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Temporal Monitoring of Puget Sound Sediments: Results of the Puget Sound Ambient Monitoring Program, 1989-2000

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Temporal Monitoring of Puget Sound Sediments: Results of the Puget Sound Ambient Monitoring Program, 1989-2000

by
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Abstract

As part of the Sediment Component of the Puget Sound Ambient Monitoring Program (PSAMP), samples from ten long-term monitoring stations collected from 1989 through 2000 were summarized to establish a record of sediment conditions for a variety of habitats and geographic locations throughout Puget Sound and to identify significant changes, if any, in physical, chemical, and biological sediment parameters that have occurred over time.

Less than one-third (32%) of almost 13,000 chemical measurements made were detected during testing. Those detected most often exceeded sediment quality guidelines in urban embayments: Sinclair Inlet (mercury), Thea Foss Waterway (polycyclic aromatic hydrocarbons, or PAHs).

In general, metals concentrations in 2000 were lower than in 1989-1996 far more often than they were higher, while the opposite was true of PAHs. At the Port Gardner and Inner Budd Inlet stations, concentrations of a number of priority pollutant and ancillary metals also decreased significantly. Individual PAH levels decreased at the Point Pully station, but increased significantly at the Bellingham Bay, Port Gardner, and East Anderson Island stations. Total HPAH levels increased significantly at the Bellingham Bay and East Anderson Island stations. Total LPAH and total PAH levels increased significantly at the Strait of Georgia, Bellingham Bay, East Anderson Island, and Budd Inlet stations. These changes may reflect changes in anthropogenic input of contaminants to the estuarine system over this 12-year study period.

Additionally, changes in grain size and benthic infaunal community composition seen at the Strait of Georgia station were probably linked to increased precipitation and subsequent increased flow and sediment loading from the Fraser River in 1996 and 1997.

This 12-year time series of Puget Sound sediment data provides a vital record of the past and existing condition of sediments, and a valuable long-term perspective against which we can measure the magnitude of future environmental changes.

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Executive Summary

Estuarine sediments accumulate potentially toxic chemicals and, therefore, can serve as a relatively stable record of toxicant inputs to the environment. They also serve as a matrix for an important component of estuarine ecosystems, namely the benthos, which includes a wide array of sediment-dwelling invertebrates that function as a critical part of the food chain. In 1989, the Sediment Component of the Puget Sound Ambient Monitoring Program (PSAMP) was established to monitor the condition of the sediments from 76 locations throughout Puget Sound. Ten of these original stations, located in/near the Strait of Georgia, Bellingham Bay, northern Hood Canal, Port Gardner, Shilshole, Sinclair Inlet, Point Pully, Thea Foss Waterway, east of Anderson Island, and Budd Inlet, continue to be monitored through this program by the Washington State Department of Ecology.

Sediments from the ten PSAMP long-term monitoring stations were collected in late March and early April of 1989 through 2000 to determine grain size, total organic carbon content, and the composition and structure of benthic infaunal invertebrate communities annually; and the levels of over 180 priority pollutant metal and organic contaminants (including polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), pesticides, and other compounds) from 1989 through 1996, and in 2000. These data were summarized and analyzed to establish a 12-year record of sediment conditions for the variety of habitats and geographic locations represented by these stations. Analyses were performed to identify significant changes in physical, chemical, and biological sediment parameters that have occurred over time; and to evaluate over time the condition of Puget Sound benthic infaunal invertebrate communities in relation to natural and anthropogenic changes in sediment quality. With the aid of summary statistics, a series of temporal trend analyses, and correlative analyses, the unique patterns in the suite of parameters at the ten long-term stations were characterized, documenting the heterogeneity of communities in a variety of habitat types throughout the estuary. While many of these parameters were stable over time, a number were identified to have changed significantly, potentially in relation to both anthropogenic and natural changes in environmental conditions.

The data from the ten stations indicated a wide variety of grain size characteristics, ranging from predominantly sand to predominantly silt-clay matrix. While the grain size composition of the majority of stations did not change over time, a notable change was seen at the Strait of Georgia station, where a significant increase in percent fines (specifically, the silt fraction) occurred during 1997. Lying within British Columbia's Fraser River discharge plume, change in grain size at this station appeared to be linked to increased precipitation and subsequent increased flow of the Fraser River in 1996 and 1997. Major changes in benthic infaunal community composition (*e.g.*, lowered taxa richness, dominance, evenness, diversity, and change in the dominant species) also occurred at this station during this period, appearing to be associated with this natural disturbance.

Reflecting the "ambient" nature of the majority of these stations, which are located at a distance from urban areas and point source discharges, only 32% of 12,909 chemical concentrations that were measured exceeded the laboratory reporting limits for the parameters tested. Of the detected pollutants, only a small percentage was detected at levels exceeding either state sediment quality criteria or national guidelines. The only persistent cases of contaminant concentrations exceeding sediment quality guidelines were mercury at the Sinclair Inlet station and a few PAH compounds at the Thea Foss Waterway station near Tacoma. The Sinclair Inlet station had the highest concentration of metals overall, and the PAH concentrations at the Thea Foss Waterway station were one to two orders of magnitude greater than at the other sediment monitoring locations.

Change and trend analysis of the chemical contaminant data set indicated that, in general, metals concentrations in 2000 were lower than in 1989-1996 far more often than they were higher, while the opposite was true of PAHs. At two of the ten stations, Port Gardner and Inner Budd Inlet, the concentrations of a number of priority pollutant metals and ancillary metals decreased significantly between 1989-1996 and 2000. Individual PAH levels decreased at the Point Pully station, but increased significantly at the Bellingham Bay, Port Gardner and East Anderson Island stations. Total HPAH levels increased significantly at the Bellingham Bay and East Anderson Island stations. Total LPAH and total PAH levels increased significantly at the Strait of Georgia, Bellingham Bay, East Anderson Island, and Budd Inlet stations. These changes in metals and PAH concentrations in the greater Puget Sound region appeared to correspond with results from other long-term contaminant monitoring programs conducted nationwide. They may reflect changes in the anthropogenic inputs of contaminants to the estuarine system (*e.g.*, decrease of metals from point source discharges, increase in PAH discharge from nonpoint sources such as urban and suburban runoff).

Among the other organic compounds detected, there generally were more increases in concentrations over time than decreases. In particular, the levels of benzoic acid and sterols were higher in 2000 than in 1989-1993. While some of the increase in those concentrations may reflect the increase in human population around Puget Sound, in the case of benzoic acid, the magnitude and extent of the increase more likely reflects increased sensitivity in laboratory analytical procedures.

Examination of the benthic infaunal community structure, in relation to the chemical and physical parameters measured at each station, helps characterize and elucidate possible relationships between the variables at each station, and provides a valuable baseline record of information regarding the structure of Puget Sound's benthic habitat. A number of observations and conclusions can be drawn from these data.

- Analyses of sediment parameters at the ten long-term stations elucidate the structural, chemical, and biological heterogeneity of benthic habitats throughout Puget Sound, and emphasize the differences between geographic locations. These stations appear to be reasonably representative of their local surrounding areas, and the differences in their sediment characteristics underscore the need for focused studies throughout Puget Sound to understand the local dynamics of the different geographic regions of the estuary.

- Changes and trends in benthic parameters at these long-term stations appear to have occurred in response to both natural environmental phenomena and anthropogenic disturbance. Many patterns are difficult to recognize, and many are recognizable only when they occur on a large scale or are observed after years of repeated sediment collection and testing. Among the more obvious patterns observed from 1989 through 2000 are the following:

- o Large-scale changes in regional climatic phenomena, *i.e.*, increase in rainfall and fluvial input of silt, clay and organic carbon to the estuarine system, appeared to influence sediment grain size and subsequent infaunal community composition at the Strait of Georgia station.

- o Changes and trends in chemical contaminant levels in the sediments were observed for specific compounds and suites of compounds both within and among stations. An overall decrease in metals contamination and an increase in PAH levels may reflect changes in anthropogenic activity that have occurred over the past decade.

- Some of the changes and trends in the structure of the biological communities at these stations as observed over time are extremely complex, subtle, and difficult to relate to changes in measured physical and chemical sediment parameters. In addition, after years of observation, some of the community structure changes appear to be related to naturally occurring population cycles and/or responding to environmental variables not measured by this program.

- Interpretation of changes in the infaunal communities in relation to other sediment variables measured would be greatly improved with the development and availability of well-tested and reliable indices of estuarine biotic condition that serve to relate and simplify the multitude of biotic parameters measured and calculated.

- Some of the observed changes and trends seen in sediment parameters at these stations may serve as indicators or "red flags", highlighting both general trends in the health of the Puget Sound ecosystem and emerging issues of concern. For example, there was a significant decrease in the overall contaminant levels at the Point Pully station, an increase in the PAH levels at the East Anderson Island station, and large changes in the dominant taxa at the Budd Inlet station. These changes raise interesting questions about the dynamics of anthropogenic activity in the Puget Sound watershed and potential impacts to the estuarine sediments, again highlighting the need for focused studies in these areas.

- It is recognized that a number of environmental variables, both natural and anthropogenic, that are not measured by this study, may influence the sediment-dwelling biota. These factors include, in part, the level of dissolved oxygen present in the sediments, concentrations of nutrients in the sediments and their flux between the sediment bed and water column, unregulated pollutants including the newly emerging pollutants of concern such as polybrominated diphenyl ethers (PBDEs) and endocrine disruptors, effects of reproduction and recruitment of infaunal species, effects of predation, oceanographic conditions, etc. The effects of these environmental variables certainly must play a large role in influencing the quality of sediments throughout Puget Sound and cannot be ignored. They should be factored into the long-term monitoring program, including further integration of the PSAMP monitoring components, as time and resources allow.

With the PSAMP Sediment Component 12-year time series of the benthic infauna community structure data (sampled annually) and sediment chemistry data (sampled annually for 7 years, then changed to every 5th year), we are beginning to discern both changes and temporal trends in these sediment parameters and some of the factors influencing them. To maintain this time series, benthic infaunal samples have been collected and processed from these 10 stations for 2001-2004, and both infauna and levels of chemical contamination were sampled in April 2005 and will be processed, extending the data record through 17 years. Comprehensive analysis of these new data will be conducted to determine recent changes and trends in Puget Sound sediments. The 2005 (and future) sediment chemistry monitoring includes collection and analysis of three replicate samples per station to allow better estimation of variability at each station.

Although sediment is collected and analyzed for many other programs and purposes in Puget Sound, no other survey exists for the simultaneous, standardized long-term monitoring of benthic conditions throughout Puget Sound's wide diversity of habitat types. The PSAMP Sediment Component data provide the only record and perspective on long-term status, changes and trends over time of the sediment biota and chemistry. These data are a vital record of past and existing conditions, and provide the only internally consistent, standardized record with which to assess the effects of catastrophic changes in the Puget Sound environment (*e.g.*, global warming, introduction of invasive species, major oil spill). When such events happen, it is impossible to measure the extent of their impact without knowledge of prior, existing conditions. For these reasons, the PSAMP Sediment Component will continue to collect and maintain a record of conditions at this small, but important, set of long-term sediment sampling stations.

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Introduction

Goals and Objectives

As part of the comprehensive Puget Sound Ambient Monitoring Program (PSAMP) Sediment Component, the Washington State Department of Ecology has sampled the sediment at ten long-term monitoring stations located throughout Puget Sound annually since 1989. The overall goals of the long-term marine sediment monitoring component of PSAMP are to

- develop a baseline of long-term data on physical and chemical sediment characteristics and benthic infaunal community structure at ten long-term monitoring stations chosen from a variety of habitats and geographic locations throughout Puget Sound;

- evaluate temporal trends in the condition of Puget Sound benthic infaunal communities and their potential relationship to natural and anthropogenic changes in sediment quality; and

- provide data for use by researchers concerned with sediment quality in Puget Sound.

Specific technical objectives for the analyses included in this report are to

- identify naturally occurring and anthropogenic changes in physical and chemical sediment characteristics over time;

- identify temporal patterns of change in benthic infaunal assemblages;

- identify potential combinations of chemical, physical, and benthic infaunal assemblage variables that are important across all stations (*i.e.*, Puget Sound-wide); and

- identify potential combinations of chemical, physical, and benthic infaunal assemblage variables that are important at each station.

Historical Background

As part of PSAMP, the Washington State Department of Ecology Marine Sediment Monitoring Team (MSMT) sampled the benthic infaunal community and measured the levels of over 180 potentially toxic contaminants (including metals, PAHs, PCBs, pesticides, and other organic contaminants) at 76 core and rotational monitoring stations located throughout Puget Sound from 1989 through 1995. The original stations were chosen according to criteria specified by the Puget Sound Water Quality Authority's Monitoring Management Committee, to represent a wide variety of physical environments and geographic locations (Puget Sound Water Quality Authority, 1988) and were located mainly in "ambient" locations, away from known point sources of contaminants.

A summary of the results indicated that contaminants were detected in only 30 percent of all analyses (primarily in urban or industrial areas), that concentrations of metals and organics were generally low (near detection limits for most stations), and that few changes in sediment quality were detected over the first seven years examined (Llansó *et al.*, 1998a; Puget Sound Water Quality Action Team, 1998). Based on those results, the MSMT reduced the scope of the original sampling design.

In 1996, the sampling effort was reduced; and in 1997, based on an external review of the 1989-1995 sampling effort, the current sampling plan was adopted (Dutch, 1998). Ten of the original stations were chosen for continued long-term monitoring of benthic communities annually and of chemical contaminants at five-year intervals. The ten long-term stations which were kept were chosen for their widespread geographic distribution throughout the Sound, their co-occurrence with other PSAMP component (*i.e.*, fish, water column) sampling locations, the pre-existence of long-term (30-year) data sets for some locations, and the variety of benthic community assemblages at the selected locations.

Since 1997, the MSMT has continued to sample these ten stations for benthic infauna and sediment composition (grain size) and, in 2000, for chemistry. In this report, results through 2000 are summarized and compared with the 1989-1995 data, and with data collected at a subset of the stations in 1996, to determine whether any significant changes occurred in the benthic communities and in the levels of chemical contaminants at these ten PSAMP sediment stations over time.

Methods

Sampling

Sample Locations and Station Positioning

The ten PSAMP sediment monitoring long-term stations are located in/near the Strait of Georgia (station 3, north of Patos Island), Bellingham Bay (station 4, near the mouth of Chuckanut Bay), northern Hood Canal (station 13R, immediately south of the bridge), Port Gardner (station 21, Everett), Shilshole (station 29), Sinclair Inlet (station 34), Point Pully (station 38, 3-Tree Point), Thea Foss Waterway (station 40, Commencement Bay), east of Anderson Island (station 44), and Budd Inlet (station 49) (Figure 1, Table 1). Hereafter in this report, stations will be designated by their name, with their number in parentheses. Following Puget Sound Estuary Program (PSEP) protocol (PSEP, 1998), the sampling vessel was positioned according to the latitude and longitude coordinates of each station (Table 1), by Loran C (until 1995) or Differential GPS (after 1995), variable radar ranging, water depth, and visual fixes (Llansó *et al.*, 1998a).

Sample Frequency and Timing

The stations were sampled once annually from 1989 to 2000. Samples for benthic infaunal and sediment grain size analyses were taken every year from 1989 to 2000; samples for sediment chemistry and total organic carbon (TOC) analysis were taken from 1989 to 1996 and in 2000. Sampling was done during the spring, in most years late March to early April, in order to assess the overwintering adult benthic infaunal populations.

Sample Collection Procedures

Sampling was conducted as specified in the PSEP protocols (PSEP, 1986, 1987, 1997a) and PSAMP Marine Sediment Quality Implementation Plan (Striplin, 1988). Five replicate sediment samples were collected at each station using a double 0.1-m^2 stainless steel van Veen grab sampler. The double van Veen consists of two separate compartments which allow simultaneous collection of chemistry and biological samples.

The sediment in the grabs was examined upon retrieval. Samples with obvious disturbance on the sediment surface or with shallow penetration were rejected and retaken. If the grab was acceptable, sediment in one compartment was collected for analyses of particle size distribution (grain size), TOC, total sulfide (discontinued after 1993), and target contaminants (1989-1996 and 2000). The sediment in the other compartment was collected for benthic infaunal analyses. Physical appearance, color, odor, and grab penetration depth were recorded. From 1994 on, Redox Potential Discontinuity (RPD) depth (*i.e.*, visual observation of sediment color and texture change), overlying water salinity (*i.e.*, refractometer measurement), and sediment surface temperature (*i.e.*, hand-held mercury or alcohol thermometer measurement) were also recorded (Field Notes, Appendix A).

For grain size, chemistry (except volatile organic compounds), and TOC analyses, the top two to three centimeters of sediment from one compartment were collected from several grabs and placed in a decontaminated stainless steel bowl, until there was sufficient surficial sediment for all of the analyses. (In 2000, a decontaminated high density polyethylene (HDPE) bucket was used instead of a stainless steel bowl.) Then the collected sediment was homogenized with a stainless steel spoon and placed in acid-cleaned sample containers. (Until 1997, Whirlpak bags were used as sample containers for grain-size samples. Acid-cleaning was not required for grain-size containers.) Samples for volatile organic compounds (discontinued after 1993) were not homogenized. Samples for total sulfide (also discontinued after 1993) were taken from single grabs, not homogenized, and placed in sample containers with zinc acetate added. Samples were stored on ice until off-loaded for transport to the laboratory, within three days. Maximum holding times specified in the PSEP protocols (PSEP, 1986, 1997a) were not exceeded.

Sampling equipment was decontaminated between stations. Except for equipment used to collect sediment for analysis of volatile organic compounds, decontamination included an Alconox wash in the laboratory, a hot water and methanol rinse in the field, and a final rinse with seawater *in situ*. In 1989 and 1990, acetone and methylene chloride were used as a rinse; in 2000, *in situ* seawater and acetone were used as a rinse. Utensils for volatile organic compound sampling (discontinued after 1993) were rinsed with organic-free water following the Alconox wash. All equipment was wrapped in aluminum foil and stored away from organic solvents and other sampling equipment.

For biological samples, the sediment from the other compartment of each replicate grab was washed through a 1.0-mm mesh screen using running ambient seawater. Benthic organisms retained on the screen were transferred to jars with 10% buffered formaldehyde in seawater.

Four replicate samples for chemical, TOC, and grain-size analysis were collected at Point Pully (38) and East Anderson Island (44) until 1995, and for metals and PAHs in 1995 at Thea Foss Waterway (40). Otherwise, one sample was taken per station. Five replicate samples for benthic infaunal analysis were taken every year at each station; however, due to financial and time constraints, only three replicates of the five were sorted and identified to species after 1993.

Laboratory Analyses

Chemical, TOC, and grain-size analyses were performed by contract laboratories (Table 2) according to U. S. EPA Contract Laboratory Program methods as modified by the PSEP protocols (PSEP, 1986, 1997a,b). The specific analyses and methods are listed by year in Table 3; a brief overview of the methods is given below.

Sediment Chemistry

Target contaminants were selected for screening purposes, including screening for chemical contaminants for which there are sediment quality guidelines, and for estimation of anthropogenic contaminant accumulation in selected areas of Puget Sound. Analyses for volatile organic compounds, resin acids, and guaiacols were discontinued after 1993 due to low and inconsistent detection in samples or due to consistent nondetection (Llansó *et al.*, 1998a). Only the priority pollutant metals, PAHs, PCBs, pesticides, and a few other organic compounds were included in the target contaminants in all years 1989-1996 and 2000 at most or all stations; ancillary metals and most of the remaining organic compounds were included in the target contaminants only during 1989-1993 and 2000 (Table 3).

- Total sulfide (discontinued after 1993) was determined by distillation of the acid-labile sulfide, followed by spectrophotometric analysis (methylene blue method). In 1990, a titrimetric analysis was used to determine sulfide content.

- Metals, except mercury, were analyzed by graphite furnace atomic absorption (GFAA), inductively coupled plasma (ICP) atomic emission spectroscopy, or inductively coupled plasma-mass spectrophotometry (ICP/MS). The analysis of some metals by GFAA was conducted to achieve lower detection limits. The choice of technique was also based on expected concentration of the metal in the samples. Method detection limits were lowered by strong acid digestion of large samples. Samples were digested in nitric acid and hydrogen peroxide, and the digestate was refluxed with either nitric acid or hydrochloric acid.

- Mercury was analyzed by cold vapor atomic absorption (CVAA) spectrophotometry. Mercury analysis was conducted using concentrated nitric and sulfuric acid digestions.

- Volatile and semi-volatile organic compounds were analyzed by gas chromatography followed by mass spectrometry (GCMS).

- Chlorinated pesticides and polychlorinated biphenyls (PCBs) were analyzed by alumina column chromatography followed by gas chromatography-electron capture detection (GC-ECD). Pesticide analysis was modified in 1994 to include an expanded target contaminant list and use of atomic emission detection (AED) with confirmation by ion-trap mass spectrometry.

Grain Size

Sediment particle-size (grain-size) analysis followed PSEP protocol (PSEP, 1986). Sand and gravel were separated from mud by wet-sieving, then dry-sieved to separate sand from gravel. The mud fraction was analyzed for percent silt and clay by pipette. In 1995, the ASTM D422 method for grain-size analysis (ASTM, 1972) was used, with the grain-size classes modified for consistency with PSEP protocol. ASTM D422 involves sieving for coarse grains (sand and gravel) and hydrometer analysis for fine grains (silt and clay).

Total Organic Carbon

TOC was measured by high-temperature combustion using a carbon analyzer (PSEP, 1986).

Benthic Infauna Analysis

In the laboratory, the samples were washed in fresh water and stored in 70% ethanol prior to sorting. Rose Bengal was added to stain the organisms when necessary. Organisms were sorted into five major taxonomic groups (Annelida, Arthropoda, Echinodermata, Mollusca, and Miscellaneous Taxa) and enumerated. Fauna were further identified to the lowest possible taxonomic level, usually to species, and enumerated by taxonomists at the Department of Ecology and by Marine Taxonomic Services (Corvallis, OR), EVS Environmental Consultants (Seattle, WA), MEC Analytical Systems (Carlsbad, CA), Ruff Systematics (Puyallup, WA), SGH Group (Seattle, WA), Oikos (Corvallis, OR), Pacific Taxonomic Consulting (Corvallis, OR), and RSEI (Wilsall, MT).

All identifications were made using binocular dissecting and compound microscopes at the appropriate magnification. For incomplete specimens, only the anterior ends, or the portions with the mouthparts (as for ophiuroids), were counted and identified, depending on the species; the exceptions were bivalves, counted by the hinge, and gastropods, counted by the operculum.

Quality Assurance/Quality Control (QA/QC)

Laboratory Analyses

Case narratives were provided by the laboratories for the grain size, TOC, and sediment chemistry analysis QA/QC, outlining laboratory methods, sample conditions, holding times, instrument calibration, procedural blanks, matrix spikes, surrogates, lab replicates, precision, quantification limits, and qualifiers. Case narratives for 1989-1992 laboratory analyses were published in earlier reports, as listed below; case narratives for 1993-2000 are contained in Appendix B of this report.

- 1989: Tetra Tech, Inc. (1990)
- 1990: Striplin *et al.* (1992)
- 1991: Washington State Department of Ecology (1994)
- 1992: EcoChem, Inc. (1993).

Sediment chemical concentration results were qualified by the laboratories. QA checks of the submitted lab data occasionally resulted in further qualification or in modifications to the qualifiers, as indicated in the case narratives. The meanings of qualifiers varied by laboratory, contaminant class, and year. In 1994, Llansó *et al.* (1998a) reduced and standardized the qualifier codes stored in the database for consistency and to limit storage space requirements.

Nondetects (cases in which a contaminant was not detected at all or in which the contaminant was determined to be present but the amount could not be quantified) were qualified as undetected or undetected estimates. The values reported for nondetects were the practical quantitation limits, or reporting limits, that the analytical laboratories were able to achieve for those particular contaminants in those particular samples.

Sediment Chemistry

General or recurring QC limit-violations are outlined below. Details may be found in the case narratives published in earlier reports (see above) and in Appendix B of this report.

- Results for antimony and silver were frequently qualified as estimates because spike recoveries were outside QC limits. Precision was frequently poor for silver.

- Zinc and copper results were occasionally qualified as estimates as a result of serial dilutions or presence in method blanks. Matrix spike recoveries were occasionally low for arsenic, cadmium, and lead.

- Among the volatile organic compounds, methylene chloride (dichloromethane) and acetone results were frequently qualified as estimates due to calibration difficulties and occasionally to contamination. A few aromatic compounds (benzene, toluene, and xylenes) were occasionally present in method and/or transport blanks for the analyses of volatile organic compounds. Samples were not analyzed for volatiles after 1993.

- Matrix spike recoveries and surrogate recoveries for high molecular weight polycyclic aromatic hydrocarbons (HPAHs) were frequently low, particularly prior to 1994, resulting in qualification of results for HPAH compounds as estimates.

- Calibration was a recurring problem for benzoic acid, cholesterol, beta-sitosterol, and beta-coprostanol. Matrix spike recoveries were often low for benzoic acid.

- A few organonitrogen compounds had low matrix spike recoveries.

- Low levels of semivolatile target compounds present in the method blanks resulted in qualification of the results as undetected when the level of the target compound was not at least five times the level in the method blank.

- All results for benzo(g,h,i)perylene in 1991 were qualified as rejected because matrix spike/matrix spike duplicate recoveries did not meet acceptance criteria.

- Surrogate recoveries tended to be low more often in 1992 than in other years.

- Calibration limits were frequently not met in 1993.

- The AED method was used instead of the GC-ECD method for pesticides and PCBs in 1994. AED is a less sensitive but more specific method than GC-ECD, therefore the quantitation limits for pesticides and PCBs were higher in 1994 than in other years (Huntamer, 1996, *personal correspondence with Llansó*).

- In 2000, a few compounds (beta-sitosterol, cholesterol, cymene) were inadvertently omitted from the target compounds for which the Base/Neutral/Acid (BNA) analysis procedures were calibrated. The 2000 samples were re-analyzed for BNA, and the results for the missing compounds were added to the data used for this report. As well, the re-extraction analysis results were used for n-nitrosodimethylamine, for which all of the original results were unusable (qualified "REJ"), and for dibenzo(a,h)anthracene at Port Gardner (21) and Shilshole (29), for which the original results were qualified as "NJ" (target substance detected, but result only an estimate). For the remainder of the contaminants from the 2000 samples, the data from the original analysis were used.

Grain Size

Grain-size data from 1995 had been excluded earlier (Llansó *et al.*, 1998a) because the PSEP protocol had not been followed. Since the ASTM D422 is an accepted method for grain-size analysis, and since sieve sizes consistent with PSEP protocol had been used, the 1995 grain-size data were reviewed for use in this report. However, errors were found in the original laboratory's method for estimating silt and clay fractions, and so the 1995 grain-size data were excluded.

The grain-size percentages in the 1997 data did not sum to 100%, and round-off error could not account for the magnitude of the difference (over 10%, in some cases). In that case, the grain-size percentages were scaled so that the total would equal 100%.

Total Organic Carbon

In 1991, the TOC results were qualified as estimates due to uncertainties in the amounts of inorganic carbon present in the samples.

Benthic Infauna Analysis

Twenty-percent aliquots of each sample were re-examined for sorting quality assurance/quality control (QA/QC) procedures. Sorting QC required recovery of at least 95% of the total number of organisms in the sample by the original sorter. Samples not meeting this criterion were completely resorted.

If available, three representative organisms of each species or taxon identified were removed from the samples and placed in a voucher collection housed at the Washington State Department of Ecology (Olympia, WA). Five percent of all samples were re-identified by senior taxonomists to identify organisms in each major taxonomic group.

Senior taxonomists also reviewed and verified all the voucher specimens generated by the primary taxonomists. Reference lists of all the taxonomic literature used to identify the species, including publications describing recent changes in species nomenclature, were prepared and kept in laboratory files at the Washington State Department of Ecology (Olympia, WA) to aid in the identification of organisms in subsequent years. Taxonomic identifications in the data were standardized and changed as necessary to reflect current nomenclature.

Data Preparation and Statistical Analyses

Data were stored in Microsoft Access and manipulated with Access and Microsoft Excel. Bioindices were calculated using Systat version 7. Statistical analyses were performed with Minitab version 13 and Systat version 10; graphs were produced with Minitab.

The data were examined for anomalies by numerical and graphical methods. Unusual values or patterns were investigated, and original lab sheets, if available, were consulted to determine whether there had been any errors in data entry. When original lab sheets were unavailable, published raw data in previous project reports and case narratives were used as the basis for comparison. Members of the Manchester Environmental Laboratory or the Laboratory Accreditation Unit of the Department of Ecology were consulted when questions on chemical analyses arose. For questions on particle-size analysis, members of the Manchester Environmental Laboratory (which performed the quality assurance checks) or the contracted geotechnical laboratory were consulted. Where anomalies were determined to be data errors, they were corrected in the database.

The raw data are available on the Marine Sediment Monitoring Program website (www.ecy.wa.gov/programs/eap/mar_sed/msm_intr.html). The data are also stored in the Washington State Department of Ecology Sediment Quality Information System version 4 (SEDQUAL).

Sediment Chemistry

Data Preparation

- The following corrections were made to the database:
    - Missing U (undetected) qualifiers for a number of BNA compounds from Station 34 in 1993 were entered (2-nitroaniline; 2-nitrophenol; 3,3'-dichlorobenzidine; 3-nitroaniline; 4-nitroaniline; 4-nitrophenol; benzyl alcohol; and cymene).
    - Typographical errors in qualifiers (*e.g.*, EE instead of E) were corrected.
- Where the concentration of a particular contaminant exceeded the calibration curve being used for that lab analysis, resulting in an estimated value, the results of only the subsequent analysis on the dilution for that particular contaminant were used.
- Results qualified by the laboratories as rejected were not used.
- Results for lab duplicates or triplicates were averaged, separately for detects and nondetects.
- When there were sample (field) replicates for chemical analysis, the median of the detected contaminant concentrations over the replicates was used in statistical analyses.
- Except as required in calculations of summed PAH concentrations for comparison to Washington State Sediment Management Standards (*cf.* following section on Comparison with Sediment Quality Values), only detected values were used in the analyses.

Comparison with Sediment Quality Values

To determine whether contaminant concentrations exceeded sediment quality values, detected results (only) for sediment contaminant levels were compared to Washington State Sediment Quality Standards and Clean-up Screening Levels (Washington State Department of Ecology, 1995) and to Effects Range-Median values (Long *et al.*, 1995). The Effects Range-Median (ERM) values are concentration levels above which adverse impacts on benthic infauna are expected frequently to occur (Long *et al.*, 1995). The Sediment Quality Standards (SQS) are sediment chemical concentration levels below which adverse biological effects are not expected to occur or above which at least minor adverse impacts on benthic infauna are expected always to occur, while the Clean-up Screening Levels (CSL) are sediment chemical concentration levels above which at least moderate adverse biological effects are expected to occur (Washington State Department of Ecology, 1995). The ERM for nickel was not employed due to the relative unreliability of this value in accurately predicting toxicity (Long *et al.*, 1995; Long and MacDonald, 1998). The SQS, CSL, and ERM values are listed in Appendix C of this report.

For polycyclic aromatic hydrocarbon (PAH) compounds and a number of other nonpolar organic contaminants, the SQS and CSL values are given in units of ppm organic carbon. For comparison to these sediment quality criteria, the measured concentrations were normalized by the measured TOC levels for each station for each year, according to procedures specified in the Washington State Sediment Management Standards rule (Washington State Department of Ecology, 1995).

Total LPAH and HPAH (low and high molecular weight polycyclic aromatic hydrocarbons) values for comparison with Washington State Sediment Quality Standards were calculated for each station and year by summing detected values of the TOC-normalized constituent compounds, according to the procedures specified in the Sediment Management Standards (Washington State Department of Ecology, 1995). If all results were qualified as undetected, the largest reporting limit was used as the total, and the total was qualified as undetected. For comparison to SQS and CSL values, the constituents of the Total LPAH and total HPAH are (Washington State Department of Ecology, 1995):

- Total LPAH: acenaphthene, acenaphthylene, anthracene, fluorene, naphthalene, and phenanthrene
- Total Benzofluoranthenes: benzo(b)fluoranthene, benzo(j)fluoranthene[1], and benzo(k)fluoranthene (HPAH compounds)
- Total HPAH: benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, chrysene, dibenzo(a,h)anthracene, fluoranthene, indeno(1,2,3-c,d)pyrene, pyrene, and total Benzofluoranthenes

Total LPAH and HPAH values for comparison with ERM values were calculated for each station and year by summing detected values of the constituent compounds, according to the procedures specified in Long *et al.* (1995). If all results were qualified as undetected, the total was not

[1] No results were available in this dataset for benzo(j)fluoranthene.

calculated. For comparison to ERM values, the constituents of the total LPAH, total HPAH, and total PAH are (Long *et al.*, 1995):

- Total LPAH: acenaphthene, acenaphthylene, anthracene, fluorene, 2-methylnaphthalene, naphthalene, and phenanthrene

- Total HPAH: benzo(a)anthracene, benzo(a)pyrene, chrysene, dibenzo(a,h)anthracene, fluoranthene, and pyrene

- Total PAH: total LPAH and total HPAH

Data Summary

For comparison of 1989-1996 and 2000 contaminant concentrations, summary statistics (mean, standard deviation, median, minimum, and maximum) were computed for detected results for each target contaminant for all stations combined for the two periods. The detection rate (percent detected) was calculated by contaminant class for all stations combined for each of the two periods.

Scatterplots of all results against year were generated for each parameter measured, with undetected results labeled (Appendix D). Where applicable, sediment quality values were indicated on the plots for comparison of raw data with these standards and guidelines.

Two summary measures were computed for each year for each station to provide overall indications of metals and of PAHs: The mean SQS quotient for metals was computed by dividing the concentration of a given metal by the Washington State Sediment Quality Standard (SQS) for that metal (Appendix C), then averaging the quotients for all metals. Total PAH was computed for comparison to the ERM sediment quality guideline (*cf.* Comparison with Sediment Quality Values, above).

Temporal Trend Analyses

For the purposes of this report, a distinction is drawn between interannual change and trend – the term change is used to indicate “jumps” in level (up or down) from the period 1989-1996 (assuming constancy) to 2000, whereas the term trend is used to indicate patterns of increase or decrease over the entire period 1989-2000 (assuming continuity of pattern during the missing years). At a given station, the concentration of a particular contaminant could display a change, a trend, both, or neither.

Change

To determine whether there had been any changes in the detected contaminant levels from the 1989-1996 period to the year 2000 at individual stations, boxplots of the 1989-1996 results and approximate 95% confidence intervals for the medians were generated for each station for each contaminant. The widths of the boxplots are proportional to the number of observations. Year 2000 results were superimposed on the graphs for visual comparison; a 2000 value outside the confidence interval for the 1989-1996 results indicated statistically significant change (α approximately = 0.05).

The equivalent comparison was conducted numerically by use of a two-tailed sign test, at an individual significance level of 5% (no Bonferroni correction for the number of simultaneous tests). Since the confidence interval for the boxplot is the same as the sign-test confidence interval (calculated by nonlinear interpolation; Minitab, 2000), the sign test results are consistent with the graphical depictions.

A weight-of-evidence approach was employed to gauge whether there were systemic changes in contaminant levels. The numbers of increases and decreases of a given contaminant (as indicated by the sign test or boxplot-comparison, described above) among all stations were tested for departure from randomness by a two-tailed sign test. If the number of increases was greater than expected by chance ($\alpha = 0.10$), that was considered to be indicative of an overall increase in the level of that contaminant. Likewise, decreases at sufficiently many stations were considered to be indicative of an overall decrease in the level of that contaminant.

Trend

The two-sided Mann-Kendall test of monotone trend (Gilbert, 1987; Hollander and Wolfe, 1973) was used to determine whether there were indications of increasing or decreasing trend over the period 1989-2000 at each station for each contaminant or summary measure. The Mann-Kendall test is a nonparametric procedure which tests for non-randomness in increases or decreases from earlier to subsequent years. The use of this test carries an implicit simplifying assumption that any pattern present was continued over the "missing" years (*i.e.*, years for which chemistry samples were not taken, usually 1997-1999, or years for which the contaminant concentrations were non-detected).

Time-series plots (*i.e.*, graphs of the contaminant concentrations against year) were examined for each station for each contaminant for which there are sediment quality criteria, for which the sign test indicated a change, or for which the Mann-Kendall test suggested a trend, as a check of whether numerically statistically significant changes or trends were practically meaningful.

Grain Size

Data Preparation

- The following corrections were made to the database:
    - The station identifier for grain-size data for Station 12 in 1989, 1991, and 1994, misidentified as Station 13R, was corrected.
    - Grain-size data for Station 29 for 1989, 1991, and 1994, missing in the database, were entered from the laboratory bench sheets.

- For some years, only the percentages of sand, silt, and clay were stored in the database; in such cases, the gravel percentage was calculated by subtraction from 100%.

- In the cases of field replicates (Stations 38 and 44 through 1995), the percentages for each grain size were averaged over the replicates.

- The 1997 grain-size percentages were scaled so that the sums would properly add to 100%.

Data Summary

Percentages of gravel, sand, silt, and clay (PSEP, 1986) were calculated and graphed for each station for each year and over all years. Summary statistics (mean, standard deviation, median, minimum, maximum, and coefficient of variation) were computed for % fines (defined as the sum of % silt and % clay) by station. Boxplots of % fines by station were generated to display a number of characteristics of the data: median and 95% confidence interval, extremes and range, quartiles and interquartile range, outliers, and distributional shape.

Temporal Trend Analyses

As for the sediment chemistry, the two-sided Mann-Kendall test of monotone trend, in conjunction with time-series plots, was used to determine whether there were any increasing or decreasing trends in percent fines (*i.e.*, silt + clay) at each station. Because grain size was measured every year, there was no gap between the period 1989-1996 and the year 2000, so the sign test for change (and equivalent graphical comparison using the boxplot) was not employed for % fines.

To determine whether any significant shifts occurred in grain-size distribution at a given station (*i.e.*, changes in the proportions of gravel, sand, silt, and clay), the chi-square test of homogeneity was employed. The chi-square test of homogeneity compares the measured proportions of gravel, sand, silt, and clay in each year to "average" proportions which would be expected if the grain-size distribution were constant over the years. One requirement of the chi-square test is that all of the expected proportions must be at least 5 percent; if any of the proportions are less than 5%, then two or more of the grain-size classes (*e.g.*, sand and gravel) must be combined so that all proportions are at least 5%. Stacked bar charts of the proportions of gravel, sand, silt, and clay are presented to display the grain-size distributions.

Total Organic Carbon

Data Summary

Summary statistics (mean, standard deviation, median, minimum, maximum, and coefficient of variation) were computed for the percent dry weight total organic carbon (% TOC), for all stations combined for the 1989-1996 and 2000 periods.

Temporal Trend Analyses

As for the sediment chemistry, boxplot and sign-test comparisons were used to determine whether there were any statistically significant changes in %TOC from 1989-1996 to 2000, and the Mann-Kendall test for trend and time-series plots were used to look for increasing or decreasing trends.

Salinity of Overlying Water

Data Summary and Temporal Trend Analyses

Boxplots were generated to display the median, confidence interval, 25^{th} and 75^{th} percentiles, and extreme values of the 1994-2000 salinity measurements for the water overlying the samples at each station. The Mann-Kendall test for trend and time-series plots were used to look for increasing or decreasing trends over this time period.

Benthic Infauna

Data Preparation

- The following changes/corrections were made to the database:
  - Misspellings in taxonomic names were corrected.
  - Taxonomic names were changed as necessary to reflect current nomenclature (*cf.* Taxonomic Standardization section, below).

Taxonomic Standardization

Data files were first standardized to ensure common species nomenclature. This was necessary because numerous taxonomists contributed to the database, many changes in nomenclature occurred since the inception of the program, and the taxonomy of many marine invertebrates in our region is poorly known. Uniform names and National Oceanographic Data Center (NODC) taxonomic codes were applied across datasets. Taxonomic differences were eliminated by cross-referencing species lists and by consulting with taxonomists to resolve discrepancies. Some of the discrepancies could be resolved only by re-examining archived specimens; however, since time limitations prevented re-examination of many specimens, some cases were treated by combining species at the genus or family levels. Also, some closely related species that are difficult to distinguish were combined in unresolved "species complexes."

Elimination of Incidental Species/Taxa

For diversity and classification analyses, organisms that represent incidental catches, which are not infauna, or which may not be fully exposed to chemical contaminants in sediments were eliminated from the data. These were:

- colonial organisms recorded as present/absent;
- organisms associated with hard substrate, such as rock or shell;
- organisms that have minimal contact with the sediment or are mostly pelagic;
- meiofauna (defined here as those species that are too small as adults to be consistently sampled with the 1 mm screen (i.e., most go through, some stay in the screen)); and
- organisms that are mostly epibionts, *i.e.*, associated with sponges, hydroids, bryozoans, algae, or vascular plants.

Organisms that are in full contact with the sediment, such as burrowers, and those that plow through or inhabit the sediment surface were kept in the analyses. Since they cannot be enumerated, colonial organisms were removed from all analyses. References used as guidance in the elimination of incidental species were Ricketts (1939), Bousfield (1973), Smith and Carlton (1975), Kozloff (1983, 1987), Behrens (1991), and Jensen (1995). Following these criteria, a total of 77 taxa were removed from the data files, 18 of which were species-level identifications (Appendix E).

Bioindices

Infaunal indices were calculated to summarize the raw data and to characterize the benthic invertebrate infaunal assemblages identified from each station. Indices were based upon all countable taxa, excluding colonial forms, for the pooled sample replicates for each year. The indices calculated were total abundance, major taxa abundance, taxa richness, Shannon-Wiener diversity, Pielou's evenness, and Swartz' dominance index, all defined in Table 4.

Data Summary

Summary statistics (mean, standard deviation, median, minimum, maximum, and coefficient of variation) were computed for each bioindex. Scatterplots and simultaneous boxplots were generated to display the bioindices and abundance of major taxa and approximate 95% confidence intervals for the medians by station and by year. The ten most abundant taxa at each station were identified for each year. The percentages of total abundance contributed by each of five major taxonomic groups (Annelida, Arthropoda, Echinodermata, Mollusca, and Miscellaneous Taxa) were calculated and graphed.

Temporal Trend Analyses

As for the grain-size distribution and percent fines, the Mann-Kendall test was used to determine whether there was evidence of increasing or decreasing trend for each bioindex, and the chi-square test for homogeneity was conducted for each station to determine whether there were any changes in the proportional representation of the major faunal groups over the years. Where necessary for test validity, when expected frequencies were below 5 percent, the echinoderm and miscellaneous taxa groups, or the arthropod, echinoderm, and miscellaneous taxa groups, were combined to achieve expected frequencies of at least 5 percent. In such cases, the test was still useful to determine whether the proportions of annelids, arthropods, and molluscs, or annelids and molluscs, respectively, had changed.

Similarity/Dissimilarity of Communities

In order to identify patterns in changing benthic infaunal assemblages, a nonmetric multidimensional scaling (MDS) analysis (Clarke and Warwick, 1994) was performed for all stations (replicates pooled as for bioindices) and years. MDS is an ordination technique which uses a matrix of Bray-Curtis dissimilarities (defined below) to produce a 2-dimensional map indicating the distance of the stations from each other and the distances between years within stations, based on abundance of individual taxa. The faunal abundances were 4th-root-transformed to mitigate against "arch effect" (Clarke and Warwick, 1994).

Bray-Curtis Dissimilarity

The Bray-Curtis coefficient of dissimilarity is a measure of the dissimilarity of infaunal assemblages between two samples and is defined as $\delta_{jk} = \frac{\sum_{i=1}^{p} | y_{ij} - y_{ik} |}{\sum_{i=1}^{p} (y_{ij} + y_{ik})}$, where p is the number of taxa and y_{ij} and y_{ik} are the counts (abundance) of taxon i in samples j and k, respectively. Bray-Curtis dissimilarity is minimized at 0 when the two samples being compared are identical and maximized at 1 when the two samples have no species in common (Clarke and Warwick, 1994). A matrix of Bray-Curtis dissimilarities calculated for all pairs of samples is the basis for ordination using MDS.

Relationships among Biological, Chemical, and Physical Parameters

To determine whether there were any relationships among the benthic infauna, bioindices, sediment chemistry, and physical parameters, at any individual station or among all stations and years, the following analyses were performed:

- Pearson correlation coefficients were computed on a set of chemical, physical, and biological parameters (listed below) for all stations combined in order to determine whether there were any general relationships among the parameters, and for individual stations to determine whether there were any relationships specific to certain areas and whether any relationships found at the global level also held at the local level. Each measure was first transformed for variance stabilization as necessary. Bonferroni-adjusted P-values were computed for each of the Pearson correlation coefficients.

Variables included in the correlation analysis for all stations combined were physical parameters (depth, salinity, and percent fines), chemical parameters (percent TOC, mean SQS quotient for metals, total PAH concentration, and cholesterol concentration), several bioindices (total abundance, taxa richness, Shannon-Wiener diversity, and Swartz' dominance standardized by taxa richness), and biological parameters (abundance of the major taxonomic groups and of several indicator species). As indicator species, the amphipods *Ampelisca* spp. and *Rhepoxinius* spp. and brittle stars of the Amphiuridae family were chosen as representatives of pollution-sensitive organisms; the bivalve *Axinopsida serricata* as slightly pollution-tolerant; and the polychaete *Aphelochaeta* spp. and the ostracod *Euphilomedes* spp. as pollution-tolerant (PTI, 1993). In addition, a common organism, the polychaete *Spiochaetopterus* spp., was included in the correlation analysis.

Variables included in the correlation analysis for individual stations were Julian day of sampling (because sampling dates varied from early March to early May), percent fines, percent TOC, mean SQS quotient for metals, total PAH concentration, and the same bioindices and biological parameters as for all stations combined.

- The trends in bioindices as determined by the Mann-Kendall tests were compared to the changes and trends in chemical and physical parameters as determined by the sign tests, Mann-Kendall tests, chi-square tests, and graphical methods.

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Results

Sediment Characteristics

With the exceptions of Point Pully (38) and East Anderson Island (44) from 1989 until 1995 and Thea Foss Waterway (40) in 1995 (metals and PAHs only), the chemistry, TOC, and grain-size results were based on a single sample for each station for each year. Therefore, the results must be interpreted with caution, although the weight-of-evidence approach used to detect systematic changes in contaminant levels lends strength to these interpretations.

Grain Size

On average, from 1989-2000, sediments in North Hood Canal (13R) and East Anderson Island (44) were composed of > 80% sand, while the sediment at Thea Foss Waterway (40) was approximately 70% sand (Tables 5, 6; Figure 2). Sediments at Strait of Georgia (3) and Port Gardner (21) were mixed, with about 60% fines (silt-clay). The stations in Bellingham Bay (4), Shilshole (29), Sinclair Inlet (34), Point Pully (38), and Budd Inlet (49) had sediments composed of ≥ 85% silt-clay with very little sand. Only Strait of Georgia (3) had a non-negligible amount of gravel, and only in the first few years of sampling.

Percent fines, the silt-clay fraction of the sediments, tended to be consistent among years at most stations, with the exception of Strait of Georgia (3), which varied from a low of 33% in 1989 to a high of 98% in 1997 (Figures 3, 4a-j). Most years, the percent fines varied within about 5% at Bellingham Bay (4), North Hood Canal (13R), Thea Foss Waterway (40), Sinclair Inlet (34), Point Pully (38), and East Anderson Island (44), and within about 10-15% at Port Gardner (21), Shilshole (29), and Inner Budd Inlet (49). The percent fines at Thea Foss Waterway (40) was unusually low in 1989 and high in 1997 (Figure 3).

Trends

The narratives below are accompanied by graphs depicting the grain-size proportions over time (Figures 4a-j).

- At Strait of Georgia (3), there was a decrease in the gravel fraction from 30% in 1989 to 2% in 1997; after 1997, no gravel was found in the sediment. In 1997, the silt proportion increased to 86%, and the sand proportion decreased. There was a significant increasing trend in percent fines from 30% in 1989 to over 70% in 1998-2000 (Mann-Kendall $K = 27$, $n = 10$ years, P-value = 0.008), with a peak of 98% in 1997.

- The only change at Bellingham Bay (4) was in the clay fraction, which was significantly smaller in 1989 and again in 1997-1998 than in other years. In 1993, the proportion of clay was somewhat larger than in other years. The percent fines was consistently 96-98% from 1990 to 1999, with "lows" of 93-94% in 1989 and 2000.

- There were no significant changes in grain-size distribution at North Hood Canal (13R). The percent fines ranged from 10% to 16%.

- At Port Gardner (21), there were proportionately less sand and more clay in 1991 than in other years. Although there was variability in the percent fines, there was no overall trend.

- The primary change at Shilshole (29) was an increase in coarse-grained sediment (sand + gravel) in 1999-2000. With the exception of 1993, when percent fines was < 80%, percent fines throughout the 1990s was approximately 87-93%. In 1999 and 2000, the percent fines dropped to about 75%.

- Sinclair Inlet (34) had an increased gravel fraction in 1993, the only significant change in the grain-size distribution. The percent fines was generally in the range 87-97% and dipped to 82% in 1993, but there was no overall trend.

- In 1997 at Point Pully (38), there were proportionately less clay and more silt than in other years. The sand fraction increased in 1999-2000. The percent fines varied between 93% and 98% from 1989 through 1998, then dropped to 85-88% in 1999-2000.

- In Thea Foss Waterway (40), the silt proportion and percent fines decreased somewhat in 1989 and increased somewhat in 1997, but overall there were no statistically significant changes.

- There were no significant changes in grain-size distribution for all four grain-size classes at East Anderson Island (44). There was a slight overall increase in percent fines, however, from around 15% in 1989-1990 to 20% in 1998-1999, but then percent fines dropped back to 15% in 2000.

- Inner Budd Inlet (49) had increased gravel in 1993. The proportion of coarse sediment (sand + gravel) was down in 1990, but up in 2000.

Total Organic Carbon

TOC levels were generally 2-3% at Bellingham Bay (4), Sinclair Inlet (34), Point Pully (38), and Inner Budd Inlet (49), 1-2% at Strait of Georgia (3), Port Gardner (21), Shilshole (29), and Thea Foss Waterway (40), and well under 1% at North Hood Canal (13R) and East Anderson Island (44) (Table 6, Figure 5a). Percent TOC decreased at Port Gardner (21) and East Anderson Island (44), but varied widely across the years at Sinclair Inlet (34), Thea Foss Waterway (40), and Inner Budd Inlet (49).

The TOC levels appear to have been higher than usual at several stations in 1992 and/or 1993; however, the TOC levels of the replicate samples were quite variable in 1993 at Point Pully (38) and in 1990 and 1992 at East Anderson Island (44). Overall, the amount of variability between field replicates (primarily at Stations 38 and 44 in 1989-1995), as measured by the relative standard deviation, or coefficient of variation, averaged 11%; median between-replicates coefficient of variation was 6%.

1989-1996 *vs.* 2000 Comparison

Based on comparisons of the 2000 TOC levels against 95% confidence limits for the median 1989-1996 levels, the percent TOC was higher in 2000 than previously at Strait of Georgia (3), Shilshole (29), and Sinclair Inlet (34), and lower than previously at Port Gardner (21) and Thea Foss Waterway (40) (Figure 5a, Table 7a). There was evidence of a strongly decreasing trend in % TOC at Port Gardner (21) (Mann-Kendall test P-value = 0.001), both supported by the sign test (P-value = 0.0156 for each) (Table 7b).

Salinity of Overlying Water

The salinity of the waters overlying the sediments collected from the VanVeen grab were similar in range for nine of the ten stations (median values ranging between 28 and 31 ppt), with Port Gardner (21), near the mouth of the Snohomish River) exhibiting the lowest range of values (median = 27 ppt) (Figure 5b). Salinity values were relatively constant between years (fluctuating ≤ 2 ppt) at two of the deep-water stations, Strait of Georgia (3) and Shilshole (29), and at No. Hood Canal (13R); and fluctuated to a greater extent at the other stations. Between 1994 and 1995, salinity at six of the ten stations (Port Gardner (21), Shilshole (29), Point Pully (38), Thea Foss (40), East Anderson Island (44), and Inner Budd Inlet (49)) dropped between 2 to 5 ppt, with increases in later years (Appendix F). No evidence of trends, however, was seen among years at any station with the Mann-Kendall test (Table 7b).

Sediment Chemistry

Sediments were analyzed for 178 contaminants during 1989-1996 and 122 contaminants in 2000. Overall, just under one-third of the analyses (32.4% in 1989-1996 and 32.5% in 2000) resulted in the detection of target contaminants (Table 8). The percent detection was about 81% for priority pollutant metals and 100% for ancillary metals during both 1989-1996 and 2000. Volatile organic compounds were not analyzed in 2000, nor were resin acids, guaiacols, or most of the ancillary metals. The detection rate for non-substituted phenols increased from 17.6% overall in 1989-1996 to 40% in 2000, though the rate of detection for chlorinated and nitro-substituted phenols remained at 0%. Detection of LPAHs and HPAHs increased to over 90% (92.2% and 93.0%, respectively) from about 59% and 85%, respectively. The rate of detection of phthalate esters dropped, however, from 19.5% overall in 1989-1996 to 8.3% in 2000. The detection rate for PCBs was quite low, but did increase from 6.8% in 1989-1996 to 14.3% in 2000. Pesticides were almost never detected: 0.4% detected in 1989-1996 and 2.1% detected in 2000.

For a number of the organic compounds, specifically most or all of the chlorinated and nitro-substituted phenols, and organonitrogens; some of the phenols, chlorinated alkanes and alkenes, phthalate esters, and a few of the PCBs and pesticides, the mean quantitation limits decreased over time. The quantitation limits for selenium were much higher in 1989 than in 1995 or 2000 (the only years samples were analyzed for that particular metal). Variance in the quantitation limits decreased dramatically over the years for several contaminants, such as the pesticide methoxychlor. The quantitation limits increased over time for the metal cadmium.

There was a pattern of quantitation limits being generally high in certain years. In particular, in 1991, quantitation limits for volatile organics, especially the halogenated alkanes and alkenes, were higher than in other years. In 1994, quantitation limits for PCBs and pesticides were relatively high; and in 1995, quantitation limits for antimony, pesticides, a few PAHs, and several other organic compounds, were higher than in other years.

The amount of variability between field replicates (primarily at Stations 38 and 44 in 1989-1995), as measured by the relative standard deviation, or coefficient of variation, averaged 11% for priority pollutant metals, 5% for ancillary metals (9% for all metals combined), though the median coefficients of variation were considerably lower: 7% for priority pollutant metals, 3% for ancillary metals, and 5% overall. The mean between-replicates coefficient of variation for PAHs was 20% (23% for LPAHs, 19% for HPAHs), with the medians generally 2% lower. Mean and median coefficient of variation were 24% for PCBs. For miscellaneous extractables (including benzoic acid and the sterols), mean and median coefficient of variation were 26% and 23%, respectively. For all other organic compounds combined, the coefficient of variation averaged 30%, with a median of 26%. The variability between field replicates was particularly high for volatile organics, up to 102% (coefficient of variation), depending on the compound.

Summary statistics for individual contaminants for 1989-1996 combined and for 2000 are given in Table 9, and for the two summary measures, mean metals SQS quotient (average of summed metals concentrations normalized by their respective SQS criteria values, a unitless number) and total PAH concentration (calculated as for comparison to the ERM value), for all years combined, in Table 6. For most contaminants, the concentration levels (detected) were similar in 2000 to the levels in 1989-1996; exceptions are discussed in the "1989-1996 *vs.* 2000 Comparison" section later in this report. The narratives below briefly describe some general observations about particular contaminants or classes of contaminants.

For only 49 of the 122 target contaminants analyzed in 2000 were there enough detected data to enable a comparison between the measured concentrations in 2000 *vs.* 1989-1996 or 1989-1993, as appropriate[2], for at least one station. For PAHs and other organic compounds for which there are SQS standards, analyses were performed on both the dry-weight concentrations and on the TOC-normalized concentrations.

Often a given station had similar patterns over time in levels of two or more metals (*e.g.*, aluminum, iron, and manganese at Port Gardner (21), Figure 6), and often two or more stations had similar patterns in levels of a given metal (*e.g.*, chromium at Shilshole (29), Sinclair Inlet (34), and Point Pully (38), Figure 7). For PAHs, however, there were sometimes similarities in patterns over time of multiple PAH compounds at a single station (*e.g.*, Sinclair Inlet (34), Figure 8), but not often similar patterns for a given PAH compound at two or more stations. The patterns in concentrations of TOC-normalized organic compounds were almost always the same as for the dry-weight concentrations. Patterns in PAHs tended to consist of single unusually large values in the midst of smaller values. Other organic compounds were too often undetected or not included in the target compounds for there to be many noticeable

[2] Target contaminants in 1989-1996 and 2000 included priority pollutant metals, PAHs, PCBs, pesticides, and a few other organic compounds; ancillary metals and most of the remaining organic compounds were targeted only in 1989-1993 and again in 2000 (Table 3).

patterns. Time-series graphs for the 49 compounds in this analysis, grouped by contaminant, are in Appendix F, and grouped by station, in Appendix G.

Metals

Overall, Sinclair Inlet (34) had higher, though more variable, levels of metals than the other stations, as measured by the mean metals SQS quotient (Figure 9). For all other stations, the mean metals SQS quotient was quite low, generally less than 0.2 (Figure 9), indicating that, overall, the concentrations of metals at those stations were far below the Washington State sediment quality standards. At Sinclair Inlet (34), the metals SQS quotient varied from 0.23 to 0.71, with a mean of 0.43. In 1991, the mean metals SQS quotient was unusually high (0.27), relative to other years, at Port Gardner (21), due to elevated concentrations of copper, chromium, nickel, zinc, and especially mercury, for which the SQS criterion was exceeded that year. The highest value of the mean metals SQS quotient was due to a spike in the concentration of arsenic at Sinclair Inlet (34) in 1995, when the measured concentration was ten times the usual level. At Point Pully (38), the mean metals SQS quotient was unusually low in 1996, compared to other years; in that year, levels of several metals, chromium, mercury, and zinc, and to a smaller extent, arsenic, copper, and nickel, were relatively low.

Although concentrations of many individual metals, particularly copper, lead, mercury, silver, and zinc, at Sinclair Inlet (34) were often considerably higher than at other stations, that was not true for all metals — some metals were found in higher concentrations at other stations. The primary metal of concern at Sinclair Inlet (34) was mercury, the concentrations of which frequently exceeded the mercury sediment quality criteria. Manganese concentrations were highest at Point Pully (38), while iron and nickel levels were highest at Bellingham Bay (4), and cadmium and aluminum concentrations were higher at Inner Budd Inlet (49) than at other stations. North Hood Canal (13R), Thea Foss Waterway (40), and East Anderson Island (44) had the lowest levels of aluminum, chromium, iron, nickel, and zinc.

A pattern which occurred for several metals consisted of relatively low concentrations in 1989, increasing to a peak concentration in 1991, then decreasing again, at about half of the stations. Those stations were usually the same group: Strait of Georgia (3), Bellingham Bay (4), Port Gardner (21), Point Pully (38), Thea Foss Waterway (40), and sometimes Shilshole (29).

The narratives below describe characteristics observed in the data for each metal. Interannual trends may be observed in the time-series plots in Appendix F.

- Antimony was not detected very often or at many stations (Figure 10). Where detected in 1993, antimony levels were high, relative to detected concentrations in other years, and where detected in 2000, they were low. Antimony levels varied considerably among years at Point Pully (38).

- Arsenic levels were similar at all of the stations, with the exception of an unusually high value at Sinclair Inlet (34) in 1995, which was ten times higher than usual at that station (Figure 11). Similar patterns in concentrations of arsenic over the years, with a large increase from 1989 to 1990, followed by a general decline back to the 1989 levels, were evident at Bellingham Bay (4), Port Gardner (21), Thea Foss Waterway (40), East Anderson Island (44), and, to a lesser extent, at Point Pully (38) (Appendix F). Another group of stations, Strait of Georgia (3), Shilshole (29), and Sinclair Inlet (34), exhibited similar patterns of arsenic concentration, with relatively consistent levels in most years and a spike in 1995. There were too few years of sampling at North Hood Canal (13R) to distinguish whether it had a pattern similar to the Stations 3-29-34 group or similar to Inner Budd Inlet (49).

- Cadmium concentrations were highest at Inner Budd Inlet (49), then higher at Sinclair Inlet (34) than at most of the remaining stations (Figure 12). Cadmium concentrations were fairly consistent except for a spike in 1994, then undetected thereafter, at five stations (Appendix F). The pattern was similar, though shifted by 2 years, at Thea Foss Waterway (40), where cadmium was not detected in 1994 or 1995. Port Gardner (21) and Inner Budd Inlet (49) had patterns of concentrations decreasing from 1989 to 1991 before increasing to 1994; the pattern at Sinclair Inlet (34) was intermediate. In 2000, cadmium was detected at only Sinclair Inlet (34) and Inner Budd Inlet (49).

- Chromium levels were generally highest at Bellingham Bay (4) and Sinclair Inlet (34) and consistently lowest at North Hood Canal (13R), Thea Foss Waterway (40), and East Anderson Island (44) (Figure 13). Strait of Georgia (3) tended to have low levels of chromium, but had a relatively unusually high level in 1995. Patterns in chromium levels were similar at Shilshole (29), Sinclair Inlet (34), and Point Pully (38), with a decline from 1989-1991 levels to a low in 1996 and a return to higher levels in 2000 (Appendix F). At Bellingham Bay (4) and Port Gardner (21), chromium concentrations increased from a low in 1989 to a high in 1991, decreased back to 1989 levels over the next 3 years, then leveled off at a slightly higher level. The pattern at Thea Foss Waterway (40) was vaguely similar to that of Stations 4 and 21. Chromium concentrations were highest in 2000 at North Hood Canal (13R) and East Anderson Island (44).

- Copper concentrations were considerably higher at Sinclair Inlet (34) and consistently lower at Strait of Georgia (3), North Hood Canal (13R), and East Anderson Island (44) than at other stations (Figure 14). Patterns in copper concentrations over the years were not as strikingly similar across stations as for other metals, but there were general similarities of concentrations increasing from 1989 to 1991, then declining to 2000, with 2000 levels often lower than 1989 levels, at several stations (Appendix F). Copper concentrations declined more than 30% from 1989-1991 to 1996-2000 at Sinclair Inlet (34).

- Lead levels were considerably higher and more variable at Sinclair Inlet (34) than at the other stations (Figure 15). Point Pully (38) tended to have higher concentrations of lead than the remaining eight stations. Similar patterns in lead levels seem to have occurred in pairs: Strait of Georgia (3) and Bellingham Bay (4); Port Gardner (21) and Inner Budd Inlet (49); Point Pully (38) and East Anderson Island (44) (Appendix F).

- Mercury levels varied considerably at Sinclair Inlet (34) and were higher than at the other stations, with the exception of an unusually high value at Port Gardner (21) in 1991 (Figure 16). Of the few years that North Hood Canal (13R) was sampled, mercury was not detected except in 2000. Mercury levels were highest in 1991 at six of the ten stations, and undetected in 1989 or both 1989 and 1990 at four of those six (Appendix F). Mercury levels were lowest in 1996 at six stations (not the same six). At Port Gardner (21), the mercury concentration measured in 1991 was more than five times as high as in subsequent years. No similarity in mercury concentration patterns across stations is evident.

- Nickel concentrations were highest at Bellingham Bay (4) and consistently lowest at Thea Foss Waterway (40) (Figure 17). At Bellingham Bay (4), nickel levels increased considerably from 1989 to 1990, then declined after 1991 (Appendix F).

- Silver concentrations were higher at Sinclair Inlet (34) than at the other stations (Figure 18), with the exception of unusually high values at Bellingham Bay (4) in 1995 and Inner Budd Inlet (49) in 1991 than in other years. Patterns in silver concentrations over time were more or less similar at Bellingham Bay (4), Port Gardner (21), Shilshole (29), Point Pully (38), Thea Foss Waterway (40), and East Anderson Island (44), with a small rise from 1989 to 1991, decline to 1992-1993, then a large increase to a maximum in 1996 (1995 for Station 4, which was not sampled in 1996), and dropping back down to 1992-1993 levels in 2000 (Appendix F).

- Zinc concentrations were higher and more variable at Sinclair Inlet (34) than at the other stations (Figure 19), with the exception of an unusually high value at Bellingham Bay (4) in 1995. North Hood Canal (13R), Thea Foss Waterway (40), and East Anderson Island (44) had lower levels of zinc than did the other stations. Patterns in zinc concentrations, decreasing gradually from 1989-1991 levels to a low in 1996, with the 2000 value being back up to an intermediate level, were similar at Shilshole (29) and Point Pully (38) (Appendix F).

- Aluminum levels were lower at North Hood Canal (13R), Thea Foss Waterway (40), and East Anderson Island (44) than at the other stations, and had a tendency to be higher at Inner Budd Inlet (49) than at the other stations (Figure 20). Aluminum levels were highest in 1991 at several stations (Appendix F).

- Iron levels were considerably lower at North Hood Canal (13R), Thea Foss Waterway (40), and East Anderson Island (44) than at the other stations, and tended to be higher at Bellingham Bay (4) than at all stations except Point Pully (38) (Figure 21). Iron concentrations peaked in 1991 at several stations (Appendix F). The level of iron at Inner Budd Inlet (49) in 2000 was considerably lower than in 1989-1993.

- Manganese was found in higher concentrations at Point Pully (38) than at the other stations (Figure 22). Manganese levels were high and consistent from 1990 through 1993 at Point Pully (38), and more than 25% lower there in 2000. The manganese levels in 1991 at Bellingham Bay (4) and at Inner Budd Inlet (49) were considerably lower than in other years (Appendix F).

PAHs

Mean total PAH concentrations (not normalized by sediment criteria values) ranged from a low of 46 ppb (range 17 to 76 ppb) at North Hood Canal (13R) to a high of 7727 ppb (range 4495 to 14,319 ppb) at Thea Foss Waterway (40) (Table 6). Generally, PAH concentrations at Thea Foss Waterway (40) were one to two orders of magnitude higher than at the other stations. PAH concentrations were unusually high at Sinclair Inlet (34) in 1995 and at Shilshole (29) in 1996, relative to the respective ranges at those two stations (Figure 23). Total PAH was relatively high in 1993 at Strait of Georgia (3) and Bellingham Bay (4) (Appendix F). In 1989-1990, total PAH levels at Thea Foss Waterway (40) were about twice the subsequent levels (Appendix F).

Of the HPAH compounds, dibenzo(a,h)anthracene was infrequently detected; of the LPAHs, acenaphthene and acenaphthylene were frequently not detected. In general, PAH compounds were often not detected at North Hood Canal (13R) and East Anderson Island (44). In contrast to the frequent situation in which levels of PAHs at Thea Foss Waterway (40) were an order of magnitude higher than at other stations, the levels of 2-methylnaphthalene, naphthalene, and perylene were only about 5 times as high as at other stations and were quite variable, while the levels of retene were generally the same as at other stations.

PCBs

Only PCB Aroclors 1248, 1254, and 1260, and total PCBs (lab measurement, not summed concentrations of individual PCBs) were detected at measurable concentrations (Table 9), and only at Port Gardner (21), Shilshole (29), Sinclair Inlet (34), Point Pully (38), Thea Foss Waterway (40), and Inner Budd Inlet (49) (Figure 24). Overall, PCBs were detected in only 11% of samples tested for PCBs. In 1994, testing for PCBs was conducted on samples from only Stations 21, 34, and 38; in 1995, only Stations 21, 34, 38, 40, and 49; and in 1996, no stations (Table 3). Only at Sinclair Inlet (34) were PCBs detected with any regularity.

The concentrations of PCB Aroclor 1260 and total PCBs (lab measurement, not summed concentrations of individual PCBs) at Sinclair Inlet (34) were an order of magnitude higher in 1995 than in other years (Figure 25, Appendix F). Total PCBs (lab measurement, not summed concentrations of individual PCBs) was not detected at any station in 2000.

Other organic compounds

Cholesterol concentrations tended to be higher at Sinclair Inlet (34) than at most of the other stations except Strait of Georgia (3) and Inner Budd Inlet (49) (Figure 26). Beta-coprostanol and beta-sitosterol levels were lower and less variable at North Hood Canal (13R) and East Anderson Island (44) than at the other stations (Figure 27). Benzoic acid levels were low and similar across stations when measurable in 1989-1993, but detected everywhere and in much higher concentrations in 2000 (Figure 28); benzoic acid is discussed in more detail in the following sections on comparison with sediment quality values and on comparison of 1989-1996 *vs.* 2000 results.

Phenol was detected in all years tested (1989-1993 and 2000) at Strait of Georgia (3) and all but one of those years at Port Gardner (21). The phenol concentrations at Strait of Georgia (3) ranged over an order of magnitude (Figure 29). The compound 4-methylphenol was frequently either not detected or at low concentrations. At Strait of Georgia (3), the concentration of 4-methylphenol in 2000 was about five times as high as in earlier years (Figure 29).

Of the phthalate esters, only butylbenzylphthalate and di-n-butylphthalate were detected measurably in both the 1989-1993 period and 2000, and at only one station, Sinclair Inlet (34) (Figures 30, 31). Cymene (p-isopropyltoluene) was largely not detected, except at Port Gardner (21) and Thea Foss Waterway (40), both in 1991-1993 and 2000 (Figure 32). 9(H)carbazole was detected infrequently or in very low concentrations except at Thea Foss Waterway (40) (Figure 33). Dibenzofuran was detected most frequently at Port Gardner (21) and Thea Foss Waterway (40), with the concentrations being higher at Thea Foss Waterway (40) than at most of the other stations (Figure 34). In 1994 and 1995, however, sediments were tested for dibenzofuran and 9(H)carbazole at only a subset of stations (Table 3). The only pesticides detected in 1989-1996 and 2000 were 4,4'-DDD at Thea Foss Waterway (40) and 4,4'-DDE at Inner Budd Inlet (49) (Figure 35).

Station Characterizations

The following narratives describe some general or recurring patterns for each station; the time-series plots on which the narratives are based are contained in Appendix G.

- **Strait of Georgia (3) -** Concentrations of several metals peaked in 1991 (mercury, zinc, aluminum, iron, manganese), while several other metals had a smaller peak in 1991 and a larger peak in 1995 (chromium, copper, nickel, silver) (Appendix G). The patterns of occurrence were quite similar for aluminum and iron, and fairly similar for copper and nickel. Concentrations of many individual PAH compounds and PAH totals peaked in 1993, though a couple of LPAH compounds increased in almost straight-line fashion throughout the years studied. Cholesterol and beta-sitosterol also increased linearly.

- **Bellingham Bay (4) -** Patterns of silver and zinc levels were similar, with fairly consistent levels 1989-1994, then a sudden, large increase in 1995, and the 2000 level being similar to the earlier levels. Aluminum and nickel patterns were somewhat similar, with large increases from 1989 to 1990, another small increase in 1991, followed by an overall decrease. PAHs tended to follow one of three general patterns: steady increase; or fluctuating up and down, with a peak in 1993; or lower levels during1989-1992 and higher plateau from 1993 on. Benzoic acid and cholesterol patterns were similar, with low, consistent levels during 1989-1993 and a much higher level in 2000.

- **North Hood Canal (13R) -** With only four observations at this station, no patterns are discernible. It is perhaps noteworthy, however, that the measured concentrations of many contaminants were higher in 2000 than in previous years.

- **Port Gardner (21) -** The patterns in concentrations of aluminum, iron, and manganese were almost identical. Nickel, zinc, and copper patterns were also similar to each other, with lead and chromium patterns slightly less similar. Concentrations of all eight of the aforementioned metals, plus mercury, peaked in 1991. Most PAHs peaked at maximum concentrations in 1994, often from minima in 1992; in many cases, the 1996 and 2000 values were similar to the 1989-1991 values. Phenol and 4-methylphenol levels rose over the time period examined.

- **Shilshole (29) -** The patterns in aluminum and iron concentrations were almost the same, while zinc and chromium concentrations were fairly similar in pattern. Other than those four chemicals, metals varied uniquely. The levels of most of the PAHs that were frequently detected peaked in 1996, with the 2000 concentrations being similar to the 1989-1993 concentrations. A few PAHs, detected infrequently, increased from minima in the early 1990s to maxima in 2000.

- **Sinclair Inlet (34) -** Aluminum and iron concentrations had similar patterns. Chromium, copper, nickel, and zinc had vaguely similar patterns, declining from maximum values in 1991 (1992 for zinc) to minimum values in 1996, in being slightly higher in 2000 than in 1996. The levels of almost all of the PAH compounds were essentially constant, except for a spike in 1995. The exception to the PAH patterns was that of acenaphthylene, which decreased from 1989 to 1992, was up in 1993, nondetected in 1994-1996, and reached a maximum in 2000. Dibenzofuran levels increased monotonically from 1991 to 2000 (undetected in 1989-1990).

- **Point Pully (38) -** Patterns in concentrations of aluminum and iron were similar, arsenic and nickel patterns were similar, and the patterns of mercury, zinc, and chromium concentrations were fairly similar. Many of the metals reached maxima in 1990 or 1991, decreasing to minima in 1995 or 1996, with 1989 and 2000 levels being intermediate. Silver concentrations, however, peaked in 1996. Cadmium concentrations almost quadrupled from the 1989-1993 levels to 1994, then was undetected. Manganese levels were consistent from 1990 through 1993, then down more than 25% in 2000 (not targeted in 1994-1996). Most of the PAHs fluctuated up and down throughout the study period.

- **Thea Foss Waterway (40) -** The levels of several metals increased from 1989 to a peak in 1991 (1990 for arsenic), then generally declined back to 1989 levels by 2000. Mercury levels generally increased until 1994-1995, then dropped to a low in 1996, while silver levels generally increased to a maximum in 1996 before declining in 2000. Concentrations of HPAH compounds tended to be highest in 1989-1990, before dropping to slightly more consistent levels 1991-2000, with minima in 1992 at about 5-40% of the 1990 maxima, depending on the particular compound, and small peaks in 1994. Many LPAH compounds, on the other hand, tended to be lower in 1989 than in 1990, then follow the same pattern as HPAHs. Other LPAHs, notably naphthalene and 2-methylnaphthalene, had completely different patterns of occurrence, rising from 1989-1993 levels to peaks in 1994 and 2000. Retene concentration increased in zigzag fashion more than threefold from 1989 to 2000.

- **East Anderson Island (44) -** Cadmium and silver levels were constant during 1989-1993, then jumped more than threefold, cadmium in 1994 (undetected thereafter) and silver in 1996 (undetected in 1994-1995 and 2000). The other metals varied uniquely. In contrast to fairly consistent levels in 1989-1993, chromium concentration was about 30% higher in 2000, while copper concentration was about 25% lower in 2000. Mercury levels decreased. After increasing considerably from 1989 to a peak in 1990, arsenic levels declined. Several LPAHs were frequently undetected. Among the HPAH compounds, however, several tended to zigzag to higher concentrations over the course of the study period, while others remained low from 1989-1996, then were statistically significantly higher in 2000.

- **Inner Budd Inlet (49) -** Cadmium, copper, and mercury concentrations peaked in 1994 and were minimum in 2000. Several other metals reached maxima in 1993 and minima in 2000. Manganese levels were low when silver levels were high, and *vice-versa*. Several LPAH compounds were frequently undetected, and in 1994 all LPAHs were undetected. HPAH compounds were more often detected and were often at considerably lower concentrations in 1990 than in other years.

Comparison with Sediment Quality Values

Because the purpose of the PSAMP program is ambient monitoring, not regulatory enforcement, and due to the uncertainty associated with nondetected results, instances of exceeded sediment quality values are reported here for detected results only (medians over field replicates where applicable). Table 10 summarizes the results described below.

- No sediment quality values were exceeded for samples taken from Strait of Georgia (3), Bellingham Bay (4), North Hood Canal (13R), Shilshole (29), or Point Pully (38).

- Three stations had a single isolated incident of a SQS being exceeded: mercury at Port Gardner (21) in 1991, hexachlorobenzene at East Anderson Island (44) in 1989, and benzoic acid at Inner Budd Inlet (49) in 2000. The level of benzoic acid at Inner Budd Inlet (49) in 2000 also exceeded the CSL.

- Sinclair Inlet (34) had three contaminants which exceeded sediment quality values, single instances for arsenic and total PCBs, both in 1995, and multiple instances for mercury. The level of arsenic in 1995 exceeded all three sediment quality values.

- Mercury contamination was a persistent problem at Sinclair Inlet (34), exceeding at least one sediment quality value every year of sampling except 1993 and 1996.

- At Thea Foss Waterway (40), a number of LPAHs and HPAHs, as well as two phthalate esters, exceeded the SQS, and in some cases exceeded the CSL and/or ERM guidelines, in 1989 and/or 1990. The concentrations of a few PAHs exceeded the SQS in one or two additional years, though only one compound in any given year except 2000, when several PAHs exceeded their respective SQS criteria.

- Neither in 1993 nor in 1996 did any of the contaminants exceed sediment quality values at any of the long-term PSAMP stations sampled those years.

Development of the Effects Range-Median (ERM) sediment quality guidelines for metals was based on use of hydrofluoric acid complete digestion of metals in the chemical laboratory analysis (Long, *pers. comm.*), whereas the strong acid incomplete digestion method was employed for the PSAMP long-term stations (PSEP, 1997b). Comparison of the mean arsenic sediment contaminant levels using partial *vs.* complete digestion in the 1997-1999 PSAMP-NOAA study (Long *et al.*, 1999; Long *et al.*, 2000; Long *et al.*, 2002) reveals that, on average, partial digestion resulted in 76% as much recovered arsenic as complete digestion. If the arsenic levels for all stations for all years of the PSAMP long-term sediment monitoring were increased by 1/.76, still only the 1995 arsenic level at Sinclair Inlet (34) would exceed the ERM.

Except for the instances at Port Gardner (21) and Sinclair Inlet (34) mentioned above, mercury levels were generally less than one-half the SQS. With the exception of the one instance at Sinclair Inlet (34) in 1995, arsenic levels were generally less than one-half the SQS.

The one instance in which the hexachlorobenzene SQS was exceeded, at East Anderson Island (44) in 1989, was the only detected result for that compound over all years sampled at all ten stations. Although the quantitation limits for hexachlorobenzene did decrease over the years, they were always higher than the SQS, and some were higher than the CSL.

Throughout 1989-1992, most of the benzoic acid analysis results were qualified as undetected. The quantitation limits and the detected values in 1989-1993 were considerably lower than the SQS. In 2000, however, all results were detected and spanned a higher and wider range than previously, with the value at Inner Budd Inlet (49) exceeding the SQS.

In 1995 and 1996, the quantitation limits for dibenzo(a,h)anthracene, acenaphthene, and fluorene were higher and more variable than in other years, occasionally higher than the sediment quality values. Although more individual PAHs exceeded sediment quality guidelines in 1989 than in 1990 at Thea Foss Waterway (40), total PAH concentration was greater in 1990 than in 1989.

The quantitation limits for bis(2-ethylhexyl)phthalate were higher and more variable in 1990 and 2000 than in other years; all of the results in 2000 and all but three results in 1990 were undetected. Most of the results for butylbenzylphthalate were undetected; in a couple of instances the quantitation limits were higher than the standards.

1989-1996 *vs.* 2000 Contaminant Comparison and Trends

As explained in the Methods section, comparisons of the year 2000 contaminant concentrations against approximate 95% confidence limits for the median 1989-1996 concentrations are equivalent to comparisons of the median 1989-1996 or 1989-1993 concentrations (*cf.* Table 3) to the 2000 concentrations using the sign test. Due to the large discrete steps of possible P-values for the sign test when sample sizes are small (as is the case in this study), there are slight differences in the achieved significance level (nominally $\alpha = 0.05$) between the use of the sign test and the use of 95% confidence intervals computed by nonlinear interpolation. Cases in which the 2000 value was outside the confidence interval for the 1989-1996 median but the sample size was too small (4 or fewer years' detected contaminant concentrations) to achieve a confidence level of at least 90%, or a significance level of 0.10, were not considered to be statistically significant unless the size of the change from median 1989-1996 to 2000 was about an order of magnitude (*e.g.*, benzoic acid).

Since the 2000 levels were represented by a single measurement for each station, caution is advised in interpreting the individual sign-test results (indications of change). With the exceptions of Point Pully (38) and East Anderson Island (44) from 1989 until 1995 and Thea Foss Waterway (40) in 1995, for which the medians over the field replicates were used, the 1989-1996 data were also single measurements at each station each year. There were too few observations from North Hood Canal (13R), sampled for chemistry and TOC in only four years (1989, 1991, 1994, and 2000), to characterize any patterns (changes or trends) in the results.

A weight-of-evidence approach can be used to examine general patterns. Table 11 also indicates such patterns as detected by use of the sign test on the indications of change over all stations for a single contaminant and over all contaminants at a single station.

Where there were sufficient years of detected measurements available, the Mann-Kendall test of monotone trend (meaning always increasing or always decreasing) can be used. The Mann-

Kendall test, however, can overstate trends; results must be tempered with close examination of the data (*e.g.*, with graphs of the results for an individual contaminant over the years at an individual station, a "time-series" plot). Table 12 for individual contaminants and 7b for mean metals SQS quotient and total PAH reflect those Mann-Kendall test results which were determined, upon examination of the time-series plots, to indicate trends.

In the narratives below, the terms "change", "increase", and "decrease" are employed to indicate comparisons of the 2000 results to the 1989-1996 results (*i.e.*, sign-test/confidence interval method); while the terms "trend", "increasing trend", and "decreasing trend" are used to indicate results of the Mann-Kendall test. Graphical summaries for each contaminant are given in Appendix F.

Of the 49 target contaminants for which at least one of the ten stations had enough detected data to enable a comparison between the measured concentrations in 2000 *vs.* 1989-1996, change was detected for at least one station for 40 of those contaminants. Of those 40, there were changes consistent in direction at five or more of the ten stations for three contaminants: benzoic acid, copper, and total benzofluoranthenes (Table 11). As well, two stations displayed consistent changes in metals concentrations, four stations displayed changes in dry-weight and/or TOC-normalized concentrations of 5 or more individual PAH compounds, and three stations displayed significant change over the set of 49 contaminants.

- Benzoic acid levels were measured to be an order of magnitude higher in samples collected in 2000 than previously at all nine stations for which there were measurable 1989-1993 concentrations (Figure 28). All 1989-1993 values at Shilshole (29) were qualified as undetected, but the 2000 value was detected. Since sediment samples were analyzed for benzoic acid only from 1989 to 1993 and again in 2000, and many of the earlier values were qualified as undetected, the time series were too small to demonstrate trends.

- Copper levels were significantly lower in samples collected in 2000 than they were in 1989-1996, at six of ten stations: Bellingham Bay (4), Port Gardner (21), Shilshole (29), Point Pully (38), East Anderson Island (44), and Inner Budd Inlet (49). No change in copper concentration was detected at the other four stations. Examination of time-series plots (Appendix F) revealed that after increasing from 1989 to 1991, copper levels decreased considerably at almost all of the stations. The Mann-Kendall test indicated a particularly strong decreasing trend at Sinclair Inlet (34) (P-value < 0.006), all the more noticeable because the copper concentrations were much higher at Sinclair Inlet (34) than at other stations. Point Pully (38) also had a statistically significant decreasing trend in copper levels (Mann-Kendall test P-value = 0.012).

- Total LPAH (calculated as for comparison to the ERM sediment quality guideline) increased from 1989-1996 to 2000 at four of the ten stations: Strait of Georgia (3), Bellingham Bay (4), East Anderson Island (44), and Inner Budd Inlet (49). No change was detected at the other six stations. The Mann-Kendall test detected an increasing trend at Strait of Georgia (3) (Table 12). What looks to the eye like an increasing trend at Bellingham Bay (4) was not found to be significant at $\alpha = 0.05$ by the Mann-Kendall test.

- Total benzofluoranthene concentrations, both dry-weight and TOC-normalized, increased at four stations (Bellingham Bay (4), Shilshole (29), East Anderson Island (44), and Inner Budd Inlet (49)); while only dry-weight concentrations increased at Strait of Georgia (3), and only TOC-normalized concentrations increased at Port Gardner (21). No change was detected at the other stations.

- At Port Gardner (21), the concentrations of six metals (copper, nickel, silver, zinc, aluminum, and iron), as well as the mean metals SQS quotient, decreased from 1989-1996 to 2000, based on comparisons of the 2000 levels against 95% confidence limits for the 1989-1996 levels. No metals concentrations were determined to have increased. The weight-of-evidence sign test indicated a significant change in metals concentrations at Port Gardner (21) (6 decreases in 11 metals, sign test P-value = 0.0313). With the exception of mercury, no significant trends (at $\alpha = 0.05$) were detected by the Mann-Kendall test (Table 12). The "trend" in mercury is strictly mathematical – following a single high value in 1991, the concentrations were nearly constant; mercury was not detected at Port Gardner (21) in 1989 or 1990 (Appendix F). After 1990 or 1991, there appear to have been downward trends in the time-series plots of several other metals (Appendix F).

- At Inner Budd Inlet (49), 9 of 12 metals were determined to have decreased from 1989-1996 levels to the 2000 levels, a highly significant overall change in metals concentrations (sign test P-value = 0.0039). The Mann-Kendall test indicates a downward trend in lead contamination (Table 12). The concentrations of several metals appear to have been higher in the 1989-1993 period than subsequently (Appendix F).

- At Point Pully (38), dry-weight concentrations of 5 of 17 individual PAH compounds and TOC-normalized concentrations of 6 of 15 individual PAHs decreased from 1989-1996 to 2000 (sign-test P-values = 0.0625 and 0.0313, respectively), though summed PAH totals did not decrease. Most of the change occurred in HPAH compounds. With the exceptions of fluorene (dry-weight), there were no indications of trends from the Mann-Kendall test (Table 12). The time-series plots do not support an interpretation of strong trends for fluorene and naphthalene (Appendix F).

- At Bellingham Bay (4), dry-weight concentrations of 6 of 14 individual PAH compounds, as well as total LPAH, total HPAH, and total PAH, increased from 1989-1996 to 2000. The weight-of-evidence sign test on the individual PAH compounds indicated a statistically significant overall increase in PAHs (P-value = 0.0313).

- At Port Gardner (21), 5 of 15 TOC-normalized PAH concentrations increased from 1989-1996 to 2000, a result significant at $\alpha = 0.10$ (sign test P-value = 0.0625). Dry-weight concentrations did not change. Although the Mann-Kendall test indicated increasing trends for naphthalene (dry weight) and several TOC-normalized LPAHs (Table 12), the time-series plots support only the trends for TOC-normalized fluorene (Appendix F).

- At East Anderson Island, 7 of 13 PAHs, total LPAH, and total HPAH, total PAH, 8 of 11 TOC-normalized PAHs, and both the TOC-normalized total LPAH and total HPAH increased from 1989-1996 to 2000. The weight-of-evidence sign test indicates the overall changes to be highly statistically significant (P-value = 0.016 for dry-weight concentrations and 0.0078 for TOC-normalized concentrations of individual PAH compounds).

- Of the 49 chemical contaminants included in the analysis, there were indications of overall increases in concentrations at Strait of Georgia (3) (6 increases and no decreases in 32 contaminants, sign test P-value = 0.0313) and East Anderson Island (44) (10 increases and 2 decreases in 28 contaminants, sign test P-value = 0.0386) and possibly an overall decrease in concentrations at Point Pully (38) (9 decreases and 2 increases in 35 contaminants, sign test P-value = 0.0654).

Overall, increases in one or more PAHs were detected at all stations except North Hood Canal (13R), for which there were insufficient data, and Point Pully (38), at which decreases in a number of PAHs were detected. The Mann-Kendall test detected evidence of trends (almost all increasing) for a few dry-weight PAH concentrations, particularly at Strait of Georgia (3), but very few among the TOC-normalized concentrations. With the exception of chromium increases at Shilshole (29), Thea Foss Waterway (40), and East Anderson Island (44), and an iron increase at East Anderson Island (44), metals concentrations either remained unchanged or decreased. However, the Mann-Kendall test indicated decreasing trends in several metals, mostly at Sinclair Inlet (34) and Point Pully (38). There were too few years sampled at North Hood Canal (13R) to make any general statements or detect any trends.

In general, metal concentrations in 2000 were lower than in 1989-1996 far more often than they were higher (35 decreases *vs.* 4 increases), based on comparisons of the 2000 levels against 95% confidence limits for the median 1989-1996 levels, while the opposite was true of PAHs (26 increases *vs.* 5 decreases in dry-weight concentrations, 23 increases *vs.* 6 decreases in TOC-normalized concentrations) (Table 11). There were many more increases than decreases among other organic compounds (17 increases *vs.* 1 decrease in dry-weight concentrations); but over all of the 49 contaminants included in the analysis, there were about as many increases as decreases (47 increases *vs.* 41 decreases).

Mean Metals SQS Quotient

The mean metals SQS quotients were higher in 1991 and/or 1995 than in other years at several stations (Appendix F). In particular, the 1991 mean metals SQS quotient at Port Gardner (21) was double the otherwise fairly consistent level all other years, due to elevated concentrations of copper, chromium, nickel, zinc, and mercury (Appendices E, F). The 2000 mean metals SQS quotient at Inner Budd Inlet (49) was significantly smaller than the 1989-1996 median (sign test, P-value = 0.0156).

Total PAH

According to the sign test, median total PAH concentrations increased significantly from 1989-1996 to 2000 at Bellingham Bay (4), East Anderson Island (44), and Inner Budd Inlet (49) (Table 7a). The time-series plots appear to demonstrate increasing trends in total PAH at Strait of Georgia (3) and Bellingham Bay (4) (Appendix F), with the Mann-Kendall test indicating an increasing trend in total PAH at Strait of Georgia (3) (Table 7b).

Other organic compounds

There were more increases than decreases among the other organic compounds (including benzoic acid and PCBs), though the concentrations of most of the compounds were either unchanged or too infrequently detected for a change to be discerned (17 increases *vs.* 1 decrease in 68 sign tests, dry-weight concentrations only). In addition to the changes in benzoic acid levels mentioned above, the following were noted:

- In 2000, the cholesterol level at Bellingham Bay (4) was measured to be an order of magnitude higher than in other years (Figure 26). Cholesterol levels were higher in 2000 than in 1989-1996 at four stations: Strait of Georgia (3), Bellingham Bay (4), Shilshole (29), and Point Pully (38) (Figure 26, Table 11).

- Although comparisons of the 2000 values to the confidence intervals for the 1989-1993 medians in the boxplots indicate lower values of beta-coprostanol and higher values of beta-sitosterol in 2000 at several stations (Figure 27), the sample sizes were too small ($n \leq 4$ years of detected concentrations) to achieve at least a 90% significance level; therefore, the changes were considered to be not statistically significant.

Benthic Infauna

Abundance

Abundance variables examined included total abundance (number of organisms per 0.1 m^2) by year for each station, total abundance for each station over all years, and total abundance and percent abundance of five major taxonomic groups of benthic infauna (Annelida, Arthropoda, Mollusca, Echinodermata, and Miscellaneous Taxa), for each station by year and for each station averaged over all years.

The total abundance of benthic infauna ranged from 57 individuals at Strait of Georgia (3) in 1990 and 1994 to 3,563 animals at North Hood Canal (13R) in 1998 (Table 13, Figure 36). Lowest total abundance (< 200 organisms per 0.1 m^2) over all years occurred at Strait of Georgia (3), Point Pully (38), and Inner Budd Inlet (49) (Table 14). Moderate total abundance (200-700 organisms per 0.1 m^2) occurred at Bellingham Bay (4), Shilshole (29), and East Anderson Island (44). Highest total abundance (>700 organisms per 0.1 m^2) occurred at North Hood Canal (13R), Port Gardner (21), Sinclair Inlet (34), and Thea Foss Waterway (40).

Abundance of annelids ranged from 18 animals at Point Pully (38) in 1990 to 1,671 annelids at Sinclair Inlet (34) in 1995 (Table 13, Figure 37). Percent abundance of annelids ranged from 6% at Shilshole (29) in 1993 to 93% at Sinclair Inlet (34) in 1995 (Table 13). North Hood Canal (13R) and Shilshole (29) had the lowest proportion of annelids over all years, while Sinclair Inlet (34), East Anderson Island (44), and Inner Budd Inlet (49) were dominated by annelids (> 50%) over the years of the study (Figure 38).

Arthropod abundance ranged from 3 organisms at Strait of Georgia (3) in 1999 to 360 animals at Port Gardner (21) in 1992 (Table 13, Figure 39). The lowest percent total abundance of arthropods (4%) occurred at Strait of Georgia (3) and Bellingham Bay (4) (Table 13). Point Pully (38) had the highest percent abundance (61%) in several years. Over all years, Strait of Georgia (3), North Hood Canal (13R), and Sinclair Inlet (34) had the lowest proportion of arthropods. Although none of the stations sampled were dominated by arthropods over all the years of the study, Point Pully (38) had highest proportion of arthropods of all the stations (Table 14, Figure 38).

Abundance of molluscs ranged from six individuals at Point Pully (38) in 1994 to 2,997 at North Hood Canal (13R) in 1998 (Table 13, Figure 40). The lowest percent of molluscs (2%) occurred at Sinclair Inlet (34) in 1995; the highest percent of molluscs (84%) occurred at North Hood Canal (13R) in 1998 (Table 13). Stations with a low proportion of molluscs over all years included Sinclair Inlet (34), East Anderson Island (44), and Inner Budd Inlet (49). North Hood Canal (13R) and Shilshole (29) were dominated by molluscs (> 50%); and Strait of Georgia (3), Port Gardner (21), and Point Pully (38) had high proportions of Mollusca over all years (Table 14, Figure 38).

No echinoderms were found at Strait of Georgia (3), Port Gardner (21), or Inner Budd Inlet (49) during several years of the study (Table 13, Figure 41). The highest echinoderm abundance (241) occurred at Thea Foss Waterway (40) in 1997. Although most stations had very low proportions of echinoderms throughout the years, almost one-third of the infauna community at Bellingham Bay (4) was made up of echinoderms in both 1991 and 1992 (Table 13). Over all years, the proportion of echinoderms at the majority of stations was 1% or less; Bellingham Bay (4) and Thea Foss Waterway (40) had the highest proportion of echinoderms (Table 14, Figure 38).

The miscellaneous taxa (*i.e.*, Cnidaria, Platyhelminthes, Nemertina, Sipuncula, Phoronida, Enteropneusta, and Ascidiacea) had relatively low abundance at most stations, ranging from no animals at Strait of Georgia (3) in several years to 90 animals at North Hood Canal (13R) in 1997 (Table 13, Figure 42). Over all the stations, the highest percent abundance of miscellaneous taxa was 6% at North Hood Canal (13R) in 2000 and Inner Budd Inlet (49) in 1989 (Table 13). The highest proportion of miscellaneous taxa averaged over all years was 4% at East Anderson Island (44) and Inner Budd Inlet (49) (Table 14, Figure 38).

Community Structure

Over the 12 years of the study, a total of 942 benthic invertebrate taxa were identified at the ten stations; those taxa are listed in Appendix E of this report. Of these, 578 (61%) were identified to the species level: 264 (46%) Polychaeta species; 97 (17%) Mollusca species; 152 (26%) Crustacea species; 13 (2%) Echinodermata species; and 52 (9%) miscellaneous taxa species. The ten most abundant taxa found each year at each station are listed in Table 15.

As discussed in the Methods section, measures of diversity, evenness, and dominance that were used to examine the community structure of the sampled stations included taxa richness, Shannon-Wiener diversity (H'), Pielou's evenness (J'), and Swartz' dominance index (SDI)

(Table 4). These bioindices were calculated for each station by year and for each station across all years.

Richness

Taxa richness ranged from 22 identified taxa at Inner Budd Inlet (49) in 1995 to 204 taxa at East Anderson Island (44) in 1992 (Table 16, Figure 43). Overall, stations with the lowest taxa richness (< 50 taxa) included Inner Budd Inlet (49) and Strait of Georgia (3). Stations with the most taxa (> 100) over the years were East Anderson Island (44), North Hood Canal (13R), and Thea Foss Waterway (40).

