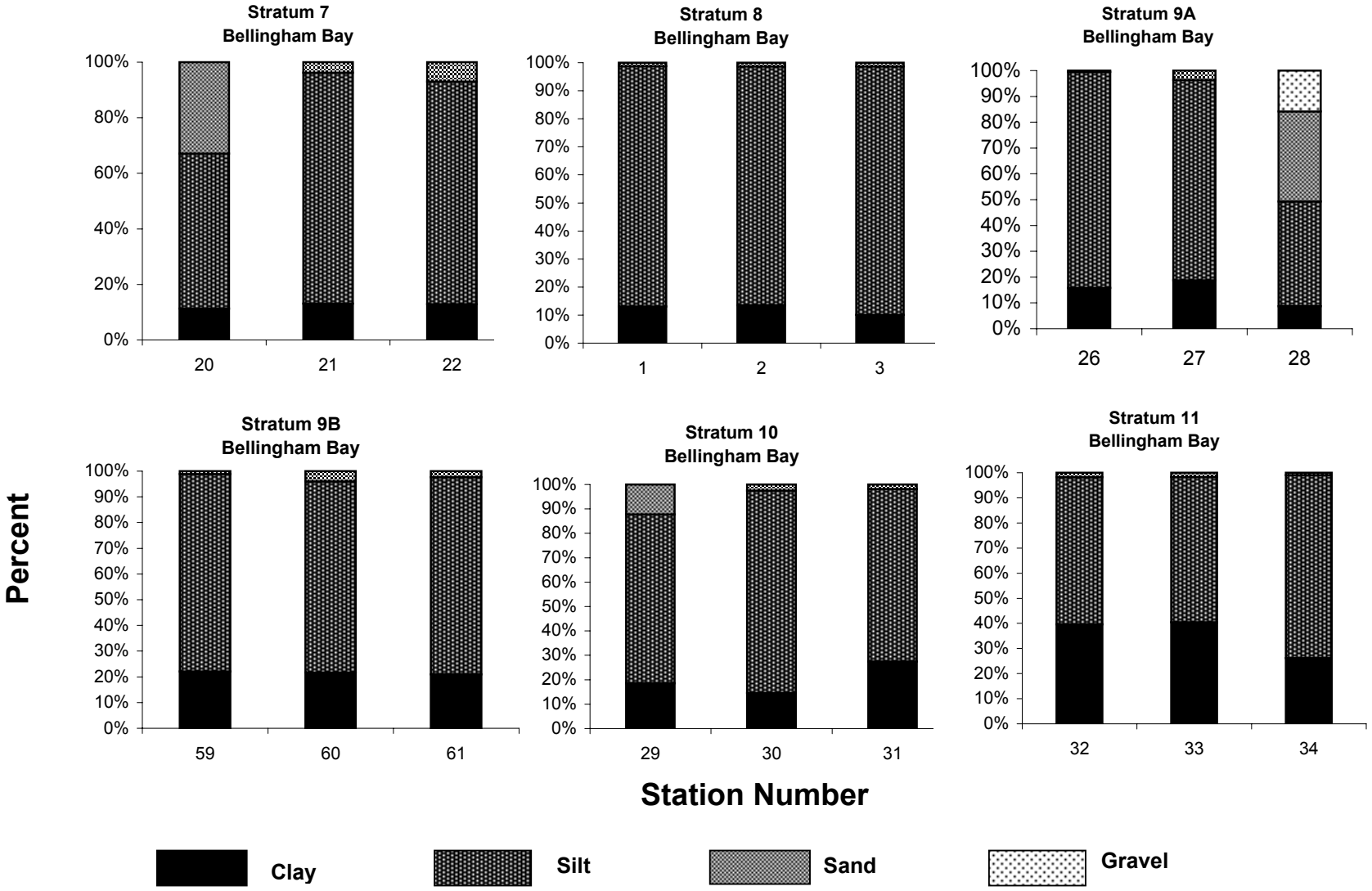
Appendix D, Table 3 - Summary Statistics for Metals and Organics Data

COMPOUND (unit of measure)	MEAN	MEDIAN	MINIMUM	MAXIMUM	RANGE	N	NO. OF NONDETECTED VALUES	NO. OF MISSING VALUES
28	20.59		0.37	240.00	239.63	13	92	0
44	1.30		1.30	1.30	0.00	1	104	0
52	4.31		0.09	20.00	19.91	6	99	0
66	19.82		0.13	320.00	319.87	18	87	0
77	21.16		0.06	370.00	369.94	19	86	0
101	28.18		0.09	190.00	189.91	7	98	0
105	4.05		0.19	15.00	14.81	4	101	0
118	36.70		0.18	350.00	349.82	10	95	0
126	22.22		0.18	170.00	169.82	8	97	0
128	260.00		260.00	260.00	0.00	1	104	0
138	94.00		94.00	94.00	0.00	1	104	0
153	12.00		12.00	12.00	0.00	1	104	0
170	5.99		0.09	59.00	58.91	12	93	0
180	6.78		1.10	34.00	32.90	6	99	0
187	13.65		0.76	120.00	119.24	10	95	0
195	4.39		0.16	62.00	61.84	18	87	0
206	0.64		0.21	2.00	1.79	10	95	0
209 (Decachlorobiphenyl)						0	105	0

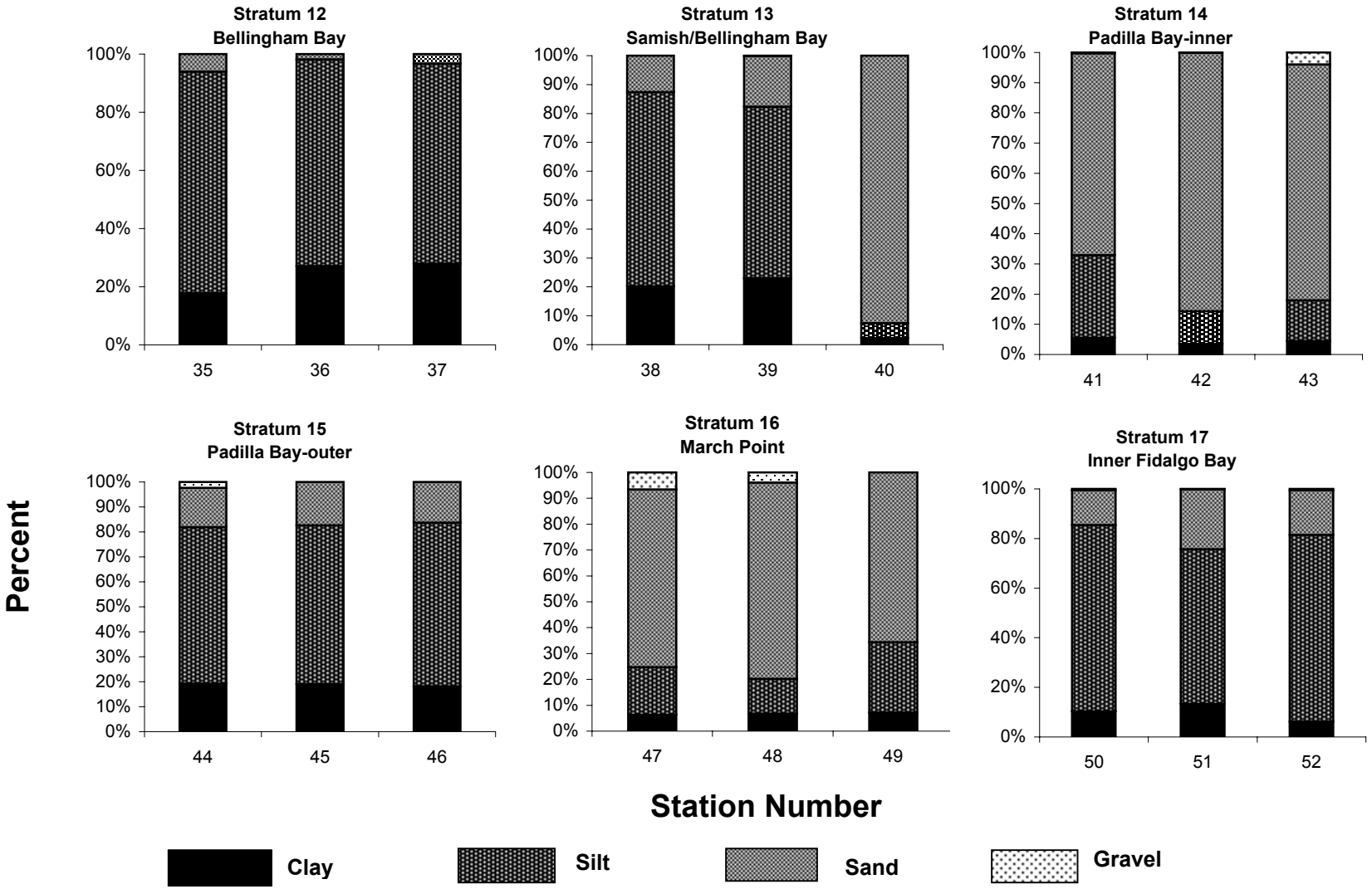
Appendix D, Figure 1. Grain size distribution for the 1997 northern Puget Sound sampling stations (grain size in fractional percent)



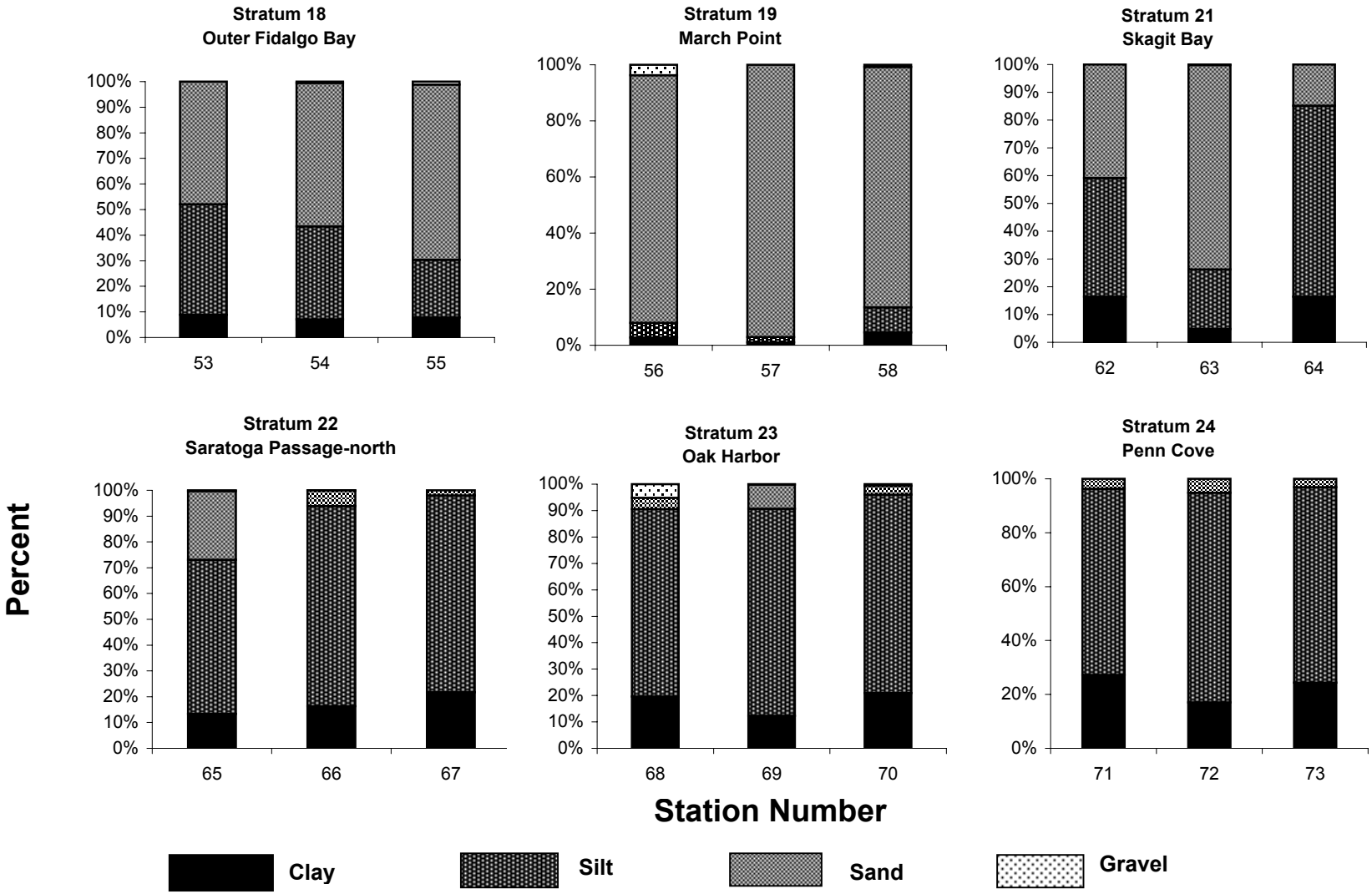
Appendix D, Figure 1. continued.



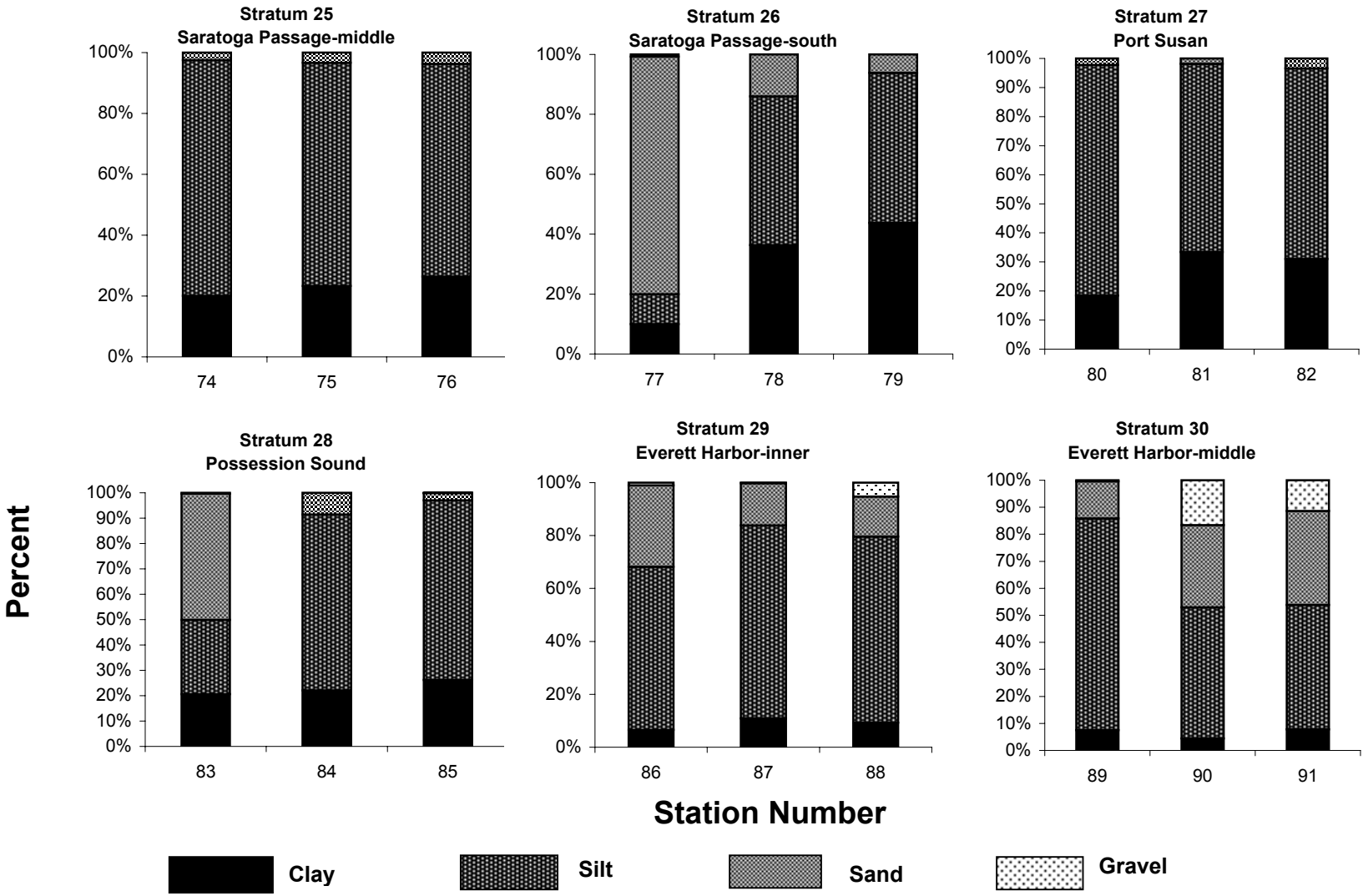
Appendix D, Figure 1. continued.