Diversity

Diversity as measured by the Shannon-Wiener index of diversity ranged from 0.57 at Inner Budd Inlet (49) in 1993 to 1.85 at East Anderson Island (44) in 1991 (Table 16, Figure 44). Over all the years, North Hood Canal (13R) and Shilshole (29) had the lowest Shannon-Wiener values, while Thea Foss Waterway (40) and East Anderson Island (44) had the highest.

Evenness

The lowest value of Pielou's evenness index (0.26) occurred at North Hood Canal (13R) in 1998; the highest value, 0.84, was found at Inner Budd Inlet (49) in 2000 (Table 16, Figure 45). All of the stations exhibited wide variation in evenness across the years of the study. Stations that generally exhibited the lowest evenness across the years included North Hood Canal (13R), Shilshole (29), and Sinclair Inlet (34); stations having the highest evenness overall were East Anderson Island (44), Bellingham Bay (4), and Point Pully (38).

Dominance

Swartz' dominance index (SDI) ranged from 1 taxon at North Hood Canal (13R) in 1998 to 37 taxa at East Anderson Island (44) in 1991 and 1992 (Table 16, Figure 46). The standardized SDI ranged from 1% at North Hood Canal (13R) in 1997 and 1998 to 34% at Inner Budd Inlet (49) in 2000 (Table 16, Figure 47). Across all the years of the study, North Hood Canal (13R) had the lowest SDI and East Anderson Island (44) had the highest SDI.

Station Characterization and Trends

Accompanying the narratives below are graphical depictions for each station of the abundance and proportional composition of major taxa (Figures 48a-j), several bioindices (Figures 49a-j), and dominant taxa (Figures 50a-j). Time-series plots are in Appendix F by parameter and in Appendix G by station.

Multidimensional scaling (MDS) is a dimension-reduction technique which reflects the distinctness of samples with respect to benthic infaunal assemblages. The MDS two-dimensional map (Figure 51) is based on the abundance of each taxon at each station for each year sampled. The more dissimilar the infaunal communities are, the farther apart the points on the map are.

Strait of Georgia (Station 3)

Strait of Georgia (3) was characterized by low total abundance and low taxa richness throughout most of the years of the study. Taxa richness and total abundance tended to increase and decrease in concert; however, in 1989, taxa richness was high, and in 2000, total abundance was high (Figure 49a). There were considerable changes in the relative proportions of major taxa from year to year (Figure 48a). In particular, the number of molluscs increased five-fold (from 31 to 169 individuals) from 1991 to 1992 and more than ten-fold (from 10 to 564 individuals) from 1999 to 2000, and the number of annelids decreased an order of magnitude (from 339 to 57 individuals) from 1989 to 1990.

Shannon-Wiener diversity decreased overall, and there was a decreasing trend in Swartz' dominance index (Tables 17a,b). Shannon-Wiener diversity, Pielou's evenness and Swartz' dominance index all dipped to low values in 1997, to a smaller extent in 1992, and again in 2000 (Appendix G). Taxa richness and annelid abundance were high in 1989, relative to all other years, whereas total abundance and mollusc abundance were considerably higher in 2000 than in the earlier years. Changes in annelid abundance were related to large numbers of *Prionospio* and *Pholoe* species in 1989; high Mollusca abundance was related to an increase in *Yoldia* and *Macoma* species in 2000 (Figure 50a).

The benthic infaunal community varied considerably over the years; in particular, species composition in 1989 was quite different from that in other years (Figure 51). This difference is reflected in the taxa richness, which was two to three times higher in 1989 than in other years.

Bellingham Bay (Station 4)

Bellingham Bay (4) exhibited moderate total abundance and taxa richness, and high evenness across the years, in comparison with other stations. It also had the highest proportion of echinoderms (up to 34%) of all the stations sampled.

The relative proportions of the major taxa varied considerably from 1989 to 1994, then remained relatively stable from 1995 through 2000 (Figure 48b). In 1989 and 1990, annelids made up about half of the total abundance, and then decreased by 80% (from 191 animals to 35 animals) in 1991. During the same time period, the number of echinoderms, primarily *Amphiodia* spp., almost doubled, from 46 individuals in 1990 to 75 in 1991 (Figure 50b). Annelid abundance was high in 1989-1990, 1994-1996, and again in 2000, suggesting a cyclical pattern. The pattern of mollusc abundance was somewhat similar, though not as pronounced. Arthropod abundance was highest in 1990, more than double than in other years. Following 1990, arthropod abundance decreased by two-thirds and remained relatively low until a marked increase from 10 animals in 1999 to 57 in 2000.

The primary long-term change at Bellingham Bay (4) was an increase in Swartz' dominance index standardized by taxa richness (SDISTD) (Table 17b). Shannon-Wiener diversity, Pielou's evenness, taxa richness, and Swartz' dominance index all dipped to low values in 1991 and again in 1997, but total abundance lagged by a year (Appendix G). Arthropod abundance was unusually high in 1990, while echinoderm abundance peaked in 1991 and again in 2000

(Figure 48b). Both annelid and mollusc abundance dropped in 1991 and increased in 1994 and again in 2000, suggesting a cyclical pattern.

The faunal composition exhibited some drift, with the early 1990s generally being slightly different from the late 1990s, and 1991 being somewhat different from the other years (Figure 51). The degree of similarity is reflected in taxa richness and other bioindices.

North Hood Canal (Station 13R)

North Hood Canal (13R) had high total abundance and taxa richness over all years; low evenness values across the years were primarily due to the numerical dominance of the bivalve *Nutricola lordi* (Figure 50c). The proportion of molluscs increased in 1997-1998, more than tripling previous counts, and subsequently decreased in 1999-2000 (Figure 48c). The number of annelids in 1991 was only about half that in most other years; in 1998 and again in 2000, the numbers of annelids were about 50% higher than in other years. Arthropod abundance was considerably higher from 1997 on, especially in 1998; however, overall, arthropod abundance was low compared to the other major taxonomic groups. North Hood Canal (13R) had high miscellaneous taxa abundance compared to other stations except for East Anderson Island (44), especially in 1997 and 2000.

North Hood Canal (13R) was sampled in too few years for any trends to be determined. There does appear to have been an increase in all of the bioindices at or toward the end of the study period, compared to the period prior to 1996.

The similarity of the infaunal assemblages across the years at North Hood Canal (13R) (Figure 51) is reflected in the taxa richness. In 1997, 1998, and 2000 the number of taxa was considerably higher than in other years, reflected in the clustering of those years in Figure 51 ("7", "8", "Z" in North Hood Canal ellipse).

Port Gardner (Station 21)

Port Gardner (21) had high total abundance and moderate taxa richness over the years of the study. The station was dominated by molluscs throughout the study, primarily the bivalves *Axinopsida serricata* and *Macoma carlottensis* (Figures 48d, 50d). The ostracod *Euphilomedes carcharodonta* also made up a significant proportion of the total abundance. Mollusc and arthropod abundance showed almost parallel patterns of increases and decreases every few years. Both arthropods and molluscs decreased in 1991, when % fines increased, then increased in 1992, when % fines decreased (Figure 48d).

Shannon-Wiener diversity, Pielou's evenness, Swartz' dominance index, and the abundance of miscellaneous taxa increased gradually over the years of the study (Tables 17a,b). Arthropod, mollusc, and total abundance peaked in 1992. Annelid abundance doubled from 1993 to 1994, then declined, but remained higher than pre-1992 levels.

The infaunal assemblages at Port Gardner (21) were quite similar from year to year, with some drift in the mid-1990s, particularly in 1994 (Figure 51). There is no apparently matching pattern in the bioindices.

Shilshole (Station 29)

Shilshole (29) showed moderate total abundance over the years, and a low proportion of annelids, diversity, and evenness. The Mollusca, specifically *Macoma carlottensis*, was the dominant taxonomic group, though the proportion and abundance varied considerably from year to year (Figures 48e, 50e). While the numbers in the other taxonomic groups remained fairly level, the molluscs varied by as much as factor 3 during the study, in a pattern suggestive of a cycle.

Taxa richness declined overall (Table 17b), though it appeared to increase somewhat from 1989 to 2000 (Figure 49e). Total abundance and annelid and arthropod abundance remained relatively stable from 1989-1999, then increased in 2000 (Figure 48e). Echinoderm abundance tended to decrease over the years (Table 17a). There were no trends in the other bioindices. Mollusc abundance was low in 1989 compared to other years. Total abundance peaked in 1992 and again in 2000.

Shilshole (29) and Point Pully (38) were similar in their benthic infaunal communities (Figure 51). At Shilshole (29), the year 2000 stood somewhat apart from the rest ("Z" in lower left of Shilshole/Point Pully ellipse in Figure 51).

Sinclair Inlet (Station 34)

Sinclair Inlet (34) had high total abundance over all years and was dominated by annelids, primarily the colonial tube-dwelling *Phyllochaetopterus prolifica* and the cirratulid *Aphelochaeta* sp. N1 (Figures 48f, 50f). Variability in other taxonomic groups was dwarfed by the five-fold swings in annelid abundance, which was driven by fluctuations in *Phyllochaetopterus* abundance.

Taxa richness was moderate at Sinclair Inlet (34) but declined across the years (Table 17b, Figure 49f). Echinoderm abundance tended to increase (Table 17a). There were no trends in the other bioindices. Annelid and total abundance peaked in 1995. Sinclair Inlet (34) exhibited some drift in faunal composition over the years (Figure 51), with generally decreasing taxa richness.

Point Pully (Station 38)

Point Pully (38) tended to have low total abundance and taxa richness, but high evenness over the years of the study. The station had low annelid abundance and relatively high abundance of arthropods and molluscs. There was a fair amount of variability in the major taxa proportions at Point Pully (38) (Figure 48g). Mollusc abundance was the most variable, with a sudden spike in 2000 due to an increase in *Axinopsida serricata* (Figure 50g). With the low numbers of molluscs in 1989-1990 and in 1994, arthropods were proportionately the largest group, comprising the ostracod *Euphilomedes producta* and the cumaceans *Eudorella pacifica* and *Eudorellopsis integra*.

Point Pully (38) exhibited gradual increases in annelid and miscellaneous taxa (Table 17a). Total abundance increased considerably in 2000 due to increases in numbers of *Axinopsida serricata* and *Macoma carlottensis*.

As indicated previously, the benthic communities were similar at Point Pully (38) and Shilshole (29) (Figure 51). In 1994, the species composition at Point Pully (38) was slightly different from that of other years at the same station ("4" in upper right of Shilshole/Point Pully ellipse in Figure 51).

Thea Foss Waterway (Station 40)

Thea Foss Waterway (40) was characterized by high total abundance, taxa richness, and Shannon-Wiener diversity over all years. The station also had the highest echinoderm abundance of all the stations, due to increasing numbers of *Amphiodia* spp. after 1995 (Figures 48h, 50h). The proportion of annelids gradually declined from almost 60% to less than 30% of the total abundance, responding to a decrease in *Aphelochaeta* sp. N1, particularly after 1992. The mollusc proportion was variable, and was considerably larger in 1998-2000 than in earlier years as numbers of *Axinopsida serricata* increased. The arthropod and echinoderm proportions varied as well. Very few echinoderms were found 1989-1992; the numbers increased one, then two orders of magnitude before peaking in 1997. Also in 1997, mollusc abundance surpassed annelid abundance. Both annelid and mollusc abundance peaked in 1989, 1998, and 2000 (Appendix G).

Echinoderm, mollusc, and total abundance increased, especially between 1995 and 1997. Miscellaneous taxa abundance, Shannon-Wiener diversity, Pielou's evenness, taxa richness, and Swartz' dominance index all increased from low values in 1989, peaked in 1994-1995, then dropped sharply to earlier levels from 1997 on. The infaunal assemblage at Thea Foss Waterway (40) was strikingly similar across the years, as evidenced by the tightly clustered points in the Thea Foss Waterway ellipse in Figure 51.

East Anderson Island (Station 44)

East Anderson Island (44) had moderate total abundance and high diversity and evenness throughout the study. The station was dominated by annelids, primarily *Phyllochaetopterus prolifica* (Figures 48i, 50i), and also showed a high abundance and diversity of miscellaneous taxa in comparison with most other stations with the exception of North Hood Canal (13R). Overall, annelids declined proportionally at East Anderson Island (44) until 1998, then increased during 1999-2000. Concomitantly, there were increases in the proportions of arthropods and echinoderms until 1998. Annelid abundance peaked in 1990 and diminished considerably in 1998. Although arthropod and echinoderm abundance increased until 1997, they, too, dropped in 1998.

Taxa richness as well as annelid and mollusc abundance decreased overall (Tables 17a,b). Shannon-Wiener diversity, Pielou's evenness and Swartz' dominance index all dipped to low values in 1997. Abundance of all taxa, and therefore total abundance, dropped sharply in 1998. While the infaunal assemblage was quite similar from 1989 to 1997, the community in

1998-2000 was somewhat different (Figure 51), consistent with the decrease in diversity of all the major taxonomic groups.

Inner Budd Inlet (Station 49)

Inner Budd Inlet (49) was characterized by low total abundance, taxa richness, and diversity. The station was dominated by annelids, and had low mollusc and arthropod abundance (Figure 48j). There was considerable change in the proportions of major taxa at Inner Budd Inlet (49) (Figure 48j). The arthropod proportion peaked in 1990, then declined. Annelid abundance approximately doubled from the levels of 1989-1992 to a peak in 1993, then declined to earlier levels, finally dropping to a low in 2000. The proportion of molluscs was about double in 1992 and again in 2000 compared to that of most of the other years (Figure 48j).

Overall, arthropod and echinoderm abundance declined (Table 17a). Taxa richness and abundance of all major taxa groups except annelids were lower after the mid-1990s than before. Annelid abundance and total abundance were considerably higher in 1993 than in other years, whereas Shannon-Wiener diversity, Pielou's evenness and Swartz' dominance index all dipped to low values in 1993 (Appendix G).

The benthic infauna were distinctly different in 1995-2000, compared to 1989-1994 (Figure 51). Except for the year 2000, when taxa richness suddenly increased to a new maximum, the number of taxa was distinctly lower after 1994 than prior to 1994 (Figure 49j).

Relationships among Biological, Chemical, and Physical Parameters

Correlations and Concordances

Pearson correlation coefficients were computed on the variables transformed for variance stabilization, in accordance with required assumptions of normality, but also separately on the untransformed ("raw") variables (Tables 18a,b). Interpretations of correlations on transformed variables are limited to the transformations (*e.g.*, correlation between the logarithm of total abundance and the square root of taxa richness) and are not extended to the untransformed variables. However, when patterns of Pearson correlation coefficients computed on the untransformed variables were the same as those computed on transformed variables, we can feel confident in reporting the correlations on the untransformed variables. The correlations discussed in the following narrative were statistically significantly different from zero at $\alpha = 0.05$ with Bonferroni correction for the number of simultaneous correlations.

For all stations and years combined, the mean metals SQS quotient, % TOC, and % fines were moderately positively correlated ($0.5 \le r < 0.9$) with each other. Percent fines was moderately negatively correlated ($-0.9 < r \le -0.5$) with taxa richness and the abundance of arthropods, miscellaneous taxa, *Ampelisca*, and *Euphilomedes*, and weakly negatively correlated ($-0.5 < r < 0$) with total abundance and mollusc abundance. Percent TOC was moderately negatively correlated with taxa richness and weakly negatively correlated with mollusc and *Euphilomedes* abundance.

The mean metals SQS quotient was moderately positively correlated with annelid and *Aphelochaeta* abundance only for the untransformed variables. Total PAH and cholesterol concentrations were uncorrelated with the physical, chemical, and biological variables or bioindices.

Although depth was numerically weakly negatively correlated with taxa richness, total abundance, and the abundance of annelids, arthropods, and *Euphilomedes*, there is nothing resembling a straight-line relationship because there is not a continuum of station depths – the station depths fall into two distinct and widely spread categories: 200-225 m and 0-25 m (Figure 52). Statistical significance was due to the large sample size resulting when all stations and years are combined. Contrary to expectation, salinity was not correlated with any of the biological parameters (or any other parameters).

Total abundance and taxa richness were moderately positively correlated with the abundance of annelids, arthropods, *Euphilomedes*, molluscs, and miscellaneous taxa, but not echinoderms or the other individual species. Swartz' dominance index standardized by taxa richness (SDISTD) was weakly to moderately negatively correlated with arthropod, mollusc, *Euphilomedes*, and total abundance. Taxa richness was moderately positively correlated with total abundance and weakly positively correlated ($0 < r < 0.5$) with SDISTD. Shannon-Wiener diversity was moderately positively correlated with SDISTD and with *Ampelisca* and *Spiochaetopterus* abundance.

Echinoderm abundance was almost perfectly positively correlated ($r \approx 1$) with abundance of *Amphiuridae*, reflecting the fact that almost all of the echinoderms found were Amphiurids. Annelid abundance was moderately positively correlated with *Aphelochaeta* and *Spiochaetopterus* abundance (the latter for untransformed variables only), reflecting the fact that when those species were found, they were found in large numbers. Likewise, there were moderate positive correlations between arthropod abundance and *Euphilomedes*, and between mollusc abundance and *Axinopsida*. Abundance of the bivalve *Axinopsida* was moderately positively correlated with abundance of both the ostracod *Euphilomedes* and the amphipod *Rhepoxinius*, indicating that the species tended to co-occur. Similarly, abundance of the polychaete *Spiochaetopterus* was moderately positively correlated with abundance of the amphipod *Ampelisca* and the brittle star *Amphiuridae* (the latter for untransformed variables only). In addition, there were weak positive correlations between Euphilomedes abundance and overall mollusc abundance, and between *Axinopsida* abundance and overall arthropod abundance.

The sample sizes (7-12) were too small for Pearson correlation coefficients at the level of the individual stations to be statistically significant ($\alpha = 0.05$, Bonferroni-corrected for the number of simultaneous correlations) except when the correlations were strong ($|r| \geq 0.9$). At several stations, abundance of a particular major taxonomic group was highly positively correlated with the abundance of a specific species (Table 19), reflecting the large contribution of that species. Similarly, highly positive correlation between total abundance and the abundance of a major taxonomic group reflected the large proportion of benthic macroinvertebrates of a particular type at several stations (Table 19). In addition, the following relationships were found:

- The mean metals SQS quotient and % fines were highly positively correlated at Port Gardner (21) (untransformed variables only).
- Arthropod and echinoderm abundance were highly positively correlated at East Anderson Island (44) and Inner Budd Inlet (49).
- Arthropod abundance was both strongly positively correlated with the abundance of *Amphiuridae* (an echinoderm) and strongly negatively correlated with the abundance of Axinopsida (a mollusc) at Thea Foss Waterway (40).
- Shannon-Wiener diversity was strongly negatively correlated with annelid abundance at Sinclair Inlet (34).
- SDISTD was highly positively correlated with the abundance of miscellaneous taxa at Shilshole (29) (untransformed variables only) and with Shannon-Wiener diversity at North Hood Canal (13R) and Thea Foss Waterway (40).
- Contrary to expectation, taxa richness, Julian day of sampling, mean metals SQS quotient, and total PAH concentration were not statistically significantly correlated with any biological variables or bioindices at any of the individual stations.

Summary of Temporal Trends and Changes in Biological, Chemical, and Physical Parameters

In general, the mean metals SQS quotient, % TOC, and % fines were positively correlated, and taxa richness was negatively correlated with both % TOC and % fines. A summary of the temporal trends and changes observed between the biological, chemical, and physical sediment variables at each station is given below.

- **Strait of Georgia (3)** - At Strait of Georgia (3) there were increases in a few PAHs and other organic compounds and in % TOC. Grain size decreased (*i.e.*, % fines increased). While the total organic content in 1989 was about average, the percent fines was unusually low (Figure 53). Shannon-Wiener diversity and Swartz' dominance index decreased. Total abundance was driven by mollusc abundance. The infaunal assemblage was quite variable and considerably different from the other stations.

- **Bellingham Bay (4)** - PAHs (dry-weight concentrations) increased at Bellingham Bay (4). Swartz' dominance index standardized by taxa richness (SDISTD) increased. Patterns in Shannon-Wiener diversity, taxa richness, annelid abundance, and echinoderm abundance were suggestive of cycles. Total abundance may have been driven by annelid abundance.

- **North Hood Canal (13R)** - Because North Hood Canal (13R) was not sampled every year between 1989 and 1996, the years sampled for chemistry, sample sizes were insufficient to determine whether there were any changes in sediment chemistry. Total abundance was driven by mollusc abundance.

- **Port Gardner (21)** - Metals concentrations decreased at Port Gardner (21), as did % TOC, while TOC-normalized concentrations of some PAH compounds increased (likely related to the decrease in TOC). Shannon-Wiener diversity, Pielou's evenness, Swartz' dominance (standardized and unstandardized), and abundance of miscellaneous fauna all increased. Patterns in abundance of echinoderms and miscellaneous taxa were suggestive of cycles. Total abundance was driven by mollusc abundance. Metals and % fines were positively correlated, though the very high metals and % fines in 1991 had a large influence (Figure 54). Salinity was lower at Port Gardner (21) than at other stations.

- **Shilshole (29)** - There were few changes in sediment contaminant concentrations at Shilshole (29). Echinoderm abundance and taxa richness declined. Patterns in arthropod and mollusc abundance were suggestive of cycles. Total abundance was driven by mollusc abundance. Swartz' dominance index was positively correlated with miscellaneous taxa abundance.

- **Sinclair Inlet (34)** - At Sinclair Inlet (34), concentrations of a few metals decreased, and concentrations of a number of contaminants spiked in 1995. Echinoderm abundance increased and taxa richness decreased. Total abundance was driven by annelid abundance, but there was a negative correlation with the diversity, evenness, and dominance indices.

- **Point Pully (38)** - PAH contamination and the concentrations of a few metals decreased significantly at Point Pully (38). Annelid abundance increased. Mollusc and total abundance increased suddenly in 2000. There were possible increasing trends in the abundance of miscellaneous taxa. Patterns in Shannon-Wiener diversity and Pielou's evenness were suggestive of cycles. Total abundance was driven by mollusc abundance.

- **Thea Foss Waterway (40)** - Percent fines was unusually low in 1989, and percent TOC was unusually high in 1992 and 1993 at Thea Foss Waterway (40) (Figure 55). PAH concentrations were high in 1989-1990, exceeding Washington State Sediment Quality Standards, but dropped by one-half to two-thirds after 1990. Echinoderm, mollusc, and total abundance all increased. Total abundance was driven by mollusc abundance.

- **East Anderson Island (44)** - PAH contamination increased significantly at East Anderson Island (44). Annelid and mollusc abundance decreased, as did taxa richness. Patterns in the diversity, evenness, and dominance bioindices, as well as arthropod and echinoderm abundance appear to be cyclical. Total abundance was driven by annelid abundance. Annelid and echinoderm abundance were positively correlated.

- **Inner Budd Inlet (49)** - At Inner Budd Inlet (49), there was a decrease in metals contamination, along with decreases in arthropod and echinoderm abundance. There was a drop in taxa richness from the level in 1989-1994 to the level in 1995-2000. Total abundance may have been driven by annelid abundance. Annelid and echinoderm abundance were positively correlated.

Discussion

Sediment Characteristics

Both chemical contaminants and benthic infauna show affinities for sediments of certain composition. The bond strength between sediment particles and chemical contaminants is a function of mineralogy and ionic charges. Adsorption and desorption are influenced by such factors as temperature, salinity, oxygen, equilibrium-partitioning, acid volatile sulfides, dissolved organic matter in porewater, redox potential, pH, and other chemical contaminants (Konasewich *et al.*, 1982). Bioavailability of organic contaminants is affected by the total organic carbon content of the sediment (DiToro *et al.*, 1991). All of these conditions affect bioaccumulation. Thus, in order to understand the meaning of trends in accumulation of chemical contaminants in sediments, it is necessary to consider as many of these parameters as possible.

The PSAMP sampling protocol specifies the collection of the top two to three centimeters of sediment for chemical analyses to characterize the most recently-deposited sediments (PSEP, 1986, 1997a). Since the average rate of sediment deposition in the central deep area of Puget Sound is about 1-2 cm/year (Lefkovitz *et al.*, 1997), it would be reasonable to examine possible factors contributing to the sediment characteristics from 1988 on.

Grain Size

Sediment grain size is an important factor in both sediment contamination and biological communities. The links between finer grain sizes, particularly silt and clay, and adsorption of metals and other contaminants, and between finer grain sizes and sediment organic content have been well established (*e.g.*, Lefkovitz *et al.*, 1997). The mineralogy of silt and clay particles is such that there are ionic attractions between the sediment particles and a number of metals, enhanced by the larger surface-to-volume ratio of the smaller particles. Links have also been established between sediment grain size and organisms inhabiting the sediment, such as grain-size preferences for making burrows and for deposit-feeding (the ingestion of sediment to obtain food from microorganisms and organic matter adhering to the sediment) (*e.g.*, Gray, 1974; Rhoads, 1974). Thus, changes in sediment chemistry, TOC, and biota can be related to changes in particle-size distribution.

The sudden and very large increase in fines, almost entirely silt, at Strait of Georgia (3) in 1997 coincides with an increase of about 50% in the flow of the Fraser River in 1997 over that in 1995 (Environment Canada, 2002; Figure 56), suggesting increased freshwater silt input. That PSAMP station is located within the plume of the Fraser River, and the silt fraction of the sediment samples taken there tracks quite well with the Fraser River flow (Figure 56). From 1989 to 1991, the gravel fraction of the surface sediments at Strait of Georgia (3) decreased from over one-third to less than 10%, coinciding with an increase in the Fraser River flow from 1989 to 1990-1991, similarly suggesting deposition of finer sediments from the Fraser River plume.

Changes in infaunal indices at Strait of Georgia (3), including significant shifts in total abundance, taxa richness, and abundance and composition of polychaete and mollusk species, appeared to fluctuate with the shift in sediment grain size, suggesting a link between rainfall, riverine sediment deposition, and benthic community structure. As a result of these observations, scientists working in estuarine embayments in the San Juan Archipelago (just south of Strait of Georgia (3), and also within the footprint of the Frasier River plume) are currently investigating possible links between the decline in eelgrass populations observed between 1995 and 2000 and sediment deposition over those years (S. Wyllie-Echeverria, *pers. comm.*). These observations and events demonstrate the use of the PSAMP long-term stations as "sentinels", with regular monitoring results providing a record of change in environmental conditions at each station over time, and clues to changes observed in other nearby locations.

Annual total precipitation over the period 1988-2000, for Washington State as a whole and as measured at the Seattle-Tacoma International Airport, on the edge of Puget Sound, was relatively low in 1989-1990, 1991-1993 (lowest in 1993), and 2000, and relatively high in 1990 and 1995-1999, peaking in 1996 (Figure 57; NOAA National Climatic Data Center, 2003; Desert Research Institute Western Regional Climate Center, 2003). It would be expected, in years of higher precipitation, for there to be changes in the grain-size distribution of sediment and in sediment chemistry, the latter largely from runoff.

Skykomish River flow is considered to be representative of freshwater flow in the Puget Sound area (Newton *et al.*, 2002). During the period 1991-2000, Skykomish River flow was considerably higher than normal in 1991, 1996, 1997, and 1999, and much lower than normal in 1992-1994 (Figure 58) (Newton *et al.*, 1994; Newton *et al.*, 1997; Newton *et al.*, 1998; Newton *et al.*, 2002). Patterns in Skykomish River flow reflected the patterns in precipitation.

The Port Gardner PSAMP station is located close to the discharge of the Snohomish River, of which the Skykomish is a tributary. There was a fair correspondence between percent fines at Port Gardner (21) and Skykomish River flow during the 1990s (Figure 59). As in the relationship between Strait of Georgia (3) fines and Fraser River flow, percent silt appears to drive the percent fines at Port Gardner (21), suggesting a primarily depositional environment at that location.

These results cannot be extended to the remainder of the PSAMP long-term stations. However, to the extent that Skykomish River flow can be used as a model for freshwater input to Puget Sound, it is evident that fluvial input affects the grain-size distribution of the sediments at the bottom of Puget Sound. Lower flows tend to coincide with El Niño events, when circulation patterns in the Pacific Ocean result in upwelling, and with lower-than-normal precipitation (Newton *et al.*, 1997), and higher flows with La Niña events and higher-than-normal precipitation.

Temperature- and salinity-stratification in the water column are also affected by El Niño conditions as a result of exchange between the Pacific Ocean and Puget Sound via the Strait of Juan de Fuca (Newton *et al.*, 2002). Since a number of metals and other chemical contaminants tend to adsorb to fine sediments, the strength of the association being affected by such factors as salinity and clay/silt mineralogy (Konasewich *et al.*, 1982), a connection can be drawn between climate and the conditions at the bottom of Puget Sound.

Total Organic Carbon

Percent TOC and percent fines were positively correlated with each other among all ten stations. Some chemical contaminants, such as copper and PAHs, are strongly associated with organic matter, and adsorption to silts and clays often increases with organic content (Konasewich *et al.*, 1982). Binding of some nonionic organic contaminants, such as PAHs, by organic matter reduces their bioavailability (DiToro *et al.*, 1991).

Salinity of Overlying Water

Salinity values at the ten long-term monitoring stations showed no trends over time and were not significantly correlated with any other variable measured. While it is well know that salinity has a large influence on benthic community composition, salinity measures taken during this study were those of opportunity, collected at only one point in time annually (*i.e.*, when the sample was collected). Temporal fluctuations in salinity values (*e.g.*, seasonally and tidally) were not quantified, so their effects on community structure at these stations are unknown.

Sediment Chemistry

Because the primary purpose of PSAMP is ambient monitoring, the long-term sediment-monitoring stations were, for the most part, chosen deliberately to be distant from known point sources of pollution. In order to interpret contaminant levels in comparison with sediment quality guidelines, it is important to understand the derivation of the guidelines and subsequent nuances in their values. In order to interpret any trends, or lack thereof, in the levels of contaminants in Puget Sound, it is helpful to understand how and where contaminants of concern enter the environment, as well as known or suspected effects on the biota inhabiting the sediment. For purposes of comparing the 1989-2000 PSAMP sediment chemistry results with trends in emissions of contaminants, data were obtained on releases of contaminants directly into surface waters and wastewater treatment plants during 1988-2000 in the counties surrounding Puget Sound.

Comparison of Contaminant Levels with Sediment Quality Guidelines

The Washington State sediment quality standards are intended to be applied to samples that represent the “biologically active zone”. The default for this zone is the surface 0-10 cm of sediment. Thus, a 0-2 cm sample that exceeds a standard may not exceed the standard for a 0-10 cm sample collected from the same location. Conversely, a 0-2 cm sample that does not exceed Washington State standards may exceed them in a slightly deeper surface sample (Gries, *pers. comm.*).

There is no assumed depth for application of the ERM sediment quality criteria. However, most of the samples on which the development of the ERM was based were taken in the top 5 cm of sediment (Long, *pers. comm.*).

The ERM values for metals are based on use of the hydrofluoric acid, or "total", digestion method of extracting metals from sediment samples, whereas PSEP protocol (PSEP, 1997b) specifies use of the strong acid, or "partial", digestion method. As the names imply, concentrations of metals extracted from sediments are higher with the "total" digestion method than with the "partial" digestion method. Thus, comparisons of metals concentrations extracted by the strong acid method to the ERM may understate the results. However, most of the metals levels at these ten PSAMP long-term sediment-monitoring stations are far below the sediment quality criteria, with the exception of mercury at Sinclair Inlet (34).

Toxics Release Inventory

The Toxics Release Inventory (TRI) is a database of toxic chemical releases and waste management reported annually by industries, maintained by the US EPA (US EPA, 2002). The Washington State Department of Ecology also maintains a TRI database. Although the federal and state databases contain information for multiple years, data are not strictly comparable year-to-year — the TRI program and its reporting requirements (chemicals, industries, thresholds, and so on) have evolved over the years (Washington State Department of Ecology, 2001; US EPA, 2002). Nevertheless, the TRI database does provide some information on direct releases of chemical contaminants into the environment or into waste-processing.

Ecology's TRI database maintains information on reported releases of specific contaminants by industry and by county within Washington. County-level TRI data from 1988 through 2000 were obtained for this report. The counties surrounding Puget Sound are shown in the map in Figure 60, with the ten PSAMP long-term sediment monitoring stations identified for reference.

TRI-reported release amounts peaked in 1999 for many contaminants (Figures 62-72, discussed below by contaminant), which undoubtedly reflects new reporting requirements, primarily addition of industries required to report, enacted in 1998. Industries newly required to report releases in 1999 included utilities, mining companies, and chemical and petroleum bulk-storage terminals (Hansen, *pers. comm.*). Although the bases for reporting have changed over the years, still it is instructive to examine patterns of emissions, to raise questions as to potential sources of contaminants in Puget Sound sediments.

Benzoic Acid

Because there was a gap of six years between the 1989-1993 and 2000 measurements of benzoic acid, it was not possible to determine any trend characteristics. However, detected concentrations of benzoic acid in 2000 were an order of magnitude higher than those in 1989-1993 for all stations, not just one or a few stations, which raises many questions.

Benzoic acid occurs naturally in low concentrations in some plants and dairy products, and in high concentrations in certain types of berries (World Health Organization, 2000). Benzoic acid is used as a preservative, antibacterial and antifungal agent in foods, dental hygiene products and cosmetics, and as a component of car antifreeze. Its industrial uses include plasticizing agent, drilling-mud additive, and intermediate in production of phenol and other chemical substances. Benzoic acid has also been detected in wastewater of some wood-production industries (World Health Organization, 2000). The primary mode of human consumption of benzoic acid is in soft drinks and juices (World Health Organization, 2000). Hence, benzoic acid could enter Puget Sound from a variety of sources, including sewage.

Between 1990 and 2000, the population in the Washington counties bordering Puget Sound increased 20% on average (Washington State Office of Financial Management, undated). In the period 1995-2000, the consumption of carbonated soft drinks in the USA rose 9.4% (Beverage Digest, 2002), while the population in the Washington counties bordering Puget Sound is estimated to have increased 8.7% during that same period (Washington State Office of Financial Management, undated). Although these statistics are not strictly comparable, their respective magnitudes suggest that soft-drink consumption increases linearly, not exponentially, with population. Thus, it seems unlikely that a tenfold increase in benzoic acid measured in the sediments of Puget Sound represents a tenfold increase in the input of benzoic acid from soft-drink consumption into the sewage stream.

Further study would be required to determine whether benzoic acid input to surface waters and sewage streams by bottling plants had increased due to plant consolidations (Saltzman *et al.*, 1999) or whether there had been increased benzoic acid input from other anthropogenic sources. Since benzoic acid is not one of the contaminants considered toxic enough to warrant reporting to the US EPA under the Toxics Release Inventory (TRI) program (US EPA, 2001), the TRI database has no records of releases of benzoic acid.

The facts that different labs were responsible for the chemical analyses, that improvements in chemical analytical technique/equipment have taken place (K. Feddersen, *pers. comm.*), and that the 2000 measurements (detected results) were an order of magnitude higher than the detected results reported in 1989-1993 at all stations suggest that the ubiquitous increase in benzoic acid may be at least partially an artifact of the chemical analysis procedures. Elevated levels of benzoic acid were found throughout all of Puget Sound in surficial sediments examined from 1997-1999, offering further evidence of its ubiquity (Long et al., 2003). The chemical analyses for the PSAMP marine sediment monitoring were performed by Analytical Resources Inc. in 1989 through 1993 and by the Manchester Environmental Laboratory from 1994 on. The Manchester Environmental Laboratory employs a different extraction procedure from other labs (G. Perez, *pers. comm.*).

Benzoic acid is difficult to quantitate and requires a clean column for best results (G. Perez, *pers. comm.*). The QA/QC case narratives published in earlier PSAMP reports (Tetra Tech, 1990; Striplin *et al.*, 1992; EcoChem, 1993; Washington State Department of Ecology, 1994) and in Appendix B of this report cite problems with matrix spikes for the analyses of benzoic acid in 1989, 1991, 1992, and 1993; with initial calibration in 1991 and 1993; and with surrogate recovery in 1991. Using the higher-yield extraction procedure and a clean column could account for a ten-fold increase in quantitated level of benzoic acid (G. Perez, *pers. comm.*).

Metals

The general decrease over time of the concentration of metals at these long-term sediment monitoring stations is in agreement with a significant decline in metals since the mid-1970s observed in other aquatic sediment trend monitoring studies (Lefkovitz *et al.*, 1997; Mahler *et al.*, 2004). These declines may be due to a decrease in point-source emission of priority pollutant metals (industrial wastewater and air) since the strengthening of environmental regulations in the early 1970s.

Concentrations of several metals followed a similar pattern, increasing from relatively low values in 1989 to relatively high values in 1991, then decreasing again, at Strait of Georgia (3), Bellingham Bay (4), Port Gardner (21), Point Pully (38), Thea Foss Waterway (40), and occasionally Shilshole (29) (Appendices E, F). In searching for possible explanations for similarities at such geographically distant points, we note that 1) the same laboratory and methods were employed for the analytical chemistry in 1989-1993 and 2) four of those stations are located in embayments close to large urban/industrialized areas at the mouths of major rivers.

That the same lab was used and that the patterns often were not found at the other stations suggest that year-to-year differences in the chemical analyses were likely not the primary factor.

As discussed in the section on grain size, above, the Strait of Georgia station is located within the Fraser River plume and appears to be influenced by silt entrained by the Fraser. The Bellingham Bay, Port Gardner, and Thea Foss Waterway stations are located close to the city of Bellingham and the Nooksack River, the city of Everett and the Snohomish River, and the city of Tacoma and the Puyallup River, respectively. The Point Pully station is located in the deep, central basin of Puget Sound, approximately equidistant from the city of Tacoma and Commencement Bay, into which the Puyallup River empties, and the city of Seattle and Elliott Bay, into which the Green and Duwamish Rivers empty. The Shilshole station is also located in the deep, central basin of Puget Sound, just north of the mouth of Elliott Bay.

Total precipitation measured at the Seattle-Tacoma International Airport, situated at the edge of Puget Sound, and for Washington State as a whole, was low in calendar years 1988-89, 1993, and 2000, and high in calendar years 1990 and 1996 (Figure 72). When precipitation is examined by water year, defined as October of the previous calendar year to September of the current calendar year, which coincides with the rainy season in the Puget Sound area, the peaks and valleys are shifted (Figure 72). For example, the peak occurring in calendar year 1990 is seen in water year 1991, indicating most of the precipitation in calendar year 1990 occurred in the last 3 months. The measured flows of the primary rivers emptying into Puget Sound follow the precipitation patterns closely (Figure 73), and the above-mentioned patterns in the metals between 1989 and 1993 follow the patterns of the river flows (Appendices E, F). The samples which had the elevated levels of metals were taken in the spring of 1991, following the rainy season.

Not only are those PSAMP stations located close to major urban/industrial areas, but also they are located close to or downcurrent of dredge-disposal sites. The Point Grey dumpsite is located just outside the city of Vancouver and the north arm of the Fraser River (Waldichuk, 1983; Mosher *et al.*, 2003) and is still actively used for the disposal of dredged material (Government of Canada, 2003). Puget Sound Dredged Disposal Analysis (PSDDA) nondispersive open-water disposal sites are located in Bellingham Bay, at Port Gardner in Everett Harbor, in Elliott Bay, in Commencement Bay, and near Anderson Island (Gries, *pers. comm.*; DMMP, 1998, 2000, 2002).

Disturbance of sediment by increased river flow and by dredging can mobilize metals (Waldichuk, 1983). Thus, it seems plausible that the elevated levels of some metals in 1991 at those stations could have resulted from a combination of runoff from increased precipitation and dredging-and-dumping. Since no sediment-chemistry analyses were performed in 1997 through

1999, and were performed for only a few stations in 1996, it is not possible to determine if the patterns in metals would have continued to follow the patterns in precipitation and river flow.

It is curious that the 1989-1993 patterns in metals were not seen at Sinclair Inlet (34), where concentrations of most metals were far higher than at the other stations, nor at East Anderson Island (44) or Inner Budd Inlet (49), both located close to river mouths (the Nisqually River and the Deschutes River, respectively). However, although the Sinclair Inlet station is located just off the Puget Sound Naval Station and close to the city of Bremerton, there is no major riverine input there, nor is there a dredge-disposal site nearby. Even though there is a dredge-disposal site close to the Anderson Island station, the dumpsite has been used little (Gries, *pers. comm.*; DMMP, 1998, 2000, 2002), and there is no urban/industrialized center nearby. Finally, while there has been some contamination of Budd Inlet (Norton, 1990), Olympia is a much smaller city with far less heavy industry than the other cities surrounding Puget Sound, and the Deschutes River is smaller than the other rivers.

Several of the metals which displayed the pattern of peaking in 1991 were crustal metals for which there are no SQS: aluminum, iron, manganese, and nickel. Indeed, the 1989-1993 pattern in some metals was not seen in the mean metals SQS quotients except at Port Gardner (21). The SQS quotients at these ten stations were driven primarily by mercury and arsenic. Although the highest mercury concentrations at some stations occurred in 1991, at many stations mercury was undetected in 1989 and 1990, making it impossible to determine whether mercury followed the 1989-1993 patterns of the other metals. Although it is not possible to state with certainty, the evidence suggests the possibility that changes in river flow could drive changes in naturally occurring metals but that additional factors contribute to changes in heavy metals of concern.

Arsenic

Some arsenic is naturally present in soils, from which it is carried by run-off to the sea and adsorbs to clays (Konasewich *et al.*, 1982). Arsenic is also released as dust in smelting. Arsenic and arsenic compounds are used in many products, including semiconductors, drugs, and wood preservatives, herbicides, and pesticides (ATSDR, 2001; Konasewich *et al.*, 1982; Habeck, undated). Except for areas in the plumes downwind, downstream, and downcurrent from the now-closed ASARCO smelter in Tacoma, the majority of the arsenic in Puget Sound waters and sediments enters in the seawater flowing in from the Strait of Juan de Fuca (Crecelius, 1974; Crecelius *et al.*, 1975). Marine biota bioaccumulate arsenic, though more from seawater than from food (Konasewich *et al.*, 1982).

Just over half of reported release of arsenic and arsenic compounds into the environment was directly into surface waters, though that amount constituted only about 7% of all reported releases (Washington State Department of Ecology EPCRA database, 2003; Figure 61). Reported releases of arsenic and arsenic compounds into surface waters were highest in 1988 in Pierce County and declined rapidly to negligible levels (Figure 61). The ASARCO smelter closed in 1985 (Dexter *et al.*, 1985), but wood-treating plants were releasing arsenic compounds in 1988 and 1989 (US EPA, 2003). The analysis of the PSAMP long-term station results in this report indicates that arsenic levels were significantly lower in 2000 than in 1989-1996 at Shilshole (29), Sinclair Inlet (34), Thea Foss Waterway (40), and East Anderson Island (44), though there appear not to have been any trends. The Thea Foss Waterway and East Anderson Island PSAMP stations are in Pierce County.

Cadmium

Cadmium emissions originate from such sources as mining, burning of coal and household wastes (*e.g.*, batteries), and leaching from contaminated sites (ATSDR, 1999; Konasewich *et al.*, 1982; Habeck, undated). Since cadmium easily dissolves in water, it is readily accessible to marine organisms (Konasewich *et al.*, 1982). Adsorption to sediments is relatively weak, though enhanced with organic matter (Konasewich *et al.*, 1982). The determining factor in the toxicity of cadmium in sediments is acid-volatile sulfide (AVS), which binds with cadmium to form an insoluble precipitate – when the concentration of cadmium exceeds that of AVS, the excess cadmium becomes available in the pore water (DiToro *et al.*, 1990). Some benthic infauna, such as crustaceans, are more affected by cadmium than are others, such as gastropods (Konasewich *et al.*, 1982).

The only reported releases of cadmium and cadmium compounds directly into surface waters were in 1990 and 1991 in Snohomish County (Washington State Department of Ecology EPCRA database, 2003; Figure 62). At eight of the ten PSAMP long-term stations, there were insufficient data on cadmium to analyze – cadmium was undetected in 27 of 117 samples throughout 1989-1993 and 8 of 10 samples in 2000. The time-series plots of the results at the majority of stations depicted nearly constant levels of cadmium from 1989 to 1993, followed by a large jump up in 1994, then undetected thereafter.

Chromium

As chromium ores, chromium and chromium compounds can be discharged into waterways from such industries as tanning, textiles, and electroplating (ATSDR, 2001; Habeck, undated). Hexavalent chromium is the most toxic form of chromium, whereas the majority of chromium in sediments occurs in the less toxic trivalent form (Berry et al. 2004). In a review by Konasewich *et al.* (1982), chromium was not considered to be a contaminant of concern.

Over 80% of release of chromium and chromium compounds into the environment in 1988-2000 was directly into surface waters, which constituted about 12% of all reported releases (Washington State Department of Ecology EPCRA database, 2003; Figure 63). Releases of chromium and chromium compounds were reported, at fluctuating levels, throughout the period 1988-2000 in Whatcom County, with the largest release reported in 1999; releases in other counties surrounding Puget Sound were minimal (Figure 63). Although a few increases in chromium concentrations in the sediments were found at some central and southern Puget Sound stations, no statistically-significant changes were found at Strait of Georgia (3) and Bellingham Bay (4), which are off the coast of Whatcom County. It cannot be determined without further study whether the increase in reported releases reflects increases in releases or increases in reporting. As well, Strait of Georgia (3) may be more greatly affected by outputs from the Fraser River (Vancouver, BC) than from Whatcom County.

Copper

Copper is a metal commonly used for building products (wire, pipe, etc.). Copper compounds have agricultural, water-treatment, and preservative uses (ATSDR, 1999; Konasewich *et al.*, 1982; Habeck, undated). Copper gets into the environment in a number of forms and is strongly associated with fine sediments and organic matter. The association between copper and sediment is influenced by a number of factors, such as salinity (Konasewich *et al.*, 1982) and the amount of acid-volatile sulfide in the sediment (Casas and Crecelius, 1994). Copper is one of the most toxic metals for marine organisms; its toxicity is affected by temperature (Konasewich *et al.*, 1982).

Reported releases of copper and copper compounds into surface waters were negligible until 1994 (Washington State Department of Ecology EPCRA database, 2003). Overall, releases into surface waters constituted over 40% of releases into the environment (Figure 64), but less than 1% of all releases. Releases into surface waters were of fluctuating amounts in Kitsap and Snohomish counties, with a peak in Kitsap in 1999 (Figure 64). Decreases in copper levels were found at seven of the ten long-term PSAMP sediment stations, with no change at the other three, two of which, North Hood Canal (13R) and Sinclair Inlet (34), lie within or adjacent to Kitsap County. Further study would be required to determine whether there had been a true increase in releases of copper into the waters of Kitsap County or whether the TRI data just reflect increases in reporting, as well as whether currents and settling rates near the 1999 release sites would have resulted in deposition of copper in the PSAMP long-term sampling locations by April 2000.

Lead

Lead enters the environment through such means as burning of fossil fuels, mining, and manufacturing, as well as leaching. Lead and lead compounds are found in batteries, ammunition, some building products, medical equipment, circuit boards, paints, and other products and equipment. The use of lead compounds as gasoline additives was phased out in the 1980s and banned after 1995 (ATSDR, 1999; Konasewich *et al.*, 1982; Habeck, undated). As with many metals, lead adsorbs to sediment (Konasewich *et al.*, 1982). The availability of lead in pore water is determined by the amount of acid-volatile sulfide in the sediment, to which it binds (Casas and Crecelius, 1994). Bivalves and crustaceans are known to bioaccumulate lead, possibly through consumption of contaminated sediment and phytoplankton (Konasewich *et al.*, 1982).

Releases of lead and lead compounds into surface waters in counties surrounding Puget Sound were quite low until 1997, when releases were reported in Kitsap County, peaking in 1999 (Washington State Department of Ecology EPCRA database, 2003; Figure 65). Overall, releases into surface waters constituted less than 0.5% of all releases. There were decreases in lead levels at two PSAMP stations, Thea Foss Waterway (40) and Inner Budd Inlet (49). Further study would be required to determine whether the water-borne releases of lead in Kitsap County represent actual increases in releases of lead in the late 1990s or just increases in reporting. Since reported releases of a number of metals spiked in 1999, and the lead concentrations in surficial sediments in 2000 were not higher than in 1989-1995/6, the apparent increases may be explained by the increased reporting requirements.

Manganese

Manganese occurs naturally in the environment and in foods, plants, and waters. Manganese is the main metal constituent of seafloor nodules, which occur only in abyssal depths, where slow mineralization occurs (Wilson, *pers. comm.*). Industrial uses of manganese include the production of other metals. Manganese is released into the environment from mining and smelting operations, power plants, and waste disposal. Manganese compounds are found in such products as nutritional supplements, batteries, and fertilizers and pesticides (ATSDR, 2001; Habeck, undated). Manganese oxides tend to form in the saltwater wedge of estuaries as flocculants and precipitate other metals into the sediments with them. (Long, *pers. comm.*, 2005)

Most of the reported releases of manganese and manganese compounds into surface waters were in Whatcom County in the late 1990s, especially 1999 (Washington State Department of Ecology EPCRA database, 2003; Figure 66). Releases into surface waters constituted over 80% of releases into the environment and 15% of all releases (Figure 66). The sign-test results in this analysis indicate that manganese levels were down at Sinclair Inlet (34) and Point Pully (38); no statistically-significant changes or trends were found at the other long-term PSAMP stations, specifically including Strait of Georgia (3) and Bellingham Bay (4), adjacent to Whatcom County. Further study would be required to determine the increase in reported releases of manganese into the waters of Whatcom County reflects increases in reporting or in releases, as well as whether currents and settling rates near the 1999 release sites would have resulted in deposition of manganese in the PSAMP long-term sampling locations by April 2000. The Strait of Georgia PSAMP station (3) may be more greatly affected by outputs from the Fraser River (Vancouver, BC) than from Whatcom County.

Mercury

Mercury enters air, water, and soil naturally from volcanic activity or mercury-containing ores, and artificially from mining or smelting and from burning of fuels and garbage. Mercury and mercury compounds are used in paints, fungicides, thermometers, batteries, and cosmetic, medical, and dental products (ATSDR, 1999; Konasewich *et al.*, 1982; Habeck, undated). Mercury adsorbs to fine sediment particles, though not strongly to clay; adsorption is enhanced by organic content (Konasewich *et al.*, 1982). Marine organisms ingest mercury in both food and seawater. Mercury is one of the most toxic metals to marine organisms, and is one of only a few metals that bioaccumulates in higher tropic levels. It is especially toxic to larval invertebrates, though its toxicity is a function of the particular chemical form, the methylated form being the most toxic. (Konasewich *et al.*, 1982).

Reported releases of mercury and mercury compounds into surface waters in Whatcom County have declined to near zero since 1988, and were essentially non-existent in other Puget Sound counties (Washington State Department of Ecology EPCRA database, 2003; Figure 67). Although air emissions remained almost constant until 2000, when no air releases were reported, releases into surface waters generally declined from 1988 to 2000 (Figure 67). Mercury concentration was significantly less in 2000 than in 1989-1993 at three of the ten long-term PSAMP stations, including Bellingham Bay (4) in Whatcom County.

Nickel

Nickel occurs naturally in the earth's crust, volcanoes, meteorites, and to some extent in seafloor nodules. Nickel and nickel compounds are employed in electroplating, batteries, and other uses, and are discharged into the environment by those industries and by power plants, trash incinerators, and mining (ATSDR, 1997; Habeck, undated). Nickel is bound to sediment by complexing with acid-volatile sulfide, and its toxicity is a function of its concentration in excess of AVS concentration (DiToro *et al.*, 1992).

Releases of nickel and nickel compounds into surface waters were reported in occasional years in the early- to mid-1990s, primarily in Skagit and Whatcom counties (Washington State Department of Ecology EPCRA database, 2003; Figure 68). Releases were reported in Kitsap County in the late 1990s, with a large increase in 1999, when almost all reported releases into the environment were into surface waters (Figure 68). Since nickel concentrations were lower in 2000 than in 1989-1996 at Sinclair Inlet (34), within Kitsap County, it is possible that high levels of reported releases of nickel in 1999 reflect new reporting.

Silver

Silver is commonly used in jewelry, silverware, dental fillings, electronic equipment, disinfectants and antibacterial agents, photographic processing, and metalworking (ATSDR, 1999; Konasewich *et al.*, 1982). Silver adsorbs strongly to clays and organic sediments, but is easily released from sediments into seawater (Konasewich *et al.*, 1982). Marine organisms take up silver primarily dissolved in seawater, as opposed to in food. Silver is extremely toxic to marine organisms, especially for earlier life stages (Konasewich *et al.*, 1982).

No releases of silver or silver compounds into surface waters and water treatment plants were reported under the TRI program during the period 1988-2000 in Puget Sound counties (Washington State Department of Ecology EPCRA database, 2003; Figure 69). Silver levels were down at two long-term PSAMP stations, no change was found at seven others, and one had insufficient (*i.e.*, undetected) silver data.

Zinc

Zinc is a common element and is found in many foods and in the earth's crust. Industrial and nonindustrial products made with zinc include rust-preventives, batteries, alloys, coins, paints/dyes, wood preservatives, and medical and cosmetic products. Mining, steel production, and burning of coal and wastes account for most of the anthropogenic releases of zinc into the environment (ATSDR, 1995; Habeck, undated). Zinc is known to be potentially toxic to marine organisms (Konasewich *et al.*, 1982). Availability of zinc in porewater is a function of its concentration in excess of the concentration of acid-volatile sulfide in the sediment, to which it binds as an insoluble precipitate (Casas and Crecelius, 1994).

Reported release amounts of zinc and zinc dust into surface waters fluctuated throughout 1988-2000, primarily in Whatcom and Kitsap counties, with a large increase in reported releases in 1999, especially in Whatcom County (Washington State Department of Ecology EPCRA database, 2003; Figure 70). Releases into surface waters represented varying, but generally relatively small, proportions of releases into the environment until 1999 and 2000, when water releases predominated (Figure 70). It is not clear whether new reporting or new releases account for the large increase in Whatcom County. Zinc levels had decreased from 1989-1993 to 2000 at four of the long-term PSAMP stations, including Bellingham Bay (4), which is in Whatcom County, and remained unchanged at the remaining six stations (Table 11). Zinc levels declined over the study period at several stations, particularly Shilshole (29), Sinclair Inlet (34), and Point Pully (38), all in Kitsap County or between Kitsap and King counties.

Polycyclic Aromatic Hydrocarbons

PAHs arise from incomplete combustion, largely from the burning of fossil fuels and municipal waste, but also from natural sources such as forest fires. The primary mode of PAH release is atmospheric (from which particulates fall into the water), though some PAHs enter directly into surface waters from industrial and wastewater treatment plants (ATSDR, 1996; US EPA, 2001). Another source of PAH emissions is the preparation and laying of asphalt (Eastern Research Group, 2001). There is some evidence, however, that leaching of PAHs from asphalt into surface waters is minimal (Townsend and Brantley, 1998; Kriech, undated), though runoff of motor oil from paved streets can introduce PAHs into the environment (Konasewich *et al.*, 1982), as can oil spills. In addition, it has recently been recognized that application of coal-tar emulsion sealant to parking lots has become a significant source of PAH loading to urban water bodies in the United States (Mahler *et al.*, in press).

PAHs, especially HPAHs, adsorb strongly to bottom and suspended sediments, especially clay and organic particles; LPAHs, such as naphthalene, can flux between sediments and seawater (Konasewich *et al.*, 1982). Because they have different chemical properties, individual PAH compounds differ in their toxicity, which is in turn affected by salinity (Konasewich *et al.*, 1982). PAHs occur as mixtures, however, and toxicity of PAH-laced sediments can be modeled as a function of the sum of the concentrations of the individual compounds (Swartz *et al.*, 1995). Most organisms can metabolize PAHs, and the metabolites may actually be more harmful than the PAH compounds themselves (Konasewich *et al.*, 1982). Marine organisms tend to bioaccumulate HPAHs to a greater extent than LPAHs (Konasewich *et al.*, 1982). As sediment TOC content increases, PAHs tend to become less bioavailable as they are bound to the organic matter (DiToro *et al.*, 1991).

Except for a small release into surface waters in Pierce County in 2000, virtually no PAH releases into surface waters between 1988 and 2000 were reported under the Toxics Release Inventory program (Washington State Department of Ecology EPCRA database, 2003). Most releases of PAHs are atmospheric, though offsite transfers accounted for about one-quarter of all releases during 1988-2000. Reported releases increased more than 5-fold from 1995 to 2000 (Figure 71). Pierce, Skagit, and Whatcom counties were the primary locations of PAH releases (Figure 71). The levels of PAHs at Thea Foss Waterway (40), in Pierce County, were one to two orders of magnitude higher than at the other PSAMP long-term sediment-monitoring stations. PAH concentrations were higher in 2000 than in 1989-1996 at Bellingham Bay (4), in Whatcom County, and at East Anderson Island (44), in Pierce County.

Stormwater discharges are known to be a major source of contaminants entering the Thea Foss Waterway and other waterways at the head of Commencement Bay (City of Tacoma, 1995). While patterns in levels of some metals at Thea Foss Waterway (40) reflected patterns in precipitation and Puyallup River flow, as discussed above, the same was not true of the PAHs (Appendix G). Remediation of a nearby petroleum tank facility was likely a factor in the drop in PAHs at this station (Coleman, *pers. comm.*).

Recent studies have suggested a connection between increasing PAH concentrations in aquatic sediments and increasing urbanization and motor vehicle use (Van Metre *et al.*, 2000; in press). However, the connection between changes in the amount of PAHs in the sediments of Puget Sound and changes in the population is not straightforward. The population in King County grew 15% in the last decade, and the population of Pierce County grew 19% (Washington State Office of Financial Management, undated). The results in this study indicate that PAHs decreased significantly at Point Pully (38), situated between Tacoma and Seattle; increased at East Anderson Island (44), between Olympia and Tacoma; and stayed the same at Shilshole (29), just north of Seattle. The Whatcom County population grew 31% during the 1990s (Washington State Office of Financial Management, undated); PAHs increased at Bellingham Bay (4) and at the Strait of Georgia (3). The Strait of Georgia PSAMP station (3) is probably more greatly affected by outputs from the Fraser River (Vancouver, BC) than from Whatcom County.

Sterols

Sterols have been used as indicators of sewage (*e.g.*, Norton, 1999). Since the population in Washington counties surrounding Puget Sound increased about 20% from 1990 to 2000 (Washington State Office of Financial Management, undated), it is possible that the increase in sterols at several PSAMP long-term stations reflects increased sewage input.

Chemical analyses of the sterols (beta-coprostanol, beta-sitosterol, and cholesterol) present some of the same difficulties as the analysis of benzoic acid (K. Feddersen, *pers. comm.*). The case narratives published in earlier PSAMP reports (Tetra Tech, 1990; EcoChem, 1993; Washington State Department of Ecology, 1994) and in Appendix B of this report cite violations of QC limits for initial and/or continuing calibration for the analyses of cholesterol, beta-sitosterol, and/or beta-coprostanol in 1989, 1991, 1992, and 1993, and for surrogate recovery in 1989 and 1992. In 1992, the calibration was judged not to have compromised the sterol results (EcoChem, 1993).[3,4]

[3] "Cholesterol and beta-sitosterol each undergo a high level of fragmentation, yielding a small abundance of primary ions and a large number of secondary ions. This results in a smaller RRF [relative response factor] for these compounds [than the EPA CLP Functional Guidelines for initial calibration]. The low average RRF for these compounds is acceptable, and no data are qualified due to this reason." (EcoChem, 1993)

[4] "Cholesterol and beta-sitosterol RRF values were all below the 0.05 minimum [EPA CLP Functional Guidelines for continuing calibration]. As discussed in Section 5.1.4 [initial calibration], this was judged to have no affect [*sic*] on the quality of the data or the detection limits." (EcoChem, 1993)

Comparisons with other studies

Since these ten long-term sediment sampling stations were hand-picked, and therefore cannot be used to state any general conclusions concerning surrounding areas, it is of interest to determine whether the conditions at the ten stations are representative of the waterbodies in which they are located. Comparison of the long-term PSAMP results with those of contemporary studies of nearby areas serves to provide insight into the levels of contaminants in various areas of Puget Sound, as well as to provide some degree of confirmation of representativeness of the single measurements in the PSAMP long-term sediment chemistry analyses. The studies chosen for comparison include the remainder of the original PSAMP sediment-monitoring stations, the 3-year spatial characterization of Puget Sound conducted as a joint effort between PSAMP and NOAA's Status and Trends Program, studies conducted at the mouth of the Thea Foss Waterway prior to cleanup at the head of the waterway, and an examination of a century-plus history of contamination from sediment cores. As described in the following narratives, the results from the PSAMP long-term sediment monitoring program were generally similar to results from studies of nearby locations.

PSAMP/NOAA and Original PSAMP Stations

Benzoic acid levels from 1989 to 1993 at other PSAMP stations (of the original 76 sediment-monitoring locations) situated close to the ten long-term PSAMP stations were similar in magnitude and range to those at the ten long-term PSAMP stations in 1989-1993 (Table 20). However, benzoic acid levels measured at PSAMP/NOAA stations (Long *et al.*, 1999; Long *et al.*, 2000; Long *et al.*, 2002) located near the ten long-term PSAMP stations from 1997 to 1999 were, in some cases, yet another order of magnitude greater than the levels measured in 2000 at the ten long-term PSAMP stations, which were, in turn, an order of magnitude greater than in 1989-1993 (Table 21). While there were no undetected benzoic acid results in 2000 for the ten long-term PSAMP stations, the quantitation limits reported with nondetected results for the PSAMP/NOAA project were 20-30 times higher than those for the ten long-term PSAMP stations in 1989-1993. Further study would be required to determine to what extent the differences in benzoic acid levels at nearby locations reflects true differences in the environment *vs.* refinements in laboratory analysis procedures.

The benzoic acid concentrations reported by the analytical laboratories exceeded the Washington State sediment quality standards only once for the ten PSAMP long-term stations, Inner Budd Inlet (49) in 2000, in contrast to 18 of 100 PSAMP/NOAA samples in northern Puget Sound in 1997, 89 of 100 PSAMP/NOAA samples in central Puget Sound in 1998, and 5 of 100 PSAMP/NOAA samples in southern Puget Sound in 1999, including two of the six stations located in Budd Inlet (Long *et al.*, 1999; Long *et al.*, 2000; Long *et al.*, 2002). Four of the ten long-term PSAMP stations (13R, 40, 44, and 49) correspond to the PSAMP/NOAA's south Puget Sound area, four (Stations 21, 29, 34, and 38) to central Puget Sound, and two (Stations 3 and 4) to northern Puget Sound. Differences in the proportions of stations exceeding the Washington State sediment quality standards may be ascribed partly to the small sample size in the long-term PSAMP stations and partly to the very real differences in the sampling designs for the two studies: many of the original PSAMP stations were chosen deliberately to be away from known point sources of contaminants for the purpose of gaining insight into temporal trends in ambient conditions (Llansó *et al.*, 1998a, 1998b), while the PSAMP/NOAA stations were chosen according to a stratified random design intended to spatially characterize Puget Sound as a whole, including the urban/industrialized embayments (Long *et al.*, 1999; Long *et al.*, 2000; Long *et al.*, 2002).

The concentrations of metals measured in 1997-1999 at PSAMP/NOAA stations near the long-term PSAMP stations were generally similar to the metals concentrations sampled at most of the corresponding long-term PSAMP stations in 2000 (Table 21). The metals concentrations at the PSAMP/NOAA stations in the Thea Foss Waterway and close to Anderson Island were higher than at the nearby PSAMP long-term stations.

The PAH concentrations measured at the long-term PSAMP stations were generally lower than at PSAMP/NOAA stations nearby (Table 21). At one-half of the long-term PSAMP stations, the total organic content was lower than at nearby PSAMP/NOAA stations.

In general, the percent fines (silt + clay) was similar at the corresponding long-term PSAMP and PSAMP/NOAA stations, indicating some degree of uniformity in the sediments over short distances. Percent fines varied widely at the stations in the deep central basin of Puget Sound, however. At the PSAMP/NOAA stations in the Thea Foss Waterway and near Anderson Island, the percent fines was higher than at the corresponding PSAMP long-term stations.

Thea Foss Waterway pre-cleanup

One of three alternatives for cleaning up the Thea Foss and Wheeler-Osgood waterways in Tacoma was a "confined aquatic disposal" (CAD), which would have involved removing sediment from an area at the mouth of the Thea Foss Waterway, disposing of dredged contaminated sediment in the pit, and capping the site (City of Tacoma, 1999). That alternative was not the one chosen for implementation. Studies of the proposed CAD site and the contaminated sites were conducted. In addition, the city of Tacoma published a compendium of all known sediment studies previously conducted in those two waterways (City of Tacoma, 1995). Table 22 compares the sediment characteristics and chemistry of the PSAMP long-term Station 40 to those of the proposed CAD site and of selected nearby stations from two previous studies in the Thea Foss Waterway.

The percent fines and TOC levels were similar at PSAMP Station 40 and the other sites (Table 22). Metals concentrations were similar at PSAMP Station 40, the proposed CAD site, and the Tetra Tech site CI-22, but were considerably higher at Parametrix site A1. Although the metals concentrations were higher at Parametrix site A1 than at PSAMP Station 40, the PAH levels were lower. PAH concentrations at PSAMP Station 40 in 1989-1990 were similar to those at Tetra Tech site CI-22 in 1984, while PAH levels at PSAMP Station 40 after 1990 were similar to those measured at the proposed CAD site.

Dated cores

In 1991, Lefkovitz *et al.* (1997) took six sediment cores approximately 1.5 m in depth from around Puget Sound and sectioned, dated, and analyzed the cores for contaminants. Of those cores, two were located in the general vicinity of PSAMP Stations 29 and 38 (Shilshole and

Point Pully). The authors reported that a number of priority pollutant metals in Core 6 (close to PSAMP Station 38) were found to have been at maximum concentration in sediments dated 1950-1965, then decreased, trends which the authors suggested may have been consequences of tightened environmental legislation (Lefkovitz *et al.*, 1997). The concentrations of those metals at the PSAMP Point Pully location (Station 38) in 1990-91 were consistent with the levels reported for the surface of Core 6 in 1991. Not all analyses were performed on all cores. Several ancillary metals were reported to have been at ambient levels throughout the depths of the cores, while manganese levels were higher in more-recently deposited sediments than in older sediments (Lefkovitz *et al.*, 1997). It was suggested that the latter reflected post-depositional migration and reduction rather than increased input (Lefkovitz *et al.*, 1997).

In sediment cores taken in 1991, Lefkovitz *et al.* (1997) found total PAH levels peaked in sediments dated circa 1940, then decreased until about 1970 and remained relatively constant thereafter. The concentrations of individual PAHs level at Point Pully (38) in the early years of PSAMP appear to have been fairly similar to, or perhaps slightly lower than, those reported for Lefkovitz *et al.*'s Core #6 in 1991 (Table 23), and total PAH was slightly lower.

Relating Benthic Infauna to Chemical and Physical Parameters

The composition of benthic invertebrate communities can be influenced by numerous interrelated physical, chemical, and biological conditions that can change over time (*i.e.*, porewater salinity, water depth and temperature, sediment composition, amount of dissolved oxygen, carbon enrichment, the presence and amounts of both natural and anthropogenic contaminants, amount, frequency and type of physical disturbance, and the presence of other species, both vertebrate and invertebrate). As stated previously, the stations sampled in this study were deliberately selected to represent a range of water depths, sediment types, potential contamination, and geographic location within Puget Sound. Thus, a variety of benthic communities was sampled due both to different physical locations and to temporal changes within the communities.

Sediment composition at some stations changed considerably over the period of study, some apparently directly related to fluvial input to Puget Sound, which is itself related to precipitation. Precipitation, in turn, is affected by hemispheric weather and ocean conditions. In particular, in the Puget Sound region, warmer, drier winters tend to accompany El Niño conditions in the southern Pacific Ocean, and cooler, wetter winters tend to accompany La Niña conditions (Newton *et al.*, 2002). As well, since there is exchange, via the Strait of Juan de Fuca, between the Pacific Ocean and Puget Sound, Pacific upwelling associated with El Niño conditions can and does affect conditions in the water column in Puget Sound, including temperature, salinity, and dissolved oxygen (Newton *et al.*, 2002), which affect the organisms inhabiting Puget Sound. Although benthic organisms are more resistant to conditions of low dissolved oxygen than are many other organisms, oxygen depletion can have a considerable impact on benthic communities (Newton *et al.*, 2002).

The multidimensional scaling (MDS) map confirms the selection of the ten long-term sediment-monitoring stations from the original 76 in 1997 based on, among other characteristics, differing benthic infaunal communities. It would be expected that, barring large shifts in community composition, samples taken in different years at the same station would cluster close together in a multidimensional scaling analysis. With the exception of 1989 at Strait of Georgia (3), that expectation was largely met, though it can be seen from the MDS map that the infaunal assemblages at some stations were more consistent over time than others (Figure 51). At Strait of Georgia (3), taxa richness was considerably higher in 1989 than in other years. The proportion of annelids among all benthic infauna at that station decreased from almost 75% in 1989 to less than 50% 1990, and the mollusc proportion increased concomitantly.

It might also be expected that stations close together geographically might have similar macrobenthic communities, which would be reflected in proximity of sample points on the MDS map. That expectation was not met, confirming that geographic proximity is not the primary controlling factor. Examination of the physical and biological characteristics of the stations indicates that the first (horizontal) dimension in the MDS map approximately corresponds with taxa richness, abundance, diversity, and grain size (Figure 74 = MDS map with arrow). No similar correspondence was found to relate to the second (vertical) dimension. The infaunal assemblages at Shilshole (29) and Point Pully (38) are quite similar (Figure 51). Both of those stations are deep-water stations (~200 m) in the central basin of Puget Sound.

Strait of Georgia (3), Shilshole (29), and Point Pully (38) are deep-water stations (> 200 m) with mixed sediments. Strait of Georgia (3) differed from both Shilshole (29) and Point Pully (38) in having more gravel and sand and less clay in the sediments. Strait of Georgia (3) also had a unique invertebrate community, characterized by high variability from year to year, generally low total abundance, and low taxa richness that decreased even more over the years of the study. Enrichment (and possibly toxicants) in the form of silt from the Fraser River appeared to have a profound effect on the community, especially in 1997 (a high flow year for the Fraser River), when the highest silt-clay proportion of all the years (about 98%) coincided with low taxa richness, SDI, evenness, and diversity values. In 1997, there also was a change in the dominant species in the community, with a spike in the abundance of *Cossura pygodactylata* and decreased abundances of *Prionospio*, *Pholoe*, and *Macoma* spp. As the silt proportion in the sediment decreased in the years following 1997, *Cossura* numbers decreased and the abundance of the other three genera increased, with a huge jump in the numbers of *Macoma* and *Yoldia* in 2000. Unfortunately, since sediment chemistry wasn't sampled in 1997 (and no sampling of the station was conducted in 1996), it is impossible to assess the presence or influence of toxicants potentially delivered with the silt from the Fraser River in 1997. Although there was an overall increase in TOC at that station, which may have been associated with the Fraser River silt deposited in the Strait of Georgia, there were no relationships detected between the bioindices and any physical parameter, including sediment chemistry.

Shilshole (29) and Point Pully (38) had similar sediments, with consistently high proportions of silt-clay over the years, though Point Pully had higher clay amounts than Shilshole. These two stations had the most similar invertebrate communities of all the stations in the study. Although Point Pully (38) generally had higher diversity, evenness, SDI values, and Mollusca abundance than Shilshole (29), while Shilshole had higher total abundance, the two stations had similar taxa richness values and proportions of the other four major taxa. Both communities were dominated by bivalves, specifically *Macoma carlottensis* and *Axinopsida serricata*, as well as the ostracod *Euphilomedes producta* and the cumacean *Eudorella pacifica*; fluctuations in the total abundance at both stations were most closely tied to changes in mollusc abundance. Mollusca, Crustacea, and Annelida abundance at the two stations appeared to fluctuate in a cyclical pattern (similar to those described in Nichols, 2003), though it was not possible to determine what specifically was causing these cycles. They may be related to naturally-occurring cycles within the invertebrate communities or to some factor or combination of factors not measured during the study. While it is possible that the increase in annelids, arthropods and especially molluscs at Point Pully (38) in 2000 may relate to changes in the sediment chemistry, specifically the decrease of several metals and PAHs between 1996 and 2000, a similar increase in these three major taxonomic groups also occurred in 2000 at Shilshole (29), where there were few changes in contaminant levels. In both cases, increases in the abundances of the bivalves *Axinopsida serricata* and *Macoma carlottensis* were largely responsible for the increase in total abundance in 2000. *Axinopsida serricata* is an opportunistic species that has been found to be pollution- and enrichment-tolerant in previous studies (Llansó *et al.*, 1998b).

Bellingham Bay (4), Sinclair Inlet (34), and Inner Budd Inlet (49) are shallow stations (<30 m) with predominantly silt-clay sediments. At all of these stations, high proportions of annelids accounted for the fluctuations in total abundance; however, the dominant species of annelids were different at each of the stations. The annelid fauna in Bellingham Bay (4) was dominated primarily by *Levinsenia gracilis* and *Cossura pygodactylata* which, after 1997, were joined by *Aricidea* spp.; Sinclair Inlet (34) was dominated by *Phyllochaetopterus prolifica* and *Aphelochaeta* sp. N1; and the majority of annelids at Inner Budd Inlet (49) were *Paraprionospio pinnata* and *Aphelochaeta* sp. N1.

Bellingham Bay (4) differed from the other two stations in being located in relatively open water in rural surroundings. It had more balanced proportions of all the major taxa groups, with a somewhat lower proportion of annelids and a higher proportion of echinoderms (the highest of all the stations in the study). The echinoderms present at Bellingham Bay (4) were primarily *Amphiodia* spp., which are considered to be sensitive to contaminants (PTI, 1993). Bellingham Bay (4) also had moderate total abundance and high evenness across all the years. Taxa richness was high at Bellingham Bay (4), though it declined between 1995 and 1998, then increased somewhat in 1999 and 2000. PAH contamination at the station increased between 1989-1996 and 2000, and concentrations of a few metals decreased. Fluctuations in the abundances of the dominant species at the station (*Amphiodia* spp., *Armandia brevis*, *Levinsenia gracilis*, and *Axinopsida serricata*) were not obviously connected to changes in grain size or sediment chemistry, and may well have been influenced by a number of factors. Based on the moderately high total abundance, the high taxa richness and diversity, and the presence of the pollution-sensitive *Amphiodia* spp., the invertebrate assemblage at Bellingham Bay (4) appears to be a relatively healthy benthic community.

Sinclair Inlet (34) and Inner Budd Inlet (49) are both urban embayments that are dominated by annelids and have low mollusc abundance. Both stations were subject to moderate to high total sulfides (Llansó *et al.*, 1998a) and periods of low dissolved oxygen (Newton *et al.*, 2002; Albertson *et al.*, 1995). Although total sulfides were not analyzed after 1993, the sediments at both stations had a notable sulfur odor when samples were taken each year (Field Notes, Appendix A). Acid-volatile sulfide (AVS) is the determining factor in the toxicity of five divalent metals (DiToro *et al.*, 1990; DiToro *et al.*, 1992; Casas and Crecelius, 1994). At Sinclair Inlet (34), the invertebrate community seemed to be structured around the presence and relative abundance of *Phyllochaetopterus prolifica*, a tube-dwelling polychaete which usually occurs in dense mats with high numbers of individuals (Scott *et al.*, 1996) and which is thought to be tolerant of higher total sulfide conditions (Llansó *et al.*, 1998b). The higher the numbers of this species at Sinclair Inlet (34), the lower the diversity, evenness and dominance index. Taxa richness, which was relatively high at Sinclair Inlet (34), also tended to decrease when *Phyllochaetopterus* abundance was higher, even though it remained relatively high throughout the years regardless of the abundance of *Phyllochaetopterus*. This phenomenon may be related to the variable community which can inhabit the tube masses of *Phyllochaetopterus prolifica*. *Aphelochaeta* sp. N1, a polychaete that has been found to be tolerant of contaminated conditions, increased in abundance from 1989 to 1997, then dropped dramatically; at the same time, *Amphiodia* spp. and *Eudorella pacifica* generally increased in abundance.

At Inner Budd Inlet (49), all of the bioindices had low values over all years. None of the species at the station were represented by more than a few individuals throughout the years of the study. There were also notable changes in the species composition at Inner Budd Inlet (49) between the early years of the study and the later years. From 1989-1991, the station was dominated by *Pinnixa schmitti* and *Paraprionospio pinnata*, then *Pinnixa* decreased in abundance, and *Aphelochaeta* spp. became a dominant species with *Paraprionospio*. *Amphiodia* spp., *Alvania compacta, Ampelisca* spp., *Eudorella pacifica, Heterophoxus* spp., *Rhepoxyynius dabious*, and *Pholoe* spp. were all present in the earlier years of the study, but were absent in the community from 1995 on; after 1994, *Acteocina culcitella, Ampharete labrops*, and *Micrura* sp. were present. Overall, the infaunal community at Inner Budd Inlet (49) appears to be affected by adverse conditions, even though metals contamination decreased between 1989-1996 and 2000. Large changes in the dominant taxa at the Budd Inlet station (49) may be influenced by site-cleanup activity around the federal superfund Cascade Pole cleanup site in Olympia.

Port Gardner (21) is a shallow station (22 m) with mixed sand and silt-clay sediments. The station had relatively high total abundance and taxa richness; and diversity, evenness and the dominance index tended to increase over the years. Molluscs dominated the station, primarily the opportunistic bivalves *Axinopsida serricata* and *Macoma carlottensis*. There was also a high proportion of arthropods compared to other stations in the study, primarily *Euphilomedes* spp. There was a strong positive correlation between percent fines and metals contamination at Port Gardner (21). Both percent fines and the mean metals SQS quotient were unusually high in 1991 (Figure 54). Metals contamination and total organic carbon content decreased from 1989-1996 to 2000. Additionally, the abundance of annelids, molluscs and arthropods tended to decrease when fines increased. For instance, from 1989 through 1991, percent fines increased; at the same time, mollusc and arthropod abundance decreased. Then, in 1992, fines decreased and mollusc and arthropod abundance rebounded. This pattern is repeated to some extent over all the years of the study. Annelids followed a similar, though not identical, pattern. Thus, there is some indication that metals contamination may have had an effect on the benthic community at this station.

North Hood Canal (13R), Thea Foss Waterway (40), and East Anderson Island (44) are all shallow stations (< 25 m) with predominantly sandy sediments. North Hood Canal (13R) was sampled for infauna only seven of the 12 years of the study, but showed remarkable stability in the benthic community over the years. There was little change in sediment composition during the study, and the three numerically-dominant species, *Nutricola lordi, Alvania compacta*, and *Euphilomedes carcharodonta*, remained the same from year to year. No trends or changes in sediment chemistry could be detected due to the sporadic nature of the chemistry sampling. Overall, North Hood Canal (13R) had low evenness and dominance index values, but very high taxa richness, and high total abundance driven mostly by large numbers of *Nutricola lordi*. The abundance of this bivalve increased and decreased in an apparent cyclical pattern, peaking in 1997 and 1998, then decreasing to abundances similar to earlier years. Unfortunately, because the station was sampled only every three years from 1989 to 1997, it is impossible to say exactly what occurred in the community in the years that were not sampled. Information from those years could differ significantly from the years sampled.

Although Thea Foss Waterway (40) differs from East Anderson Island (44) in being in an urban embayment close to known contaminated sites, both stations have high taxa richness, diversity and dominance values and moderate evenness values, though the values of all of these bioindices are higher at East Anderson Island (44). Both stations have a moderately high total abundance with good representation from all of the major taxa groups, including echinoderms and miscellaneous taxa. The benthic invertebrate community at Thea Foss Waterway (40) underwent some changes in dominant species over the years of the study. The station was dominated primarily by *Aphelochaeta* sp. N1, *Axinopsida serricata*, and *Euphilomedes carcharodonta* from 1989-1993, then *Aphelochaeta* abundance dropped off and *Prionospio* spp. abundance increased. By 1995, *Amphiodia* spp. were increasing in abundance, and by 1997 *Amphiodia* was in the top three numerically-dominant species. In 2000, however, *Amphiodia* abundance declined and *Aphelochaeta* sp. N1 was once again one of the top three most-abundant species at the station. These changes in species composition, and simultaneous increases in echinoderm, mollusc, and total abundance, may be related to decreases in several primary pollutant metals and lower PAH levels at Thea Foss Waterway (40) from 1991 on, though a few individual LPAH values increased between 1989-1996 and 2000. Remediation of a nearby petroleum tank facility was likely a factor in the drop in PAHs at station 40 (Coleman, *pers. comm.*)

East Anderson Island (44) also showed a shift in species composition between 1989-1991 and 1992-2000. In the earlier years, the station was dominated by *Phyllochaetopterus prolifica, Prionospio* spp., and *Pinnixa schmitti*. *Phyllochaetopterus* decreased in abundance until 1997, when it completely disappeared from the station. During that time, *Amphiodia* spp. increased in numbers, and became the second most abundant species in 1997. Between 1997 and 1998, abundances of annelids and arthropods decreased by 50%, and then increased again in 2000, though not to the levels of previous years. Echinoderm abundance increased gradually from 1989 to a high in 1997, then decreased sharply in 1998-2000. As in Thea Foss Waterway (40), these changes in the community at East Anderson Island (44) seem to be cyclical. The benthic community composition changes may be related to increases in PAH concentrations between 1989-1996 and 2000. However, since chemical analyses were not performed in the critical years from 1995 to 1999, when *Amphiodia* (a pollution-sensitive species) peaked and then declined, the exact relationship between the benthic community and chemical contamination cannot be defined.

Summary and Conclusions

Summary

Data from ten long-term sediment monitoring stations were collected from 1989 through 2000 as part of the Puget Sound Ambient Monitoring Program's Sediment Component. These data have been summarized and analyzed to establish a 12-year record of sediment conditions for a variety of habitats and geographic locations throughout Puget Sound, to identify significant changes in physical, chemical, and biological sediment parameters that have occurred over time; and to evaluate over time the condition of Puget Sound benthic infaunal invertebrate communities in relation to natural and anthropogenic changes in sediment quality. With the aid of summary statistics, a series of temporal change and trend analyses, and correlative analyses, the unique patterns in the suite of parameters at the ten long-term stations have been well-characterized, documenting the heterogeneity of habitat types throughout the estuary. While many of these parameters were stable over time, a number were identified as having changed significantly, potentially in relation to both anthropogenic and natural changes in environmental conditions.

The ten stations had a wide variety of grain size characteristics, ranging from predominantly sand to a predominantly silt-clay matrix. While the grain size composition of the majority of stations did not change over time, a notable change was seen at Strait of Georgia (3), which displayed a significant increase in percent fines (specifically, the silt fraction) during 1997. Lying within the influence of British Columbia's Fraser River discharge plume, change in grain size at this station appeared to be linked to increased precipitation and subsequent increased flow of the Fraser River in 1996 and 1997. Major changes in benthic infaunal community composition (*e.g.*, lowered taxa richness, SDI, evenness, diversity, and change in the dominant species) also occurred at this station during this time period, appearing to be associated with this natural disturbance.

Reflecting the "ambient" nature of the majority of these stations, which are located at a distance from urban areas and point source discharges, only about one-third (32%) of 12,909 chemical analyses resulted in values reported above the laboratory reporting limits for the parameters tested. Of the detected pollutants, only a small percentage was detected at levels exceeding either state sediment quality criteria or national guidelines. The only persistent cases of contaminant concentrations exceeding sediment quality guidelines were mercury at Sinclair Inlet (34) and a few PAH compounds at Thea Foss Waterway (Station 40). Sinclair Inlet had the highest concentration of metals overall, and the PAH concentrations at the Thea Foss Waterway station were one to two orders of magnitude greater than at the other sediment monitoring locations.

Change and trend analysis of the chemical contaminant data set indicated that, in general, metals concentrations in 2000 were lower than in 1989-1996 far more often than they were higher, while the opposite was true of PAHs. At two of the ten stations, Port Gardner (21) and Inner Budd Inlet (49), the concentrations of a number of priority pollutant and ancillary metals decreased significantly. Individual PAH levels decreased at the Point Pully (38) station, but increased significantly at the Bellingham Bay (4), Port Gardner, and East Anderson Island (44) stations. Total HPAH levels increased significantly at the Bellingham Bay (4) and East Anderson Island (44) stations. Total LPAH levels increased significantly at the Strait of Georgia (3), Bellingham Bay (4), East Anderson Island (44), and Budd Inlet (49) stations. Total PAH levels increased significantly at the Bellingham Bay (4), East Anderson Island (44), and Budd Inlet (49) stations. These decreases and increases in metal and PAH concentrations, respectively, appear to correspond with results from other aquatic sediment contaminant trend monitoring programs, and may reflect changes in anthropogenic input of contaminants to the estuarine system (*e.g.*, decrease of metals from point source discharges, increase in PAH discharge from nonpoint sources such as urban and suburban runoff).

Among the other organic compounds detected, there generally were more increases in concentration over time than decreases. In particular, the levels of benzoic acid and sterols were higher in 2000 than in 1989-1993. While some of the increase in those compounds may reflect the increase in human population around Puget Sound, in the case of benzoic acid, the magnitude and extent of the increase more likely reflects increased sensitivity in laboratory analytical procedures.

Examination of the benthic infaunal community structure, in relation to the chemical and physical parameters measured at each station, helps to characterize and elucidate possible relationships between the variables at each station. First, as per the program design and intent, it was apparent that each station had a unique combination of station variables, underscoring the heterogeneity of Puget Sound's benthic environment. This was not an unexpected finding, as these stations were chosen from the original set of 76 long-term monitoring stations because of their differences from one another. Unique patterns seen at the ten stations include, in brief, the following:

- **Strait of Georgia (3)** – This is a deep station (~223m), with grain size composition that changed significantly over time. As indicated above, enrichment in the form of silt from the Fraser River appeared to have a profound effect on the physical structure of the sediment matrix and the infaunal invertebrate community at this station, especially in 1997 (a high flow year for the Fraser River), when the highest silt-clay proportion of all the years (about 98%) coincided with low taxa richness, SDI, evenness, and diversity values. In 1997, there also was a change in the dominant species in the community. The community tended to shift back toward its original structure as the percent fines decreased in subsequent years.

- **Bellingham Bay (4)** – This shallow station (~20m), with predominantly silt-clay sediments located in open water rural surroundings, possessed a relatively healthy benthic community with high total abundance, taxa richness, and diversity. Dominant organisms included the annelids *Levinsenia gracilis* and *Cossura pygodactylata*, and the pollution-sensitive echinoderm *Amphiodia* spp. was present. Although PAH contamination at this station increased between 1989-1996 and 2000, and concentrations of a few metals decreased, fluctuations in the community structure were not obviously connected to changes in grain size or sediment chemistry, and may have been influenced by other unmeasured variables.

- **North Hood Canal (13R) –** Although originally one of the program's rotational stations, and therefore only sampled three times through 1996, this shallow (~20m), rural station showed little change in its predominantly sandy sediment composition during the study, and remarkable stability in the benthic community over the years. The infaunal community was characterized by low evenness and dominance values, but very high taxa richness, and high total abundance driven mostly by large numbers of *Nutricola lordi*, which increased and decreased in an apparent cyclical pattern. Three species, *Nutricola lordi, Alvania compacta*, and *Euphilomedes carcharodonta*, remained dominant from year to year. No trends or changes in sediment chemistry could be detected due to the sporadic nature of the chemistry sampling.

- **Port Gardner (21) –** This is a shallow station (~20m) with mixed sand and silt-clay sediments. The station had relatively high total abundance and taxa richness; and the diversity, evenness, and dominance indices tended to increase over the years. Molluscs dominated the station, including the opportunistic bivalves *Axinopsida serricata* and *Macoma carlottensis*, along with a high proportion of the arthropod *Euphilomedes* spp. Metals contamination and total organic carbon content decreased from 1989-1996 to 2000; there was a strong positive correlation between percent fines and metals contamination; and the abundance of annelids, molluscs and arthropods tended to decrease when fines increased. Thus, there is some indication that change in grain size distribution (*i.e.*, decrease in percent fines) and the associated metals contamination may have had an effect on the benthic community at this station.

- **Shilshole (29) and Point Pully (38)** – These two deep (~200m), depositional stations, located in the main basin of central Puget Sound, had the most similar sediment characteristics of all the stations. Both had high proportions of silt-clay over the years, and communities dominated by two opportunistic pollution-tolerant bivalves, *Macoma carlottensis* and *Axinopsida serricata*. Abundance of Mollusca, Crustacea, and Annelida at these two stations appeared to fluctuate in a cyclical pattern. Although PAH levels appeared to decrease at Point Pully from 1989-1996 *vs.* 2000, no clear patterns in these cyclical fluctuations were seen in relation to measured sediment variables. They may be related to naturally occurring cycles within the invertebrate communities, or to some factor or combination of factors not measured during the study.

- **Sinclair Inlet (34)** – This shallow urban station (~10m), with predominantly silt-clay sediments and a strong sulfur odor, had an infaunal community dominated by the annelids *Phyllochaetopterus prolifica* (tolerant of higher total sulfide conditions) and a species of *Aphelochaeta* polychaete (also thought to be pollution-tolerant), and low mollusc abundance. Although there were no definitive patterns seen between community structure and chemical contaminants levels at this station, there was a significant decreasing trend in the levels of some metals, along with an increase in the abundance of pollution sensitive echinoderm species, *Amphiodia* spp.

- **Thea Foss Waterway (40) –** This is a shallow urban station (~10m), close to known contaminated sites, with predominantly sandy sediments. Infaunal communities had high taxa richness, diversity and dominance values, moderate evenness values, and moderately

- high total abundance with good representation from all of the major taxa groups, including echinoderms and miscellaneous taxa. Changes in the suite of dominant species occurred over the years of the study, shifting from a pollution-tolerant species of polychaete, *Aphelochaeta* sp. N1, to the polychaete *Prionospio* spp., and then to the pollution-sensitive echinoderm Amp*hiodia* spp. In 2000, however, *Amphiodia* spp. abundance declined and *Aphelochaeta* sp. N1 was once again one of the top three most abundant species at the station. These changes in species composition, and simultaneous increases in echinoderm, mollusc, and total abundance are suggestive of a cyclical pattern in the population structure, though may be related to decreases in several primary pollutant metals and lower PAH levels at Thea Foss Waterway from 1991 on (though a few individual LPAH concentrations increased between 1989-1996 and 2000).

- **East Anderson Island (44) –**East Anderson Island is a shallow (20m), rural/suburban station with predominantly sandy sediments. The infaunal community possessed high taxa richness, diversity and dominance values, moderate evenness values, and moderately high total abundance with good representation from all of the major taxa groups, including echinoderms and miscellaneous taxa. As in the Thea Foss Waterway (40), East Anderson Island also showed a shift in species composition between 1989-1991 and 1992-2000, with the echinoderm abundance and numbers of *Amphiodia* spp. increasing gradually from 1989 to a high in 1997, then decreased sharply in 1998-2000. Also like the Thea Foss Waterway (40), these changes in the community at East Anderson Island seem to be cyclical, but may be related to significant increases in PAH values at this station between 1989-1996 and 2000.

- **Inner Budd Inlet (49)** – This shallow station (5-6m), with predominantly silt-clay sediments, located in an urban environment, was characterized by infaunal communities with extremely low abundance and species composition that changed dramatically between years. Despite a significant decrease in the levels of nine of twelve metals between 1989-1996 and 2000, the infaunal community appears to be adversely affected by conditions at this station.

Conclusions

The data collected at these ten monitoring stations provide a valuable record of the physical, chemical, and biological structure, and changes over time, of Puget Sound's benthic habitat. A number of observations and conclusions are noteworthy based on examination of these data.

- Analyses of sediment parameters at the ten long-term stations elucidate the structural, chemical, and biological heterogeneity of benthic habitats throughout Puget Sound, and emphasize the differences between geographic locations. These stations appear to be reasonably representative of their local surrounding areas, and the differences in their sediment characteristics underscore the need for focused studies throughout Puget Sound to understand the local dynamics of the different geographic regions of the estuary.

- Changes and trends in benthic parameters at these long-term stations appear to have occurred in response to both natural environmental phenomena and anthropogenic disturbance. Many patterns are difficult to recognize, and many are recognizable only when they occur on a large scale or are observed after years of repeated sediment collection and testing. Among the more obvious patterns observed from 1989 through 2000 are the following:

- Changes and trends in sediment grain size at one station in the Strait of Georgia appeared to be related to large scale changes in regional climatic phenomena, *i.e.*, increases in rainfall and fluvial input of silt, clay, and organic carbon to the estuarine system. These changes appeared to have a major influence on the infaunal community composition at this station, and were detected and recognized only because samples were collected annually.
- Changes and trends in chemical contaminant levels in the sediments were observed for specific compounds and suites of compounds both within and among stations. An overall decrease in metals contamination and an increase in PAH levels may reflect changes in anthropogenic activity that have occurred over the past decade.

- Some of the changes and trends in the structure of the biological communities at these stations as observed over time are extremely complex, subtle, and difficult to relate to changes in measured physical and chemical sediment parameters. In addition, after years of observation, some of the community structure changes appear to be related to naturally occurring population cycles (also reported by Nichols, 2003) and/or responding to environmental variables not measured by this program.

- Interpretation of changes in the infaunal communities in relation to other sediment variables measured would be greatly improved with the development of well-tested and reliable indices of estuarine biotic condition, as have been developed elsewhere in the US (Weisberg *et al.*, 1997; Van Dolah et al., 1999; Smith *et al.*, 2001; Llansó *et al.*, 2002; Thompson and Lowe, 2004) that serve to relate and simplify the multitude of biotic parameters measured and calculated. Such indices should be generated based on relationships seen and interpreted from this and other existing benthic infaunal data sets that have been collected from Puget Sound and taxonomically standardized to one another.

- Some of the observed changes and trends seen in sediment parameters at these stations may serve as indicators or “red flags”, highlighting both general trends in the health of the Puget Sound ecosystem and emerging issues of concern. Some specific changes and trends seen in these data raise interesting questions about the dynamics of anthropogenic activity in the Puget Sound watershed and potential impacts to the estuarine sediments. For example, a decrease in the overall contaminant levels at Point Pully (38), generally considered a deep depositional station in the central basin of Puget Sound near a large urban center, may indicate a general improvement in point- and nonpoint source discharge of the measured contaminants to this area. The increase in the PAH levels at the East Anderson Island station (44) may be indicative of nonpoint sources of runoff and pollutants from the rapidly growing urban and suburban areas in the southern part of the Puget Sound basin. Large changes in the dominant taxa at the Budd Inlet station (49) may be influenced by site-cleanup activity around the federal superfund Cascade Pole cleanup site in Olympia. These changes raise interesting questions about the dynamics of anthropogenic activity in the Puget Sound watershed and potential impacts to the estuarine sediments, again highlighting the need for focused studies in these areas.

- It is recognized that a number of environmental variables, both natural and anthropogenic, that are not measured by this study, may influence the sediment-dwelling biota. These factors include, in part, the level of dissolved oxygen present in the sediments, concentrations of nutrients in the sediments and their flux between the sediment bed and water column, unregulated pollutants including the newly emerging pollutants of concern such as polybrominated diphenyl ethers (PBDEs) and endocrine disruptors, effects of reproduction and recruitment of infaunal species, effects of predation, oceanographic conditions, etc. The effects of these environmental variables certainly must play a large role in influencing the quality of sediments throughout Puget Sound and cannot be ignored. They should be factored into the long-term monitoring program, including further integration of the PSAMP monitoring components, as time and money allow.

Sediments play an important role in the estuary, harboring microorganisms and invertebrates important in nutrient cycling and in the food web, and they are the ultimate repository and record of both natural changes (*e.g.*, grain size changes due to fluvial input) and anthropogenic contaminants entering the estuary through both point and nonpoint sources. With this PSAMP Sediment Component 12-year time series of the benthic infauna community structure (sampled annually) and sediment chemistry (sampled annually for 7 years, then changed to every 5^{th} year), we are beginning to discern both changes and temporal trends in these sediment parameters, and some of the factors influencing them. To maintain this time series, benthic infaunal samples have been collected and processed from these 10 stations for 2001-2004, and both infauna and levels of chemical contamination were sampled in April 2005 and will be processed, extending the data record through 17 years. Comprehensive analysis of these new data will be conducted to determine recent changes and trends in Puget Sound sediments. The 2005 (and future) sediment chemistry monitoring includes collection and analysis of three replicate samples per station to allow better estimation of variability at each station.

Although sediment is collected and analyzed for many other programs and purposes in Puget Sound, no other survey exists for the simultaneous, standardized long-term monitoring of benthic conditions throughout Puget Sound's wide diversity of habitat types. The PSAMP Sediment Component data provide the only record and perspective on long-term status, changes, and trends over time of the sediment biota and chemistry. These data are a vital record of past and existing conditions, and provide the only internally consistent, standardized record with which to assess the effects of catastrophic changes in the Puget Sound environment (*e.g.*, global warming, introduction of invasive species, major oil spill). When such events happen, it is impossible to measure the extent of their impact without knowledge of prior, existing conditions. For these reasons, the PSAMP Sediment Component will continue to collect and maintain a record of conditions at this small, but important, set of long-term sediment sampling stations.

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Figures

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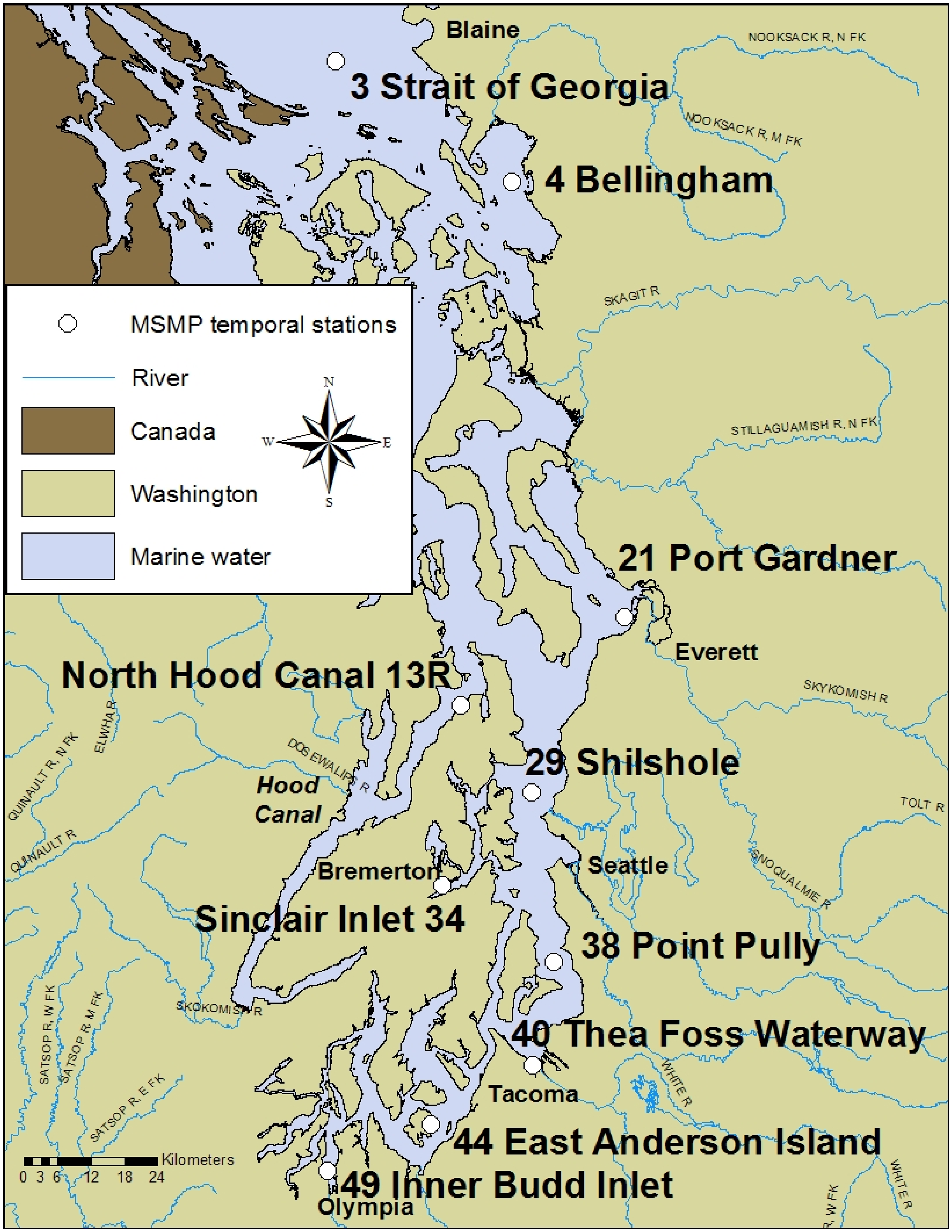


Figure 1. PSAMP long-term sediment monitoring station locations.

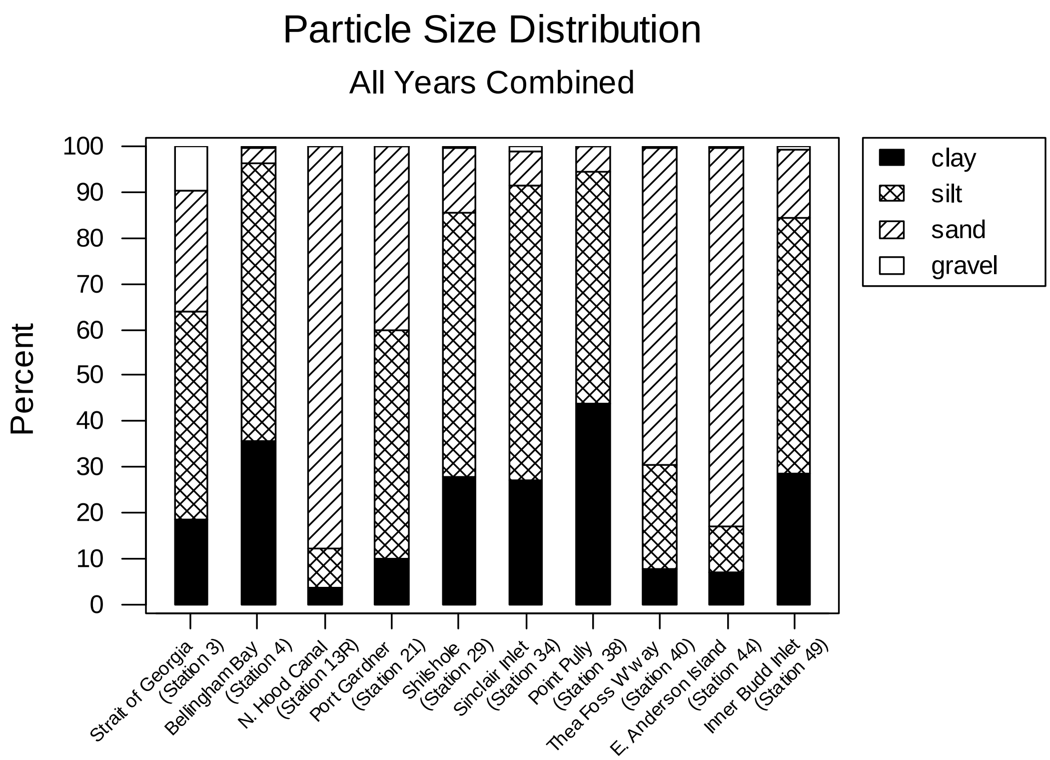


Figure 2. Grain-size distribution at the PSAMP long-term sediment monitoring stations, 1989-2000.

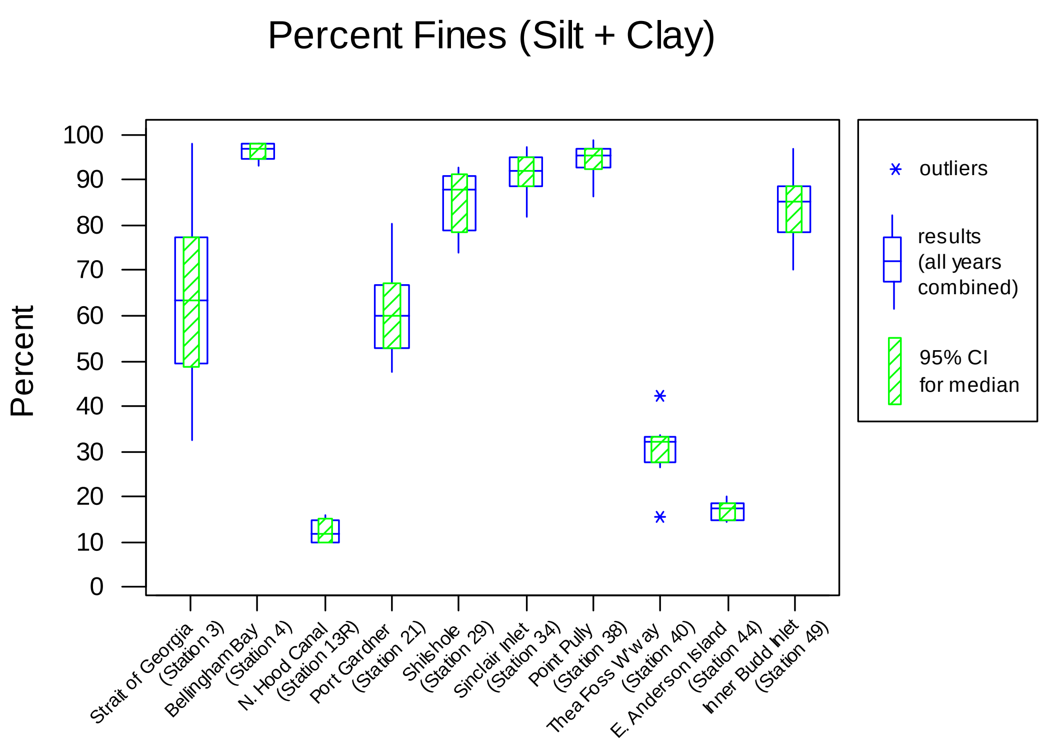
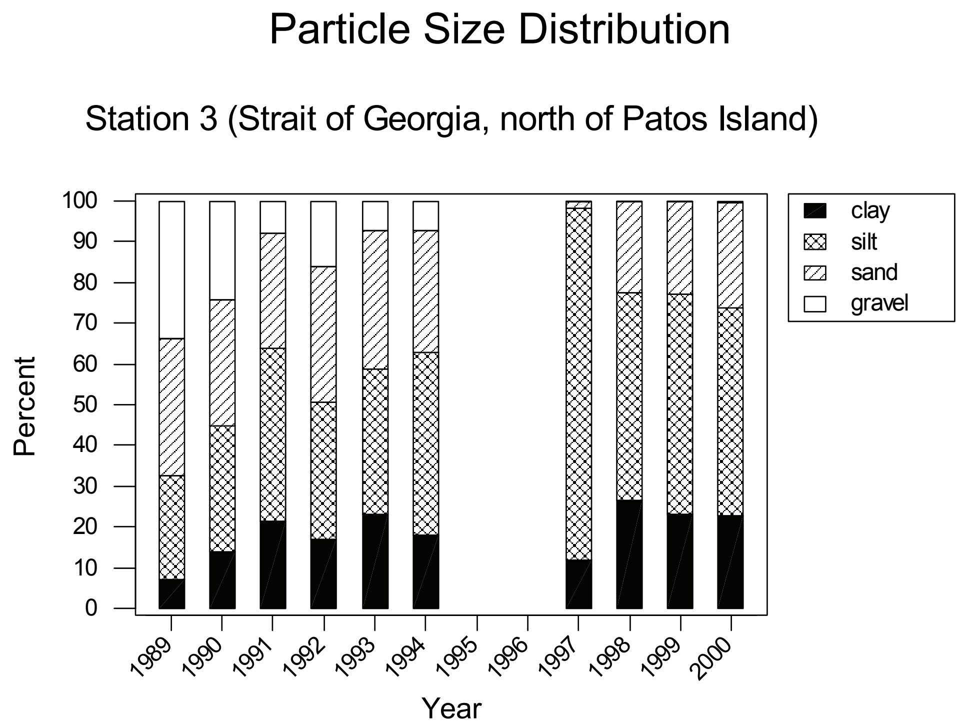


Figure 3. Percent fines (silt-clay) at the PSAMP long-term sediment monitoring stations, 1989-2000. Boxplots display median (50th-percentile), 25th-percentile, 75th-percentile, and extreme values of the results, with a 95% confidence interval for the median (diagonally-striped rectangle). The width of the boxplot is proportional to the number of observations.



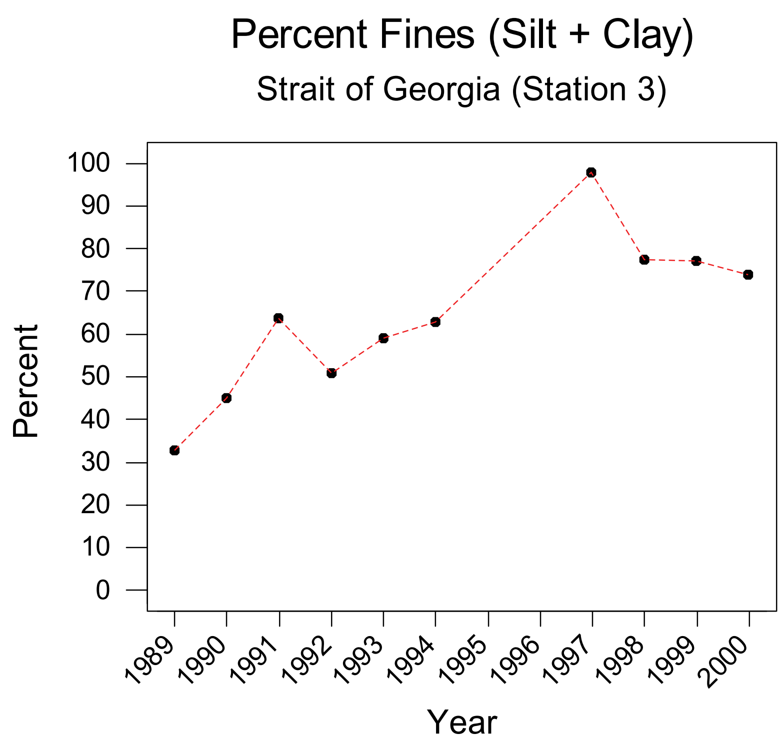
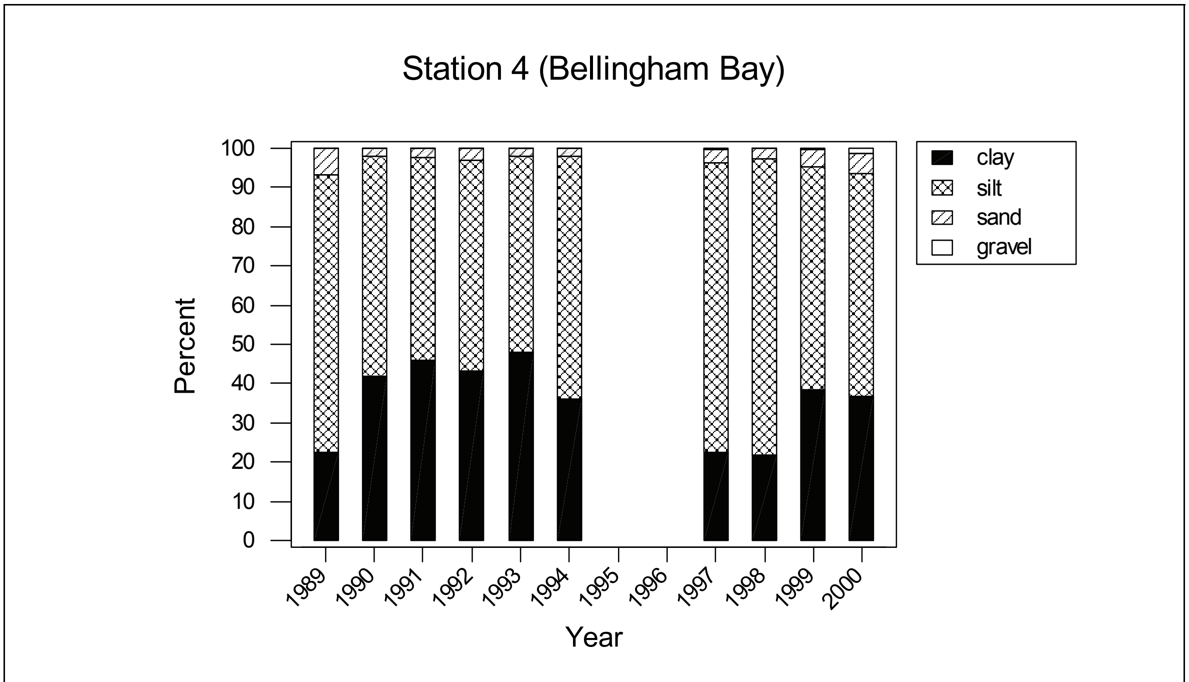


Figure 4a. Sediment grain-size distribution (top) and percent fines (bottom) by year for the Strait of Georgia station.

Particle Size Distribution



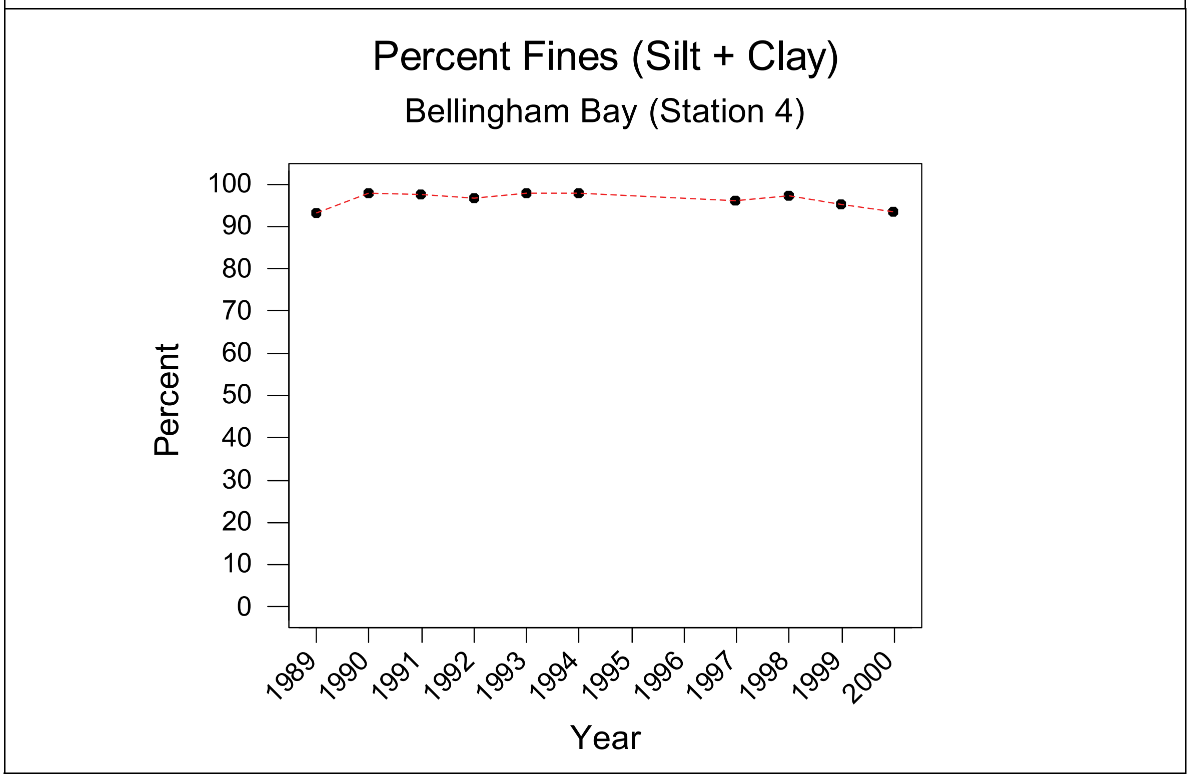
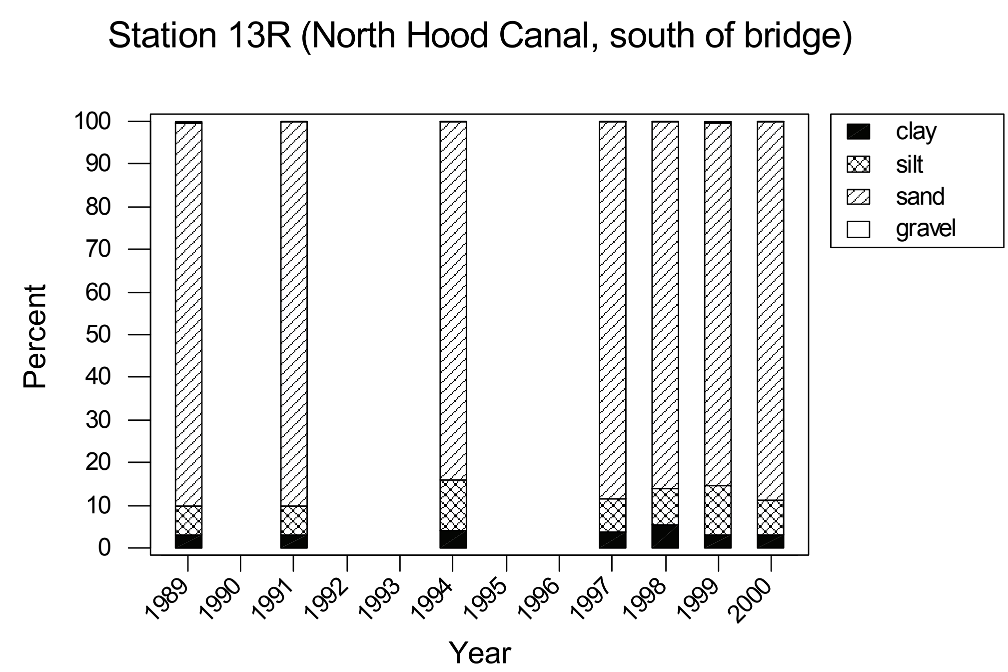


Figure 4b. Sediment grain-size distribution (top) and percent fines (bottom) by year for the Bellingham Bay station.

Particle Size Distribution



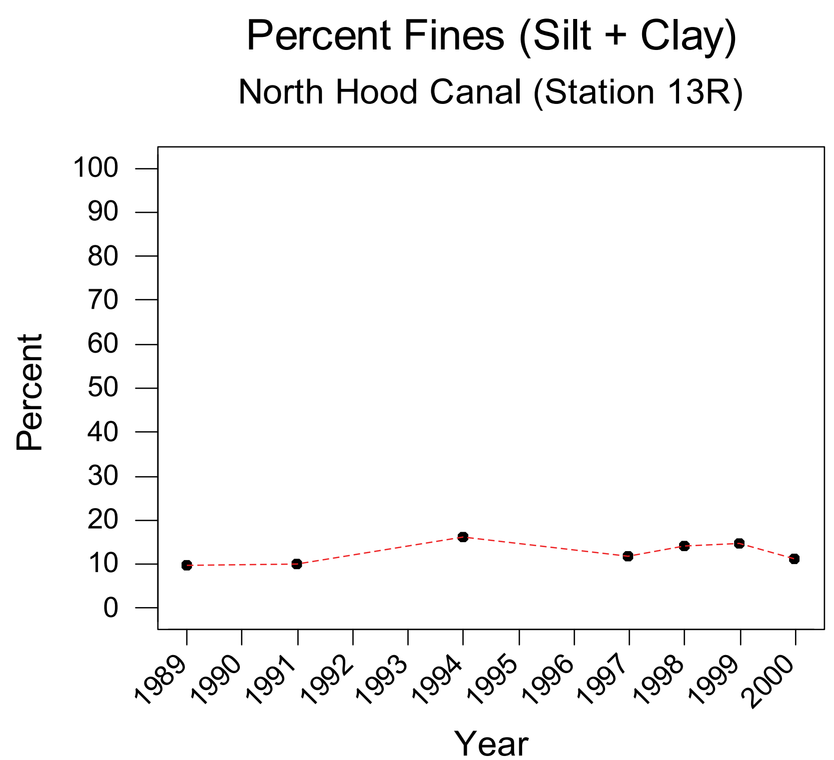
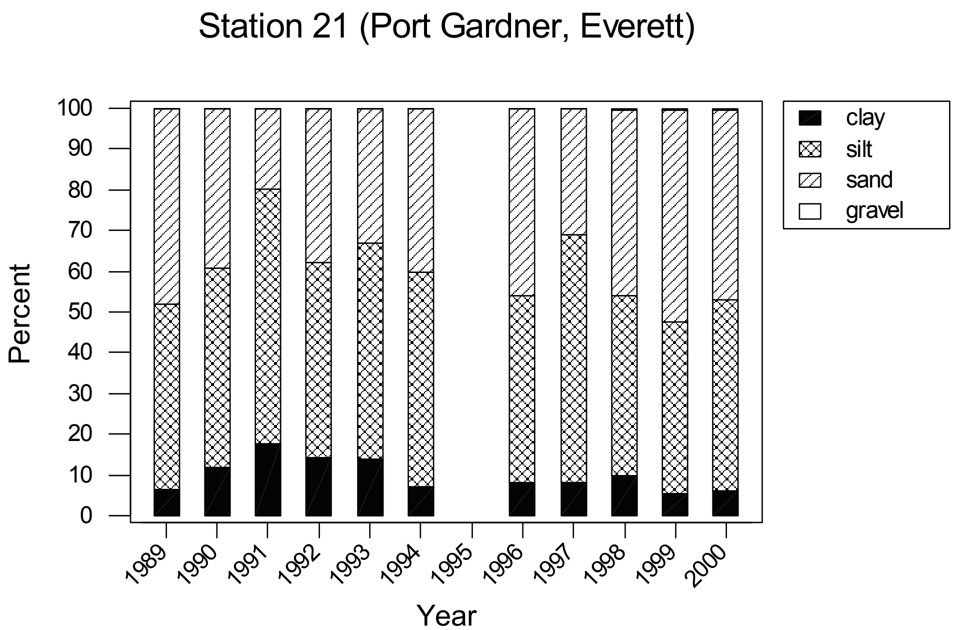


Figure 4c. Sediment grain-size distribution (top) and percent fines (bottom) by year for the North Hood Canal station.

Particle Size Distribution



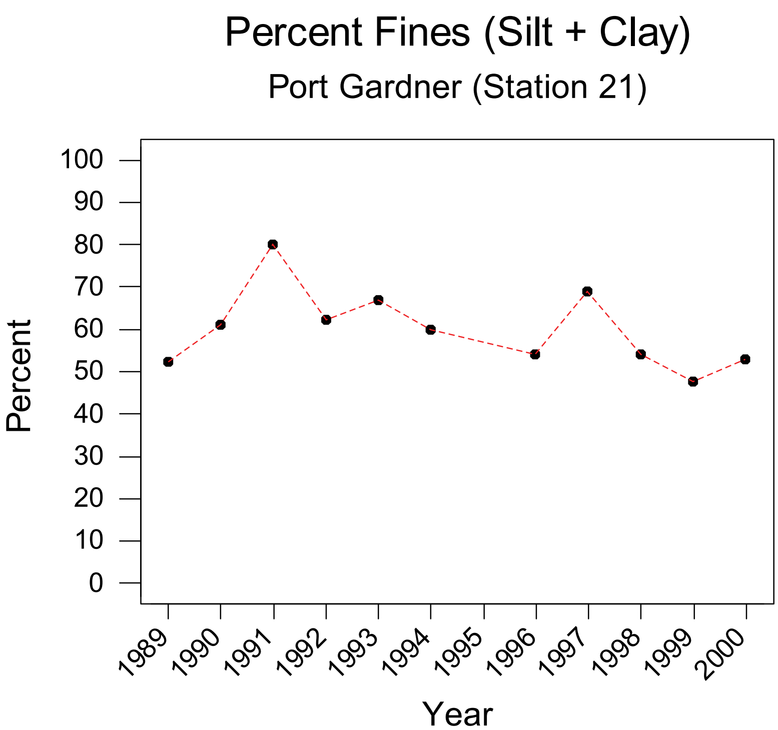
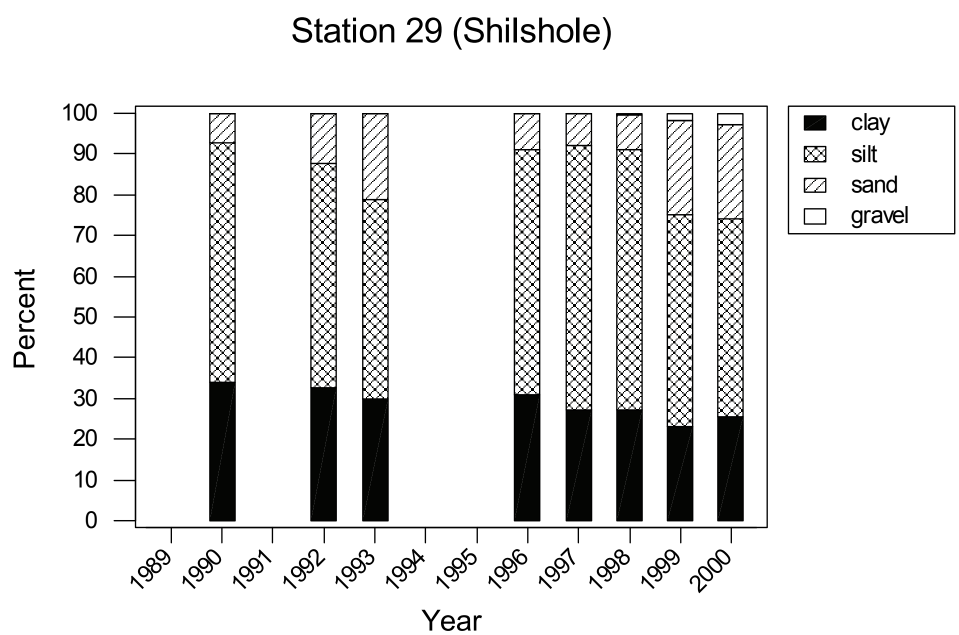


Figure 4d. Sediment grain-size distribution (top) and percent fines (bottom) by year for the Port Gardner station.

Particle Size Distribution



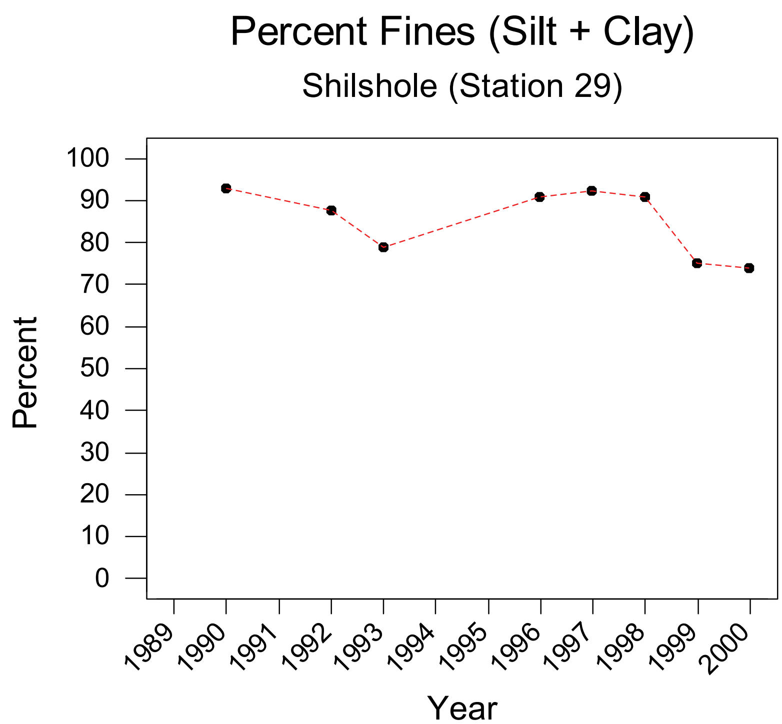
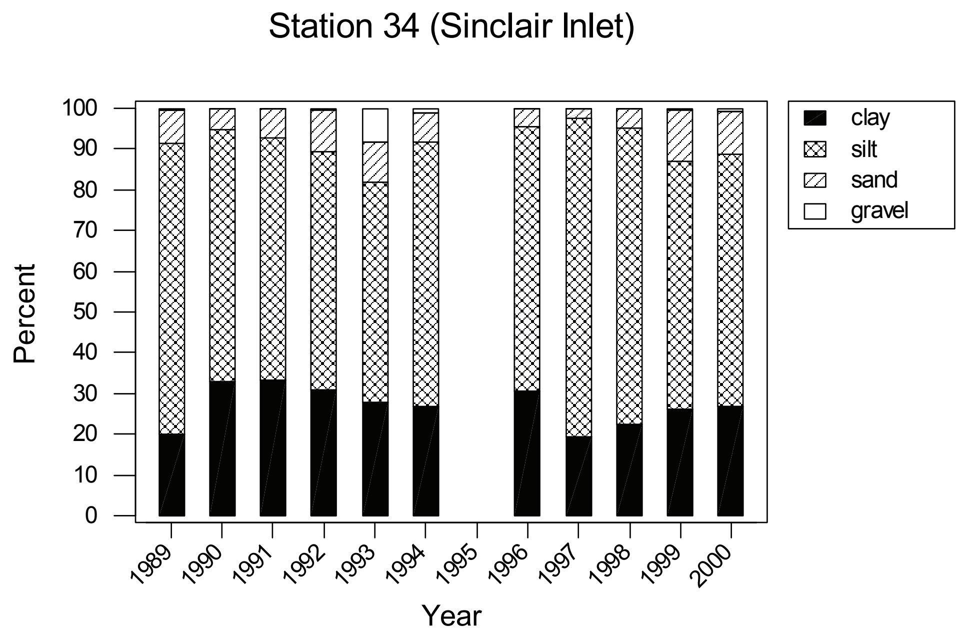


Figure 4e. Sediment grain-size distribution (top) and percent fines (bottom) by year for the Shilshole station.

Particle Size Distribution



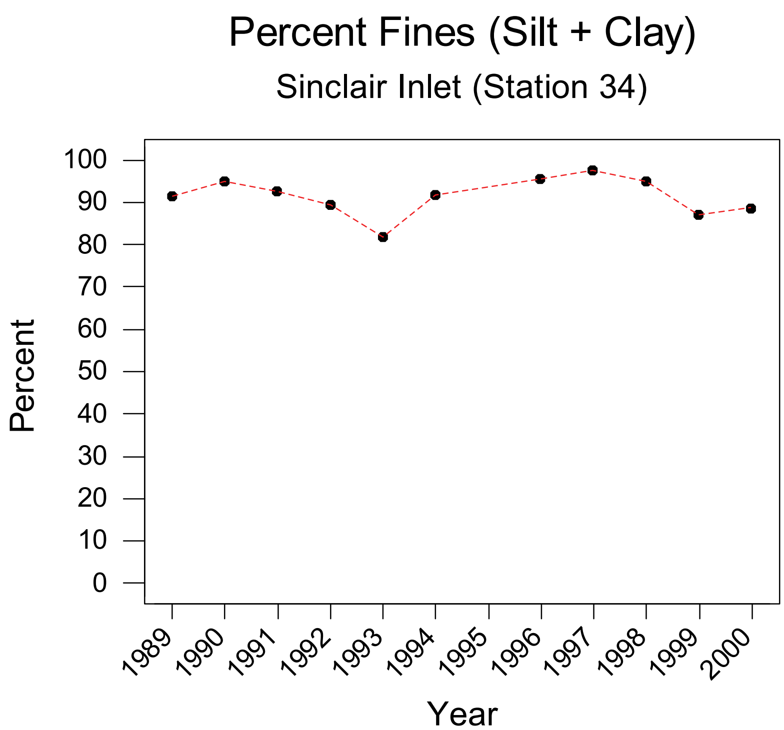
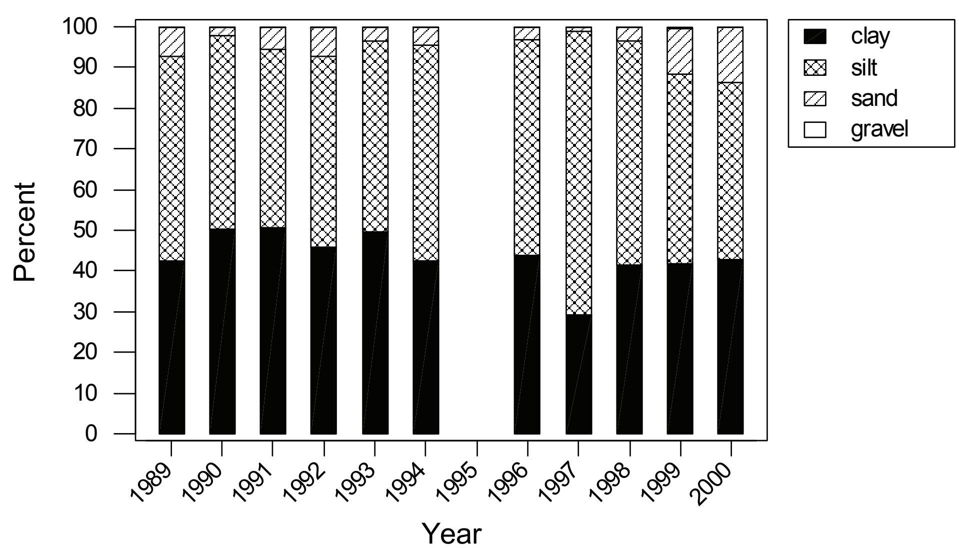


Figure 4f. Sediment grain-size distribution (top) and percent fines (bottom) by year for the Sinclair Inlet station.

Particle Size Distribution



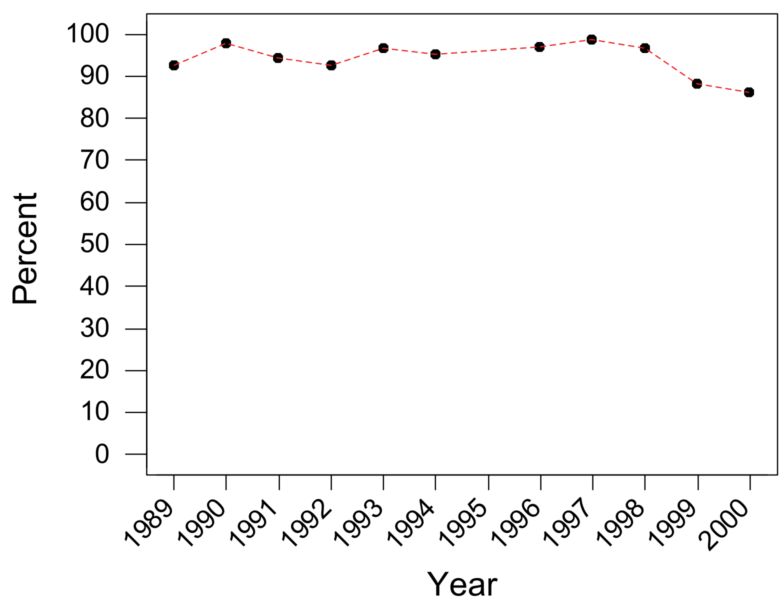
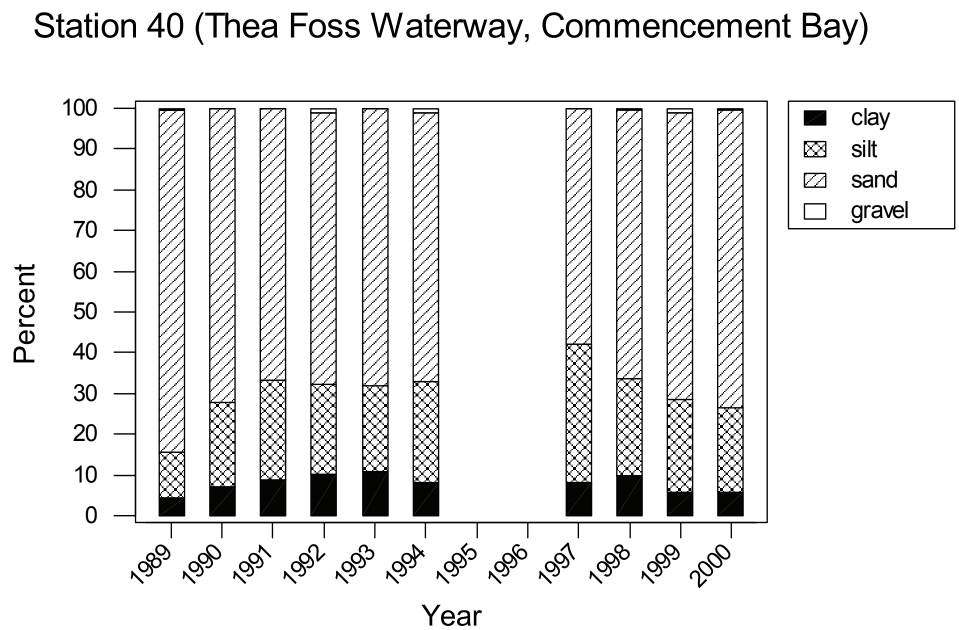


Figure 4g. Sediment grain-size distribution (top) and percent fines (bottom) by year for the Point Pully station.

Particle Size Distribution



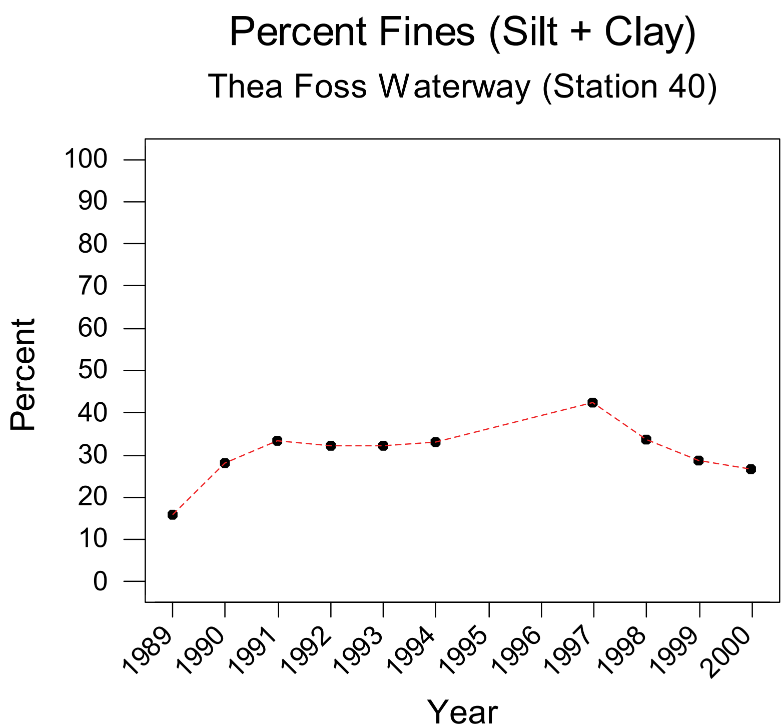
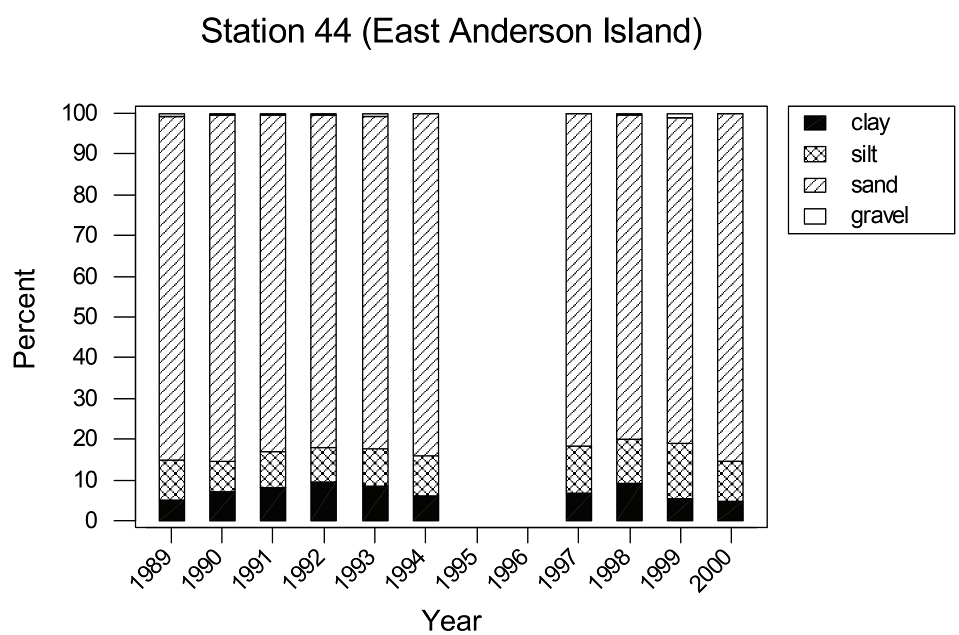


Figure 4h. Sediment grain-size distribution (top) and percent fines (bottom) by year for the Thea Foss Waterway station.

Particle Size Distribution



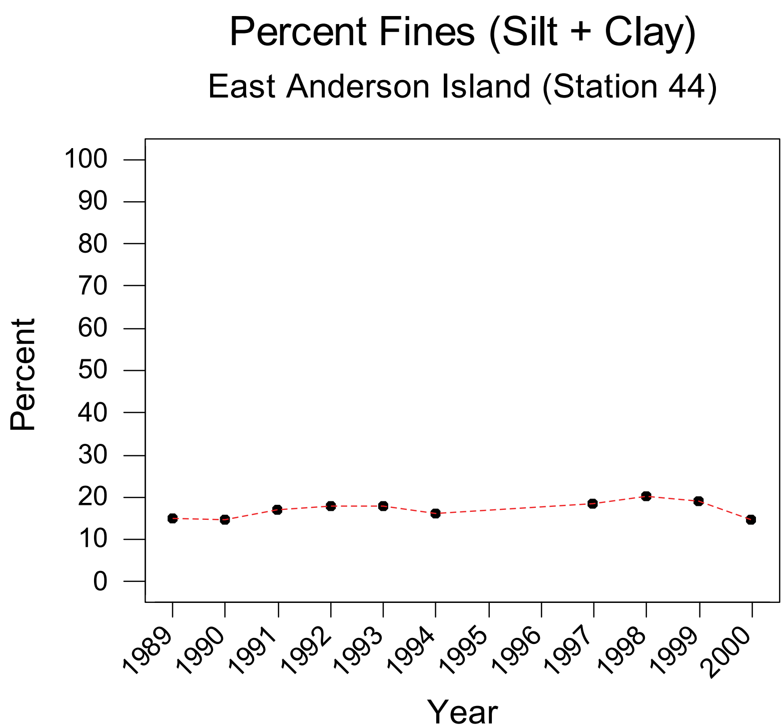
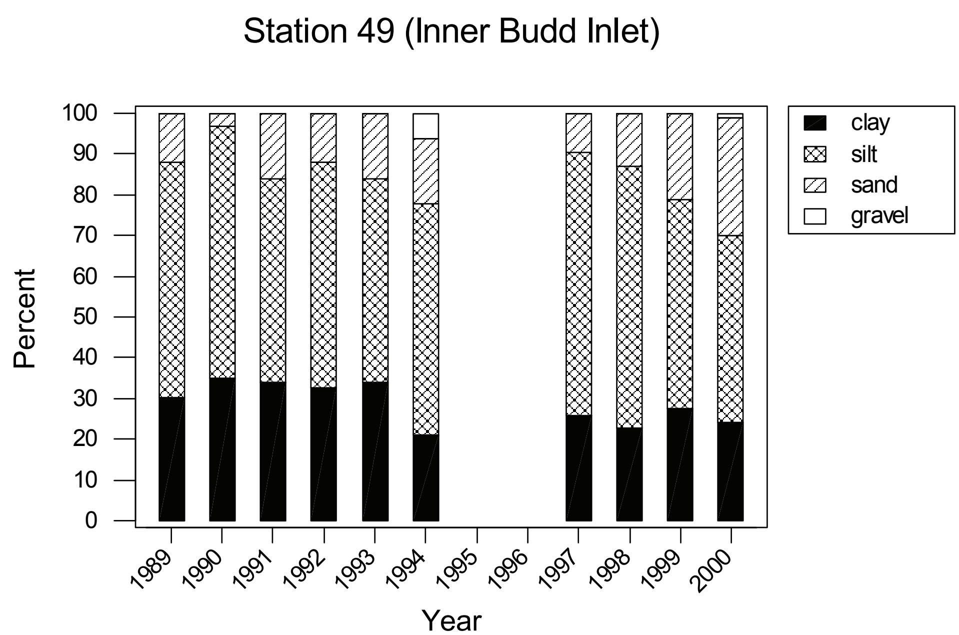


Figure 4i. Sediment grain-size distribution (top) and percent fines (bottom) by year for the East Anderson Island station.

Particle Size Distribution



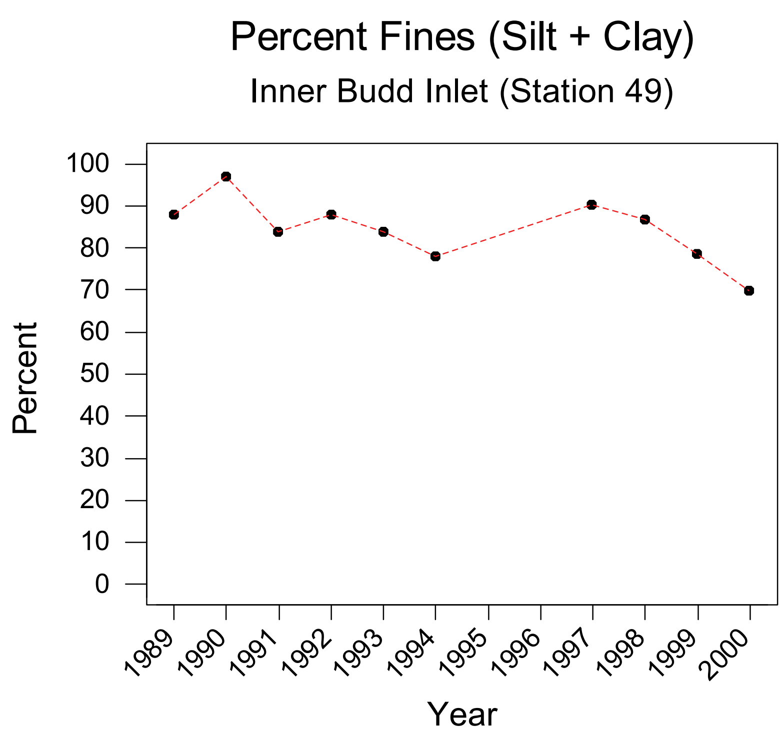


Figure 4j. Sediment grain-size distribution (top) and percent fines (bottom) by year for the Inner Budd Inlet station.

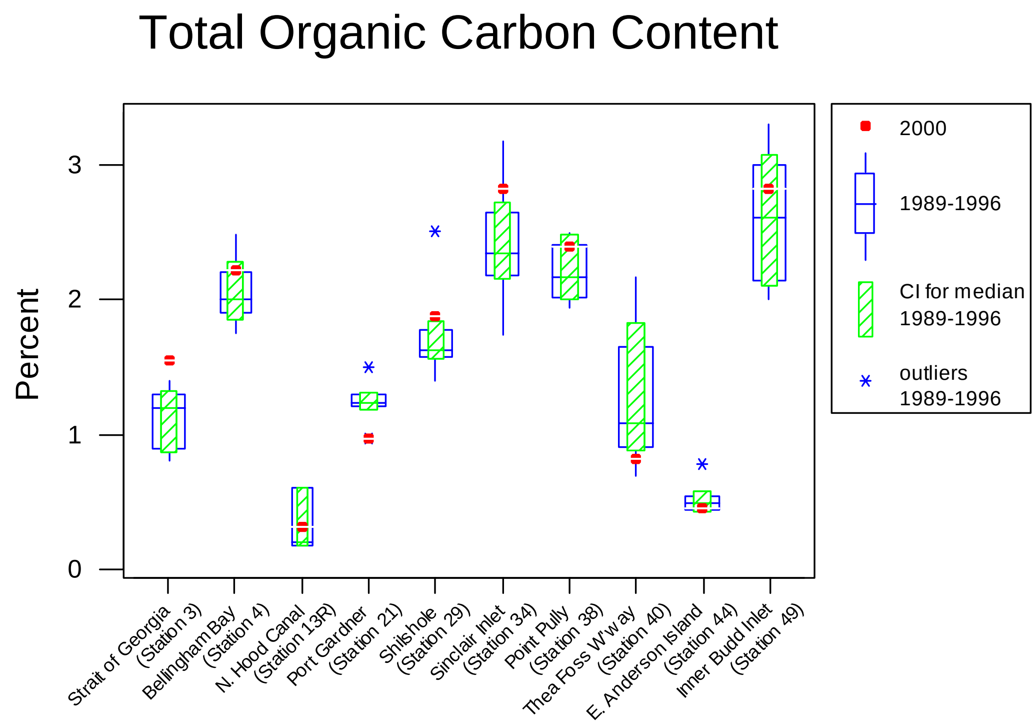


Figure 5a. Total organic carbon content at the PSAMP long-term sediment monitoring stations, 1989-1996 and 2000. Boxplots display median (50th-percentile), 25th-percentile, 75th-percentile, and extreme values of the 1989-1996 results, with a 95% confidence interval for the median (diagonally-striped rectangle). The 2000 results are displayed as solid circles. The width of the boxplot is proportional to the number of observations.

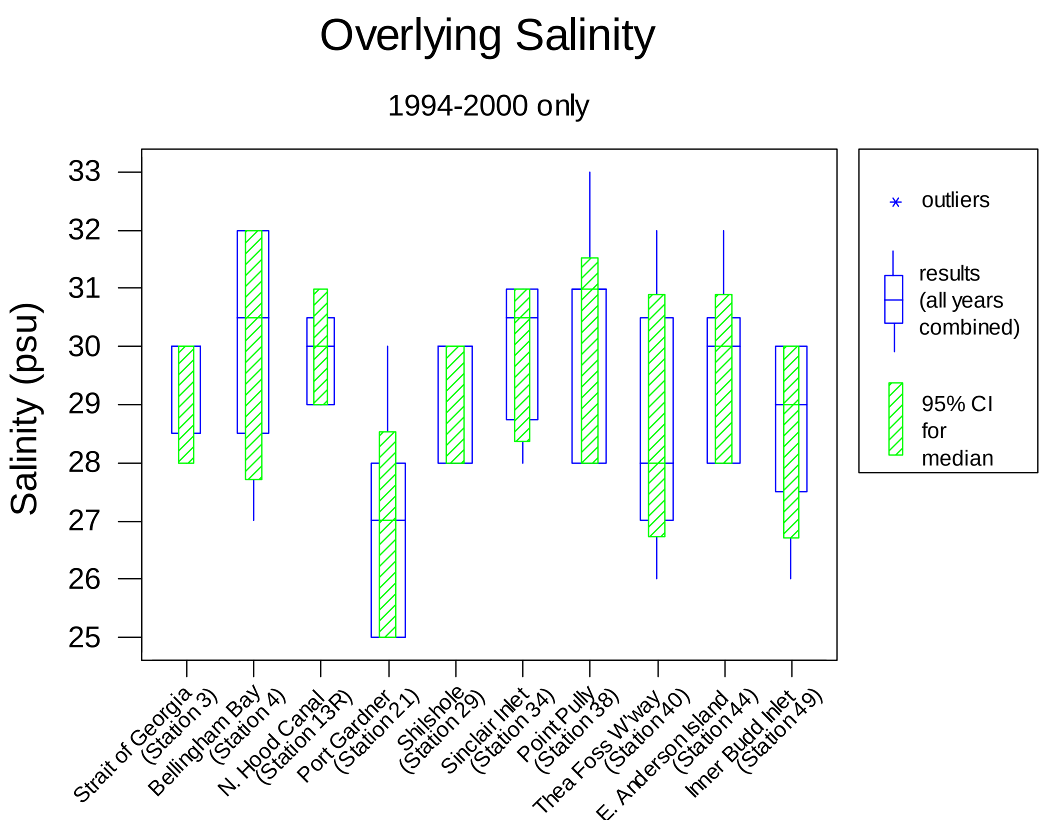


Figure 5b. Salinity of overlying water at the PSAMP long-term sediment monitoring stations, 1989-1996 and 2000. Boxplots display median (50th-percentile), 25th-percentile, 75th-percentile, and extreme values of the 1994-2000 results, with a 95% confidence interval for the median (diagonally-striped rectangle). The width of the boxplot is proportional to the number of observations.

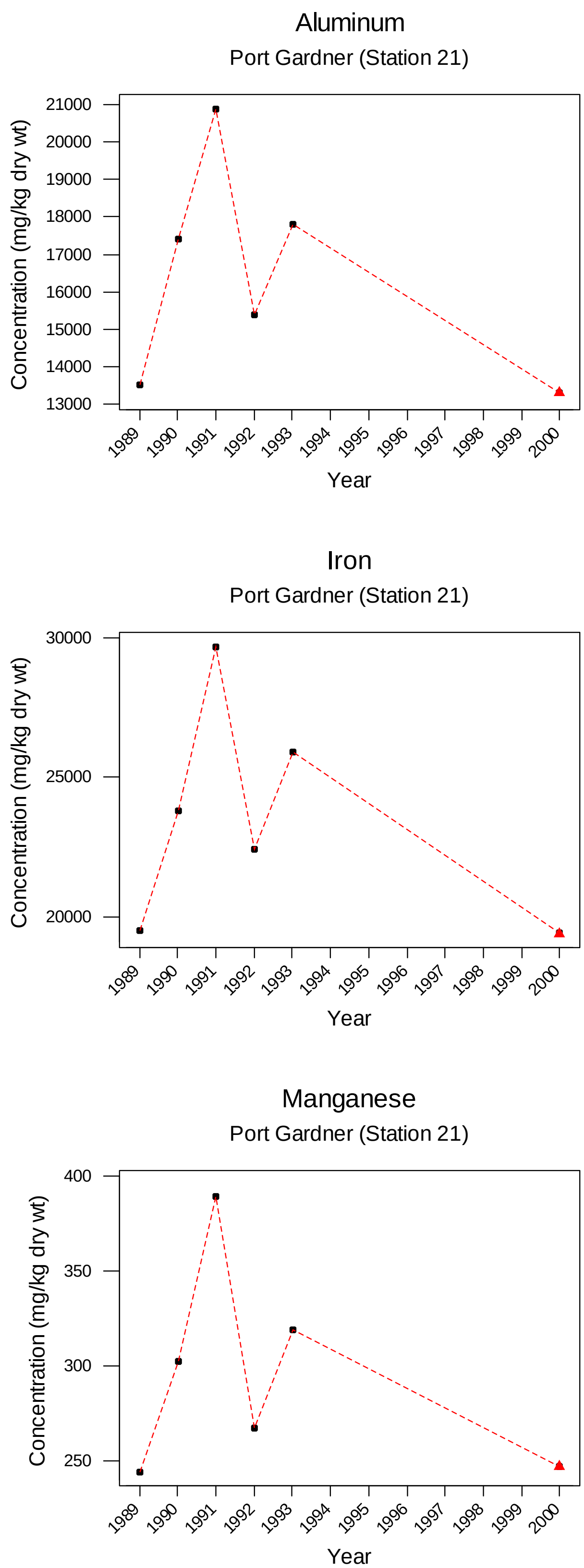


Figure 6. Similar patterns in concentrations of aluminum (top), iron (middle), and manganese (bottom) at the Port Gardner station.

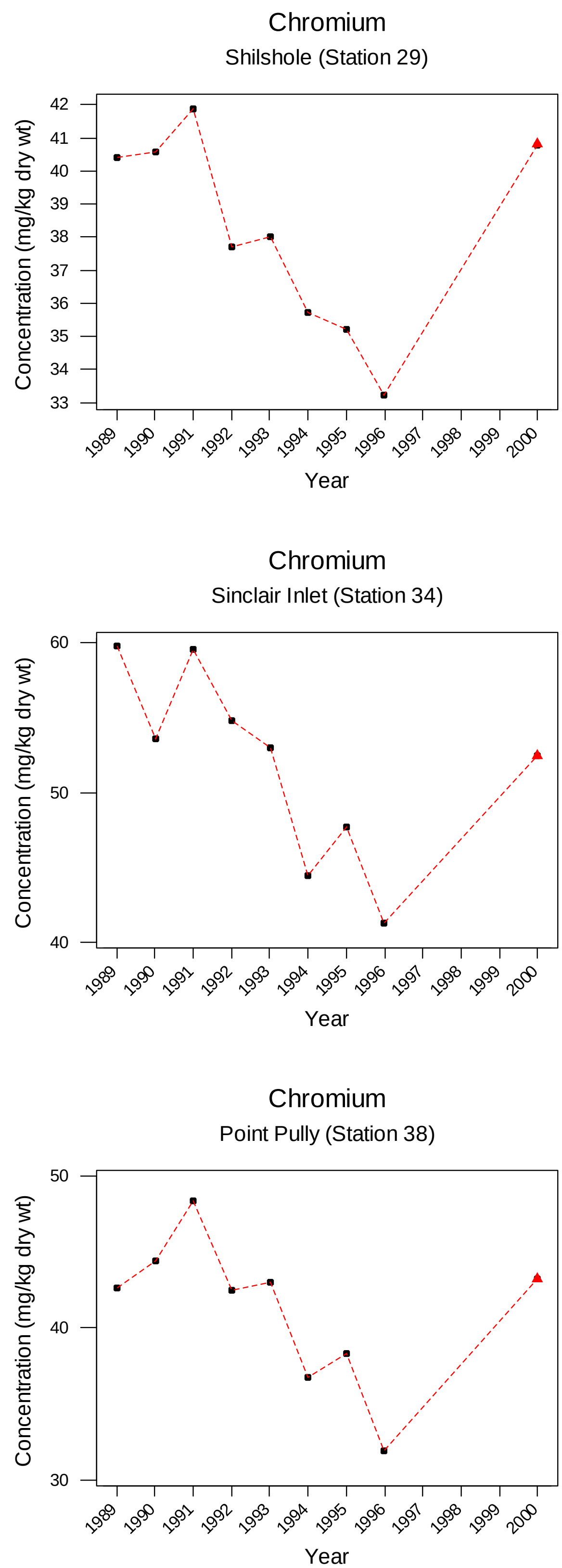


Figure 7. Similar patterns in chromium concentrations at the Shilshole (top), Sinclair Inlet (middle), and Point Pully (bottom) stations.

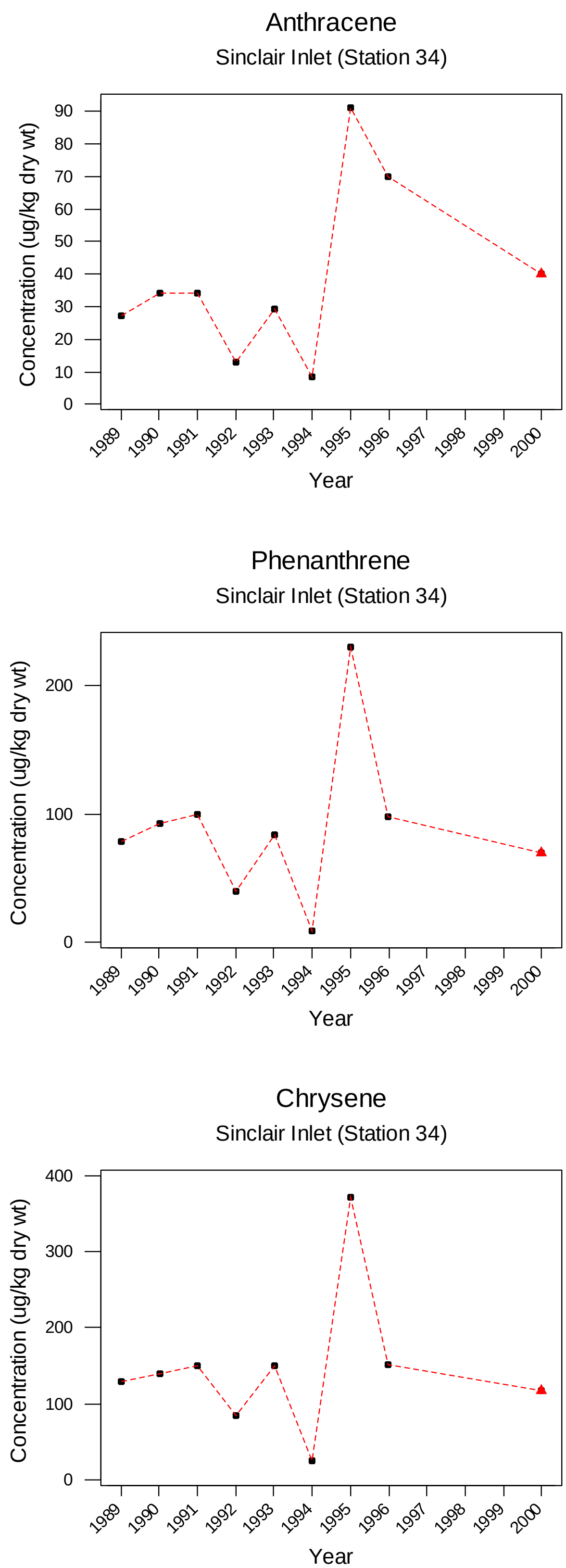


Figure 8. Similar patterns in concentrations of multiple PAH compounds at the Sinclair Inlet station.

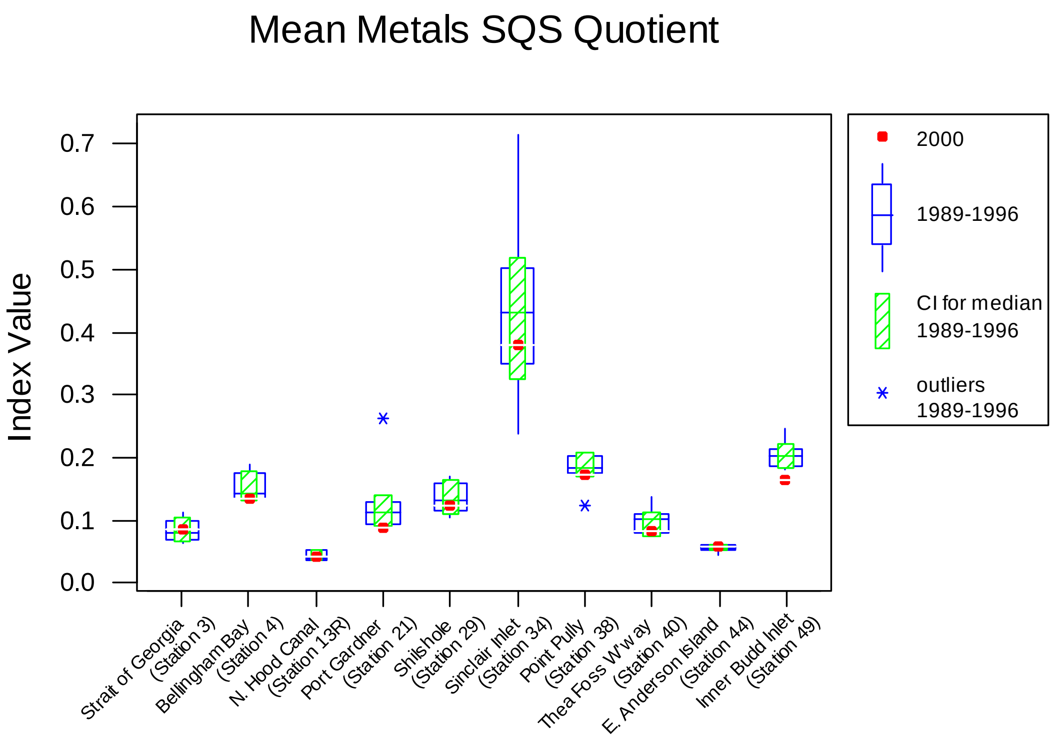


Figure 9. Mean metals SQS quotient at the PSAMP long-term sediment monitoring stations, 1989-1996 and 2000. Boxplots display median (50^{th}-percentile), 25^{th}-percentile, 75^{th}-percentile, and extreme values of the 1989-1996 results, with a 95% confidence interval for the median (diagonally-striped rectangle). The 2000 results are displayed as solid circles. The width of the boxplot is proportional to the number of observations.

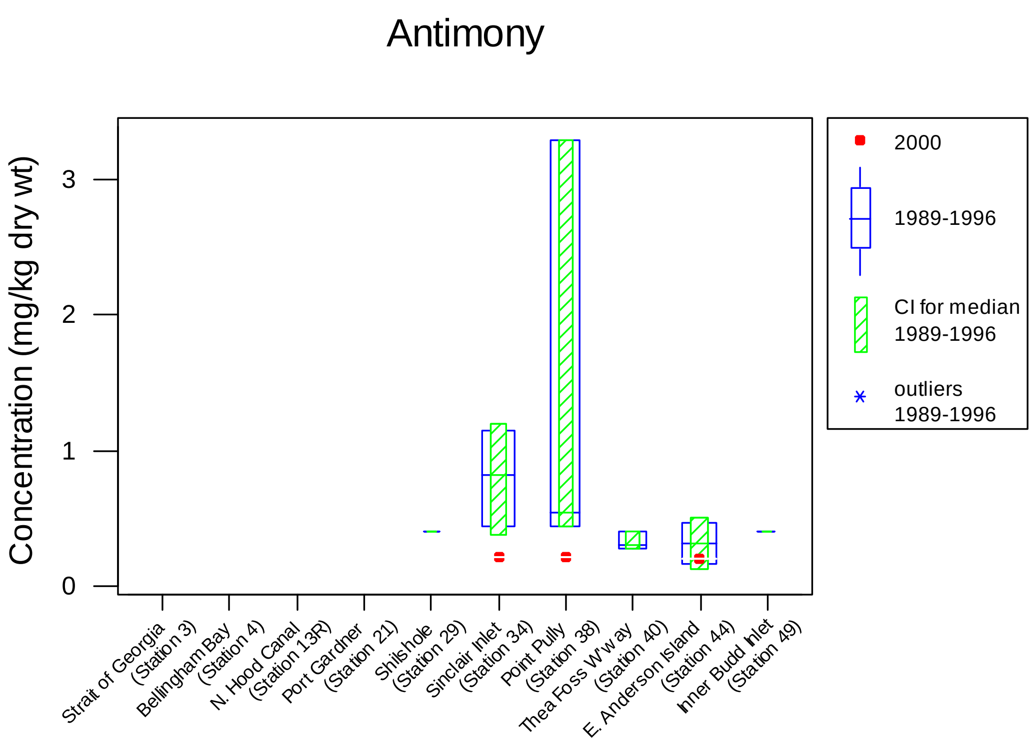
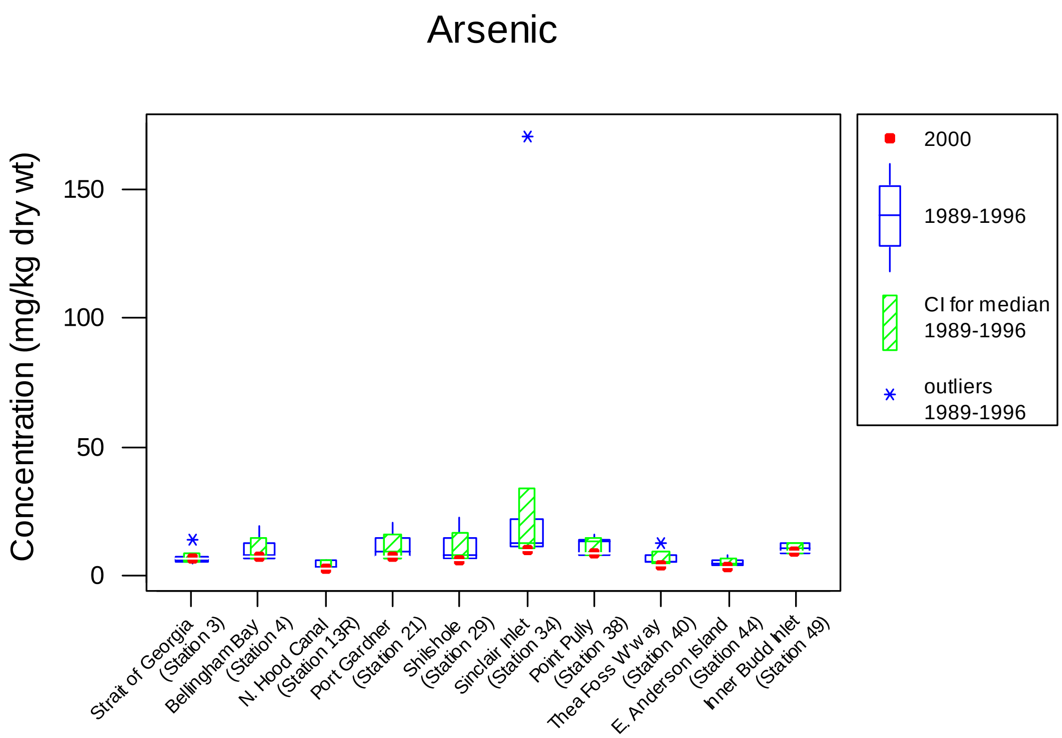


Figure 10. Antimony concentration at the PSAMP long-term sediment monitoring stations, 1989-1996 and 2000. Boxplots display median (50^{th}-percentile), 25^{th}-percentile, 75^{th}-percentile, and extreme values of the 1989-1996 results, with a 95% confidence interval for the median (diagonally-striped rectangle). The 2000 results are displayed as solid circles. The width of the boxplot is proportional to the number of observations.



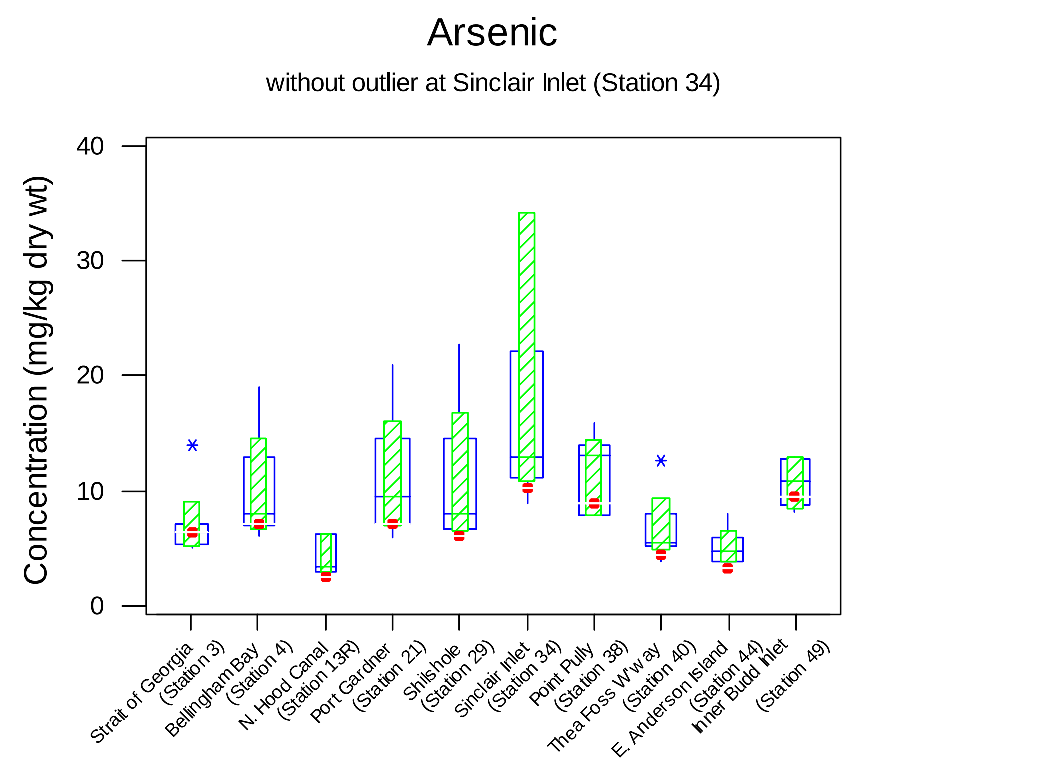


Figure 11. Arsenic concentration at the PSAMP long-term sediment monitoring stations, 1989-2000, with (top) and without (bottom) the outlier at the Sinclair Inlet station. Boxplots display median (50^{th}-percentile), 25^{th}-percentile, 75^{th}-percentile, and extreme values of the 1989-1996 results, with a 95% confidence interval for the median (diagonally-striped rectangle). The 2000 results are displayed as solid circles. The width of the boxplot is proportional to the number of observations.

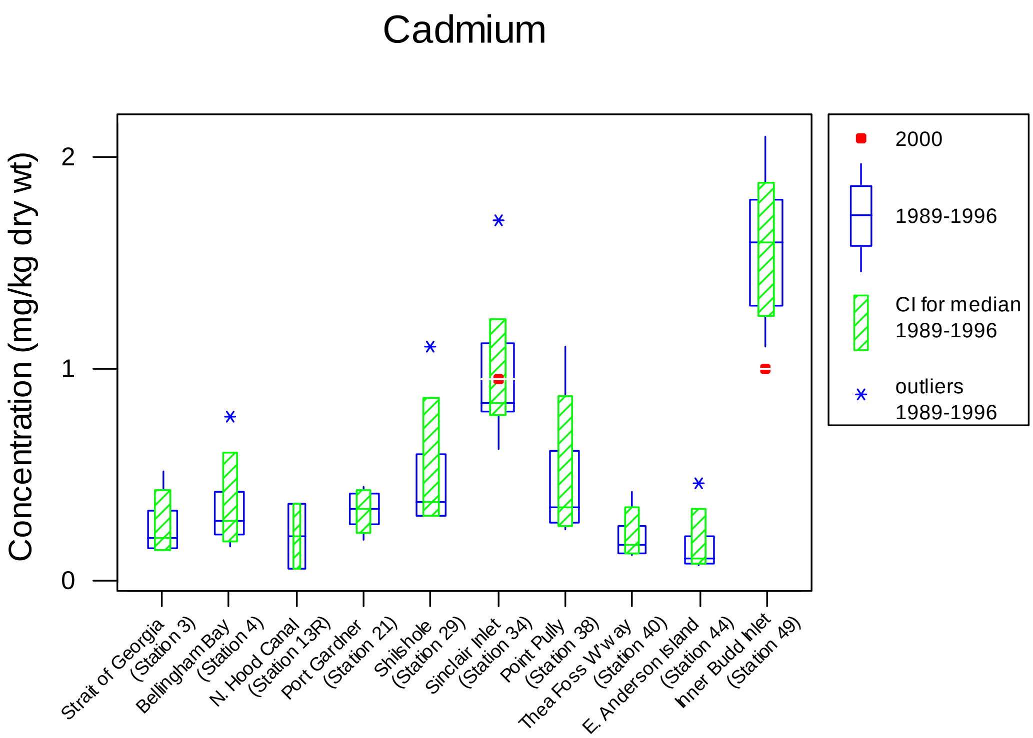


Figure 12. Cadmium concentration at the PSAMP long-term sediment monitoring stations, 1989-1996 and 2000. Boxplots display median (50th-percentile), 25th-percentile, 75th-percentile, and extreme values of the 1989-1996 results, with a 95% confidence interval for the median (diagonally-striped rectangle). The 2000 results are displayed as solid circles. The width of the boxplot is proportional to the number of observations.

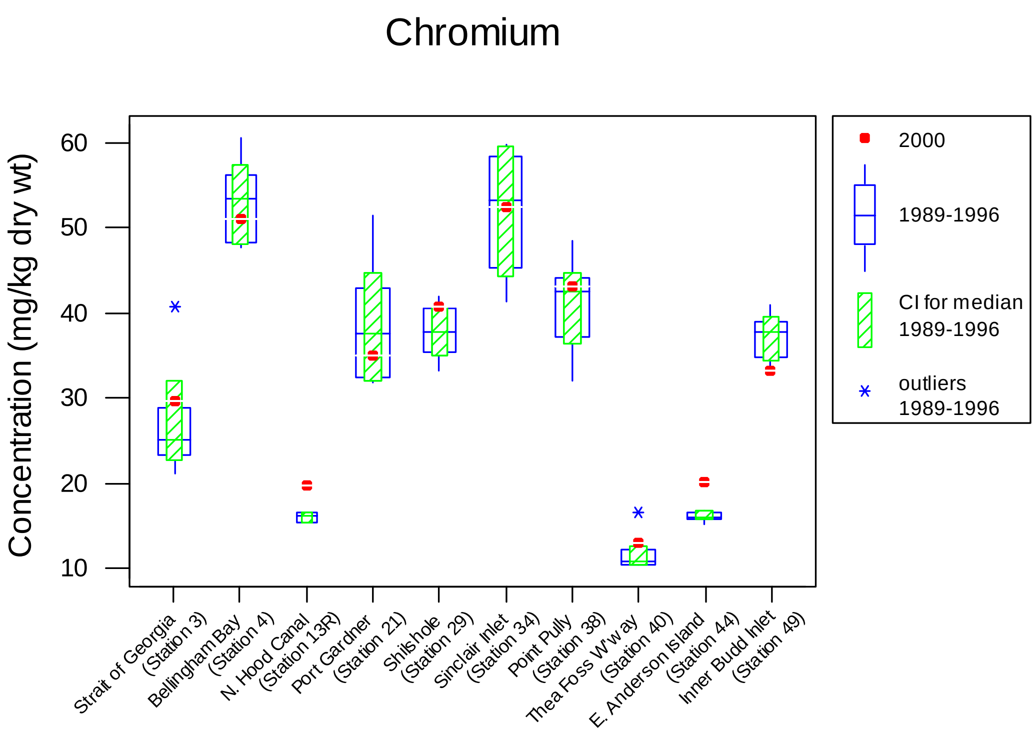


Figure 13. Chromium concentration at the PSAMP long-term sediment monitoring stations, 1989-1996 and 2000. Boxplots display median (50th-percentile), 25th-percentile, 75th-percentile, and extreme values of the 1989-1996 results, with a 95% confidence interval for the median (diagonally-striped rectangle). The 2000 results are displayed as solid circles. The width of the boxplot is proportional to the number of observations.

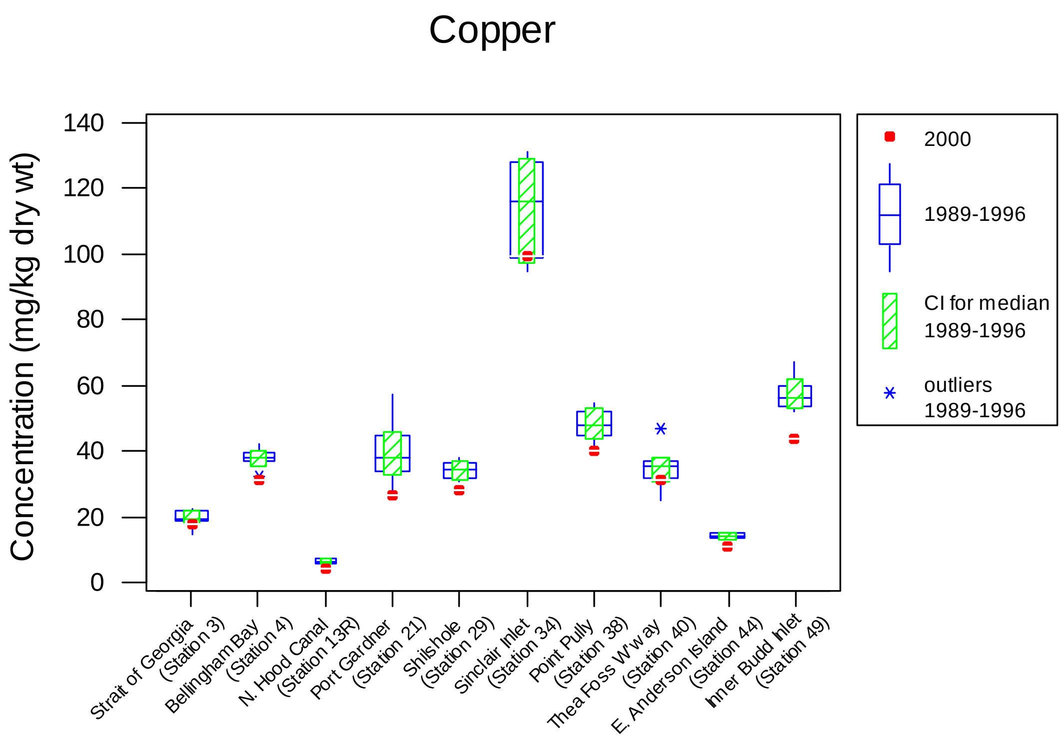


Figure 14. Copper concentration at the PSAMP long-term sediment monitoring stations, 1989-1996 and 2000. Boxplots display median (50th-percentile), 25th-percentile, 75th-percentile, and extreme values of the 1989-1996 results, with a 95% confidence interval for the median (diagonally-striped rectangle). The 2000 results are displayed as solid circles. The width of the boxplot is proportional to the number of observations.

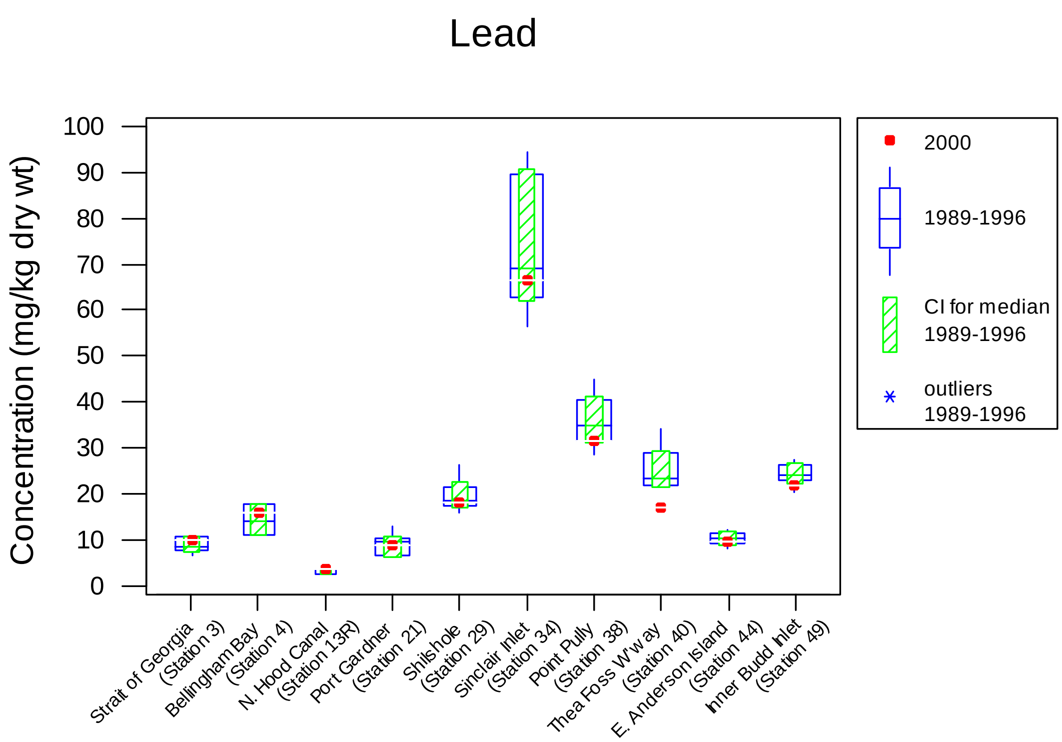


Figure 15. Lead concentration at the PSAMP long-term sediment monitoring stations, 1989-1996 and 2000. Boxplots display median (50th-percentile), 25th-percentile, 75th-percentile, and extreme values of the 1989-1996 results, with a 95% confidence interval for the median (diagonally-striped rectangle). The 2000 results are displayed as solid circles. The width of the boxplot is proportional to the number of observations.

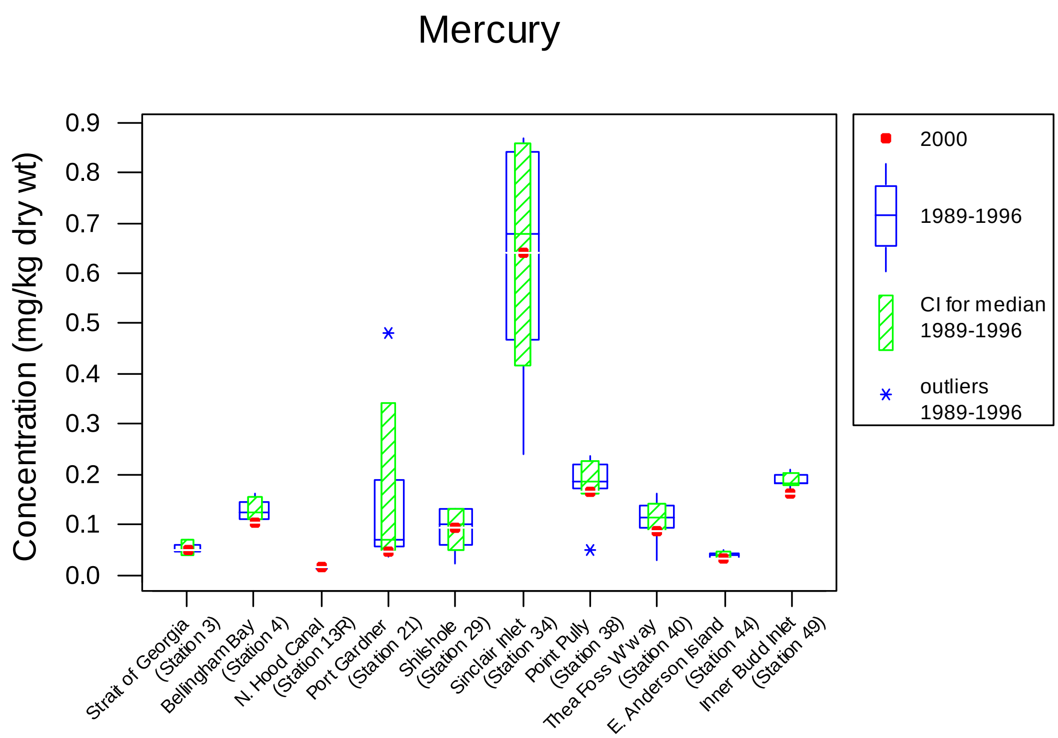


Figure 16. Mercury concentration at the PSAMP long-term sediment monitoring stations, 1989-1996 and 2000. Boxplots display median (50th-percentile), 25th-percentile, 75th-percentile, and extreme values of the 1989-1996 results, with a 95% confidence interval for the median (diagonally-striped rectangle). The 2000 results are displayed as solid circles. The width of the boxplot is proportional to the number of observations.

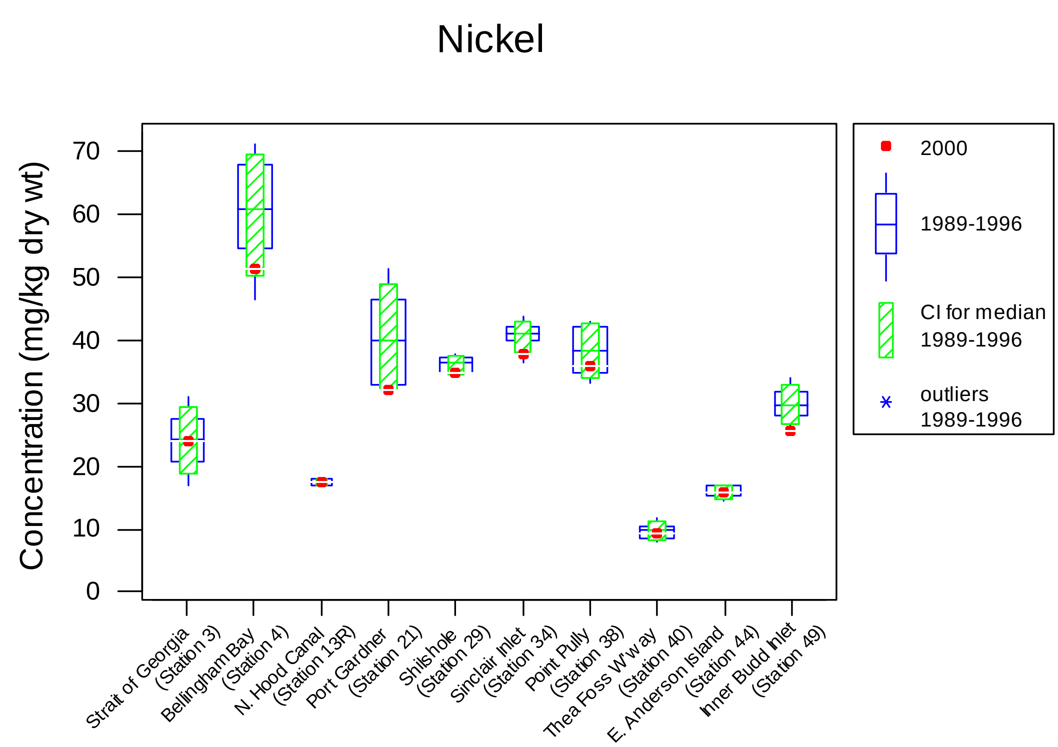


Figure 17. Nickel concentration at the PSAMP long-term sediment monitoring stations, 1989-1996 and 2000. Boxplots display median (50th-percentile), 25th-percentile, 75th-percentile, and extreme values of the 1989-1996 results, with a 95% confidence interval for the median (diagonally-striped rectangle). The 2000 results are displayed as solid circles. The width of the boxplot is proportional to the number of observations.

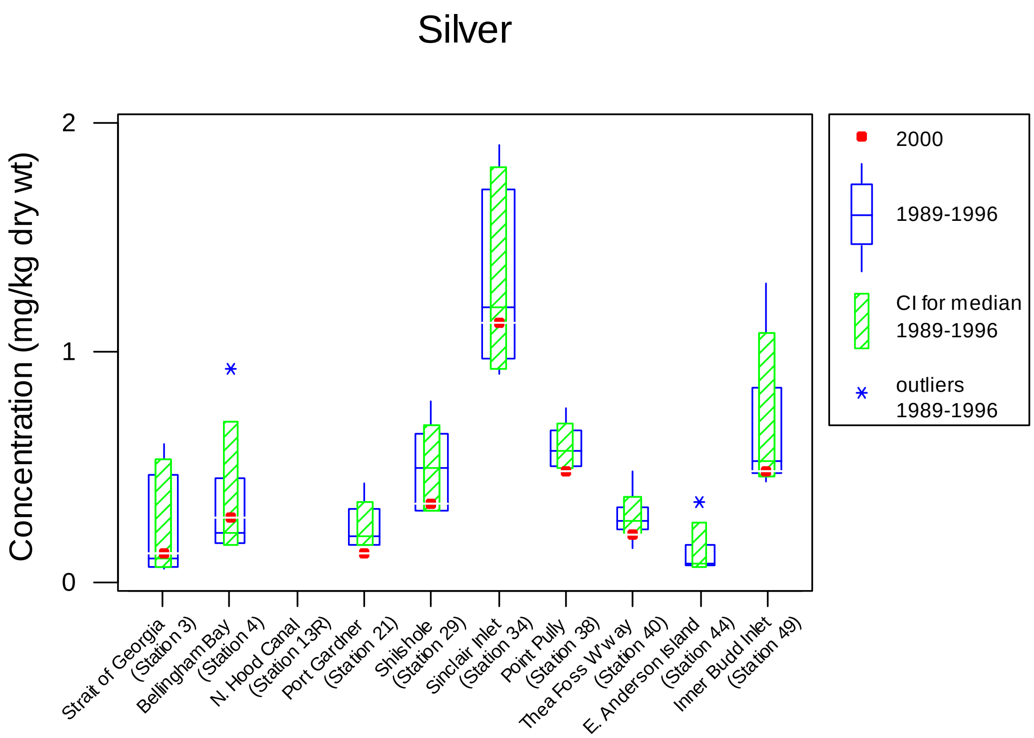


Figure 18. Silver concentration at the PSAMP long-term sediment monitoring stations, 1989-1996 and 2000. Boxplots display median (50th-percentile), 25th-percentile, 75th-percentile, and extreme values of the 1989-1996 results, with a 95% confidence interval for the median (diagonally-striped rectangle). The 2000 results are displayed as solid circles. The width of the boxplot is proportional to the number of observations.