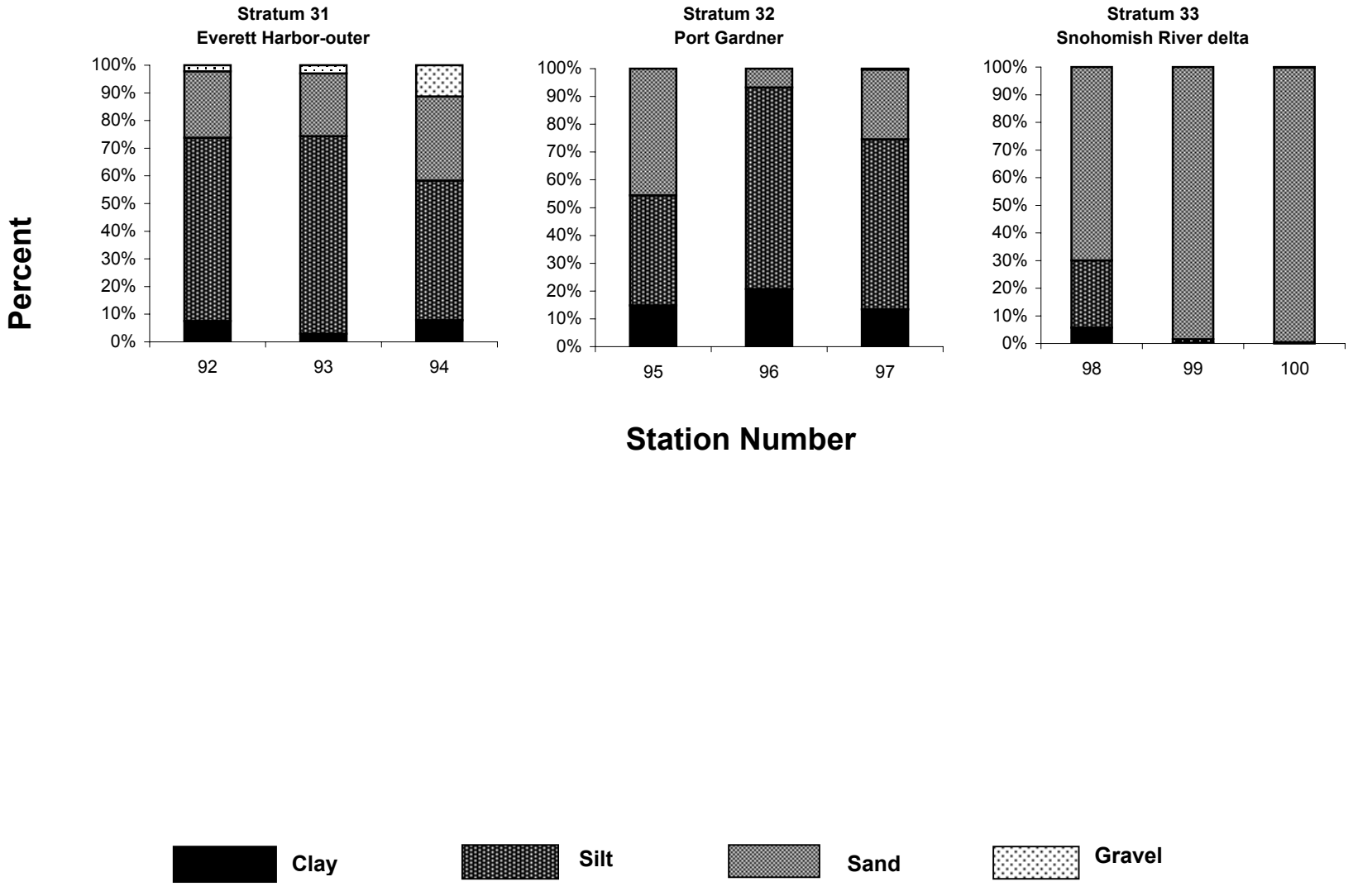
Appendix D, Figure 1. continued.



Appendix D, Figure 1. continued.



Appendix D, Figure 1. continued.



Appendix E

1997 Benthic Infaunal Species List

Appendix E. 1997 Benthic Infaunal Species List

Phylum	Class	Family	Taxon
Cnidaria	Hydrozoa	Corymorphidae	Euphysa sp.
		Virgulariidae	Virgularia sp.
		Edwardsiidae	Edwardsia sipunculoides
		Halcampidae	Halcampa decemtentaculata
		Actiniidae	Actiniidae
Platyhelminthes	Tubellaria	Stylochidae	Kaburakia excelsa
		Notoplanidae	Notoplana cf. iniquita
Nemertina	Anopla		Anopla
		Tubulanidae	Tubulanidae
			Tubulanus sp.
		Lineidae	Lineidae
			Lineidae sp. indet.
			Lineidae spp. indet.
			Cerebratulus sp.
			Cerebratulus sp. indet
			Lineus sp.
			Micrura sp.
			Micrura cf. alaskensis
	Enopla		Enopla
			Enopla sp. A
			Monostylifera spp. indet.
		Amphiporidae	Amphiporus sp. indet
			Zygonemertes virescens
		Tetrastemmatidae	Tetrastemma sp. indet
Annelida	Polychaeta	Aphroditidae	Aphrodita parva
		Polynoidae	Polynoidae
			Bylgides macrolepidus
			Eunoe sp.
			Eunoe uniseriata
			Gattyana treadwelli
			Harmothoe sp.
			Harmothoe imbricata
			Harmothoe fragilis
			Hesperonoe laevis
			Lepidasthenia berkeleyae
			Lepidasthenia longicirrata
			Tenonia priops
			Malmgreniella sp.
			Malmgreniella nigralba
			Malmgreniella bansei
			Malmgreniella liei
		Pholoidae	Pholoides asperus
		Sigalionidae	Sigalionidae
			Pholoe sp.
			Sthenelais tertiaglabra
		Chrysopetalidae	Paleanotus bellis
		Phyllodocidae	Eteone sp.
			Eteone spilotus
			Eteone leptotes

Appendix E. 1997 Benthic Infaunal Species List

Phylum	Class	Family	Taxon
			Eulalia (Eulalia) sp.
			Eulalia (Eulalia) quadrioculata
			Eumida longicornuta
			Phyllodoce (Aponaitides) hartmanae
			Phyllodoce cuspidata
			Phyllodoce (Anaitides) groenlandica
			Phyllodoce (Anaitides) longipes
			Phyllodoce (Anaitides) williamsi
		Hesionidae	Gyptis sp.
			Microphthalmus sczelkowii
			Micropodarke dubia
			Heteropodarke heteromorpha
			Podarke pugettensis
			Podarkeopsis glabrus
		Pilargidae	Sigambra tentaculata
			Pilargis maculata
			Parandalia fauveli
		Syllidae	Syllidae
			Pionosyllis sp.
			Syllis (Ehlersia) hyperioni
			Syllis (Ehlersia) heterochaeta
			Syllis (Typosyllis) armillaris
			Syllis (Typosyllis) harti
			Trypanosyllis sp.
			Eusyllis blomstrandi
			Exogone (E.) lourei
			Exogone (Parexogone) molesta
			Exogone dwisula
			Sphaerosyllis sp.
			Sphaerosyllis californiensis
			Sphaerosyllis ranunculus
			Brania brevipharyngea
			Proceraea cornuta
		Nereididae	Neanthes virens
			Nereis procera
			Platynereis bicanaliculata
		Nephtyidae	Nephtys caeca
			Nephtys cornuta
			Nephtys punctata
			Nepthys ferruginea
			Nephtys caecoides
		Sphaerodoridae	Sphaerodoropsis sphaerulifer
		Glyceridae	Glycera americana
			Glycera nana
		Goniadidae	Glycinde armigera
			Glycinde polygnatha
			Goniada maculata
			Goniada brunnea

Appendix E. 1997 Benthic Infaunal Species List

Phylum	Class	Family	Taxon
		Onuphidae	Onuphidae
			Onuphis sp.
			Onuphis iridescens
			Onuphis elegans
			Diopatra ornata
		Lumbrineridae	Lumbrineridae
			Eranno bicirrata
			Scoletoma luti
			Lumbrineris cruzensis
			Lumbrineris californiensis
		Oenonidae	Drilonereis longa
		Dorvilleidae	Dorvillea sp.
			Dorvillea (Schistomeringos) annulata
			Protodorvillea gracilis
			Pettiboneia pugettensis
		Orbiniidae	Orbiniidae
			Leitoscoloplos panamensis
			Leitoscoloplos pugettensis
			Scoloplos armiger
			Scoloplos acmeceps
		Paraonidae	Aricidea antennata
			Aricidea sp.
			Aricidea (Aricidea) minuta
			Aricidea (Acmira) lopezi
			Aricidea (Allia) ramosa
			Levinsenia gracilis
			Paradoneis spinifera
		Apistobranchidae	Apistobranchus ornatus
		Spionidae	Laonice cirrata
			Dipolydora socialis
			Dipolydora caulleryi
			Polydora websteri
			Dipolydora cardalia
			Prionospio sp.
			Prionospio steenstrupi
			Prionospio (Minuspio) lighti
			Prionospio jubata
			Prionospio (Minuspio) multibranchiata
			Spio cirrifera
			Boccardia pugettensis
			Spiophanes bombyx
			Spiophanes berkeleyorum
			Pygospio sp. 1
			Pygospio elegans
			Malacoceros (Rhynchospio) glutaeus
			Paraprionospio pinnata
			Boccardiella hamata
		Magelonidae	Magelonidae

Appendix E. 1997 Benthic Infaunal Species List

Phylum	Class	Family	Taxon
			Magelona sp.
			Magelona longicornis
		Trochochaetidae	Trochochaeta multisetosa
		Chaetopteridae	Phyllochaetopterus claparedii
			Spiochaetopterus costarum
		Cirratulidae	Cirratulidae
			Cirratulus spectabilis
			Caulleriella pacifica
			Aphelochaeta sp.
			Aphelochaeta nr. monilaris
			Aphelochaeta monilaris
			Aphelochaeta marioni
			Aphelochaeta sp. 2
			Aphelochaeta sp. N1
			Tharyx sp.
			Tharyx nr. parvus
			Chaetozone sp.
			Chaetozone nr. setosa
			Chaetozone acuta
			Chaetozone commonalis
		Ctenodrilidae	Raricirrus maculatus
		Cossuridae	Cossuridae
			Cossura sp.
			Cossura longocirrata
			Cossura pygodactylata
			Cossura bansei
		Flabelligeridae	Brada villosa
			Brada sachalina
			Pherusa plumosa
		Scalibregmidae	Scalibregma inflatum
			Asclerocheilus beringianus
		Opheliidae	Armandia brevis
			Ophelia limacina
			Travisia brevis
			Travisia pupa
			Ophelina acuminata
		Sternaspidae	Sternaspis scutata
		Capitellidae	Capitellidae
			Capitella capitata hyperspecies
			Heteromastus filiformis
			Heteromastus filobranchus
			Notomastus sp.
			Notomastus tenuis
			Notomastus latericeus
			Mediomastus sp.
			Mediomastus ambiseta
			Mediomastus californiensis
			Decamastus gracilis

Appendix E. 1997 Benthic Infaunal Species List

Phylum	Class	Family	Taxon
			Barantolla nr. americana
		Maldanidae	Maldanidae
			Chirimia similis
			Maldane sarsi
			Axiothella rubrocincta
			Praxillella sp.
			Praxillella gracilis
			Praxillella pacifica
			Euclymeninae
			Euclymene sp.
			Euclymene cf. zonalis
			Clymenura gracilis
			Microclymene caudata
		Oweniidae	Oweniidae
			Owenia fusiformis
			Myriochele sp.
			Galathowenia oculata
		Sabellariidae	Neosabellaria cementarium
		Pectinaridae	Pectinaria granulata
			Pectinaria californiensis
		Ampharetidae	Ampharetidae
			Amage sp.
			Amage anops
			Ampharete sp.
			Ampharete acutifrons
			Ampharete finmarchica
			Ampharete labrops
			Ampharete cf. crassiseta
			Amphicteis scaphobranchiata
			Lysippe labiata
			Melinna sp.
			Melinna elisabethae
			Melinna oculata
			Anobothrus gracilis
			Asabellides lineata
		Terebellidae	Amphitrite edwardsi
			Eupolymnia heterobranchia
			Pista sp.
			Pista brevibranchiata
			Pista moorei
			Pista wui
			Polycirrus sp.
			Polycirrus californicus
			Polycirrus sp. I
			Artacama coniferi
			Lanassa venusta
			Proclea graffii
		Trichobranchidae	Terebellides sp.