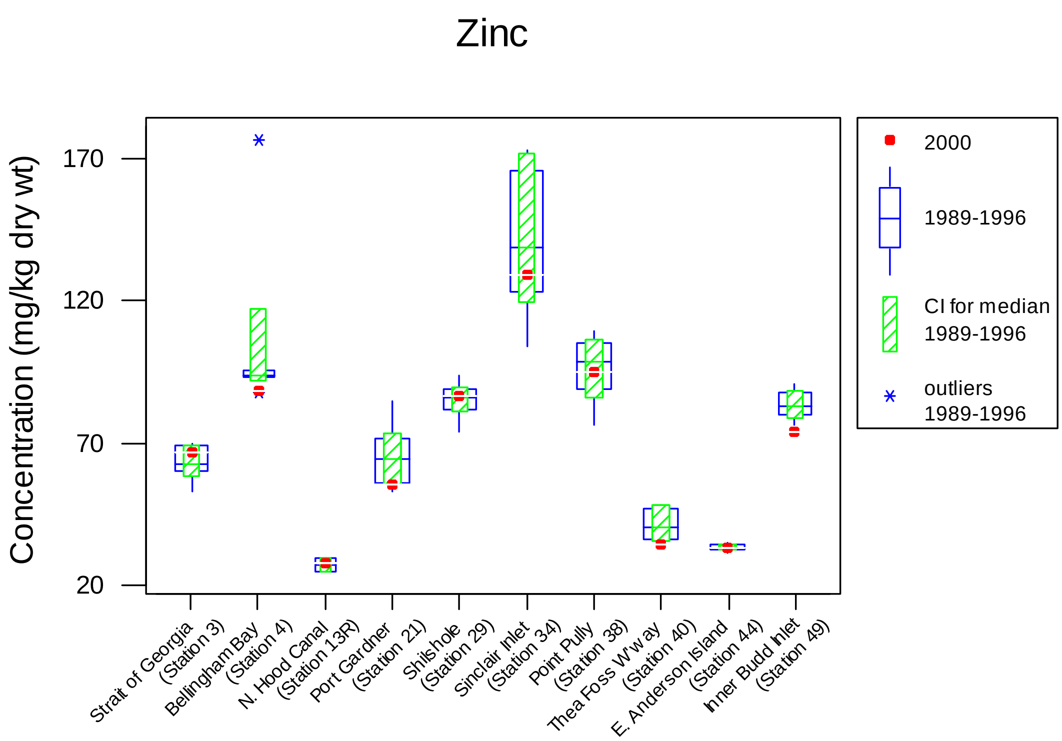


Figure 19. Zinc concentration at the PSAMP long-term sediment monitoring stations, 1989-1996 and 2000. Boxplots display median (50th-percentile), 25th-percentile, 75th-percentile, and extreme values of the 1989-1996 results, with a 95% confidence interval for the median (diagonally-striped rectangle). The 2000 results are displayed as solid circles. The width of the boxplot is proportional to the number of observations.

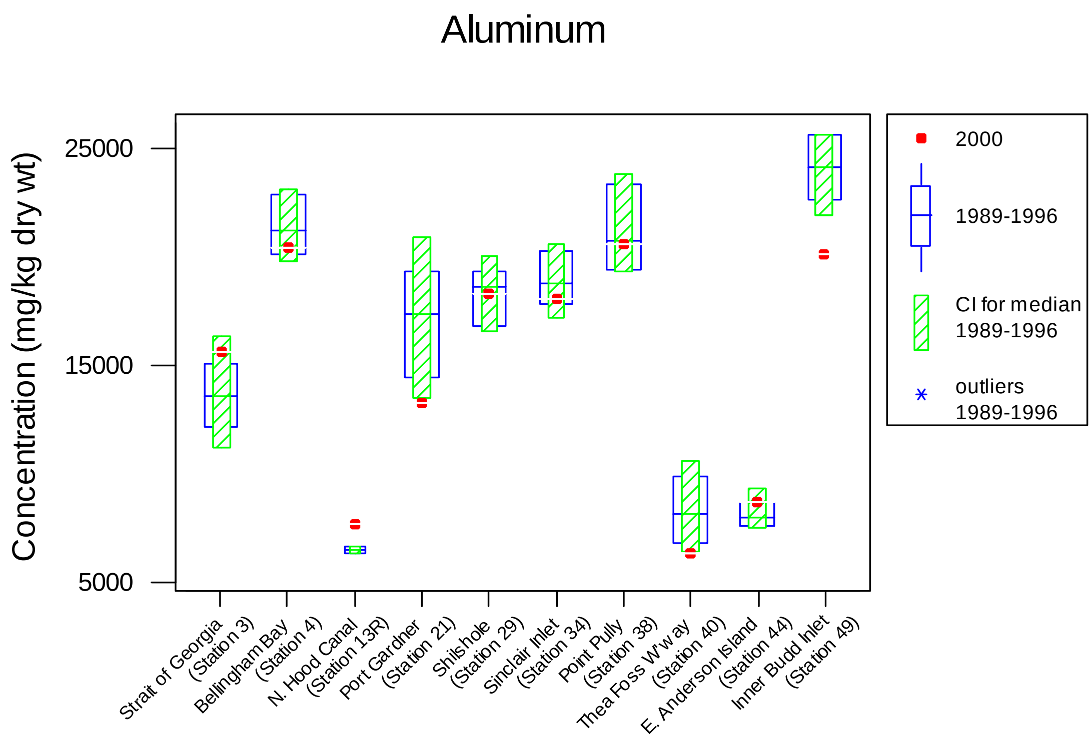


Figure 20. Aluminum concentration at the PSAMP long-term sediment monitoring stations, 1989-1996 and 2000. Boxplots display median (50th-percentile), 25th-percentile, 75th-percentile, and extreme values of the 1989-1996 results, with a 95% confidence interval for the median (diagonally-striped rectangle). The 2000 results are displayed as solid circles. The width of the boxplot is proportional to the number of observations.

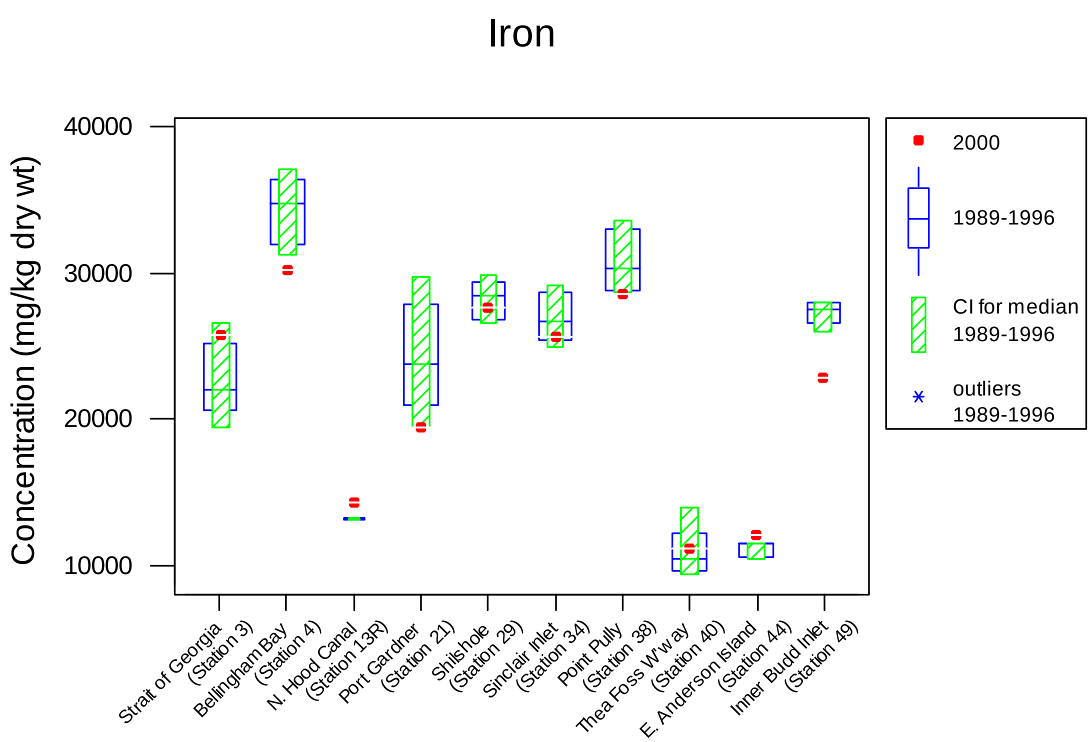


Figure 21. Iron concentration at the PSAMP long-term sediment monitoring stations, 1989-1996 and 2000. Boxplots display median (50th-percentile), 25th-percentile, 75th-percentile, and extreme values of the 1989-1996 results, with a 95% confidence interval for the median (diagonally-striped rectangle). The 2000 results are displayed as solid circles. The width of the boxplot is proportional to the number of observations.

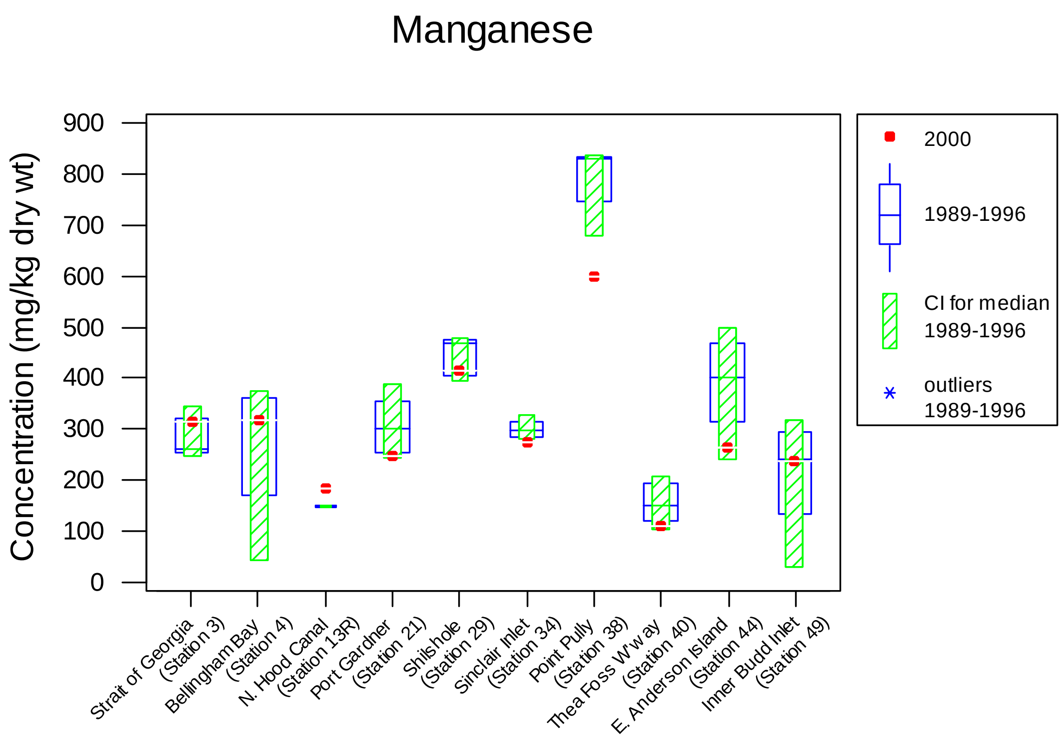
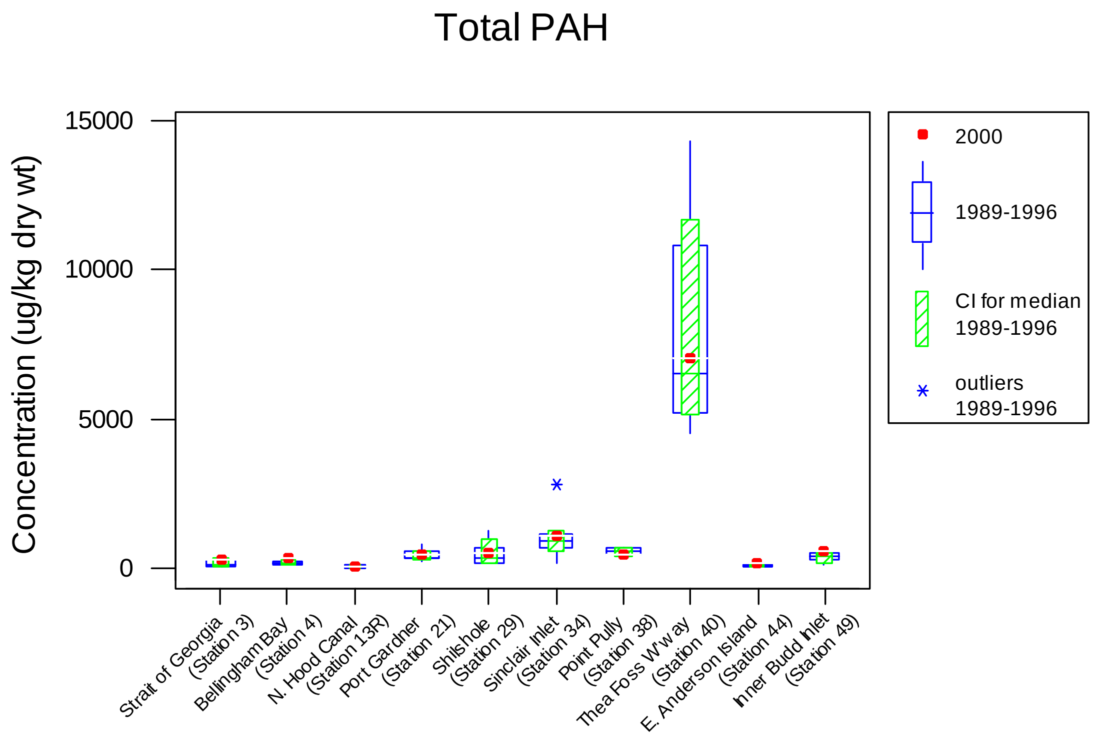


Figure 22. Manganese concentration at the PSAMP long-term sediment monitoring stations, 1989-1996 and 2000. Boxplots display median (50th-percentile), 25th-percentile, 75th-percentile, and extreme values of the 1989-1996 results, with a 95% confidence interval for the median (diagonally-striped rectangle). The 2000 results are displayed as solid circles. The width of the boxplot is proportional to the number of observations.



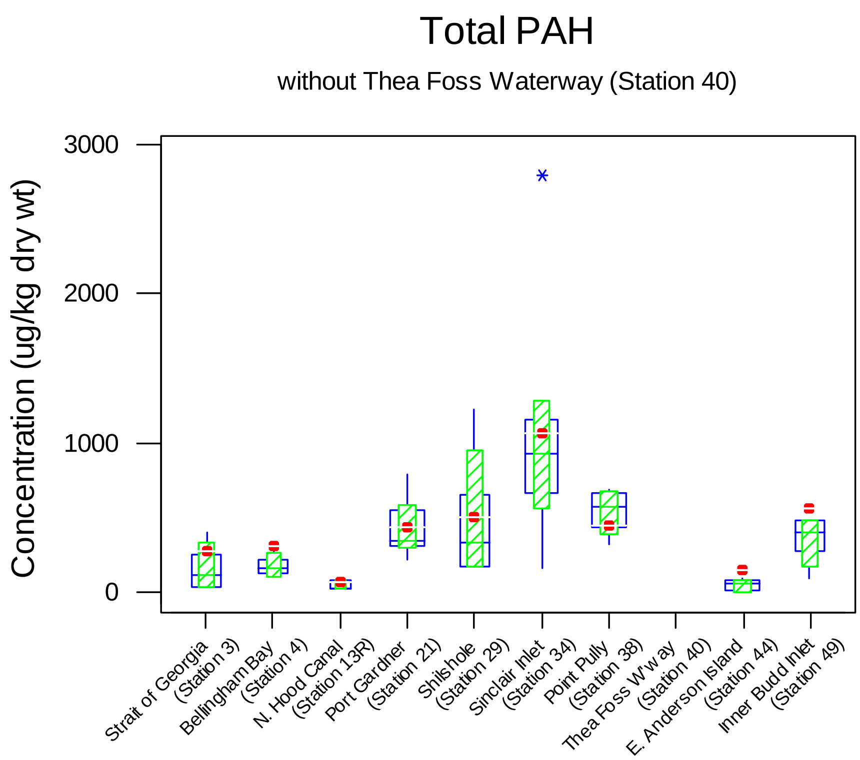
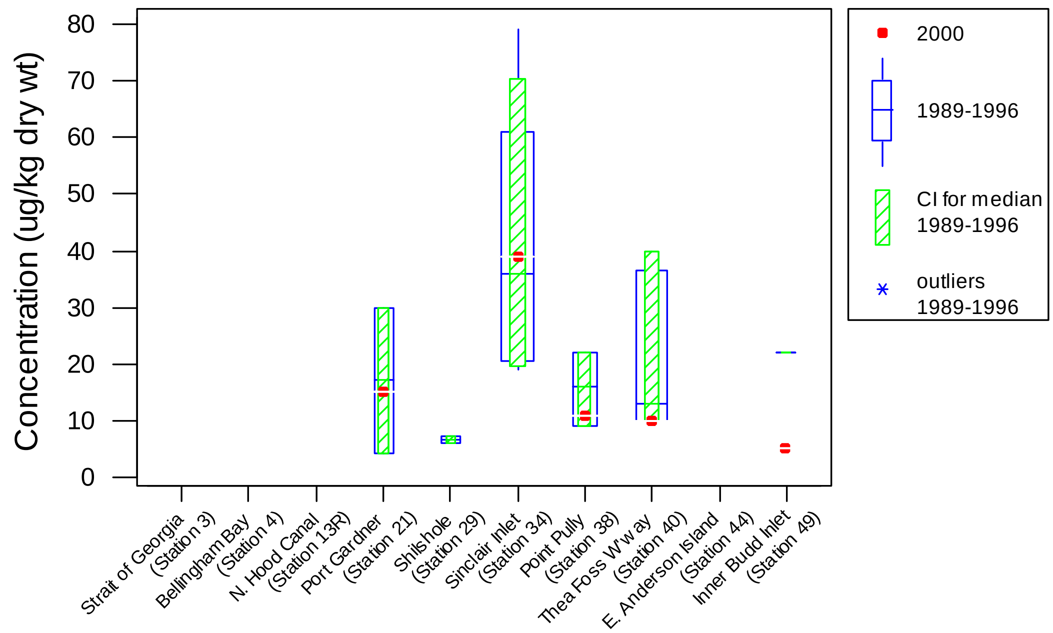


Figure 23. Total PAH concentration at the PSAMP long-term sediment monitoring stations, 1989-2000, all stations (top) and without the Thea Foss Waterway station (bottom). Boxplots display median (50^{th}-percentile), 25^{th}-percentile, 75^{th}-percentile, and extreme values of the 1989-1996 results, with a 95% confidence interval for the median (diagonally-striped rectangle). The 2000 results are displayed as solid circles. The width of the boxplot is proportional to the number of observations.

PCB Aroclor 1254



PCB Aroclor 1260

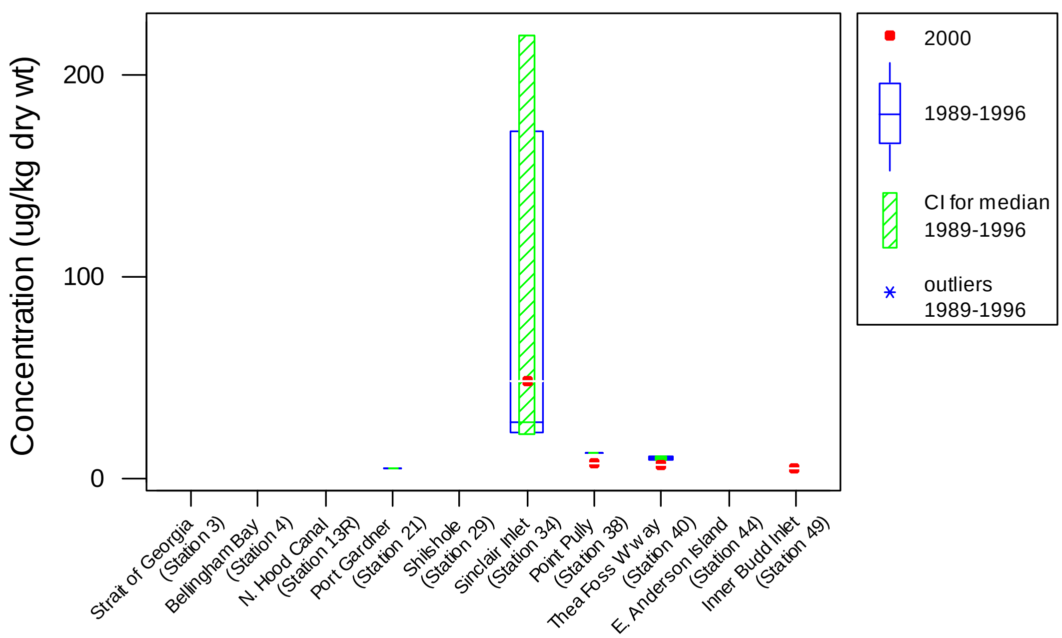


Figure 24. PCB Aroclor 1254 concentration (top) and PCB Aroclor 1260 concentration (bottom) at the PSAMP long-term sediment monitoring stations, 1989-2000. Boxplots display median (50^{th}-percentile), 25^{th}-percentile, 75^{th}-percentile, and extreme values of the 1989-1996 results, with a 95% confidence interval for the median (diagonally-striped rectangle). The 2000 results are displayed as solid circles. The width of the boxplot is proportional to the number of observations.

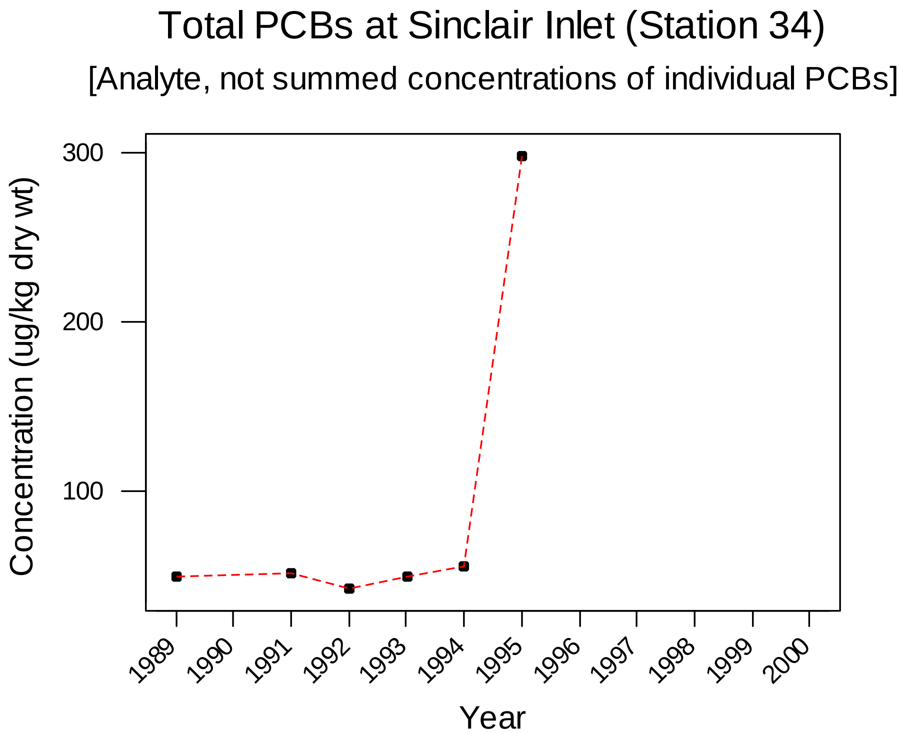


Figure 25. Total detected PCBs concentration (analyte concentration, not summed concentrations of individual PCBs) at the PSAMP long-term sediment monitoring stations, 1989-1996 and 2000.

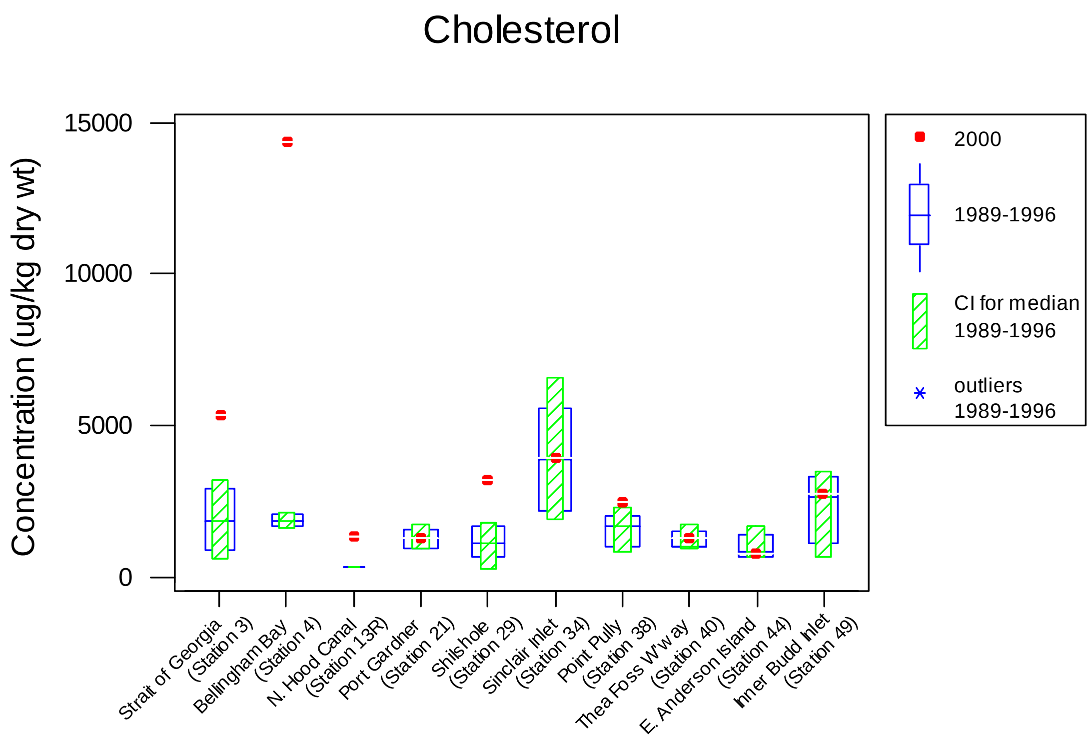
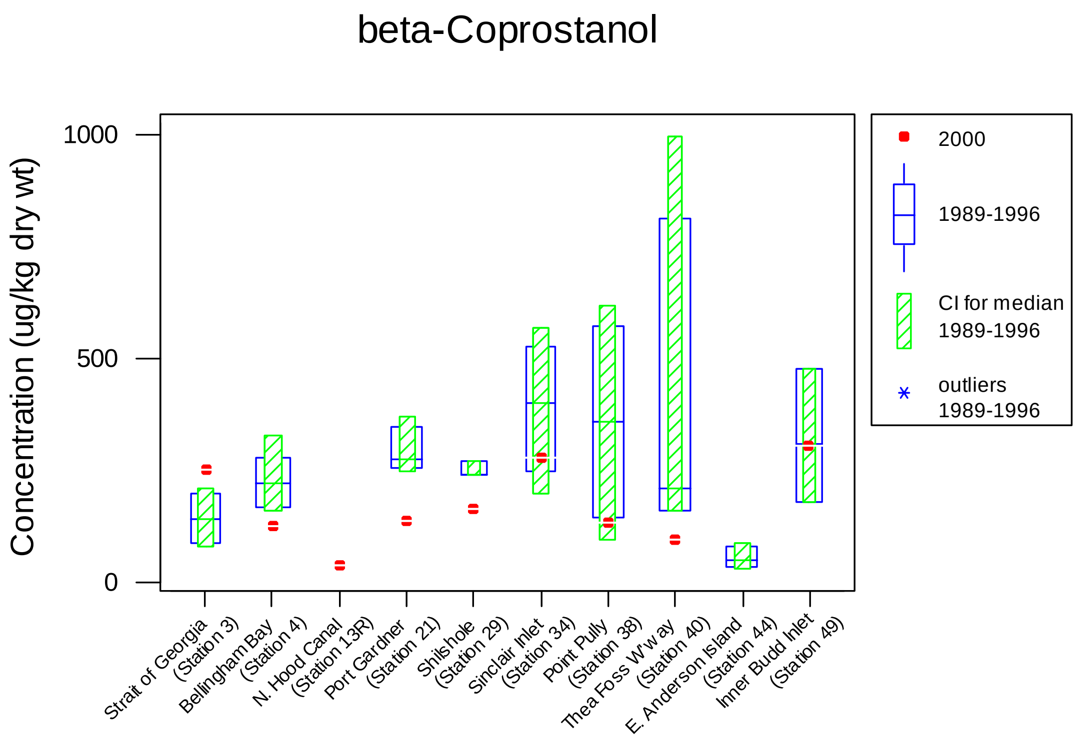


Figure 26. Cholesterol concentration at the PSAMP long-term sediment monitoring stations, 1989-1996 and 2000. Boxplots display median (50th-percentile), 25th-percentile, 75th-percentile, and extreme values of the 1989-1996 results, with a 95% confidence interval for the median (diagonally-striped rectangle). The 2000 results are displayed as solid circles. The width of the boxplot is proportional to the number of observations.



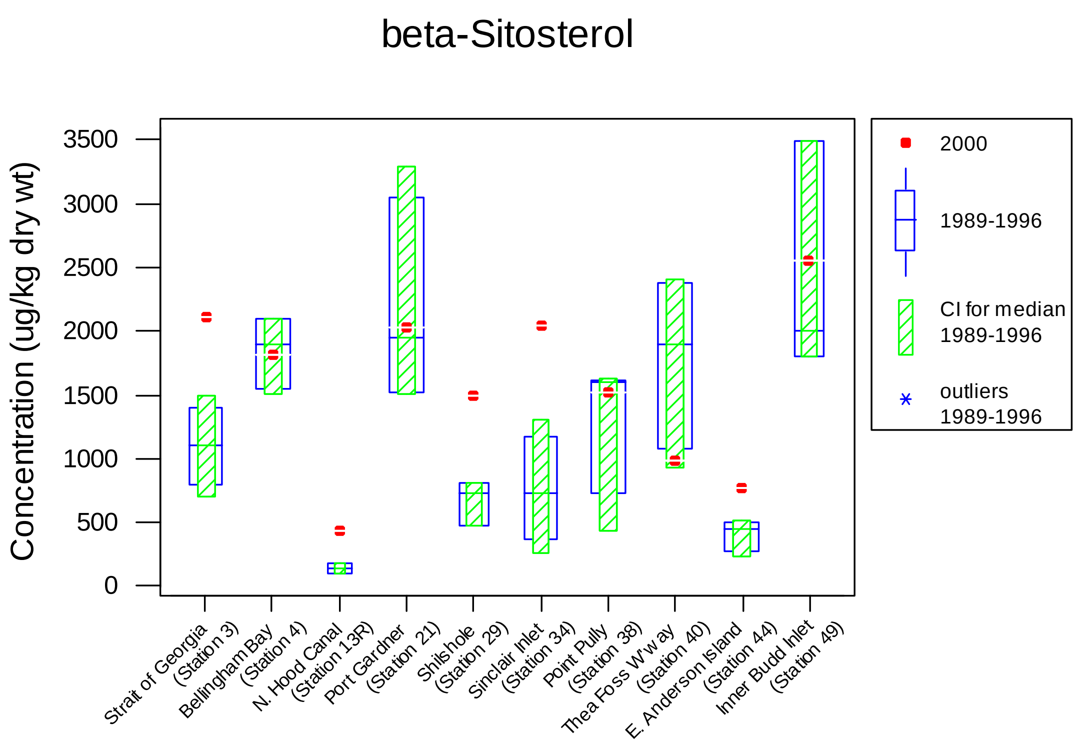


Figure 27. Concentration of beta-coprostanol (top) and beta-sitosterol (bottom) at the PSAMP long-term sediment monitoring stations, 1989-1996 and 2000. Boxplots display median (50^{th}-percentile), 25^{th}-percentile, 75^{th}-percentile, and extreme values of the 1989-1996 results, with a 95% confidence interval for the median (diagonally-striped rectangle). The 2000 results are displayed as solid circles. The width of the boxplot is proportional to the number of observations.

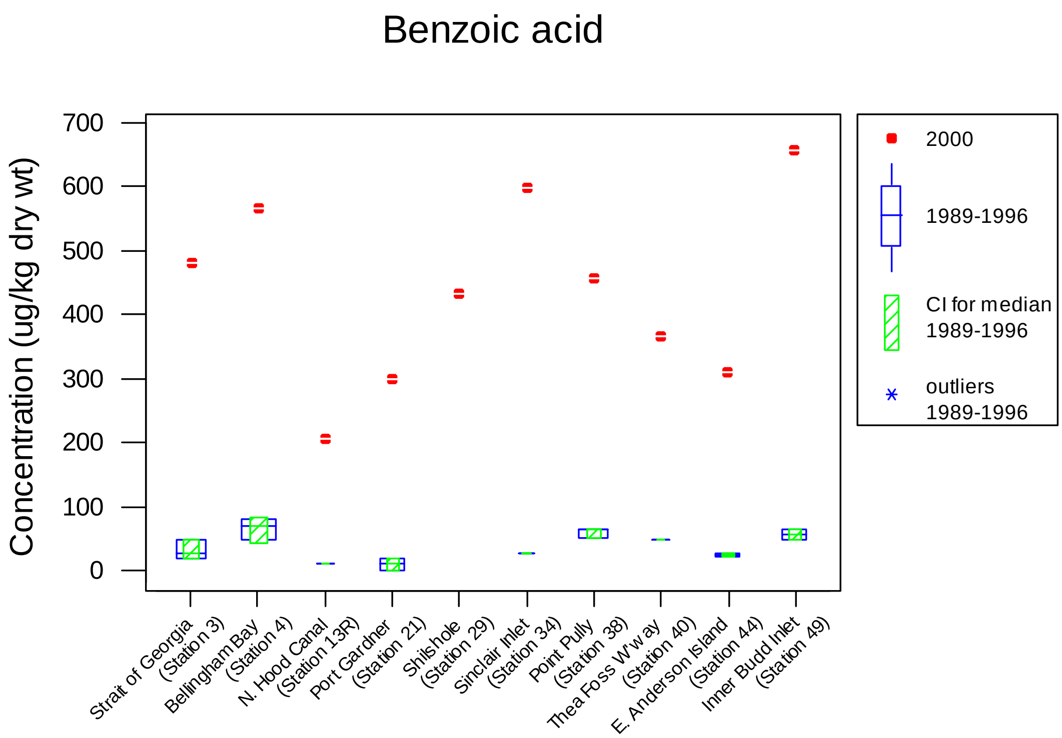
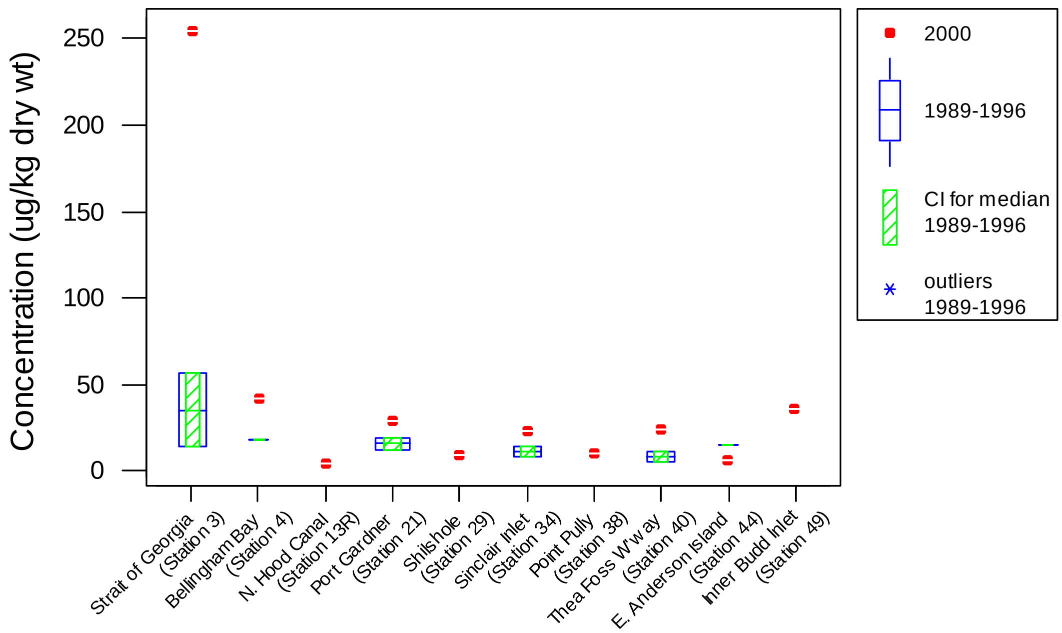


Figure 28. Benzoic acid concentration at the PSAMP long-term sediment monitoring stations, 1989-1996 and 2000. Boxplots display median (50th-percentile), 25th-percentile, 75th-percentile, and extreme values of the 1989-1996 results, with a 95% confidence interval for the median (diagonally-striped rectangle). The 2000 results are displayed as solid circles. The width of the boxplot is proportional to the number of observations.

4-Methylphenol



Phenol

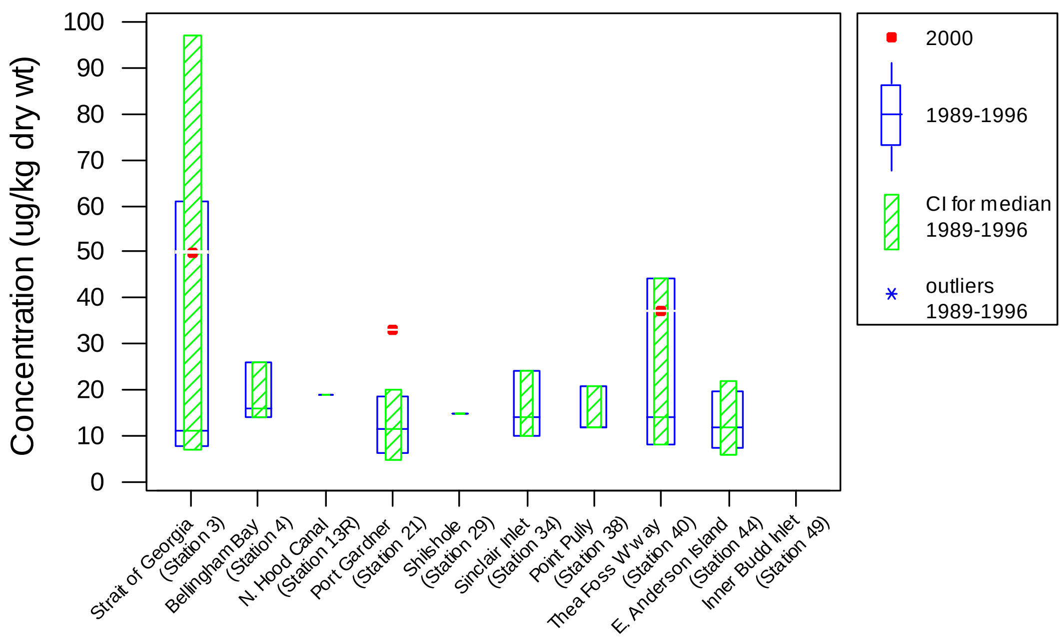
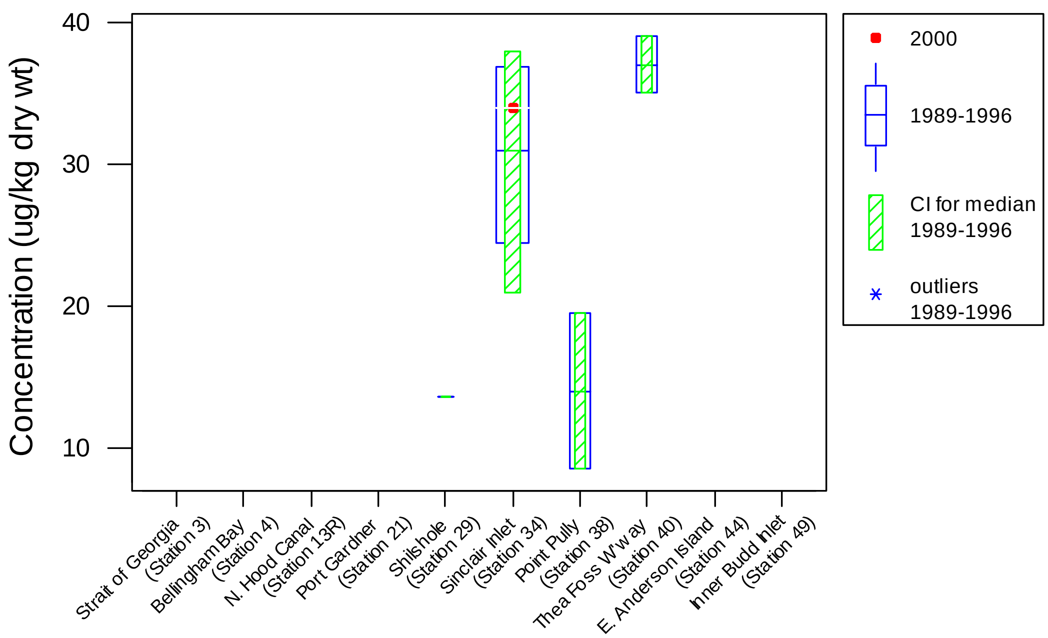


Figure 29. 4-Methylphenol concentration (top) and Phenol concentration (bottom), at the PSAMP long-term sediment monitoring stations, 1989-1996 and 2000. Boxplots display median (50th-percentile), 25th-percentile, 75th-percentile, and extreme values of the 1989-1996 results, with a 95% confidence interval for the median (diagonally-striped rectangle). The 2000 results are displayed as solid circles. The width of the boxplot is proportional to the number of observations.

Butylbenzylphthalate



Butylbenzylphthalate (TOC-normalized)

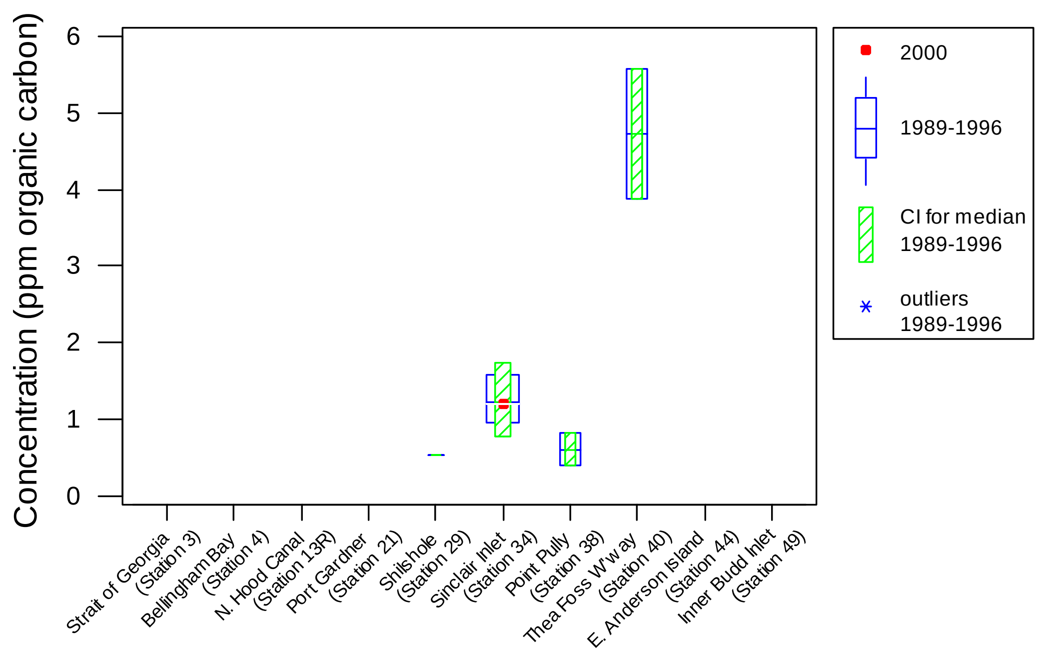
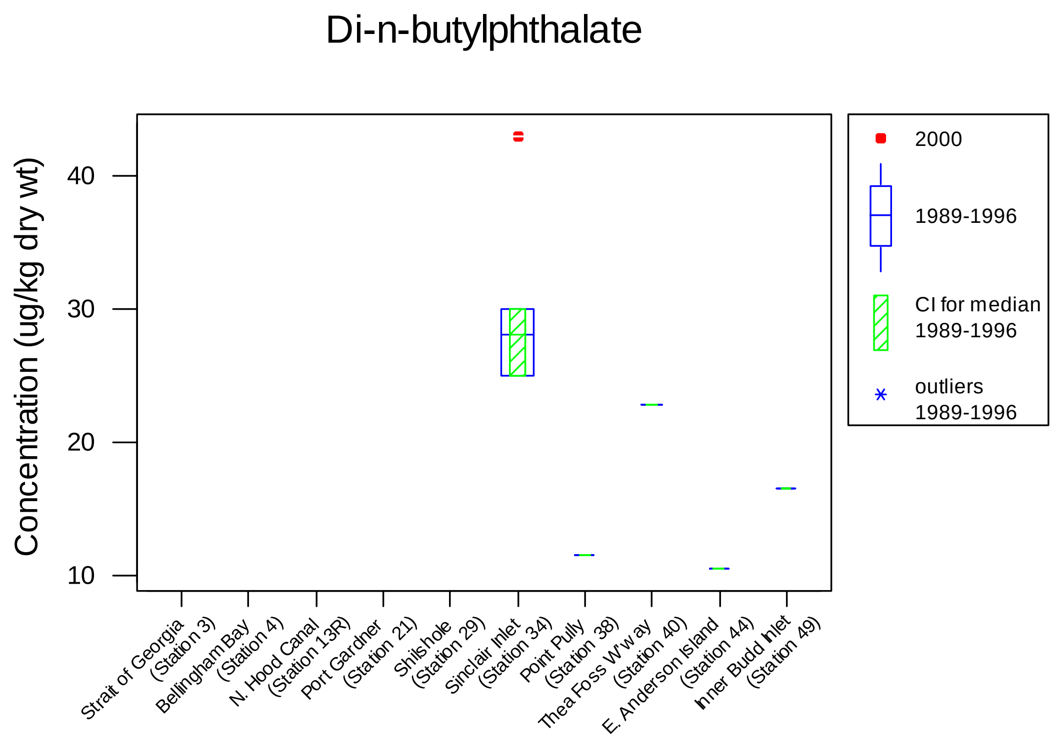


Figure 30. Butylbenzylphthalate concentration, dry weight (top) and TOC-normalized (bottom), at the PSAMP long-term sediment monitoring stations, 1989-1996 and 2000. Boxplots display median (50^{th}-percentile), 25^{th}-percentile, 75^{th}-percentile, and extreme values of the 1989-1996 results, with a 95% confidence interval for the median (diagonally-striped rectangle). The 2000 results are displayed as solid circles. The width of the boxplot is proportional to the number of observations.



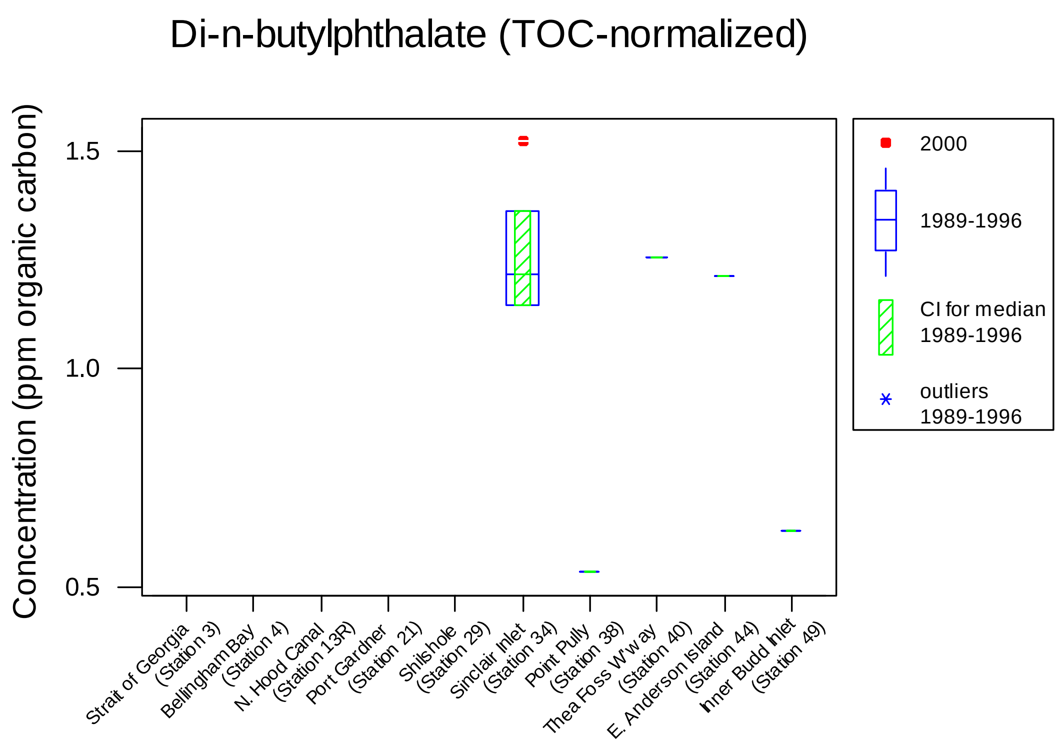


Figure 31. Di-n-butylphthalate concentration, dry weight (top) and TOC-normalized (bottom), at the PSAMP long-term sediment monitoring stations, 1989-1996 and 2000. Boxplots display median (50th-percentile), 25th-percentile, 75th-percentile, and extreme values of the 1989-1996 results, with a 95% confidence interval for the median (diagonally-striped rectangle). The 2000 results are displayed as solid circles. The width of the boxplot is proportional to the number of observations.

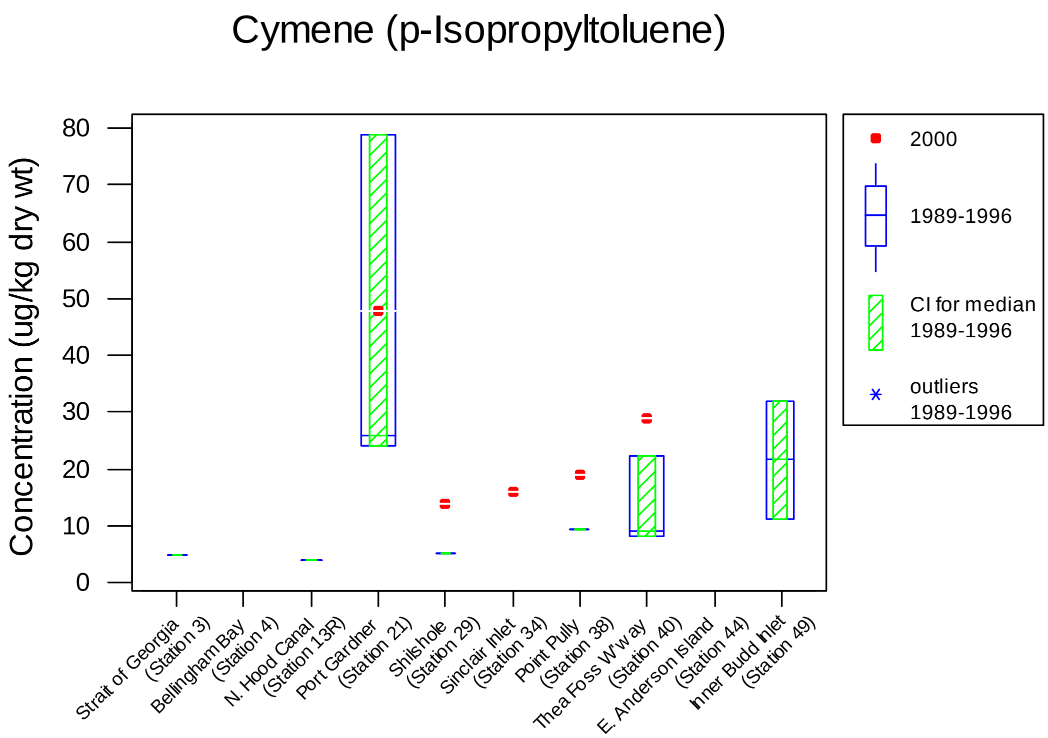


Figure 32. Cymene (p-Isopropyltoluene) concentration at the PSAMP long-term sediment monitoring stations, 1989-1996 and 2000. Boxplots display median (50th-percentile), 25th-percentile, 75th-percentile, and extreme values of the 1989-1996 results, with a 95% confidence interval for the median (diagonally-striped rectangle). The 2000 results are displayed as solid circles. The width of the boxplot is proportional to the number of observations.

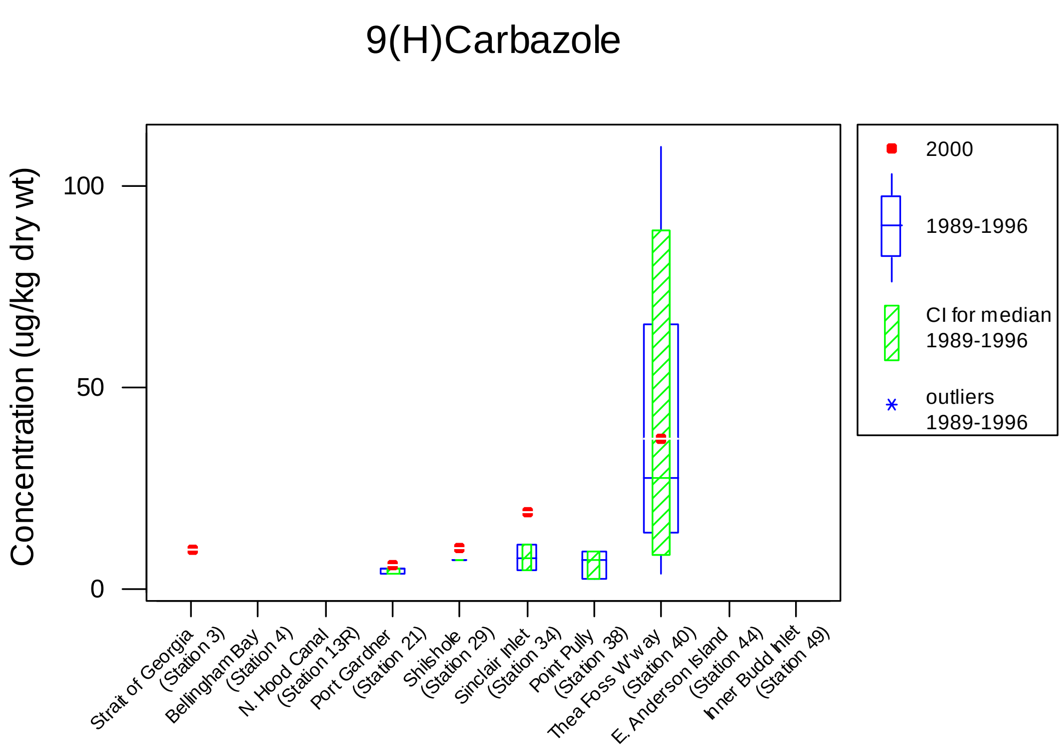
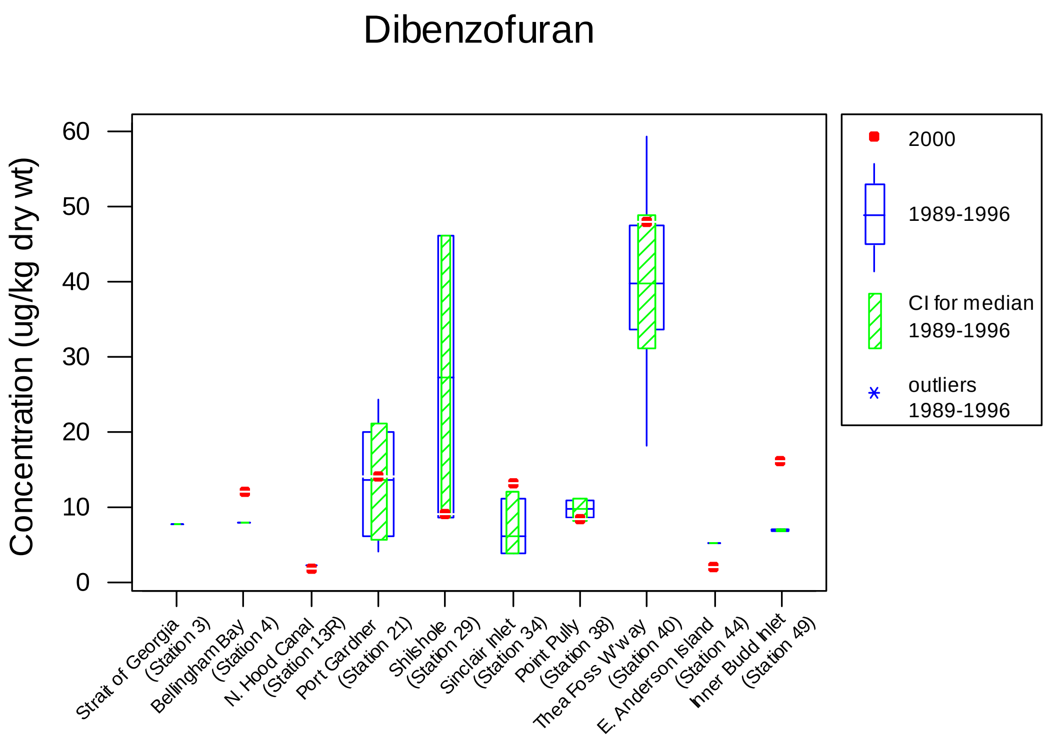


Figure 33. 9(H)Carbazole concentration at the PSAMP long-term sediment monitoring stations, 1989-1996 and 2000. Boxplots display median (50th-percentile), 25th-percentile, 75th-percentile, and extreme values of the 1989-1996 results, with a 95% confidence interval for the median (diagonally-striped rectangle). The 2000 results are displayed as solid circles. The width of the boxplot is proportional to the number of observations.



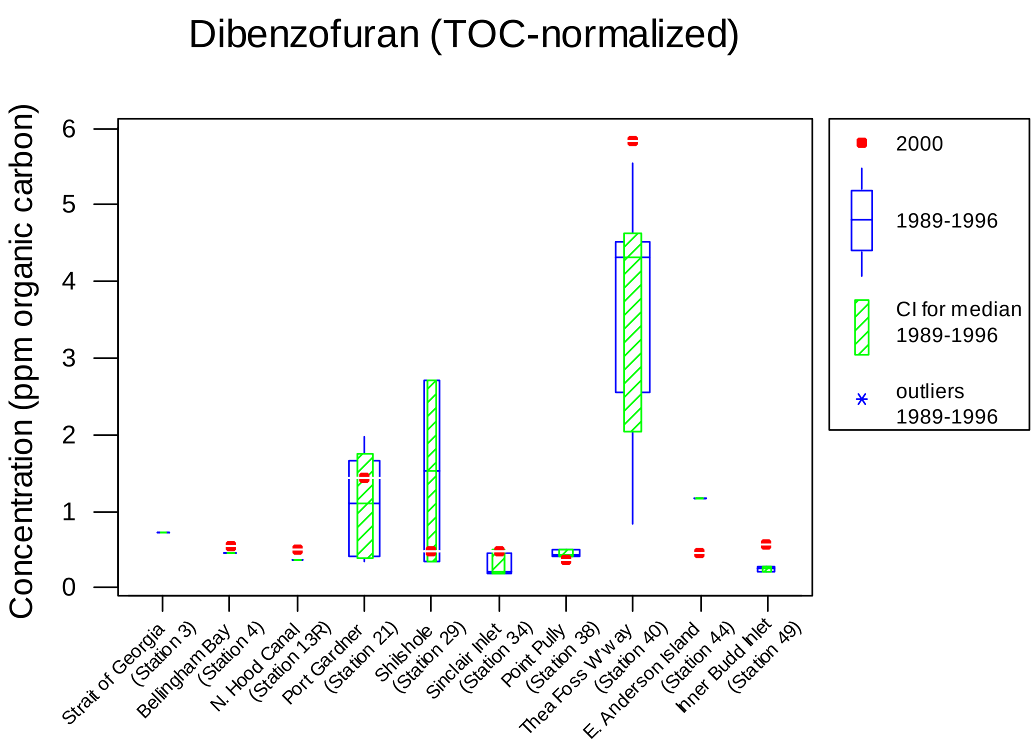
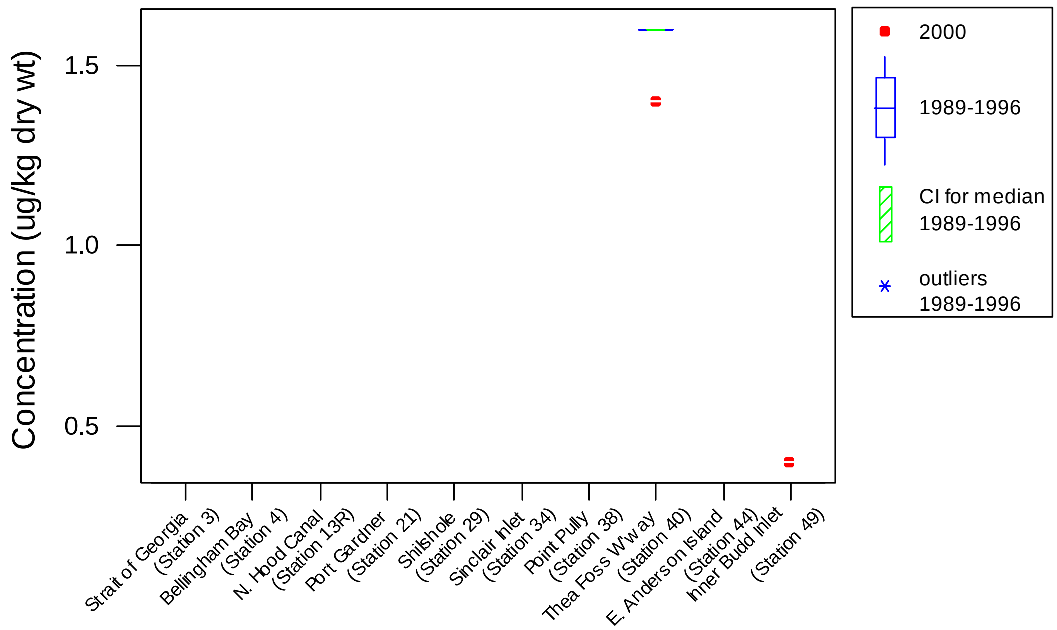


Figure 34. Dibenzofuran concentration, dry weight (top) and TOC-normalized (bottom), at the PSAMP long-term sediment monitoring stations, 1989-1996 and 2000. Boxplots display median (50th-percentile), 25th-percentile, 75th-percentile, and extreme values of the 1989-1996 results, with a 95% confidence interval for the median (diagonally-striped rectangle). The 2000 results are displayed as solid circles. The width of the boxplot is proportional to the number of observations.

4,4'-DDD



4,4'-DDE

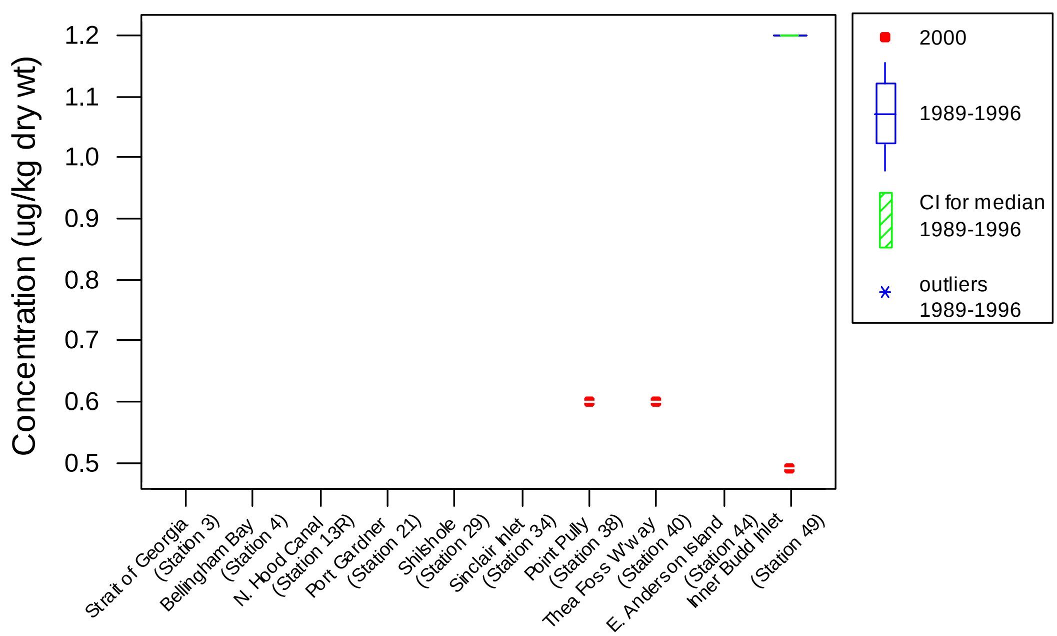
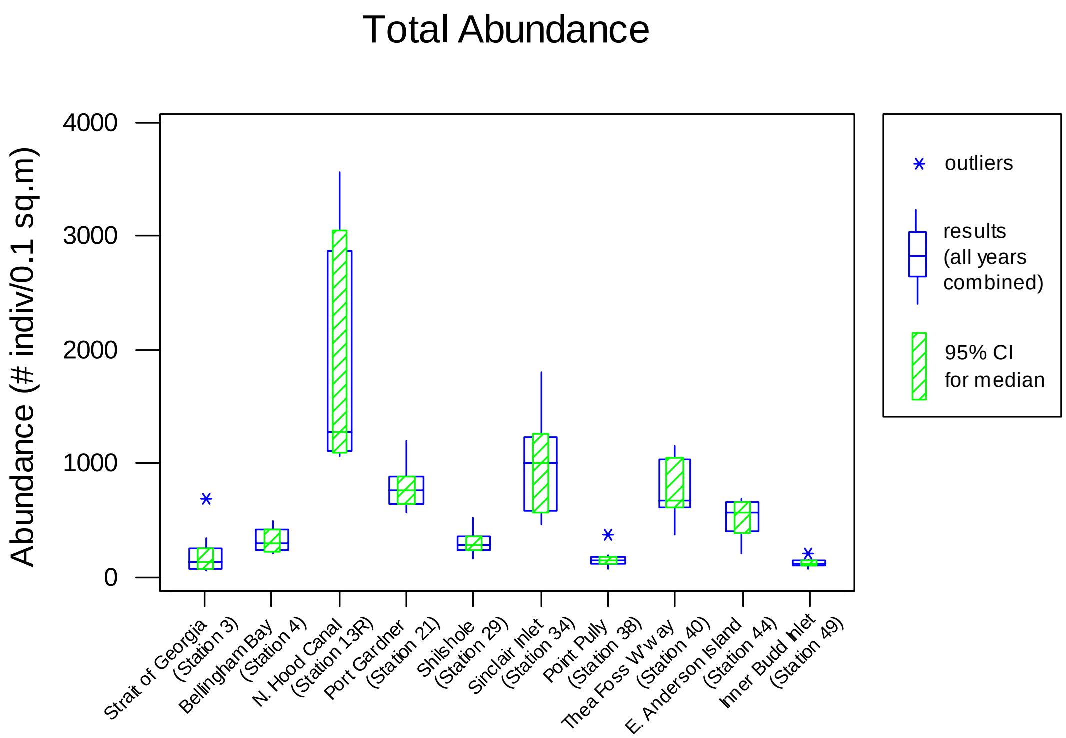


Figure 35. Concentration of 4,4'-DDD (top) and 4,4'-DDE (bottom) at the PSAMP long-term sediment monitoring stations, 1989-1996 and 2000. Boxplots display median (50th-percentile), 25th-percentile, 75th-percentile, and extreme values of the 1989-1996 results, with a 95% confidence interval for the median (diagonally-striped rectangle). The 2000 results are displayed as solid circles. The width of the boxplot is proportional to the number of observations.



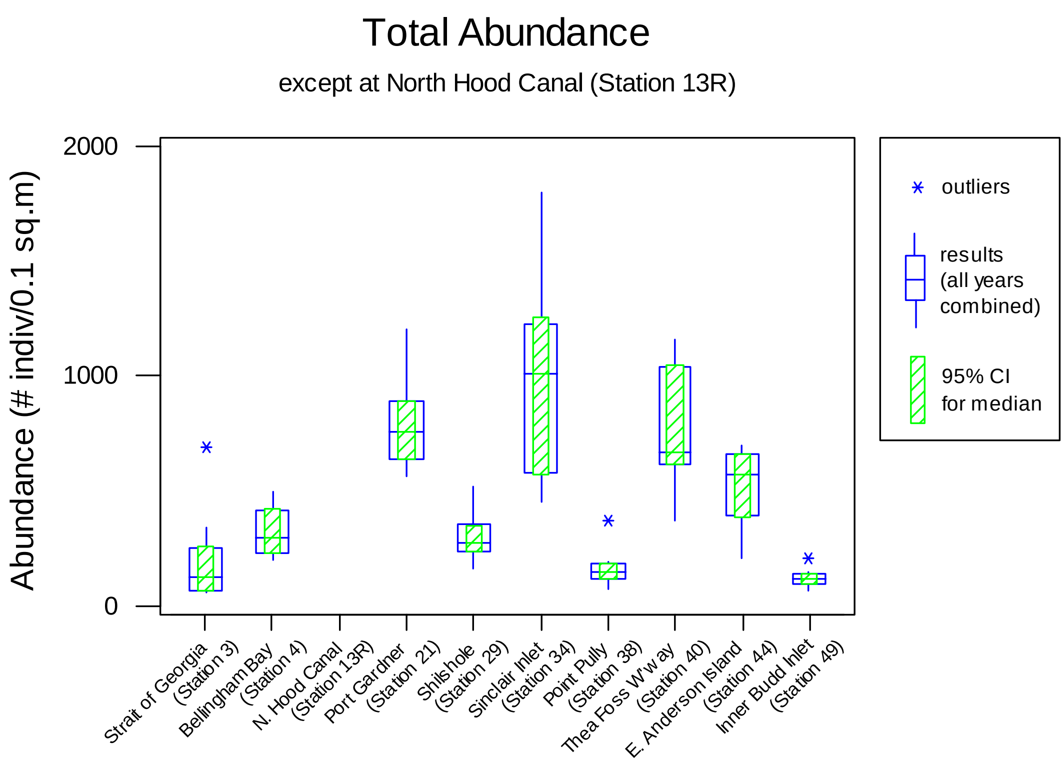
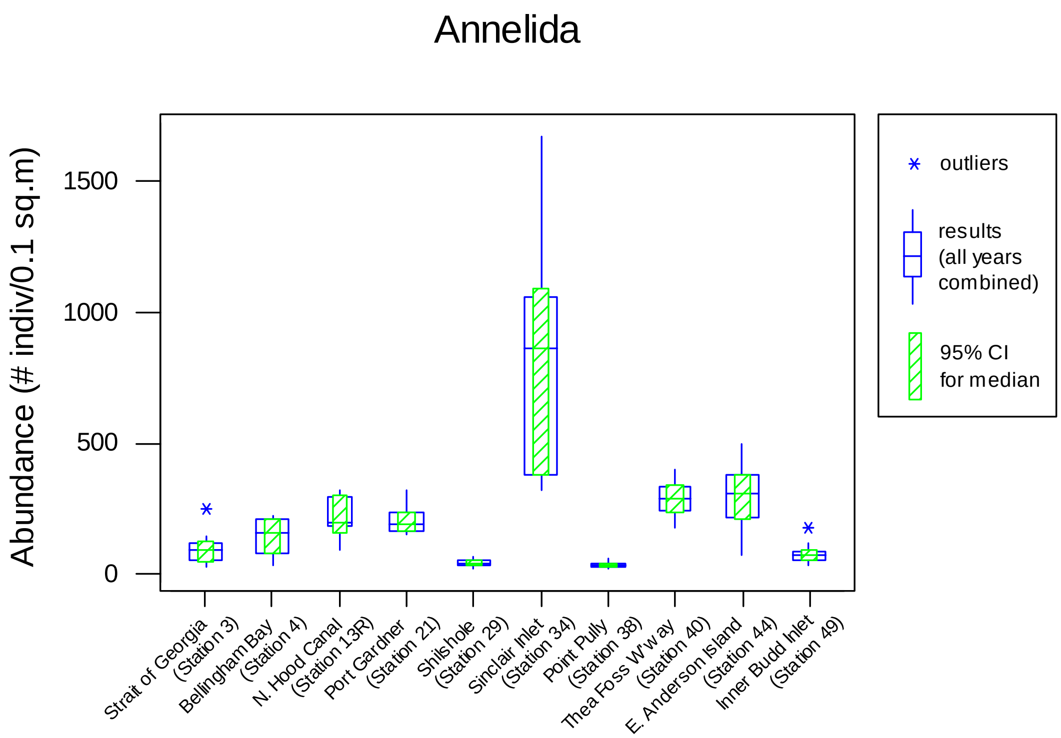


Figure 36. Total benthic macroinvertebrate abundance at the PSAMP long-term sediment monitoring stations, 1989-2000, all stations (top) and without the North Hood Canal station (bottom). Boxplots display median (50th-percentile), 25th-percentile, 75th-percentile, and extreme values of the results, with a 95% confidence interval for the median (diagonally-striped rectangle). The width of the boxplot is proportional to the number of observations.



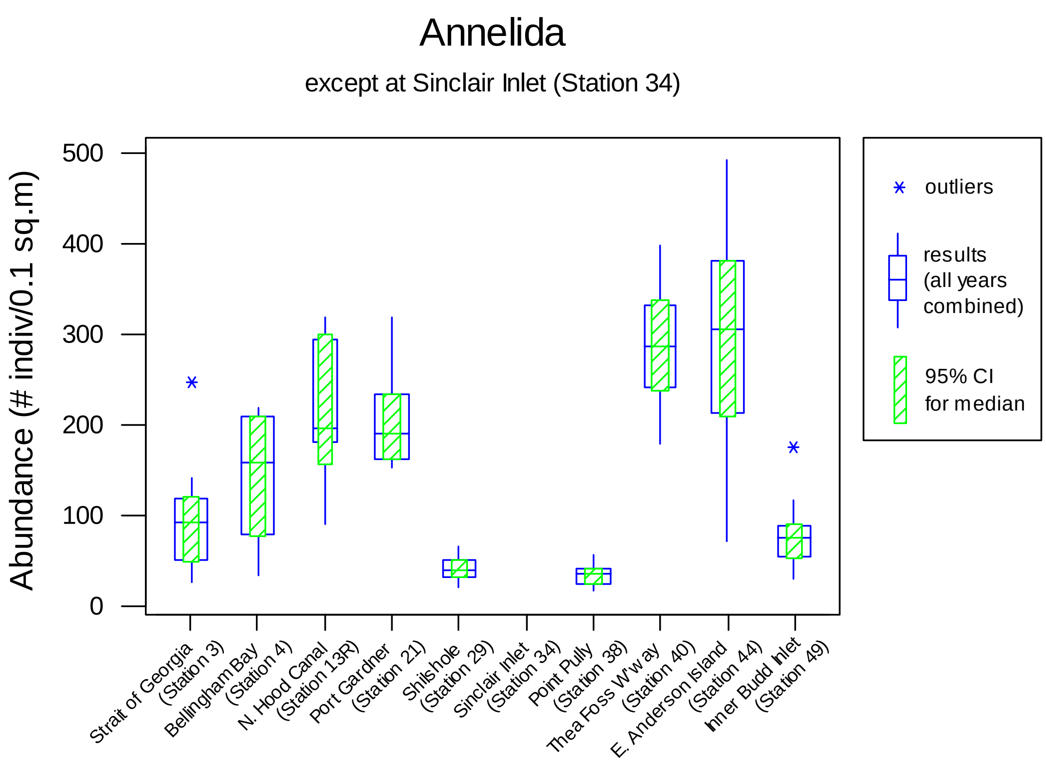


Figure 37. Annelid abundance at the PSAMP long-term sediment monitoring stations, 1989-2000, all stations (top) and without the Sinclair Inlet station (bottom). Boxplots display median (50^{th}-percentile), 25^{th}-percentile, 75^{th}-percentile, and extreme values of the results, with a 95% confidence interval for the median (diagonally-striped rectangle). The width of the boxplot is proportional to the number of observations.

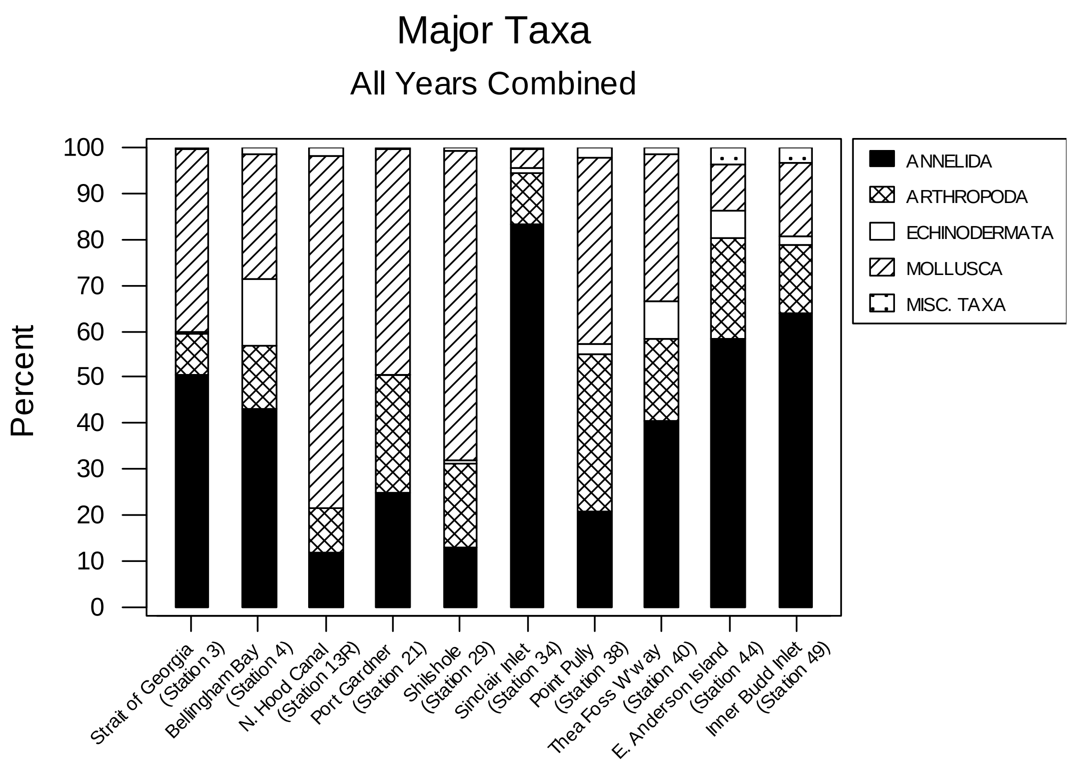


Figure 38. Major taxa at the PSAMP long-term sediment monitoring stations, 1989-2000.

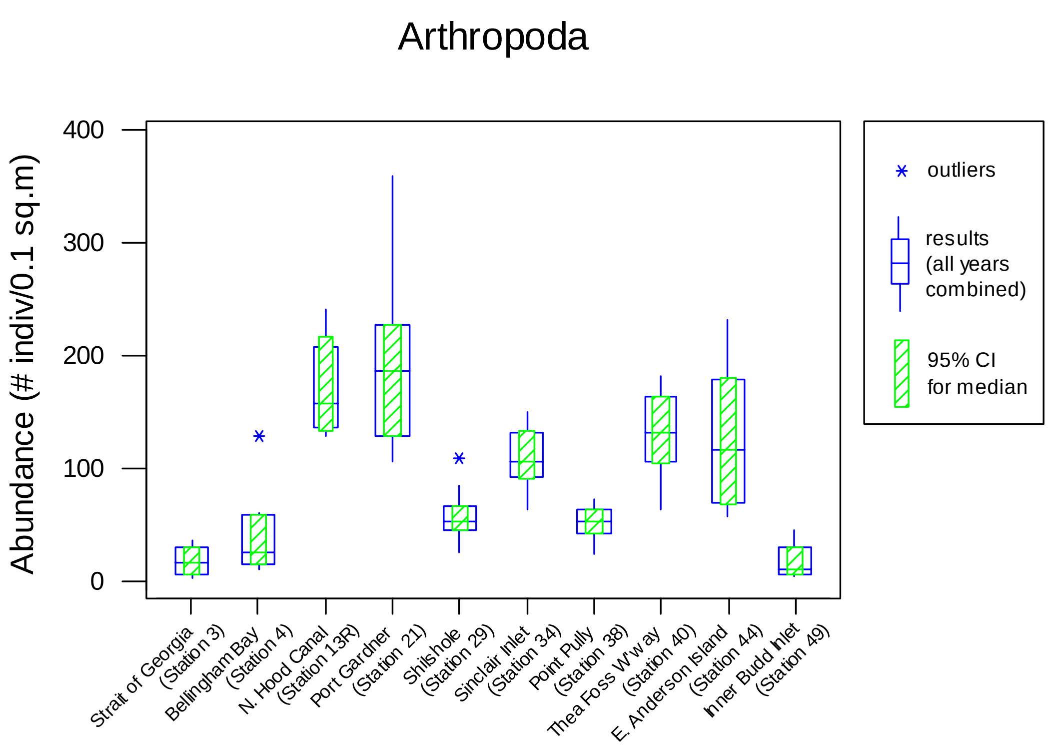
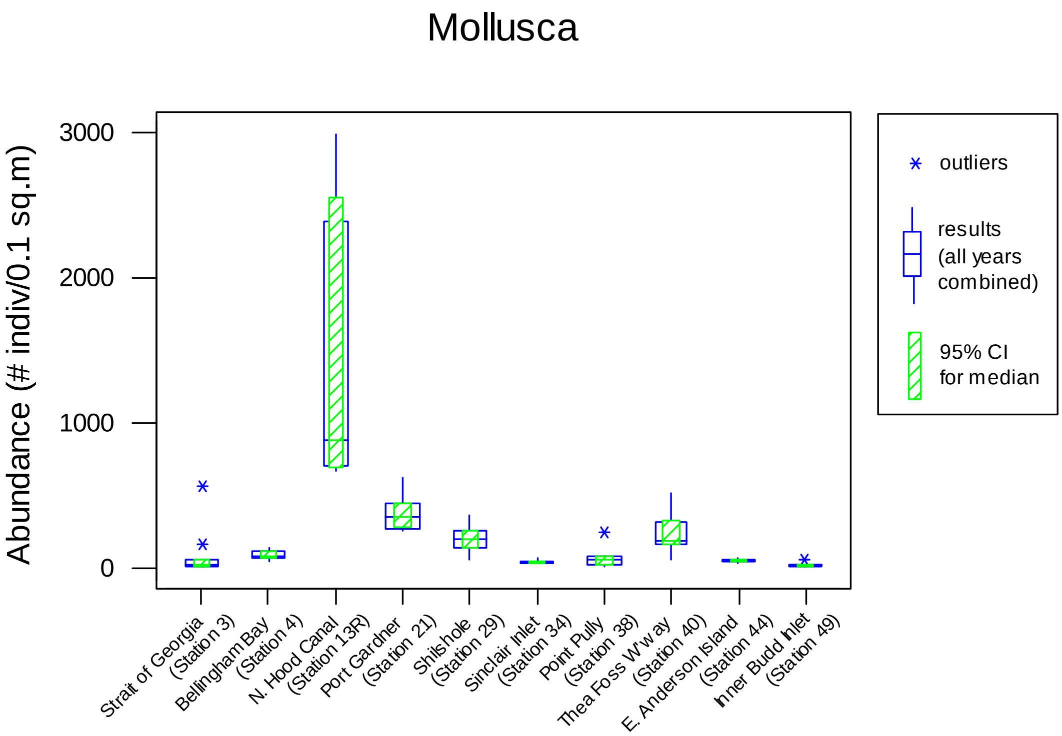


Figure 39. Arthropod abundance at the PSAMP long-term sediment monitoring stations, 1989-2000. Boxplots display median (50^{th}-percentile), 25^{th}-percentile, 75^{th}-percentile, and extreme values of the results, with a 95% confidence interval for the median (diagonally-striped rectangle). The width of the boxplot is proportional to the number of observations.



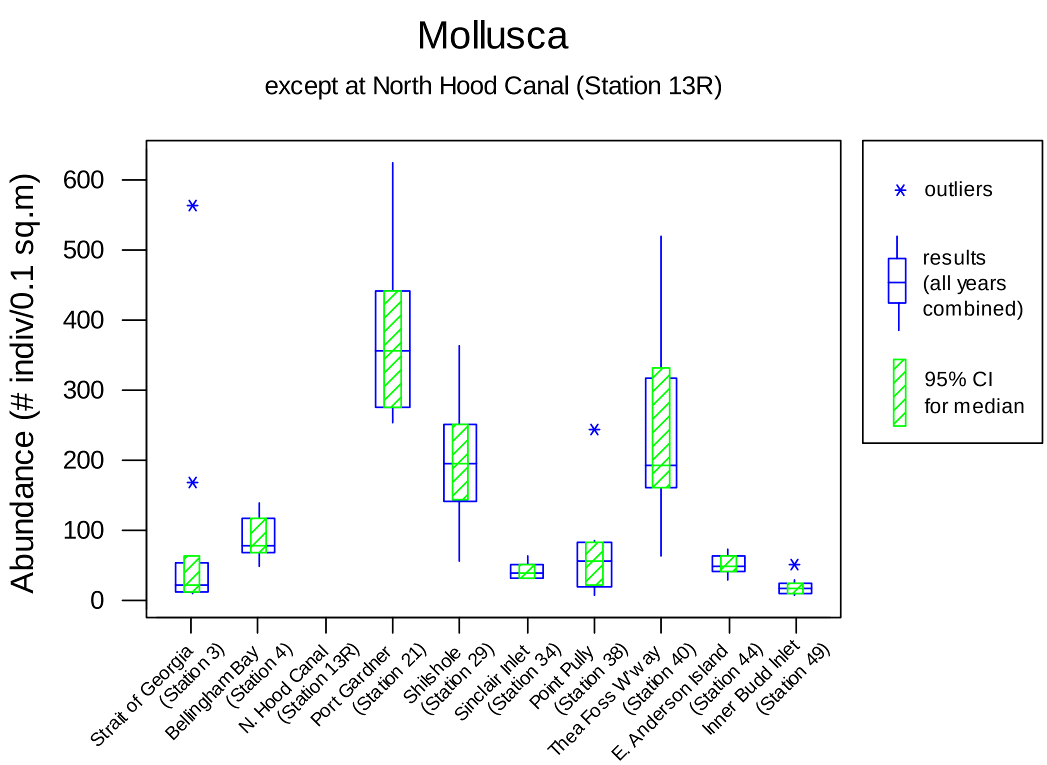
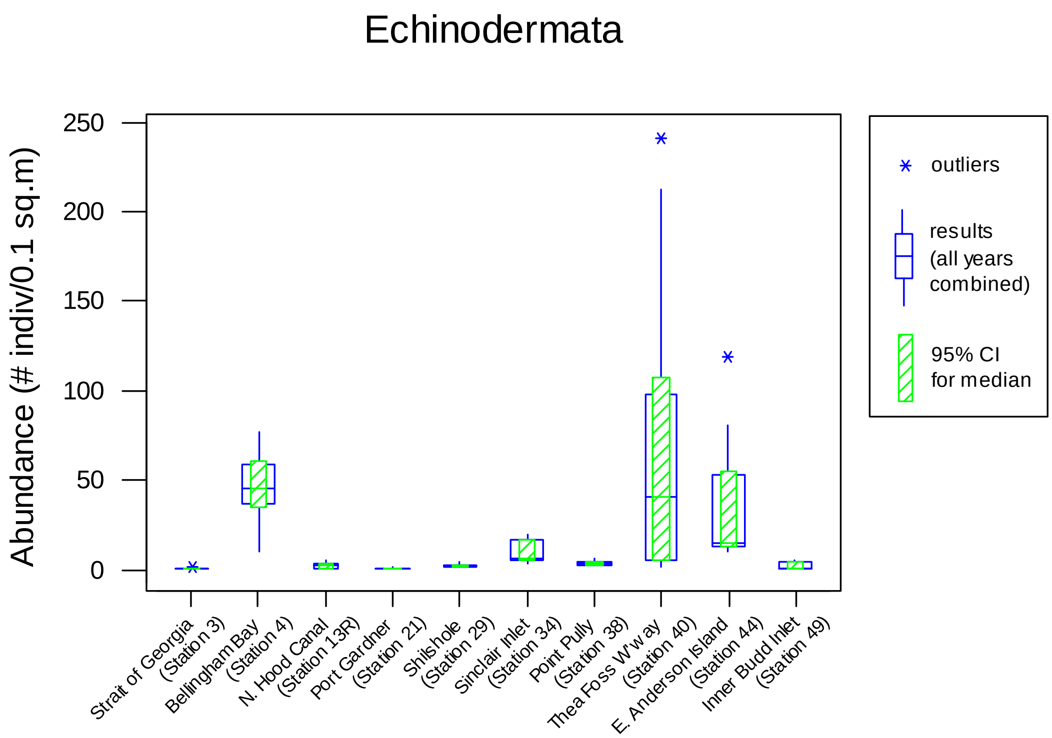


Figure 40. Mollusc abundance at the PSAMP long-term sediment monitoring stations, 1989-2000, all stations (top) and without the North Hood Canal station (bottom). Boxplots display median (50^{th}-percentile), 25^{th}-percentile, 75^{th}-percentile, and extreme values of the results, with a 95% confidence interval for the median (diagonally-striped rectangle). The width of the boxplot is proportional to the number of observations.



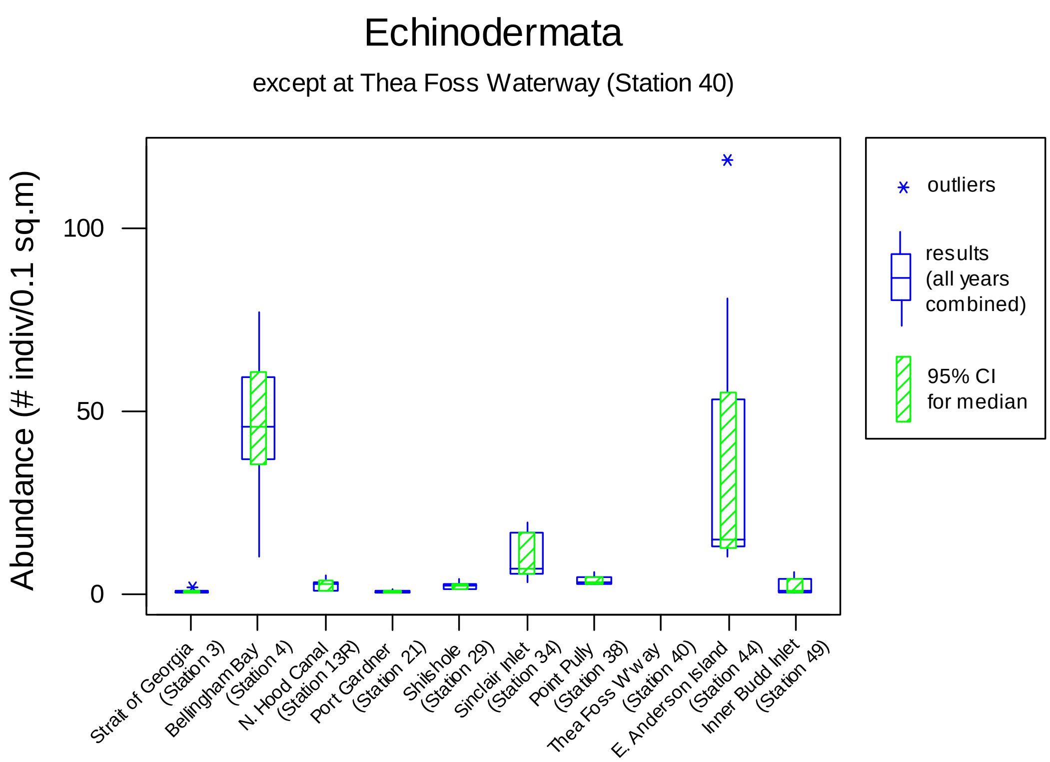
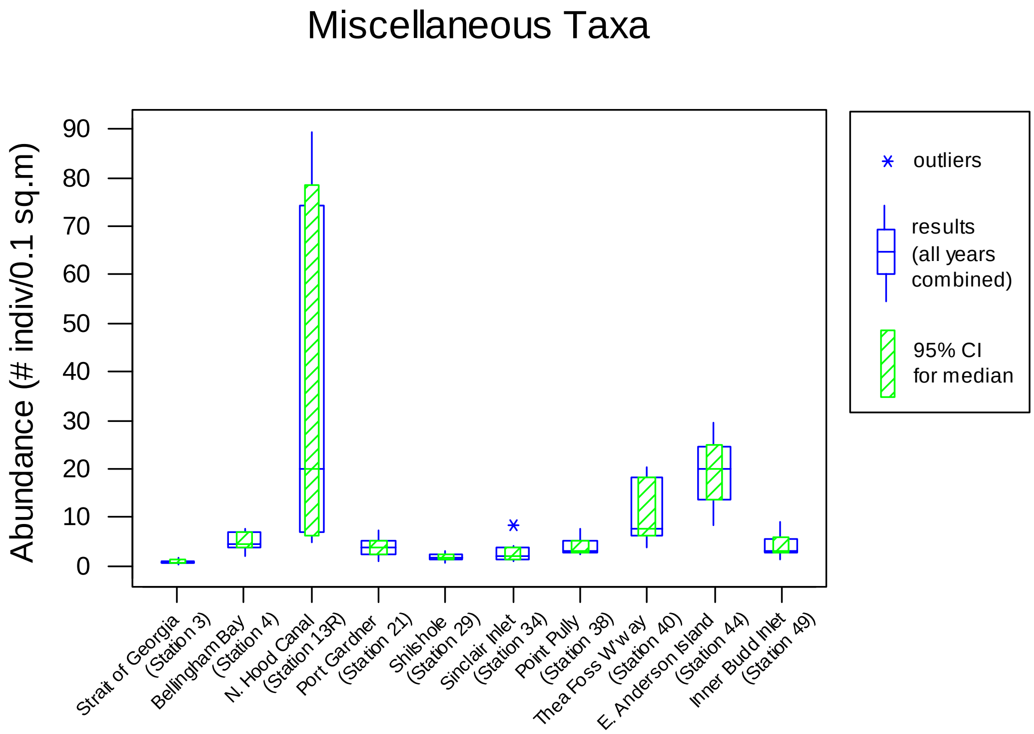


Figure 41. Echinoderm abundance at the PSAMP long-term sediment monitoring stations, 1989-2000, all stations (top) and without the Thea Foss Waterway station (bottom). Boxplots display median (50^{th}-percentile), 25^{th}-percentile, 75^{th}-percentile, and extreme values of the results, with a 95% confidence interval for the median (diagonally-striped rectangle). The width of the boxplot is proportional to the number of observations.