Appendix E. 1997 Benthic Infaunal Species List

Phylum	Class	Family	Taxon
			Terebellides stroemi
			Terebellides californica
			Terebellides nr. kobei
			Terebellides sp. 1 (nr. lineata)
		Sabellidae	Sabellidae
			Chone sp.
			Chone ecaudata
			Eudistylia sp.
			Eudistylia catherinae
			Myxicola infundibulum
			Laonome kroyeri
		Saccocirridae	Saccocirridae
	Oligochaeta		Oligochaeta
Mollusca	Gastropoda		Gastropoda
		Trochidae	Trochidae
			Margarites pupillus
			Lirularia lirulata
		Lacunidae	Lacuna sp.
			Lacuna vincta
		Littorinidae	Littorina sp.
		Rissoidae	Alvania compacta
		Cerithiidae	Lirobittium sp.
		Calyptraeidae	Calyptraea fastigiata
		Naticidae	Euspira pallida
		Nucellidae (Thaisidae)	Nucella lamellosa
		Columbellidae	Alia carinata
			Astyris gausapata
		Nassariidae	Nassarius mendicus
		Marginellidae	Granulina margaritula
		Turridae	Turridae
		Turridae	Kurtziella crebricostata
		Pyramidellidae	Odostomia sp.
			Turbonilla spp.
			Cyclostremella cf. concordia
		Acteonidae	Rictaxis punctocaelatus
		Cylichnidae	Acteocina sp.
			Acteocina culcitella
			Cylichna attonsa
			Scaphander sp.
		Aglajidae	Melanochlamys diomedea
		Gastropteridae	Gastropteron pacificum
		Diaphanidae	Diaphanidae
			Diaphana sp.
		Atyidae	Haminoea vesicula
		Aplysiidae	Phyllaplysia taylori
		Onchidoridídae	Onchidoris bilamellata
		Corambidae	Corambe cf. pacifica
			Corambe pacifica

Appendix E. 1997 Benthic Infaunal Species List

Phylum	Class	Family	Taxon
	Aplacophora	Chaetodermatidae	Chaetoderma sp.
			Chaetoderma argenteum
	Bivalvia		Bivalvia
		Nuculidae	Acila castrensis
			Ennucula tenuis
		Nuculanidae	Nuculana sp.
			Nuculana minuta
		Sareptidae	Yoldia sp.
			Yoldia hyperborea
			Yoldia scissurata
			Yoldia thraciaeformis
		Mytilidae	Mytilidae
			Mytilus sp.
			Solamen columbiana
			Musculus sp.
		Lucinidae	Lucinidae
			Parvilucina tenuisculpta
			Lucinoma annulata
		Thyasiridae	Thyasiridae
			Adontorhina cyclia
			Axinopsida serricata
			Thyasira flexuosa
		Lasaeidae	Rochefortia tumida
			Rochefortia sp. 1
		Cardiidae	Clinocardium sp.
			Clinocardium nuttallii
			Clinocardium blandum
			Nemocardium centifilosum
		Mactridae	Mactromeris polynyma
		Tellinidae	Macoma sp.
			Macoma calcarea
			Macoma elimata
			Macoma obliqua
			Macoma moesta
			Macoma yoldiformis
			Macoma carlottensis
			Macoma nasuta
			Macoma inquinata
			Macoma balthica
			Tellina sp.
			Tellina nuculoides
			Tellina modesta
		Veneridae	Saxidomus giganteus
			Compsomyax subdiaphana
			Psephidia lordi
			Protothaca staminea
		Myidae	Cryptomya californica
			Mya arenaria

Appendix E. 1997 Benthic Infaunal Species List

Phylum	Class	Family	Taxon
		Hiatellidae	Hiatella arctica
			Panomya ampla
		Teredinidae	Bankia setacea
		Pandoridae	Pandora sp.
			Pandora filosa
		Lyonsiidae	Lyonsia californica
		Thraciidae	Thracia sp.
		Cuspidariidae	Cardiomya pectinata
			Cardiomya planetica
	Scaphopoda	Dentaliidae	Rhabdus rectius
		Pulsellidae	Pulsellum salishorum
Arthropoda	Arachnida		Acarina
	Ostrocoda		Ostracoda
		Cylindroleberididae	Bathyleberis
		Rutidermatidae	Rutiderma apex
		Philomedidae	Euphilomedes carcharodonta
			Euphilomedes carcharodonta producta
			Euphilomedes carcharodonta carcharodonta
			Euphilomedes longiseta
			Euphilomedes producta
	Malacostraca	Nebaliidae	Nebalia pugettensis
			Mysidacea
		Mysidae	Archaeomysis grebnitzkii
			Inusitatomysis insolita
			Neomysis kadiakensis
			Neomysis mercedis
			Pseudomma berkeleyi
			Alienacanthomysis macropsis
			Cumacea
		Lampropidae	Lamprops carinata
			Lamprops quadriplicata
		Leuconiidae	Leucon subnasica
			Eudorella (Tridentata) pacifica
			Eudorellopsis longirostris
		Diastylidae	Diastylis alaskensis
			Diastylis bidentata
			Diastylis pellucida
			Diastylis paraspinulosa
			Diastylis cf. nucella (sp. A?)
			Diastylopsis tenuis
		Nannastacidae	Campylaspis canaliculata
			Campylaspis biplicata
			Cumella californica
		Tanaidae	Zeuxo normani
		Paratanaidae	Leptochelia dubia
			Leptochelia savignyi
		Anarthruridae	Araphura breviaria
		Anthuridae	Haliophasma geminata

Appendix E. 1997 Benthic Infaunal Species List

Phylum	Class	Family	Taxon
		Sphaeromatidae	Sphaeromatidae
		Limnoriidae	Limnoria lignorum
		Aegidae	Rocinela belliceps
		Idoteidae	Synidotea nebulosa
			Idotea ochotensis
		Munnidae	Munna ubiquita
		Munnopsidae	Munnopsurus sp. A
		Paramunnidae	Pleurogonium rubicundum
			Munnogonium tillerae
			Gammaridea
		Ampeliscidae	Ampelisca sp.
			Ampelisca agassizi
			Ampelisca hancocki
			Ampelisca pugetica
			Ampelisca brevisimulata
			Ampelisca careyi
			Byblis millsi
		Ampithoidae	Ampithoe lacertosa
		Aoridae	Aoroides sp.
			Aoroides inermis
			Aoroides spinosus
			Aoroides intermedius
		Argissidae	Argissa hamatipes
		Atylidae	Atylus levidensus
		Calliopiidae	Calliopius columbiana
		Corophiidae	Corophium (Monocorophium) acherusicum
			Corophium (Americorophium) spinicorne
			Corophium (Monocorophium) carlottensis
		Pontogeneiidae	Accedomoera vagor
		Eusiridae	Eusirus sp. A
			Rhachotropis sp.
			Rhachotropis barnardi
		Melitidae	Desdimelita desdichada
		Melphidippidae	Eogammarus oclairi
		Melitidae	Megamoera borealis
		Haustoriidae	Eohaustorius washingtonianus
		Eusiridae	Pontoporeia femorata
		Isaeidae	Photis sp.
			Photis brevipes
			Photis bifurcata
			Photis macinerneyi
			Photis parvidons
			Protomedeia sp.
			Protomedeia grandimana
			Protomedeia articulata
			Protomedeia prudens
			Cheirimedeia zotea
		Ischyroceridae	Ischyrocerus sp.

Appendix E. 1997 Benthic Infaunal Species List

Phylum	Class	Family	Taxon
			Ischyrocerus anguipes
		Oedicerotidae	Americhelidium variabilum
			Americhelidium pectinatum
		Lysianassidae	Orchomene cf. pinguis
			Anonyx sp.
			Anonyx cf. lilljeborgi
			Cyphocaris challengeri
			Lepidepecreum gurjanovae
			Lepidepecreum garthi
			Orchomene pacificus
		Oedicerotidae	Bathymedon pumilus
			Synchelidium rectipalmum
			Westwoodilla sp.
			Americhelidium millsi
			Deflexilodes enigmaticus
		Phoxocephalidae	Harpiniopsis fulgens
			Heterophoxus affinis
			Metaphoxus frequens
			Paraphoxus cf. gracilis
			Rhepoxynius boreovariatus
			Grandifoxus grandis
			Foxiphalus cf. similis
		Pleustidae	Parapleustes americanus
			Pleusymtes coquilla
		Podoceridae	Dyopedos sp.
		Synopiidae	Syrrhoe longifrons
		Aeginellidae	Mayerella banksia
			Tritella pilimana
		Caprellidae	Caprella laeviuscula
			Caprella californica
			Caprella mendax
			Euphausia pacifica
			Metacaprella kennerlyi
		Pasiphaeidae	Pasiphaea pacifica
		Hippolytidae	Hippolytidae immature
			Spironticaris sica
		Crangonidae	Crangon sp.
			Crangon alaskensis
			Crangon franciscorum franciscorum
		Callianassidae	Neotrypaea sp.
		Paguridae	Pagurus sp.
			Brachyura
		Majidae	Majidae
		Xanthidae	Lophopanopeus bellus
		Pinnotheridae	Pinnixa schmitti
			Pinnixa tubicola
			Scleroplax granulata
Sipuncula	Sipunculidea	Golfingiidae	Thysanocardia sp.

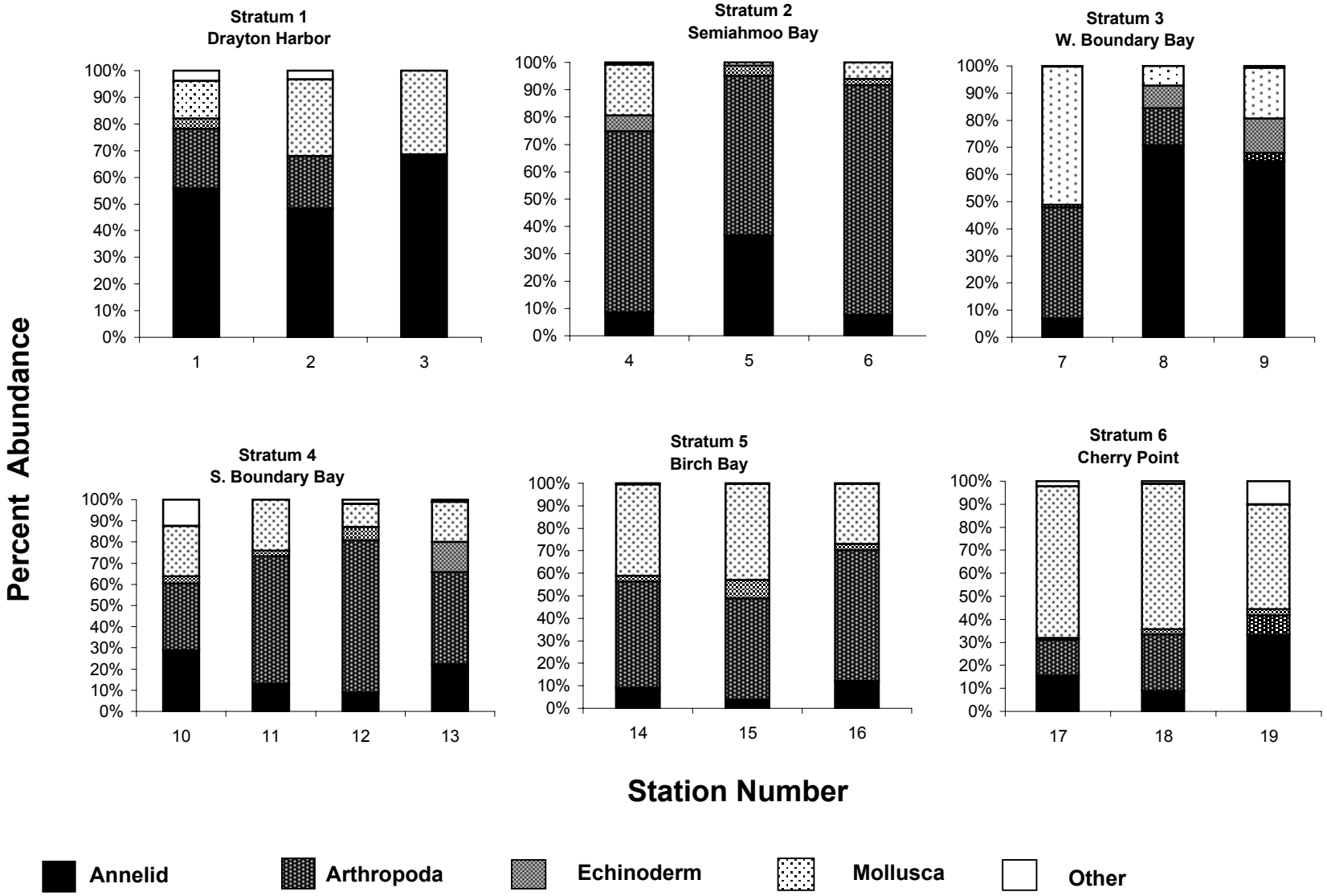
Appendix E. 1997 Benthic Infaunal Species List

Phylum	Class	Family	Taxon
			Nephasoma sp.
			Thysanocardia nigra
Phorona		Phoronidae	Phoronopsis harmeri
Echinodermata	Asteroidea	Luidiidae	Luidia foliolata
		Asteriidae	Leptasterias hexactis
	Ophiuroidea	Amphiuridae	Amphiuridae
			Amphiuridae sp. indet.
			Amphiodia sp. indet.
			Amphiodia urtica
			Amphiodia periercta
			Amphipholis sp.
			Amphipholis pugetana
			Amphipholis squamata
			Amphioplus sp.
			Amphioplus (Amphioplus) strongyloplax macraspis
			Amphioplus macraspis
			Amphiura sp.
			Amphiura carchara
	Echinoidea	Schizasteridae	Brisaster latifrons
	Holothuroidea		Holothuroidea
		Phyllophoridae	Pentamera pseudocalcigera
			Pentamera lissoplaca
		Synaptidae	Leptosynapta clarki
		Mopadiidae	Molpadia intermedia
Hemichordata	Enteropneusta		Enteropneusta
Chordata	Ascidiacea	Styelidae	Styela gibbsii