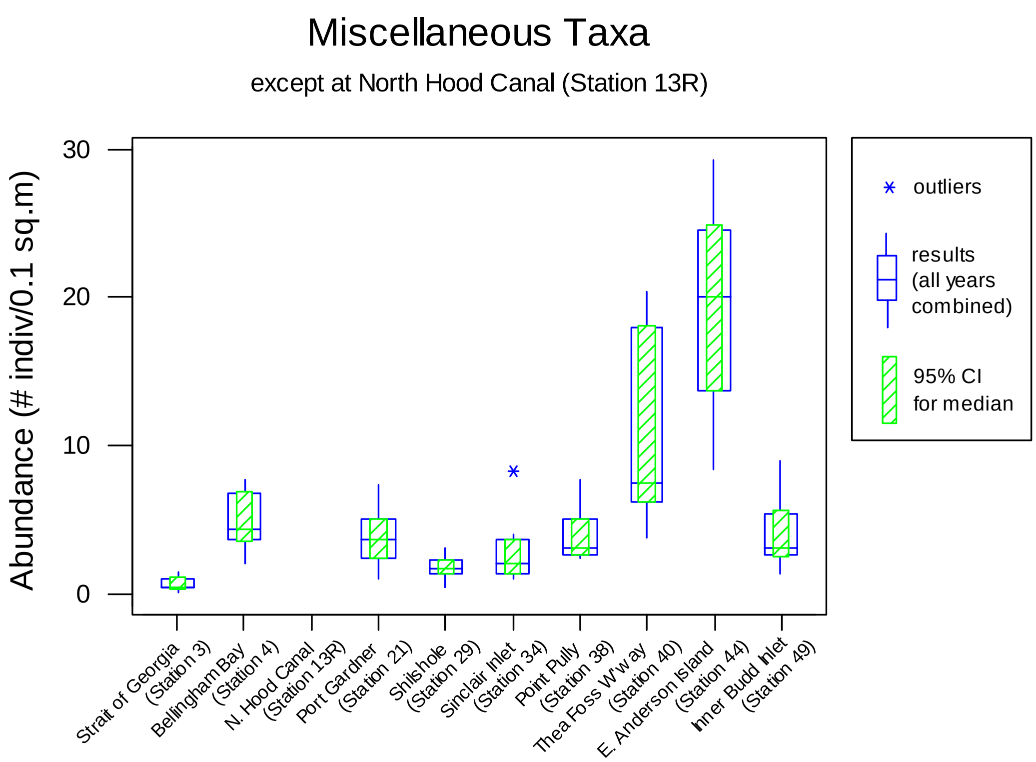


Figure 42. Abundance of miscellaneous benthic macroinvertebrate taxa at the PSAMP long-term sediment monitoring stations, 1989-2000, all stations (top) and without the North Hood Canal station (bottom). Boxplots display median (50^{th}-percentile), 25^{th}-percentile, 75^{th}-percentile, and extreme values of the results, with a 95% confidence interval for the median (diagonally-striped rectangle). The width of the boxplot is proportional to the number of observations.

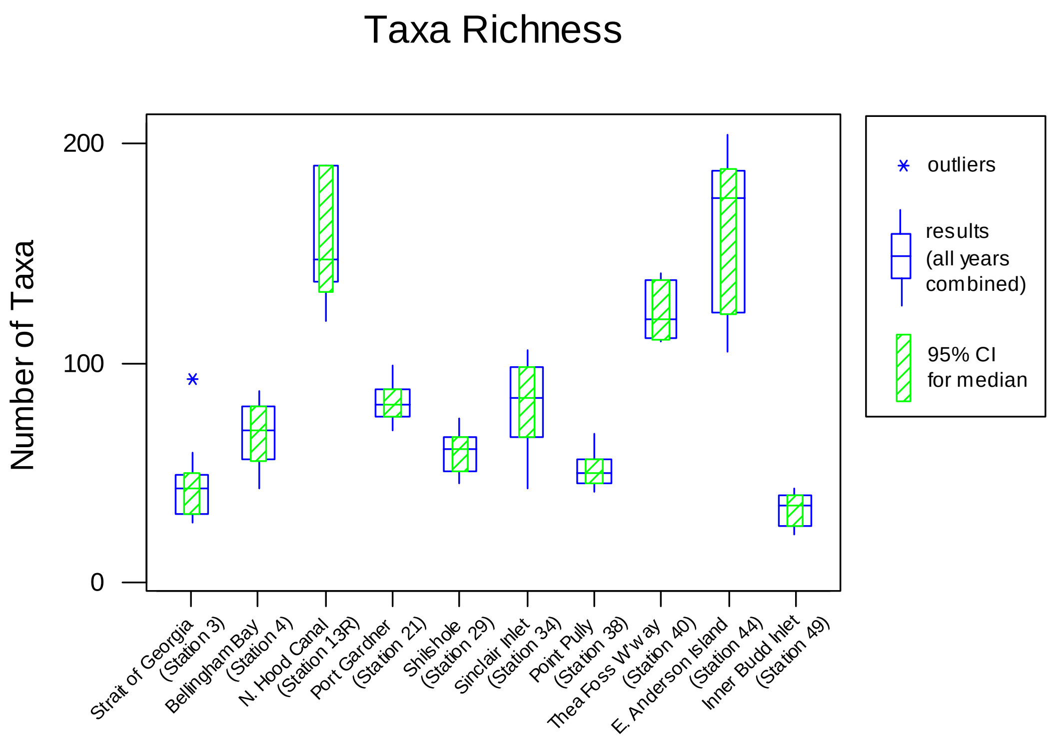


Figure 43. Benthic macroinvertebrate taxa richness at the PSAMP long-term sediment monitoring stations, 1989-2000. Boxplots display median (50th-percentile), 25th-percentile, 75th-percentile, and extreme values of the results, with a 95% confidence interval for the median (diagonally-striped rectangle). The width of the boxplot is proportional to the number of observations.

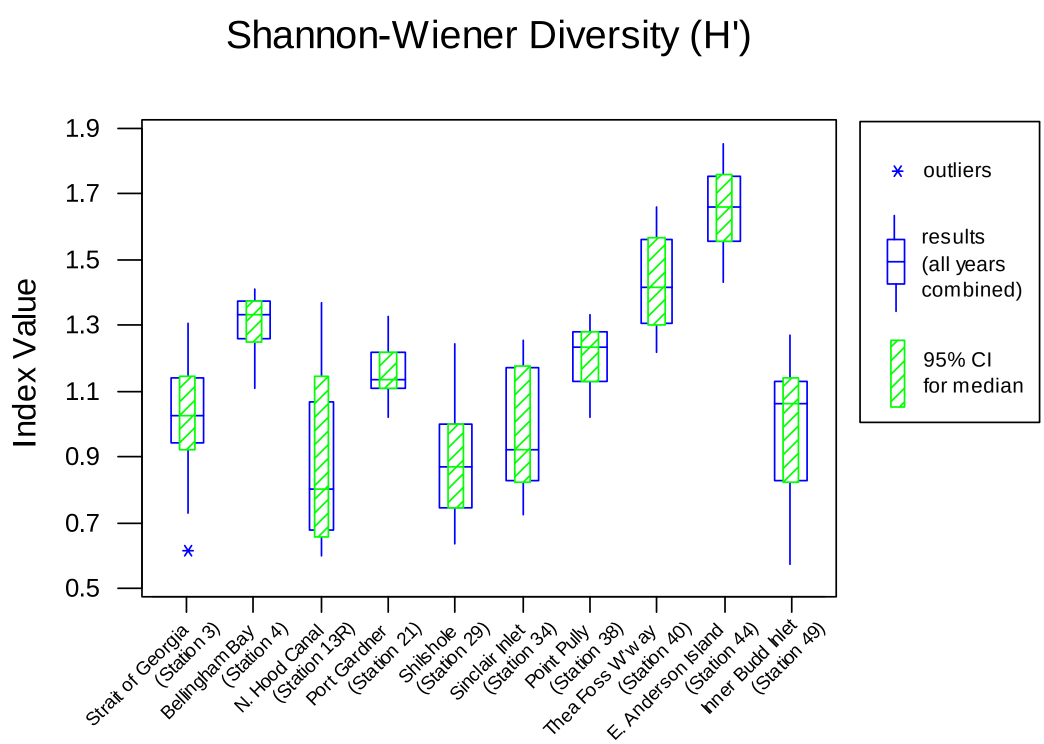


Figure 44. Shannon-Wiener diversity index (H') calculated for benthic macroinvertebrates at the PSAMP long-term sediment monitoring stations, 1989-2000. Boxplots display median (50th-percentile), 25th-percentile, 75th-percentile, and extreme values of the results, with a 95% confidence interval for the median (diagonally-striped rectangle). The width of the boxplot is proportional to the number of observations.

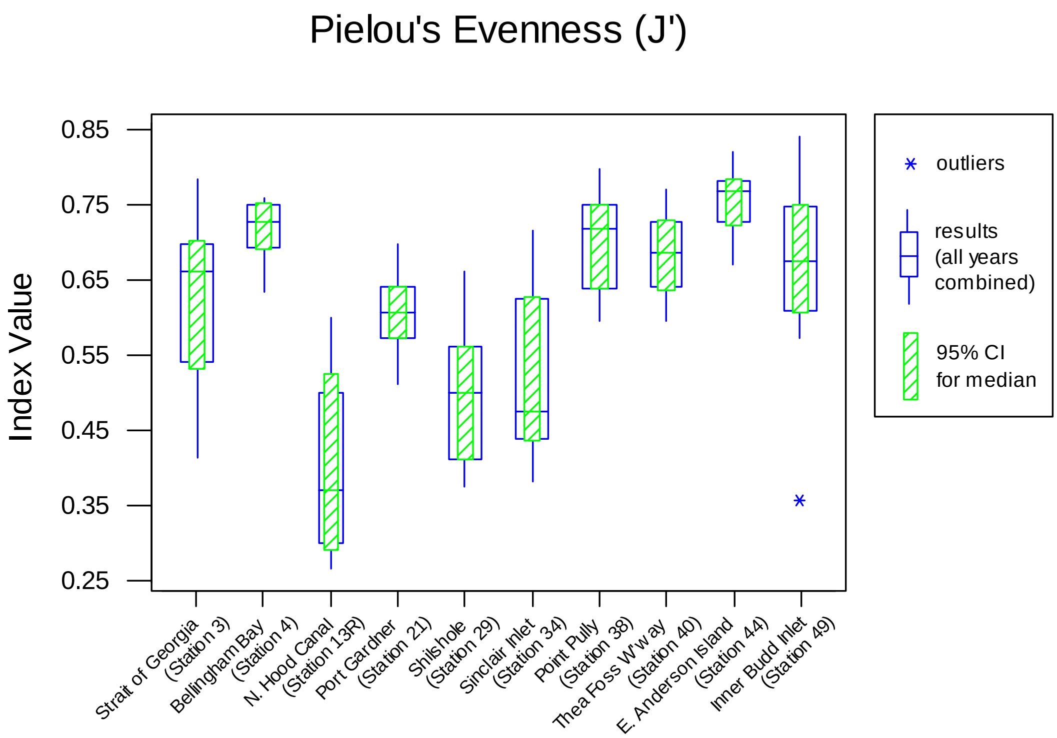


Figure 45. Pielou's evenness index (J') calculated for benthic macroinvertebrates at the PSAMP long-term sediment monitoring stations, 1989-2000. Boxplots display median (50th-percentile), 25th-percentile, 75th-percentile, and extreme values of the results, with a 95% confidence interval for the median (diagonally-striped rectangle). The width of the boxplot is proportional to the number of observations.

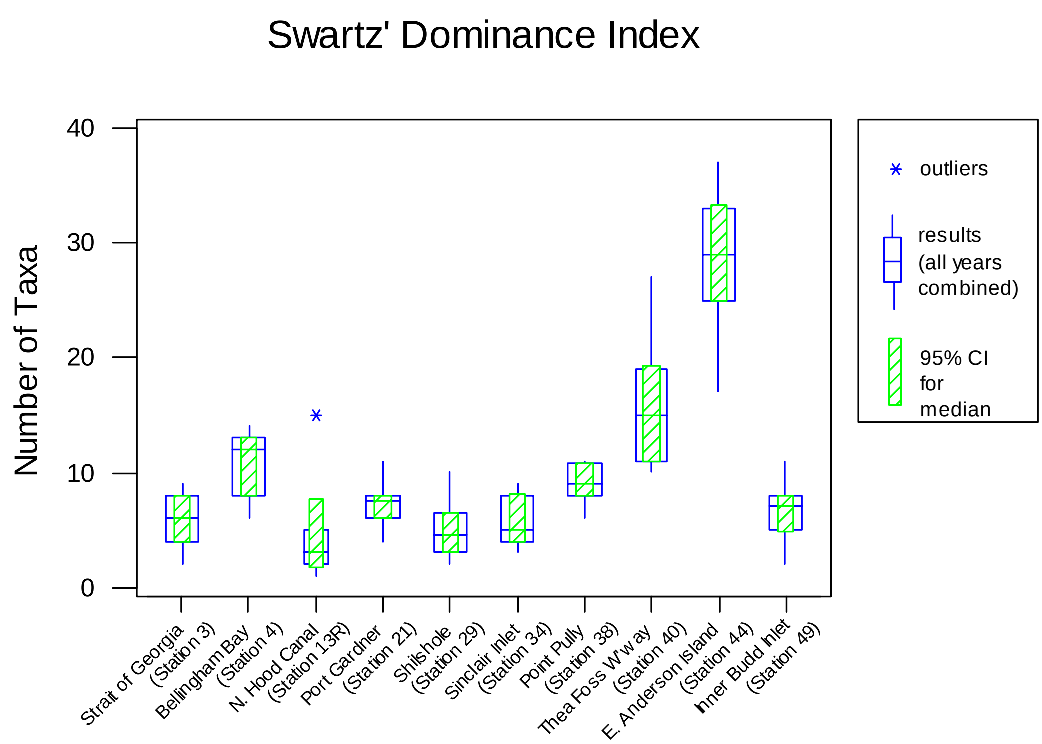


Figure 46. Swartz' dominance index, the number of taxa comprising the most abundant 75% of benthic macroinvertebrates, at the PSAMP long-term sediment monitoring stations, 1989-2000. Boxplots display median (50th-percentile), 25th-percentile, 75th-percentile, and extreme values of the results, with a 95% confidence interval for the median (diagonally-striped rectangle). The width of the boxplot is proportional to the number of observations.

Swartz' Dominance standardized by Taxa Richness

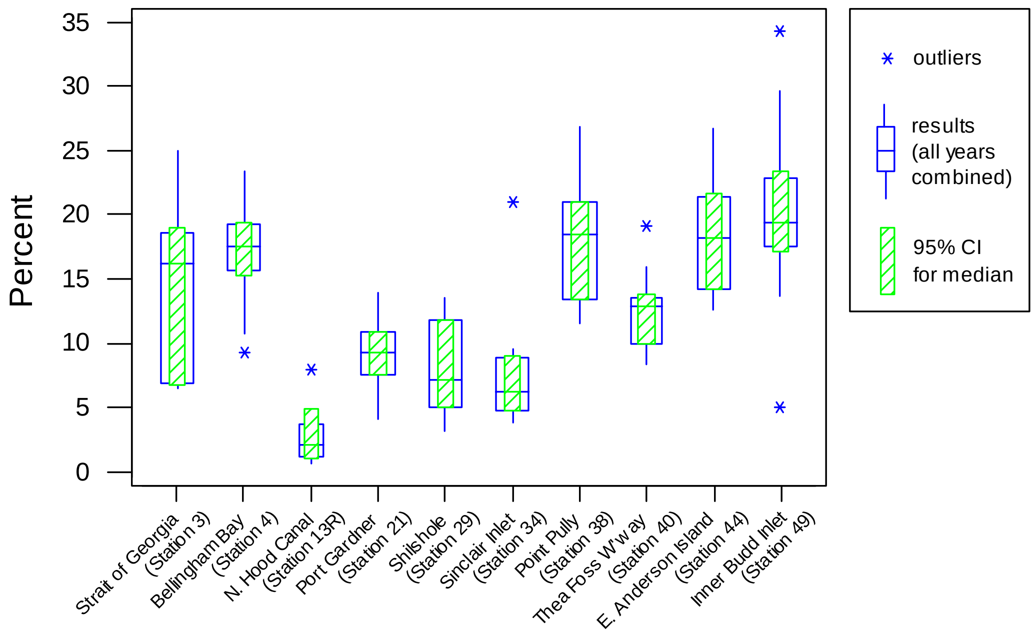


Figure 47. Swartz' dominance index, standardized by taxa richness, at the PSAMP long-term sediment monitoring stations, 1989-2000. Boxplots display median (50th-percentile), 25th-percentile, 75th-percentile, and extreme values of the results, with a 95% confidence interval for the median (diagonally-striped rectangle). The width of the boxplot is proportional to the number of observations.

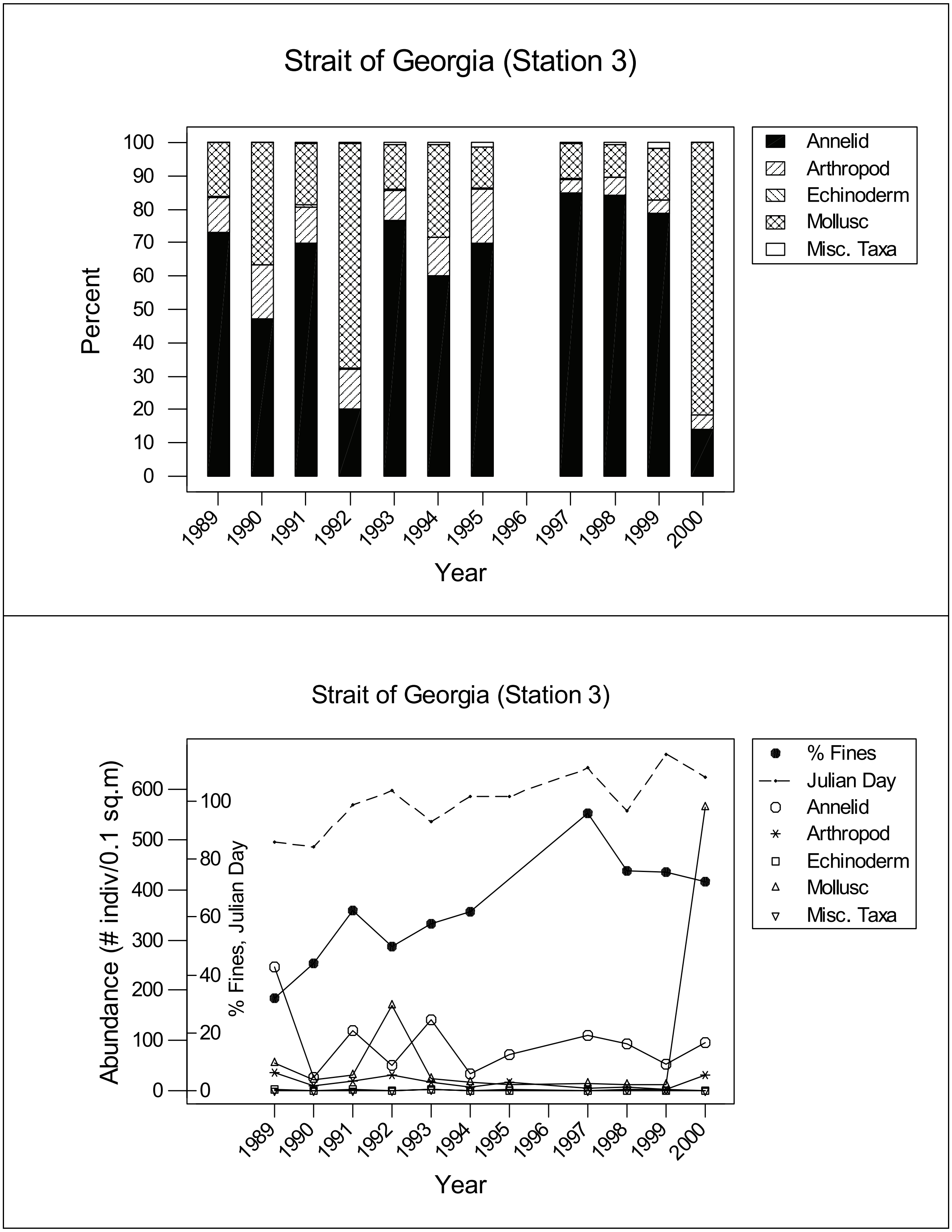
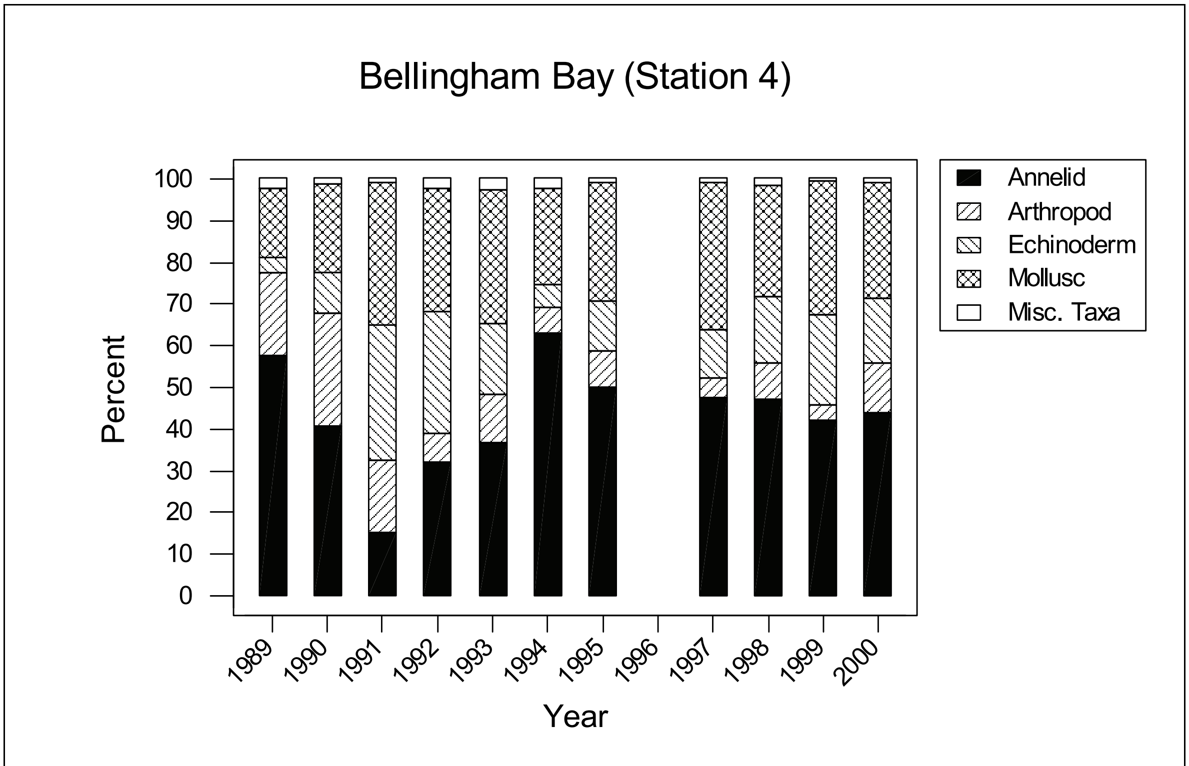


Figure 48a. Percent abundance (top) and absolute abundance (bottom) of major taxa groups at the Strait of Georgia station, 1989-2000.



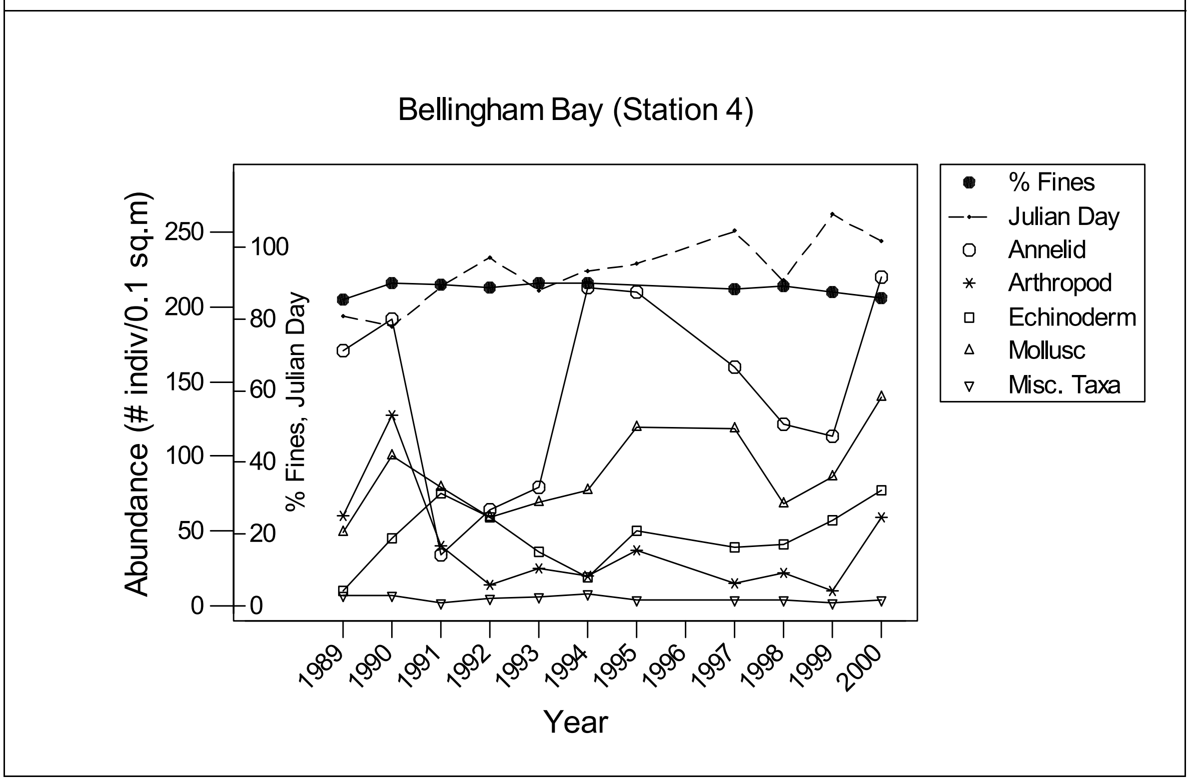


Figure 48b. Percent abundance (top) and absolute abundance (bottom) of major taxa groups at the Bellingham Bay station, 1989-2000.

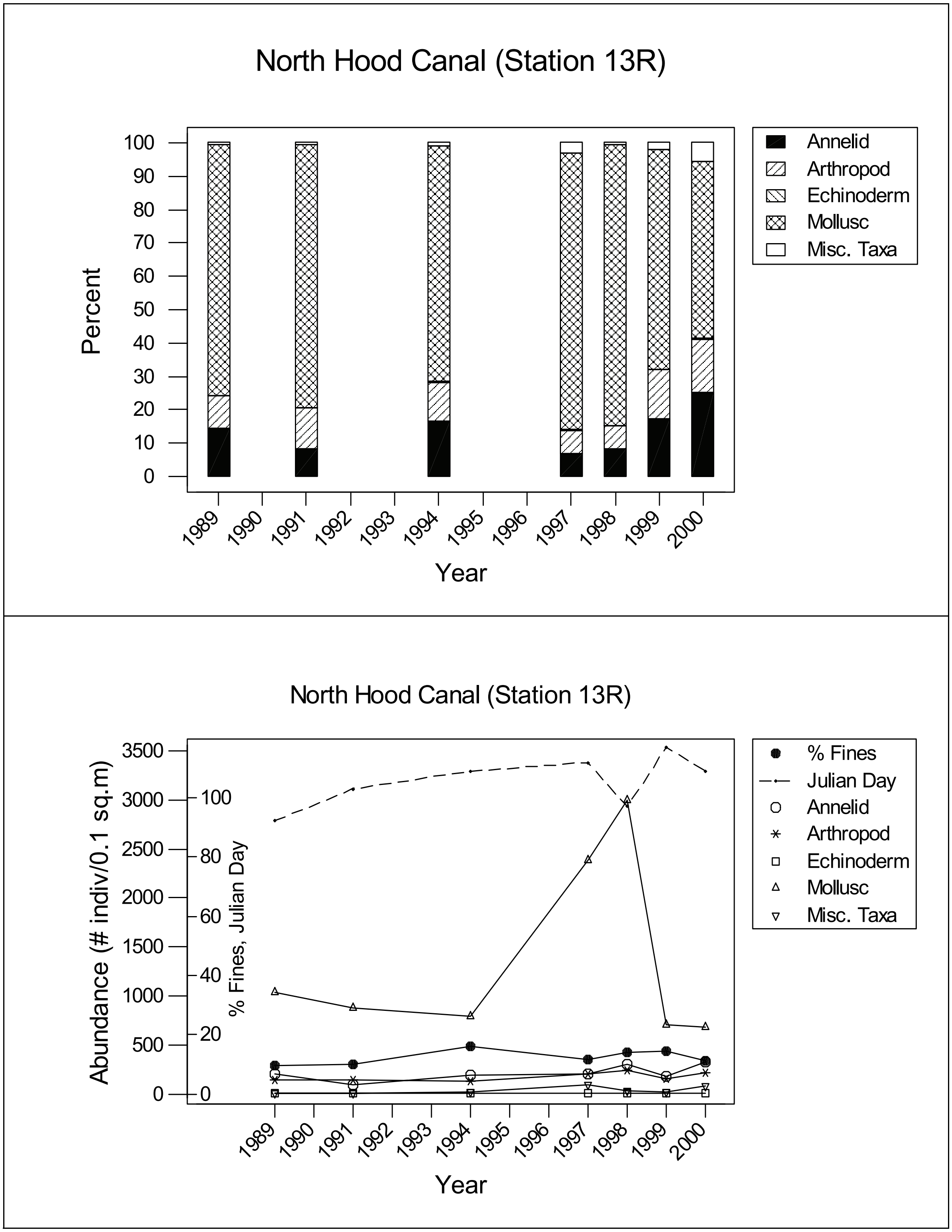


Figure 48c. Percent abundance (top) and absolute abundance (bottom) of major taxa groups at the North Hood Canal station, 1989-2000.

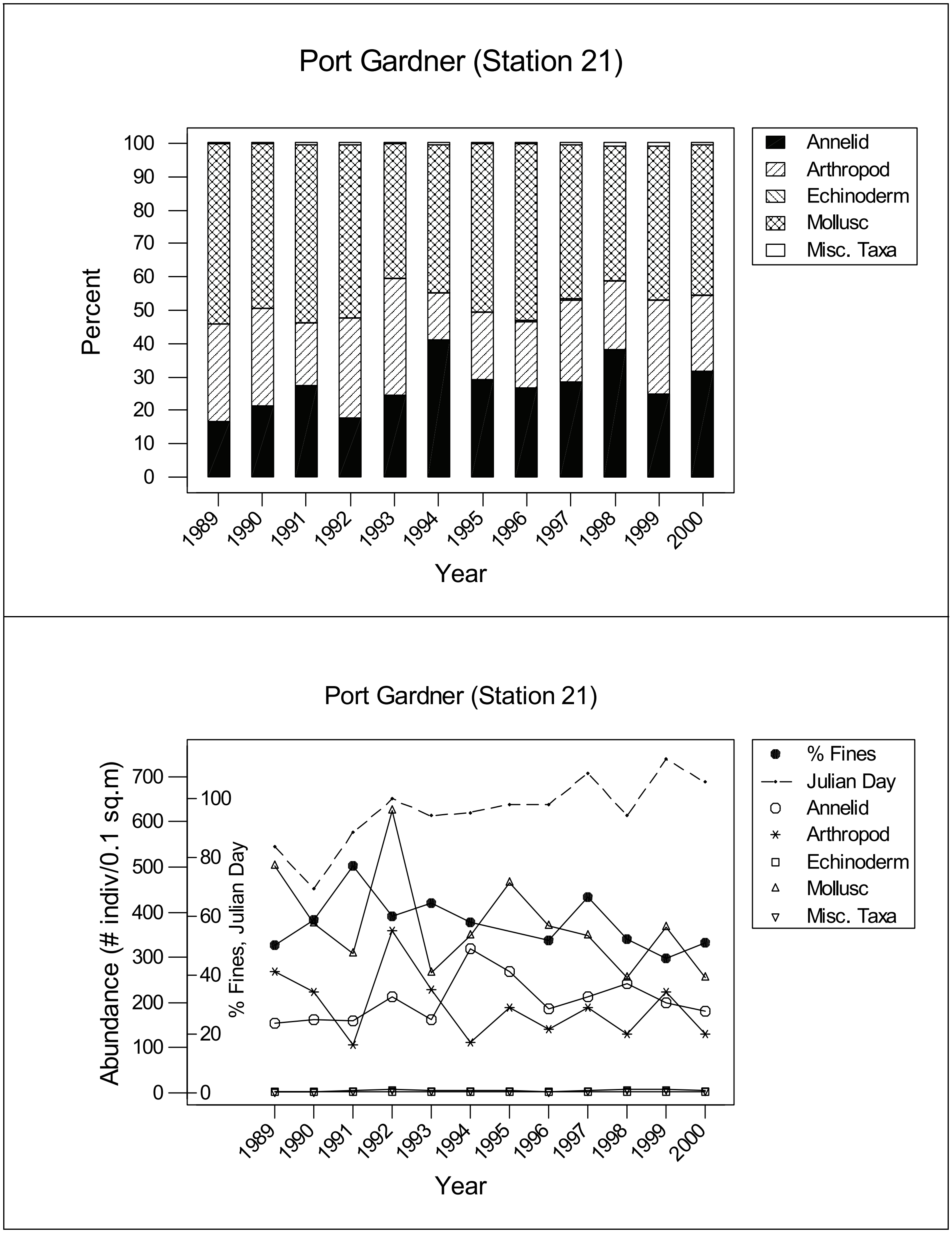
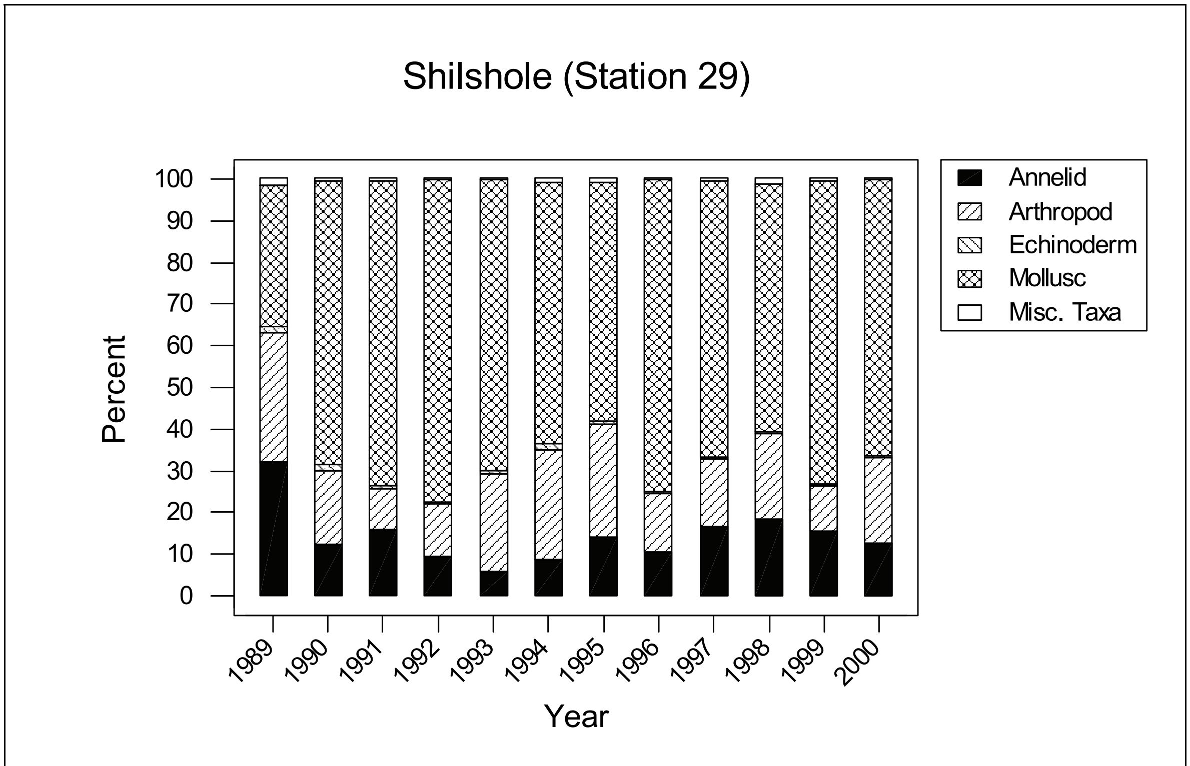


Figure 48d. Percent abundance (top) and absolute abundance (bottom) of major taxa groups at the Port Gardner station, 1989-2000.



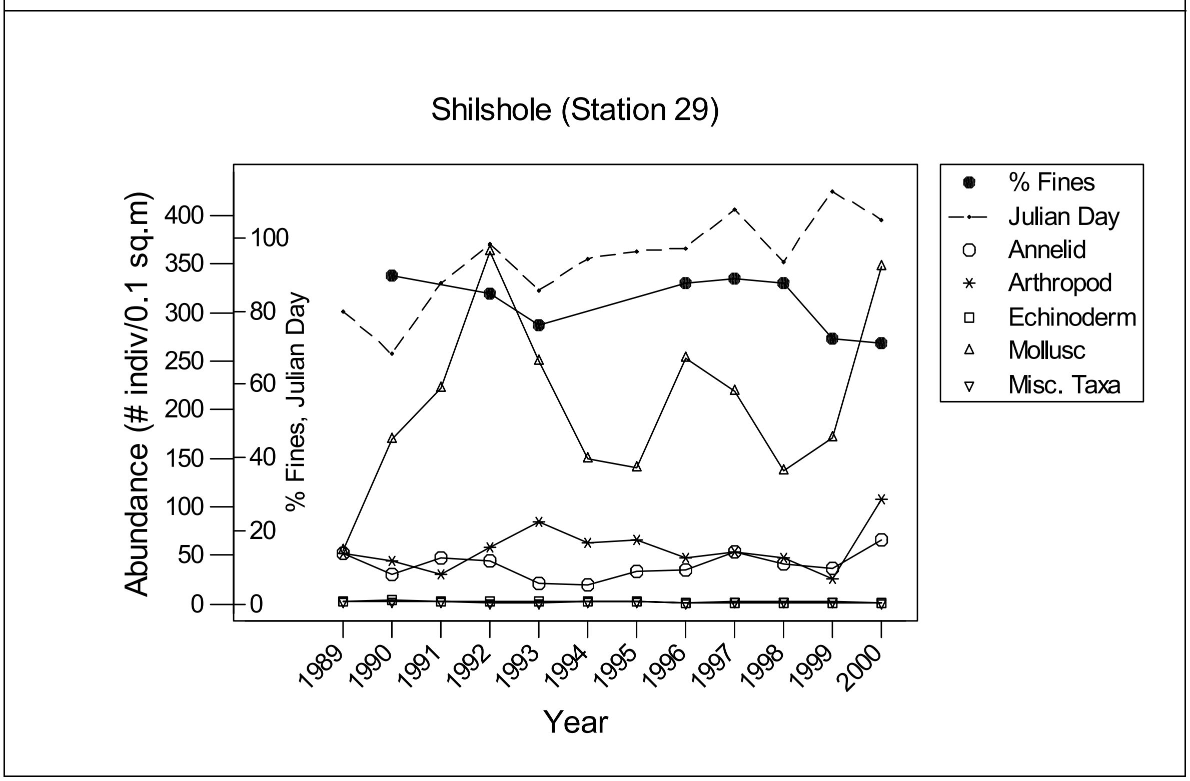


Figure 48e. Percent abundance (top) and absolute abundance (bottom) of major taxa groups at the Shilshole station, 1989-2000.

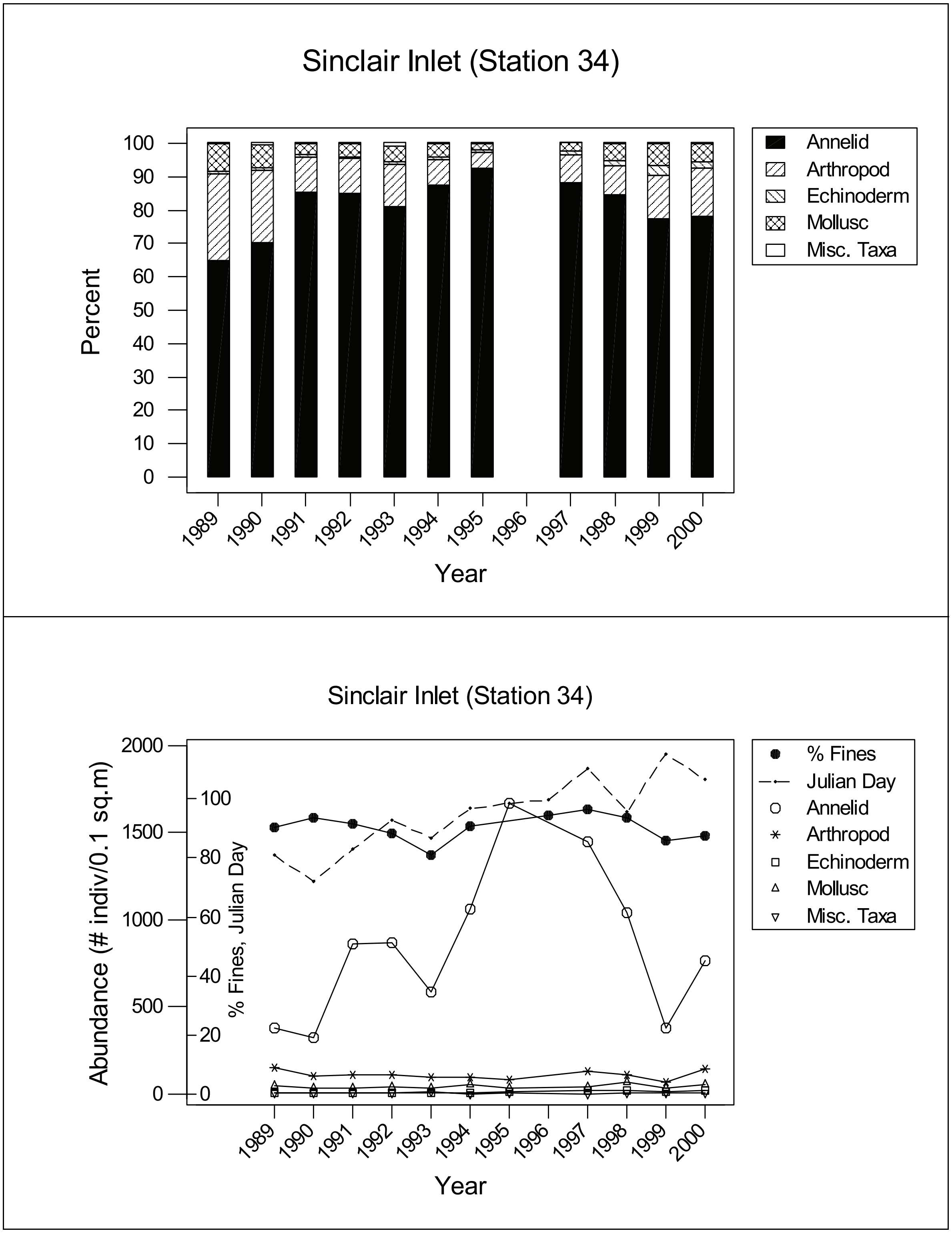


Figure 48f. Percent abundance (top) and absolute abundance (bottom) of major taxa groups at the Sinclair Inlet station, 1989-2000.

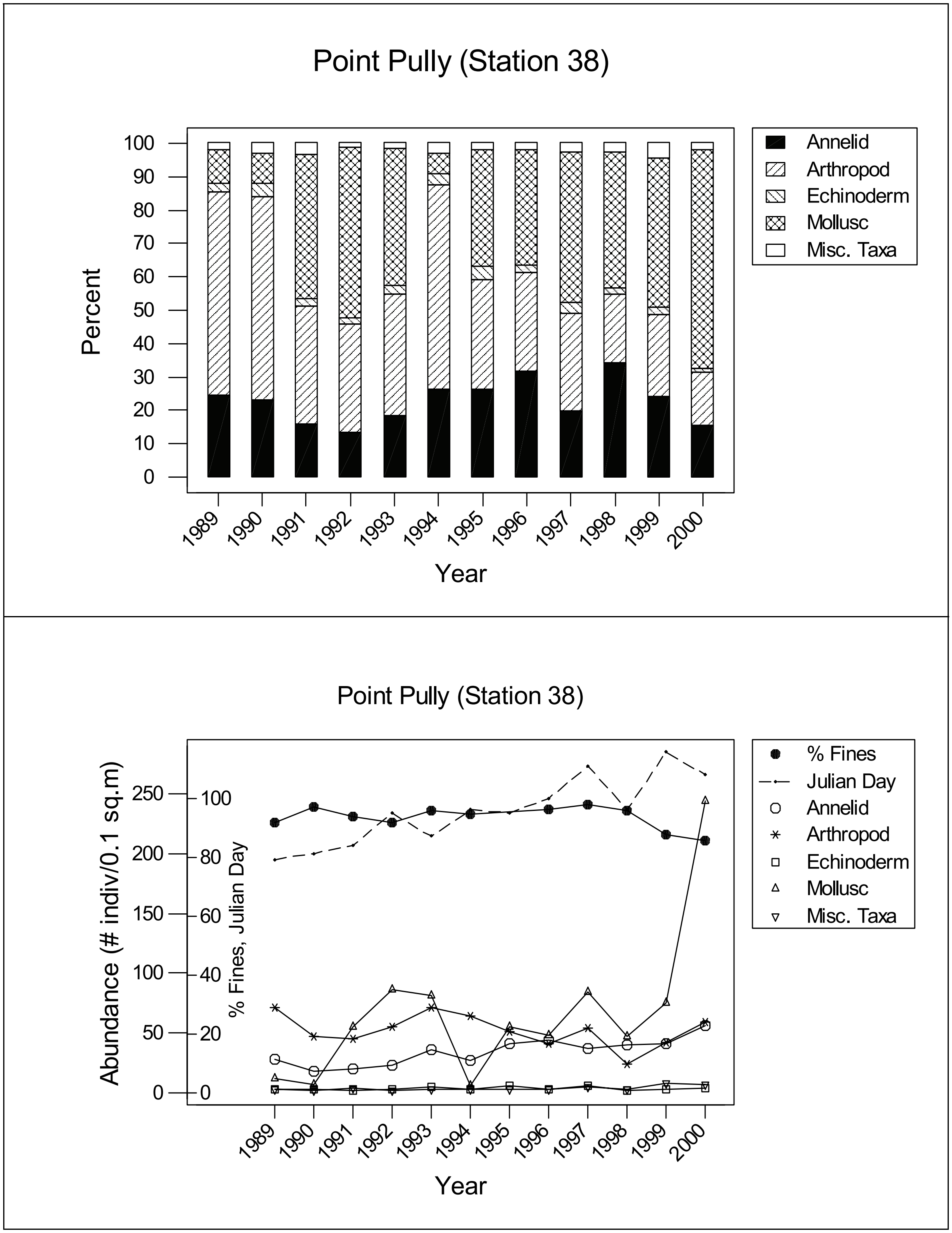


Figure 48g. Percent abundance (top) and absolute abundance (bottom) of major taxa groups at the Point Pully station, 1989-2000.

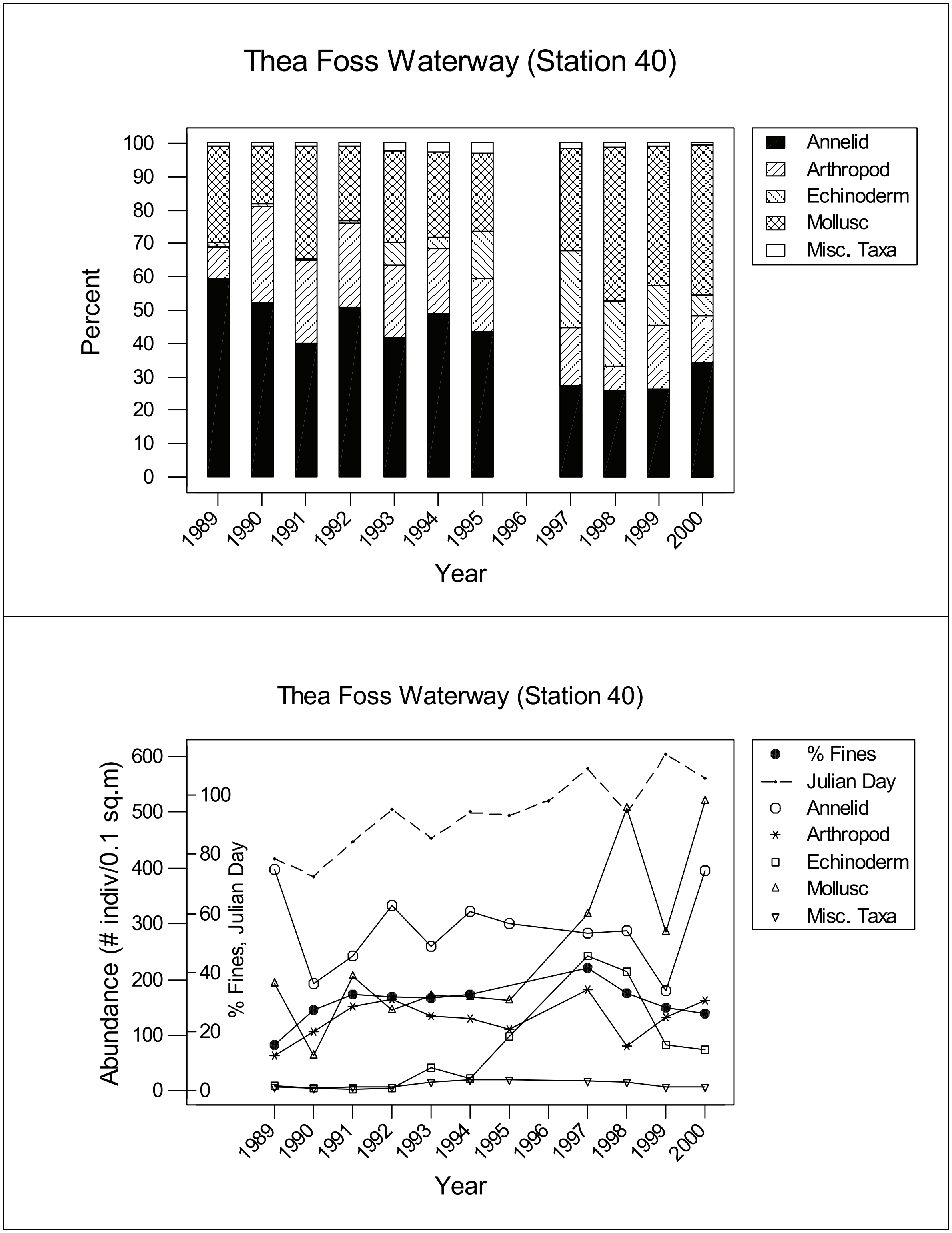


Figure 48h. Percent abundance (top) and absolute abundance (bottom) of major taxa groups at the Thea Foss Waterway station, 1989-2000.

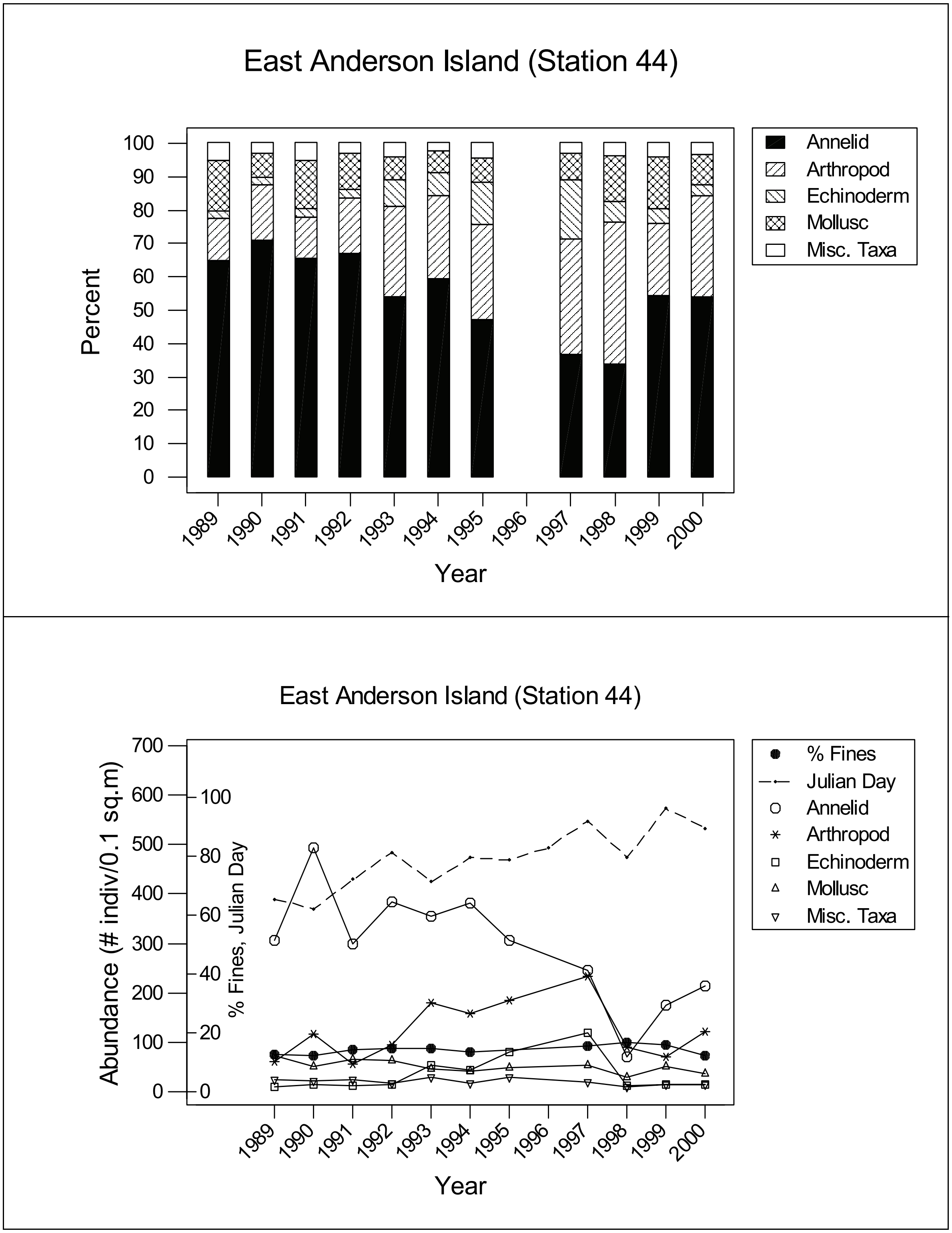


Figure 48i. Percent abundance (top) and absolute abundance (bottom) of major taxa groups at the East Anderson Island station, 1989-2000.

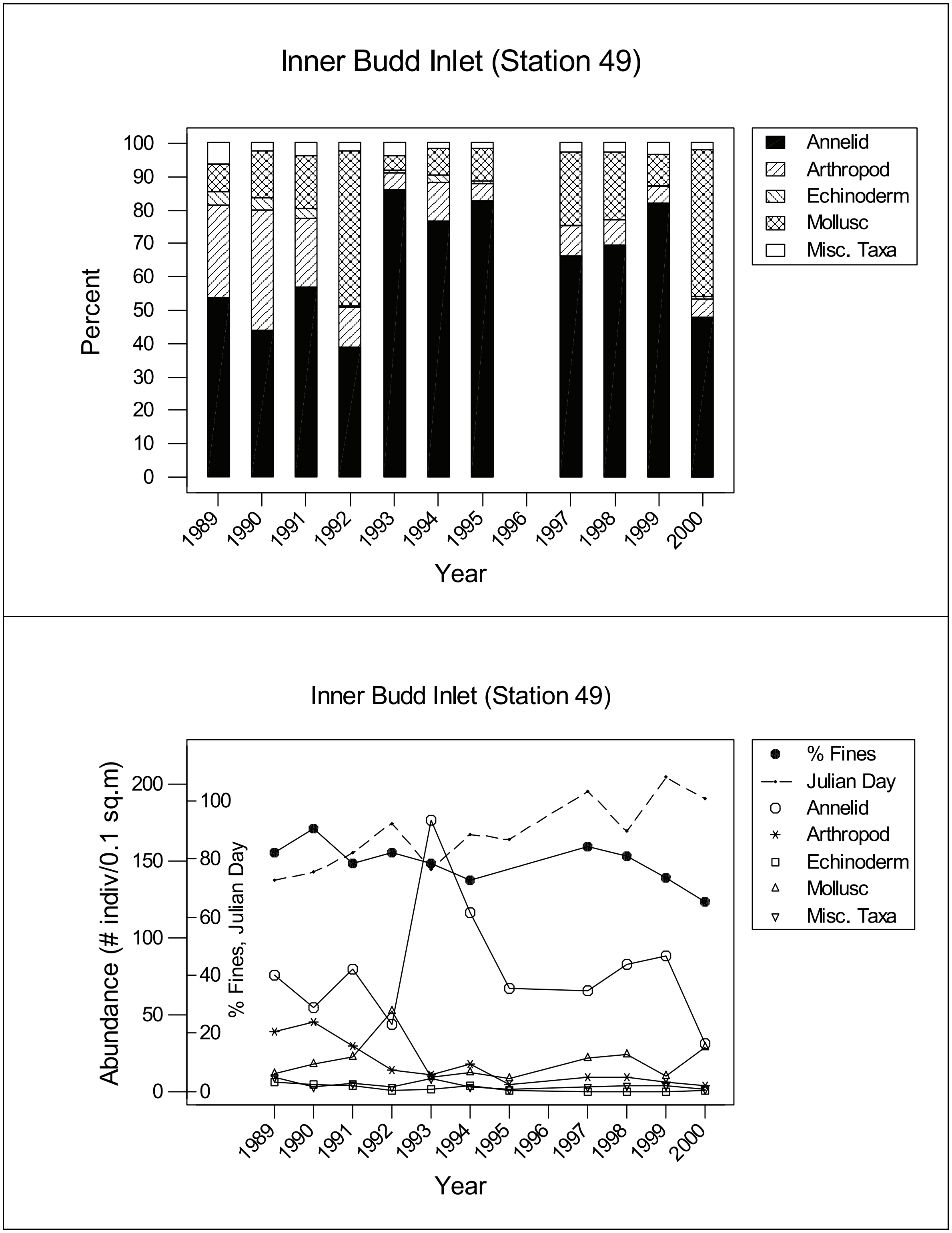
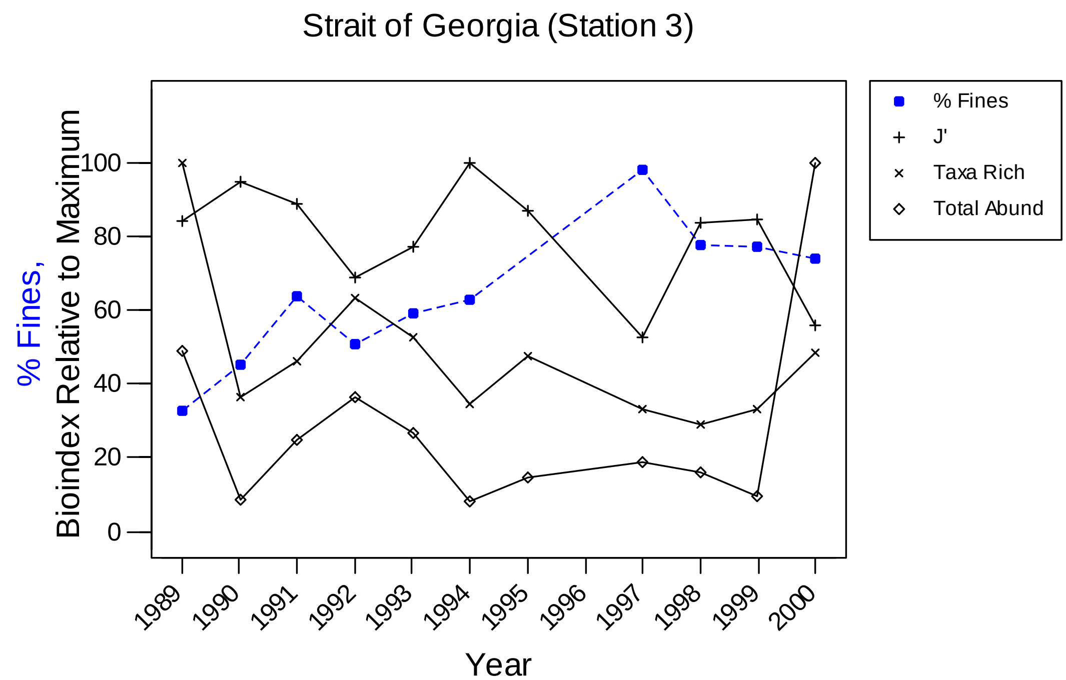


Figure 48j. Percent abundance (top) and absolute abundance (bottom) of major taxa groups at the Inner Budd Inlet station, 1989-2000.



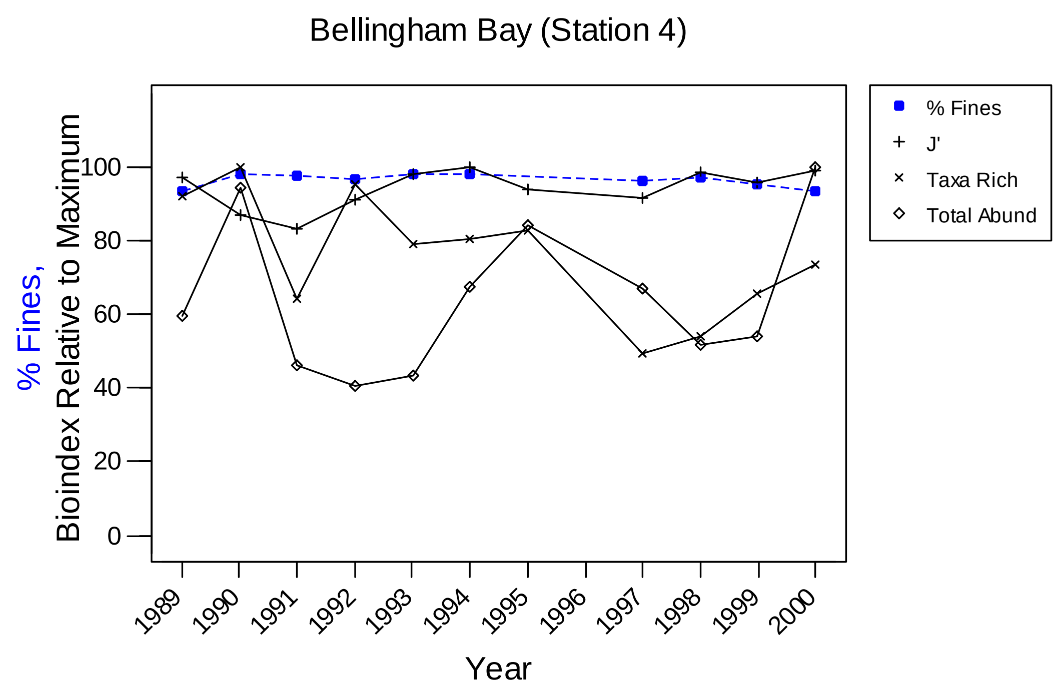
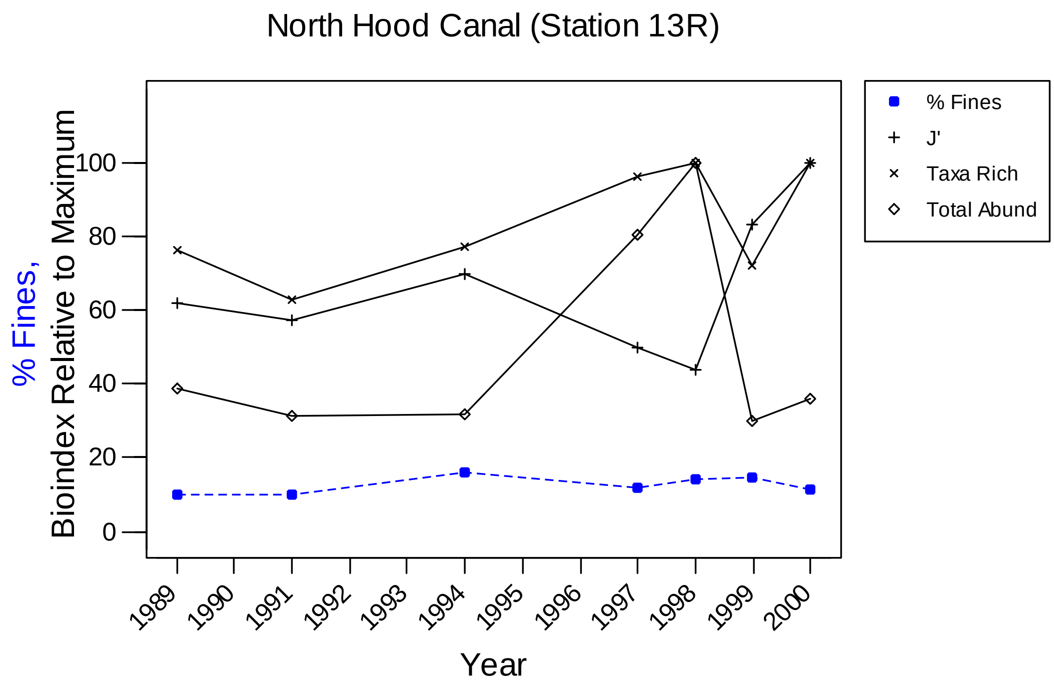


Figure 49a,b. Percent fines, Pielou's Evenness (J'), taxa richness, and total benthic macrofaunal abundance at the Strait of Georgia (top) and Bellingham Bay (bottom) stations. J', taxa richness, and total abundance have been scaled relative to their maximum values for graphing.



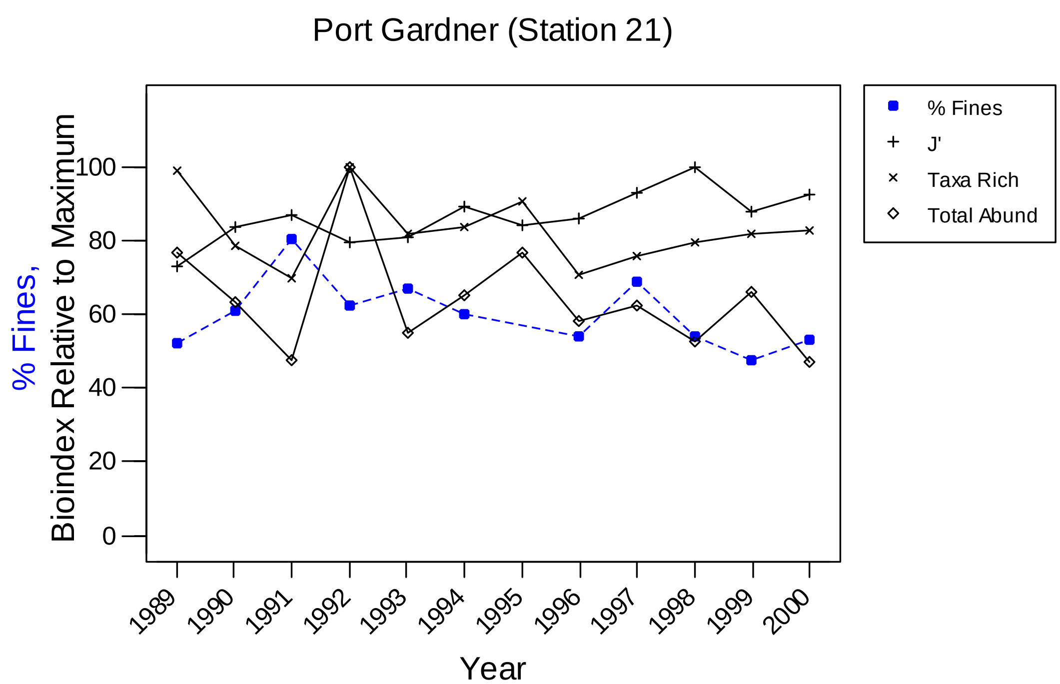
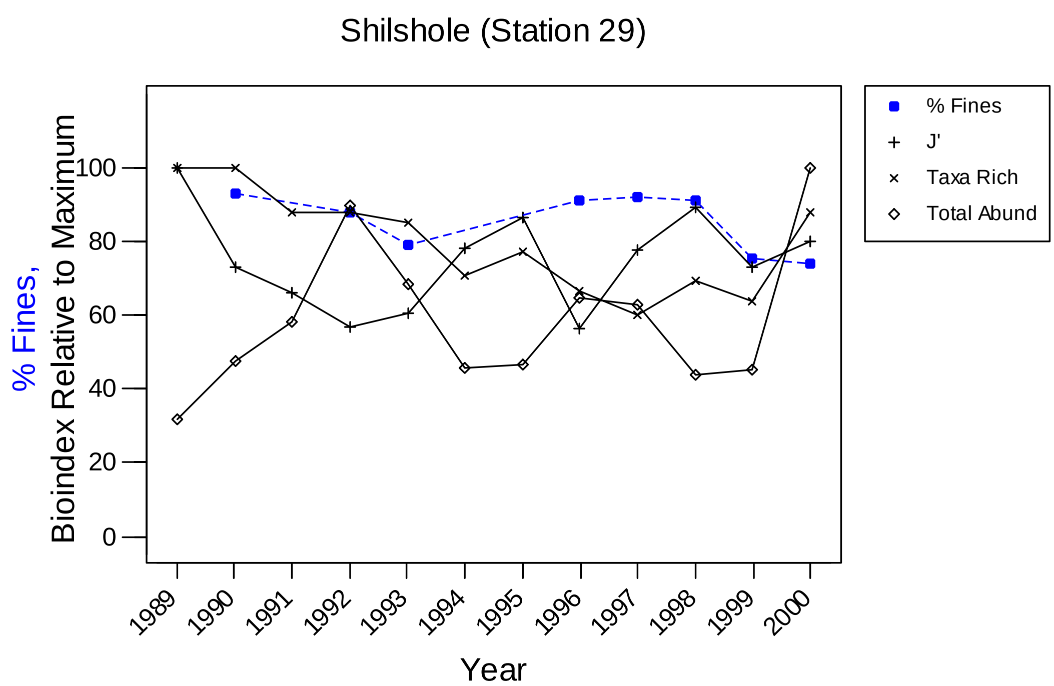


Figure 49c,d. Percent fines, Pielou's Evenness (J'), taxa richness, and total benthic macrofaunal abundance at the North Hood Canal (top) and Port Gardner (bottom) stations. J', taxa richness, and total abundance have been scaled relative to their maximum values for graphing.



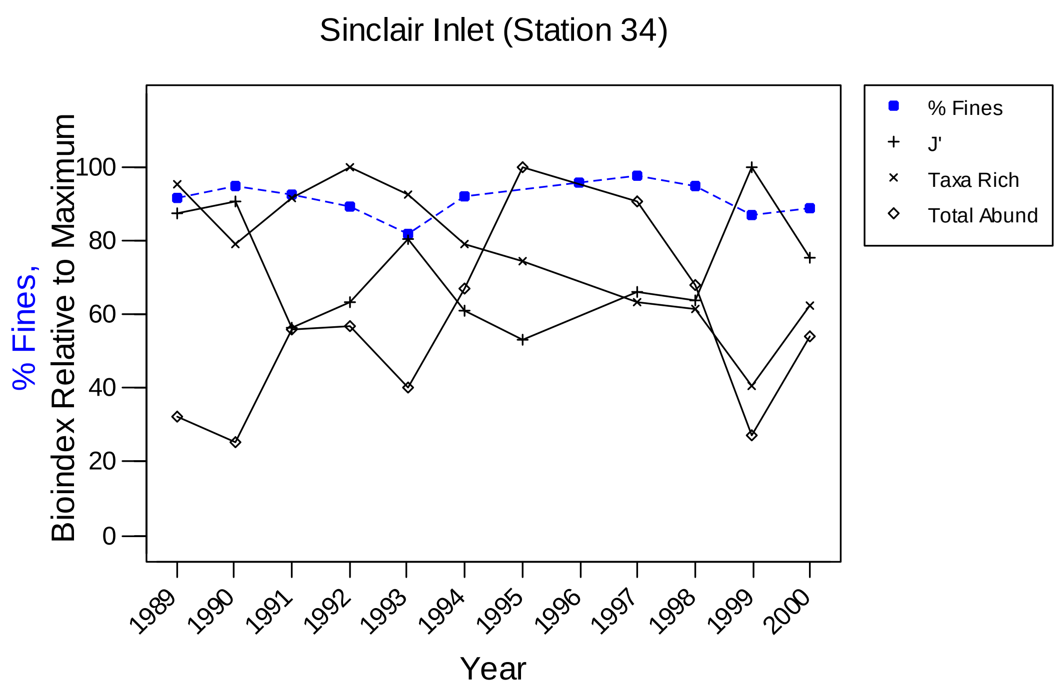
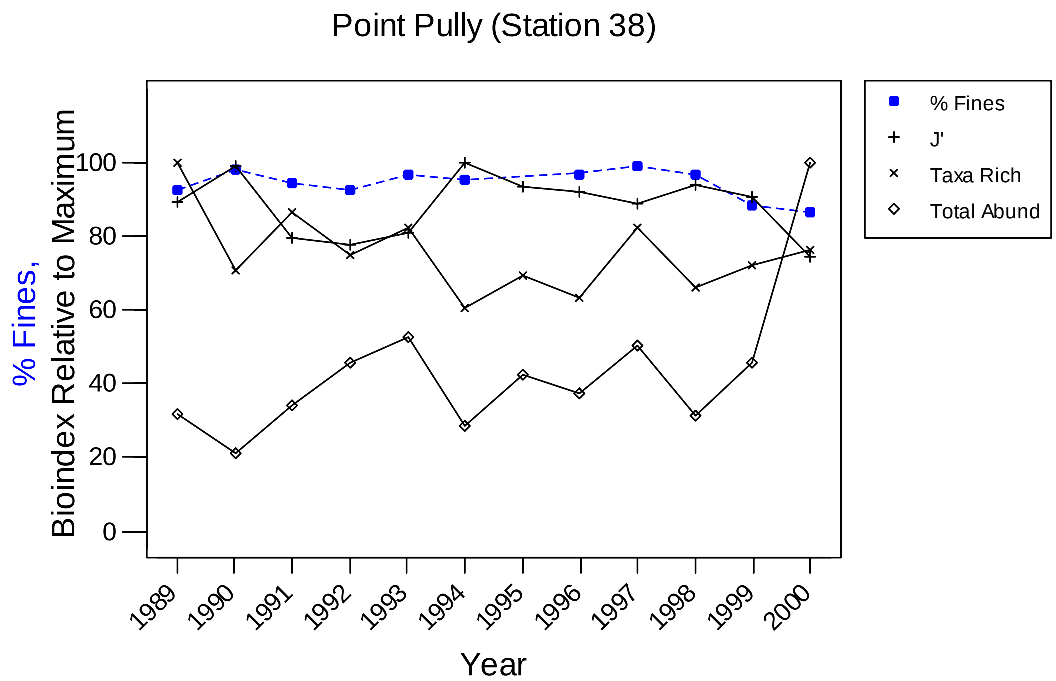


Figure 49e,f. Percent fines, Pielou's Evenness (J'), taxa richness, and total benthic macrofaunal abundance at the Shilshole (top) and Sinclair Inlet (bottom) stations. J', taxa richness, and total abundance have been scaled relative to their maximum values for graphing.



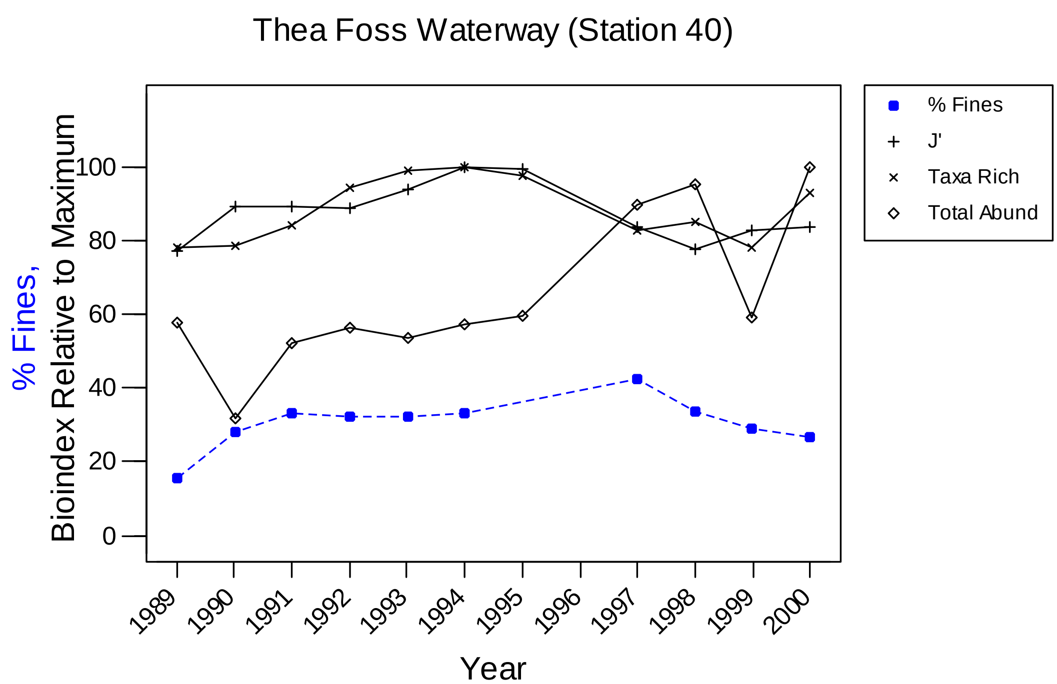
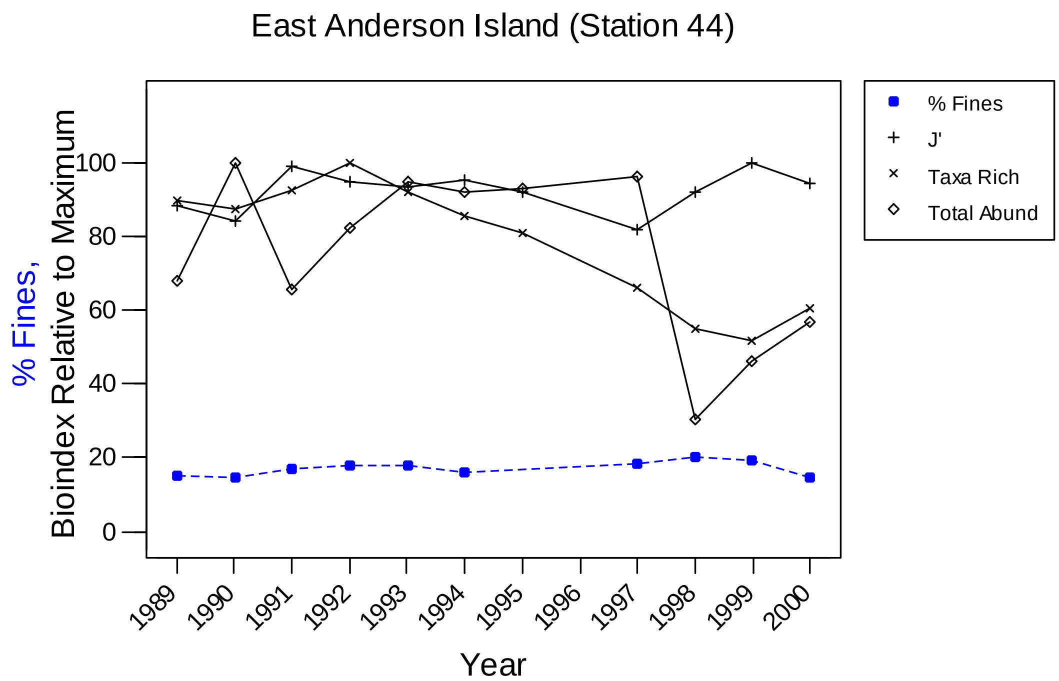


Figure 49g,h. Percent fines, Pielou's Evenness (J'), taxa richness, and total benthic macrofaunal abundance at the Point Pully (top) and Thea Foss Waterway (bottom) stations. J', taxa richness, and total abundance have been scaled relative to their maximum values for graphing.



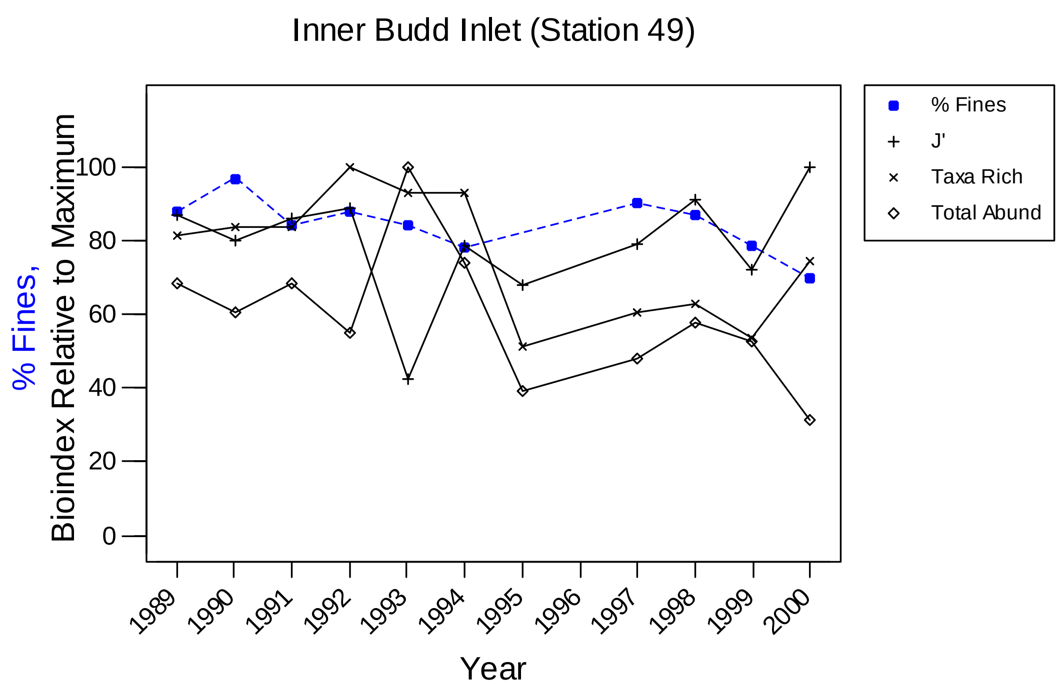
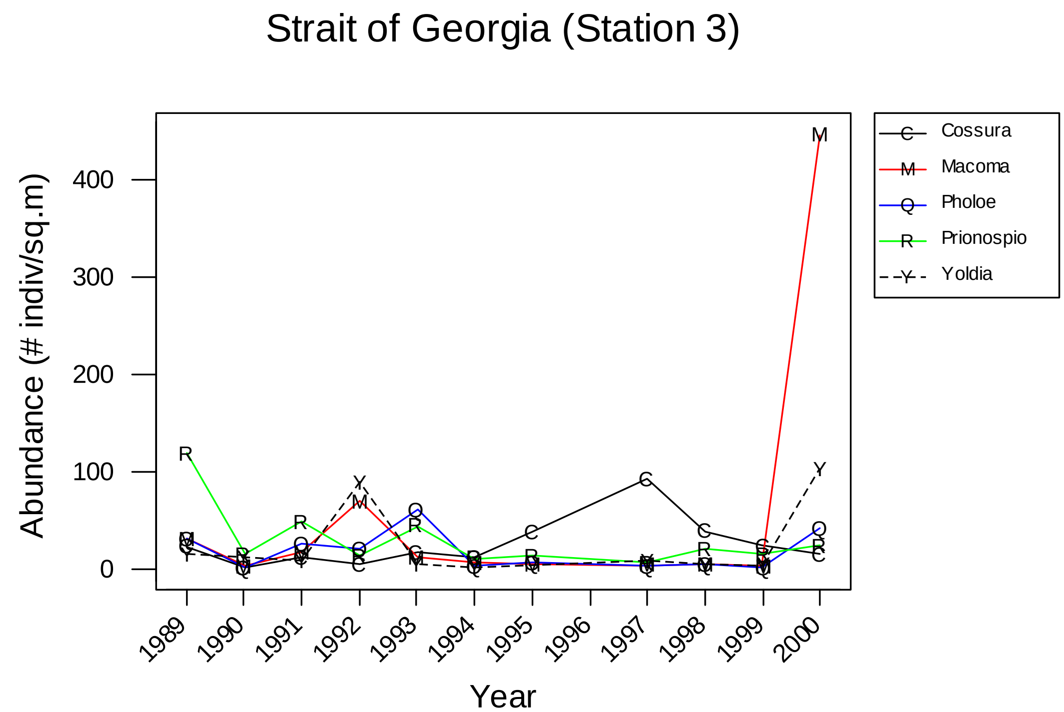


Figure 49i,j. Percent fines, Pielou's Evenness (J'), taxa richness, and total benthic macrofaunal abundance at the East Anderson Island (top) and Inner Budd Inlet (bottom) stations. J', taxa richness, and total abundance have been scaled relative to their maximum values for graphing.



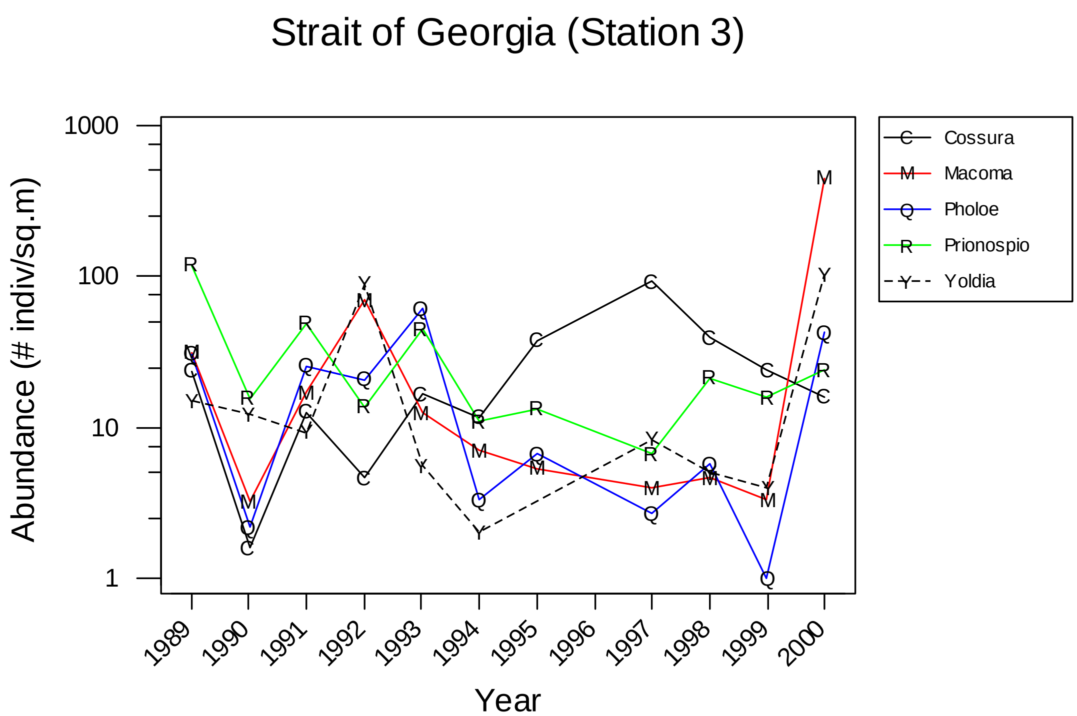
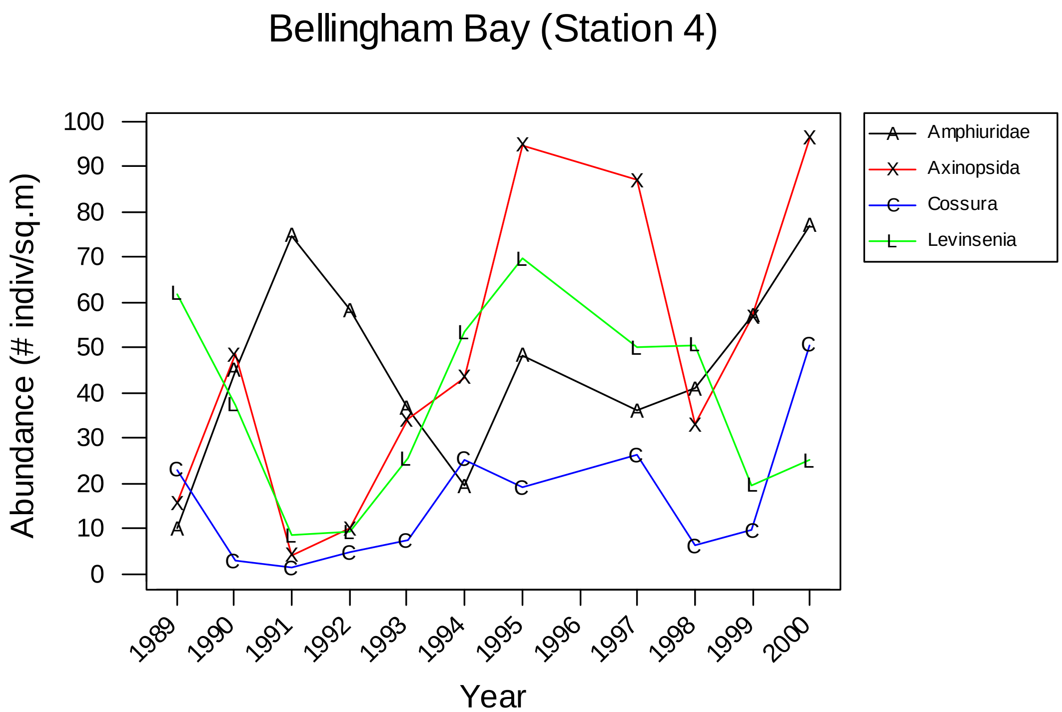


Figure 50a. Abundance of important taxa at the Strait of Georgia station, in arithmetic scale (top) and logarithmic scale (bottom), at the PSAMP long-term sediment monitoring stations, 1989-2000. Species were summed into the following taxa for this graph: *Cossura pygodactylata*, *Macoma* spp., *Pholoe* sp. complex, *Prionospio* spp., and *Yoldia* spp.



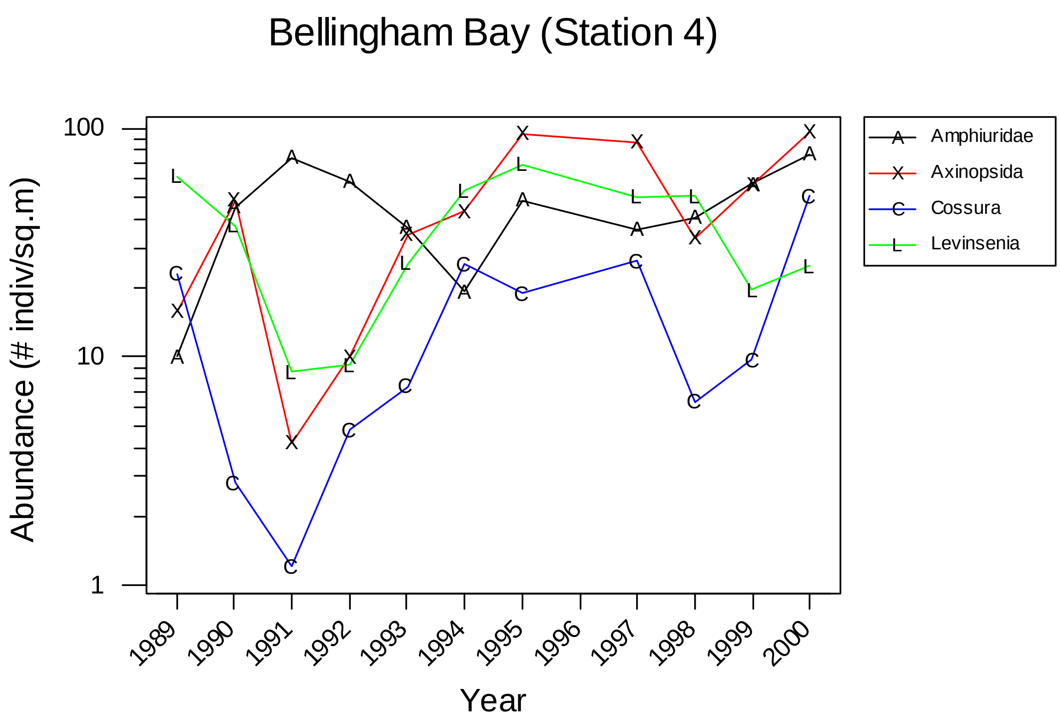
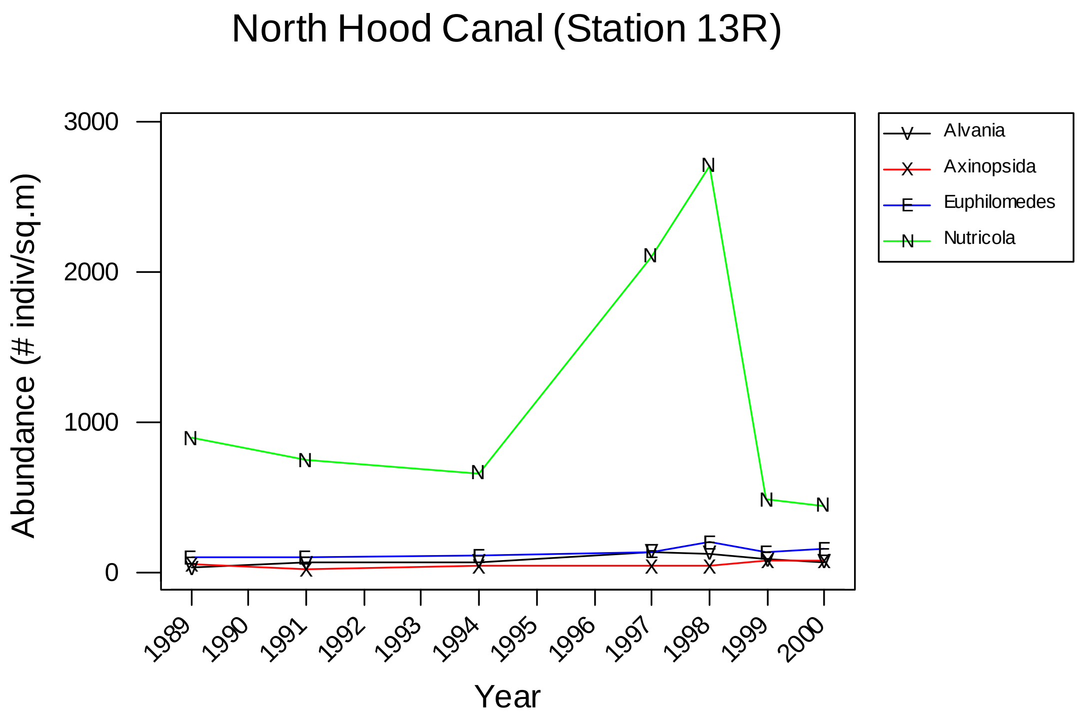


Figure 50b. Abundance of important taxa at the Bellingham Bay station, in arithmetic scale (top) and logarithmic scale (bottom), at the PSAMP long-term sediment monitoring stations, 1989-2000. Species were summed into the following taxa for this graph: Amphiuridae, *Axinopsida serricata*, *Cossura pygodactylata*, and *Levinsenia* spp.



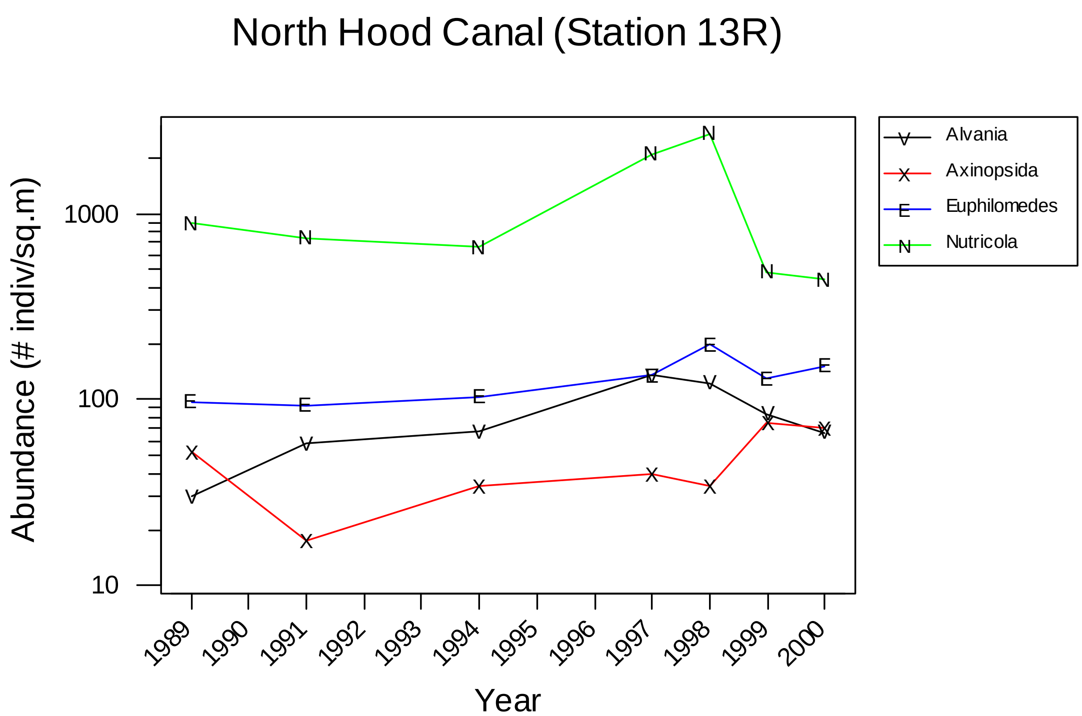
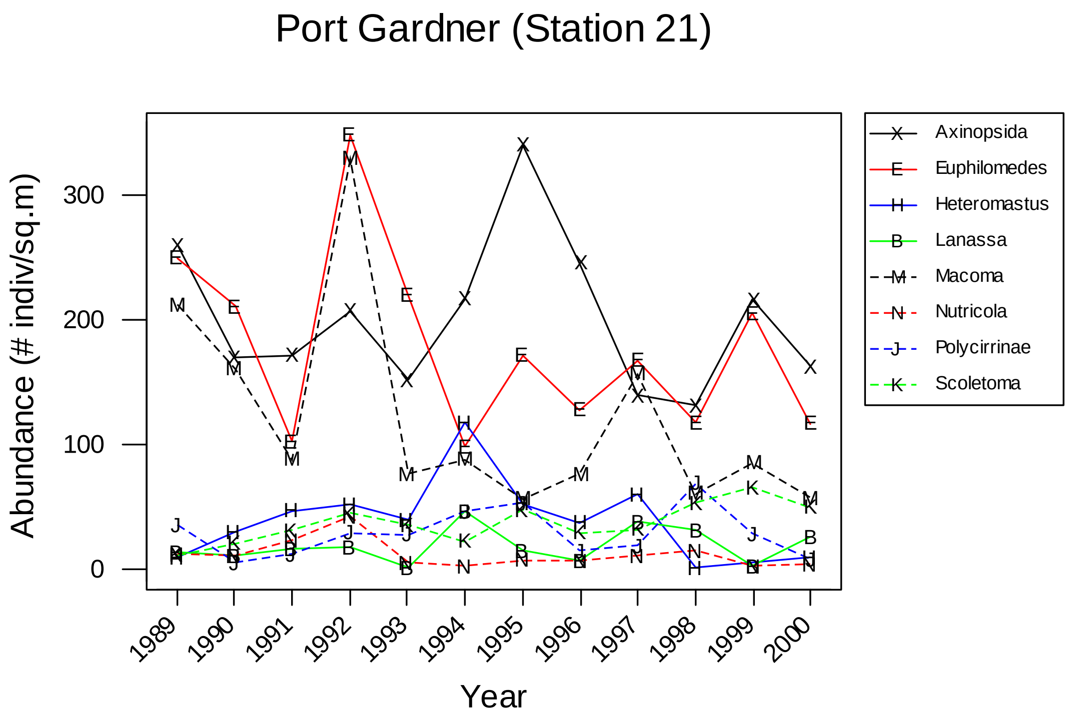


Figure 50c. Abundance of important taxa at the North Hood Canal station, in arithmetic scale (top) and logarithmic scale (bottom), at the PSAMP long-term sediment monitoring stations, 1989-2000. Species were summed into the following taxa for this graph: *Alvania compacta*, *Axinopsida serricata*, *Euphilomedes* spp., and *Psephidia lordi*.



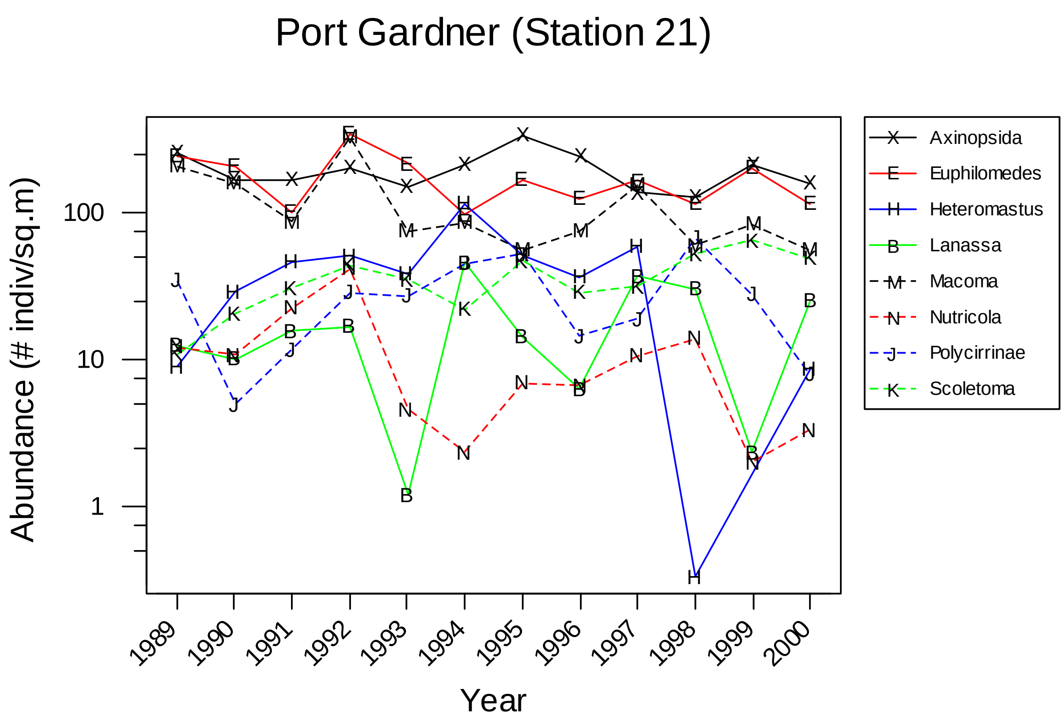
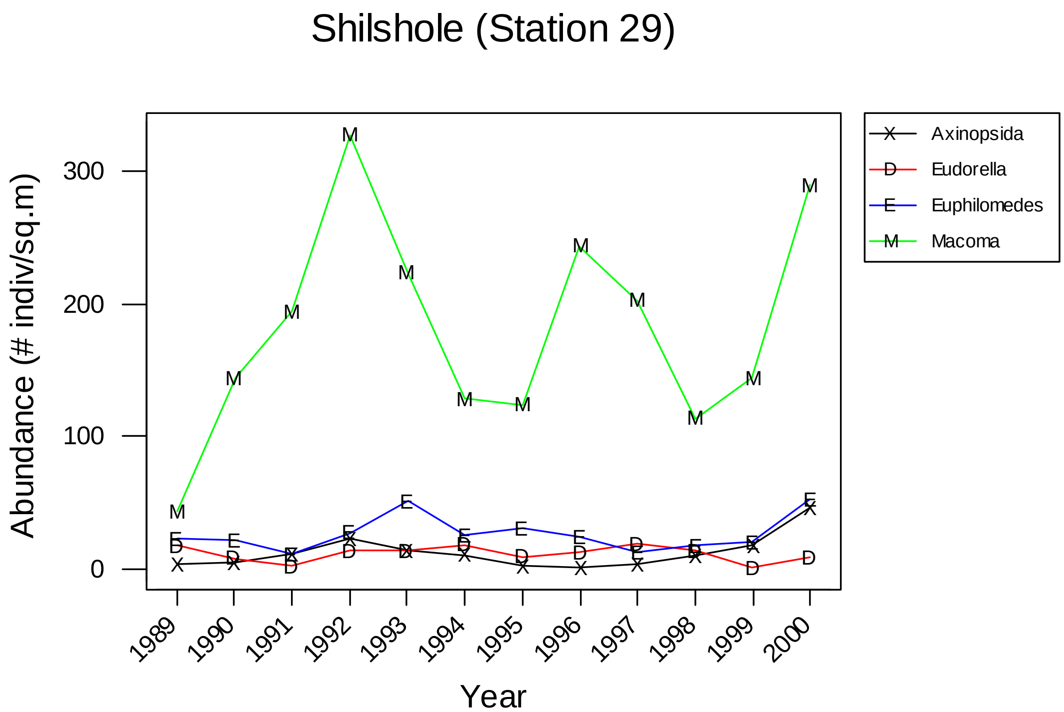


Figure 50d. Abundance of important taxa at the Port Gardner station, in arithmetic scale (top) and logarithmic scale (bottom), at the PSAMP long-term sediment monitoring stations, 1989-2000. Species were summed into the following taxa for this graph: *Axinopsida serricata*, *Euphilomedes* spp., *Heteromastus* spp., *Lanassa* spp., *Macoma* spp., *Psephidia lordi*, *Polycirrus* spp., and *Scoletoma* spp.



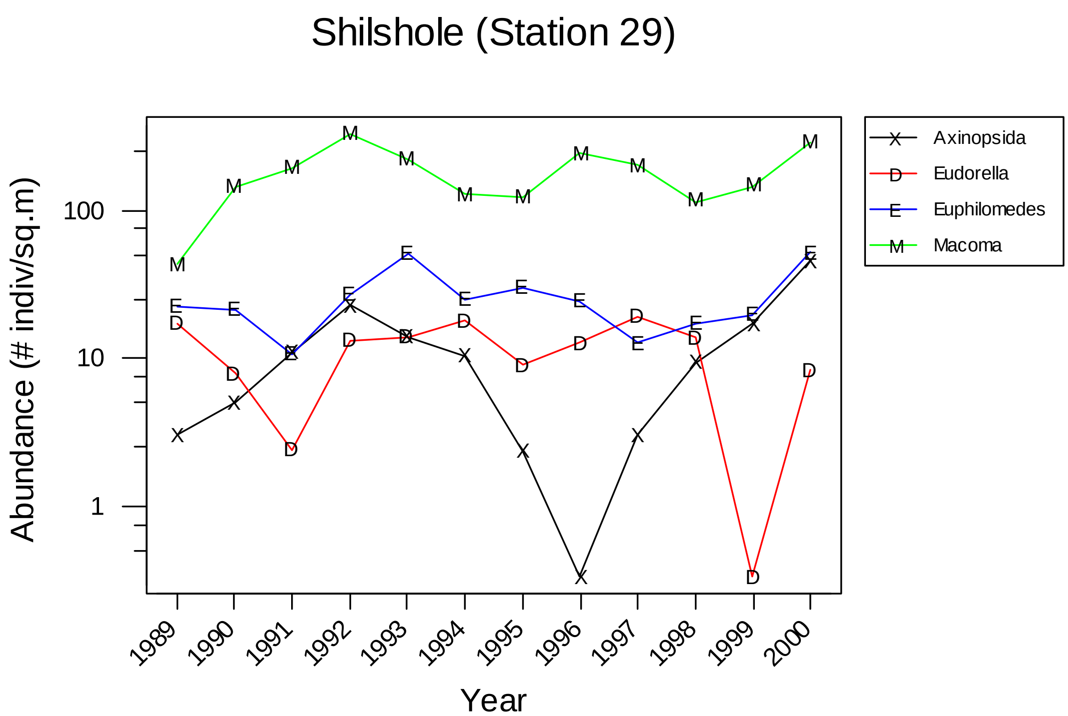
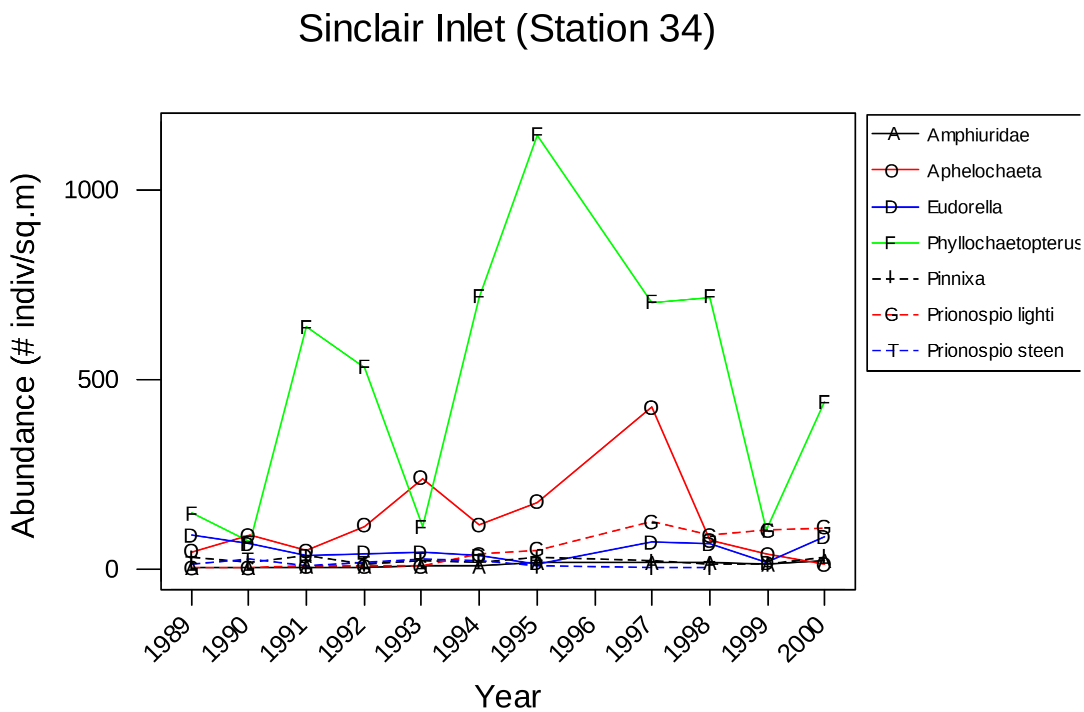


Figure 50e. Abundance of important taxa at the Shilshole station, in arithmetic scale (top) and logarithmic scale (bottom), at the PSAMP long-term sediment monitoring stations, 1989-2000. Species were summed into the following taxa for this graph: *Axinopsida serricata*, *Eudorella pacifica*, *Euphilomedes producta*, and *Macoma* spp.



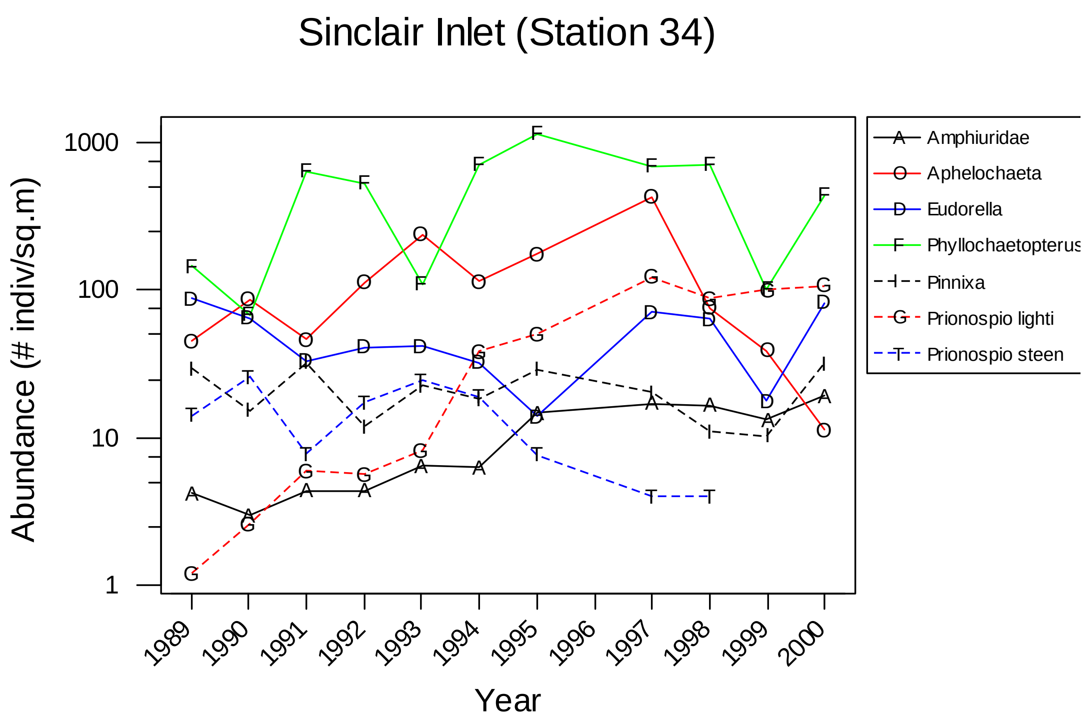
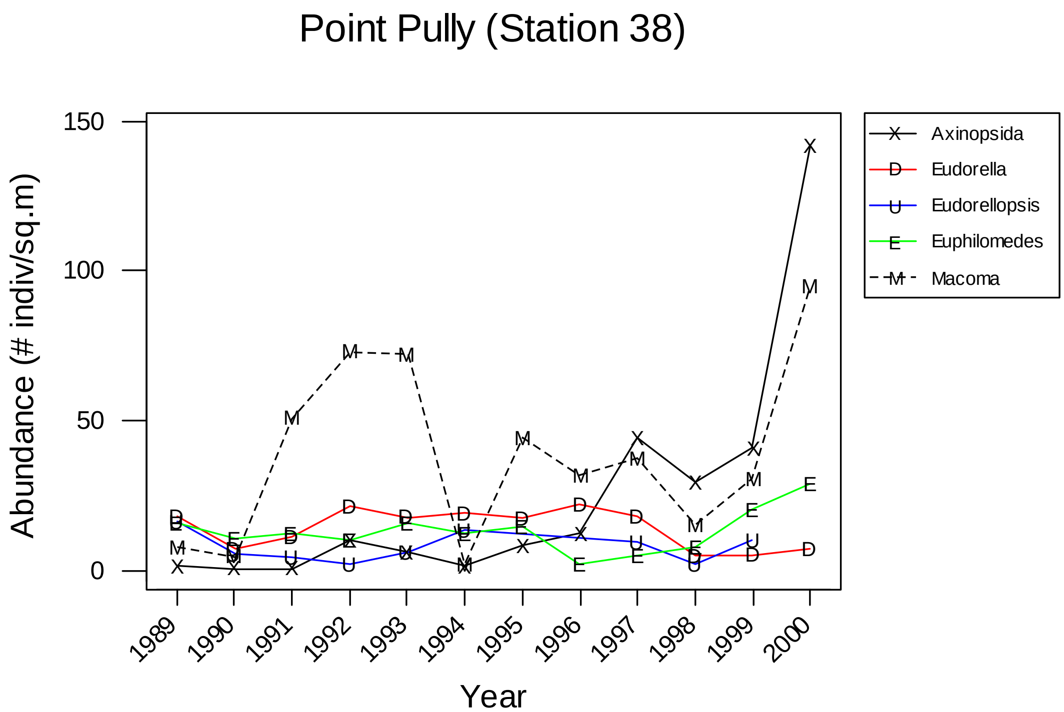


Figure 50f. Abundance of important taxa at the Sinclair Inlet station, in arithmetic scale (top) and logarithmic scale (bottom), at the PSAMP long-term sediment monitoring stations, 1989-2000. Species were summed into the following taxa for this graph: Amphiuridae, *Aphelochaeta* sp. N1, *Eudorella pacifica*, *Phyllochaetopterus prolifica*, *Pinnixa* spp., *Prionospio lighti*, and *Prionospio steenstrupi/jubata*.



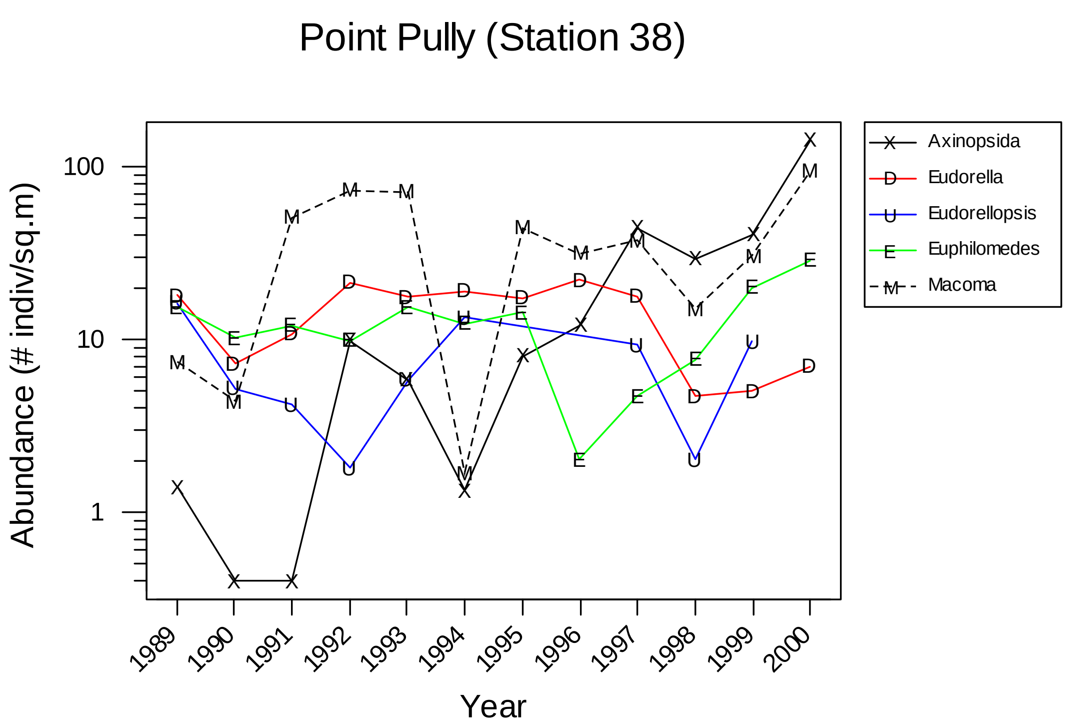
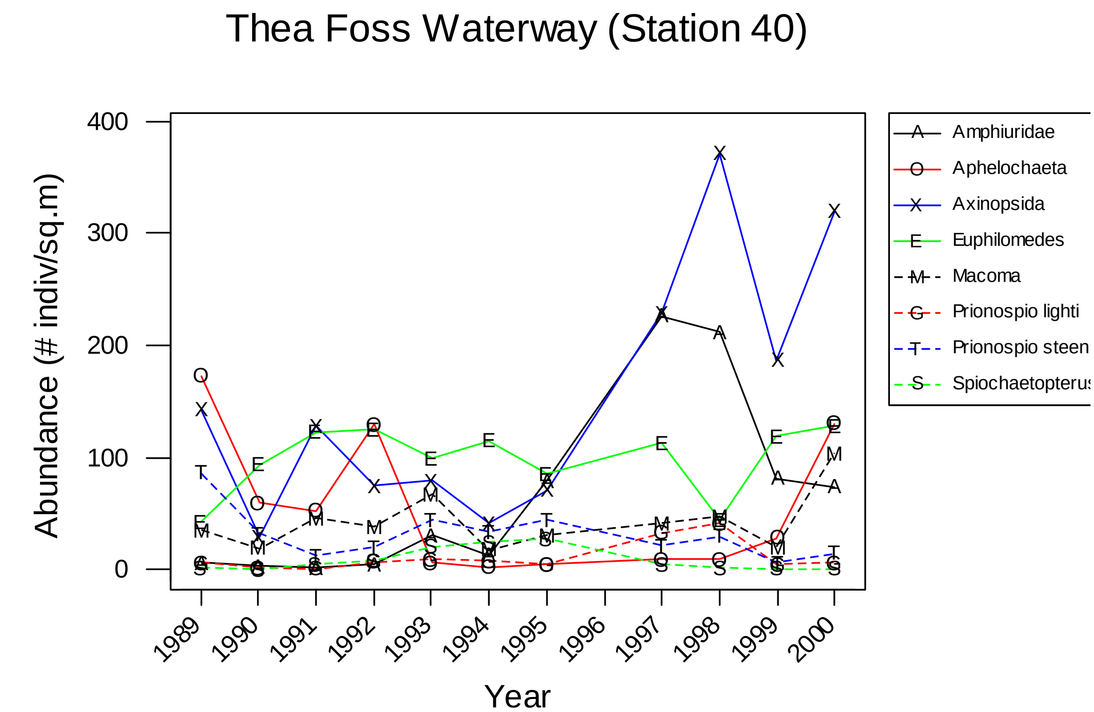


Figure 50g. Abundance of important taxa at the Point Pully station, in arithmetic scale (top) and logarithmic scale (bottom), at the PSAMP long-term sediment monitoring stations, 1989-2000. Species were summed into the following taxa for this graph: *Axinopsida serricata*, *Eudorella pacifica*, *Eudorellopsis integra*, *Euphilomedes producta*, *Macoma* spp.



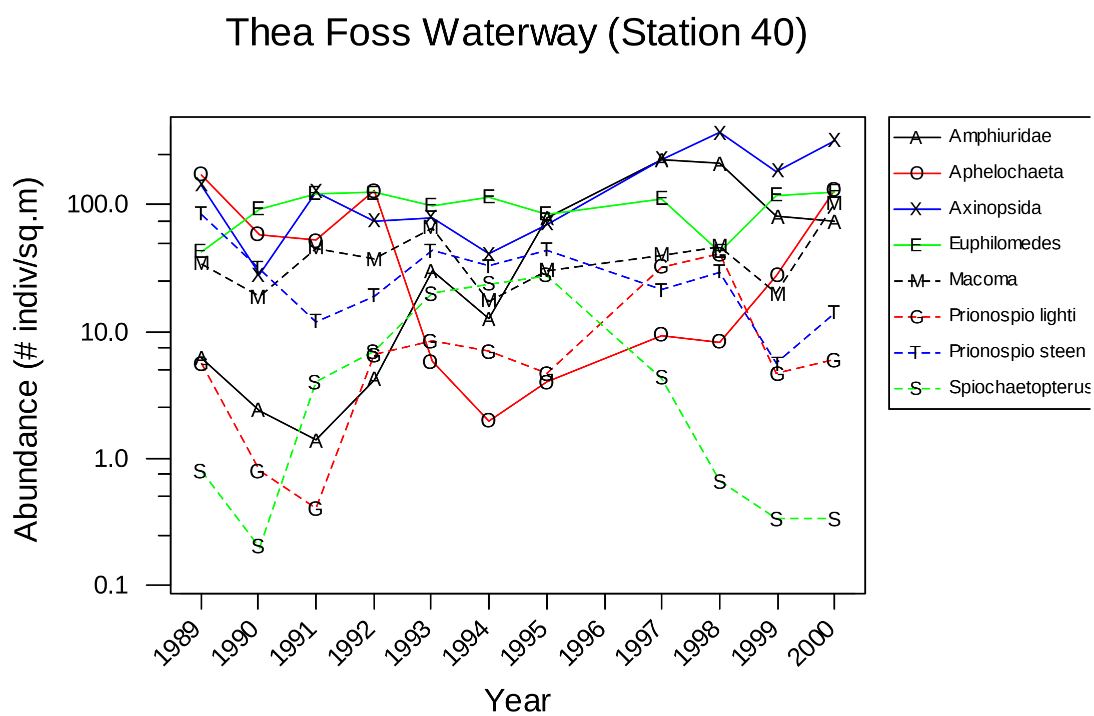
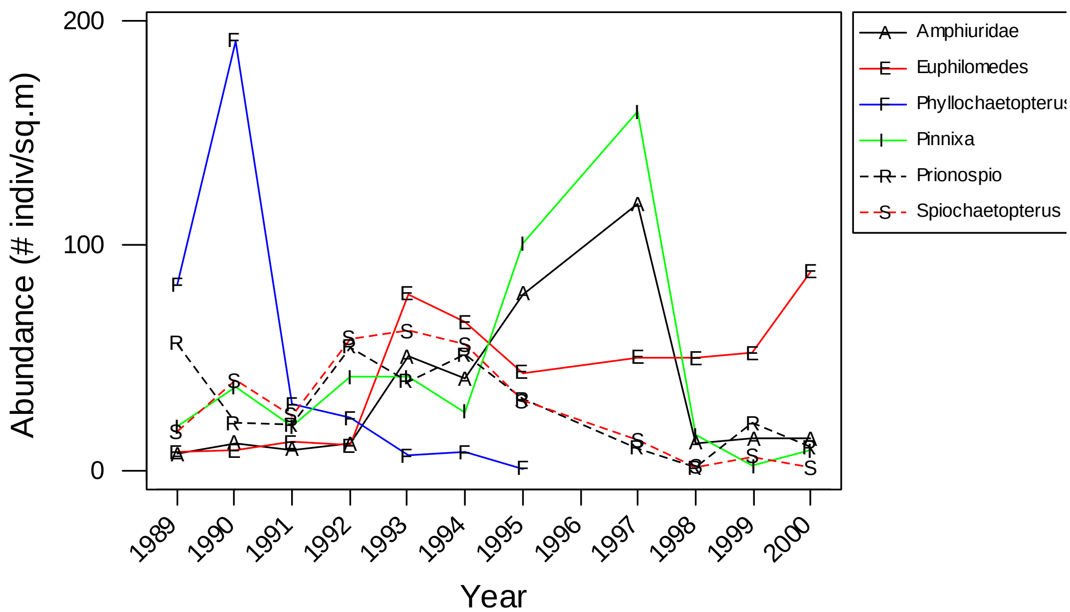


Figure 50h. Abundance of important taxa at the Thea Foss Waterway station, in arithmetic scale (top) and logarithmic scale (bottom), at the PSAMP long-term sediment monitoring stations, 1989-2000. Species were summed into the following taxa for this graph: Amphiuridae, *Aphelochaeta* spp., *Axinopsida serricata*, *Euphilomedes* spp., *Macoma* spp., *Prionospio lighti*, *Prionospio steenstrupi/jubata*, and *Spiochaetopterus costarum*.

East Anderson Island (Station 44)



East Anderson Island (Station 44)

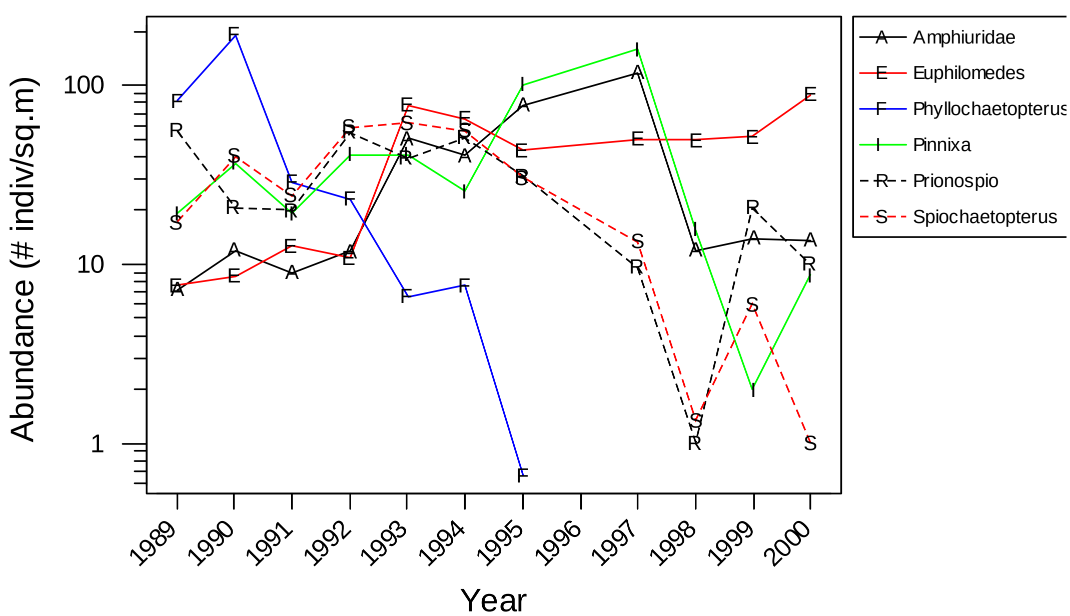
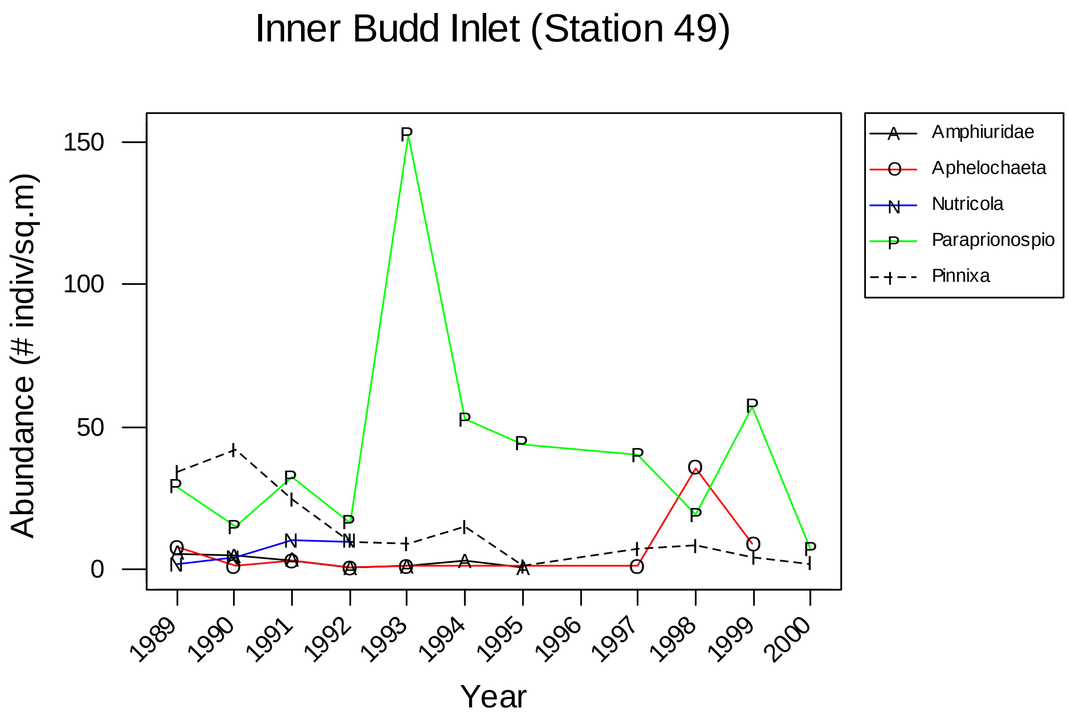


Figure 50i. Abundance of important taxa at the East Anderson Island station, in arithmetic scale (top) and logarithmic scale (bottom), at the PSAMP long-term sediment monitoring stations, 1989-2000. Species were summed into the following taxa for this graph: Amphiuridae, *Euphilomedes carcharodonta*, *Phyllochaetopterus prolifica*, *Pinnixa* spp., and *Spiochaetopterus costarum*.



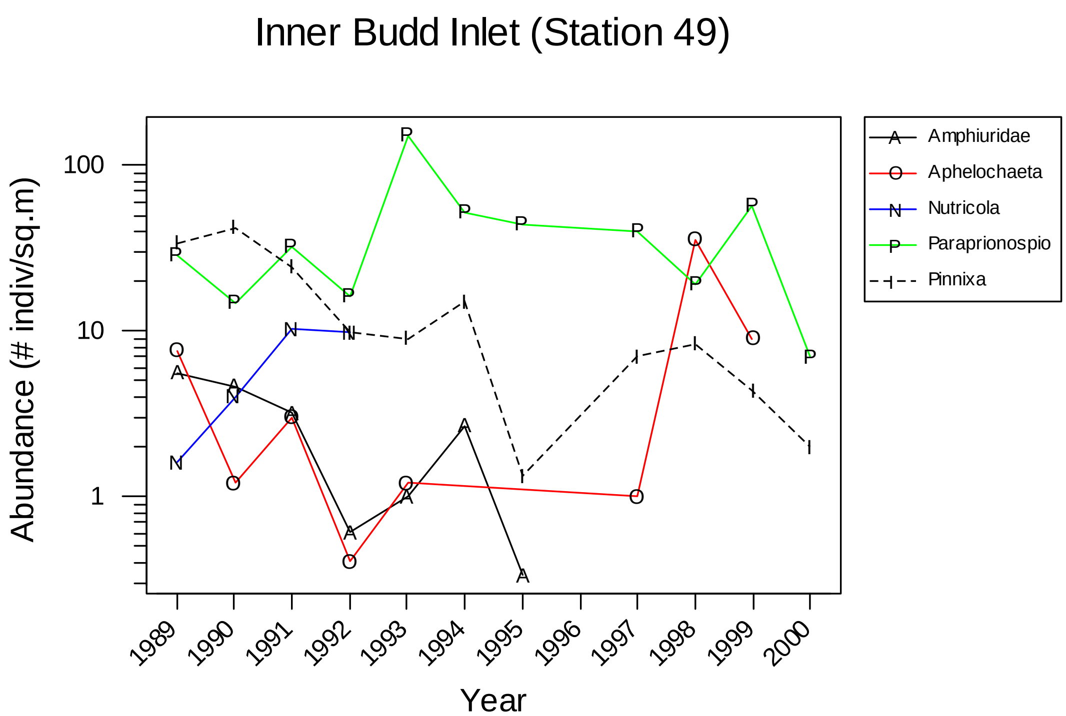


Figure 50j. Abundance of important taxa at the Inner Budd Inlet station, in arithmetic scale (top) and logarithmic scale (bottom), at the PSAMP long-term sediment monitoring stations, 1989-2000. Species were summed into the following taxa for this graph: Amphiuridae, *Aphelochaeta* spp., *Paraprionospio pinnata*, *Pinnixa* spp., and *Psephidia lordi*.

MDS ordination of infaunal assemblages

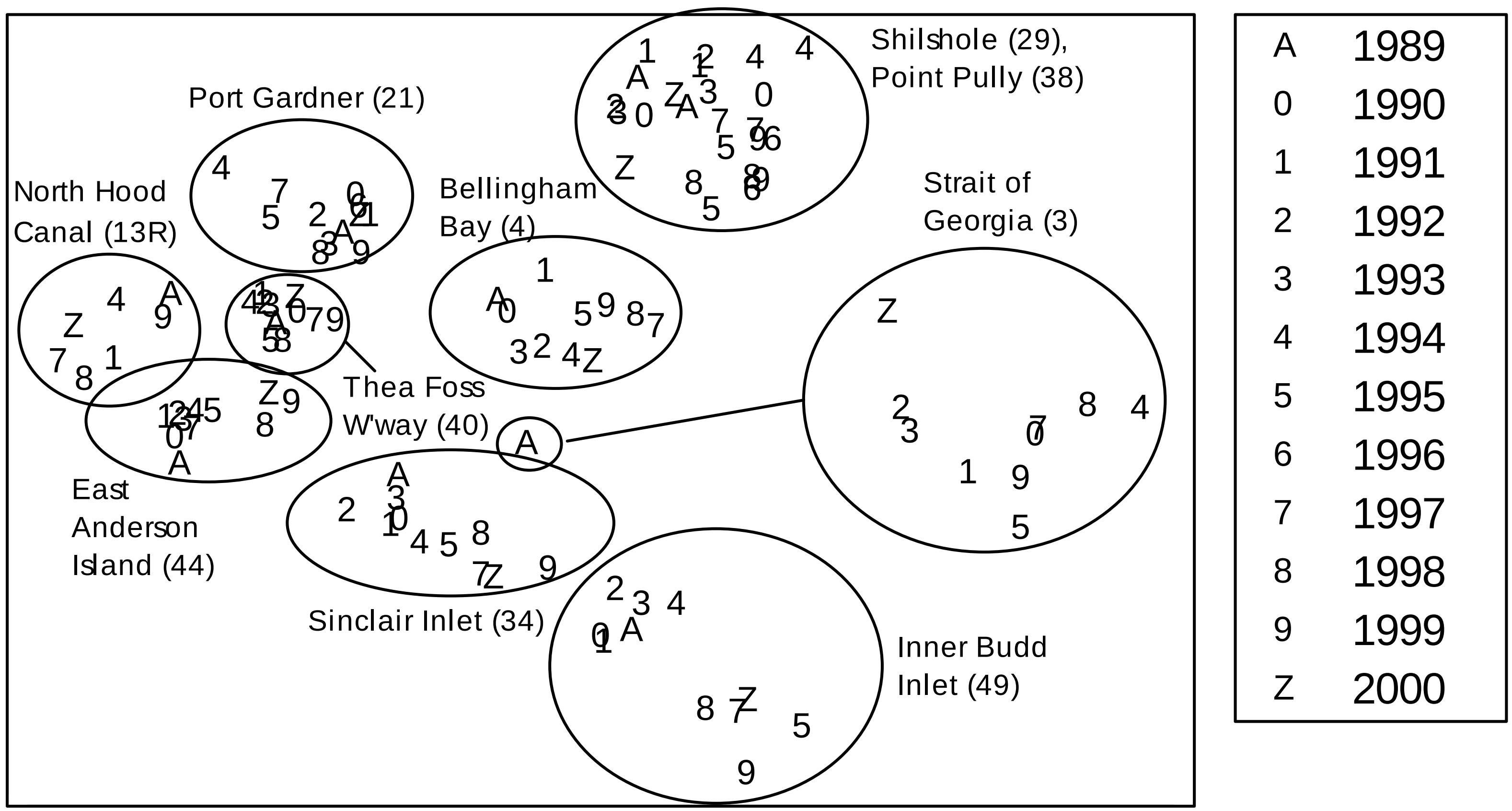


Figure 51. Multidimensional scaling ordination of infaunal assemblages by year by station.

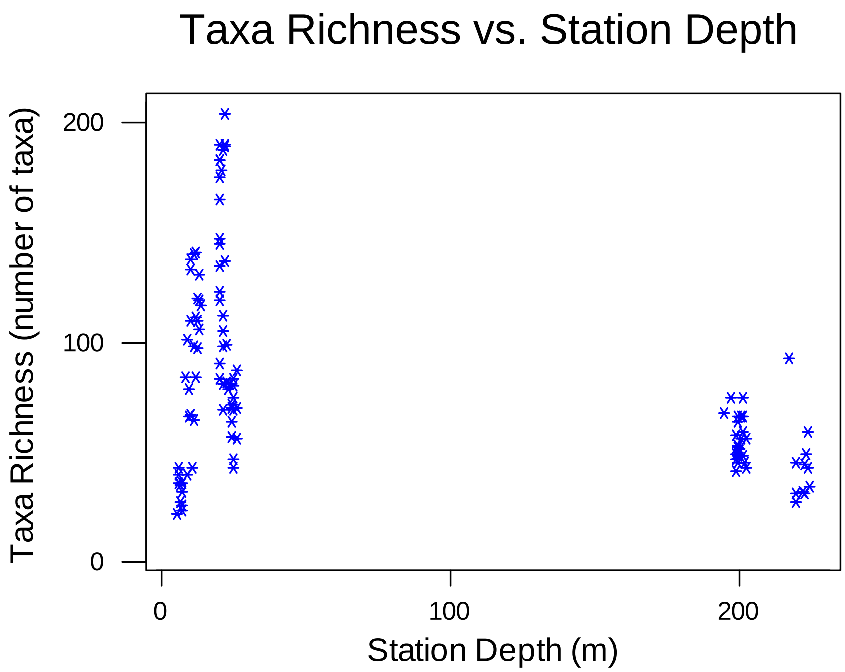


Figure 52. Taxa richness *vs*. station depth at the PSAMP long-term sediment monitoring stations, 1989-2000.

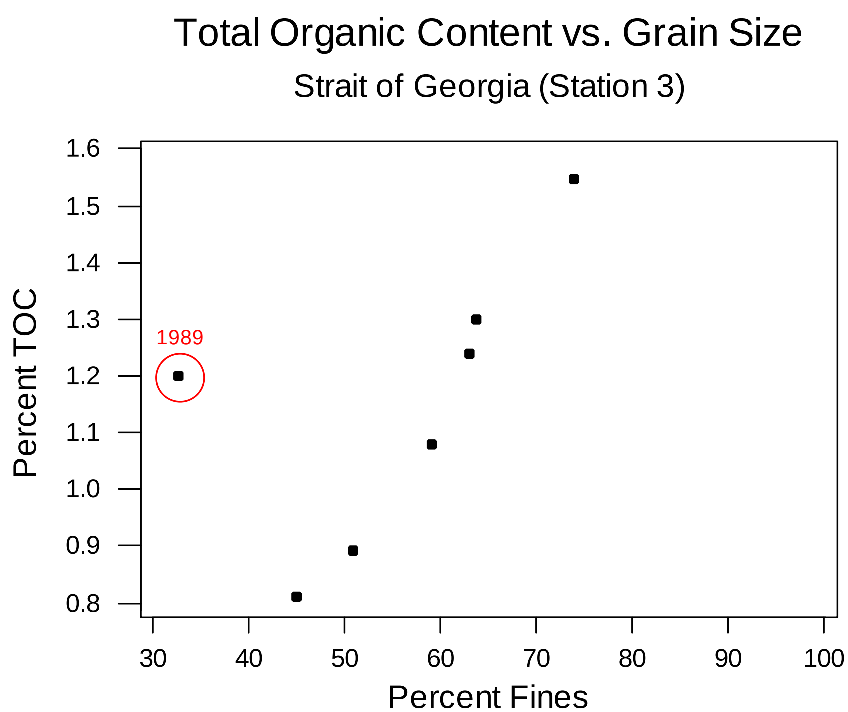


Figure 53. TOC *vs*. percent fines at the Strait of Georgia station.

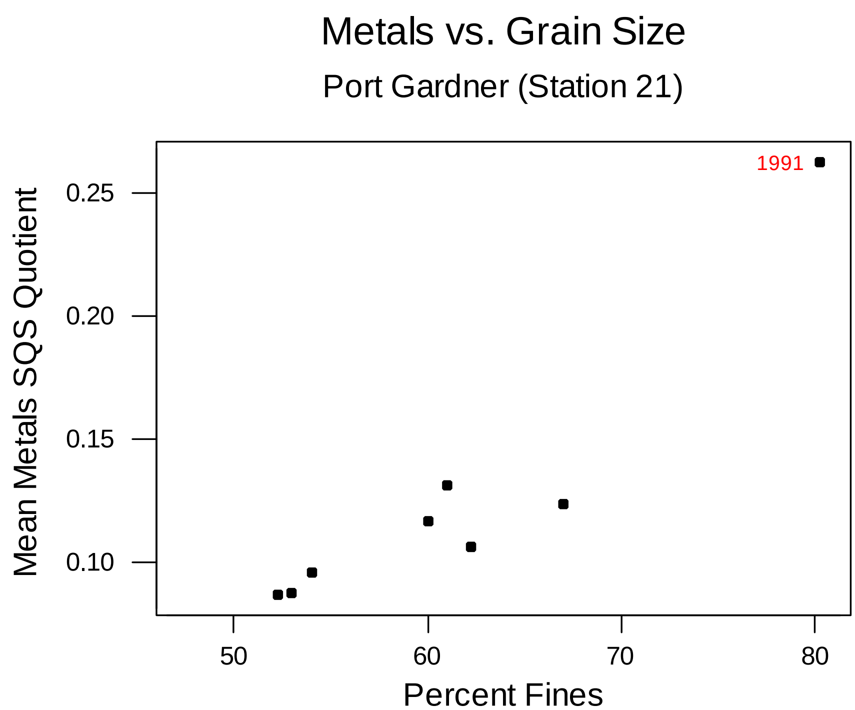


Figure 54. Mean metals SQS quotient *vs*. percent fines at the Port Gardner station.

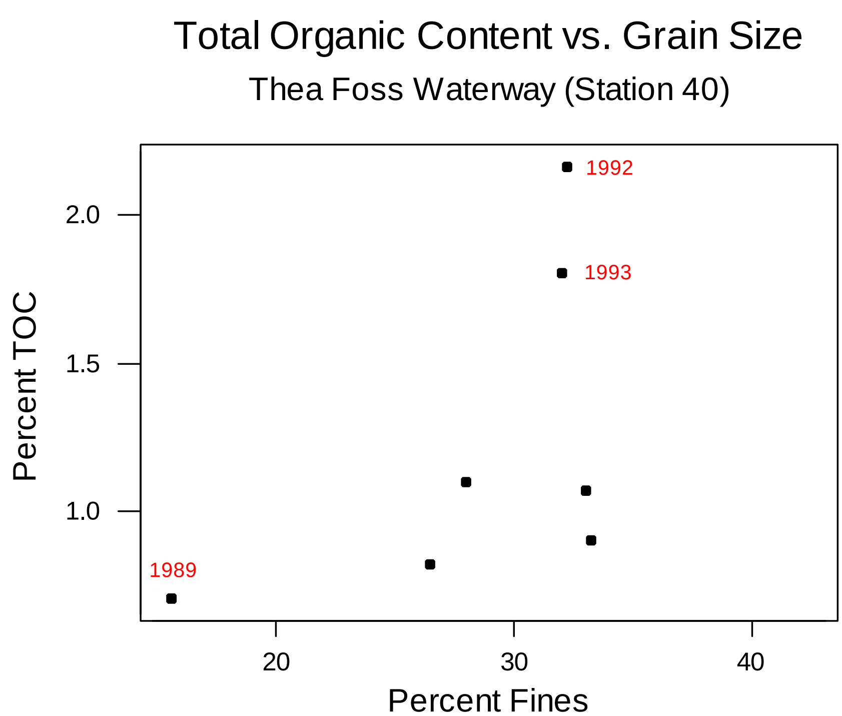


Figure 55. TOC *vs*. percent fines at the Thea Foss Waterway station.

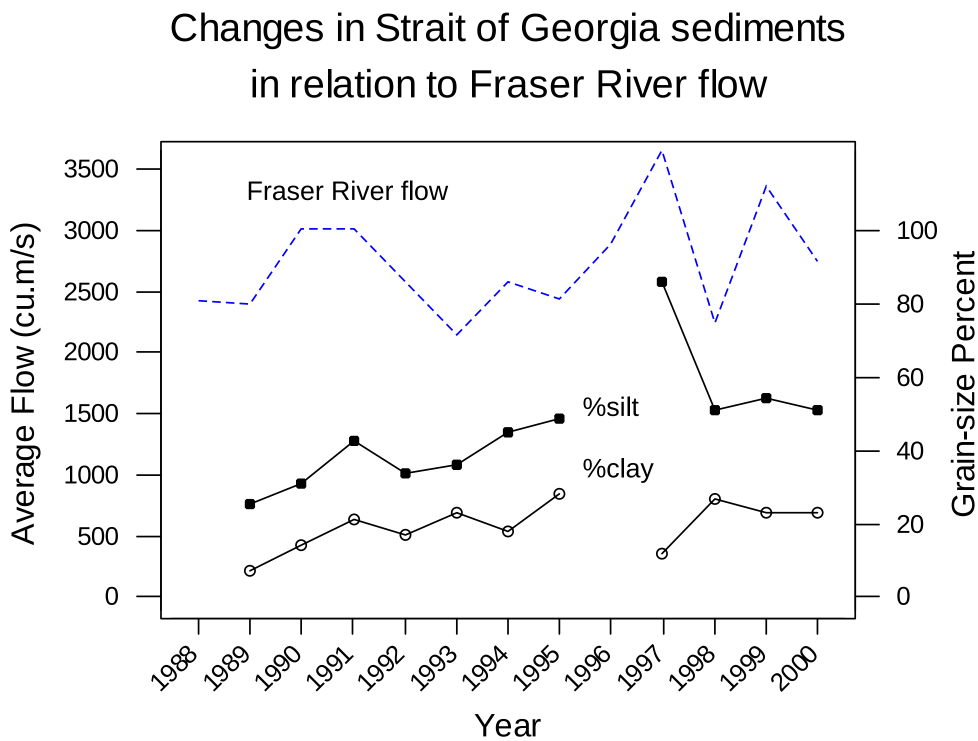


Figure 56. Changes in sediment grain-size distribution at the Strait of Georgia station in relation to Fraser River flow. Source of Fraser River flow data: Environment Canada, 2002.

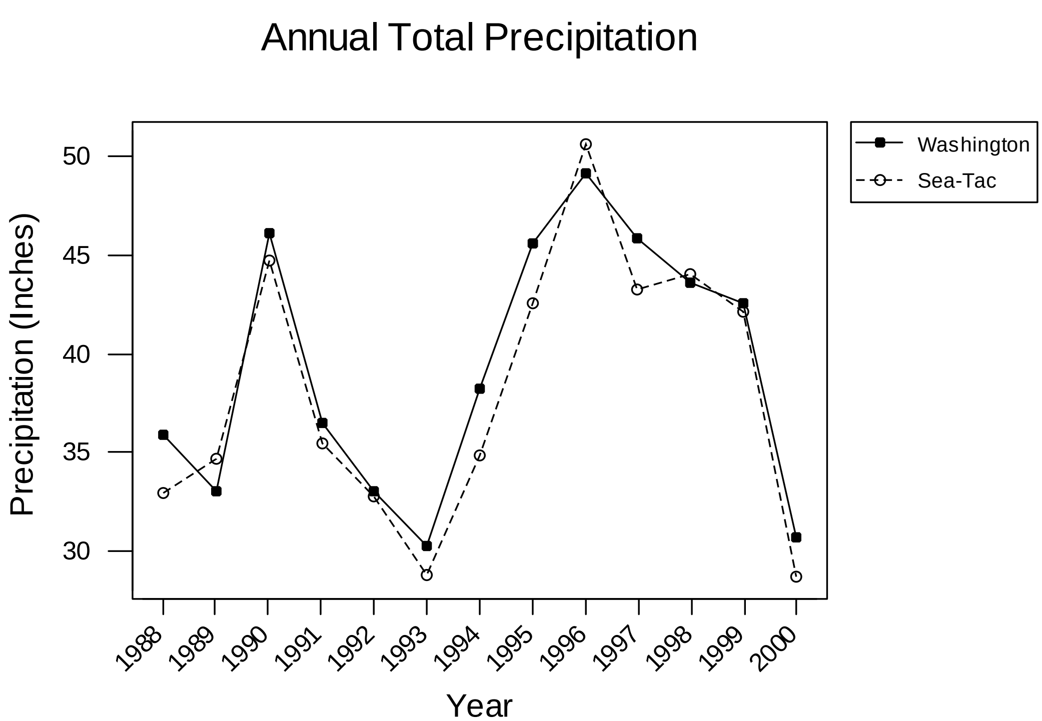


Figure 57. Annual total precipitation for Washington State and at the Seattle-Tacoma International Airport, 1988-2000. Sources: Washington: NOAA National Climatic Data Center (2003); SeaTac: Desert Research Institute Western Regional Climate Center (2003).

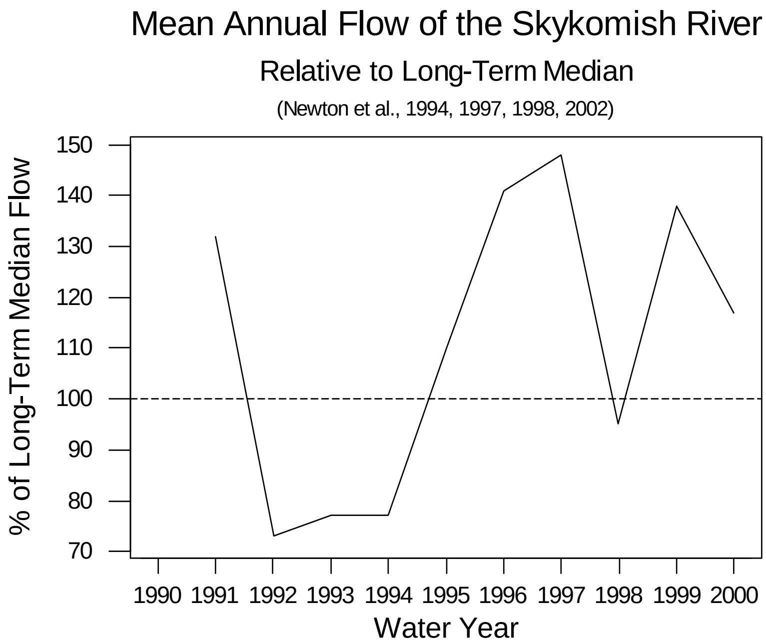


Figure 58. Mean annual flow of the Skykomish River relative to long-term median. (Source: Newton *et al.*, 1994, 1997, 1998, 2002)

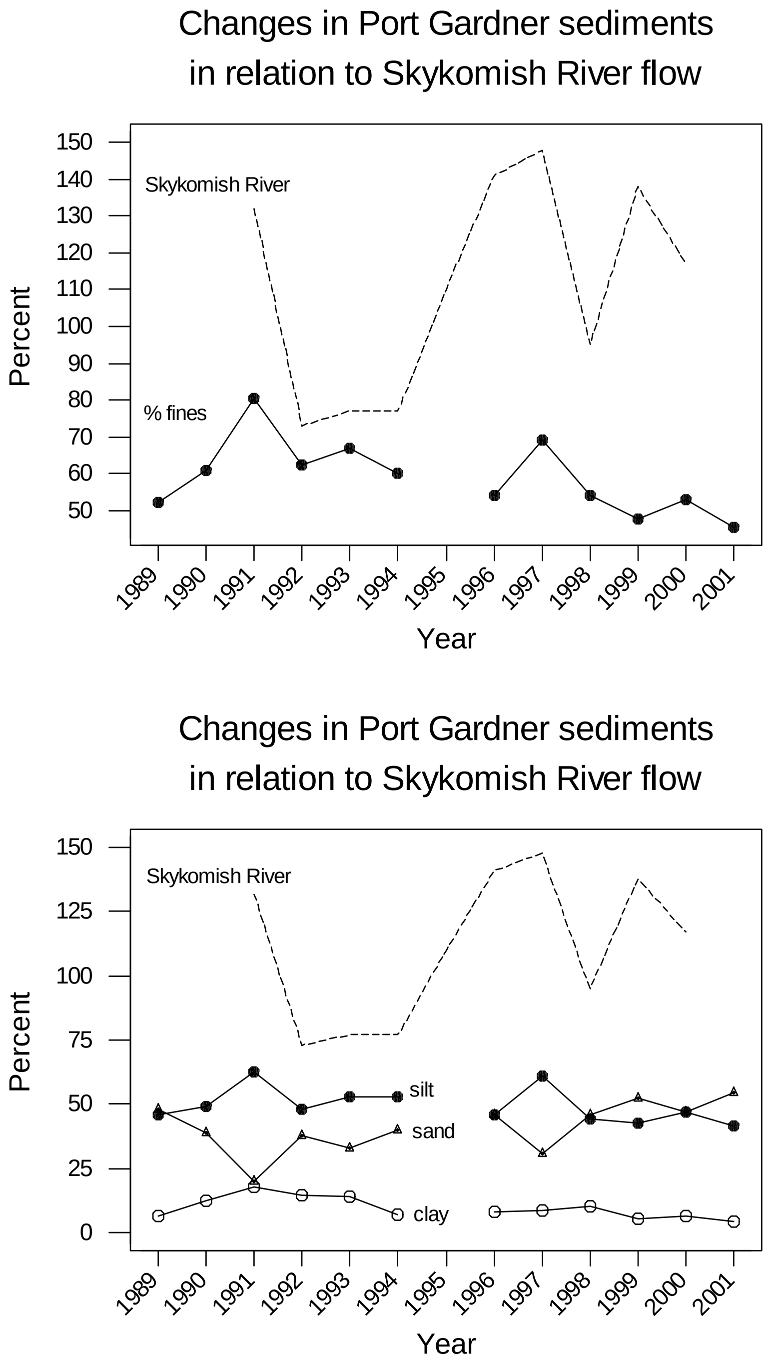


Figure 59. Changes in sediment grain-size distribution at Port Gardner (Station 21) in relation to Skykomish River flow. Top: percent fines; bottom: sand, silt, and clay.

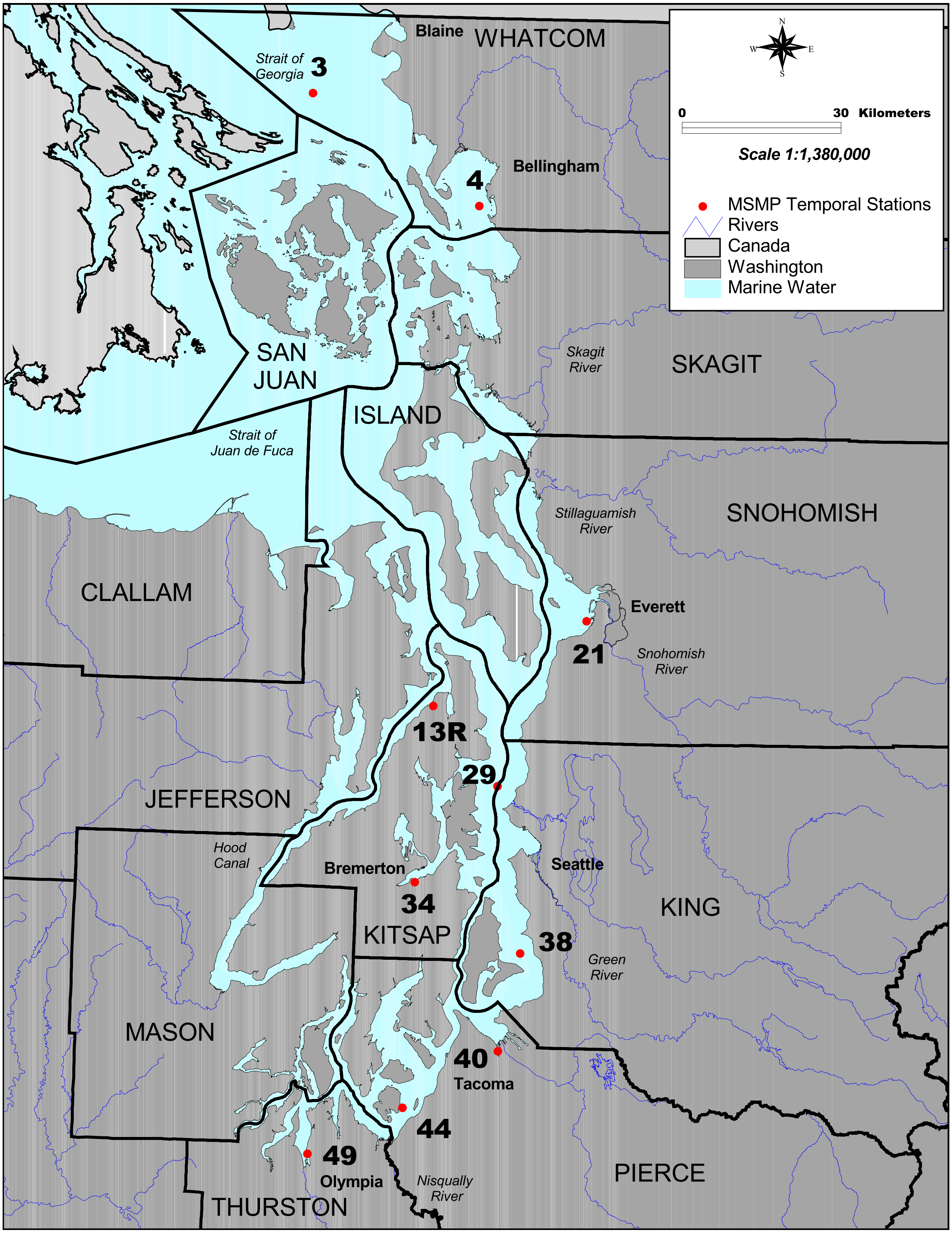


Figure 60. PSAMP long-term sediment monitoring stations in relation to county boundaries.

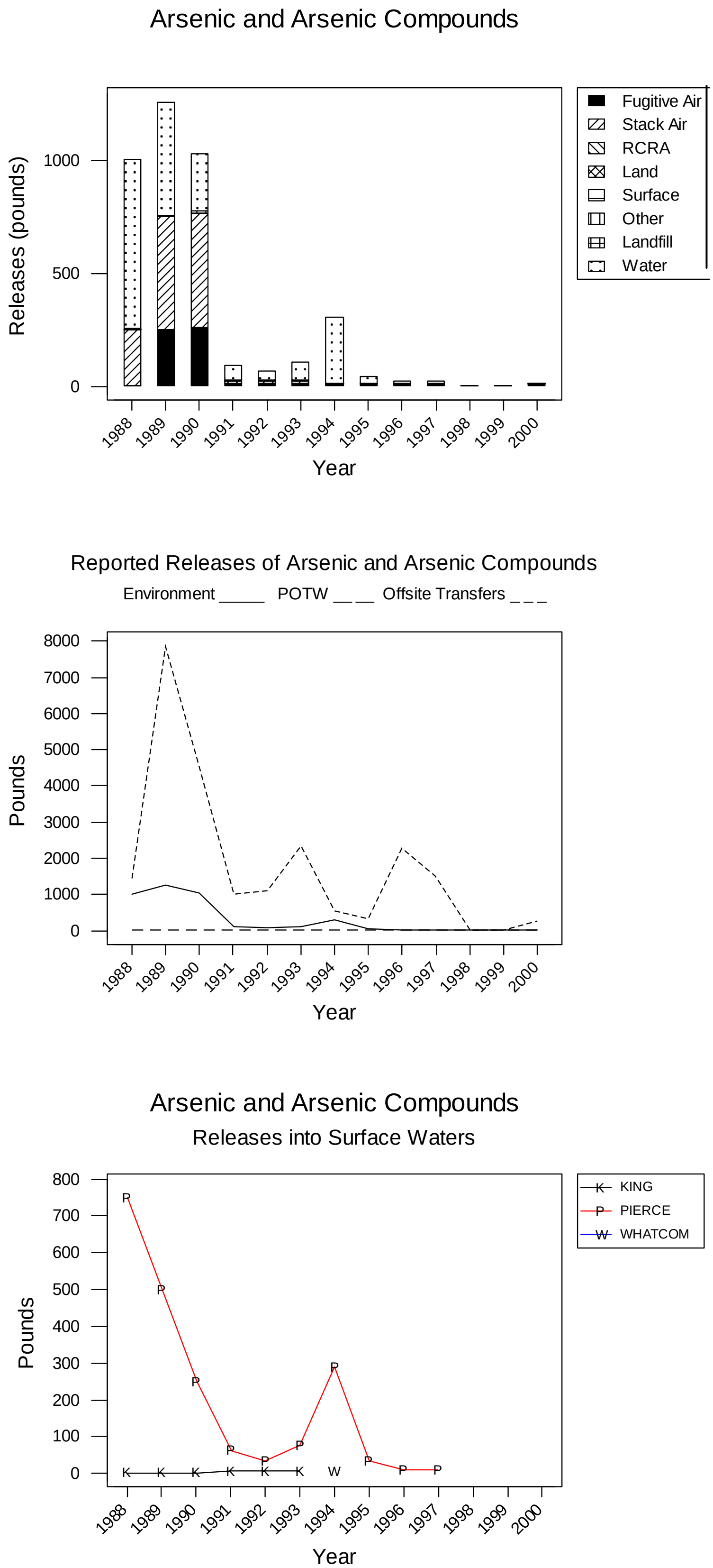
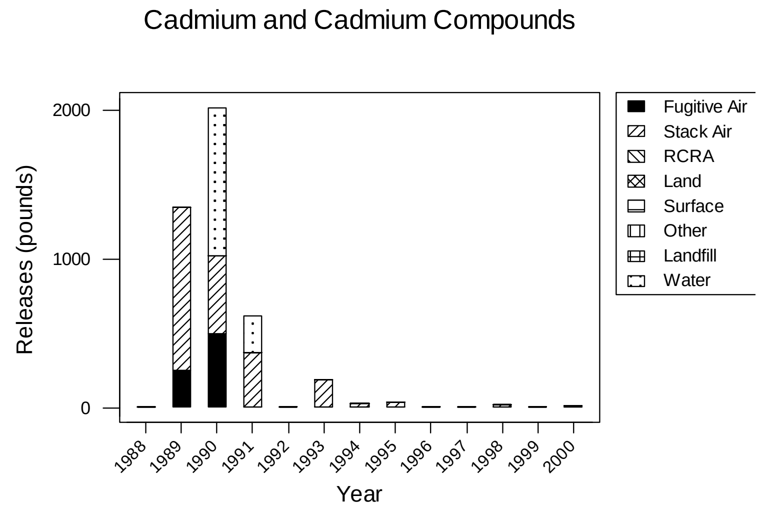
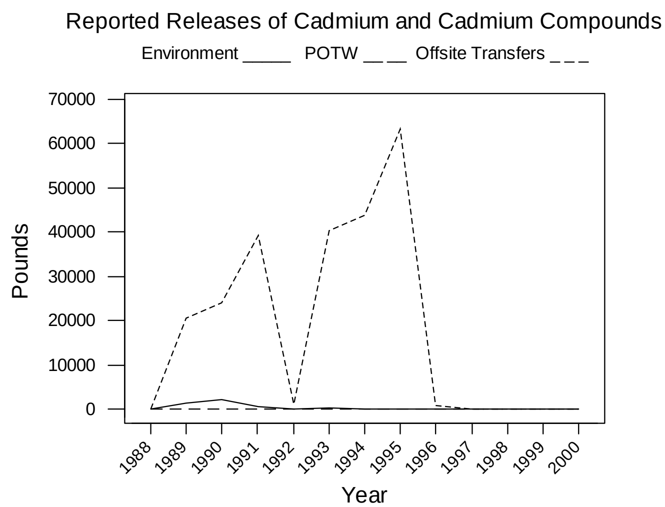


Figure 61. Reported releases of arsenic and arsenic compounds into the environment by mode (top), all releases (middle), and into surface waters only by county (bottom) in 1988-2000. Source: Washington State Department of Ecology EPCRA database (2003).





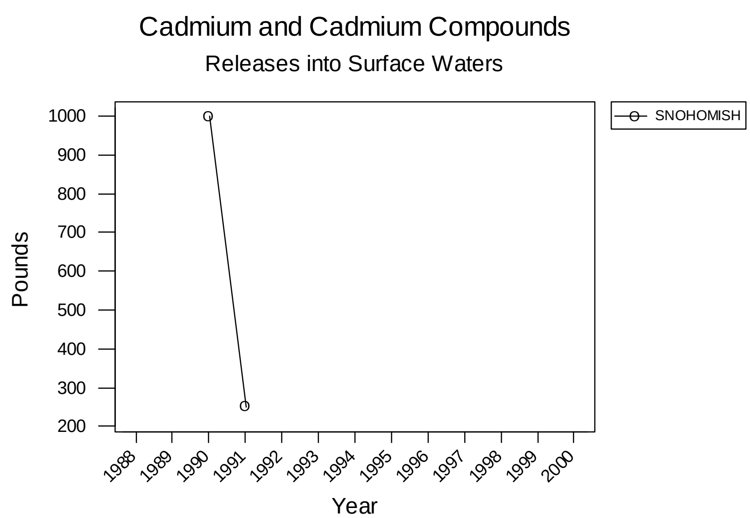
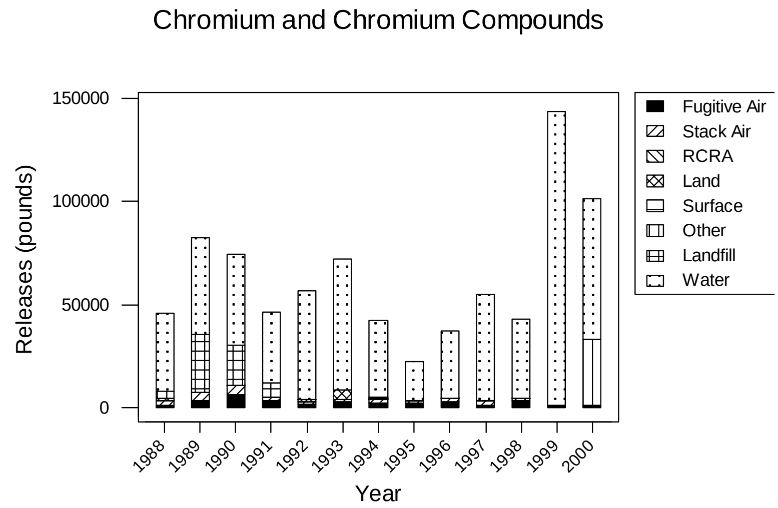
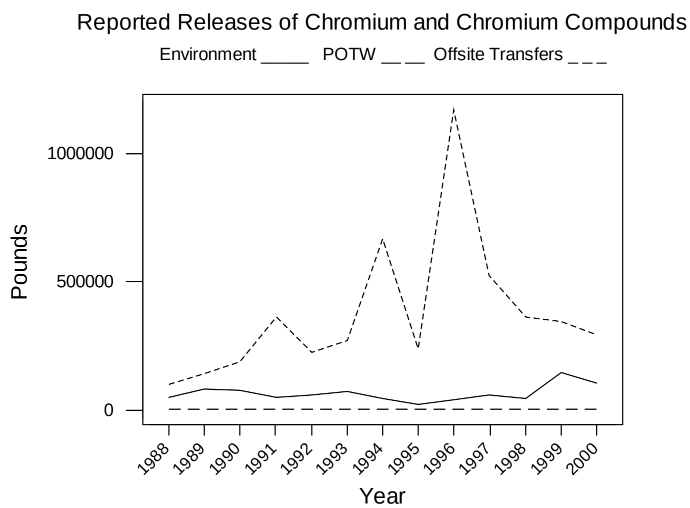


Figure 62. Reported releases of cadmium and cadmium compounds into the environment by mode (top), all releases (middle), and into surface waters only by county (bottom) in 1988-2000. Source: Washington State Department of Ecology EPCRA database (2003).





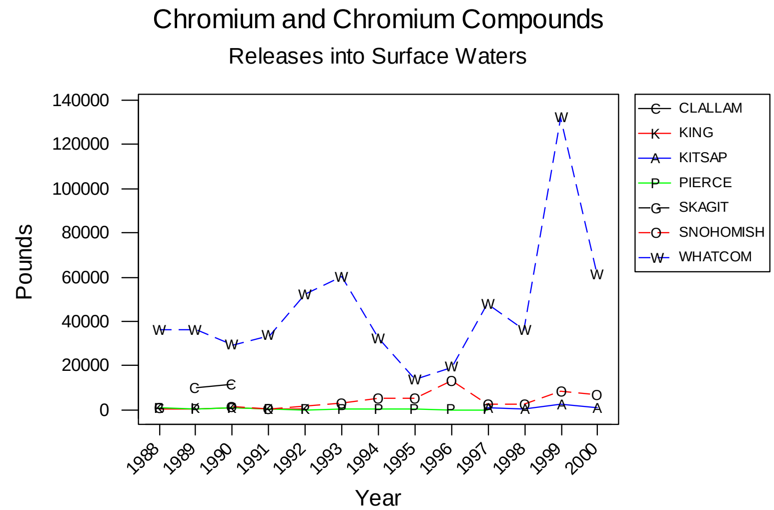
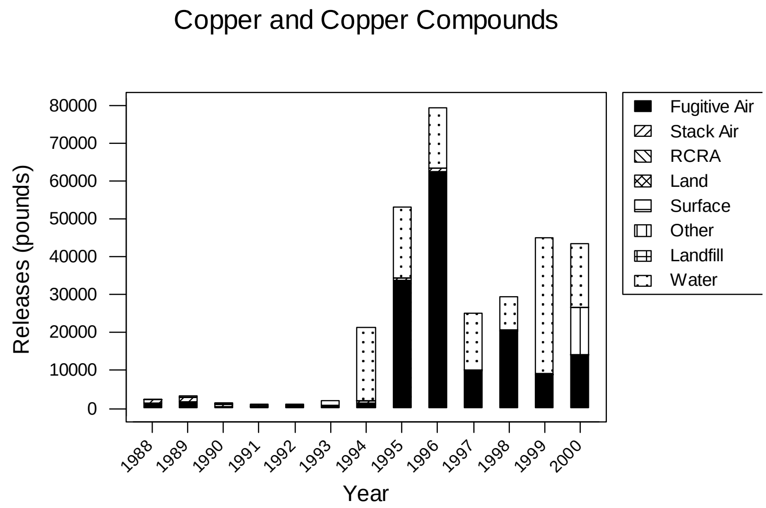
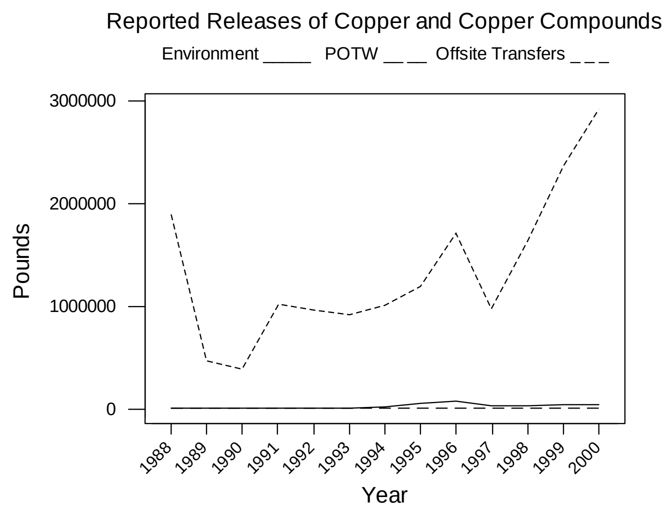


Figure 63. Reported releases of chromium and chromium compounds into the environment by mode (top), all releases (middle), and into surface waters only by county (bottom) in 1988-2000. Source: Washington State Department of Ecology EPCRA database (2003).





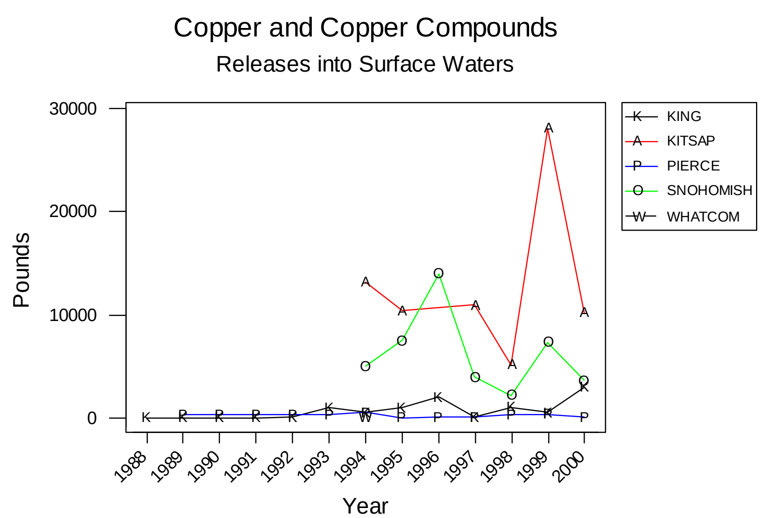
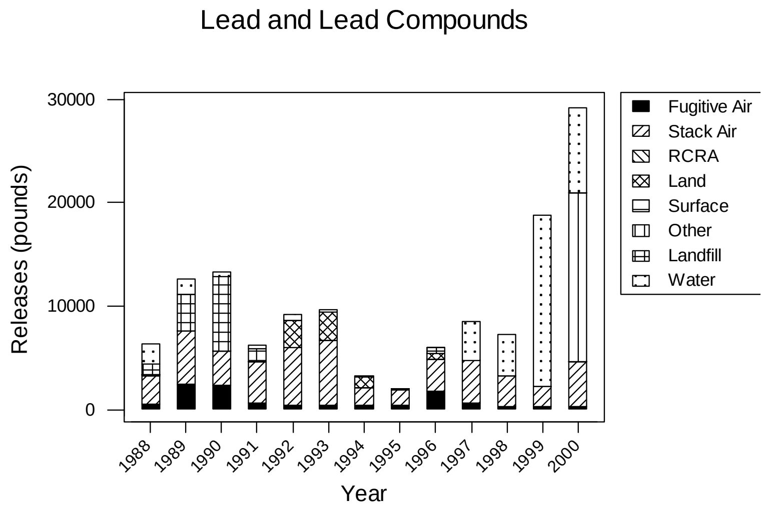
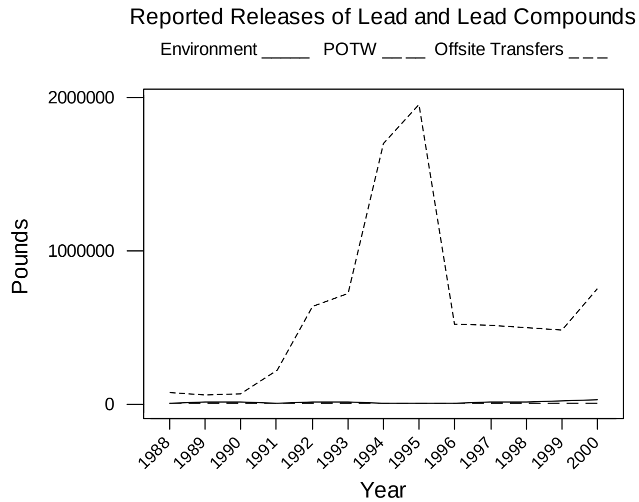


Figure 64. Reported releases of copper and copper compounds into the environment by mode (top), all releases (middle), and into surface waters only by county (bottom) in 1988-2000. Source: Washington State Department of Ecology EPCRA database (2003).





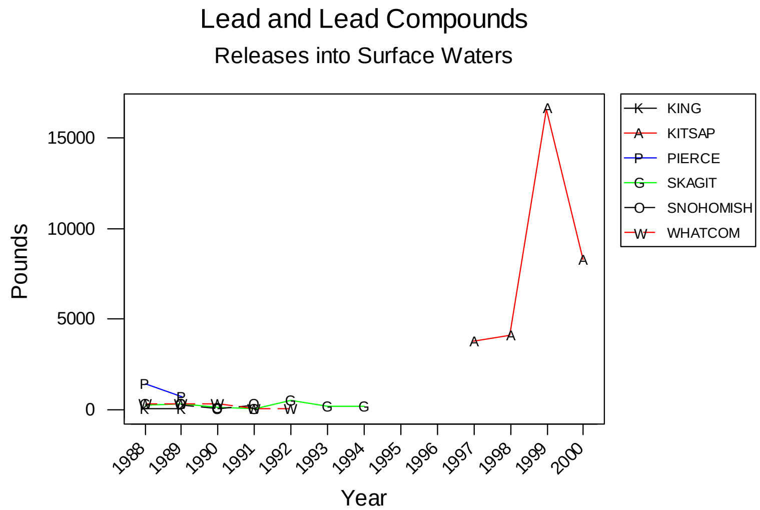


Figure 65. Reported releases of lead and lead compounds into the environment by mode (top), all releases (middle), and into surface waters only by county (bottom) in 1988-2000. Source: Washington State Department of Ecology EPCRA database (2003).

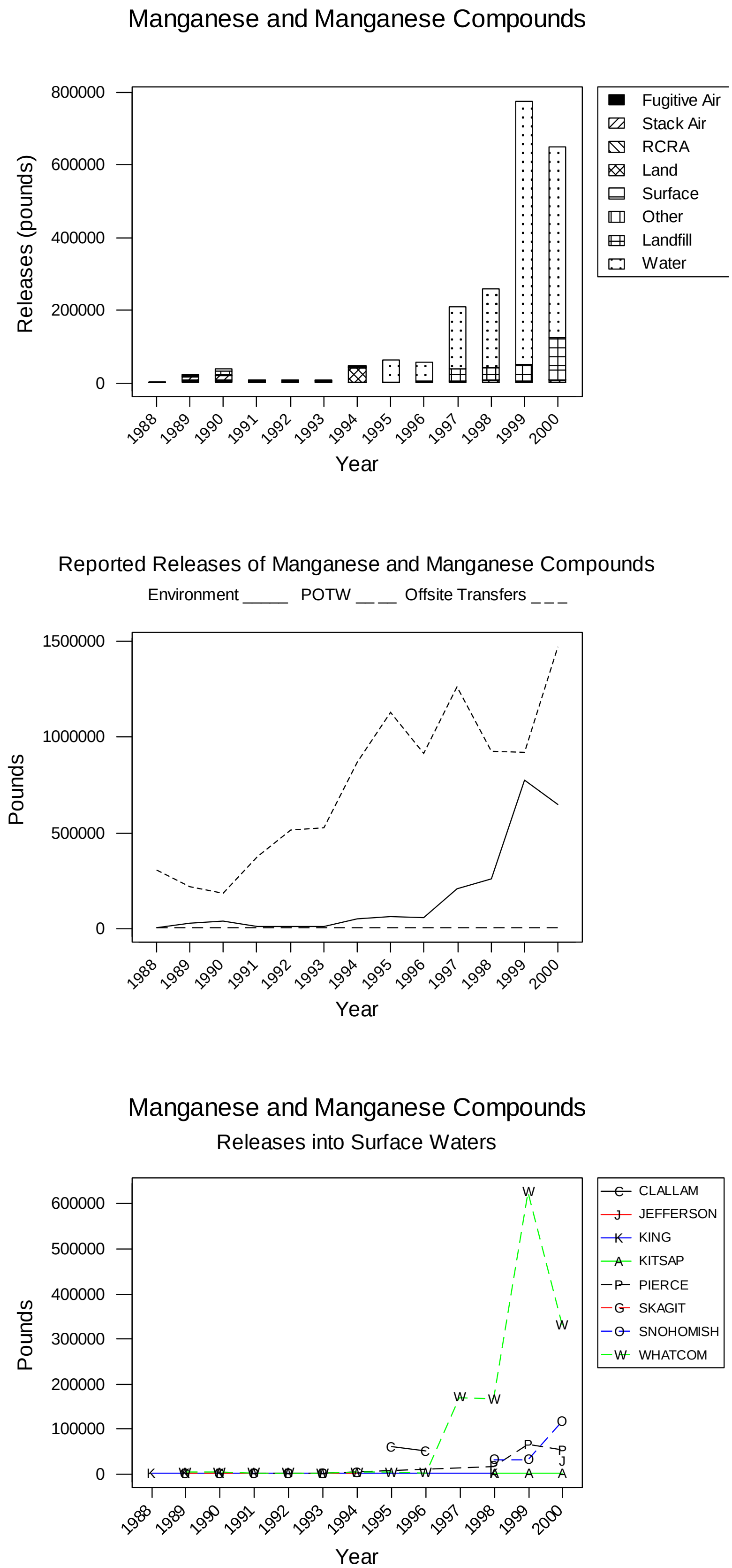
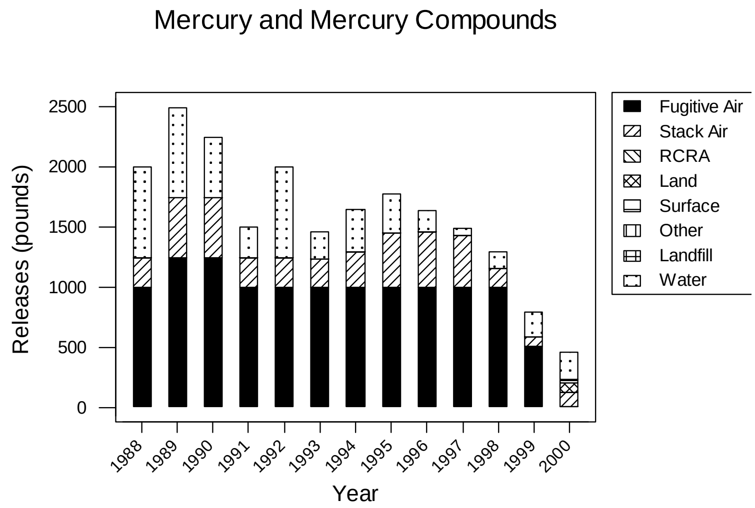
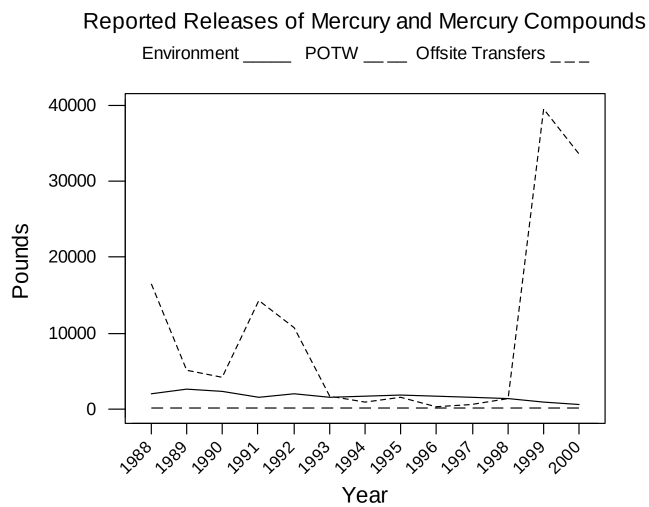


Figure 66. Reported releases of manganese and manganese compounds into the environment by mode (top), all releases (middle), and into surface waters only by county (bottom) in 1988-2000. Source: Washington State Department of Ecology EPCRA database (2003).





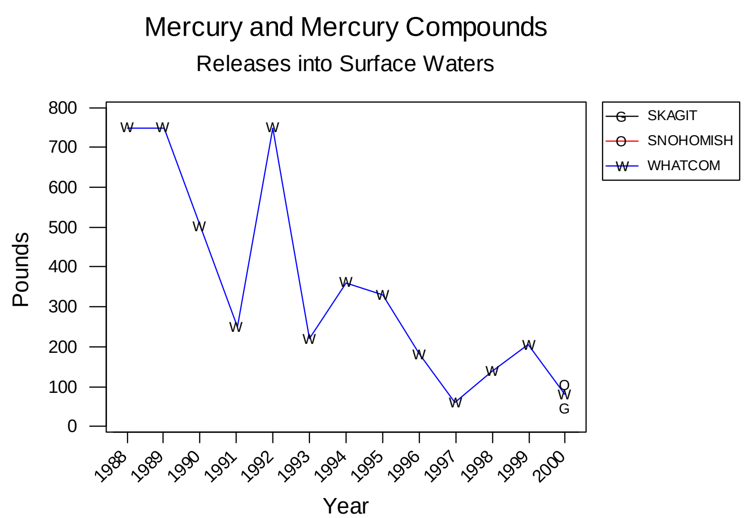


Figure 67. Reported releases of mercury and mercury compounds into the environment by mode (top), all releases (middle), and into surface waters only by county (bottom) in 1988-2000. Source: Washington State Department of Ecology EPCRA database (2003).

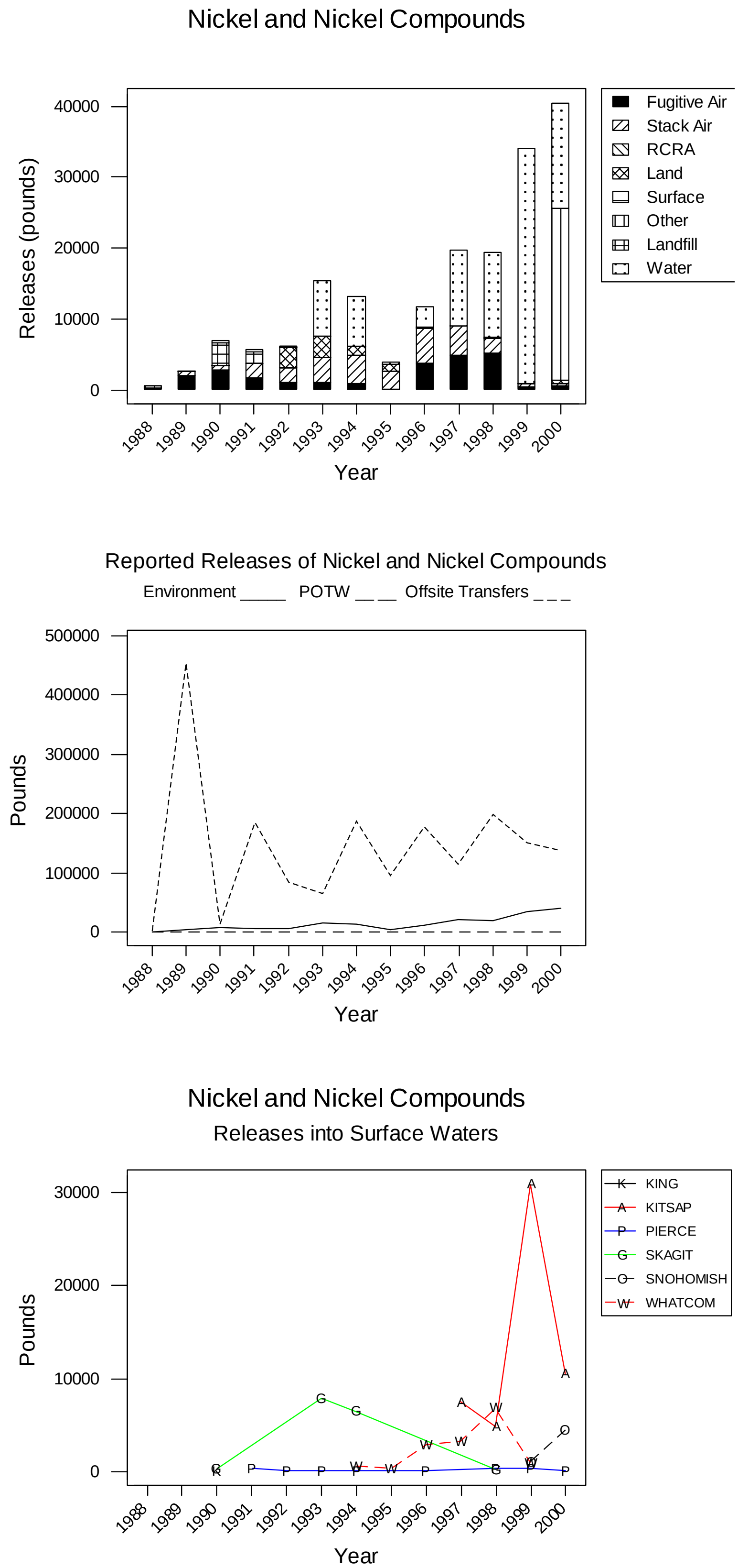
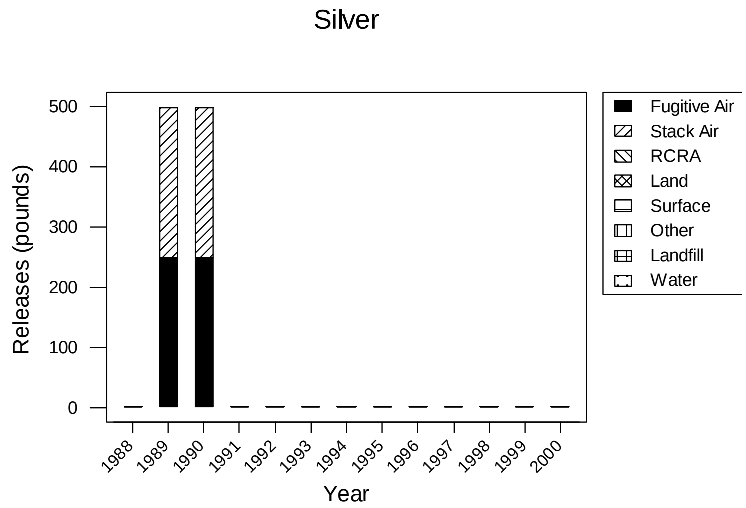
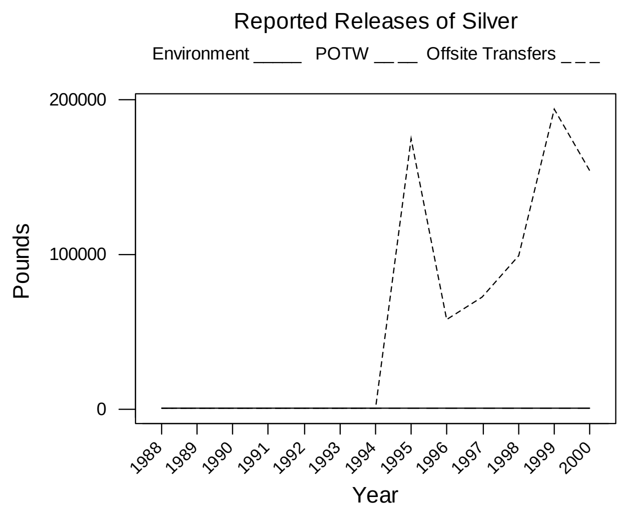


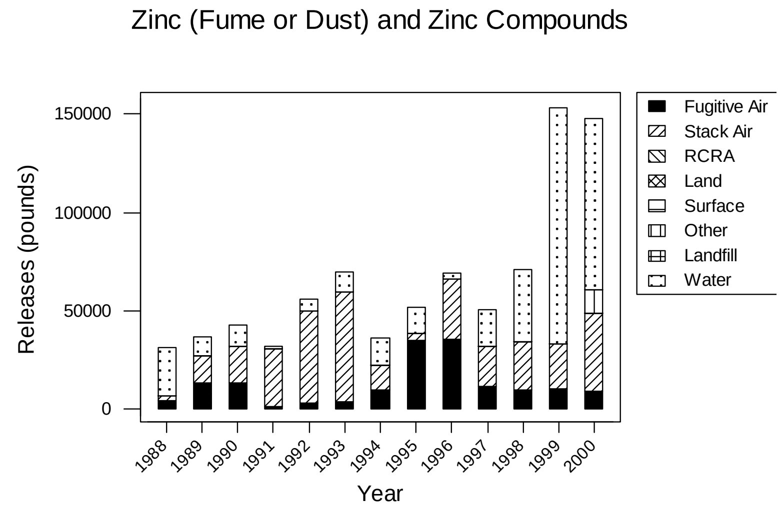
Figure 68. Reported releases of nickel and nickel compounds into the environment by mode (top), all releases (middle), and into surface waters only by county (bottom) in 1988-2000. Source: Washington State Department of Ecology EPCRA database (2003).