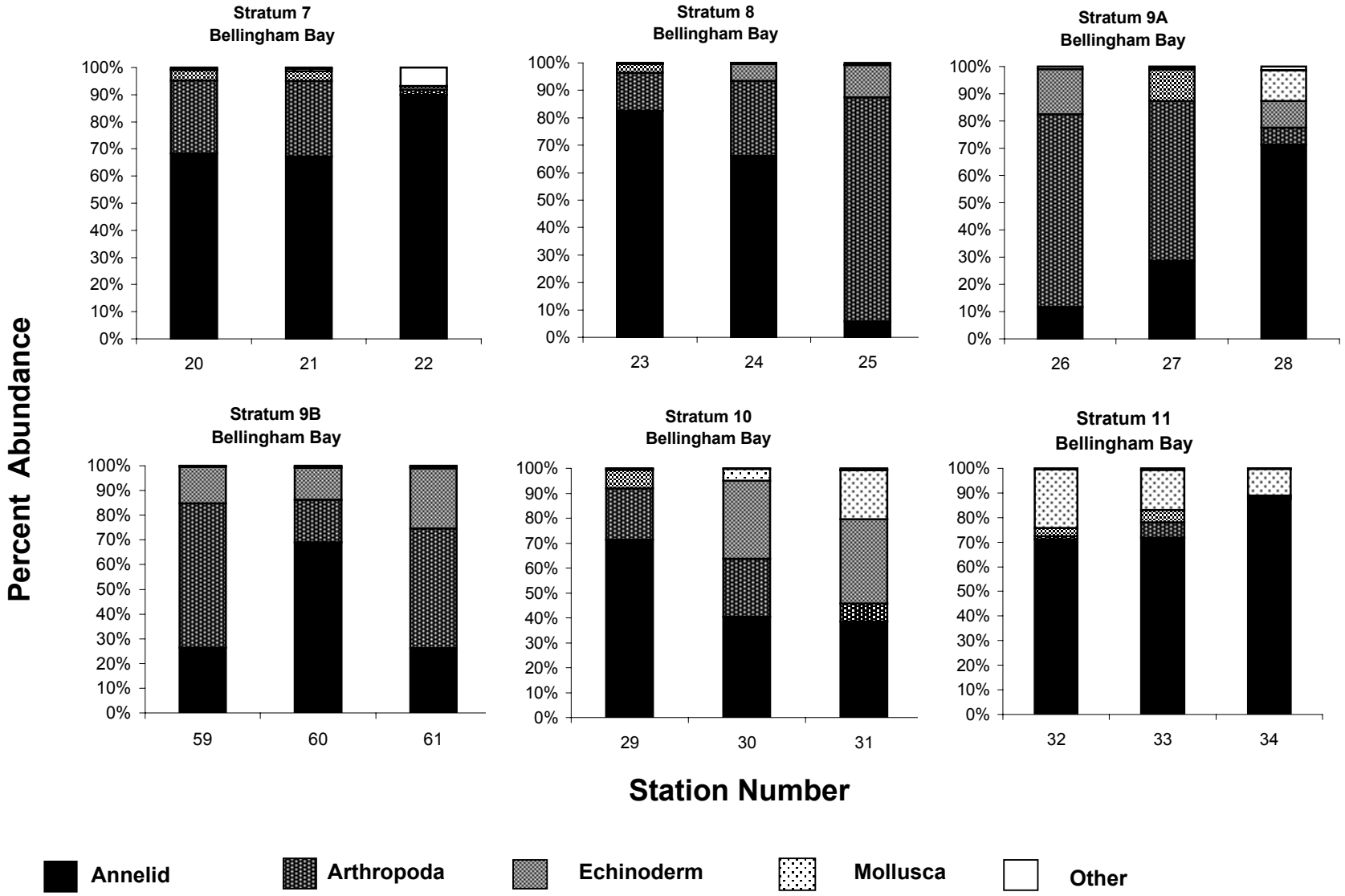
Appendix F

Percent taxa abundance for the 1997 Northern Puget Sound sampling stations

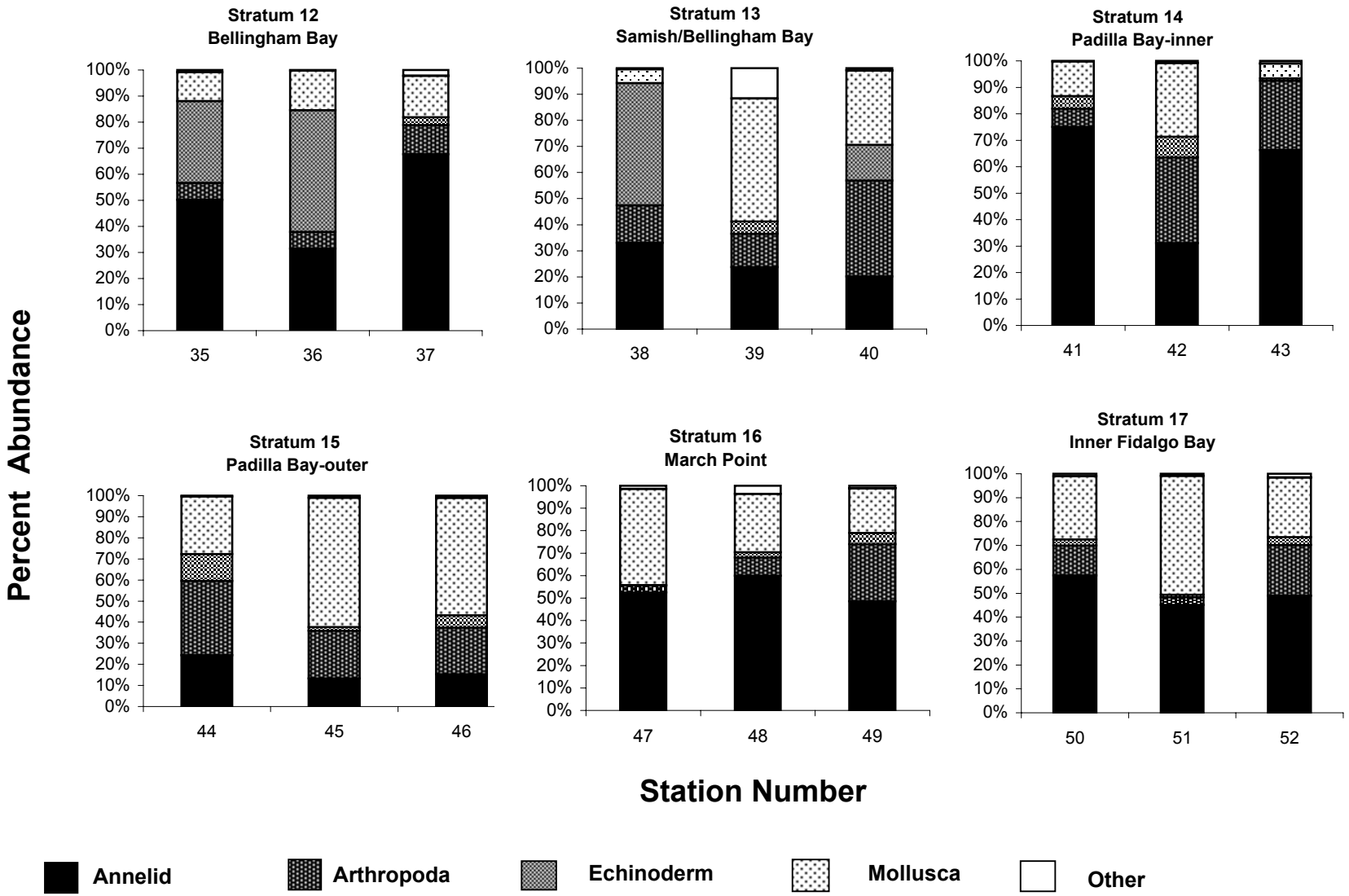
Appendix F. Percent taxa abundance for the 1997 Northern Puget Sound sampling stations



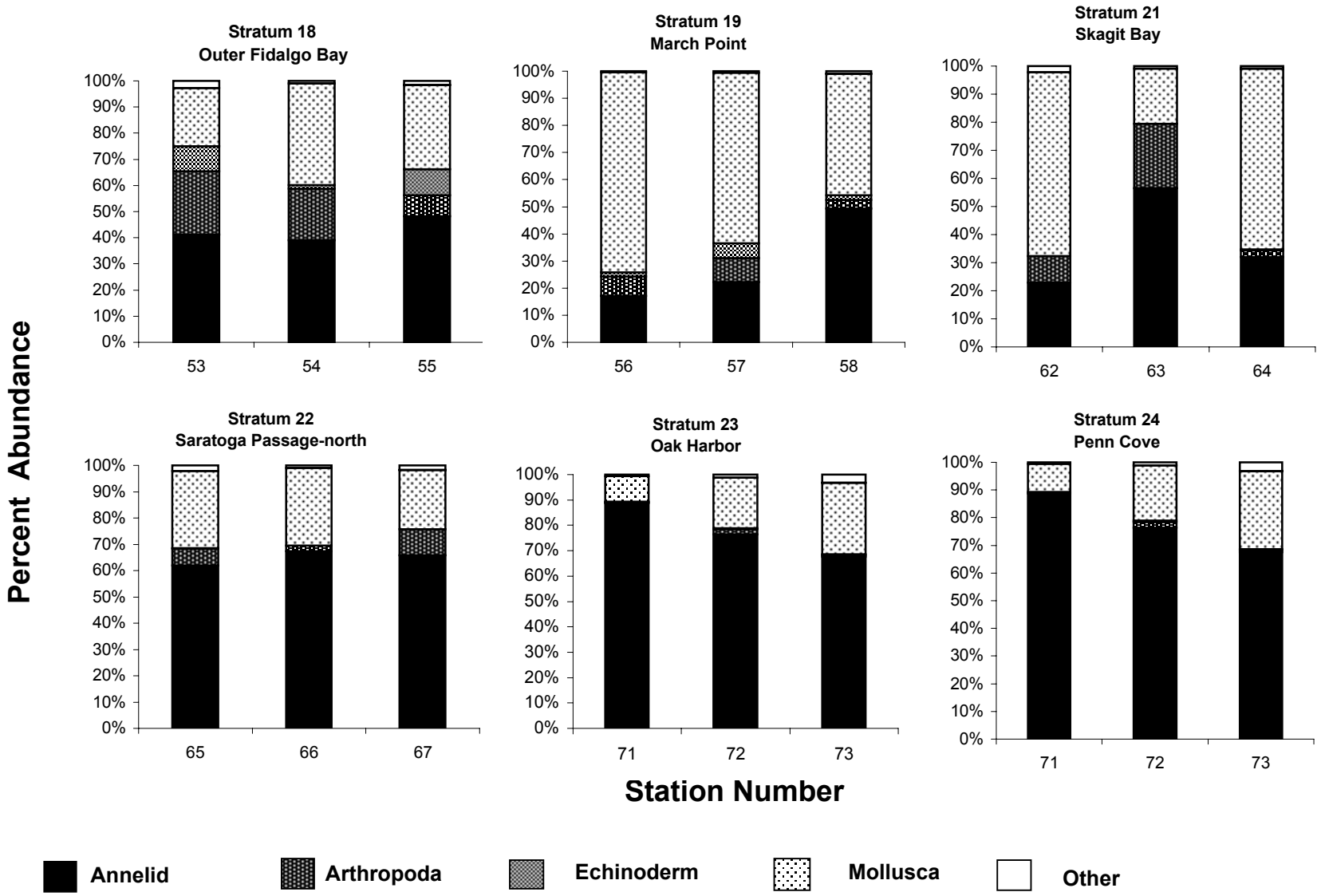
Appendix F, continued. Percent taxa abundance for the 1997 Northern Puget Sound sampling stations



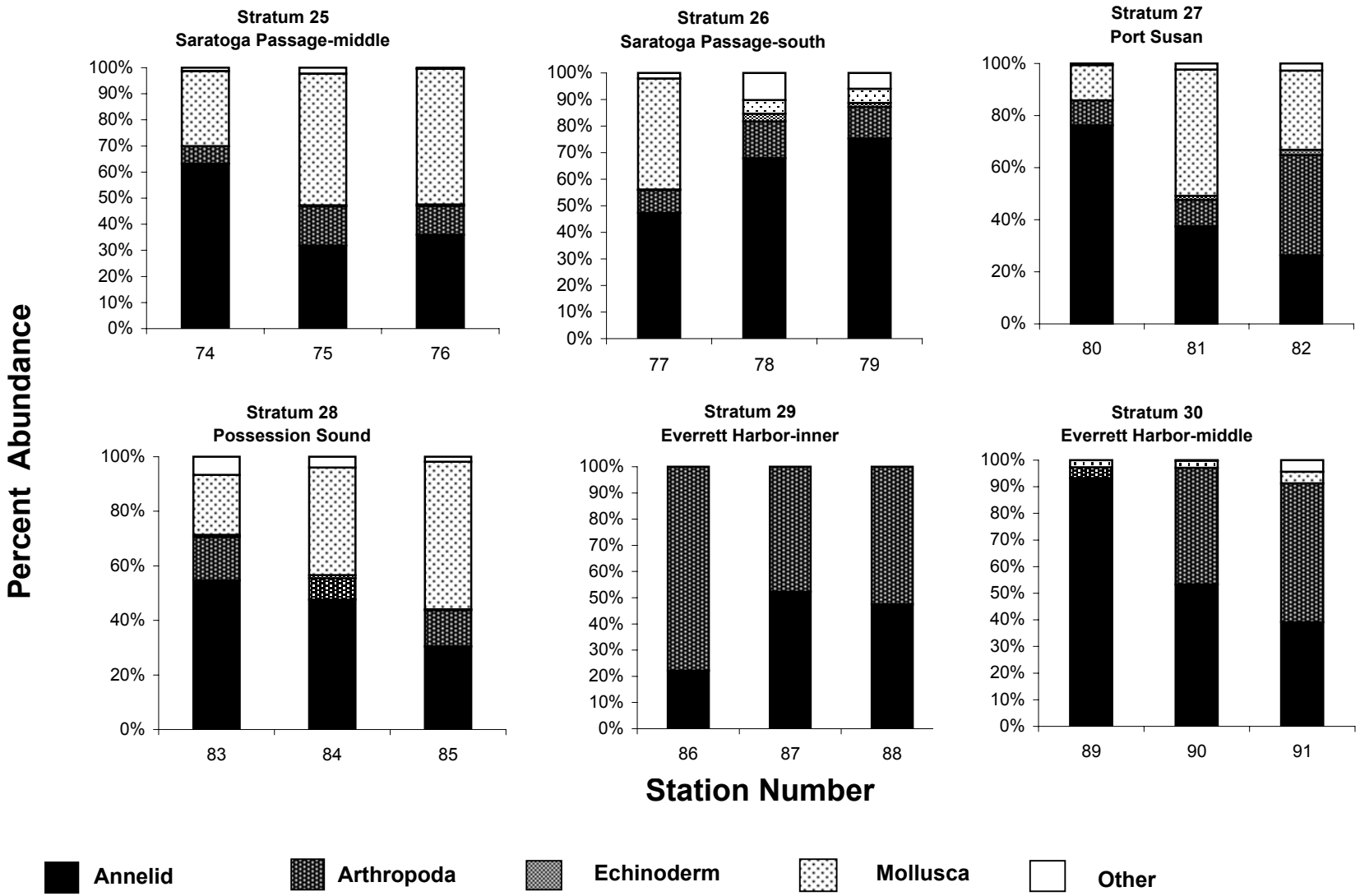
Appendix F, continued. Percent taxa abundance for the 1997 Northern Puget Sound sampling stations



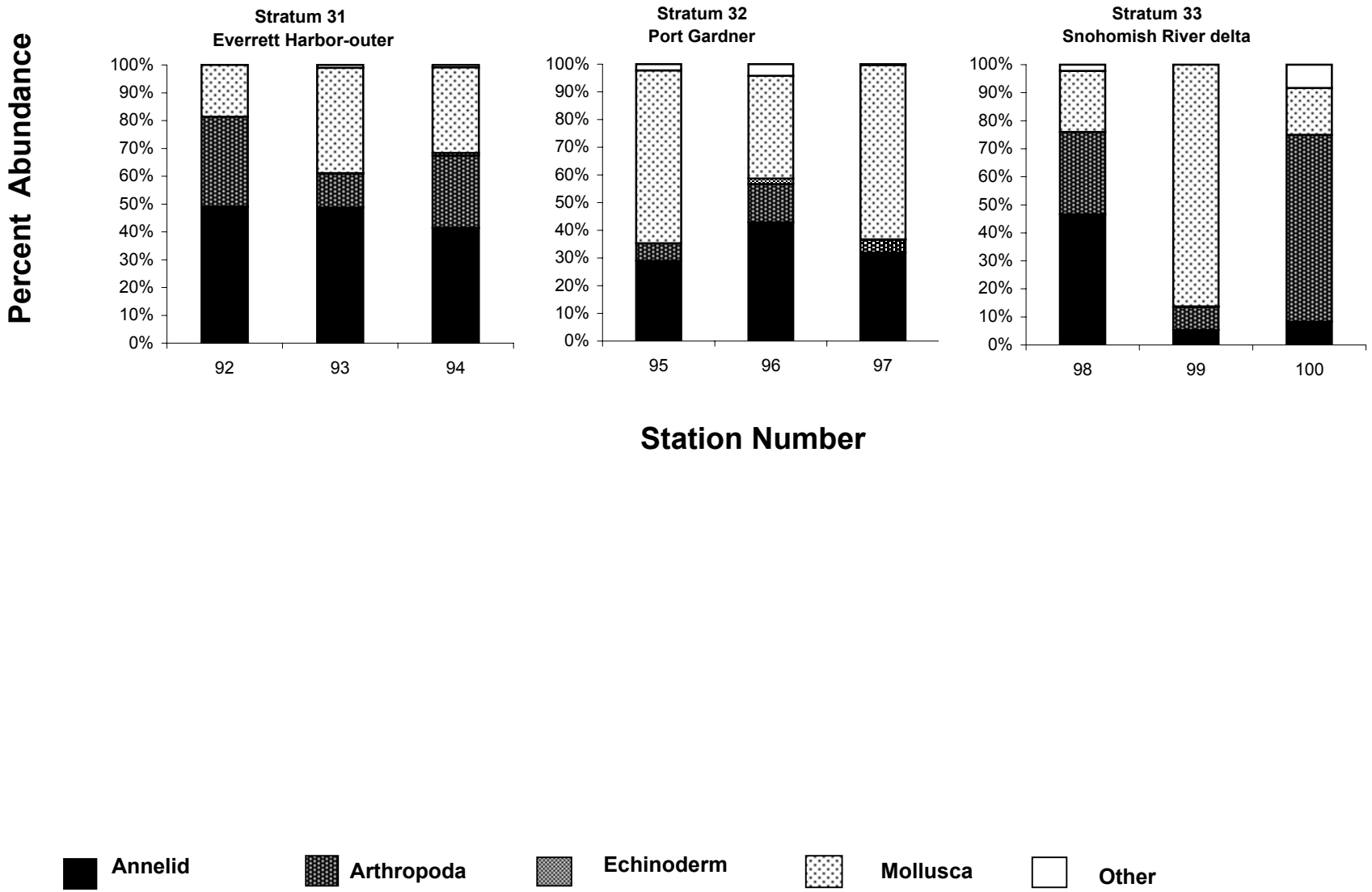
Appendix F, continued. Percent taxa abundance for the 1997 Northern Puget Sound sampling stations