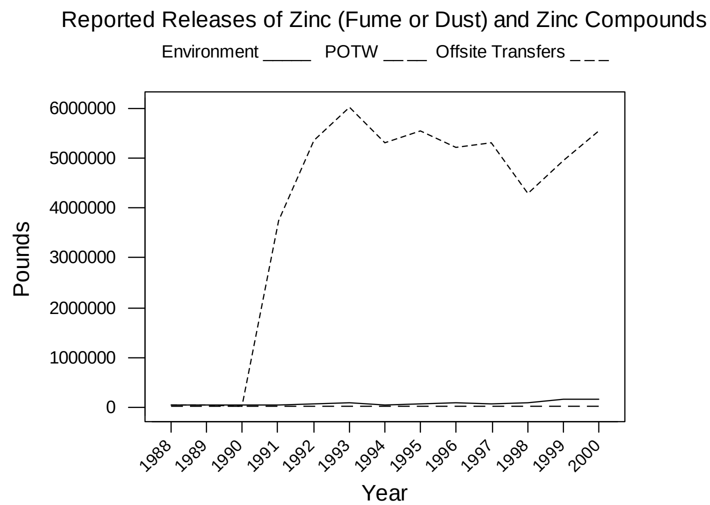




No releases of silver into surface waters during 1988-2000.

Figure 69. Reported releases of silver into the environment by mode (top), all releases (middle), and into surface waters only by county (bottom) in 1988-2000. Source: Washington State Department of Ecology EPCRA database (2003).





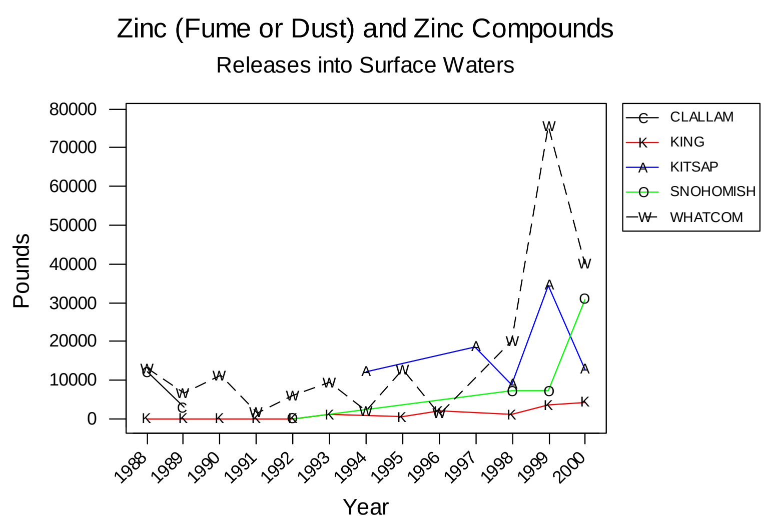
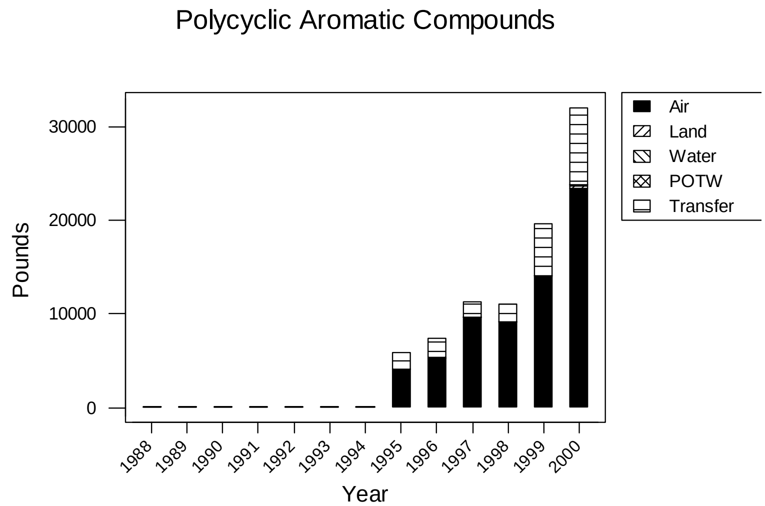
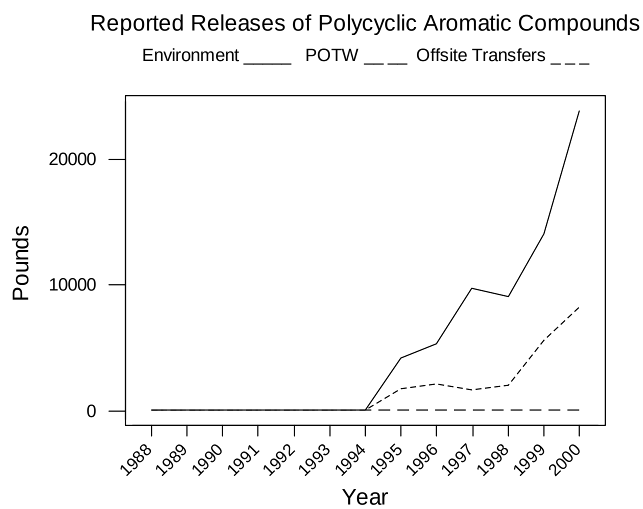


Figure 70. Reported releases of zinc and zinc compounds into the environment by mode (top), all releases (middle), and into surface waters only by county (bottom) in 1988-2000.
Source: Washington State Department of Ecology EPCRA database (2003).





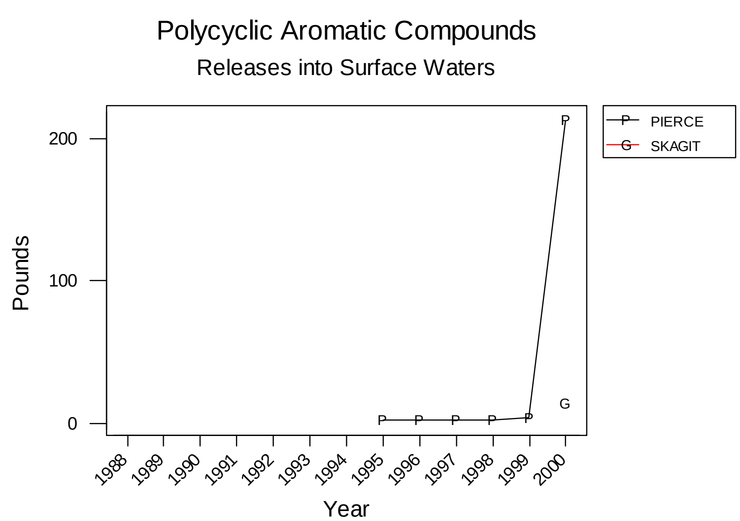


Figure 71. Reported releases of PAHs into the environment by mode (top), all releases (middle), and into surface waters only by county (bottom) in 1988-2000. Source: Washington State Department of Ecology EPCRA database (2003).

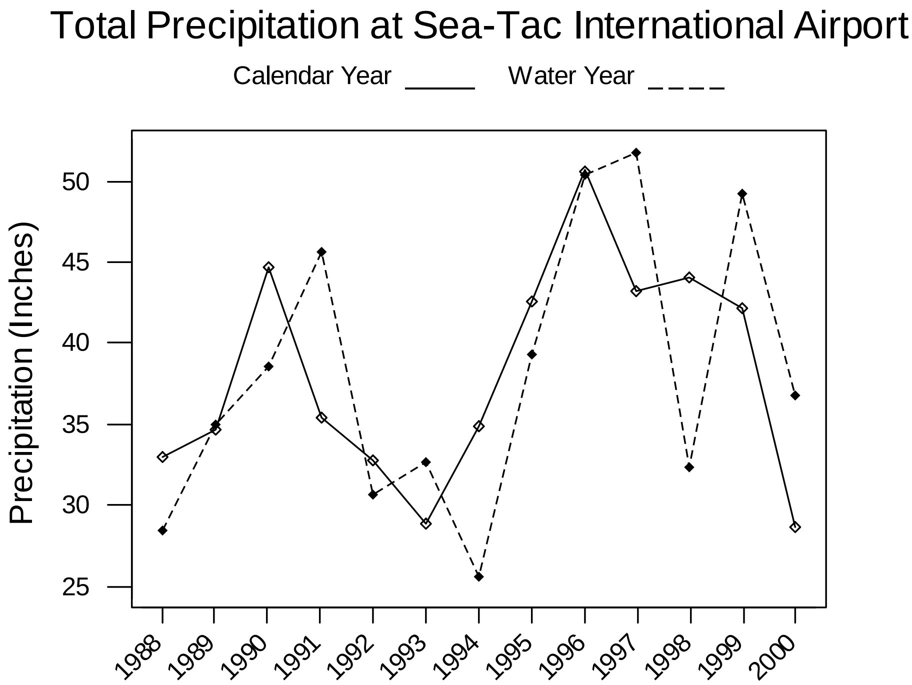


Figure 72. Total precipitation at the Seattle-Tacoma International Airport by calendar year and by water year, 1988-2000. Source: Desert Research Institute Western Regional Climate Center (2003).

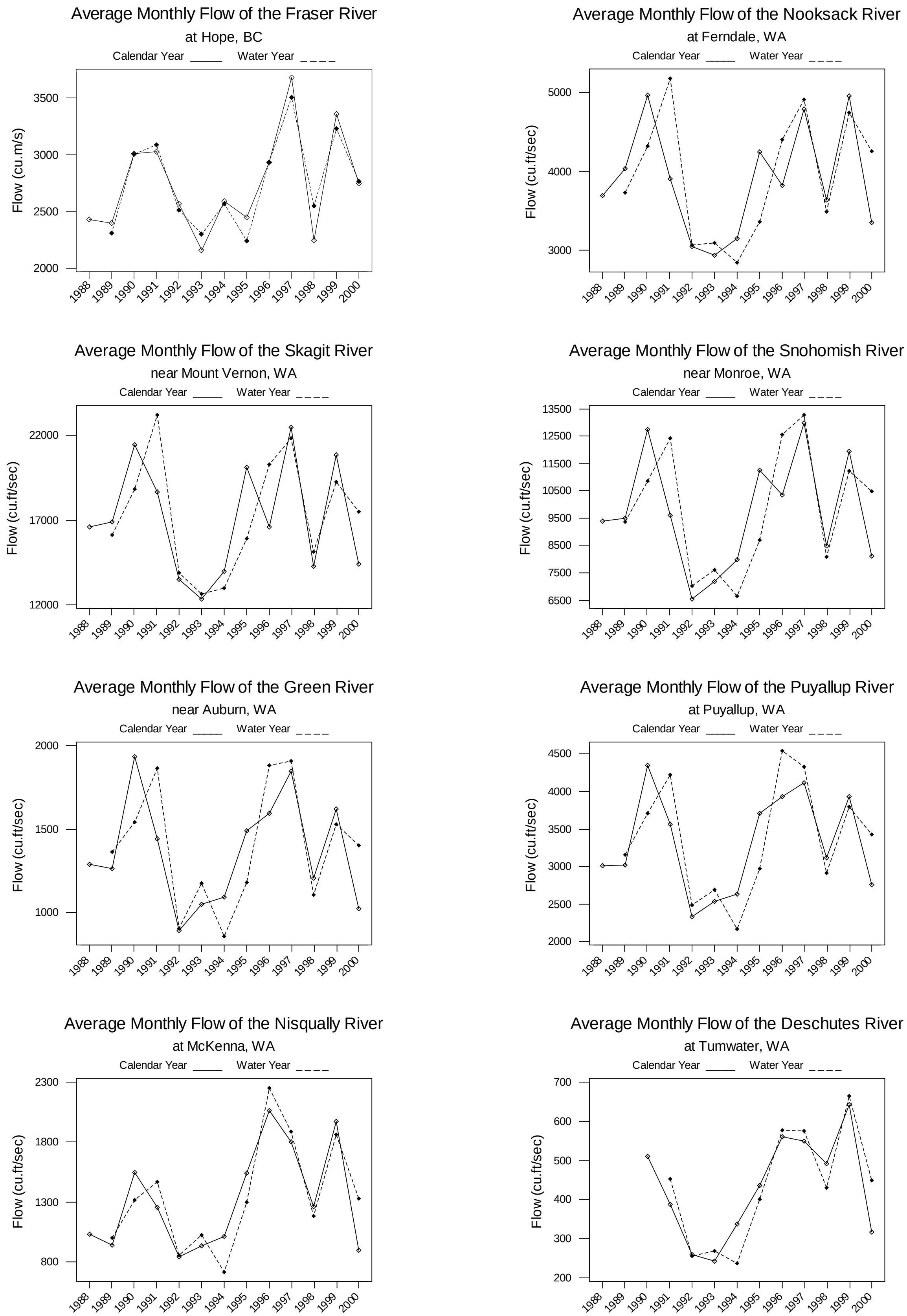


Figure 73. Average monthly flows of major rivers feeding Puget Sound and the Strait of Georgia, 1988-2000. Sources: Fraser River: Environment Canada, 2002; all other rivers: USGS, 2003.

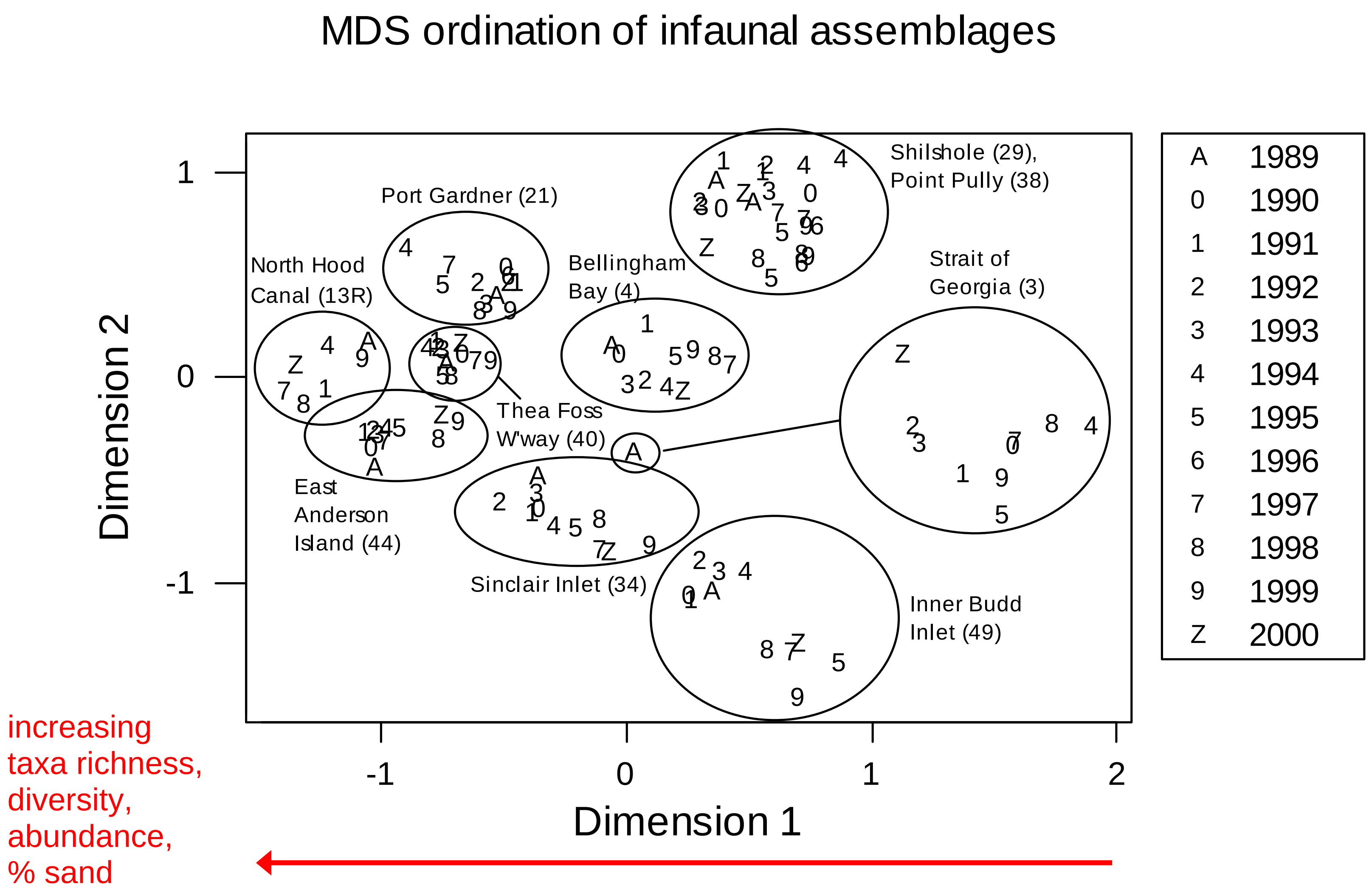


Figure 74. MDS map indicating approximate correspondence of physical and biological characteristics with 1st dimension.

Tables

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Table 1. Station number, location and sampling schedule of marine sediment monitoring stations. An "X" denotes sampling for sediment chemistry, grain size, and benthic macrofauna; an "*" denotes sampling for benthos and grain size only; an "&" denotes sampling for chemistry and grain size only; and a "+" denotes sampling for chemistry only.

Station	Station Name	Latitude (deg min N)	Longitude (deg min W)	Approx. Water Depth (meters)	Year 1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
3	Strait of Georgia (North of Patos Island)	48 52.22	122 58.695	223.0	X	X	X	X	X	X	X		*	*	*	X
4	Bellingham Bay	48 41.04	122 32.29	24.0	X	X	X	X	X	X	X		*	*	*	X
13R	North Hood Canal (South of Bridge)	47 50.26	122 37.74	20.0	X		X			X			*	*	*	X
21	Port Gardner (Everett)	47 59.13	122 14.575	20.0	X	X	X	X	X	X	X	X	*	*	*	X
29	Shilshole	47 42.06	122 27.23	199.0	X	X	X	X	X	X	X	X	*	*	*	X
34	Sinclair Inlet	47 32.84	122 39.725	9.5	X	X	X	X	X	X	X	&	*	*	*	X
38	Point Pully (3-Tree Point)	47 25.71	122 23.61	199.0	X	X	X	X	X	X	X	X	*	*	*	X
40	Thea Foss Waterway (Commencement Bay)	47 15.68	122 26.22	10.0	X	X	X	X	X	X	X	+	*	*	*	X
44	East Anderson Island	47 09.68	122 40.41	20.0	X	X	X	X	X	X	X	+	*	*	*	X
49	Inner Budd Inlet	47 04.82	122 54.82	5.3	X	X	X	X	X	X	X		*	*	*	X

Table 2. Analytical services for PSAMP long-term marine sediment monitoring samples.

Year	Laboratory	Parameters analyzed
1989	Analytical Resources, Inc.	Metals, organics, total organic carbon
	Columbia Analytical Services, Inc.	Total sulfides, grain size
1990	Analytical Resources, Inc.	Metals, organics, total sulfides, total organic carbon
	Hart Crowser	Grain size
1991	Analytical Resources, Inc.	Metals, organics, total sulfides, total organic carbon
	Soil Technology, Inc.	Grain size
1992	Analytical Resources, Inc.	Metals, organics, total sulfides, total organic carbon
	Soil Technology, Inc.	Grain size
1993	Analytical Resources, Inc.	Metals, organics, total sulfides, total organic carbon
	Soil Technology, Inc.	Grain size
1994	Manchester Environmental Laboratory	Metals, organics
	Soil Technology, Inc.	Grain size
	Weyerhaeuser Analytical and Testing Services	Total organic carbon
1995	Manchester Environmental Laboratory	Metals, organics
	Columbia Analytical Services, Inc.	Grain size
	Analytical Resources, Inc.	Total organic carbon
1996	Manchester Environmental Laboratory	Metals, organics
	Soil Technology, Inc.	Grain size
	Sound Analytical	Total organic carbon
1997	Columbia Analytical Services, Inc.	Grain size
1998	Hart Crowser	Grain size
1999	Rosa Environmental and Geotechnical Laboratory	Grain size
2000	Rosa Environmental and Geotechnical Laboratory	Grain size
	Manchester Environmental Laboratory	Metals, organics, total organic carbon

Table 3. Parameters monitored, analysis methods, reporting units, and stations and years sampled in the PSAMP long-term marine sediment monitoring. Station 13R was a rotating station and was sampled in 1989, 1991, 1994, and 2000 only. In 1996 samples were collected from only a subset of stations. Key to symbols is given at end of table.

Parameter	Sampling Year												Method
	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
BENTHIC MACROFAUNA (individuals/0.1m^2) **1996:** Stations 21, 29, 38 only	X	X	X	X	X	X	X	X	X	X	X	X	PSEP
SAND, SILT AND CLAY (%) **1996:** Stations 21, 29, 34, 38 only	X	X	X	X	X	X	X	X	X	X	X	X	PSEP (except 1995), ASTM D422 (1995)
TOTAL SULFIDES (mg/kg)	X	X	X	X	X								PSEP
TOTAL ORGANIC CARBON (%) **1996:** Stations 21, 29, 34, 38, 40, 44 only	X	X	X	X	X	X	X	X				X	PSEP
CHEMICALS **1996:** Stations 21, 29, 34, 38, 40, 44 only **Metals** (mg/kg) **Priority Pollutant Metals**													As indicated below
Antimony (Sb)	X	X	X	X	X		X					X	GFAA (1989-93), ICP (1995), ICP/MS (96, 2000)
Arsenic (As)	X	X	X	X	X	X	X	X				X	GFAA (1989-93, 95-96 2000), ICP (1994)
Beryllium (Be)	X	X	X	X	X		X						ICP
Cadmium (Cd)	X	X	X	X	X	X	X	X				X	GFAA (1989-93), ICP (1994-96, 2000)
Chromium (Cr)	X	X	X	X	X	X	X	X				X	ICP
Copper (Cu)	X	X	X	X	X	X	X	X				X	ICP
Lead (Pb)	X	X	X	X	X	X	X	X				X	GFAA (1989-93, 95-96 2000), ICP (1994; stn 34 1995)
Mercury (Hg)	X	X	X	X	X	X	X	X				X	CVAA
Nickel (Ni)	X	X	X	X	X		X					X	ICP
Selenium (Se)	X	X	X				X					X	GFAA (1989-91, 95, 2000)
Silver (Ag)	X	X	X	X	X	X	X	X				X	GFAA (1989-93), ICP (1994-96, 2000)
Thallium (Tl)	X	X	X				X						GFAA
Zinc (Zn)	X	X	X	X	X	X	X	X				X	ICP

Parameter	Sampling Year												Method
	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
Ancillary Metals													ICP
Aluminum (Al)	X	X	X	X	X							X	
Barium (Ba)	X	X	X	X	X								
Calcium(Ca)	X	X	X	X	X								
Cobalt (Co)	X	X	X	X	X								
Iron (Fe)	X	X	X	X	X							X	
Magnesium (Mg)	X	X	X	X	X								
Manganese (Mn)	X	X	X	X	X							X	
Potassium (K)	X	X	X										
Sodium (Na)	X	X	X										
Vanadium (V)	X	X	X	X	X								
<u>Organics</u> (µk/kg)													
Volatile Organics													
Halogenated Alkanes (Alkyl Halides)													Purge and Trap, GC/MS
Bromodichloromethane	A	A	A	A	A								
Bromoform	A	A	A	A	A								
Bromomethane	A	A	A	A	A								
Carbon tetrachloride	A	A	A	A	A								
Chlorodibromomethane	A	A	A	A	A								
Chloroethane (ethyl chloride)	A	A	A	A	A								
Chloroform	A	A	A	A	A								
Chloromethane	A	A	A	A	A								
Dichloromethane (methylene chloride)	A	A	A	A	A								
1,1-dichloroethane	A	A	A	A	A								
1,2-dichloroethane	A	A	A	A	A								
1,2-dichloropropane	A	A	A	A	A								
1,1,2,2-tetratchloroethane	A	A	A	A	A								
1,1,1-trichloroethane (methyl chloroform)	A	A	A	A	A								
1,1,2-trichloroethane	A	A	A	A	A								
Trichlorofluoromethane		A	A	A	A								
1,1,2-trichloro-1,2,2-trifluoroethane	A	A	A	A	A								

Parameter	Sampling Year												Method
	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
Halogenated Alkenes (Alkenyl Halides)													Purge and Trap, GC/MS
1,1-dichloroethene (1,1-dichloroethylene)	A	A	A	A	A								
Cis-1,2-dichloroethene	A		A	A	A								
Trans-1,2-dichloroethene	A	A	A	A	A								
Cis-1,3-dichloropropene	A	A	A	A	A								
Trans-1,3-dichloropropene	A	A	A	A	A								
Monochloroethylene (vinyl chloride)	A	A	A	A	A								
Tetrachloroethene	A	A	A	A	A								
Trichloroethene	A	A	A	A	A								
Aromatic and Chlorinated Aromatic Compounds													Purge and Trap, GC/MS
Benzene	A	A	A	A	A								
Chlorobenzene	A	A	A	A	A								
Ethylbenzene	A	A	A	A	A								
Styrene (vinylbenzene)	A	A	A	A	A								
Toluene	A	A	A	A	A								
Total xylenes	A	A	A	A	A								
Ketones													Purge and Trap, GC/MS
Acetone	A	A	A	A	A								
2-butanone	A	A	A	A	A								
2-hexanone	A	A	A	A	A								
4-methyl-2-pentanone	A	A	A	A	A								
Ethers													
2-chloro-ethyl vinyl ether	A	A	A	A	A								Purge and Trap, GC/MS
Esters													
Vinyl acetate	A	A	A	A	A								Purge and Trap, GC/MS
Organosulfur Compounds													
Carbon disulfide	A	A	A	A	A								Purge and Trap, GC/MS

Parameter	Sampling Year												Method
	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
Semivolatile Organics													
Acid Extractables													
Phenols													Extraction, GC/MS
2,4-dimethylphenol	X	X	X	X	X							X	
2-methylphenol (o-Cresol)	X	X	X	X	X							X	
4-methylphenol (p-Cresol)	X	X	X	X	X							X	
Phenol	X	X	X	X	X							X	
Chlorinated and Nitro-Substituted Phenols													Extraction, GC/MS
4-chloro-3-methylphenol	X	X	X	X	X							X	
2-chlorophenol	X	X	X	X	X							X	
2,4-dichlorophenol	X	X	X	X	X							X	
4,6-dinitro-2methylphenol	X	X	X	X	X							X	
2,4-dinitrophenol	X	X	X	X	X							X	
2-nitrophenol	X	X	X	X	X							X	
4-nitrophenol	X	X	X	X	X							X	
Pentachlorophenol	X	X	X	X	X							X	
2,4,5-trichlorophenol	X	X	X	X	X							X	
2,4,6-trichlorophenol	X	X	X	X	X							X	
Resin Acids													Extraction, GC/MS
Abietic acid	B	B	B	B	B								
Chlorodehydroabietic acid	B	B											
1,2-chlorodehydroabietic acid			B	B	B								
1,4-chlorodehydroabietic acid			B	B	B								
Dehydroabietic acid	B	B	B	B	B								
Dichlorodehydroabietic acid	B	B	B	B	B								
Isopimaric acid	B	B	B	B	B								
Neoabietic acid	B	B	B	B	B								
Palustric acid	B	B	B	B	B								
Pimaric acid	B	B	B	B	B								
Sandarocopimaric acid	B	B	B	B	B								

Parameter	Sampling Year												Method
	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
Guaiacols													Extraction, GC/MS
2-methoxyphenol (Guaiacol)	B	B	B	B	B								
Tetrachloroguaiacol	B	B	B	B	B								
3,4,5-trichloroguaiacol		B	B	B	B								
4,5,6-trichloroguaiacol	B	B	B	B	B								
Base Neutrals													
Low-Molecular Weight Polycyclic Aromatic Hydrocarbons													Extraction, GC/MS
Acenaphthene	X	X	X	X	X	C	C	X				X	
Acenaphthylene	X	X	X	X	X	C	C					X	
Anthracene	X	X	X	X	X	C	C	X				X	
Fluorene	X	X	X	X	X	C	C	X				X	
1-methylnaphthalene												X	
2-methylnaphthalene	X		X	X	X	C	C					X	
Naphthalene	X	X	X	X	X	C	C					X	
Phenanthrene	X	X	X	X	X	C	C	X				X	
Retene	X		X	X	X		C	X				X	
High-Molecular Weight Polycyclic Aromatic Hydrocarbons													Extraction, GC/MS
Benzo(a)anthracene	X	X	X	X	X	C	C	X				X	
Benzo(a)pyrene	X	X	X	X	X	C	C	X				X	
Benzo(b)fluoranthene						C	C					X	
Benzo(b+k)fluoranthene	X	X	X	X	X	C	C						
Benzo(g,h,i)perylene	X	X	X	X	X	C	C					X	
Benzo(k)fluoranthene						C	C					X	
Chrysene	X	X	X	X	X	C	C	X				X	
Dibenzo(a,h)anthracene	X	X	X	X	X	C	C	X				X	
Fluoranthene	X	X	X	X	X	C	C	X				X	
Indeno(1,2,3-c,d)pyrene	X	X	X	X	X	C	C					X	
Perylene	X		X	X	X							X	
Pyrene	X	X	X	X	X	C	C	X				X	

Parameter	Sampling Year												Method
	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
Chlorinated Aromatic Compounds													Extraction, GC/MS
1,3-dichlorobenzene	X	X	X	X	X							X	
1,4-dichlorobenzene	X	X	X	X	X							X	
1,2-dichlorobenzene	X	X	X	X	X							X	
1,2,4-trichlorobenzene	X	X	X	X	X							X	
2-chloronaphthalene	X	X	X	X	X	C	C	X				X	
Hexachlorobenzene	X	X	X	X	X			X				X	
Chlorinated Alkanes													Extraction, GC/MS
Hexachloroethane	X	X	X	X	X							X	
Chlorinated Alkenes													Extraction, GC/MS
Hexachlorobutadiene	X	X	X	X	X							X	
Hexachlorocyclo-pentadiene	X	X	X	X	X							X	
Phthalate Esters													Extraction, GC/MS
Bis(2-ethylhexyl) phthalate	X	X	X	X	X							X	
Butyl benzyl phthalate	X	X	X	X	X							X	
Di-n-butyl phthalate	X	X	X	X	X							X	
Di-n-octyl phthalate	X	X	X	X	X							X	
Diethyl phthalate	X	X	X	X	X							X	
Dimethyl phthalate	X	X	X	X	X							X	
Miscellaneous Extractable Compounds													Extraction, GC/MS
Benzoic acid	X	X	X	X	X							X	
Benzyl alcohol	X	X	X	X	X							X	
beta-Coprostanol	X	X	X	X	X							X	
beta-Sitosterol	X		X	X	X							X	
Cholesterol	X		X	X	X			X				X	
Cymene	X		X	X	X							X	
Dibenzofuran	X	X	X	X	X	C	C	X				X	
Isophorone	X	X	X	X	X							X	
gamma-Sitosterol												X	
1,2-diphenylhydrazine												X	
Benzidine												X	
Pyridine												X	

Parameter	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Method
	Sampling Year												
Organonitrogen Compounds													Extraction, GC/MS
Caffeine	X		X	X	X							X	
9(H)-Carbazole	X	X	X	X	X	C	C	X				X	
4-chloroaniline	X		X	X	X							X	
3,3-dichlorobenzidine	X		X	X	X							X	
2,4-dinitrotoluene	X		X	X	X							X	
2,6-dinitrotoluene	X		X	X	X							X	
Diphenylnitrosamine (N-nitrosodiphenylamine)	X		X	X	X							X	
2-nitroaniline	X		X	X	X							X	
3-nitroaniline	X		X	X	X							X	
4-nitroaniline	X		X	X	X							X	
Nitrobenzene	X		X	X	X							X	
N-nitroso-di-n-propylamine	X	X	X	X	X							X	
Aniline												X	
N-nitrosodimethylamine												X	
Ethers													Extraction, GC/MS
Bis-(2-chloroethoxy) methane	X		X	X	X							X	
Bis-(2-chloroisopropyl) ether	X		X	X	X							X	
4-bromophenyl-phenyl ether	X		X	X	X							X	
4-chlorophenyl-phenyl ether	X		X	X	X							X	
Dichloroethyl ether [bis-(2-chloroethyl) ether]	X		X	X	X							X	
Chlorinated Pesticides													Extraction, GC-ECD (1989-93, 95-2000), AED (1994)
Aldrin	X	X	X	X	X	D	D					X	
alpha-Chlordane	X	X	X	X	X	D	D					X	
alpha-Endosulfan (Endosulfan I)	X	X	X	X	X	D						X	
alpha-HCH (alpha hexachlorocyclo-hexane	X	X	X	X	X	D	D					X	
beta-Endosulfan (Endosulfan II)	X	X	X	X	X	D						X	
beta-HCH (beta-BHC)	X	X	X	X	X	D	D					X	
delta-HCH (delta-BHC)	X	X	X	X	X	D	D					X	
Dieldrin	X	X	X	X	X	D	D					X	

Parameter	Sampling Year												Method
	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
Chlorinated Pesticides (continued)													Extraction, GC-ECD (1989-93, 95-2000), AED (1994)
Endosulfan sulfate	X	X	X	X	X	D	D					X	
Endrin	X	X	X	X	X	D	D					X	
Endrin aldehyde		X		X	X	D						X	
Endrin ketone	X	X	X	X	X	D						X	
gamma-Chlordane	X	X	X	X	X	D	D					X	
gamma-HCH (Lindane)	X	X	X	X	X	D	D					X	
Heptachlor	X	X	X	X	X	D	D					X	
Heptachlor epoxide	X	X	X	X	X	D	D					X	
Methoxychlor	X	X	X	X	X	D	D					X	
2,4'-DDD												X	
4,4'-DDD	X	X	X	X	X	D	D					X	
2,4'-DDE												X	
4,4'-DDE	X	X	X	X	X	D	D					X	
2,4'-DDT												X	
4,4'-DDT	X	X	X	X	X	D	D					X	
Toxaphene	X	X	X	X	X	D	D					X	
trans-Chlordane (gamma)												X	
Polychlorinated Biphenyls													Extraction, GC-ECD (1989-93, 95-2000), AED (1994)
Aroclor 1016					X		D					X	
Aroclor 1221			X	X	X	D	D					X	
Aroclor 1232			X	X	X	D	D					X	
Aroclor 1242					X	D	D					X	
Aroclor 1248	X	X	X	X	X	D	D					X	
Aroclor 1254	X	X	X	X	X	D	D					X	
Aroclor 1260	X	X	X	X	X	D	D					X	
Aroclor 1016/1242	X	X	X	X	X								

X = All Stations
A = 1989-90: Stations 3, 29, 38 only; **1991-93:** Stations 3, 29, 34, 38 only
B = 1989: Stations 4, 21 only; **1990:** Station 21 only; **1991-93:** Station 4 only
C = 1994: Stations 13R, 21, 34, 38, 40 only; **1995:** Stations 21, 3, 4, 34, 38, 40, 49 only
D = 1994: Stations 21, 34, 38 only; **1995:** Stations 21, 34, 38, 40, 49 only

Table 4. Infaunal indices calculated to characterize the benthic macrofaunal invertebrate assemblages identified at each PSAMP station.

Infaunal index	Definition	Calculation
Total Abundance	A measure of density equal to the total number of organisms per unit area ($0.1\ m^2$, for this report).	Sum of all organisms counted in each replicate, divided by the number of $0.1\ m^2$ replicates.
Major Taxa Abundance	A measure of density equal to the total number of organisms in each major taxon group (Annelida, Arthropoda, Echinodermata, Mollusca, and Other Taxa) per unit area ($0.1\ m^2$, for this report).	Sum of all organisms counted in each major taxon group in each replicate, divided by the number of $0.1\ m^2$ replicates.
Taxa Richness	Total number of taxa (lowest level of identification for each organism).	Count of all taxa identified at each station in each year.
Shannon-Wiener Diversity (H')	A measure of the number and abundance of taxa. Minimized at 0 for a single taxon comprising all individuals; maximized at log *S* when each taxon has an equal number of individuals (Clarke and Warwick, 1994).	$H' = -\sum_{i=1}^{S}\left(\frac{n_i}{N}\right)\log\left(\frac{n_i}{N}\right)$, where n_i is the number of individuals in the i^{th} taxon, *N* is the total number of individuals over all taxa (total abundance), and *S* is the number of taxa (taxa richness).
Pielou's Evenness (J')	The observed diversity as a proportion of the maximum possible diversity; a measure of how equitably distributed the taxa are. Ranges from 0, for a single taxon comprising all individuals, to 1, when individuals are completely equally distributed among the taxa (Clarke and Warwick, 1994).	$J' = \frac{H'}{\log S}$, where *H'* is the Shannon-Wiener diversity index and *S* is the number of taxa (taxa richness).
Swartz' Dominance Index (SDI)	The minimum number of taxa composing the top 75% of the total abundance in a sample. The fewer the taxa composing the bulk of the total abundance, the smaller the value of Swartz's dominance index.	Count of the minimum number of taxa whose combined abundance accounts for 75 percent of the total abundance, *i.e.*, when the individual taxa are ordered from largest proportion of total abundance to smallest, the number of taxa corresponding to a cumulative proportion of at least 75%.
Swartz's dominance index, standardized by the number of taxa (SDISTD)	When divided by the taxa richness, Swartz's dominance index is thus normalized, or standardized, by the number of taxa in a sample.	$SDISTD = \frac{SDI}{S}$, where S*DI* is the Swartz' dominance index and *S* is the number of taxa (taxa richness).

Table 5. Mean grain size distribution by station. Mean (± Std. Dev.)

Station	% Gravel	% Sand	% Silt	% Clay
Strait of Georgia (3)	9.6 (± 11.6)	26.3 (± 9.6)	45.6 (± 17.1)	18.5 (± 6.1)
Bellingham Bay (4)	0.2 (± 0.4)	3.3 (± 1.6)	60.8 (± 9.4)	35.7 (± 10.0)
North Hood Canal (13R)	0.1 (± 0.1)	87.5 (± 2.5)	8.8 (± 2.2)	3.6 (± 0.8)
Port Gardner (21)	0.1 (± 0.1)	39.9 (± 9.4)	50.1 (± 6.6)	9.9 (± 4.0)
Shilshole (29)	0.6 (± 1.1)	13.9 (± 7.2)	56.6 (± 6.4)	28.8 (± 3.7)
Sinclair Inlet (34)	1.0 (± 2.3)	7.5 (± 3.15)	64.6 (± 7.1)	27.0 (± 4.9)
Point Pully (38)	0.1 (± 0.1)	5.6 (± 3.9)	50.6 (± 7.3)	43.7 (± 6.0)
Thea Foss Waterway (40)	0.5 (± 0.5)	69.0 (± 6.7)	22.6 (± 5.6)	7.9 (± 2.2)
East Anderson Island (44)	0.4 (± 0.3)	82.6 (± 2.0)	10.0 (± 1.7)	7.0 (± 1.7)
Inner Budd Inlet (49)	0.7 (± 1.9)	14.7 (± 6.9)	55.8 (± 6.5)	28.7 (± 5.2)

Table 6. Summary statistics of sediment percent fines, TOC, mean metals SQS quotient, and total PAH.

Station	Strait of Georgia (3)	Bellingham Bay (4)	North Hood Canal (13R)	Port Gardner (21)	Shilshole (29)	Sinclair Inlet (34)	Point Pully (38)	Thea Foss Waterway (40)	East Anderson Island (44)	Inner Budd Inlet (49)
Percent Fines										
Mean	64.1	96.5	12.4	60.1	85.5	91.5	94.4	30.5	17.0	84.5
Std. Dev.	18.8	1.8	2.5	9.4	8.0	4.5	4.0	6.8	2.0	7.5
Median	63.4	97.1	11.6	60.0	89.5	92.0	95.5	32.1	17.3	85.5
Minimum	32.6	93.4	9.7	47.6	74.0	82.0	86.4	15.6	14.5	70.0
Maximum	98.1	98.0	16.0	80.3	93.0	97.6	98.9	42.3	20.2	97.0
N	10	10	7	11	8	11	11	10	10	10
C.V.	29.3%	1.8%	20.0%	15.7%	9.4%	4.9%	4.2%	22.3%	11.5%	8.9%
Percent TOC										
Mean	1.18	2.06	0.33	1.21	1.75	2.45	2.21	1.19	0.51	2.60
Std. Dev.	0.25	0.24	0.20	0.16	0.32	0.42	0.20	0.49	0.11	0.45
Median	1.22	2.00	0.26	1.23	1.66	2.40	2.20	1.07	0.48	2.66
Minimum	0.81	1.75	0.18	0.97	1.40	1.74	1.94	0.70	0.43	2.00
Maximum	1.60	2.50	0.60	1.50	2.50	3.20	2.50	2.20	0.80	3.30
N	8	8	4	9	9	9	9	9	9	8
C.V.	21.0%	11.4%	60.2%	13.6%	18.2%	17.1%	9.2%	40.8%	21.6%	17.5%
Mean Metals SQS quotient										
Mean	0.083	0.150	0.042	0.122	0.134	0.437	0.181	0.098	0.055	0.200
Std. Dev.	0.017	0.022	0.007	0.055	0.022	0.133	0.025	0.020	0.006	0.025
Median	0.082	0.139	0.040	0.106	0.132	0.433	0.182	0.098	0.057	0.200
Minimum	0.063	0.128	0.036	0.086	0.103	0.238	0.124	0.075	0.043	0.163
Maximum	0.112	0.187	0.052	0.262	0.168	0.715	0.207	0.136	0.064	0.245
N	8	8	4	9	9	9	9	9	9	8
C.V.	20.0%	14.8%	16.6%	44.9%	16.7%	30.4%	13.8%	20.1%	10.5%	12.5%
Total PAH (µg/kg)										
Mean	166.2	188.4	45.6	421.8	454.1	1069.3	539.1	7727.1	77.5	391.2
Std. Dev.	136.1	87.3	29.9	174.4	362.1	717.9	129.7	3292.0	32.9	155.5
Median	114.0	164.6	44.7	346.0	332.0	959.0	563.0	7038.0	70.5	444.0
Minimum	30.0	94.0	17.0	217.8	168.0	157.7	319.8	4495.0	48.0	83.0
Maximum	402.9	311.0	76.0	789.7	1223.0	2792.5	680.1	14319.0	144.3	558.0
N	7	7	4	9	7	9	9	9	7	7
C.V.	81.9%	46.4%	65.6%	41.3%	79.8%	67.1%	24.1%	42.6%	42.5%	39.8%

Table 7a. Indications of change from 1989-1996 to 2000 in sediment parameters from two-sided sign test.
↑, ↓ = significant at α = 0.05; ↑↑, ↓↓ = significant at α = 0.01; -- = no change.

Station	Strait of Georgia (3)	Bellingham Bay (4)	North Hood Canal (13R)	Port Gardner (21)	Shilshole (29)	Sinclair Inlet (34)	Point Pully (38)	Thea Foss Waterway (40)	East Anderson Island (44)	Inner Budd Inlet (49)
% TOC	↑	--	--	↓	↑	↑	--	↓	--	--
Metals SQS quotient	--	--	--	↓↓	↓	--	--	--	↓	--
Total PAH	--	↑	--	--	--	--	--	--	↑↑	↑

Table 7b. Indications of increasing or decreasing trend in sediment parameters from Mann-Kendall test of monotone trend.
↑, ↓ = significant at α = 0.05; ↑↑, ↓↓ = significant at α = 0.01; -- = no change.

Station	Strait of Georgia (3)	Bellingham Bay (4)	North Hood Canal (13R)	Port Gardner (21)	Shilshole (29)	Sinclair Inlet (34)	Point Pully (38)	Thea Foss Waterway (40)	East Anderson Island (44)	Inner Budd Inlet (49)
% Fines	↑*	--	--	--*	--	--	--	--	--	--*
% TOC	--	--	--	↓↓	--	--	--	--	--	--
Salinity of overlying water	--	--	--	--	--	--	--	--	--	--
Metals SQS quotient	--	--	--	--	--	--	↓*	--	--	--
Total PAH	↑	--	--	--	--	--	--	--	--	--

* = Apparent trend or strength of trend in time-series plots may differ from calculated test results.

Table 8. Percent detections by chemical group for 1989-1996 and 2000. Number of analyses = number of target compounds (detected and undetected) for which analysis was conducted multiplied by the number of samples collected in the field.

	1989-1996 (* = 1989-1993)		2000	
Chemical Group	Number of Analyses	% Detections	Number of Analyses	% Detections
Metals				
Priority Pollutant Metals	1293	80.7%	110	80.9%
Ancillary Metals*	710	100.0%	30	100.0%
Organics				
Volatile Organics				
Halogenated Alkanes (Alkyl Halides)*	708	4.2%	Not Analyzed	
Halogenated Alkenes (Alkenyl Halides)*	330	4.8%	Not Analyzed	
Aromatic and Chlorinated Aromatic Compounds*	252	23.4%	Not Analyzed	
Ketones*	167	35.9%	Not Analyzed	
Ethers*	42	0.0%	Not Analyzed	
Esters*	42	0.0%	Not Analyzed	
Organosulfur Compounds*	42	90.5%	Not Analyzed	
Semivolatile Organics				
Acid Extractables				
Phenols*	307	17.6%	40	40.0%
Chlorinated and Nitro-Substituted Phenols*	769	0.0%	98	0.0%
Resin Acids*	124	31.5%	Not Analyzed	
Guaiacols*	63	0.0%	Not Analyzed	
Base Neutrals				
Low-Molecular Weight Polycyclic	838	58.8%	90	92.2%
High-Molecular Weight Polycyclic	965	84.6%	100	93.0%
Chlorinated Aromatic Compounds*	489	0.6%	60	1.7%
Chlorinated Alkanes*	77	0.0%	10	0.0%
Chlorinated Alkenes*	108	0.9%	10	0.0%
Phthalate Esters*	462	19.5%	60	8.3%
Miscellaneous Extractable Compounds*	596	45.5%	119	52.1%
Organonitrogen Compounds*	721	3.1%	140	3.6%
Ethers*	310	0.6%	50	0.0%
PCBs and Pesticides				
Chlorinated Pesticides	1782	0.4%	240	2.1%
Polycyclic Chlorinated Biphenyls	485	6.8%	70	14.3%
Overall Total	**11682**	**32.4%**	**1227**	**32.5%**

Table 9. Summary statistics of detected contaminant concentrations from sediment chemistry analyses, 1989-1996 and 2000.

	1989-1996							2000						
Compound	Mean	Std. Dev.	Median	Minimum	Maximum	N	Nondetects	Mean	Std. Dev.	Median	Minimum	Maximum	N	Nondetects
Metals (mg/kg)														
Priority Pollutant Metals														
Antimony (Sb)	0.70	0.75	0.40	0.13	3.30	16	28	0.20	0.01	0.20	0.20	0.20	3	7
Arsenic (As)	11.90	20.27	8.00	2.90	171.00	67	5	6.60	2.59	6.80	2.50	10.20	10	0
Beryllium (Be)	0.30	0.13	0.30	0.11	0.60	28	29						0	0
Cadmium (Cd)	0.50	0.51	0.30	0.05	2.10	59	16	1.00	0.04	1.00	0.90	1.00	2	8
Chromium (Cr)	33.90	14.57	36.60	10.25	60.70	72	0	33.80	13.45	34.00	13.00	52.50	10	0
Copper (Cu)	43.10	29.26	36.90	5.70	131.00	72	0	33.30	26.19	29.60	4.30	99.30	10	0
Lead (Pb)	24.10	20.62	17.90	2.70	94.40	72	0	20.30	18.10	16.50	3.60	66.70	10	0
Mercury (Hg)	0.20	0.21	0.10	0.01	0.90	62	11	0.10	0.18	0.10	0.00	0.60	10	0
Nickel (Ni)	32.30	15.04	33.60	7.90	71.30	56	0	28.40	12.46	28.80	9.20	51.30	10	0
Selenium (Se)	0.70	0.19	0.70	0.43	1.00	7	12	0.80	0.12	0.80	0.60	1.00	6	4
Silver (Ag)	0.50	0.42	0.40	0.06	1.90	60	13	0.40	0.33	0.30	0.10	1.10	8	2
Thallium (Tl)	0.20	0.11	0.20	0.09	0.40	6	33						0	0
Zinc (Zn)	77.00	35.62	78.30	24.50	177.00	72	0	69.10	32.31	70.70	27.70	129.00	10	0
Ancillary Metals														
Aluminum (Al)	16340.70	5914.29	17800.00	6300.00	25600.00	47	0	14908.00	5567.85	16850.00	6340.00	20600.00	10	0
Barium (Ba)	39.40	17.48	42.10	11.20	90.50	47	0						0	0
Calcium (Ca)	7341.00	5839.31	6225.00	2840.00	31400.00	47	0						0	0
Cobalt (Co)	8.90	2.97	8.90	3.60	14.00	47	0						0	0
Iron (Fe)	23584.70	8134.36	26600.00	9420.00	37100.00	47	0	21740.00	7056.63	24200.00	11200.00	30200.00	10	0
Magnesium (Mg)	9403.90	3718.25	10300.00	2950.00	16200.00	47	0						0	0
Manganese (Mn)	344.10	191.77	302.00	30.00	837.00	47	0	296.10	133.77	269.00	109.00	598.00	10	0
Potassium (K)	2758.60	1240.20	3210.00	744.00	4480.00	29	0						0	0
Sodium (Na)	16688.40	9541.09	20200.00	3050.00	32300.00	29	0						0	0
Vanadium (V)	46.30	14.02	49.70	20.60	69.10	47	0						0	0

	1989-1996							2000						
Compound	Mean	Std. Dev.	Median	Minimum	Maximum	N	Nondetects	Mean	Std. Dev.	Median	Minimum	Maximum	N	Nondetects
Organics (mg/kg)														
Volatile Organics														
Halogenated Alkanes (Alkyl Halides)														
Bromodichloromethane						0	18						0	0
Bromoform	0.00		0.00	0.02	0.00	1	17						0	0
Bromomethane	0.90		0.90	0.86	0.90	1	18						0	0
Carbon tetrachloride						0	18						0	0
Chlorodibromomethane						0	18						0	0
Chloroethane (ethyl chloride)						0	18						0	0
Chloroform	0.20	0.10	0.10	0.08	0.30	5	16						0	0
Chloromethane						0	18						0	0
Dichloromethane (methylene chloride)	26.20	42.13	8.50	1.75	130.00	9	11						0	0
1,1-Dichloroethane	0.80	0.41	0.80	0.52	1.10	2	16						0	0
1,2-Dichloroethane						0	18						0	0
1,2-Dichloropropane						0	18						0	0
1,1,2,2-Tetrachloroethane						0	18						0	0
1,1,1-Trichloroethane (methyl chloroform)	2.40	3.62	0.50	0.18	6.60	3	16						0	0
1,1,2-Trichloroethane						0	18						0	0
Trichlorofluoromethane	0.40		0.40	0.43	0.40	1	15						0	0
1,1,2-Trichloro-1,2,2-trifluoroethane	0.80		0.80	0.81	0.80	1	17						0	0
Halogenated Alkenes (Alkenyl Halides)														
1,1-Dichloroethene (1,1-dichloroethylene)						0	18						0	0
cis-1,2-Dichloroethene	0.10		0.10	0.05	0.10	1	15						0	0
trans-1,2-Dichloroethene						0	18						0	0
cis-1,3-Dichloropropene						0	18						0	0
trans-1,3-Dichloropropene						0	18						0	0
Monochloroethylene (vinyl chloride)						0	18						0	0
Tetrachloroethene	0.10	0.02	0.10	0.06	0.10	7	13						0	0
Trichloroethene						0	18						0	0

Compound	1989-1996 Mean	Std. Dev.	Median	Minimum	Maximum	N	Nondetects	2000 Mean	Std. Dev.	Median	Minimum	Maximum	N	Nondetects
Aromatic and Chlorinated Aromatic Compounds														
Benzene	0.20	0.05	0.10	0.08	0.20	9	11						0	0
Chlorobenzene	0.10		0.10	0.05	0.10	1	17						0	0
Ethylbenzene	0.20	0.27	0.10	0.05	0.70	6	14						0	0
Styrene (vinylbenzene)	0.10	0.02	0.10	0.11	0.10	2	16						0	0
Toluene	0.20	0.05	0.20	0.14	0.20	3	15						0	0
Total xylenes	0.80	1.31	0.40	0.22	5.10	13	10						0	0
Ketones														
Acetone	21.30	13.74	17.00	9.10	53.00	11	8						0	0
2-Butanone (methyl ethyl ketone)	7.20	2.99	6.40	3.70	13.00	14	6						0	0
2-Hexanone	4.40		4.40	4.40	4.40	1	18						0	0
4-Methyl-2-pentanone	3.30	2.99	3.90	0.10	6.30	5	13						0	0
Ethers														
2-Chloroethyl vinyl ether						0	18						0	0
Esters														
Vinyl acetate						0	18						0	0
Organosulfur Compounds														
Carbon disulfide	1.90	1.27	1.60	0.12	5.30	17	3						0	0
Semivolatile Organics														
Acid Extractables														
Phenols														
2,4-Dimethylphenol	5.60		5.60	5.63	5.60	1	46	11.00		11.00	11.00	11.00	1	9
2-Methylphenol (o-Cresol)						0	47	4.60	1.27	4.60	3.70	5.50	2	8
4-Methylphenol (p-Cresol)	16.90	13.63	14.10	4.60	56.00	11	37	43.70	75.39	23.50	3.60	255.00	10	0
Phenol	18.40	17.71	14.00	5.00	97.10	27	23	40.00	8.89	37.00	33.00	50.00	3	7

Compound	1989-1996 Mean	Std. Dev.	Median	Minimum	Maximum	N	Nondetects	2000 Mean	Std. Dev.	Median	Minimum	Maximum	N	Nondetects
Chlorinated and Nitro-Substituted Phenols														
4-Chloro-3-methylphenol						0	47						0	10
2-Chlorophenol						0	46						0	10
2,4-Dichlorophenol						0	47						0	10
4,6-Dinitro-2-methylphenol						0	47						0	10
2,4-Dinitrophenol						0	47						0	8
2-Nitrophenol						0	47						0	10
4-Nitrophenol						0	47						0	10
Pentachlorophenol						0	47						0	10
2,4,5-Trichlorophenol						0	47						0	10
2,4,6-Trichlorophenol						0	47						0	10
Resin Acids														
Abietic acid	115.10	87.42	116.30	28.00	200.00	4	3						0	0
Chlorodehydroabietic acid	155.00	77.78	155.00	100.00	210.00	2	1						0	0
1,2-Chloro-dehydroabietic acid	48.50		48.50	48.50	48.50	1	2						0	0
1,4-Chloro-dehydroabietic acid	16.50		16.50	16.50	16.50	1	2						0	0
Dehydroabietic acid	230.20	185.85	172.50	61.50	520.00	6	0						0	0
Dichlorodehydro-abietic acid	87.30	88.74	87.30	24.50	150.00	2	4						0	0
Isopimaric acid	91.70	55.74	110.00	30.50	160.00	5	4						0	0
Neoabietic acid						0	6						0	0
Palustric acid						0	5						0	0
Pimaric acid						0	6						0	0
Sanadarocopimaric acid						0	6						0	0
Guaiacols														
2-Methoxyphenol (Guaiacol)						0	6						0	0
Tetrachloroguaiacol						0	6						0	0
3,4,5-Trichloroguaiacol						0	4						0	0
4,5,6-Trichloroguaiacol						0	6						0	0
4,5-Dichloroguaiacol						0	6						0	0

	1989-1996							2000						
Compound	Mean	Std. Dev.	Median	Minimum	Maximum	N	Nondetects	Mean	Std. Dev.	Median	Minimum	Maximum	N	Nondetects
Base Neutrals														
Low Molecular Weight Polycyclic Aromatic Hydrocarbons (LPAHs)														
1-Methylnaphthalene						0	0	20.40	22.50	14.50	2.50	80.00	10	0
2-Methylnaphthalene	18.70	19.72	10.40	3.00	94.80	34	20	28.90	27.66	22.50	3.60	100.00	10	0
2-Methylnaphthalene (TOC-normalized)	1.50	2.01	0.70	0.18	8.90	34	20	2.40	3.50	1.20	0.60	12.20	10	0
Acenaphthene	32.90	48.29	10.10	0.92	230.00	27	41	22.60	25.64	11.00	7.50	61.00	4	6
Acenaphthene (TOC-normalized)	2.90	4.62	0.80	0.15	20.90	27	41	2.30	3.44	0.80	0.30	7.40	4	6
Acenaphthylene	50.70	88.38	9.00	2.50	330.00	26	37	26.40	54.09	8.70	2.50	170.00	9	1
Acenaphthylene (TOC-normalized)	4.90	10.50	0.40	0.18	47.10	26	37	2.80	6.73	0.60	0.30	20.70	9	1
Anthracene	139.90	330.57	20.00	1.70	1800.00	50	19	69.80	175.08	15.00	1.20	567.00	10	0
Anthracene (TOC-normalized)	13.00	34.60	1.00	0.23	163.60	50	19	7.70	21.60	0.80	0.30	69.20	10	0
Fluorene	48.80	90.40	11.00	3.00	450.00	39	30	24.80	38.68	15.50	3.20	134.00	10	0
Fluorene (TOC-normalized)	4.40	9.33	0.60	0.18	40.90	39	30	2.40	4.91	0.90	0.50	16.30	10	0
Naphthalene	35.70	54.79	10.80	2.00	266.00	42	22	47.80	68.59	23.00	6.00	237.00	10	0
Naphthalene (TOC-normalized)	2.90	5.20	0.80	0.21	24.90	42	22	4.60	8.67	1.40	0.80	28.90	10	0
Phenanthrene	208.50	511.10	53.80	6.30	3400.00	64	1	135.60	277.76	59.00	11.00	924.00	10	0
Phenanthrene (TOC-normalized)	18.10	50.49	3.10	0.47	309.10	64	1	14.10	34.65	3.10	2.00	112.70	10	0
Retene	86.90	73.47	72.80	4.00	306.00	46	7	95.50	94.28	72.00	8.10	344.00	10	0
Total LPAH*	407.78	997.72	90.50	0.00	6259.00	65		339.85	653.96	146.70	28.10	2193.00	10	
Total LPAH** (TOC-normalized)	35.80	100.89	4.90	0.47	569.00	64		32.30	78.44	6.50	4.30	255.20	10	

* 2-Methylnaphthalene, Acenaphthene, Acenaphthylene, Anthracene, Fluorene, Naphthalene, Phenanthrene
** Acenaphthene, Acenaphthylene, Anthracene, Fluorene, Naphthalene, Phenanthrene
TOC-normalized compound concentrations are in units of ppm organic carbon.

Compound	1989-1996 Mean	Std. Dev.	Median	Minimum	Maximum	N	Nondetects	2000 Mean	Std. Dev.	Median	Minimum	Maximum	N	Nondetects
High Molecular Weight Polycyclic Aromatic Hydrocarbons (HPAHs)														
Benzo(a)anthracene	138.40	282.78	29.80	3.00	1300.00	58	7	104.20	206.30	34.00	12.90	649.00	9	1
Benzo(a)anthracene (TOC-normalized)	12.00	31.29	1.80	0.27	185.70	58	7	10.60	25.74	2.00	0.80	79.20	9	1
Benzo(a)pyrene	142.60	275.10	32.50	3.00	1400.00	56	10	100.30	183.52	38.00	9.00	610.00	10	0
Benzo(a)pyrene (TOC-normalized)	11.90	31.19	1.90	0.23	200.00	56	10	9.80	22.74	2.40	1.30	74.40	10	0
Total Benzofluoranthenes	223.40	403.94	63.40	8.00	1900.00	54	5	180.90	260.19	91.50	20.60	876.00	10	0
Total Benzofluoranthenes (TOC-normalized)	18.20	44.88	4.00	0.67	271.40	54	5	16.20	31.96	5.60	3.30	106.80	10	0
Benzo(g,h,i)perylene	90.00	140.32	28.50	4.70	670.00	34	18	65.60	83.22	39.00	7.20	281.00	10	0
Benzo(g,h,i)perylene (TOC-normalized)	7.20	17.00	1.90	0.48	95.70	34	18	5.60	10.13	2.30	1.40	34.30	10	0
Chrysene	161.40	314.51	46.50	4.00	1500.00	61	4	102.10	209.95	33.00	4.30	693.00	10	0
Chrysene (TOC-normalized)	13.70	35.14	2.70	0.47	214.30	61	4	10.40	26.06	2.00	0.90	84.50	10	0
Dibenzo(a,h) anthracene	52.70	69.90	21.00	3.40	340.00	32	37	41.50	23.01	37.00	19.00	73.00	4	6
Dibenzo(a,h) anthracene (TOC-normalized)	4.40	9.13	0.90	0.28	48.60	32	37	3.30	3.81	1.70	0.80	8.90	4	6
Fluoranthene	231.10	407.68	79.80	5.00	1700.00	65	0	176.50	331.36	79.50	11.00	1110.00	10	0
Fluoranthene (TOC-normalized)	18.70	42.29	4.50	0.67	242.90	65	0	17.60	41.43	4.00	2.30	135.40	10	0
Indeno(1,2,3-c,d) pyrene	108.50	175.93	38.50	3.60	830.00	40	22	65.80	89.79	36.50	8.20	302.00	10	0
Indeno(1,2,3-c,d) pyrene (TOC-normalized)	8.90	20.66	1.90	0.47	118.60	40	22	5.80	10.96	2.20	1.30	36.80	10	0
Perylene	56.60	66.79	39.00	8.00	360.00	33	5	80.00	38.03	83.50	15.00	142.00	10	0
Pyrene	262.30	510.28	73.00	4.00	2400.00	65	0	253.80	517.26	86.00	14.00	1710.00	10	0
Pyrene (TOC-normalized)	21.30	51.63	4.10	0.50	271.40	65	0	25.70	64.28	5.20	2.20	208.50	10	0
Total HPAH*	916.72	1782.78	259.00	9.00	8140.00	65		743.03	1459.61	278.00	38.30	4845.00	10	
Total HPAH** (TOC-normalized)	100.20	259.08	20.60	1.33	1648.60	65		101.80	234.63	26.40	14.30	768.80	10	
Total PAH***	1324.78	2742.33	346.00	17.00	14319.00	65		1082.88	2110.15	436.05	66.40	7038.00	10	

* Benz(a)anthracene, Benzo(a)pyrene, Chrysene, Dibenz(a,h)anthracene, Fluoranthene, Pyrene
** Benz(a)anthracene, Benzo(a)pyrene, Total Benzofluoranthenes, Benzo(g,h,i)perylene, Chrysene, Dibenz(a,h)anthracene, Fluoranthene, Indeno(1,2,3-c,d)pyrene, Pyrene
*** Total LPAH + Total HPAH
TOC-normalized compound concentrations are in units of ppm organic carbon.

Compound	1989-1996 Mean	Std. Dev.	Median	Minimum	Maximum	N	Nondetects	2000 Mean	Std. Dev.	Median	Minimum	Maximum	N	Nondetects
Chlorinated Aromatic Compounds														
1,3-Dichlorobenzene						0	47						0	10
1,3-Dichlorobenzene (TOC-normalized)						0	47						0	10
1,4-Dichlorobenzene						0	47	2.80		2.80	2.80	2.80	1	9
1,4-Dichlorobenzene (TOC-normalized)						0	47	0.30		0.30	0.30	0.30	1	9
1,2-Dichlorobenzene	4.00		4.00	4.00	4.00	1	47						0	10
1,2-Dichlorobenzene (TOC-normalized)	0.90		0.90	0.93	0.90	1	47						0	10
1,2,4-Trichlorobenzene						0	47						0	10
1,2,4-Trichlorobenzene (TOC-normalized)						0	47						0	10
2-Chloronaphthalene	4.00		4.00	4.00	4.00	1	65						0	10
Hexachlorobenzene	5.00		5.00	5.00	5.00	1	47						0	10
Hexachlorobenzene (TOC-normalized)	1.20		1.20	1.16	1.20	1	47						0	10
Chlorinated Alkanes														
Hexachloroethane						0	47						0	10
Chlorinated Alkenes														
Hexachlorobutadiene	3.00		3.00	3.00	3.00	1	47						0	10
Hexachlorobutadiene (TOC-normalized)	0.70		0.70	0.70	0.70	1	47						0	10
Hexachloro-cyclopentadiene						0	19						0	0

TOC-normalized compound concentrations are in units of ppm organic carbon.

Compound	1989-1996 Mean	Std. Dev.	Median	Minimum	Maximum	N	Nondetects	2000 Mean	Std. Dev.	Median	Minimum	Maximum	N	Nondetects
Phthalate Esters														
Bis(2-ethylhexyl) phthalate	114.60	161.08	50.60	7.00	740.00	36	13						0	10
Bis(2-ethylhexyl) phthalate (TOC-normalized)	8.00	13.46	2.80	0.54	67.10	36	13						0	10
Butylbenzylphthalate	26.90	10.73	29.50	8.50	39.00	10	37	34.00		34.00	34.00	34.00	1	9
Butylbenzylphthalate (TOC-normalized)	1.70	1.67	1.20	0.40	5.60	10	37	1.20		1.20	1.20	1.20	1	9
Di-n-butylphthalate	20.60	7.88	22.80	10.36	30.00	7	41	43.00		43.00	43.00	43.00	1	9
Di-n-butylphthalate (TOC-normalized)	1.10	0.33	1.20	0.54	1.40	7	41	1.50		1.50	1.50	1.50	1	9
Di-n-octylphthalate	10.20	2.23	10.20	8.65	11.80	2	45	14.00		14.00	14.00	14.00	1	9
Di-n-octylphthalate (TOC-normalized)	0.40	0.02	0.40	0.34	0.40	2	45	1.40		1.40	1.40	1.40	1	9
Diethylphthalate	8.10	2.57	6.80	6.00	12.20	5	42						0	10
Diethylphthalate (TOC-normalized)	0.40	0.13	0.40	0.21	0.50	5	42						0	10
Dimethylphthalate	6.00		6.00	6.00	6.00	1	46	1.20	0.71	1.20	0.70	1.70	2	8
Dimethylphthalate (TOC-normalized)	0.70		0.70	0.67	0.70	1	46	0.10	0.11	0.10	0.00	0.20	2	8
Miscellaneous Extractable Compounds														
Benzoic acid	42.40	23.34	47.70	1.12	83.60	19	25	437.60	144.28	445.50	207.00	658.00	10	0
Benzyl alcohol						0	47						0	10
beta-Coprostanol	268.10	189.57	240.00	30.50	1000.00	35	13	170.60	90.03	137.00	39.00	306.00	9	1
beta-Sitosterol	1307.60	846.79	1395.00	90.00	3500.00	36	2	1575.40	671.65	1670.00	430.00	2560.00	10	0
Cholesterol	1701.70	1199.80	1600.00	230.00	6600.00	44	0	3662.50	4027.65	2580.00	750.00	14400.00	10	0
Cymene (p-Isopropyltoluene)	19.50	20.93	10.20	4.00	78.80	12	27	25.20	13.99	19.00	14.00	48.00	5	5
Dibenzofuran	18.10	16.13	10.70	2.20	59.40	32	36	13.80	13.78	12.00	1.60	48.00	9	1
Dibenzofuran (TOC-normalized)	1.50	1.61	0.60	0.17	5.50	32	36	1.20	1.78	0.50	0.30	5.80	9	1
Isophorone						0	47						0	10
gamma-Sitosterol						0	0	278.20	512.15	121.00	34.00	1640.00	9	0
1,2-Diphenylhydrazine						0	0						0	10
Benzidine						0	0						0	10
Pyridine						0	0						0	10

TOC-normalized compound concentrations are in units of ppm organic carbon.

Compound	1989-1996 Mean	Std. Dev.	Median	Minimum	Maximum	N	Nondetects	2000 Mean	Std. Dev.	Median	Minimum	Maximum	N	Nondetects
Organonitrogen Compounds														
Caffeine	9.30		9.30	9.31	9.30	1	37						0	10
9(H)-Carbazole	19.30	28.48	7.20	2.20	110.00	15	47	16.20	12.58	9.80	5.80	37.00	5	5
4-Chloroaniline						0	20						0	10
3,3-Dichlorobenzidine						0	12						0	10
2,4-Dinitrotoluene						0	38						0	10
2,6-Dinitrotoluene						0	38						0	10
Diphenylnitrosamine (n-nitrosodiphenylamine)						0	47						0	10
n-Nitrosodiphenylamine (TOC-normalized)						0	47						0	10
2-Nitroaniline						0	38						0	10
3-Nitroaniline						0	38						0	10
4-Nitroaniline						0	38						0	10
Nitrobenzene						0	38						0	10
n-Nitroso-di-n-propylamine						0	38						0	10
Aniline						0	0						0	10
n-Nitrosodimethylamine						0	0						0	10
Ethers														
Bis-(2-chloroethoxy) methane						0	38						0	10
Bis-(2-chloroisopropyl) ether						0	38						0	10
4-Bromophenyl-phenyl ether	4.00		4.00	4.00	4.00	1	38						0	10
4-Chlorophenyl-phenyl ether	5.00		5.00	5.00	5.00	1	38						0	10
Dichloroethyl ether [bis-(2-chloroethyl)ether]						0	38						0	10

TOC-normalized compound concentrations are in units of ppm organic carbon.

	1989-1996							2000						
Compound	Mean	Std. Dev.	Median	Minimum	Maximum	N	Nondetects	Mean	Std. Dev.	Median	Minimum	Maximum	N	Nondetects
PCBs and Pesticides														
Chlorinated Pesticides														
Aldrin						0	55						0	10
alpha-Chlordane (cis-Chlordane)						0	55						0	10
alpha-Endosulfan (Endosulfan I)						0	50						0	10
alpha-HCH (alpha-BHC)						0	55						0	10
beta-Endosulfan (Endosulfan II)						0	50						0	10
beta-HCH (beta-BHC)	0.50		0.50	0.54	0.50	1	54						0	10
delta-HCH (delta-BHC)						0	55						0	10
Dieldrin						0	55						0	10
Endosulfan sulfate						0	55						0	10
Endrin	0.80		0.80	0.76	0.80	1	54						0	10
Endrin aldehyde	4.60	1.84	4.60	3.30	5.90	2	21						0	10
Endrin ketone						0	50						0	10
gamma-Chlordane						0	55						0	0
gamma-HCH (Lindane)						0	55						0	10
Heptachlor						0	55						0	10
Heptachlor epoxide						0	55						0	10
Methoxychlor						0	55						0	10
2,4'-DDD						0	0						0	10
4,4'-DDD	1.60		1.60	1.60	1.60	1	54	0.90	0.71	0.90	0.40	1.40	2	8
2,4'-DDE						0	0						0	10
4,4'-DDE	1.20		1.20	1.20	1.20	1	54	0.60	0.06	0.60	0.50	0.60	3	7
2,4'-DDT						0	0						0	10
4,4'-DDT	1.20		1.20	1.20	1.20	1	54						0	10
Toxaphene						0	55						0	10
trans-Chlordane (gamma)						0	0						0	10
Polycyclic Chlorinated Biphenyls (PCBs)														
Aroclor 1016						0	13						0	10
Aroclor 1221						0	36						0	10
Aroclor 1232						0	36						0	10
Aroclor 1242						0	16						0	10
Aroclor 1248						0	55	5.70		5.70	5.70	5.70	1	9
Aroclor 1254	24.50	18.95	21.50	4.20	79.00	20	37	16.00	13.30	11.00	5.20	39.00	5	5
Aroclor 1260	42.00	72.46	17.50	4.70	220.00	8	47	16.80	20.82	7.00	5.30	48.00	4	6
Aroclor 1016/1242						0	39						0	0
Total detected PCBs	37.50	60.63	22.00	4.20	299.00	22	33						0	0

Table 10. Stations and detected chemical contaminants which exceeded sediment quality values, by year. Blanks indicate concentrations below the sediment quality values. No sediment quality values were exceeded at Strait of Georgia (Station 3), Bellingham Bay (Station 4), North Hood Canal (Station 13R), Shilshole (Station 29), or Point Pully (Station 38); hence, those stations are not listed below.

	Year																										
Station (Station Number)	1989			1990			1991			1992			1993			1994			1995			1996			2000		
Contaminant	ERM	SQS	CSL	ERM	SQS	CSL	ERM	SQS	CSL	ERM	SQS	CSL	ERM	SQS	CSL	ERM	SQS	CSL	ERM	SQS	CSL	ERM	SQS	CSL	ERM	SQS	CSL
Port Gardner (21)																											
Mercury*								X																			
Sinclair Inlet (34)																											
Arsenic*																			X	X	X						
Mercury*	X	X	X	X	X	X		X	X		X	X				X	X	X		X	X					X	X
Total detected PCBs																			X								
Thea Foss Waterway (40)																											
Acenaphthene					X																						
Anthracene	X			X																							
Fluorene		X			X																						
Phenanthrene	X	X		X	X												X									X	
Total LPAH	X	X		X	X																						
Benzo(a)anthracene		X			X																						
Benzo(a)pyrene		X																									
Total Benzofluoranthenes		X																								X	
Benzo(g,h,i)perylene		X	X																	X						X	
Chrysene		X			X																						
Dibenzo(a,h)anthracene	X	X	X		X			X																			
Fluoranthene		X																									
Indeno(1,2,3-c,d)pyrene		X	X		X																					X	
Total HPAH		X																									
Bis(2-ethylhexyl) phthalate		X																									
Butyl benzyl phthalate		X																									
East Anderson Island (44)																											
Hexachlorobenzene		X																									
Inner Budd Inlet (49)																							Not Sampled				
Benzoic Acid																										X	X

* ERM values for metals are based on use of a hydrofluoric acid digestion preparation method (Long *et al.* , 1995). Nitric acid digestion method was used in this study.

Table 11. Comparison of 1989-1996 *vs.* 2000 concentrations of metals, PAHs, and other organic compounds at individual PSAMP Sediment Component Long Term monitoring stations.

↑ = increase (α=0.05), ↓ = decrease (α=0.05), -- = no change, blank = insufficient data. Shaded results indicate changes for all stations combined for a single compound or for all compounds combined for a single station, at individual significance level α=0.05 (dark) or α=0.10 (light).

Contaminant	Station													
	Strait of Georgia (3)	Bellingham Bay (4)	North Hood Canal (13R)	Port Gardner (21)	Shilshole (29)	Sinclair Inlet (34)	Point Pully (38)	Thea Foss W'way (40)	E. Anderson Island (44)	Inner Budd Inlet (49)	# Incr	# Decr	N	Sign test P-value
Metals														
Priority Pollutant Metals														
Antimony						--	--		--		0	0	3	1.000
Arsenic	--	--	--	--	↓	↓	--	↓	↓	--	0	4	10	0.125
Cadmium						--				↓	0	1	2	1.000
Chromium	--	--	--	--	↑	--	--	↑	↑	↓	3	1	10	0.625
Copper	--	↓	--	↓	↓	--	↓	--	↓	↓	0	6	10	0.031
Lead	--	--	--	--	--	--	--	↓	--	↓	0	2	10	0.500
Mercury	--	↓		--	--	--	--	↓	--	↓	0	3	9	0.250
Nickel	--	--	--	↓	--	↓	--	--	--	↓	0	3	10	0.250
Silver	--	--	--	↓	--	--	↓	--		--	0	2	9	0.500
Zinc	--	↓	--	↓	--	--	--	↓	--	↓	0	4	10	0.125
Ancillary Metals														
Aluminum	--	--	--	↓	--	--	--	↓	--	↓	0	3	10	0.250
Iron	--	↓	--	↓	--	--	↓	--	↑	↓	1	4	10	0.375
Manganese	--	--	--	--	--	↓	↓	--	--	--	0	2	10	0.500
Mean Metals SQS Quotient	--	--	--	↓	↓	--	--	--	↓	--	0	3	10	0.250
Individual Metals														
# Increases	0	0	0	0	1	0	0	1	2	0				
# Decreases	0	4	0	6	2	3	4	5	2	9				
N	11	11	10	11	11	13	12	11	11	12				
Sign test P-value	1.000	0.125	1.000	0.031	1.000	0.250	0.125	0.219	1.000	0.004				

PAH Compounds Individual LPAH Compounds	Station 3	4	13R	21	29	34	38	40	44	49	# Incr	# Decr	N	Sign test P-value
2-Methylnaphthalene	↑	↑		--	--	--	--	↑			3	0	7	0.250
Acenaphthene				--		--		--			0	0	3	1.000
Acenaphthylene				--		↑	--	--			1	0	4	1.000
Anthracene	--	--		--	--	--	↓	--	--	--	0	1	9	1.000
Fluorene	--	--		--	--	--	--	--		--	0	0	8	1.000
Naphthalene	--	↑		--	--	--	--	↑	--	--	2	0	9	0.500
Phenanthrene	--	--	--	--	--	--	↓	--	↑	--	1	1	10	1.000
Retene	--	--		--	--	--	--	↑	--	--	1	0	9	1.000
Total LPAH	↑	↑	--	--	--	--	--	--	↑	↑	4	0	10	0.125
Individual HPAH Compounds														
Benzo(a)anthracene	--	↑		--	--	--	--	--	↑	--	2	0	9	0.500
Benzo(a)pyrene	--	--		--	--	--	--	--	↑	↑	2	0	9	0.500
Total Benzofluoranthenes	↑	↑	--	--	↑	--	--	--	↑	↑	5	0	10	0.063
Benzo(g,h,i)perylene	--			--	--	--	--	--	--	--	0	0	8	1.000
Chrysene	--	--		--	--	--	↓	--	↑	--	1	1	9	1.000
Dibenzo(a,h)anthracene					--	--	--	--			0	0	4	1.000
Fluoranthene	--	--	--	--	--	--	↓	--	↑	--	1	1	10	1.000
Indeno(1,2,3-c,d)pyrene	--	--		↑	--	--	--	--	--	--	1	0	9	1.000
Perylene	↑	↑		--	↑	--	--	--	--	--	3	0	9	0.250
Pyrene	--	↑	--	--	--	--	↓	--	↑	↑	3	1	10	0.625
Total HPAH	--	↑	--	--	--	--	--	--	↑	--	2	0	10	0.500
Total PAH	--	↑	--	--	--	--	--	--	↑	↑	3	0	10	0.250
Individual PAH Compounds														
# Increases	3	6	0	1	2	1	0	3	7	3				
# Decreases	0	0	0	0	0	0	5	0	0	0				
N	15	14	4	17	16	18	17	18	13	14				
Sign test P-value	0.250	0.031	1.000	1.000	0.500	1.000	0.063	0.250	0.016	0.250				

TOC-normalized PAHs	Station										#	#		Sign test
Individual LPAH Compounds	**3**	**4**	**13R**	**21**	**29**	**34**	**38**	**40**	**44**	**49**	**Incr**	**Decr**	**N**	**P-value**
2-Methylnaphthalene	↑	↑		--	--	--	--	↑			3	0	7	0.250
Acenaphthene				--		--		--			0	0	3	1.000
Acenaphthylene				--		↑	--	--			1	0	4	1.000
Anthracene	--	--		--	--	--	↓	--	--	--	0	1	9	1.000
Fluorene	--	--		↑	--	--	--	--		--	1	0	8	1.000
Naphthalene	--	↑		--	--	--	--	↑	--	--	2	0	9	0.500
Phenanthrene	--	--	--	--	--	--	↓	--	↑	--	1	1	10	1.000
Total LPAH (TOC-normalized)	--	--	--	--	--	--	--	--	↑	↑	2	0	10	0.500
Individual HPAH Compounds														
Benzo(a)anthracene	--	↑		↑	--	--	↓	--	↑	--	3	1	9	0.625
Benzo(a)pyrene	--	--		--	--	--	--	--	↑	--	1	0	9	1.000
Total Benzofluoranthenes	--	↑	--	↑	↑	--	--	--	↑	↑	5	0	10	0.063
Benzo(g,h,i)perylene	--			--	--	--	--	--	--	--	0	0	8	1.000
Chrysene	--	--		--	--	--	↓	--	↑	--	1	1	9	1.000
Dibenzo(a,h)anthracene					--	--	--	--			0	0	4	1.000
Fluoranthene	--	--	--	--	--	--	↓	--	↑	--	1	1	10	1.000
Indeno(1,2,3-c,d)pyrene	--	--		↑	--	--	--	--	↑	--	2	0	9	0.500
Pyrene	--	--	--	↑	--	--	↓	--	↑	--	2	1	10	1.000
Total HPAH (TOC-normalized)	--	↑	--	--	--	--	--	--	↑	--	2	0	10	0.500
Individual TOC-normalized PAHs														
# Increases	1	4	0	5	1	1	0	2	8	1				
# Decreases	0	0	0	0	0	0	6	0	0	0				
N	13	12	4	15	14	16	15	16	11	12				
Sign test P-value	1.000	0.125	1.000	0.063	1.000	1.000	0.031	0.500	0.008	1.000				

Other Organic Compounds	Station										#	#		Sign test
Phenols	**3**	**4**	**13R**	**21**	**29**	**34**	**38**	**40**	**44**	**49**	**Incr**	**Decr**	**N**	**P-value**
4-Methylphenol	↑			--		--		--			1	0	4	1.000
Phenol	--			↑				--			1	0	3	1.000
Phthalate Esters														
Butylbenzylphthalate						--					0	0	1	1.000
Butylbenzylphthalate (TOC-norm.)						--					0	0	1	1.000
Di-n-butylphthalate						--					0	0	1	1.000
Di-n-butylphthalate (TOC-norm.)						--					0	0	1	1.000
Miscellaneous Compounds														
Benzoic acid	↑	↑	↑	↑		↑	↑	↑	↑	↑	9	0	9	0.004
beta-Coprostanol	--	↓	--	--	--	--	--	--	--	--	0	1	10	1.000
beta-Sitosterol	--	--	--	--	--	↑	--	--	--	--	1	0	10	1.000
Cholesterol	↑	↑	--	--	↑	--	↑	--	--	--	4	0	10	0.125
Cymene (p-Isopropyltoluene)				--				↑			1	0	2	0.500
Dibenzofuran				--	--	--	--	--		--	0	0	6	1.000
Dibenzofuran (TOC-normalized)				--	--	--	↓	↑		--	1	1	6	1.000
Organonitrogen Compounds														
9(H)Carbazole				--		--		--			0	0	3	1.000
Chlorinated Pesticides														
4,4'-DDD								--			0	0	1	1.000
4,4'-DDE										--	0	0	1	1.000
PCBs														
PCB Aroclor 1254				--		--	--	--		--	0	0	5	1.000
PCB Aroclor 1260						--		--			0	0	2	1.000
Other Organic Compounds (dry-weight concentrations only)														
# Increases	3	2	1	2	1	2	2	2	1	1				
# Decreases	0	1	0	0	0	0	0	0	0	0				
N	6	4	4	10	4	11	6	12	4	7				
Sign test P-value	0.250	1.000	1.000	0.500	1.000	0.500	0.500	0.500	1.000	1.000				
Total individual contaminants	**Station**													
(dry-weight concentrations only)	**3**	**4**	**13R**	**21**	**29**	**34**	**38**	**40**	**44**	**49**				
# Increases	6	8	1	3	4	3	2	6	10	4				
# Decreases	0	5	0	6	2	3	9	5	2	9				
N	32	29	18	38	31	42	35	41	28	33				
Sign test P-value	0.031	0.581	1.000	0.508	0.688	1.000	0.065	1.000	0.039	0.267				

Table 12. Results of Mann-Kendall test for trend in concentrations of metals, PAHs, and other organic compounds for individual PSAMP Sediment Component Long Term monitoring stations over the period 1989-2000.
↑, ↓ = significant at $\alpha = 0.05$; ↑↑, ↓↓ = significant at $\alpha = 0.01$; -- = no change.

	Station									
Contaminant	Strait of Georgia (3)	Bellingham Bay (4)	North Hood Canal (13R)	Port Gardner (21)	Shilshole (29)	Sinclair Inlet (34)	Point Pully (38)	Thea Foss W'way (40)	E. Anderson Island (44)	Inner Budd Inlet (49)
Metals										
Priority Pollutant Metals										
Antimony						--	--	--	--	
Arsenic	--	--	--	--	--	--	--	--	--	--
Cadmium	--	--	--	--	--	--	↑	↑*	↑	--
Chromium	--	--	--	--	--	↓	--*	--	--	--
Copper	--	--	--	--	--	↓	↓	--	--	--
Lead	--	--	--	--	--	--	--	--	--	↓
Mercury	--	--	--	↓*	--	--	↓	--	↓	--
Nickel	--	--	--	--	--	--	--	--	--	--
Silver	--	--		--	--	--	--	--	--	--
Zinc	--	--	--	--	↓	↓↓	↓	--	--*	--
Ancillary Metals										
Aluminum	--	--	--	--	--	--*	--	--	--	--
Iron	--	--	--	--	--	--	--	--	--	--
Manganese	--	--	--	--	--	--	--	--	--	--
Mean Metals SQS quotient	--	--	--	--	--	--	↓*	--	--	--

* = Apparent trend or strength of trend in time-series plots (see Appendix F-G) may differ from calculated test results.

PAH Compounds	Station									
Individual LPAH Compounds	**3**	**4**	**13R**	**21**	**29**	**34**	**38**	**40**	**44**	**49**
2-Methylnaphthalene	↑	--	--	--	--	--	--	--*	--	--
Acenaphthene				--	--	--	--	--		--
Acenaphthylene			--	--	--	--	--	--	--	--
Anthracene	--	--	--	--	--	--	--	--	--	--
Fluorene	--	--		--*	--	↑	↑*	--	--	--
Naphthalene	↑	--	--	↑*	--	--	--	--*	--	--
Phenanthrene	--*	--	--	--	--	--	--	--	--	--
Retene	--	--	--	--	--*	--	--	↑	--*	--
Total LPAH	↑↑	--*	--	--	--	--	--	--	--	--
Individual HPAH Compounds										
Benzo(a)anthracene	--	--	--	--	--	--	--	--	--	--
Benzo(a)pyrene	--	--	--	--	--	--	--	--	--	--
Total Benzofluoranthenes	--	--	--	--	--	--	--	--	--	--
Benzo(g,h,i)perylene	--	--	--	--	--	--	--	--	--	--
Chrysene	--	--	--	--	--	--	--	--	--	--
Dibenzo(a,h)anthracene				--	--	--	--	↓		
Fluoranthene	--	--	--	--	↑*	--	--	--	--	--
Indeno(1,2,3-c,d)pyrene	--	--	--	--	--	--	--	--	--	--
Perylene	--*	--		--	--	--	--	--	--	--
Pyrene	--	--	--	--	--	--	--	--	--	--*
Total HPAH	↑	--*	--	--	--	--	--	--	--	--
Total PAH	↑	--	--	--	--	--	--	--	--	--

* = Apparent trend or strength of trend in time-series plots (see Appendix F-G) may differ from calculated test results.

TOC-normalized PAHs	Station									
Individual LPAH Compounds	**3**	**4**	**13R**	**21**	**29**	**34**	**38**	**40**	**44**	**49**
2-Methylnaphthalene	↑	--	--	--	--	--	--	--	--	--
Acenaphthene				--	--	--	--	--		--
Acenaphthylene			--	--	--	--	--	--	--	--
Anthracene	--	--	--	--	--	--	--	--	--	--
Fluorene	--	--		↑	--	--	--	--	--	--
Naphthalene	--*	--	--	↑	--	--	--	--	--	--
Phenanthrene	--	--	--	--	--	--	--	--	--	--
Total LPAH (TOC-normalized)	↑*	--	--	↑	--	--	--	--	--	--
Individual HPAH Compounds										
Benzo(a)anthracene	--	--	--	--	--	--	--	--	--	--
Benzo(a)pyrene	--	--	--	--	--	--	--	--	--	--
Total Benzofluoranthenes	--	--	--	--	--	--	--	--	--	--
Benzo(g,h,i)perylene	--	--	--	--	--	--	--	--	--	--
Chrysene	--	--	--	--	--	--	--	--	--	--
Dibenzo(a,h)anthracene				--	--	--	--	--		
Fluoranthene	--	--	--	--	--	--	--	--	--	--
Indeno(1,2,3-c,d)pyrene	--	--	--	--	--	--	--	--	--	--
Pyrene	↑*	--	--	--	--	--	--	--	--	--
Total HPAH (TOC-normalized)	↑↑	--	--	--	--	--	--	--	--	--

* = Apparent trend or strength of trend in time-series plots (see Appendix F-G) may differ from calculated test results.

Other Organic Compounds	**Station**									
Phenols	**3**	**4**	**13R**	**21**	**29**	**34**	**38**	**40**	**44**	**49**
4-Methylphenol	--	--		--*		--		--	--	
Phenol	--	--		--*		--	--	--	--	
Phthalate Esters										
Butylbenzylphthalate						--	--	--		
Butylbenzylphthalate (TOC-normalized)						--	--	--		
Di-n-butylphthalate						--				
Di-n-butylphthalate (TOC-normalized)						--				
Miscellaneous Compounds										
Benzoic acid	--	--	--	--		--	--	--	--	--
beta-Coprostanol	--	--		--	--	--	--	--	--	--
beta-Sitosterol	--*	--	--	--	--	--	--	--	--	--
Cholesterol	↑	--	--	--	--	--	--	--	--	--
Cymene (p-Isopropyltoluene)				--	--		--	--		--
Dibenzofuran		--	--	--	--	--*	--	--	--	--
Dibenzofuran (TOC-normalized)		--	--	--	--	--	--	--	--	--
Organonitrogen Compounds										
9(H)Carbazole				--	--	--	--	--		
Chlorinated Pesticides										
4,4'-DDD								--		
4,4'-DDE										--
PCBs										
PCB Aroclor 1254				--	--	--	--	--		--
PCB Aroclor 1260						--	--	--		

* = Apparent trend or strength of trend in time-series plots (see Appendix F-G) may differ from calculated test results.

Table 13. Abundance (individuals/0.1 sq.m) and percent abundance of major taxa by year for each station.