Appendix F, continued. Percent taxa abundance for the 1997 Northern Puget Sound sampling stations



Appendix F, continued. Percent taxa abundance for the 1997 Northern Puget Sound sampling stations



Appendix G

Triad data - Results of selected toxicity, chemistry, and infaunal analysis for all northern Puget Sound stations

Appendix G. Triad data - Results of selected toxicity, chemistry, and infaunal analysis for all northern Puget Sound

	Chemistry						Toxicity			Infauna											
Statum, Sample, Location	Number of ERMs exceeded	Compounds Exceeding ERM	Number of SQSs exceeded	Compounds Exceeding SQS	Number of CSLs exceeded	Compounds Exceeding CSL	Mean Urchin Fertilization in 100% pore water as % of Control (and statistical significance)	Microtox EC50 (mg/ml) (and statistical significance)	P-450 induction (ug/g) (and statistical significance)	Total Abundance	Species Richness	Annelid Abundance	Arthropod Abundance	Echinoderm Abundance	Mollusca Abundance	Misc. Abundance	Pielou's Evenness (J')	Swartz's Dominance Index (SDI)	Dominant Species	Count
1, 1, Drayton Harbor		none	1	Phenol		none	117ns	2.37ns	6.46ns	487	53	272	109	19	68	19	0.85	16	Nephtys cornuta Protomedeia grandimana Amage sp. Rochefortia tumida	45 45 33 32
1, 2, Drayton Harbor		none	1	Phenol	1	Phenol	29**	1.8ns	8.51ns	122	24	59	24	0	35	4	0.88	10	Nephtys cornuta Protomedeia grandimana Glycinde polygnatha Macoma nasuta	17 15 13 13
1, 3, Drayton Harbor		none	1	Phenol		none	0**	1.33ns	10.51ns	54	11	37	0	0	17	0	0.89	5	Nephtys cornuta Prionospio (Minuspio) lighti Terebellides californica Macoma nasuta	14 8 8 7
2, 4, Semiahmoo Bay		none		none		none	118ns	2.73ns	2.72ns	864	49	74	572	51	160	7	0.56	5	Eudorella (tridentata) pacifica Psephidia lordi Protomedeia grandimana Amphiodia urtica/periercta complex	388 109 103 43
2, 5, Semiahmoo Bay		none	2	Benzoic acid, Phenol	2	Benzoic acid, Phenol	118ns	1.06ns	2.51ns	1118	29	411	653	41	13	0	0.44	2	Protomedeia grandimana Terebellides nr. kobei Prionospio (Minuspio) lighti Amphiodia urtica/periercta complex	612 273 90 39
2, 6, Semiahmoo Bay		none	2	Benzoic acid, Phenol	2	Benzoic acid, Phenol	117ns	2.5ns	8.71ns	1100	37	85	925	24	66	0	0.44	2	Protomedeia grandimana Pontoporeia femorata Terebellides nr. kobei Pinnixa schmitti	675 176 44 38

Appendix G. Triad data - Results of selected toxicity, chemistry, and infaunal analysis for all northern Puget Sound

	Chemistry						Toxicity			Infauna											
Statum, Sample, Location	Number of ERMs exceeded	Compounds Exceeding ERM	Number of SQSs exceeded	Compounds Exceeding SQS	Number of CSLs exceeded	Compounds Exceeding CSL	Mean Urchin Fertilization in 100% pore water as % of Control (and statistical significance)	Microtox EC50 (mg/ml) (and statistical significance)	P-450 induction (ug/g) (and statistical significance)	Total Abundance	Species Richness	Annelid Abundance	Arthropod Abundance	Echinoderm Abundance	Mollusca Abundance	Misc. Abundance	Pielou's Evenness (J')	Swartz's Dominance Index (SDI)	Dominant Species	Count
3, 7, West Boundary Bay		none		none		none	117ns	6.83ns	0.27ns	5055	66	358	2062	46	2581	8	0.48	3	Rochefortia tumida Ampelisca agassizi Psephidia lordi Euphilomedes carcharodonta	1635 1299 885 373
3, 8, West Boundary Bay		none	1	Phenol	1	Phenol	117ns	1.02ns	2.17ns	783	43	555	106	65	57	0	0.61	5	Prionospio (Minuspio) lighti Terebellides nr. kobei Protomedeia grandimana Paraprionospio pinnata	283 141 79 67
3, 9, West Boundary Bay	1	Mercury	3	Mercury, Benzoic acid, Phenol	3	Mercury, Benzoic acid, Phenol	118ns	1.67ns	2.32ns	197	34	128	6	25	37	1	0.73	8	Terebellides nr. kobei Amphiodia urtica/periercta complex Lumbrineris cruzensis Axinopsida serricata	63 23 23 15
4, 10, South Boundary Bay		none	1	Phenol	1	Phenol	118ns	9.37ns	5.83ns	521	56	150	165	18	123	65	0.76	11	Eudorella (tridentata) pacifica Acila castrensis Pulsellum salishorum Levinsenia gracilis	91 65 63 52
4, 11, South Boundary Bay		none		none		none	117ns	1.57ns	3.03ns	1083	39	141	653	28	261	0	0.56	4	Protomedeia grandimana Eudorella (tridentata) pacifica Psephidia lordi Lumbrineris cruzensis	447 170 162 48
4, 12, South Boundary Bay		none		none		none	116ns	2.23ns	2.57ns	856	51	77	615	54	94	16	0.58	5	Eudorella (tridentata) pacifica Protomedeia grandimana Amphiodia urtica/periercta complex Psephidia lordi	304 238 50 30

Appendix G. Triad data - Results of selected toxicity, chemistry, and infaunal analysis for all northern Puget Sound

	Chemistry						Toxicity			Infauna											
Statum, Sample, Location	Number of ERMs exceeded	Compounds Exceeding ERM	Number of SQSs exceeded	Compounds Exceeding SQS	Number of CSLs exceeded	Compounds Exceeding CSL	Mean Urchin Fertilization in 100% pore water as % of Control (and statistical significance)	Microtox EC50 (mg/ml) (and statistical significance)	P-450 induction (ug/g) (and statistical significance)	Total Abundance	Species Richness	Annelid Abundance	Arthropod Abundance	Echinoderm Abundance	Mollusca Abundance	Misc. Abundance	Pielou's Evenness (J')	Swartz's Dominance Index (SDI)	Dominant Species	Count
4, 13, South Boundary Bay		none	1	Phenol	1	Phenol	116ns	4.37ns	3.95ns	554	60	124	240	80	105	5	0.76	13	Eudorella (tridentata) pacifica Amphiodia urtica/periercta complex Acila castrensis Protomedeia grandimana	104 74 50 45
5, 14, Birch Bay		none	2	4-Methylphenol, Phenol	1	4-Methylphenol	117ns	1.46ns	2.01ns	965	41	89	455	24	392	5	0.63	5	Protomedeia grandimana Rochefortia tumida Psephidia lordi Megamoera borealis	280 197 153 59
5, 15, Birch Bay		none	1	4-Methylphenol	1	4-Methylphenol	118ns	2.9ns	2.4ns	1235	43	48	554	103	527	3	0.56	4	Psephidia lordi Eudorella (tridentata) pacifica Protomedeia grandimana Amphiodia urtica/periercta complex	436 307 146 85
5, 16, Birch Bay		none	1	4-Methylphenol	1	4-Methylphenol	118ns	2.63ns	2.67ns	746	38	90	434	21	199	2	0.58	5	Protomedeia grandimana Rochefortia tumida Psephidia lordi Pontoporeia femorata	351 111 63 23
6, 17, Cherry Point		none		none		none	115ns	4.9ns	3.01ns	1454	74	227	223	14	956	34	0.62	9	Psephidia lordi Axinopsida serricata Eudorella (tridentata) pacifica Levinsenia gracilis	586 112 85 71
6, 18, Cherry Point		none	1	Phenol	1	Phenol	112ns	2.4ns	2.83ns	1092	53	98	268	25	689	12	0.52	4	Rochefortia tumida Rhepoxynius boreovariatus Tellina modesta Protomedeia grandimana	548 110 104 74

Appendix G. Triad data - Results of selected toxicity, chemistry, and infaunal analysis for all northern Puget Sound

	Chemistry						Toxicity			Infauna											
Statum, Sample, Location	Number of ERMs exceeded	Compounds Exceeding ERM	Number of SQSs exceeded	Compounds Exceeding SQS	Number of CSLs exceeded	Compounds Exceeding CSL	Mean Urchin Fertilization in 100% pore water as % of Control (and statistical significance)	Microtox EC50 (mg/ml) (and statistical significance)	P-450 induction (ug/g) (and statistical significance)	Total Abundance	Species Richness	Annelid Abundance	Arthropod Abundance	Echinoderm Abundance	Mollusca Abundance	Misc. Abundance	Pielou's Evenness (J')	Swartz's Dominance Index (SDI)	Dominant Species	Count
6, 19, Cherry Point		none	1	Phenol	1	Phenol	115ns	12.17ns	3.04ns	792	63	263	68	20	362	79	0.77	13	Axinopsida serricata Levinsenia gracilis Acila castrensis Pulsellum salishorum	105 85 81 74
7, 20, Bellingham Bay		none	1	Phenol	1	Phenol	113ns	7.33ns	1.49ns	1860	49	1270	503	70	7	10	0.39	2	Owenia fusiformis Euphilomedes carcharodonta Protomedeia prudens/Cheirimedeia zotea Amphiodia urtica/periercta complex	1145 260 186 54
7, 21, Bellingham Bay		none	1	Phenol	1	Phenol	113ns	5.43ns	1.72ns	2672	55	1794	748	93	25	12	0.39	2	Owenia fusiformis Euphilomedes carcharodonta Protomedeia prudens/Cheirimedeia zotea Amphiodia urtica/periercta complex	1620 408 235 79
7, 22, Bellingham Bay		none	1	Phenol	1	Phenol	46**	1.57ns	1.63ns	1846	41	1661	36	20	4	125	0.51	5	Aphelochaeta monilaris Nephtys cornuta Scoletoma luti Heteromastus filobranchus	1059 124 107 71
8, 23, Bellingham Bay		none	1	Phenol		none	114ns	8.23ns	2.63ns	5125	32	4228	712	170	7	8	0.25	1	Owenia fusiformis Euphilomedes carcharodonta Protomedeia prudens/Cheirimedeia zotea Amphiodia urtica/periercta complex	4155 384 203 152

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8, 24, Bellingham Bay		none	1	Phenol		none	115ns	5.93ns	2.98ns	2786	36	1843	759	173	4	7	0.40	3	Owenia fusiformis Euphilomedes carcharodonta Protomedeia prudens/Cheirimedeia zotea Amphiodia urtica/periercta complex	1720 347 294 164
8, 25, Bellingham Bay		none	1	Phenol	1	Phenol	114ns	4ns	2.06ns	984	37	58	802	116	1	7	0.49	3	Protomedeia prudens/Cheirimedeia zotea Euphilomedes carcharodonta Amphiodia urtica/periercta complex Eudorella (tridentata) pacifica	358 355 109 17
9A, 26, Bellingham Bay		none	1	Phenol		none	119ns	12.87ns	4.7ns	1602	30	186	1135	266	0	15	0.55	3	Protomedeia prudens/Cheirimedeia zotea Euphilomedes carcharodonta Amphiodia urtica/periercta complex Owenia fusiformis	594 423 250 57
9A, 27, Bellingham Bay		none	1	Mercury		none	119ns	12ns	3.31ns	1908	40	549	1118	221	4	16	0.57	4	Protomedeia prudens/Cheirimedeia zotea Euphilomedes carcharodonta Cirratulus spectabilis Amphiodia urtica/periercta complex	600 381 319 216
9A, 28, Bellingham Bay		none	2	Mercury, Phenol		none	117ns	0.63ns	19.09++	143	35	102	9	14	16	2	0.79	11	Nephtys cornuta Aphelochaeta monilaris Amphiuridae Glycinde polygnatha	40 14 13 8

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9B, 59, Bellingham Bay		none		none		none	103ns	4.13ns	3.08ns	1232	32	326	720	180	4	2	0.62	4	Euphilomedes carcharodonta Protomedeia prudens/Cheirimedeia zotea Owenia fusiformis Amphiodia urtica/periercta complex	321 264 189 170
9B, 60, Bellingham Bay		none	2	Mercury, 4-Methylphenol	1	4-Methylphenol	104ns	3.47ns	8.64ns	3444	39	2380	595	437	16	16	0.42	3	Owenia fusiformis Amphiodia urtica/periercta complex Protomedeia prudens/Cheirimedeia zotea Euphilomedes carcharodonta	2146 402 186 167
9B, 61, Bellingham Bay		none	1	4-Methylphenol	1	4-Methylphenol	98ns	2.73ns	2.41ns	2672	38	702	1294	650	15	11	0.57	4	Amphiodia urtica/periercta complex Owenia fusiformis Euphilomedes carcharodonta Protomedeia prudens/Cheirimedeia zotea	589 584 565 453
11, 32, Bellingham Bay		none		none		none	94ns	0.47^	3.31ns	403	33	287	5	13	96	2	0.61	5	Aphelochaeta monilaris Axinopsida serricata Heteromastus filobranchus Glycera nana	170 78 35 17
11, 33, Bellingham Bay		none		none		none	117ns	2.17ns	4.09ns	379	47	272	24	19	62	2	0.71	10	Aphelochaeta monilaris Axinopsida serricata Heteromastus filobranchus Lumbrineris cruzensis	119 51 42 15
11, 34, Bellingham Bay		none		none		none	103ns	0.51ns	2.76ns	1303	30	1139	11	10	141	2	0.28	1	Aphelochaeta monilaris Axinopsida serricata Heteromastus filiformis Lumbrineris cruzensis	1037 127 24 20

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12, 35, Bellingham Bay		none	1	4-Methylphenol	1	4-Methylphenol	117ns	2.9ns	3.12ns	520	41	261	34	163	58	4	0.68	7	Amphiodia urtica/periercta complex Levinsenia gracilis Cossura pygodactylata Ennucula tenuis	142 126 38 35
12, 36, Bellingham Bay		none	1	Phenol		none	109ns	20.97ns	3.01ns	409	34	129	26	191	62	1	0.68	5	Amphiodia urtica/periercta complex Amphiuridae Levinsenia gracilis Axinopsida serricata	128 62 60 43
12, 37, Bellingham Bay		none	2	Bis(2-ethylhexyl) phthalate, Phenol	1	Phenol	114ns	2.67ns	4.5ns	232	44	157	26	7	37	5	0.83	14	Aphelochaeta monilaris Heteromastus filiformis Axinopsida serricata Lumbrineris cruzensis	32 32 21 18
13, 38, Samish / Bellingham Bay		none	2	4-Methylphenol, Phenol	1	4-Methylphenol	116ns	21.03ns	9.23ns	1202	41	397	173	564	63	5	0.55	4	Amphiodia urtica/periercta complex Prionospio (Minuspio) lighti Eudorella (tridentata) pacifica Levinsenia gracilis	507 246 110 64
13, 39, Samish / Bellingham Bay		none	2	4-Methylphenol, Phenol	1	4-Methylphenol	117ns	5.17ns	3.8ns	509	49	121	65	24	240	59	0.75	12	Acila castrensis Pulsellum salishorum Eudorella (tridentata) pacifica Levinsenia gracilis	140 58 35 29
13, 40, Samish / Bellingham Bay		none		none		none	115ns	0.98ns	2.99ns	2529	83	511	928	347	722	21	0.58	5	Rochefortia tumida Ampelisca agassizi Amphiodia urtica/periercta complex Owenia fusiformis	598 597 334 334

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14, 41, Inner Padilla Bay		none		none		none	103ns	0.54ns	12.41++	2651	78	1989	185	124	349	4	0.56	7	Oligochaeta Exogone (E.) lourei Dorvillea (Schistomeringos) annulata Rochefortia tumida	1168 323 139 139
14, 42, Inner Padilla Bay		none	1	Phenol		none	112ns	2.8ns	7.64ns	1189	73	370	385	93	332	9	0.69	11	Rochefortia tumida Aoroides intermedius Owenia fusiformis Caprella laeviuscula	224 222 156 85
14, 43, Inner Padilla Bay		none	2	4-Methylphenol, Phenol	1	4-Methylphenol	51**	1.83ns	1.78ns	7671	110	5084	2016	66	430	75	0.48	4	Owenia fusiformis Leptochelia savignyi Exogone (E.) lourei Exogone dwisula	2996 1680 910 192
15, 44, Outer Padilla Bay		none	2	4-Methylphenol, Phenol	1	4-Methylphenol	116ns	6.47ns	6.32ns	498	52	121	176	63	136	2	0.80	12	Eudorella (tridentata) pacifica Acila castrensis Amphiodia urtica/periercta complex Levinsenia gracilis	68 57 56 35
15, 45, Outer Padilla Bay		none	1	4-Methylphenol	1	4-Methylphenol	120ns	2.67ns	1.5ns	634	49	85	143	11	389	6	0.74	10	Acila castrensis Psephidia lordi Eudorella (tridentata) pacifica Ennucula tenuis	148 81 79 39
15, 46, Outer Padilla Bay		none	3	Di-n-butyl phathalate, 4-Methylphenol, Phenol	2	Di-n-butyl phathalate, 4-Methylphenol, Phenol	118ns	4.73ns	2.68ns	398	54	61	88	23	222	4	0.80	14	Psephidia lordi Eudorella (tridentata) pacifica Protomedeia grandimana Amphiodia urtica/periercta complex	436 307 146 85

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16, 47, March Point		none	1	4-Methylphenol	1	4-Methylphenol	114ns	3.7ns	11.1ns	633	92	333	19	1	271	9	0.80	22	Psephidia lordi Axinopsida serricata Prionospio steenstrupi Maldane sarsi	88 71 41 32
16, 48, March Point		none		none		none	114ns	6.47ns	12.19++	582	88	349	47	14	151	21	0.80	19	Prionospio jubata Tharyx nr. parvus Axinopsida serricata Ampharete sp.	87 40 38 32
16, 49, March Point		none	3	Di-n-butyl phathalate, 4-Methylphenol, Phenol	2	4-Methylphenol, Phenol	112ns	1.23ns	9.79ns	1555	65	755	396	78	309	17	0.65	8	Owenia fusiformis Protomedeia grandimana Rochefortia tumida Oligochaeta	424 249 190 105
17, 50, Inner Fidalgo Bay		none	2	4-Methylphenol, Phenol	2	4-Methylphenol, Phenol	115ns	1.1ns	1.89ns	623	50	358	78	16	165	6	0.68	9	Oligochaeta Rochefortia tumida Euphilomedes carcharodonta Capitella capitata hyperspecies	220 59 51 35
17, 51, Inner Fidalgo Bay		none	1	4-Methylphenol	1	4-Methylphenol	51**	3.83ns	3.7ns	1358	74	613	43	15	675	12	0.51	5	Psephidia lordi Owenia fusiformis Aricidea (Acmira) lopezi Terebellides nr. kobei	569 386 26 24
17, 52, Inner Fidalgo Bay		none	1	Phenol		none	101ns	0.89ns	3.72ns	339	41	166	72	11	85	5	0.74	8	Euphilomedes carcharodonta Oligochaeta Psephidia lordi Glycinde polygnatha	67 48 37 33

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18, 53, Outer Fidalgo Bay		none	3	Di-n-butyl phathalate, 4-Methylphenol, Phenol	1	4-Methylphenol	113ns	2.8ns	10.79ns	748	63	308	181	72	167	20	0.78	14	Protomedeia grandimana	127
																			Amphiodia urtica/periercta complex	71
																			Aphelochaeta sp. N1	69
																			Rochefortia tumida	68
18, 54, Outer Fidalgo Bay		none	2	4-Methylphenol, Phenol	1	4-Methylphenol	111ns	3.27ns	12.11++	707	50	276	140	9	275	7	0.71	9	Rochefortia tumida	204
																			Protomedeia grandimana	90
																			Aphelochaeta monilaris	75
																			Owenia fusiformis	41
18, 55, Outer Fidalgo Bay		none		none		none	115ns	11.33ns	6.6ns	633	103	305	51	63	204	10	0.82	25	Psephidia lordi	75
																			Amphiodia urtica/periercta complex	59
																			Scoletoma luti	41
																			Nephtys cornuta	36
19, 56, March Point		none	2	Di-n-butyl phathalate, Phenol		none	119ns	15.73ns	4.88ns	495	71	85	35	8	365	2	0.67	17	Psephidia lordi	217
																			Alvania compacta	22
																			Axinopsida serricata	16
																			Protothaca staminea	16
19, 57, March Point		none	1	Phenol		none	121ns	19ns	8.91ns	203	45	45	18	11	128	1	0.85	14	Psephidia lordi	28
																			Leitoscoloplos pugettensis	19
																			Axinopsida serricata	16
																			Parvilucina tenuisculpta	15
19, 58, March Point		none	1	Phenol		none	120ns	9.8ns	5.12ns	646	96	319	21	10	290	6	0.82	24	Axinopsida serricata	76
																			Owenia fusiformis	65
																			Psephidia lordi	56
																			Magelona longicornis	32

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21, 62, Skagit Bay		none	2	Di-n-butyl phathalate, 4-Methylphenol	1	4-Methylphenol	102ns	6.3ns	0.62ns	900	51	206	85	1	588	20	0.49	4	Axinopsida serricata Sternaspis scutata Euphilomedes carcharodonta Scoletoma luti	536 90 37 26
21, 63, Skagit Bay		none		none		none	100ns	8.9ns	0.36ns	408	64	231	93	0	80	4	0.76	13	Scalibregma inflatum Scoletoma luti Astyris gausapata Rhepoxynius boreovariatus	93 46 36 27
21, 64, Skagit Bay		none	1	4-Methylphenol	1	4-Methylphenol	95ns	3.97ns	0.87ns	796	71	254	19	3	513	7	0.51	6	Axinopsida serricata Sternaspis scutata Prionospio jubata Heteromastus filobranchus	448 82 19 18
22, 65, North Saratoga Passage		none	1	4-Methylphenol	1	4-Methylphenol	90ns	1.5ns	1.1ns	603	61	373	39	1	177	13	0.64	7	Spiochaetopterus costarum Axinopsida serricata Heteromastus filobranchus Aoroides intermedius	184 106 68 32
22, 66, North Saratoga Passage		none	2	4-Methylphenol, Phenol	1	4-Methylphenol	88ns	2.13ns	2.43ns	600	36	404	13	0	177	6	0.59	3	Heteromastus filiformis Axinopsida serricata Scalibregma inflatum Sternaspis scutata	204 142 109 24
22, 67, North Saratoga Passage		none	2	4-Methylphenol, Phenol	1	4-Methylphenol	96ns	2.43ns	3.04ns	272	40	179	27	0	61	5	0.77	9	Axinopsida serricata Cossura pygodactylata Prionospio jubata Heteromastus filobranchus	54 42 29 20

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23, 68, Oak Harbor		none	2	Benzoic acid, 4-Methylphenol	2	Benzoic acid, 4-Methylphenol	103ns	1.16ns	4.72ns	1110	43	966	5	0	134	5	0.57	5	Aphelochaeta sp. N1 Oligochaeta Aphelochaeta monilaris Psephidia lordi	450 173 138 71
23, 69, Oak Harbor		none	3	Phenol, Benzoic acid, 4-Methylphenol	3	Phenol, Benzoic acid, 4-Methylphenol	103ns	1.11ns	4.54ns	194	33	95	6	0	90	3	0.81	10	Psephidia lordi Heteromastus filobranchus Macoma nasuta Rochefortia tumida	46 29 12 11
23, 70, Oak Harbor		none	1	4-Methylphenol	1	4-Methylphenol	103ns	0.61ns	3.5ns	1159	41	980	4	0	163	12	0.49	4	Aphelochaeta sp. N1 Aphelochaeta sp. Psephidia lordi Oligochaeta	623 119 112 81
24, 71, Penn Cove		none	3	Bis(2-ethylhexyl) phthalate, 4-Methylphenol, Benzoic acid	3	Bis(2-ethylhexyl) phthalate, 4-Methylphenol, Benzoic acid	104ns	2.13ns	2.28ns	650	23	577	3	1	65	4	0.55	3	Paraprionospio pinnata Scalibregma inflatum Heteromastus filiformis Axinopsida serricata	288 140 65 63
24, 72, Penn Cove		none	1	4-Methylphenol	1	4-Methylphenol	100ns	13.77ns	3.63ns	697	51	533	14	3	139	8	0.57	4	Heteromastus filobranchus Axinopsida serricata Scalibregma inflatum Sigambra tentaculata	309 95 64 57
24, 73, Penn Cove		none	2	4-Methylphenol, Benzoic acid	2	4-Methylphenol, Benzoic acid	102ns	0.94ns	2.74ns	318	36	215	2	1	90	10	0.71	6	Axinopsida serricata Paraprionospio pinnata Sigambra tentaculata Scalibregma inflatum	62 53 51 50

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25, 74, Mid-Saratoga Passage		none	1	4-Methylphenol	1	4-Methylphenol	97ns	4.2ns	2.61ns	223	32	141	15	0	64	3	0.81	10	Axinopsida serricata Cossura pygodactylata Heteromastus filobranchus Prionospio (Minuspio) lighti	59 21 18 15
25, 75, Mid-Saratoga Passage		none	1	4-Methylphenol	1	4-Methylphenol	92ns	4.1ns	2.83ns	254	32	81	38	1	128	6	0.63	6	Axinopsida serricata Cossura bansei Prionospio jubata Eudorella (tridentata) pacifica	125 21 15 13
25, 76, Mid-Saratoga Passage		none	1	Benzoic acid	1	Benzoic acid	94ns	3.8ns	4.66ns	225	36	81	25	1	117	1	0.60	5	Axinopsida serricata Levinsenia gracilis Cossuridae Eudorella (tridentata) pacifica	115 22 16 8
26, 77, South Saratoga Passage		none	2	Bis(2-ethylhexyl) phthalate, Phenol	2	Bis(2-ethylhexyl) phthalate, Phenol	101ns	45.5ns	1.06ns	429	71	203	37	1	179	9	0.73	15	Myriochele sp. Axinopsida serricata Adontorhina cyclia Leitoscoloplos pugettensis	93 84 42 14
26, 78, South Saratoga Passage		none	1	4-Methylphenol	1	4-Methylphenol	102ns	11.13ns	4.15ns	137	44	93	19	4	7	14	0.88	16	Heteromastus filobranchus Eudorella pacifica Chaetoderma sp. Euclymeninae	17 10 9 9
26, 79, South Saratoga Passage		none	2	4-Methylphenol, Benzoic acid	2	4-Methylphenol, Benzoic acid	101ns	9.67ns	3.78ns	203	44	153	24	3	11	12	0.76	10	Prionospio (Minuspio) lighti Heteromastus filobranchus Prionospio jubata Eudorella (tridentata) pacifica	51 24 19 14

Appendix G. Triad data - Results of selected toxicity, chemistry, and infaunal analysis for all northern Puget Sound

	Chemistry						Toxicity			Infauna											
Statum, Sample, Location	Number of ERMs exceeded	Compounds Exceeding ERM	Number of SQSs exceeded	Compounds Exceeding SQS	Number of CSLs exceeded	Compounds Exceeding CSL	Mean Urchin Fertilization in 100% pore water as % of Control (and statistical significance)	Microtox EC50 (mg/ml) (and statistical significance)	P-450 induction (ug/g) (and statistical significance)	Total Abundance	Species Richness	Annelid Abundance	Arthropod Abundance	Echinoderm Abundance	Mollusca Abundance	Misc. Abundance	Pielou's Evenness (J')	Swartz's Dominance Index (SDI)	Dominant Species	Count
27, 80, Port Susan		none	1	Phenol		none	98ns	77.73ns	3.72ns	312	44	238	30	0	42	2	0.70	10	Levinsenia gracilis Scoletoma luti Ennucula tenuis Trochochaeta multisetosa	111 41 20 14
27, 81, Port Susan		none		none		none	95ns	12.6ns	2.79ns	128	33	48	13	2	62	3	0.72	10	Axinopsida serricata Levinsenia gracilis Onuphis elegans Chaetozone spp.	54 9 7 6
27, 82, Port Susan		none		none		none	76**	6.7ns	5.76ns	148	18	39	57	3	45	4	0.72	4	Eudorella (tridentata) pacifica Axinopsida serricata Pista wui Bathymedon pumilus	44 37 23 9
28, 83, Possession Sound		none		none		none	121ns	7.07ns	7.05ns	269	70	147	43	2	59	18	0.87	25	Adontorhina cyclia Scoletoma luti Leitoscoloplos pugettensis Sternaspis scutata	36 24 14 14
28, 84, Possession Sound		none		none		none	120ns	8.13ns	4.83ns	332	44	158	26	4	131	13	0.73	10	Axinopsida serricata Heteromastus filobranchus Microclymene caudata Prionospio (Minuspio) lighti	102 40 22 20
28, 85, Possession Sound		none		none		none	119ns	9.67ns	5.46ns	322	31	98	43	1	174	6	0.62	5	Axinopsida serricata Eudorella (tridentata) pacifica Chaetozone commonalis Prionospio jubata	154 31 22 21

Appendix G. Triad data - Results of selected toxicity, chemistry, and infaunal analysis for all northern Puget Sound

	Chemistry						Toxicity			Infauna											
Statum, Sample, Location	Number of ERMs exceeded	Compounds Exceeding ERM	Number of SQSs exceeded	Compounds Exceeding SQS	Number of CSLs exceeded	Compounds Exceeding CSL	Mean Urchin Fertilization in 100% pore water as % of Control (and statistical significance)	Microtox EC50 (mg/ml) (and statistical significance)	P-450 induction (ug/g) (and statistical significance)	Total Abundance	Species Richness	Annelid Abundance	Arthropod Abundance	Echinoderm Abundance	Mollusca Abundance	Misc. Abundance	Pielou's Evenness (J')	Swartz's Dominance Index (SDI)	Dominant Species	Count
29, 86, Inner Everett Harbor	9	Acenaphthene, Anthracene, Fluorene, Phenanthrene, Total 7 LPAH, Fluroanthene, Pyrene, Total 6 HPAH, Total PCB	3	Total Arochlors, 4-Methylphenol, Benzoic acid	2	Benzoic acid, 4-Methylphenol	23**	0.51ns	202.2+++	54	7	12	42	0	0	0	0.73	3	Nebalia pugettensis Aoroides spinosus Capitella capitata hyperspecies Eteone sp.	22 18 7 4
29, 87, Inner Everett Harbor	1	Total 7 LPAH	2	Benzoic acid, 4-Methylphenol	2	Benzoic acid, 4-Methylphenol	12**	0.69ns	33.1++	109	9	57	52	0	0	0	0.57	2	Capitella capitata hyperspecies Aoroides spinosus Nebalia pugettensis Desdimelita desdichada	52 40 8 3
29, 88, Inner Everett Harbor	1	Total 7 LPAH	3	Benzoic acid, 4-Methylphenol	2	Benzoic acid, 4-Methylphenol	50**	0.94ns	115.8+++	40	4	19	21	0	0	0	0.64	2	Nebalia pugettensis Capitella capitata hyperspecies Aoroides sp. Eteone sp.	20 18 1 1
30, 89, Middle Everett Harbor	5	Phenanthrene, Acenaphthene, Fluorene, Total 7 LPAH, Pyrene	2	Benzoic acid, 4-Methylphenol	2	Benzoic acid, 4-Methylphenol	0**	0.2ns	25.8++	74	7	69	3	0	2	0	0.25	1	Capitella capitata hyperspecies Macoma carlottensis Aoroides sp. Eteone sp.	67 2 1 1
30, 90, Middle Everett Harbor	2	Total 7 LPAH, Pyrene	2	Benzoic acid, 4-Methylphenol	2	Benzoic acid, 4-Methylphenol	1**	0.71ns	129.2+++	663	46	354	290	0	18	1	0.67	6	Leptochelia savignyi Capitella capitata hyperspecies Prionospio (Minuspio) lighti Nebalia pugettensis	146 106 102 88
30, 91, Middle Everett Harbor		none	2	Benzoic acid, 4-Methylphenol	2	4-Methylphenol	0**	0.58ns	86.4+++	92	21	36	48	0	4	4	0.82	8	Euphilomedes carcharodonta Capitella capitata hyperspecies Americhelidium variabilum Nebalia pugettensis	28 9 8 7

Appendix G. Triad data - Results of selected toxicity, chemistry, and infaunal analysis for all northern Puget Sound

	Chemistry						Toxicity			Infauna											
Statum, Sample, Location	Number of ERMs exceeded	Compounds Exceeding ERM	Number of SQSs exceeded	Compounds Exceeding SQS	Number of CSLs exceeded	Compounds Exceeding CSL	Mean Urchin Fertilization in 100% pore water as % of Control (and statistical significance)	Microtox EC50 (mg/ml) (and statistical significance)	P-450 induction (ug/g) (and statistical significance)	Total Abundance	Species Richness	Annelid Abundance	Arthropod Abundance	Echinoderm Abundance	Mollusca Abundance	Misc. Abundance	Pielou's Evenness (J')	Swartz's Dominance Index (SDI)	Dominant Species	Count
31, 92, Outer Everett Harbor	5	Phenanthrene, Acenaphthene, Fluorene, Total 7 LPAH, Pyrene	3	Benzoic acid, 4-Methylphenol, Phenol	2	Benzoic acid, 4-Methylphenol	5**	0.4^	28.8++	226	34	111	73	0	42	0	0.75	9	Capitella capitata hyperspecies Euphilomedes carcharodonta Macoma carlottensis Pleusymtes coquilla	69 32 15 14
31, 93, Outer Everett Harbor	4	Acenaphthene, Phenanthrene, Fluorene, Total 7 LPAH	2	Benzoic acid, 4-Methylphenol	2	Benzoic acid, 4-Methylphenol	2**	0.42^	29.2++	574	50	280	70	1	217	6	0.74	10	Capitella capitata hyperspecies Rochefortia tumida Axinopsida serricata Euphilomedes carcharodonta	134 65 62 48
31, 94, Outer Everett Harbor	6	Lead, Copper, Arsenic, Zinc, Phenanthrene, Toal 7 LPAH	5	Arsenic, Copper, Zinc, Benzoic acid, 4-Methylphenol	3	Copper, Benzoic acid, 4-Methylphenol	68**	0.44^	28.7++	813	78	337	211	8	250	7	0.78	16	Euphilomedes carcharodonta Axinopsida serricata Rochefortia tumida Capitella capitata hyperspecies	136 67 63 59
32, 95, Port Gardner		none	1	Bis(2-ethylhexyl) phthalate	1	Bis(2-ethylhexyl) phthalate	120ns	145ns	3.2ns	583	63	169	37	0	364	13	0.66	10	Axinopsida serricata Macoma carlottensis Adontorhina cyclia Macoma sp.	224 45 41 41
32, 96, Port Gardner		none	2	Bis(2-ethylhexyl) phthalate, Phenol	2	Bis(2-ethylhexyl) phthalate, Phenol	119ns	4.63ns	7.7ns	259	51	111	36	5	96	11	0.80	14	Axinopsida serricata Heteromastus filobranchus Eudorella (tridentata) pacifica Macoma sp.	58 24 17 15
32, 97, Port Gardner		none	1	4-Methylphenol	1	4-Methylphenol	113ns	9.17ns	22.9++	855	60	273	40	1	539	2	0.53	6	Axinopsida serricata Prionospio (Minuspio) lighti Heteromastus filiformis Macoma carlottensis	462 64 39 33

Appendix G. Triad data - Results of selected toxicity, chemistry, and infaunal analysis for all northern Puget Sound

	Chemistry						Toxicity			Infauna											
Statum, Sample, Location	Number of ERMs exceeded	Compounds Exceeding ERM	Number of SQSs exceeded	Compounds Exceeding SQS	Number of CSLs exceeded	Compounds Exceeding CSL	Mean Urchin Fertilization in 100% pore water as % of Control (and statistical significance)	Microtox EC50 (mg/ml) (and statistical significance)	P-450 induction (ug/g) (and statistical significance)	Total Abundance	Species Richness	Annelid Abundance	Arthropod Abundance	Echinoderm Abundance	Mollusca Abundance	Misc. Abundance	Pielou's Evenness (J')	Swartz's Dominance Index (SDI)	Dominant Species	Count
33, 98, Snohomish River Delta		none	1	Phenol	1	Phenol	121ns	2.5ns	4.2ns	579	57	270	170	0	126	13	0.80	14	Euphilomedes carcharodonta Scoletoma luti Heteromastus filobranchus Euphilomedes producta	84 75 57 32
33, 99, Snohomish River Delta		none		none		none	119ns	57.57ns	0.3ns	537	23	29	44	1	463	0	0.51	2	Tellina nuculoides Psephidia lordi Rochefortia tumida Lamprops quadriplicata	231 174 52 18
33, 100, Snohomish River Delta		none	1	Phenol	1	Phenol	94ns	120.63ns	0.3ns	24	6	2	16	0	4	2	0.88	3	Eohaustorius washingtonianus Grandifoxus grandis Macoma balthica Lineidae sp. indet.	8 7 4 2

ns=not significant

**=p<0.01

^ = mean EC50<0.51 mg/ml determined as the 80% lower prediction limit (LPL) with the lowest (i.e., most toxic) samples removed, but ≥0.06 mg/ml determined as the 90% lower prediction limit (LPL) earlier in this report.

++ = value > 11.1 benzo[a]pyrene equivalents (ug/g sediment) determined as the 80% upper prediction limit (UPL), but ≤37.1 benzo[a]pyrene equivalents (ug/g sediment) determined as the 90% upper prediction limit (UPL) earlier in this report.

+++ = value > 37.1 benzo[a]pyrene equivalents (ug/g sediment) determined as the 90% upper prediction limit (UPL) earlier in this report.

Appendix H

Ranges in detected chemical concentrations and numbers of samples for national, SEDQUAL, and 1997 PSAMP/NOAA data

Appendix H. Ranges in detected chemical concentrations and numbers of samples for national, SEDQUAL and 97 PSAMP/NOAA data.

Chemical	Units	Range in National Data[1]				Range in SEDQUAL Data[2]				Range in PSAMP/NOAA Data[3]			
		No. of Samples	Min	Median	Max	No. of Samples	Min	Median	Max	No. of Samples	Min	Median	Max
Amines and Aromatic amines													
1,2-Diphenylhydrazine	ppb	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	5	59	88	93
Aniline	ppb	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	3	13	14	17
Benzidine	ppb	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0	0	0	0
N-nitrosodimethylamine	ppb	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	5	26	54	78
Pyridine	ppb	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0	0	0	0
Chlorinated Alkanes													
Hexachlorobutadiene	ppb	n/a	n/a	n/a	n/a	35	0.2	3.3	580	5	33	56	89
Hexachlorocyclopentadiene	ppb	n/a	n/a	n/a	n/a	3	40	220	230	0	0	0	0
Hexachloroethane	ppb	n/a	n/a	n/a	n/a	6	86	195	330	5	7	31	51
Chlorinated and Nitro-Substituted Phenols													
2,4,5-Trichlorophenol	ppb	n/a	n/a	n/a	n/a	2	1,100	1,100	1,100	5	87	96	106
2,4,6-Trichlorophenol	ppb	n/a	n/a	n/a	n/a	2	220	225	230	20	7.7	49	456
2,4-Dichlorophenol	ppb	n/a	n/a	n/a	n/a	2	220	225	230	13	13	54	292
2,4-Dinitrophenol	ppb	n/a	n/a	n/a	n/a	1	1,100	1,100	1,100	5	48	82	98
2-Chlorophenol	ppb	n/a	n/a	n/a	n/a	4	62	225	540	5	38	71	101
2-Nitrophenol	ppb	n/a	n/a	n/a	n/a	4	90.09	225	601	5	39	71	111
4,6-Dinitro-2-Methylphenol	ppb	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	5	58	77	99
4-Chloro-3-Methylphenol	ppb	n/a	n/a	n/a	n/a	4	68	225	820	5	71	85	107
4-Nitrophenol	ppb	n/a	n/a	n/a	n/a	3	16	90.09	1,100	5	44	94	100
Pentachlorophenol	ppb	n/a	n/a	n/a	n/a	30	4	52.5	1,400	12	58	103	331
Chlorinated Aromatic Compounds													
1,2,4-Trichlorobenzene	ppb	n/a	n/a	n/a	n/a	11	8	53	280	5	34	59	90

Appendix H. Continued

1,2-Dichlorobenzene	ppb	n/a	n/a	n/a	n/a	9	2.2	210	230	5	29	50	86
1,3-Dichlorobenzene	ppb	n/a	n/a	n/a	n/a	8	4	30.5	601	5	24	44	82
1,4-Dichlorobenzene	ppb	n/a	n/a	n/a	n/a	36	0.11	42.5	420	7	3.6	31	82
2-Chloronaphthalene	ppb	n/a	n/a	n/a	n/a	4	4	112.3	230	5	50	76	96
Hexachlorobenzene	ppb	n/a	n/a	n/a	n/a	43	0.01	4	1,900	5	84	91	117
Ethers													
4-Bromophenyl-Phenyl Ether	ppb	n/a	n/a	n/a	n/a	7	4	130	1,900	5	90	96	123
4-Chlorophenyl-Phenyl Ether	ppb	n/a	n/a	n/a	n/a	6	3	36	230	5	76	83	97
Bis(2-Chloroethyl)Ether	ppb	n/a	n/a	n/a	n/a	2	220	225	230	5	23	61	97
Bis(2-chloroisopropyl)-ether	ppb	n/a	n/a	n/a	n/a	2	220	225	230	5	30	57	92
Mixcellaneous Extractable Compounds													
Benzoic acid	ppb	n/a	n/a	n/a	n/a	187	0.064	47.94	3,500	51	63	535	4,300
Benzyl alcohol	ppb	n/a	n/a	n/a	n/a	27	1.3	130	1,000	20	13	28	103
Beta-coprostanol	ppb	n/a	n/a	n/a	n/a	161	15.76	120	4,700	47	54	257	1,520
Dibenzofuran	ppb	n/a	n/a	n/a	n/a	468	0.0014	60	34,000	105	0.61	9.3	1,350
Isophorone	ppb	n/a	n/a	n/a	n/a	23	7.3	77	230	13	4.4	13	100
Organonitrogen Compounds													
2,4-Dinitrotoluene	ppb	n/a	n/a	n/a	n/a	2	220	225	230	5	80	97	100
2,6-Dinitrotoluene	ppb	n/a	n/a	n/a	n/a	3	220	230	1,900	6	83	98	212
2-Nitroaniline	ppb	n/a	n/a	n/a	n/a	2	90.09	595.045	1,100	5	77	91	97
3,3'-Dichlorobenzidine	ppb	n/a	n/a	n/a	n/a	4	90.09	265.5	470	0	0	0	0
3-Nitroaniline	ppb	n/a	n/a	n/a	n/a	3	90.09	1,100	1,100	5	18	49	64
4-Chloroaniline	ppb	n/a	n/a	n/a	n/a	3	54	220	230	5	2	18	26
4-Nitroaniline	ppb	n/a	n/a	n/a	n/a	3	90.09	1,100	1,100	5	40	67	84
9(H)Carbazole	ppb	n/a	n/a	n/a	n/a	173	1.8	69	4,510	28	1.9	15	430
Caffeine	ppb	n/a	n/a	n/a	n/a	3	2.2	9.31	1,500	2	18	18.5	19
Nitrobenzene	ppb	n/a	n/a	n/a	n/a	2	220	225	230	5	37	81	99
N-Nitroso-Di-N-Propylamine	ppb	n/a	n/a	n/a	n/a	3	205	230	280	5	39	74	106
N-nitrosodiphenylamine	ppb	n/a	n/a	n/a	n/a	8	3	70	1,900	5	91	105	160

Appendix H. Continued

Phenols													
2,4-Dimethylphenol	ppb	n/a	n/a	n/a	n/a	8	4.4	31.5	230	5	59	84	106
2-Methylphenol	ppb	n/a	n/a	n/a	n/a	10	9	34.5	396	5	40	77	102
4-Methylphenol	ppb	n/a	n/a	n/a	n/a	200	0.0088	100	16,000	102	8.5	610	12,000
Bis(2-Chloroethoxy)Methane	ppb	n/a	n/a	n/a	n/a	2	220	225	230	5	36	69	98
Phenol	ppb	n/a	n/a	n/a	n/a	317	0.021	48	4,800	62	50	740	6,260
P-nonylphenol	ppb	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	6	9.6	91	104
Phthalate Esters													
Bis(2-Ethylhexyl) Phthalate	ppb	n/a	n/a	n/a	n/a	588	0.3	150	63,000	18	86	373	37,800
Butylbenzylphthalate	ppb	n/a	n/a	n/a	n/a	220	0.0049	61.25	11,000	8	16	95.5	134
Diethylphthalate	ppb	n/a	n/a	n/a	n/a	61	1	12.22	3,900	7	45	83	96
Dimethylphthalate	ppb	n/a	n/a	n/a	n/a	65	6	42	59,000	7	31	83	175
Di-N-Butylphthalate	ppb	n/a	n/a	n/a	n/a	142	2	27.97	250,000	29	83	394	5,630
Di-N-Octyl Phthalate	ppb	n/a	n/a	n/a	n/a	53	0.018	15	13,677	6	23	102.5	172
Organotin, Butyl tin													
Dibutyltin Chloride	ppb	n/a	n/a	n/a	n/a	27	2.6	163	1,380	53	1.1	9.4	135
Monobutyltin Chloride	ppb	n/a	n/a	n/a	n/a	26	9.5	76	1,535	29	3	19	64
Tributyltin Chloride	ppb	n/a	n/a	n/a	n/a	28	71	441	7,260	51	0.0033	8.5	417
Ancillary Metals (Partial Digestion Method)													
Aluminum	ppm	n/a	n/a	n/a	n/a	505	2,800	17,500	121,000	105	4,460	16,000	29,000
Barium	ppm	n/a	n/a	n/a	n/a	373	4.7	39.8	785	105	9.12	40.3	101
Calcium	ppm	n/a	n/a	n/a	n/a	401	1,500	6,550	139,000	105	1,940	5440	36,100
Cobalt	ppm	n/a	n/a	n/a	n/a	362	1	8.9	535	105	2	9.67	26.8
Iron	ppm	n/a	n/a	n/a	n/a	455	5,310	24,700	103,000	105	5,540	25,300	51,700
Magnesium	ppm	n/a	n/a	n/a	n/a	407	1,950	8,240	24,600	105	2,060	10,600	24,000
Manganese	ppm	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	105	56.3	268	930
Potassium	ppm	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	105	543	2250	3,810
Sodium	ppm	n/a	n/a	n/a	n/a	311	128	10,700	39,000	105	1,070	12,300	27,500
Vanadium	ppm	n/a	n/a	n/a	n/a	401	10.7	51.4	146	105	12.9	49.8	93.1

Appendix H. Continued

Ancillary Metals (Total Digestion Method)

Aluminum	ppm	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	105	32,800	69,300	88,900
Barium	ppm	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	105	233	408	518
Calcium	ppm	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	105	5,010	17,900	62,800
Cobalt	ppm	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	105	5.3	14	44.2
Iron	ppm	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	105	14,400	36,300	62,300
Magnesium	ppm	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	105	3,520	15,000	29,600
Manganese	ppm	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	105	268	507	1,060
Potassium	ppm	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	105	9,530	12,800	16,200
Sodium	ppm	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	105	17,600	29,400	38,500
Vanadium	ppm	n/a	n/a	n/a	n/a	1	91.2	91.2	91.2	105	57.8	110	176

Priority Pollutant Metals (Partial Digestion Method)

Antimony	ppm	n/a	n/a	n/a	n/a	346	0.09	3.5	1,540	8	0.21	17	67.9
Arsenic	ppm	n/a	n/a	n/a	n/a	1,069	0.3	10	1,200	105	2.91	7.56	205
Beryllium	ppm	n/a	n/a	n/a	n/a	204	0.079	0.32	2	105	0.1	0.36	93
Cadmium	ppm	n/a	n/a	n/a	n/a	932	0.03	0.73	11	24	0.54	1.05	94
Chromium	ppm	n/a	n/a	n/a	n/a	951	6.1	40.2	411	105	7.74	39.3	135
Copper	ppm	n/a	n/a	n/a	n/a	1,177	1	44.8	2,880	105	4.4	32.9	464
Lead	ppm	n/a	n/a	n/a	n/a	1,221	0.5	24.2	2,620	78	3	6.8	190
Mercury	ppm	n/a	n/a	n/a	n/a	1,057	0.003	0.15	7.3	105	0.012	0.084	0.81
Nickel	ppm	n/a	n/a	n/a	n/a	937	4	30	728	105	7.6	41.3	140
Selenium	ppm	n/a	n/a	n/a	n/a	77	0.1	0.74	4	84	0.3	0.475	81
Silver	ppm	n/a	n/a	n/a	n/a	662	0.014	0.33	7.7	75	0.31	0.66	90
Thallium	ppm	n/a	n/a	n/a	n/a	75	0.02	0.27	2.4	7	86	88	94
Titanium	ppm	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	105	343	792	1,250
Zinc	ppm	n/a	n/a	n/a	n/a	1,170	10.6	89.15	16,000	105	15.2	71.2	776

Priority Pollutant Metals (Total Digestion Method)

Antimony	ppm	n/a	n/a	n/a	n/a	65	0.5	1.8	30	15	0.87	1.3	365
Arsenic	ppm	913	0.1	7.1	41	98	3.3	12	36	105	5.3	9.6	537
Beryllium	ppm	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	105	0.77	1.2	1.8

Appendix H. Continued

Cadmium	ppm	987	0.03	0.3	19.8		51	0.3	1.4	5.1	14	1.5	3.45	118
Chromium	ppm	1045	1	57.8	1220		52	24	75.5	110	105	23.2	81.7	196
Copper	ppm	1031	0.7	20.7	1770		108	16	59	690	105	7.1	33.2	527
Lead	ppm	1038	1.4	26.3	510		106	8.2	39.5	220	105	6.8	13.3	313
Mercury	ppm	994	0.01	0.1	15		31	0.03	0.2	0.58	n/a	n/a	n/a	n/a
Nickel	ppm	1006	0.3	21	136		68	14	39	100	105	15	53	147
Selenium	ppm	n/a	n/a	n/a	n/a		n/a	n/a	n/a	n/a	38	0.5	0.75	108
Silver	ppm	866	0.01	0.2	10.1		101	0.06	0.8	2.2	11	1.5	2.1	117
Thallium	ppm	n/a	n/a	n/a	n/a		n/a	n/a	n/a	n/a	26	0.4	0.53	99
Titanium	ppm	n/a	n/a	n/a	n/a		1	3,680	3,680	3,680	105	2,220	3,950	5,210
Zinc	ppm	1060	1	93.3	1880		109	34	120	610	105	40	94	1,220
HPAH														
Benzo(a)anthracene	ppb	652	0.3	96.2	59,298	1	781	0.0024	240	350,000	105	0.85	29	1,250
Benzo(a)pyrene	ppb	631	0.2	147	54,862	2	853	0.0082	220	386,000	105	0.27	29	597
Benzo(b)fluoranthene	ppb	n/a	n/a	n/a	n/a	3	491	0.002	660	330,000	105	1.6	48	1,380
Benzo(e)pyrene	ppb	n/a	n/a	n/a	n/a	4	56	4	82.5	3,000	105	0.68	24	580
Benzo(g,h,i)perylene	ppb	n/a	n/a	n/a	n/a	5	612	0.0046	126	278,000	105	0.59	27	261
Benzo(k)fluoranthene	ppb	n/a	n/a	n/a	n/a	6	483	0.0022	540	116,000	105	0.39	18	408
Chrysene	ppb	688	0.2	118	60,331	7	896	0.0027	292.6	369,000	105	1.5	40	1,610
Dibenzo(a,h)anthracene	ppb	363	0.4	45.8	4,534	8	427	1.4	86	45,800	87	0.063	5.1	100
Fluoranthene	ppb	755	0.3	160	108,236	9	982	0.0016	278.5	1,220,000	105	3	78	4,550
Indeno(1,2,3-c,d)pyrene	ppb	n/a	n/a	n/a	n/a	10	692	0.0041	140	230,000	103	0.39	28	278
Perylene	ppb	n/a	n/a	n/a	n/a	11	163	2	19	510	105	7.9	70	350
Pyrene	ppb	819	0.4	136	143,132	12	974	0.0028	290	1,410,000	105	2.2	71	3,790
Total HPAH	ppb	925	2	405	461,675		576	5.07	452.6	868,000	87	36.703	514.7	15,133
Total Benzofluoranthenes	ppb	n/a	n/a	n/a	n/a		859	3.8	500	440,000	105	1.99	67	1,788
LPAH														
1,6,7-Trimethylnaphthalene	ppb	n/a	n/a	n/a	n/a		n/a	n/a	n/a	n/a	105	0.9	12	100
1-Methylnaphthalene	ppb	n/a	n/a	n/a	n/a		13	1	3	10	104	0.6	13	170
1-Methylphenanthrene	ppb	n/a	n/a	n/a	n/a		9	2	8	15	103	0.56	15	310
2,6-Dimethylnaphthalene	ppb	n/a	n/a	n/a	n/a		4	1	6.5	20	104	1.4	29.5	263
2-Methylnaphthalene	ppb	591	0.4	22.1	15557		510	0.0029	37	26,500	104	0.93	20	304
2-Methylphenanthrene	ppb	n/a	n/a	n/a	n/a		n/a	n/a	n/a	n/a	103	0.66	22	1,000

Appendix H. Continued

Acenaphthene	ppb	394	0.1	25.7	56338	492	0.001	92	228,000	91	0.15	3.9	672
Acenaphthylene	ppb	254	0.4	45.4	12915	428	0.0011	44.25	56,400	105	0.13	4.1	112
Anthracene	ppb	521	0.2	63.9	89366	751	0.0029	140	324,000	105	0.46	12	1,190
Biphenyl	ppb	n/a	n/a	n/a	n/a	12	2	8	25	102	0.68	7.65	270
Dibenzothiophene	ppb	n/a	n/a	n/a	n/a	6	2	5	10	105	0.26	3.9	258
Fluorene	ppb	530	0.1	28.7	54,209	602	0.0019	78.5	127,000	103	0.48	12	986
Naphthalene	ppb	456	0.7	39.5	17,414	611	0.97	60	57,200	103	1.1	15	1,360
Phenanthrene	ppb	779	0.4	75	194,343	897	0.0058	210	1,320,000	104	4.7	62.5	2,270
Retene	ppb	n/a	n/a	n/a	n/a	262	3.5	55.2	74,000	105	2.7	39	8,930
Total LPAH	ppb	956	0.2	118	552,124	571	1.47	151	180,000	91	39.59	310.3	15,632
Chlorinated Pesticides													
2,4'-DDD	ppb	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	8	0.25	62.5	80
2,4'-DDE	ppb	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	5	47	73	77
2,4'-DDT	ppb	n/a	n/a	n/a	n/a	1	6	6	6	4	20	30	38
4,4'-DDD	ppb	666	0.004	1.4	784	88	0.6	8.18	220	11	0.86	62	98
4,4'-DDE	ppb	741	0.004	2	2,900	56	0.15	6.25	120	17	1.1	1.5	89
4,4'-DDT	ppb	543	0.004	1	3,517	40	0.1	6.2	750	6	2.9	58	135
Total DDTs	ppb	813	0.01	4.3	4,631	119	0.15	69	870	0	0	0	0
Aldrin	ppb	n/a	n/a	n/a	n/a	14	0.98	2.05	26	6	35	68	79
Alpha-BHC	ppb	n/a	n/a	n/a	n/a	1	1.7	1.7	1.7	6	23	87.5	100
Alpha-chlordane	ppb	n/a	n/a	n/a	n/a	59	0.2	4.3	17	6	33	65	83
Beta-BHC	ppb	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	6	50	91.5	120
Chlorpyriphos	ppb	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	1	70	70	70
Cis-Nonachlor	ppb	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	6	25	51	94
Delta-BHC	ppb	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	6	55	95	120
Dieldrin	ppb	490	0.002	0.5	21.2	15	1.6	4.3	8.6	6	55	81	98
Endosulfan I	ppb	n/a	n/a	n/a	n/a	3	3.5	5.2	17	6	41	75	95
Endosulfan II	ppb	n/a	n/a	n/a	n/a	3	2.2	3.8	4.4	6	55	72	98
Endosulfan sulfate	ppb	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	6	50	88.5	140
Endrin	ppb	n/a	n/a	n/a	n/a	3	0.76	3.1	4.6	6	38	87.5	105
Endrin Aldehyde	ppb	n/a	n/a	n/a	n/a	3	3.3	4.15	5.9	4	7	15.5	58
Endrin Ketone	ppb	n/a	n/a	n/a	n/a	1	42	42	42	6	17	33.5	55
Gamma-BHC (Lindane)	ppb	306	0.01	0.2	157	51	0.68	4.2	24	6	48	86.5	110
Heptachlor	ppb	n/a	n/a	n/a	n/a	13	0.55	1.8	28	4	31	59	91

Appendix H. Continued

Heptachlor Epoxide	ppb	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	6	47	84	106
Methoxychlor	ppb	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	6	16	81	150
Mirex	ppb	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	5	63	80	84
Oxychlordane	ppb	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	6	50	70	83
Toxaphene	ppb	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0	0	0	0
Trans-Chlordane (Gamma)	ppb	n/a	n/a	n/a	n/a	51	0.68	4.2	24	6	45	74.5	90
Trans-Nonachlor	ppb	n/a	n/a	n/a	n/a	1	0.2	0.2	0.2	5	52	67	76
Polycyclic Chlorinated Biphenyls													
PCB Aroclor 1016	ppb	n/a	n/a	n/a	n/a	1	30	30	30	0	0	0	0
PCB Aroclor 1221	ppb	n/a	n/a	n/a	n/a	5	28	51	200	0	0	0	0
PCB Aroclor 1232	ppb	n/a	n/a	n/a	n/a	1	300	300	300	0	0	0	0
PCB Aroclor 1242	ppb	n/a	n/a	n/a	n/a	25	0.1	34	1,810	3	6.9	9.6	11
PCB Aroclor 1248	ppb	n/a	n/a	n/a	n/a	61	1.59	58	450	3	3.7	4.9	8.1
PCB Aroclor 1254	ppb	n/a	n/a	n/a	n/a	328	1.1	77	5,145	17	3.3	9.7	50
PCB Aroclor 1260	ppb	n/a	n/a	n/a	n/a	259	2.2	80	7,600	7	19	23	3,400
PCB Congener 101	ppb	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	23	0.25	2.8	120
PCB Congener 105	ppb	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	12	0.27	20.5	81
PCB Congener 118	ppb	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	19	0.37	3.3	240
PCB Congener 126	ppb	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	5	1.3	76	150
PCB Congener 128	ppb	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	12	0.089	39	84
PCB Congener 138	ppb	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	23	0.13	3.1	320
PCB Congener 153	ppb	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	24	0.063	2.5	370
PCB Congener 170	ppb	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	13	0.089	72	190
PCB Congener 18	ppb	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	10	0.19	59	84
PCB Congener 180	ppb	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	16	0.18	3.4	350
PCB Congener 187	ppb	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	14	0.18	36.35	170
PCB Congener 195	ppb	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	7	77	83	260
PCB Congener 206	ppb	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	7	75	83	94
PCB Congener 209	ppb	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	7	12	79	88
PCB Congener 28	ppb	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	18	0.089	1.9	88
PCB Congener 44	ppb	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	12	1.1	49	89
PCB Congener 52	ppb	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	16	0.76	2.75	120
PCB Congener 66	ppb	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	23	0.16	1.2	79

Appendix H. Continued

PCB Congener 77	ppb	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	13	0.21	0.65	90
PCB Congener 8	ppb	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	6	30	74	86
Total PCB's	ppb	830	0.1	26.5	16,675	201	0.285	49	2,800	0	0	0	0

[1]Studies performed by the National Oceanic and Atmospheric Administration (NOAA) and U.S Environmental Protection Agency (Long et. al., 1998).
[2]Studies performed in Washington State and stored by Washington State Dept. of Ecology in the SEDQUAL database.
[3]Data collected in Northern Puget Sound by the National Oceanic and Atmospheric Administration (NOAA) and the Washington State Dept. of Ecology.