		Abundance (Percent)										
Station	Year	Annelida		Arthropoda		Echinodermata		Mollusca		Misc. Taxa		Total
Strait of Georgia (3)	1989	247	(73.1%)	36	(10.6%)	1	(0.2%)	54	(16.0%)	0	(0.1%)	338
	1990	27	(47.0%)	9	(16.5%)	0	(0.0%)	21	(36.5%)	0	(0.0%)	57
	1991	120	(70.0%)	18	(10.5%)	2	(0.9%)	31	(18.3%)	0	(0.2%)	171
	1992	51	(20.2%)	30	(11.9%)	0	(0.1%)	169	(67.6%)	0	(0.2%)	250
	1993	141	(76.7%)	16	(8.9%)	1	(0.3%)	24	(13.3%)	1	(0.8%)	183
	1994	34	(60.0%)	7	(11.8%)	0	(0.0%)	16	(27.6%)	0	(0.6%)	57
	1995	70	(69.9%)	16	(16.2%)	0	(0.3%)	12	(12.3%)	1	(1.3%)	99
	1996	not sampled										
	1997	111	(85.1%)	5	(3.8%)	0	(0.3%)	14	(10.5%)	0	(0.3%)	130
	1998	70	(84.2%)	5	(5.5%)	0	(0.0%)	8	(9.7%)	1	(0.6%)	84
	1999	52	(78.7%)	3	(4.1%)	0	(0.0%)	10	(15.7%)	1	(1.5%)	66
	2000	95	(13.8%)	31	(4.5%)	0	(0.0%)	564	(81.6%)	0	(0.0%)	690
Bellingham Bay (4)	1989	171	(57.4%)	60	(20.1%)	10	(3.4%)	49	(16.6%)	7	(2.5%)	297
	1990	191	(40.5%)	128	(27.1%)	46	(9.7%)	101	(21.3%)	7	(1.4%)	473
	1991	35	(15.0%)	40	(17.3%)	75	(32.6%)	79	(34.3%)	2	(0.9%)	231
	1992	64	(31.9%)	14	(6.8%)	59	(29.4%)	59	(29.5%)	5	(2.4%)	201
	1993	79	(36.6%)	25	(11.5%)	37	(17.0%)	69	(32.1%)	6	(2.8%)	216
	1994	212	(63.0%)	20	(5.9%)	19	(5.7%)	78	(23.0%)	8	(2.3%)	337
	1995	210	(49.9%)	37	(8.7%)	51	(12.1%)	119	(28.3%)	4	(1.0%)	421
	1996	not sampled										
	1997	159	(47.5%)	15	(4.6%)	39	(11.5%)	118	(35.3%)	4	(1.1%)	335
	1998	121	(47.1%)	22	(8.7%)	41	(16.0%)	69	(26.7%)	4	(1.6%)	257
	1999	113	(42.1%)	10	(3.7%)	57	(21.3%)	86	(32.1%)	2	(0.7%)	268
	2000	220	(44.0%)	59	(11.9%)	77	(15.4%)	139	(27.8%)	4	(0.9%)	499

Station	Year	Abundance (Percent)										
		Annelida		Arthropoda		Echinodermata		Mollusca		Misc. Taxa		Total
North Hood Canal (13R)	1989	196	(14.2%)	135	(9.8%)	1	(0.1%)	1040	(75.4%)	7	(0.5%)	1379
	1990	not sampled										
	1991	90	(8.1%)	137	(12.3%)	1	(0.1%)	878	(79.1%)	5	(0.4%)	1111
	1992	not sampled										
	1993	not sampled										
	1994	186	(16.5%)	128	(11.4%)	3	(0.2%)	795	(70.7%)	13	(1.1%)	1125
	1995	not sampled										
	1996	not sampled										
	1997	198	(6.9%)	197	(6.8%)	3	(0.1%)	2388	(83.0%)	90	(3.1%)	2876
	1998	294	(8.3%)	240	(6.7%)	5	(0.1%)	2997	(84.1%)	27	(0.8%)	3563
	1999	182	(17.1%)	157	(14.8%)	1	(0.1%)	702	(66.1%)	20	(1.9%)	1062
	2000	319	(25.0%)	207	(16.2%)	3	(0.2%)	674	(52.8%)	74	(5.8%)	1277
Port Gardner (21)	1989	152	(16.5%)	268	(29.0%)	0	(0.0%)	502	(54.3%)	1	(0.1%)	923
	1990	162	(21.2%)	223	(29.3%)	0	(0.0%)	375	(49.2%)	2	(0.3%)	762
	1991	157	(27.5%)	106	(18.4%)	0	(0.0%)	307	(53.5%)	4	(0.6%)	574
	1992	212	(17.6%)	360	(29.9%)	0	(0.0%)	627	(52.1%)	5	(0.4%)	1204
	1993	162	(24.6%)	229	(34.7%)	1	(0.1%)	266	(40.3%)	3	(0.4%)	661
	1994	320	(40.8%)	111	(14.2%)	1	(0.1%)	348	(44.4%)	4	(0.5%)	784
	1995	268	(29.0%)	187	(20.2%)	1	(0.1%)	467	(50.4%)	3	(0.4%)	926
	1996	184	(26.4%)	140	(20.1%)	1	(0.2%)	370	(53.0%)	2	(0.3%)	697
	1997	128	(28.3%)	112	(24.8%)	0	(0.0%)	209	(46.3%)	3	(0.6%)	452
	1998	241	(38.1%)	130	(20.5%)	1	(0.1%)	255	(40.4%)	6	(0.9%)	633
	1999	197	(24.9%)	222	(27.9%)	0	(0.0%)	367	(46.2%)	7	(0.9%)	793
	2000	180	(31.7%)	129	(22.8%)	0	(0.0%)	254	(44.9%)	4	(0.7%)	567

Station	Year	Abundance (Percent) Annelida		Arthropoda		Echinodermata		Mollusca		Misc. Taxa		Total
Shilshole (29)	1989	53	(31.9%)	51	(31.2%)	2	(1.5%)	56	(33.7%)	3	(1.8%)	165
	1990	31	(12.2%)	44	(17.5%)	4	(1.5%)	170	(68.1%)	2	(0.6%)	251
	1991	48	(15.6%)	30	(9.7%)	3	(0.9%)	223	(73.2%)	2	(0.5%)	306
	1992	44	(9.3%)	59	(12.5%)	2	(0.4%)	363	(77.4%)	1	(0.3%)	469
	1993	20	(5.7%)	84	(23.5%)	3	(0.7%)	251	(70.0%)	0	(0.1%)	358
	1994	20	(8.4%)	63	(26.6%)	3	(1.3%)	150	(62.9%)	2	(0.8%)	238
	1995	34	(13.9%)	66	(27.1%)	2	(0.7%)	141	(57.5%)	2	(0.8%)	245
	1996	35	(10.4%)	48	(14.1%)	1	(0.3%)	254	(74.9%)	1	(0.3%)	339
	1997	54	(16.4%)	54	(16.4%)	1	(0.4%)	218	(66.2%)	2	(0.7%)	329
	1998	42	(18.1%)	47	(20.6%)	1	(0.6%)	137	(59.5%)	3	(1.2%)	230
	1999	36	(15.3%)	26	(10.9%)	1	(0.4%)	172	(72.7%)	2	(0.7%)	237
	2000	66	(12.5%)	108	(20.7%)	1	(0.3%)	347	(66.3%)	1	(0.3%)	523
Sinclair Inlet (34)	1989	376	(64.9%)	150	(25.9%)	4	(0.7%)	48	(8.2%)	2	(0.3%)	580
	1990	320	(70.2%)	98	(21.5%)	3	(0.7%)	32	(7.0%)	3	(0.6%)	456
	1991	860	(85.2%)	108	(10.7%)	5	(0.5%)	34	(3.4%)	2	(0.2%)	1009
	1992	871	(84.9%)	106	(10.4%)	5	(0.5%)	39	(3.8%)	4	(0.4%)	1025
	1993	585	(80.8%)	91	(12.6%)	7	(0.9%)	32	(4.5%)	8	(1.1%)	723
	1994	1058	(87.4%)	94	(7.8%)	6	(0.5%)	50	(4.2%)	1	(0.1%)	1209
	1995	1671	(92.7%)	80	(4.4%)	15	(0.8%)	33	(1.8%)	4	(0.2%)	1803
	1996	not sampled										
	1997	1445	(88.3%)	132	(8.1%)	18	(1.1%)	40	(2.4%)	1	(0.1%)	1636
	1998	1039	(84.7%)	106	(8.6%)	17	(1.4%)	64	(5.2%)	1	(0.1%)	1227
	1999	375	(77.4%)	63	(13.1%)	13	(2.8%)	31	(6.5%)	2	(0.3%)	484
	2000	761	(78.1%)	139	(14.3%)	19	(2.0%)	52	(5.3%)	3	(0.3%)	974

		Abundance (Percent)										
Station	Year	Annelida		Arthropoda		Echinodermata		Mollusca		Misc. Taxa		Total
Point Pully (38)	1989	28	(24.2%)	72	(61.1%)	3	(2.4%)	12	(10.1%)	3	(2.2%)	118
	1990	18	(22.9%)	48	(61.2%)	3	(3.9%)	7	(9.0%)	2	(3.1%)	78
	1991	20	(15.6%)	45	(35.6%)	2	(1.9%)	55	(43.5%)	4	(3.3%)	126
	1992	23	(13.4%)	55	(32.4%)	3	(1.5%)	87	(51.2%)	2	(1.4%)	170
	1993	36	(18.3%)	71	(36.4%)	5	(2.4%)	81	(41.4%)	3	(1.5%)	196
	1994	27	(26.1%)	64	(61.5%)	3	(3.2%)	6	(6.1%)	3	(3.2%)	103
	1995	41	(26.3%)	52	(32.8%)	6	(3.8%)	55	(35.2%)	3	(1.9%)	157
	1996	44	(31.6%)	41	(29.7%)	3	(1.9%)	48	(34.8%)	3	(1.9%)	139
	1997	37	(19.8%)	55	(29.2%)	6	(3.2%)	84	(44.9%)	5	(2.9%)	187
	1998	40	(34.2%)	24	(20.4%)	2	(2.0%)	47	(40.8%)	3	(2.6%)	116
	1999	41	(24.1%)	42	(24.7%)	3	(2.0%)	76	(44.8%)	8	(4.5%)	170
	2000	57	(15.3%)	59	(16.0%)	4	(1.0%)	244	(65.8%)	7	(1.9%)	371
Thea Foss Waterway (40)	1989	397	(59.5%)	63	(9.4%)	8	(1.2%)	193	(28.9%)	7	(1.0%)	668
	1990	193	(52.3%)	106	(28.7%)	3	(0.9%)	63	(17.1%)	4	(1.0%)	369
	1991	242	(39.9%)	151	(25.0%)	2	(0.3%)	205	(33.8%)	6	(1.0%)	606
	1992	332	(50.8%)	164	(25.0%)	5	(0.8%)	145	(22.2%)	7	(1.1%)	653
	1993	259	(41.8%)	135	(21.7%)	41	(6.6%)	171	(27.5%)	15	(2.4%)	621
	1994	322	(48.8%)	131	(19.8%)	21	(3.1%)	168	(25.4%)	19	(2.9%)	661
	1995	300	(43.5%)	110	(15.9%)	98	(14.2%)	162	(23.5%)	20	(3.0%)	690
	1996	not sampled										
	1997	283	(27.2%)	182	(17.4%)	242	(23.2%)	317	(30.5%)	18	(1.7%)	1042
	1998	286	(26.0%)	79	(7.2%)	213	(19.3%)	509	(46.1%)	16	(1.5%)	1103
	1999	179	(26.2%)	132	(19.3%)	81	(11.9%)	285	(41.7%)	7	(1.0%)	684
	2000	395	(34.1%)	163	(14.0%)	74	(6.4%)	521	(45.0%)	6	(0.5%)	1159

Station	Year	Annelida		Arthropoda		Echinodermata		Mollusca		Misc. Taxa		Total
		Abundance (Percent)										
East Anderson Island (44)	1989	307	(64.9%)	60	(12.7%)	10	(2.1%)	72	(15.3%)	24	(5.1%)	473
	1990	493	(70.9%)	116	(16.7%)	14	(2.0%)	51	(7.3%)	21	(3.1%)	695
	1991	299	(65.5%)	57	(12.4%)	11	(2.5%)	65	(14.2%)	25	(5.4%)	457
	1992	383	(67.0%)	94	(16.5%)	15	(2.6%)	62	(10.9%)	18	(3.1%)	572
	1993	356	(53.8%)	179	(27.1%)	53	(8.0%)	45	(6.9%)	28	(4.2%)	661
	1994	381	(59.5%)	158	(24.7%)	44	(6.8%)	42	(6.5%)	16	(2.4%)	641
	1995	305	(47.2%)	184	(28.5%)	81	(12.5%)	48	(7.4%)	29	(4.5%)	647
	1996	not sampled										
	1997	244	(36.5%)	232	(34.7%)	119	(17.8%)	54	(8.0%)	20	(3.0%)	669
	1998	71	(33.6%)	91	(42.9%)	13	(6.0%)	29	(13.6%)	8	(3.9%)	212
	1999	175	(54.4%)	69	(21.4%)	15	(4.6%)	50	(15.5%)	13	(4.1%)	322
	2000	213	(53.8%)	120	(30.3%)	14	(3.4%)	36	(9.0%)	14	(3.4%)	397
Inner Budd Inlet (49)	1989	75	(53.7%)	39	(27.6%)	6	(4.0%)	12	(8.3%)	9	(6.4%)	141
	1990	54	(43.7%)	45	(36.1%)	5	(3.7%)	17	(14.0%)	3	(2.4%)	124
	1991	80	(56.7%)	29	(20.8%)	4	(2.7%)	22	(16.0%)	5	(3.8%)	140
	1992	43	(38.7%)	13	(11.9%)	1	(0.5%)	52	(46.5%)	3	(2.3%)	112
	1993	176	(86.0%)	11	(5.3%)	1	(0.5%)	9	(4.4%)	8	(3.9%)	205
	1994	116	(76.5%)	18	(11.6%)	3	(2.2%)	12	(7.9%)	3	(1.8%)	152
	1995	67	(82.6%)	4	(5.4%)	0	(0.4%)	8	(9.9%)	1	(1.7%)	80
	1996	not sampled										
	1997	65	(66.2%)	9	(9.1%)	0	(0.0%)	22	(22.0%)	3	(2.7%)	99
	1998	82	(69.4%)	9	(7.6%)	0	(0.0%)	24	(20.2%)	3	(2.8%)	118
	1999	88	(82.0%)	6	(5.3%)	0	(0.0%)	10	(9.3%)	4	(3.4%)	108
	2000	31	(47.7%)	4	(5.7%)	0	(0.5%)	28	(44.0%)	1	(2.1%)	64

Table 14. Mean abundance (individuals/0.1 sq.m) and percent abundance of major taxa by station.

Station	Mean Abundance (Percent)										
	Annelida		Arthropoda		Echinodermata		Mollusca		Misc. Taxa		Total
Strait of Georgia (3)	92.4	(47.8%)	16.0	(8.3%)	0.4	(0.2%)	84.0	(43.4%)	0.6	(0.3%)	193.4
Bellingham Bay (4)	143.2	(44.6%)	39.1	(12.2%)	46.4	(14.4%)	87.9	(27.3%)	4.8	(1.5%)	321.4
North Hood Canal (13R)	209.2	(11.8%)	171.7	(9.7%)	2.3	(0.1%)	1353.4	(76.5%)	33.6	(1.9%)	1770.2
Port Gardner (21)	196.9	(26.3%)	184.7	(24.7%)	0.4	(0.1%)	362.3	(48.4%)	3.6	(0.5%)	748.0
Shilshole (29)	40.1	(13.1%)	56.7	(18.4%)	2.0	(0.7%)	206.7	(67.3%)	1.8	(0.6%)	307.2
Sinclair Inlet (34)	850.9	(84.1%)	106.3	(10.5%)	10.3	(1.0%)	41.4	(4.1%)	2.7	(0.3%)	1011.6
Point Pully (38)	34.2	(21.3%)	52.2	(32.5%)	3.6	(2.2%)	66.8	(41.6%)	3.9	(2.4%)	160.7
Thea Foss Waterway (40)	289.9	(38.6%)	128.6	(17.1%)	71.6	(9.5%)	249.0	(33.2%)	11.4	(1.5%)	750.4
East Anderson Island (44)	293.4	(56.2%)	123.7	(23.7%)	35.2	(6.7%)	50.3	(9.6%)	19.7	(3.8%)	522.3
Inner Budd Inlet (49)	79.8	(65.4%)	16.9	(13.9%)	1.8	(1.5%)	19.7	(16.1%)	3.9	(3.2%)	122.2

Table 15. Ten most abundant taxa at each of the PSAMP long-term sediment monitoring stations in each year, with taxa richness (TR = number of taxa) and Swartz' dominance index (SDI = number of taxa comprising at least 75% of the total abundance; bold taxa names) indicated.

Year	Rank	Strait of Georgia (3)	Bellingham Bay (4)	North Hood Canal (13R)	Port Gardner (21)	Shilshole (29)
1989	1	***Prionospio Cmplx****	***Levinsenia gracilis***	***Nutricola lordi***	***Axinopsida serricata***	***Macoma carlottensis***
1989	2	***Prionospio lighti***	***Protomedeia grandimana***	***Euphilomedes carcharodonta***	***Macoma carlottensis***	***Pectinaria californiensis***
1989	3	***Pholoe sp Cmplx***	***Cossura pygodactylata***	***Mediomastus sp***	***Euphilomedes carcharodonta***	***Euphilomedes producta***
1989	4	***Pinnixa sp***	***Axinopsida serricata***	*Axinopsida serricata*	***Euphilomedes producta***	***Eudorella pacifica***
1989	5	***Cossura pygodactylata***	***Acila castrensis***	*Alvania compacta*	*Polycirrus sp*	***Levinsenia gracilis***
1989	6	***Macoma sp***	***Aphelochaeta sp***	*Boccardia pugettensis*	*Lanassa venusta*	***Lirobittium attenuatum***
1989	7	***Yoldia seminuda***	***Heterophoxus sp***	*Dipolydora socialis/cardalia*	*Nutricola lordi*	***Paraphoxus oculatus***
1989	8	***Euclymene cf zonalis***	***Terebellides sp***	*Rochefortia tumida*	*Scoletoma luti*	***Ampharete acutifrons***
1989	9	***Macoma calcarea***	***Amphiodia Cmplx*****	*Tellina modesta*	*Nephtys ferruginea*	***Axinopsida serricata***
1989	10	*Prionospio multibranchiata*	***Polycirrus sp***	*Pinnixa occidentalis*	*Heteromastus sp*	***Nephtys cornuta***
		TR=93, SDI=9	TR=80, SDI=14	TR=145, SDI=3	TR=98, SDI=4	TR=75, SDI=10
1990	1	***Prionospio Cmplx****	***Armandia brevis***		***Axinopsida serricata***	***Macoma carlottensis***
1990	2	***Yoldia seminuda***	***Heterophoxus sp***		***Macoma carlottensis***	***Euphilomedes producta***
1990	3	***Cryptonatica affinis***	***Axinopsida serricata***		***Euphilomedes carcharodonta***	***Lirobittium attenuatum***
1990	4	***Pinnixa sp***	***Amphiodia Cmplx*****		***Euphilomedes producta***	***Eudorella pacifica***
1990	5	***Protomedeia grandimana***	***Levinsenia gracilis***		***Heteromastus sp***	***Axinopsida serricata***
1990	6	***Prionospio lighti***	***Euphilomedes producta***		***Scoletoma luti***	*Ampharete sp*
1990	7	***Spiophanes berkeleyorum***	***Eudorella pacifica***		*Rochefortia tumida*	*Nephtys ferruginea*
1990	8	***Macoma calcarea***	***Rochefortia tumida***		*Leitoscoloplos pugettensis*	*Acila castrensis*
1990	9	*Pholoe sp Cmplx*	*Lumbrineris cruzensis*		*Nephtys ferruginea*	*Levinsenia gracilis*
1990	10	*Cossura pygodactylata*	*Acila castrensis*		*Nutricola lordi*	*Heterophoxus sp*
		TR=34, SDI=8	TR=87, SDI=8		TR=78, SDI=6	TR=75, SDI=5
1991	1	***Pholoe sp Cmplx***	***Amphiodia Cmplx*****	***Nutricola lordi***	***Axinopsida serricata***	***Macoma carlottensis***
1991	2	***Prionospio lighti***	***Acila castrensis***	***Euphilomedes carcharodonta***	***Macoma carlottensis***	***Ampharete acutifrons***
1991	3	***Prionospio Cmplx****	***Rochefortia tumida***	*Alvania compacta*	***Euphilomedes carcharodonta***	***Axinopsida serricata***
1991	4	***Macoma calcarea***	***Heterophoxus sp***	*Astyris gausapata*	***Heteromastus filobranchus***	***Euphilomedes producta***
1991	5	***Spiophanes berkeleyorum***	***Ennucula tenuis***	*Caprella mendax*	***Euphilomedes producta***	*Lirobittium attenuatum*
1991	6	***Pinnixa sp***	***Euphilomedes producta***	*Mediomastus sp*	***Scoletoma luti***	*Pectinaria californiensis*
1991	7	***Cossura pygodactylata***	*Levinsenia gracilis*	*Axinopsida serricata*	***Nutricola lordi***	*Spiophanes berkeleyorum*
1991	8	*Yoldia seminuda*	*Lumbrineris cruzensis*	*Rochefortia tumida*	*Lanassa sp*	*Diastylis sp*
1991	9	*Oligochaeta*	*Scoletoma luti*	*Leitoscoloplos pugettensis*	*Polycirrus sp*	*Nephtys ferruginea*
1991	10	*Nephtys cornuta*	*Axinopsida serricata*	*Boccardia pugettensis*	*Macoma elimata*	*Protomedeia prudens*
		TR=43, SDI=7	TR=56, SDI=6	TR=119, SDI=2	TR=69, SDI=7	TR=66, SDI=4

Year	Rank	Strait of Georgia (3)	Bellingham Bay (4)	North Hood Canal (13R)	Port Gardner (21)	Shilshole (29)
1992	1	***Yoldia hyperborea***	***Amphiodia Cmplx*****		***Euphilomedes carcharodonta***	***Macoma carlottensis***
1992	2	***Macoma calcarea***	***Acila castrensis***		***Macoma carlottensis***	***Euphilomedes producta***
1992	3	***Pinnixa sp***	***Axinopsida serricata***		***Axinopsida serricata***	***Pectinaria californiensis***
1992	4	***Pholoe sp Cmplx***	***Levinsenia gracilis***		***Macoma sp***	*Axinopsida serricata*
1992	5	*Prionospio lighti*	***Ennucula tenuis***		***Euphilomedes producta***	*Eudorella pacifica*
1992	6	*Prionospio Cmplx**	***Prionospio lighti***		***Heteromastus filobranchus***	*Macoma sp*
1992	7	*Cossura pygodactylata*	***Terebellides sp***		*Scoletoma luti*	*Lirobittium attenuatum*
1992	8	*Macoma sp*	***Rochefortia tumida***		*Nutricola lordi*	*Nephtys ferruginea*
1992	9	*Macoma carlottensis*	***Lumbrineris cruzensis***		*Polycirrus sp*	*Paraphoxus oculatus*
1992	10	*Euspira pallida*	***Eudorella pacifica***		*Lanassa sp*	*Maera danae*
		TR=59, SDI=4	TR=83, SDI=13		TR=99, SDI=6	TR=66, SDI=3
1993	1	***Pholoe sp Cmplx***	***Axinopsida serricata***		***Euphilomedes carcharodonta***	***Macoma sp***
1993	2	***Prionospio lighti***	***Levinsenia gracilis***		***Axinopsida serricata***	***Euphilomedes producta***
1993	3	***Cossura pygodactylata***	***Acila castrensis***		***Macoma sp***	*Eudorella pacifica*
1993	4	***Pinnixa sp***	***Amphiodia sp***		***Euphilomedes producta***	*Axinopsida serricata*
1993	5	***Macoma sp***	***Amphiodia Cmplx*****		***Heteromastus filobranchus***	*Protomedeia sp*
1993	6	***Prionospio Cmplx****	***Protomedeia sp***		***Scoletoma luti***	*Pectinaria californiensis*
1993	7	*Oligochaeta*	***Eudorella pacifica***		*Polycirrus sp*	*Heterophoxus sp*
1993	8	*Yoldia hyperborea*	***Prionospio lighti***		*Rochefortia tumida*	*Lirobittium attenuatum*
1993	9	*Nephtys cornuta*	***Cossura pygodactylata***		*Glycera nana*	*Ennucula tenuis*
1993	10	*Prionospio multibranchiata*	***Rochefortia tumida***		*Mediomastus sp*	*Diastylis sp*
		TR=49, SDI=6	TR=69, SDI=12		TR=81, SDI=6	TR=64, SDI=2
1994	1	***Cossura pygodactylata***	***Levinsenia gracilis***	***Nutricola lordi***	***Axinopsida serricata***	***Macoma sp***
1994	2	***Macoma sp***	***Axinopsida serricata***	***Euphilomedes carcharodonta***	***Macoma sp***	***Euphilomedes producta***
1994	3	***Cryptonatica affinis***	***Cossura pygodactylata***	***Alvania compacta***	***Euphilomedes carcharodonta***	***Eudorella pacifica***
1994	4	***Prionospio Cmplx****	***Acila castrensis***	***Axinopsida serricata***	***Heteromastus filobranchus***	***Axinopsida serricata***
1994	5	***Prionospio lighti***	***Terebellides sp***	*Mediomastus sp*	***Heteromastus sp***	*Heterophoxus affinis*
1994	6	***Pinnixa occidentalis***	***Prionospio lighti***	*Euclymene cf zonalis*	***Lanassa venusta***	*Lirobittium attenuatum*
1994	7	***Pholoe sp Cmplx***	***Aphelochaeta monilaris***	*Decamastus cf gracilis*	***Polycirrus sp***	*Protomedeia sp*
1994	8	***Nephtys cornuta***	***Laonice cirrata***	*Leitoscoloplos pugettensis*	***Rochefortia tumida***	*Pholoe sp Cmplx*
1994	9	*Yoldia hyperborea*	***Terebellides californica***	*Boccardia pugettensis*	*Euphilomedes producta*	*Prionospio lighti*
1994	10	*Prionospio multibranchiata*	***Amphiodia Cmplx*****	*Lineidae*	*Scoletoma luti*	*Acila castrensis*
		TR=32, SDI=8	TR=70, SDI=13	TR=147, SDI=4	TR=83, SDI=8	TR=53, SDI=4

Year	Rank	Strait of Georgia (3)	Bellingham Bay (4)	North Hood Canal (13R)	Port Gardner (21)	Shilshole (29)
1995	1	***Cossura pygodactylata***	***Axinopsida serricata***		***Axinopsida serricata***	***Macoma carlottensis***
1995	2	***Pinnixa schmitti***	***Levinsenia gracilis***		***Euphilomedes carcharodonta***	***Euphilomedes producta***
1995	3	***Prionospio lighti***	***Heterophoxus affinis***		***Euphilomedes producta***	***Macoma sp***
1995	4	***Pholoe sp Cmplx***	***Amphiuridae***		***Heteromastus filobranchus***	***Protomedeia prudens***
1995	5	***Euspira pallida***	***Cossura pygodactylata***		***Scoletoma luti***	***Lirobittium sp***
1995	6	***Macoma calcarea***	***Amphiodia Cmplx*****		***Macoma carlottensis***	***Eudorella pacifica***
1995	7	***Cirripedia***	***Aricidea lopezi/catherinae***		***Polycirrus californicus***	***Heterophoxus affinis***
1995	8	***Prionospio Cmplx****	***Laonice cirrata***		***Polycirrus sp***	*Ampharete cf crassiseta*
1995	9	*Nephtys cornuta*	***Aphelochaeta monilaris***		*Astyris gausapata*	*Spiophanes berkeleyorum*
1995	10	*Protomedeia prudens*	***Amphiodia sp***		*Glycera nana*	*Nephtys ferruginea*
		TR=44, SDI=8	TR=72, SDI=13		TR=90, SDI=8	TR=58, SDI=7
1996	1				***Axinopsida serricata***	***Macoma carlottensis***
1996	2				***Euphilomedes carcharodonta***	***Euphilomedes producta***
1996	3				***Euphilomedes producta***	*Eudorella pacifica*
1996	4				***Macoma carlottensis***	*Nephtys ferruginea*
1996	5				***Dipolydora sp***	*Levinsenia oculata*
1996	6				***Heteromastus filobranchus***	*Lirobittium sp*
1996	7				***Scoletoma luti***	*Diastylis pellucida*
1996	8				***Nephtys ferruginea***	*Nephtys cornuta*
1996	9				*Macoma sp*	*Heterophoxus affinis*
1996	10				*Rochefortia tumida*	*Prionospio multibranchiata*
					TR=70, SDI=8	TR=50, SDI=2
1997	1	***Cossura pygodactylata***	***Axinopsida serricata***	***Nutricola lordi***	***Axinopsida serricata***	***Macoma carlottensis***
1997	2	***Yoldia hyperborea***	***Levinsenia gracilis***	***Alvania compacta***	***Euphilomedes carcharodonta***	***Eudorella pacifica***
1997	3	*Prionospio lighti*	***Amphiodia Cmplx*****	*Euphilomedes carcharodonta*	***Macoma carlottensis***	***Ampharete cf crassiseta***
1997	4	*Macoma calcarea*	***Aricidea lopezi/catherinae***	*Phoronida*	***Heteromastus filobranchus***	***Prionospio lighti***
1997	5	*Pholoe sp Cmplx*	***Cossura pygodactylata***	*Axinopsida serricata*	***Macoma sp***	***Macoma sp***
1997	6	*Nephtys cornuta*	***Rochefortia tumida***	*Mediomastus sp*	***Euphilomedes producta***	*Euphilomedes producta*
1997	7	*Prionospio Cmplx**	***Lumbrineris cruzensis***	*Phoronopsis harmeri*	***Lanassa venusta***	*Protomedeia prudens*
1997	8	*Oligochaeta*	*Heterophoxus affinis*	*Phyllochaetopterus prolifica*	***Scoletoma luti***	*Levinsenia gracilis*
1997	9	*Spiophanes berkeleyorum*	*Oligochaeta*	*Tellina modesta*	*Turbonilla sp*	*Harpiniopsis fulgens*
1997	10	*Pinnixa schmitti*	*Paraprionospio pinnata*	*Rochefortia tumida*	*Rhepoxynius barnardi*	*Diastylis alaskensis*
		TR=31, SDI=2	TR=43, SDI=7	TR=183, SDI=2	TR=75, SDI=8	TR=45, SDI=5

Year	Rank	Strait of Georgia (3)	Bellingham Bay (4)	North Hood Canal (13R)	Port Gardner (21)	Shilshole (29)
1998	1	***Cossura pygodactylata***	***Levinsenia gracilis***	***Nutricola lordi***	***Axinopsida serricata***	***Macoma carlottensis***
1998	2	***Prionospio lighti***	***Amphiodia Cmplx*****	*Euphilomedes carcharodonta*	***Euphilomedes carcharodonta***	***Euphilomedes producta***
1998	3	***Oligochaeta***	***Axinopsida serricata***	*Alvania compacta*	***Scoletoma luti***	***Eudorella pacifica***
1998	4	***Nephtys cornuta***	***Rochefortia tumida***	*Mediomastus sp*	***Polycirrus sp I***	***Ampharete cf crassiseta***
1998	5	***Pholoe sp Cmplx***	***Aricidea lopezi/catherinae***	*Phyllochaetopterus prolifica*	***Macoma carlottensis***	***Axinopsida serricata***
1998	6	*Yoldia hyperborea*	***Heterophoxus affinis***	*Rochefortia tumida*	***Euphilomedes producta***	***Parvilucina tenuisculpta***
1998	7	*Macoma calcarea*	***Lumbrineris cruzensis***	*Axinopsida serricata*	***Lanassa venusta***	***Spiophanes berkeleyorum***
1998	8	*Calanoida*	***Paraprionospio pinnata***	*Decamastus cf gracilis*	***Polycirrus sp***	*Diastylis santamariensis*
1998	9	*Heterophoxus affinis*	***Protomedeia grandimana***	*Phoronis sp*	***Macoma sp***	*Levinsenia gracilis*
1998	10	*Pinnixa occidentalis*	***Eudorella pacifica***	*Tellina modesta*	***Rochefortia tumida***	*Nephtys ferruginea*
		TR=27, SDI=5	TR=47, SDI=11	TR=190, SDI=1	TR=79, SDI=11	TR=52, SDI=7
1999	1	***Cossura pygodactylata***	***Axinopsida serricata***	***Nutricola lordi***	***Axinopsida serricata***	***Macoma carlottensis***
1999	2	***Prionospio lighti***	***Amphiodia Cmplx*****	***Euphilomedes carcharodonta***	***Euphilomedes carcharodonta***	***Euphilomedes producta***
1999	3	***Oligochaeta***	***Lumbrineris cruzensis***	***Alvania compacta***	***Scoletoma luti***	***Axinopsida serricata***
1999	4	***Nephtys cornuta***	***Levinsenia gracilis***	***Axinopsida serricata***	***Macoma carlottensis***	*Ampharete cf crassiseta*
1999	5	***Yoldia hyperborea***	***Rochefortia tumida***	***Mediomastus sp***	***Euphilomedes producta***	*Levinsenia oculata*
1999	6	*Macoma calcarea*	***Heteromastus filobranchus***	*Decamastus cf gracilis*	***Astyris gausapata***	*Parvilucina tenuisculpta*
1999	7	*Prionospio Cmplx**	***Cossura pygodactylata***	*Boccardia pugettensis*	***Prionospio Cmplx****	*Prionospio multibranchiata*
1999	8	*Pinnixa schmitti*	***Aricidea lopezi/catherinae***	*Rochefortia tumida*	*Macoma sp*	*Diastylis pellucida*
1999	9	*Axinopsida serricata*	***Amphiodia sp***	*Phoronis sp*	*Rochefortia tumida*	*Lirobittium sp*
1999	10	*Pholoe sp Cmplx*	***Eudorella pacifica***	*Euclymene cf zonalis*	*Rhepoxynius barnardi*	*Nephtys cornuta*
		TR=31, SDI=5	TR=57, SDI=11	TR=137, SDI=5	TR=81, SDI=7	TR=48, SDI=3
2000	1	***Macoma carlottensis***	***Axinopsida serricata***	***Nutricola lordi***	***Axinopsida serricata***	***Macoma carlottensis***
2000	2	***Yoldia hyperborea***	***Cossura pygodactylata***	***Euphilomedes carcharodonta***	***Euphilomedes carcharodonta***	***Macoma sp***
2000	3	***Calanoida***	***Amphiodia Cmplx*****	***Axinopsida serricata***	***Scoletoma luti***	***Euphilomedes producta***
2000	4	*Pholoe sp Cmplx*	***Eudorella pacifica***	***Alvania compacta***	***Macoma carlottensis***	***Axinopsida serricata***
2000	5	*Macoma sp*	***Levinsenia gracilis***	***Phoronis sp***	***Euphilomedes producta***	***Ampharete cf crassiseta***
2000	6	*Prionospio lighti*	***Aricidea lopezi/catherinae***	***Phyllochaetopterus prolifica***	***Lanassa venusta***	*Diastylis pellucida*
2000	7	*Protomedeia sp*	***Lumbrineris cruzensis***	***Euclymene cf zonalis***	***Macoma sp***	*Eudorella pacifica*
2000	8	*Cossura pygodactylata*	***Amphiuridae***	***Mediomastus sp***	***Rochefortia tumida***	*Zoea (Decapoda)*
2000	9	*Zoea (Decapoda)*	***Amphiodia sp***	***Spio cirrifera***	***Leitoscoloplos pugettensis***	*Dyopedos sp*
2000	10	*Axinopsida serricata*	***Heteromastus filobranchus***	***Rochefortia tumida***	*Phyllodoce mucosa*	*Pectinaria californiensis*
		TR=45, SDI=3	TR=64, SDI=13	TR=190, SDI=15	TR=82, SDI=9	TR=66, SDI=5

Year	Rank	Sinclair Inlet (34)	Point Pully (38)	Thea Foss Waterway (40)	East Anderson Island (44)	Inner Budd Inlet (49)
1989	1	***Phyllochaetopterus prolifica***	***Eudorella pacifica***	***Aphelochaeta sp N1***	***Phyllochaetopterus prolifica***	***Pinnixa schmitti***
1989	2	***Eudorella pacifica***	***Eudorellopsis integra***	***Axinopsida serricata***	***Prionospio Cmplx*** *	***Paraprionospio pinnata***
1989	3	***Aphelochaeta sp N1***	***Euphilomedes producta***	***Prionospio Cmplx*** *	***Pinnixa schmitti***	***Nemertina***
1989	4	***Scoletoma luti***	***Pectinaria californiensis***	***Euphilomedes carcharodonta***	***Spiophanes berkeleyorum***	***Nephtys cornuta***
1989	5	***Pinnixa sp***	***Heterophoxus sp***	***Notomastus sp***	***Macoma yoldiformis***	***Spiophanes berkeleyorum***
1989	6	***Paraprionospio pinnata***	***Macoma sp***	***Chaetozone nr setosa***	***Spiochaetopterus costarum***	***Aphelochaeta sp***
1989	7	***Heterophoxus sp***	***Protomedeia prudens***	***Euphilomedes producta***	***Nemertina***	***Sigambra nr bassi***
1989	8	***Lumbrineris sp***	***Levinsenia gracilis***	***Lumbrineris sp***	***Mediomastus sp***	***Amphiodia Cmplx*** **
1989	9	***Lumbrineris cruzensis***	***Molpadia intermedia***	***Macoma yoldiformis***	***Neosabellaria cementarium***	*Podarkeopsis glabrus*
1989	10	*Terebellides sp*	*Cossura bansei*	***Scoletoma luti***	***Lumbrineris californiensis***	*Odostomia sp*
		TR=101, SDI=9	TR=68, SDI=9	TR=110, SDI=10	TR=183, SDI=26	TR=35, SDI=8
1990	1	***Aphelochaeta sp N1***	***Euphilomedes producta***	***Euphilomedes carcharodonta***	***Phyllochaetopterus prolifica***	***Pinnixa schmitti***
1990	2	***Phyllochaetopterus prolifica***	***Heterophoxus sp***	***Aphelochaeta sp N1***	***Spiophanes berkeleyorum***	***Spiophanes berkeleyorum***
1990	3	***Eudorella pacifica***	***Eudorella pacifica***	***Prionospio Cmplx*** *	***Spiochaetopterus costarum***	***Paraprionospio pinnata***
1990	4	***Lumbrineris cruzensis***	***Paraphoxus oculatus***	***Euphilomedes producta***	***Pinnixa schmitti***	***Podarkeopsis glabrus***
1990	5	***Scoletoma luti***	***Levinsenia gracilis***	***Axinopsida serricata***	***Prionospio Cmplx*** *	***Sigambra nr bassi***
1990	6	***Prionospio Cmplx*** *	***Eudorellopsis integra***	***Terebellidae***	***Mediomastus sp***	***Amphiodia Cmplx*** **
1990	7	***Pinnixa sp***	***Macoma carlottensis***	***Macoma carlottensis***	***Erichthonius rubricornis***	***Odostomia sp***
1990	8	***Paraprionospio pinnata***	***Protomedeia prudens***	***Mediomastus sp***	***Amphiodia Cmplx*** **	*Pholoe sp Cmplx*
1990	9	*Heterophoxus sp*	***Cossura bansei***	***Spiophanes berkeleyorum***	***Mesochaetopterus taylori***	*Nutricola lordi*
1990	10	*Odostomia sp*	***Harpiniopsis fulgens***	***Nephtys ferruginea***	***Lumbrineris californiensis***	*Macoma nasuta*
		TR=84, SDI=8	TR=48, SDI=11	TR=111, SDI=15	TR=178, SDI=25	TR=36, SDI=7
1991	1	***Phyllochaetopterus prolifica***	***Macoma carlottensis***	***Axinopsida serricata***	***Phyllochaetopterus prolifica***	***Paraprionospio pinnata***
1991	2	***Aphelochaeta sp N1***	***Euphilomedes producta***	***Euphilomedes carcharodonta***	***Spiophanes berkeleyorum***	***Pinnixa schmitti***
1991	3	***Heterophoxus sp***	***Eudorella pacifica***	***Aphelochaeta sp N1***	***Spiochaetopterus costarum***	***Spiophanes berkeleyorum***
1991	4	***Eudorella pacifica***	***Pectinaria californiensis***	***Euphilomedes producta***	***Prionospio Cmplx*** *	***Sigambra nr bassi***
1991	5	***Pinnixa sp***	***Protomedeia prudens***	***Macoma carlottensis***	***Mediomastus sp***	***Nutricola lordi***
1991	6	*Lumbrineris cruzensis*	***Eudorellopsis integra***	***Scoletoma luti***	***Pinnixa schmitti***	***Nemertina***
1991	7	*Scoletoma luti*	***Heterophoxus sp***	***Mediomastus sp***	***Lumbrineris californiensis***	***Podarkeopsis glabrus***
1991	8	*Paraprionospio pinnata*	***Chaetoderma sp***	***Leptochelia savignyi***	***Euphilomedes carcharodonta***	*Odostomia sp*
1991	9	*Dipolydora socialis/cardalia*	*Paraprionospio pinnata*	***Notomastus hemipodus***	***Pholoides asperus***	*Nephtys cornuta*
1991	10	*Cirratulidae*	*Paraphoxus oculatus*	***Terebellidae***	***Leitoscoloplos pugettensis***	*Amphiodia Cmplx***
		TR=97, SDI=5	TR=59, SDI=8	TR=119, SDI=16	TR=189, SDI=37	TR=36, SDI=7

Year	Rank	Sinclair Inlet (34)	Point Pully (38)	Thea Foss Waterway (40)	East Anderson Island (44)	Inner Budd Inlet (49)
1992	1	***Phyllochaetopterus prolifica***	***Macoma carlottensis***	***Aphelochaeta sp N1***	***Spiochaetopterus costarum***	***Paraprionospio pinnata***
1992	2	***Aphelochaeta sp N1***	***Eudorella pacifica***	***Axinopsida serricata***	***Prionospio Cmplx****	***Cylichnidae***
1992	3	***Circeis armoricana***	***Pectinaria californiensis***	***Euphilomedes carcharodonta***	***Pinnixa schmitti***	***Sigambra nr bassi***
1992	4	***Heterophoxus sp***	***Axinopsida serricata***	***Euphilomedes producta***	***Mediomastus sp***	***Odostomia sp***
1992	5	***Eudorella pacifica***	***Euphilomedes producta***	***Macoma sp***	***Phyllochaetopterus prolifica***	***Pinnixa schmitti***
1992	6	*Scoletoma luti*	***Protomedeia prudens***	***Prionospio Cmplx****	***Spiophanes berkeleyorum***	***Nutricola lordi***
1992	7	*Lumbrineris cruzensis*	*Macoma sp*	***Pectinaria californiensis***	***Amphiodia Cmplx*****	***Spiophanes berkeleyorum***
1992	8	*Dipolydora socialis/cardalia*	*Heterophoxus sp*	***Lumbrineris sp***	***Rochefortia tumida***	***Astyris gausapata***
1992	9	*Prionospio Cmplx**	*Harpiniopsis fulgens*	***Mediomastus sp***	***Diopatra ornata***	*Macoma nasuta*
1992	10	*Paraprionospio pinnata*	*Paraphoxus oculatus*	***Neotrypaea gigas***	***Euphilomedes carcharodonta***	*Nassarius mendicus*
		TR=106, SDI=5	TR=51, SDI=6	TR=133, SDI=17	TR=204, SDI=37	TR=43, SDI=8
1993	1	***Aphelochaeta sp N1***	***Macoma sp***	***Axinopsida serricata***	***Euphilomedes carcharodonta***	***Paraprionospio pinnata***
1993	2	***Phyllochaetopterus prolifica***	***Eudorella pacifica***	***Macoma sp***	***Spiochaetopterus costarum***	***Sigambra nr bassi***
1993	3	***Paraprionospio pinnata***	***Euphilomedes producta***	***Euphilomedes producta***	***Prionospio Cmplx****	*Lineidae*
1993	4	***Eudorella pacifica***	***Pectinaria californiensis***	***Euphilomedes carcharodonta***	***Pinnixa schmitti***	*Pinnixa schmitti*
1993	5	***Lumbrineris cruzensis***	***Heterophoxus sp***	***Prionospio Cmplx****	***Amphiodia sp***	*Pinnixa sp*
1993	6	***Scoletoma luti***	***Protomedeia sp***	***Notomastus hemipodus***	***Amphiodia Cmplx*****	*Podarkeopsis glabrus*
1993	7	***Prionospio Cmplx****	***Axinopsida serricata***	***Spiochaetopterus costarum***	***Heterophoxus sp***	*Odostomia sp*
1993	8	***Pinnixa sp***	***Eudorellopsis integra***	***Amphiuridae***	***Mediomastus sp***	*Astyris gausapata*
1993	9	*Heterophoxus sp*	*Prionospio lighti*	***Lumbrineris californiensis***	***Lineidae***	*Spiophanes berkeleyorum*
1993	10	*Dipolydora socialis/cardalia*	*Levinsenia gracilis*	***Pinnixa schmitti***	***Mesochaetopterus taylori***	*Glycinde polygnatha*
		TR=98, SDI=8	TR=56, SDI=8	TR=140, SDI=19	TR=188, SDI=32	TR=40, SDI=2
1994	1	***Phyllochaetopterus prolifica***	***Eudorella pacifica***	***Bivalvia***	***Euphilomedes carcharodonta***	***Paraprionospio pinnata***
1994	2	***Aphelochaeta sp N1***	***Eudorellopsis integra***	***Euphilomedes carcharodonta***	***Spiochaetopterus costarum***	***Aphelochaeta sp N1***
1994	3	***Paraprionospio pinnata***	***Euphilomedes producta***	***Euphilomedes producta***	***Prionospio Cmplx****	***Pinnixa schmitti***
1994	4	***Prionospio lighti***	***Heterophoxus affinis***	***Axinopsida serricata***	***Amphiodia Cmplx*****	***Sigambra nr bassi***
1994	5	*Eudorella pacifica*	***Levinsenia gracilis***	***Prionospio Cmplx****	***Lumbrineris californiensis***	***Spiophanes berkeleyorum***
1994	6	*Heterophoxus conlanae*	***Paraprionospio pinnata***	***Notomastus hemipodus***	***Pinnixa schmitti***	***Eteone spilotus***
1994	7	*Lumbrineris cruzensis*	***Heterophoxus ellisi***	***Spiochaetopterus costarum***	***Diopatra ornata***	***Terebellides californica***
1994	8	*Prionospio Cmplx**	***Cossura sp***	***Mediomastus sp***	***Mediomastus sp***	*Prionospio lighti*
1994	9	*Alvania compacta*	***Molpadia intermedia***	***Asabellides lineata***	***Prionospio lighti***	*Rochefortia tumida*
1994	10	*Pinnixa schmitti*	***Ennucula tenuis***	***Amphiodia Cmplx*****	***Eumida longicornuta***	*Ocenebra sp*
		TR=84, SDI=4	TR=41, SDI=11	TR=141, SDI=27	TR=175, SDI=33	TR=40, SDI=7

Year	Rank	Sinclair Inlet (34)	Point Pully (38)	Thea Foss Waterway (40)	East Anderson Island (44)	Inner Budd Inlet (49)
1995	1	***Phyllochaetopterus prolifica***	***Macoma carlottensis***	***Axinopsida serricata***	***Pinnixa schmitti***	***Paraprionospio pinnata***
1995	2	***Aphelochaeta sp N1***	***Eudorella pacifica***	***Euphilomedes carcharodonta***	***Amphiodia Cmplx******	***Sigambra nr bassi***
1995	3	***Paraprionospio pinnata***	***Euphilomedes producta***	***Prionospio Cmplx****	***Euphilomedes carcharodonta***	***Aphelochaeta sp N1***
1995	4	*Circeis sp*	***Paraprionospio pinnata***	***Amphiuridae***	***Prionospio Cmplx****	*Odostomia sp*
1995	5	*Prionospio lighti*	***Heterophoxus affinis***	***Euphilomedes producta***	***Spiochaetopterus costarum***	*Crangon alaskensis*
1995	6	*Dipolydora socialis/cardalia*	***Axinopsida serricata***	***Notomastus hemipodus***	***Mesochaetopterus taylori***	*Podarkeopsis glabrus*
1995	7	*Scoletoma luti*	***Cossura bansei***	***Spiochaetopterus costarum***	***Amphiodia sp***	*Pinnixa schmitti*
1995	8	*Pinnixa schmitti*	***Macoma sp***	***Amphiodia Cmplx******	***Mediomastus sp***	*Prionospio lighti*
1995	9	*Heterophoxus affinis*	***Protomedeia sp***	***Mediomastus sp***	***Heterophoxus conlanae***	*Macoma nasuta*
1995	10	*Lumbrineris cruzensis*	***Prionospio lighti***	***Pinnixa schmitti***	***Diopatra ornata***	*Macoma yoldiformis*
		TR=79, SDI=3	TR=47, SDI=10	TR=138, SDI=22	TR=165, SDI=29	TR=22, SDI=3
1996	1		***Macoma carlottensis***			
1996	2		***Eudorella pacifica***			
1996	3		***Cossura bansei***			
1996	4		***Axinopsida serricata***			
1996	5		***Levinsenia oculata***			
1996	6		***Nippoleucon hinumensis***			
1996	7		***Heterophoxus affinis***			
1996	8		***Paraprionospio pinnata***			
1996	9		*Levinsenia gracilis*			
1996	10		*Prionospio lighti*			
			TR=43, SDI=8			
1997	1	***Phyllochaetopterus prolifica***	***Axinopsida serricata***	***Axinopsida serricata***	***Pinnixa schmitti***	***Paraprionospio pinnata***
1997	2	***Aphelochaeta sp N1***	***Macoma carlottensis***	***Amphiodia Cmplx******	***Amphiodia Cmplx******	***Odostomia sp***
1997	3	***Prionospio lighti***	***Eudorella pacifica***	***Euphilomedes carcharodonta***	***Euphilomedes carcharodonta***	***Pinnixa schmitti***
1997	4	*Eudorella pacifica*	***Eudorellopsis integra***	***Pinnixa schmitti***	***Mesochaetopterus taylori***	***Spiophanes berkeleyorum***
1997	5	*Paraprionospio pinnata*	***Cossura bansei***	***Euphilomedes producta***	***Mediomastus sp***	***Sigambra nr bassi***
1997	6	*Lumbrineris cruzensis*	***Protomedeia prudens***	***Prionospio lighti***	***Astyris gausapata***	*Nephtys cornuta*
1997	7	*Pinnixa schmitti*	***Prionospio lighti***	***Notomastus hemipodus***	***Spiochaetopterus costarum***	*Macoma nasuta*
1997	8	*Dipolydora socialis/cardalia*	***Molpadia intermedia***	***Mediomastus sp***	***Diopatra ornata***	*Podarkeopsis glabrus*
1997	9	*Heterophoxus affinis*	***Harpiniopsis fulgens***	***Prionospio Cmplx****	***Clymenura gracilis***	*Prionospio lighti*
1997	10	*Amphiodia Cmplx****	***Euphilomedes producta***	***Macoma carlottensis***	***Euclymeninae***	*Glycinde polygnatha*
		TR=67, SDI=3	TR=56, SDI=11	TR=117, SDI=12	TR=135, SDI=17	TR=26, SDI=5

Year	Rank	Sinclair Inlet (34)	Point Pully (38)	Thea Foss Waterway (40)	East Anderson Island (44)	Inner Budd Inlet (49)
1998	1	___Phyllochaetopterus prolifica___	___Axinopsida serricata___	___Axinopsida serricata___	___Euphilomedes carcharodonta___	___Aphelochaeta sp N1___
1998	2	___Prionospio lighti___	___Macoma carlottensis___	___Amphiodia Cmplx**___	___Mediomastus sp___	___Paraprionospio pinnata___
1998	3	___Aphelochaeta sp N1___	___Prionospio lighti___	___Rochefortia tumida___	___Pinnixa schmitti___	___Pinnixa schmitti___
1998	4	___Eudorella pacifica___	___Levinsenia gracilis___	___Amphiodia sp___	___Heterophoxus oculatus___	___Macoma nasuta___
1998	5	_Paraprionospio pinnata_	___Cossura bansei___	___Prionospio lighti___	___Parvilucina tenuisculpta___	___Sigambra nr bassi___
1998	6	_Heterophoxus affinis_	___Euphilomedes producta___	___Notomastus hemipodus___	___Platynereis bicanaliculata___	___Acteocina culcitella___
1998	7	_Astyris gausapata_	___Macoma sp___	___Pinnixa schmitti___	___Onuphis elegans___	___Odostomia sp___
1998	8	_Dipolydora socialis/cardalia_	___Eudorella pacifica___	___Prionospio Cmplx*___	___Amphiodia Cmplx**___	___Podarkeopsis glabrus___
1998	9	_Lumbrineris cruzensis_	___Paraphoxus sp A___	___Euphilomedes carcharodonta___	___Macoma sp___	_Nephtys cornuta_
1998	10	_Rochefortia tumida_	_Paraprionospio pinnata_	___Macoma carlottensis___	___Amphiodia sp___	_Spiophanes berkeleyorum_
		TR=65, SDI=4	TR=45, SDI=9	TR=120, SDI=10	TR=112, SDI=24	TR=27, SDI=8
1999	1	___Phyllochaetopterus prolifica___	___Axinopsida serricata___	___Axinopsida serricata___	___Euphilomedes carcharodonta___	___Paraprionospio pinnata___
1999	2	___Prionospio lighti___	___Macoma carlottensis___	___Euphilomedes carcharodonta___	___Prionospio Cmplx*___	___Aphelochaeta sp N1___
1999	3	___Paraprionospio pinnata___	___Euphilomedes producta___	___Amphiodia Cmplx**___	___Amphiodia Cmplx**___	___Prionospio lighti___
1999	4	___Aphelochaeta sp N1___	___Eudorellopsis integra___	___Rochefortia tumida___	___Dipolydora socialis/cardalia___	___Nephtys cornuta___
1999	5	___Eudorella pacifica___	___Levinsenia oculata___	___Euphilomedes producta___	___Mediomastus sp___	___Sigambra nr bassi___
1999	6	___Caprella mendax___	___Cossura bansei___	___Notomastus hemipodus___	___Leitoscoloplos pugettensis___	_Pinnixa schmitti_
1999	7	___Lumbrineris cruzensis___	___Paraprionospio pinnata___	___Aphelochaeta sp N1___	___Scoletoma luti___	_Podarkeopsis glabrus_
1999	8	___Amphiodia Cmplx**___	___Eudorella pacifica___	___Astyris gausapata___	___Magelona longicornis___	_Macoma nasuta_
1999	9	___Pinnixa schmitti___	___Prionospio lighti___	___Euclymeninae___	___Lumbrineris californiensis___	_Odostomia sp_
1999	10	_Scoletoma luti_	_Heterophoxus conlanae_	___Pinnixa schmitti___	___Astyris gausapata___	_Micrura sp_
		TR=43, SDI=9	TR=49, SDI=9	TR=110, SDI=11	TR=105, SDI=28	TR=23, SDI=5
2000	1	___Phyllochaetopterus prolifica___	___Axinopsida serricata___	___Axinopsida serricata___	___Euphilomedes carcharodonta___	___Odostomia sp___
2000	2	___Prionospio lighti___	___Macoma carlottensis___	___Aphelochaeta sp N1___	___Euclymene cf zonalis___	___Sigambra nr bassi___
2000	3	___Eudorella pacifica___	___Euphilomedes producta___	___Euphilomedes producta___	___Anobothrus gracilis___	___Paraprionospio pinnata___
2000	4	___Dipolydora socialis/cardalia___	___Macoma sp___	___Amphiodia Cmplx**___	___Scoletoma luti___	___Macoma nasuta___
2000	5	___Paraprionospio pinnata___	___Ampharete cf crassiseta___	___Rochefortia tumida___	___Dipolydora socialis/cardalia___	___Astyris gausapata___
2000	6	_Pinnixa schmitti_	___Levinsenia oculata___	___Macoma carlottensis___	___Mediomastus sp___	___Nassarius mendicus___
2000	7	_Amphiodia Cmplx**_	_Nippoleucon hinumensis_	___Euphilomedes carcharodonta___	___Prionospio Cmplx*___	___Spiophanes berkeleyorum___
2000	8	_Scoletoma luti_	_Eudorella pacifica_	___Pinnixa schmitti___	___Amphiodia Cmplx**___	___Haminoea vesicula___
2000	9	_Heterophoxus conlanae_	_Pectinaria californiensis_	___Rhodine bitorquata___	___Leitoscoloplos pugettensis___	___Nephtys cornuta___
2000	10	_Circeis spirillum_	_Paraprionospio pinnata_	___Notomastus hemipodus___	___Pinnixa schmitti___	___Podarkeopsis glabrus___
		TR=66, SDI=5	TR=52, SDI=6	TR=131, SDI=13	TR=123, SDI=30	TR=32, SDI=11

* Prionospio Cmplx = Prionospio steenstrupi and Prionospio jubata

** Amphiodia Cmplx = Amphiodia urtica and Amphiodia periercta

Table 16. Indices of infaunal community diversity and evenness, by year for each station.

Station	Year	Shannon-Wiener Diversity, H'	Pielou's Evenness, J'	Taxa Richness (number of taxa)	Swartz' Dominance Index (number of taxa)	SDI standardized by taxa richness (%)
Strait of Georgia (3)	1989	1.30	0.66	93	9	9.7%
	1990	1.14	0.75	34	8	23.5%
	1991	1.14	0.70	43	7	16.3%
	1992	0.96	0.54	59	4	6.8%
	1993	1.03	0.61	49	6	12.2%
	1994	1.18	0.79	32	8	25.0%
	1995	1.13	0.69	44	8	18.2%
	1996	not sampled				
	1997	0.62	0.41	31	2	6.5%
	1998	0.94	0.66	27	5	18.5%
	1999	0.99	0.66	31	5	16.1%
	2000	0.73	0.44	45	3	6.7%
Bellingham Bay (4)	1989	1.41	0.74	80	14	17.5%
	1990	1.28	0.66	87	8	9.2%
	1991	1.11	0.64	56	6	10.7%
	1992	1.33	0.69	83	13	15.7%
	1993	1.37	0.75	69	12	17.4%
	1994	1.40	0.76	70	13	18.6%
	1995	1.33	0.72	72	13	18.1%
	1996	not sampled				
	1997	1.14	0.70	43	7	16.3%
	1998	1.26	0.75	47	11	23.4%
	1999	1.28	0.73	57	11	19.3%
	2000	1.36	0.75	64	13	20.3%
North Hood Canal (13R)	1989	0.80	0.37	145	3	2.1%
	1990	not sampled				
	1991	0.71	0.34	119	2	1.7%
	1992	not sampled				
	1993	not sampled				
	1994	0.91	0.42	147	4	2.7%
	1995	not sampled				
	1996	not sampled				
	1997	0.67	0.30	183	2	1.1%
	1998	0.60	0.26	190	1	0.5%
	1999	1.07	0.50	137	5	3.6%
	2000	1.37	0.60	190	15	7.9%

Station	Year	Shannon-Wiener Diversity, H'	Pielou's Evenness, J'	Taxa Richness (number of taxa)	Swartz' Dominance Index (number of taxa)	SDI standardized by taxa richness (%)
Port Gardner (21)	1989	1.02	0.51	98	4	4.1%
	1990	1.11	0.59	78	6	7.7%
	1991	1.12	0.61	69	7	10.1%
	1992	1.11	0.56	99	6	6.1%
	1993	1.08	0.57	81	6	7.4%
	1994	1.20	0.63	83	8	9.6%
	1995	1.15	0.59	90	8	8.9%
	1996	1.11	0.60	70	8	11.4%
	1997	1.22	0.65	75	8	10.7%
	1998	1.33	0.70	79	11	13.9%
	1999	1.17	0.61	81	7	8.6%
	2000	1.24	0.65	82	9	11.0%
Shilshole (29)	1989	1.24	0.66	75	10	13.3%
	1990	0.91	0.49	75	5	6.7%
	1991	0.79	0.44	66	4	6.1%
	1992	0.69	0.38	66	3	4.5%
	1993	0.73	0.40	64	2	3.1%
	1994	0.89	0.52	53	4	7.5%
	1995	1.01	0.57	58	7	12.1%
	1996	0.64	0.37	50	2	4.0%
	1997	0.85	0.51	45	5	11.1%
	1998	1.01	0.59	52	7	13.5%
	1999	0.82	0.48	48	3	6.3%
	2000	0.96	0.53	66	5	7.6%
Sinclair Inlet (34)	1989	1.25	0.63	101	9	8.9%
	1990	1.25	0.65	84	8	9.5%
	1991	0.80	0.40	97	5	5.2%
	1992	0.92	0.45	106	5	4.7%
	1993	1.15	0.58	98	8	8.2%
	1994	0.84	0.44	84	4	4.8%
	1995	0.72	0.38	79	3	3.8%
	1996	not sampled				
	1997	0.87	0.47	67	3	4.5%
	1998	0.83	0.46	65	4	6.2%
	1999	1.17	0.72	43	9	20.9%
	2000	0.98	0.54	66	5	7.6%
Point Pully (38)	1989	1.31	0.71	68	9	13.2%
	1990	1.33	0.79	48	11	22.9%
	1991	1.13	0.64	59	8	13.6%
	1992	1.06	0.62	51	6	11.8%
	1993	1.13	0.65	56	8	14.3%
	1994	1.29	0.80	41	11	26.8%
	1995	1.25	0.75	47	10	21.3%
	1996	1.21	0.74	43	8	18.6%
	1997	1.25	0.71	56	11	19.6%
	1998	1.24	0.75	45	9	20.0%
	1999	1.23	0.73	49	9	18.4%
	2000	1.02	0.59	52	6	11.5%

Station	Year	Shannon-Wiener Diversity, H'	Pielou's Evenness, J'	Taxa Richness (number of taxa)	Swartz' Dominance Index (number of taxa)	SDI standardized by taxa richness (%)
Thea Foss Waterway (40)	1989	1.22	0.60	110	10	9.1%
	1990	1.41	0.69	111	15	13.5%
	1991	1.43	0.69	119	16	13.4%
	1992	1.46	0.69	133	17	12.8%
	1993	1.56	0.73	140	19	13.6%
	1994	1.66	0.77	141	27	19.1%
	1995	1.65	0.77	138	22	15.9%
	1996	not sampled				
	1997	1.34	0.65	117	12	10.3%
	1998	1.25	0.60	120	10	8.3%
	1999	1.31	0.64	110	11	10.0%
	2000	1.37	0.65	131	13	9.9%
East Anderson Island (44)	1989	1.65	0.73	183	26	14.2%
	1990	1.55	0.69	178	25	14.0%
	1991	1.85	0.81	189	37	19.6%
	1992	1.80	0.78	204	37	18.1%
	1993	1.75	0.77	188	32	17.0%
	1994	1.75	0.78	175	33	18.9%
	1995	1.68	0.76	165	29	17.6%
	1996	not sampled				
	1997	1.43	0.67	135	17	12.6%
	1998	1.55	0.76	112	24	21.4%
	1999	1.66	0.82	105	28	26.7%
	2000	1.62	0.78	123	30	24.4%
Inner Budd Inlet (49)	1989	1.13	0.73	35	8	22.9%
	1990	1.05	0.68	36	7	19.4%
	1991	1.13	0.73	36	7	19.4%
	1992	1.22	0.75	43	8	18.6%
	1993	0.57	0.36	40	2	5.0%
	1994	1.06	0.66	40	7	17.5%
	1995	0.77	0.57	22	3	13.6%
	1996	not sampled				
	1997	0.95	0.67	26	5	19.2%
	1998	1.10	0.77	27	8	29.6%
	1999	0.83	0.61	23	5	21.7%
	2000	1.27	0.84	32	11	34.4%

Table 17a. Indications of increasing or decreasing trend in infaunal community indices of abundance from the Mann-Kendall test of monotone trend. ↑, ↓ = significant at $\alpha = 0.05$; ↑↑, ↓↓ = significant at $\alpha = 0.01$; -- = no change.

Station	Strait of Georgia (3)	Bellingham Bay (4)	North Hood Canal (13R)	Port Gardner (21)	Shilshole (29)	Sinclair Inlet (34)	Point Pully (38)	Thea Foss Waterway (40)	East Anderson Island (44)	Inner Budd Inlet (49)
Total Abundance	--	--	--	--	--	--	--	↑↑	--	--
Annelida Abundance	--	--	--	--	--	--	↑↑	--	↓	--
Arthropoda Abundance	--	--	--	--	--	--	--	--	--	↓↓
Echino-dermata Abundance	--	--	--	--	↓↓	↑↑	--	↑	--	↓↓
Mollusca Abundance	--	--	--	--	--	--	--	↑	↓	--
Misc. Taxa Abundance	--	--	--	↑	--	--	↑	--	--	--

Table 17b. Indications of increasing or decreasing trend in infaunal community indices from the Mann-Kendall test of monotone trend. ↑, ↓ = significant at $\alpha = 0.05$; ↑↑, ↓↓ = significant at $\alpha = 0.01$; -- = no change.

Station	Strait of Georgia (3)	Bellingham Bay (4)	North Hood Canal (13R)	Port Gardner (21)	Shilshole (29)	Sinclair Inlet (34)	Point Pully (38)	Thea Foss Waterway (40)	East Anderson Island (44)	Inner Budd Inlet (49)
Shannon-Wiener Diversity, H'	↓	--	--	↑↑	--	--	--	--	--	--
Pielou's Evenness, J'	--	--	--	↑↑	--	--	--	--	--	--
Taxa Richness	--	--	--	--	↓↓	↓↓	--	--	↓↓	--
Swartz' Dominance Index (SDI)	↓	--	--	↑↑	--	--	--	--	--	--
SDI, std. by taxa richness (SDISTD)	--	↑↑	--	↑	--	--	--	--	↑	--

Table 18a. Pearson correlation coefficients. Bold values indicate correlation coefficients significantly different from zero at α = 0.05 (Bonferroni-corrected). Footnotes indicate explanation of some of these results as determine examination of regression plots of the data.

	Depth	Salinity	Fines	TOC	Mean Metals SQS Quotient	Total PAH	Cholesterol	Total Abundance	Taxa Richness	Shannon-Wiener Diversity (H')	Swartz' Dominance Std. by Taxa Rich.	Annelids	Arthropods	Echinoderms	Molluscs	Misc. Taxa	*Ampelisca*
Depth	1.000																
Salinity	0.160	1.000															
Fines	0.325	0.102	1.000														
TOC	0.065	0.001	**0.824**	1.000													
Mean Metals SQS Quotient	-0.170	0.102	**0.616**	**0.624**	1.000												
Total PAH	-0.252	-0.111	-0.340	-0.147	-0.055	1.000											
Cholesterol	-0.055	0.303	0.359	0.422	0.288	-0.087	1.000										
Total Abundance	**-0.411**[1]	-0.063	**-0.458**	-0.340	0.212	0.147	-0.023	1.000									
Taxa Richness	**-0.457**[1]	-0.009	**-0.803**	**-0.647**	-0.275	0.253	-0.254	**0.595**	1.000								
Shannon-Wiener Diversity (H')	-0.293	0.033	**-0.375**	-0.334	-0.315	0.271	-0.080	-0.222	**0.475**	1.000							
Swartz' Dominance Std. by Taxa Rich.	0.019	0.114	0.137	0.117	-0.176	0.013	0.130	**-0.593**	-0.267	**0.568**	1.000						
Annelids	**-0.429**[1]	0.063	-0.085	0.014	**0.624**	0.169	0.177	**0.543**	0.295	-0.051	-0.330	1.000					
Arthropods	**-0.433**[1]	-0.195	**-0.503**	-0.371	-0.092	0.139	-0.155	**0.660**	**0.633**	0.151	**-0.453**	0.285	1.000				
Echinoderms	-0.286	0.006	-0.159	-0.096	-0.103	0.206	0.349	0.140	0.268	0.324	0.028	0.099	0.165	1.000			
Molluscs	-0.142	-0.089	**-0.423**	**-0.459**	-0.347	-0.022	-0.169	**0.814**	**0.433**	-0.324	**-0.483**	-0.023	**0.481**	-0.010	1.000		
Misc. Taxa	-0.299	0.050	**-0.544**	**-0.431**	-0.272	0.066	-0.108	**0.531**	**0.687**	0.238	-0.111	0.083	**0.399**	0.189	**0.532**[3]	1.000	
Ampelisca	-0.271	0.270	**-0.530**	-0.409	-0.203	-0.241	-0.102	0.040	**0.659**	**0.545**	0.297	0.182	0.023	0.197	-0.084	0.317	1.000
Amphiuridae	-0.253	0.014	-0.125	-0.124	-0.152	0.115	0.380	0.085	0.187	0.275	0.052	0.034	0.132	**0.998**[2]	-0.030	0.125	0.134
Aphelochaeta	-0.190	0.073	0.115	0.220	**0.506**	0.386	0.156	0.279	-0.026	-0.185	-0.272	**0.728**	0.032	-0.048	-0.124	-0.155	-0.126
Axinopsida	-0.334	-0.397	-0.242	-0.242	-0.214	0.185	-0.059	0.246	0.108	0.069	-0.206	-0.027	**0.477**	0.346	0.225	0.005	-0.244
Euphilomedes	**-0.454**[1]	-0.363	**-0.446**	-0.388	-0.289	0.145	-0.297	**0.540**	0.336	-0.053	**-0.416**	0.093	**0.879**	-0.026	**0.481**	0.203	-0.173
Rhepoxinius	-0.181	-0.759	0.220	0.038	0.024	-0.134	0.368	-0.218	-0.535	-0.029	-0.041	-0.276	0.141	-0.389	-0.111	-0.469	-0.326
Spiochaetopterus	-0.087	0.183	-0.335	-0.380	-0.252	-0.040	-0.038	-0.082	**0.623**	**0.603**	0.354	0.151	0.093	0.146	-0.220	0.295	**0.706**

[1] Stations fall into two depth categories: shallow stations ≤24m and deep stations ≥199m, therefore no data was available to validate the relationship for depths in between these two extremes.

[2] Amphiuridae was typically the only Echinoderm found at many stations

[3] Most of the Mollusca and Miscellaneous Taxa abundance data clustered at 0 or very low numbers. Three outlying data points appear to drive the correlation.

Table 18b. Pearson correlation coefficients for transformed variables. Bold indicates correlation coefficient significantly different from zero at $\alpha = 0.05$ (Bonferroni-corrected).

	Depth	Salinity	Fines (1)	TOC	Mean Metals SQS Quotient (2)	Total PAH (3)	Cholesterol (3)	Total Abundance (3)	Taxa Richness (2)	Shannon-Wiener Diversity (H')	Swartz' Dominance Std. by Taxa Rich.	Annelids (3)	Arthropods (2)	Echinoderms (4)	Molluscs (3)	Misc. Taxa (5)	*Ampelisca* (4)
Depth	1.000																
Salinity	0.160	1.000															
Fines (1)	0.313	0.116	1.000														
TOC	0.065	0.001	**0.820**	1.000													
Mean Metals SQS Quotient (2)	-0.118	0.068	**0.708**	**0.731**	1.000												
Total PAH (3)	-0.169	-0.187	0.124	0.275	0.324	1.000											
Cholesterol (3)	-0.007	0.290	**0.494**	**0.582**	0.480	0.329	1.000										
Total Abundance (3)	**-0.518**[1]	-0.052	**-0.487**	-0.384	-0.017	0.117	-0.138	1.000									
Taxa Richness (2)	**-0.460**[1]	-0.015	**-0.758**	**-0.634**	-0.363	-0.025	-0.380	**0.739**	1.000								
Shannon-Wiener Diversity (H')	-0.293	0.033	-0.342	-0.334	-0.335	0.086	-0.086	-0.018	**0.472**	1.000							
Swartz' Dominance Std. by Taxa Rich.	0.019	0.114	0.149	0.117	-0.115	0.001	0.168	**-0.661**	-0.317	**0.568**	1.000						
Annelids (3)	**-0.685**[1]	-0.049	**-0.377**	-0.243	0.170	0.183	0.119	**0.758**	**0.583**	0.197	-0.306	1.000					
Arthropods (2)	**-0.424**[1]	-0.142	**-0.499**	-0.374	-0.118	0.163	-0.198	**0.811**	**0.728**	0.197	**-0.478**	**0.519**	1.000				
Echinoderms (4)	**-0.389**[1]	0.246	-0.047	0.060	0.086	0.195	0.174	0.319	**0.446**	**0.490**	0.104	**0.379**	0.205	1.000			
Molluscs (3)	-0.145	-0.163	**-0.428**	**-0.447**	-0.391	-0.003	-0.357	**0.710**	**0.502**	-0.143	**-0.604**	0.165	**0.611**	0.014	1.000		
Misc. Taxa (5)	**-0.521**[1]	0.046	**-0.542**	-0.313	-0.240	0.056	-0.125	**0.486**	**0.745**	**0.461**	-0.019	**0.389**	**0.494**	**0.483**	0.318	1.000	
Ampelisca (4)	-0.306	0.254	**-0.545**	-0.397	-0.246	-0.348	0.055	0.190	**0.645**	**0.514**	0.287	0.387	0.097	0.453	-0.101	0.498	1.000
Amphiuridae (4)	**-0.523**[1]	0.243	-0.089	-0.059	-0.002	0.064	0.251	0.257	0.335	**0.481**	0.248	**0.448**	0.067	**0.970**[3]	-0.063	0.350	0.399
Aphelochaeta (4)	**-0.422**[1]	-0.160	0.042	0.137	0.409	**0.497**	0.217	0.306	0.048	0.039	-0.092	**0.688**	0.105	0.197	-0.212	-0.203	0.049
Axinopsida (3)	**-0.381**[1]	-0.280	-0.217	-0.241	-0.229	0.229	-0.121	**0.483**	0.214	0.055	-0.233	0.223	**0.457**	0.039	**0.701**	0.221	-0.218
Euphilomedes (5)	-0.401	-0.274	**-0.586**	**-0.516**	-0.446[2]	0.162	-0.448	**0.627**	**0.474**	0.019	**-0.405**	0.327	**0.835**	-0.215	**0.655**	0.299	-0.065
Rhepoxinius (2)	-0.199	-0.775	0.188	0.054	0.160	0.419	0.452	-0.041	-0.565	-0.051	-0.067	-0.234	0.214	-0.720	0.384	-0.480	-0.434
Spiochaetopterus (4)	-0.220	0.175	-0.201	-0.263	-0.082	-0.046	0.061	0.190	**0.540**	**0.527**	0.258	**0.560**	0.133	**0.513**	-0.327	0.376	0.567

(1) arcsine square-root transformation (2) square-root transformation (3) log transformation (4) double-log transformation (log10 (log10 (x+1)+1))(log10 (x+1)) (5) 4th-root transformation

[1] Stations fall into two depth categories: shallow stations ≤24m and deep stations ≥199m, therefore no data was available to validate the relationship for depths in between these two extremes.

[2] Regression appears to be driven by three data points

[3] Amphiuridae was typically the only Echinoderm found at many stations

[4] Regression appears to be driven by instances where many stations had no *Rhepoxinius* species.

Table 19. Statistically significant ($\alpha = 0.05$, Bonferroni-corrected) correlations between total, major taxa, and species abundances at individual PSAMP long-term sediment sampling stations. "+" indicates highly positive correlation ($r \geq 0.9$); "−" indicates highly negative correlation ($r \leq -0.9$). (No highly negative correlations were observed.)

Variables	Strait of Georgia (3)	Bellingham Bay (4)	North Hood Canal (13R)	Port Gardner (21)	Shilshole (29)	Sinclair Inlet (34)	Point Pully (38)	Thea Foss W'way (40)	E. Anderson Island (44)	Inner Budd Inlet (49)
Total abundance & Annelid abundance						+			+	
Total abundance & Mollusc abundance	+		+	+	+		+	+		
Total abundance & *Axinopsida* abundance							+			
Arthropod abundance & *Euphilomedes* abundance				+	+			+		
Echinoderm abundance & *Amphiodia* abundance		+		+		+		+	+	+
Mollusc abundance & *Axinopsida* abundance		+					+	+		

Table 20. Comparison of benzoic acid levels (detected results only) at the ten PSAMP long-term stations and nearby original PSAMP and PSAMP/NOAA stations.

Benzoic acid concentration (μg/kg)	PSAMP long-term stations 1989-1993	Other PSAMP stations 1989-1993	PSAMP long-term stations 2000	PSAMP/NOAA stations 1997-1999
Mean	41.4	51.7	437.6	2866.3
Standard deviation	22.6	32.4	144.3	3706.2
Median	33.5	44	445.5	2320
Minimum	1.1	14	207	117
Maximum	83.6	140	658	12900
N	28	30	10	10

Table 21. Comparison of sediment parameters from PSAMP/NOAA (Long *et al.*, 1999, 2000, 2002) and PSAMP Long-Term Sediment Monitoring Stations 4 (Bellingham Bay), 13R (North Hood Canal), 21 (Port Gardner), 29 (Shilshole), 34 (Sinclair Inlet), 38 (Point Pully), 40 (Thea Foss Waterway), 44 (East Anderson Island), and 49 (Inner Budd Inlet).

	PSAMP/NOAA		PSAMP Long-Term	
Variable	Station (Year)	Results	Station (2000)	Results
% Fines	36, 37 (1997)	96.7 - 98.2	4	93.6
	209, 210 (1999)	19.6 - 21.3	13R	11.1
	92, 93, 94, 95 (1997)	54.4 - 74.4	21	53.0
	113, 122, 127, 128, 129 (1998)	42.4 - 90.2	29	74.0
	160, 161, 162, 163, 164, 165 (1998)	86.8 - 96.2	34	88.8
	139, 140 (1998)	54.2 - 97.8	38	86.4
	295, 296 (1999)	65.8 - 66.1	40	26.5
	260, 261 (1999)	23.8 - 42.7	44	14.6
	242, 243 (1999)	78.2 - 78.3	49	70.0
% TOC	36, 37 (1997)	1.92 - 2	4	2.22
	209, 210 (1999)	0.48 - 0.6	13R	0.32
	92, 93, 94, 95 (1997)	1.21 - 6.2	21	0.97
	113, 122, 127, 128, 129 (1998)	1.02 - 1.9	29	1.88
	160, 161, 162, 163, 164, 165 (1998)	2.31 - 4.2	34	2.82
	139, 140 (1998)	1.35 - 2.3	38	2.4
	295, 296 (1999)	2.2 - 2.3	40	0.82
	260, 261 (1999)	0.69 - 1.3	44	0.45
	242, 243 (1999)	3.8 - 4	49	2.82
Benzoic acid	36, 37 (1997)	Undetected	4	566
(µg/kg dry weight)	209, 210 (1999)	110 - 117	13R	207
	92, 93, 94, 95 (1997)	535 - 801	21	300
	113, 122, 127, 128, 129 (1998)	2430 - 4110	29	433
	160, 161, 162, 163, 164, 165 (1998)	2210 - 12900	34	599
	139, 140 (1998)	3280 - 4210	38	458
	295, 296 (1999)	Undetected	40	365
	260, 261 (1999)	512 - 742	44	309
	242, 243 (1999)	962.5 - 962.5	49	658

	PSAMP/NOAA		PSAMP Long-Term	
Variable	Station (Year)	Results	Station (2000)	Results
Metals (mg/kg dry weight)				
Arsenic	36, 37 (1997)	6.38 - 8.7	4	7.1
	209, 210 (1999)	3.91 - 4.8	13R	2.5
	92, 93, 94, 95 (1997)	7.35 - 205	21	7.1
	113, 122, 127, 128, 129 (1998)	6.49 - 6.8	29	6.2
	160, 161, 162, 163, 164, 165 (1998)	9.95 - 13.4	34	10.2
	139, 140 (1998)	8.82 - 10.4	38	8.9
	295, 296 (1999)	9.63 - 11.0	40	4.4
	260, 261 (1999)	8.12 - 10.4	44	3.3
	242, 243 (1999)	7.11 - 7.6	49	9.6
Cadmium	36, 37 (1997)	Undetected	4	Undetected
	209, 210 (1999)	0.13 - 0.1	13R	Undetected
	92, 93, 94, 95 (1997)	1 - 1.1	21	Undetected
	113, 122, 127, 128, 129 (1998)	0.21 - 0.4	29	Undetected
	160, 161, 162, 163, 164, 165 (1998)	0.61 - 1.7	34	0.9
	139, 140 (1998)	0.3 - 0.4	38	Undetected
	295, 296 (1999)	0.5 - 0.54	40	Undetected
	260, 261 (1999)	0.21 - 0.3	44	Undetected
	242, 243 (1999)	1.9 - 2.2	49	1
Chromium	36, 37 (1997)	46.5 - 62.8	4	51
	209, 210 (1999)	23.3 - 23.5	13R	19.6
	92, 93, 94, 95 (1997)	39.1 - 50.4	21	34.9
	113, 122, 127, 128, 129 (1998)	35.1 - 39.8	29	40.8
	160, 161, 162, 163, 164, 165 (1998)	44.1 - 55.2	34	52.5
	139, 140 (1998)	32.5 - 40.4	38	43.2
	295, 296 (1999)	20.6 - 21.7	40	13
	260, 261 (1999)	17.8 - 19.3	44	20
	242, 243 (1999)	34.4 - 35.6	49	33.1
Copper	36, 37 (1997)	33.4 - 44.3	4	31.3
	209, 210 (1999)	7.59 - 7.7	13R	4.3
	92, 93, 94, 95 (1997)	29.7 - 464	21	26.5
	113, 122, 127, 128, 129 (1998)	22.2 - 32.6	29	28.1
	160, 161, 162, 163, 164, 165 (1998)	94.8 - 130	34	99.3
	139, 140 (1998)	28.9 - 46.3	38	40.1
	295, 296 (1999)	69.2 - 75.0	40	31
	260, 261 (1999)	15.2 - 26.6	44	10.9
	242, 243 (1999)	72.7 - 78	49	43.5

	PSAMP/NOAA		PSAMP Long-Term	
Variable	Station (Year)	Results	Station (2000)	Results
Lead	36, 37 (1997)	8 - 8.8	4	16
	209, 210 (1999)	4.77 - 5.4	13R	3.6
	92, 93, 94, 95 (1997)	5.2 - 190	21	8.8
	113, 122, 127, 128, 129 (1998)	13.2 - 22	29	18
	160, 161, 162, 163, 164, 165 (1998)	66.9 - 96	34	66.7
	139, 140 (1998)	19.5 - 34.3	38	31.7
	295, 296 (1999)	67.7 - 69.7	40	17
	260, 261 (1999)	13.6 - 19	44	9.7
	242, 243 (1999)	31.7 - 50.2	49	21.9
Manganese	36, 37 (1997)	287 - 363	4	318
	209, 210 (1999)	229 - 239	13R	183
	92, 93, 94, 95 (1997)	268 - 341	21	247
	113, 122, 127, 128, 129 (1998)	342 - 401	29	414
	160, 161, 162, 163, 164, 165 (1998)	217 - 248	34	275
	139, 140 (1998)	566 - 655	38	598
	295, 296 (1999)	136 - 161	40	109
	260, 261 (1999)	369 - 412	44	263
	242, 243 (1999)	220 - 235	49	238
Mercury	36, 37 (1997)	0.11 - 0.2	4	0.1
	209, 210 (1999)	0.02 - 0.03	13R	0.014
	92, 93, 94, 95 (1997)	0.08 - 0.2	21	0.045
	113, 122, 127, 128, 129 (1998)	0.06 - 0.2	29	0.1
	160, 161, 162, 163, 164, 165 (1998)	0.61 - 0.9	34	0.6
	139, 140 (1998)	0.13 - 0.2	38	0.2
	295, 296 (1999)	0.3 - 0.33	40	0.1
	260, 261 (1999)	0.06 - 0.1	44	0.032
	242, 243 (1999)	0.16 - 0.2	49	0.2
Silver	36, 37 (1997)	1 - 1.1	4	0.3
	209, 210 (1999)	Undetected	13R	Undetected
	92, 93, 94, 95 (1997)	0.39 - 0.7	21	0.1
	113, 122, 127, 128, 129 (1998)	0.25 - 0.4	29	0.3
	160, 161, 162, 163, 164, 165 (1998)	1.04 - 1.9	34	1.1
	139, 140 (1998)	0.65 - 0.7	38	0.5
	295, 296 (1999)	0.81 - 0.83	40	0.2
	260, 261 (1999)	0.24 - 0.3	44	Undetected
	242, 243 (1999)	0.76 - 0.8	49	0.5

Variable	PSAMP/NOAA Station (Year)	PSAMP/NOAA Results	PSAMP Long-Term Station (2000)	PSAMP Long-Term Results
Zinc	36, 37 (1997)	78.7 - 91.4	4	88.3
	209, 210 (1999)	41.2 - 41.9	13R	27.7
	92, 93, 94, 95 (1997)	55.3 - 776	21	55.3
	113, 122, 127, 128, 129 (1998)	63.4 - 83	29	86.5
	160, 161, 162, 163, 164, 165 (1998)	120 - 153	34	129
	139, 140 (1998)	63.9 - 90.7	38	95.3
	295, 296 (1999)	79.8 - 87.0	40	34.2
	260, 261 (1999)	51.9 - 66.8	44	33.1
	242, 243 (1999)	102.5 - 122	49	74.3
LPAHs (µg/kg dry weight)				
2-Methylnaphthalene	36, 37 (1997)	27 - 42	4	27
	209, 210 (1999)	17.5 - 19	13R	4.1
	92, 93, 94, 95 (1997)	11 - 287	21	19
	113, 122, 127, 128, 129 (1998)	26 - 55	29	27
	160, 161, 162, 163, 164, 165 (1998)	24 - 31	34	18
	139, 140 (1998)	24 - 47	38	20
	295, 296 (1999)	310.67 - 373	40	100
	260, 261 (1999)	17 - 17	44	3.6
	242, 243 (1999)	65 - 99	49	25
Acenaphthene	36, 37 (1997)	2 - 6.7	4	Undetected
	209, 210 (1999)	2.8 - 3.3	13R	Undetected
	92, 93, 94, 95 (1997)	6 - 597	21	11
	113, 122, 127, 128, 129 (1998)	5.2 - 11	29	Undetected
	160, 161, 162, 163, 164, 165 (1998)	7.5 - 15	34	7.5
	139, 140 (1998)	Undetected	38	Undetected
	295, 296 (1999)	137.67 - 162	40	61
	260, 261 (1999)	5 - 5.2	44	Undetected
	242, 243 (1999)	24 - 34	49	11
Acenaphthylene	36, 37 (1997)	4.1 - 16	4	6
	209, 210 (1999)	14 - 16	13R	2.6
	92, 93, 94, 95 (1997)	9.9 - 105	21	9.1
	113, 122, 127, 128, 129 (1998)	15 - 90	29	8.7
	160, 161, 162, 163, 164, 165 (1998)	13 - 28	34	20
	139, 140 (1998)	6.6 - 14	38	7
	295, 296 (1999)	214.67 - 278	40	170
	260, 261 (1999)	7.9 - 10	44	2.5
	242, 243 (1999)	36 - 49	49	12

Variable	PSAMP/NOAA Station (Year)	PSAMP/NOAA Results	PSAMP Long-Term Station (2000)	PSAMP Long-Term Results
Anthracene	36, 37 (1997)	6.2 - 19	4	6
	209, 210 (1999)	5.7 - 7.8	13R	1.2
	92, 93, 94, 95 (1997)	28 - 753	21	21
	113, 122, 127, 128, 129 (1998)	21 - 128	29	14
	160, 161, 162, 163, 164, 165 (1998)	34 - 64	34	40
	139, 140 (1998)	16 - 28	38	16
	295, 296 (1999)	441.33 - 602	40	567
	260, 261 (1999)	7.3 - 11	44	4.3
	242, 243 (1999)	107 - 132	49	24
Fluorene	36, 37 (1997)	10 - 19	4	13
	209, 210 (1999)	7.05 - 8.5	13R	3.2
	92, 93, 94, 95 (1997)	18 - 814	21	17
	113, 122, 127, 128, 129 (1998)	15 - 38	29	15
	160, 161, 162, 163, 164, 165 (1998)	16 - 25	34	16
	139, 140 (1998)	11 - 19	38	13
	295, 296 (1999)	227.67 - 281	40	134
	260, 261 (1999)	6.1 - 6.2	44	4.3
	242, 243 (1999)	47 - 90	49	17
Naphthalene	36, 37 (1997)	25 - 108	4	31
	209, 210 (1999)	35 - 50	13R	6
	92, 93, 94, 95 (1997)	14 - 526	21	56
	113, 122, 127, 128, 129 (1998)	34 - 104	29	23
	160, 161, 162, 163, 164, 165 (1998)	33 - 55	34	23
	139, 140 (1998)	25 - 48	38	21
	295, 296 (1999)	835.33 - 1140	40	237
	260, 261 (1999)	24 - 37	44	6.7
	242, 243 (1999)	249 - 336	49	54
Phenanthrene	36, 37 (1997)	49 - 129	4	49
	209, 210 (1999)	43 - 47	13R	11
	92, 93, 94, 95 (1997)	85 - 1950	21	59
	113, 122, 127, 128, 129 (1998)	86 - 436	29	59
	160, 161, 162, 163, 164, 165 (1998)	84 - 167	34	70
	139, 140 (1998)	57 - 106	38	47
	295, 296 (1999)	1025.33 - 1390	40	924
	260, 261 (1999)	38 - 42	44	13.6
	242, 243 (1999)	234 - 422	49	62

Variable	PSAMP/NOAA Station (Year)	PSAMP/NOAA Results	PSAMP Long-Term Station (2000)	PSAMP Long-Term Results
HPAHs (µg/kg dry weight)				
Benzo(a)anthracene	36, 37 (1997)	14 - 31	4	20
	209, 210 (1999)	9.2 - 13.1	13R	Undetected
	92, 93, 94, 95 (1997)	46 - 895	21	28
	113, 122, 127, 128, 129 (1998)	41 - 367	29	38
	160, 161, 162, 163, 164, 165 (1998)	99 - 175	34	108
	139, 140 (1998)	35 - 66	38	35
	295, 296 (1999)	654 - 995	40	649
	260, 261 (1999)	15 - 19	44	12.9
	242, 243 (1999)	212 - 298	49	34
Benzo(a)pyrene	36, 37 (1997)	15 - 32	4	29
	209, 210 (1999)	9.3 - 10.7	13R	9
	92, 93, 94, 95 (1997)	37 - 413	21	17
	113, 122, 127, 128, 129 (1998)	55 - 606	29	50
	160, 161, 162, 163, 164, 165 (1998)	203 - 373	34	150
	139, 140 (1998)	57 - 103	38	49
	295, 296 (1999)	1030.67 - 1300	40	610
	260, 261 (1999)	20 - 21	44	19.5
	242, 243 (1999)	258 - 391	49	47
Benzo(g,h,i)perylene	36, 37 (1997)	19 - 47	4	31
	209, 210 (1999)	9.9 - 13	13R	7.2
	92, 93, 94, 95 (1997)	31 - 194	21	16
	113, 122, 127, 128, 129 (1998)	56 - 358	29	49
	160, 161, 162, 163, 164, 165 (1998)	169 - 224	34	128
	139, 140 (1998)	49 - 91	38	58
	295, 296 (1999)	619 - 696	40	281
	260, 261 (1999)	19 - 20	44	15
	242, 243 (1999)	204 - 340	49	47
Chrysene	36, 37 (1997)	25 - 49	4	21
	209, 210 (1999)	15 - 15.5	13R	4.3
	92, 93, 94, 95 (1997)	64 - 1010	21	35
	113, 122, 127, 128, 129 (1998)	65 - 435	29	41
	160, 161, 162, 163, 164, 165 (1998)	142 - 270	34	118
	139, 140 (1998)	52 - 100	38	42
	295, 296 (1999)	1031.33 - 1320	40	693
	260, 261 (1999)	23 - 31	44	13.6
	242, 243 (1999)	347 - 514	49	31

	PSAMP/NOAA		PSAMP Long-Term	
Variable	Station (Year)	Results	Station (2000)	Results
Dibenzo(a,h)anthracene	36, 37 (1997)	2.1 - 4.7	4	Undetected
	209, 210 (1999)	Undetected	13R	Undetected
	92, 93, 94, 95 (1997)	6.2 - 52	21	Undetected
	113, 122, 127, 128, 129 (1998)	8.8 - 53	29	42
	160, 161, 162, 163, 164, 165 (1998)	35 - 44	34	32
	139, 140 (1998)	6.6 - 15	38	19
	295, 296 (1999)	112.67 - 188	40	73
	260, 261 (1999)	3.5 - 3.8	44	Undetected
	242, 243 (1999)	34 - 72	49	Undetected
Fluoranthene	36, 37 (1997)	57 - 151	4	56
	209, 210 (1999)	31 - 36.5	13R	11
	92, 93, 94, 95 (1997)	115 - 3520	21	79
	113, 122, 127, 128, 129 (1998)	114 - 1080	29	85
	160, 161, 162, 163, 164, 165 (1998)	216 - 375	34	179
	139, 140 (1998)	87 - 182	38	80
	295, 296 (1999)	1290 - 1620	40	1110
	260, 261 (1999)	43 - 67	44	27.5
	242, 243 (1999)	829 - 1120	49	101
Indeno(1,2,3-c,d)pyrene	36, 37 (1997)	15 - 38	4	29
	209, 210 (1999)	7.4 - 8.3	13R	8.2
	92, 93, 94, 95 (1997)	29 - 187	21	16
	113, 122, 127, 128, 129 (1998)	52 - 349	29	44
	160, 161, 162, 163, 164, 165 (1998)	166 - 240	34	128
	139, 140 (1998)	45 - 86	38	49
	295, 296 (1999)	486 - 902	40	302
	260, 261 (1999)	16 - 32	44	15.9
	242, 243 (1999)	235 - 262	49	46
Pyrene	36, 37 (1997)	49 - 122	4	53
	209, 210 (1999)	33 - 36.5	13R	14
	92, 93, 94, 95 (1997)	92 - 2650	21	80
	113, 122, 127, 128, 129 (1998)	126 - 1290	29	101
	160, 161, 162, 163, 164, 165 (1998)	315 - 513	34	279
	139, 140 (1998)	110 - 179	38	92
	295, 296 (1999)	2003.33 - 2800	40	1710
	260, 261 (1999)	60 - 90	44	34.5
	242, 243 (1999)	950 - 951	49	140

	PSAMP/NOAA		PSAMP Long-Term	
Variable	Station (Year)	Results	Station (2000)	Results
Total Benzofluoranthenes	36, 37 (1997)	40.6 - 91	4	78
	209, 210 (1999)	21.4 - 25.9	13R	20.6
	92, 93, 94, 95 (1997)	86 - 944	21	54
	113, 122, 127, 128, 129 (1998)	113 - 715	29	105
	160, 161, 162, 163, 164, 165 (1998)	412 - 614	34	338
	139, 140 (1998)	108 - 202	38	121
	295, 296 (1999)	1041.34 - 1780	40	876
	260, 261 (1999)	29 - 114	44	40.5
	242, 243 (1999)	432 - 598	49	125

Table 22. Comparison of sediment parameters from Thea Foss Waterway (City of Tacoma, 1995, 1999) and PSAMP Station 40 (Thea Foss Waterway).

Location	Tetra Tech site CI-22 (City of Tacoma, 1995)	Parametrix site A1 (City of Tacoma, 1995)	Proposed Confined Aquatic Disposal Site (City of Tacoma, 1999)	PSAMP Station 40
Years	1984	1989	1997	1989-2000
% Fines	28	26	17.2 - 44.4	15.6 - 42.3
% TOC	1.21	0.813	0.29 - 1.6	0.7 - 2.2
Benzoic acid (µg/kg dry weight)	Undetected	Undetected	Undetected	47.7 - 365
Metals (mg/kg dry weight)				
Antimony	0.22	3.8	≤ 0.4	≤ 0.4
Arsenic	8	19.1	1.5 - 5.9	3.9 - 12.7
Cadmium	1.5	2.9	≤ 0.39	≤ 0.4
Chromium	8.4	106	10.0 - 13.5	10.3 - 16.4
Copper	40	203	9.6 - 30.5	25.2 - 46.8
Lead	49	854	1.2 - 24.1	17.0 - 34.3
Mercury	0.22	0.15	0.01 - 0.26	≤ 0.2
Nickel	9	65	7.4 - 10.4	7.9 - 11.8
Silver	0.4	1.78	0.2 - 0.7	0.1 - 0.5
Zinc	44	426	15.8 - 43.4	33.6 - 48.4
LPAHs (µg/kg dry weight)				
2-Methylnaphthalene	460	Undetected	≤ 61	18 - 100
Acenaphthene	190	Undetected	≤ 66	37 - 230
Acenaphthylene	330	Undetected	≤ 150	59 - 330
Anthracene	960	110	≤ 570	340 - 1800
Fluorene	280	Undetected	≤ 140	72 - 450
Naphthalene	1200	Undetected	≤ 130	51 - 266
Phenanthrene	1500	370	≤ 770	520 - 3400
HPAHs (µg/kg dry weight)				
Benzo(a)anthracene	1300	260	≤ 730	458.5 - 1300
Benzo(a)pyrene	1200	250	≤ 770	400 - 1400
Benzo(g,h,i)perylene	380	110	≤ 490	28 - 670
Chrysene	1300	360	≤ 740	550 - 1500
Dibenzo(a,h) anthracene	150	96	≤ 130	58.3 - 340
Fluoranthene	1500	710	≤ 860	610 - 1700
Indeno(1,2,3-c,d) pyrene	410	95	≤ 520	240 - 830
Pyrene	2600	640	≤ 1200	780 - 2400
Total Benzofluoranthenes	2800	440	≤ 1000	580 - 1900

Table 23. Comparison of sediment parameters from cores taken in Puget Sound (Lefkovitz *et al.*, 1997) and PSAMP Stations 29 (Shilshole) and 38 (Point Pully, 3-Tree Point).

Location	Core 2	PSAMP Station 29		Core 6	PSAMP Station 38	
Years	~1989-90	1989-1991	2000	~1989-90	1989-1991	2000
Depth	0-2 cm			0-2 cm		
% Fines				90.6	86.4	86.4
% TOC				2.17	2.4	2.4
Metals (mg/kg dry weight)						
Arsenic	10.0	6.7 - 14.6	6.2	17.3	7.5 - 18.8	8.9
Cadmium				0.4	0.1 - 0.4	Undetected
Chromium	80.0	40.4 - 41.9	40.8	83.0	41.1 - 50.7	43.2
Copper	42.2	33.8 - 36.9	28.1	52.7	45.7 - 57.1	40.1
Lead	16.6	17.8 - 26.2	18.0	44.7	24.1 - 50.5	31.7
Manganese	597.0	395 - 480	414.0	826.0	665 - 864	598
Mercury				0.3	0.2 - 0.3	0.2
Nickel	54.2	35.7 - 37.7	34.8	42.8	34.8 - 44.7	35.8
Silver				0.6	0.5 - 0.7	0.5
Zinc	108.5	89.2 - 94	86.5	115.5	97.6 - 138	95.3
LPAHs (µg/kg dry weight)						
2-Methylnaphthalene				40.3	6 - 8	20
Acenaphthene				6.4	6	Undetected
Acenaphthylene				13.6	5 - 10	7
Anthracene				29.5	15 - 29	16
Fluorene				18.2	5 - 14	13
Naphthalene				28.5	6 - 27	21
Phenanthrene				98.5	49 - 120	47
HPAHs (µg/kg dry weight)						
Benzo(a)anthracene				78.9	29 - 64	35
Benzo(a)pyrene				87.6	28 - 110	49
Benzo(g,h,i)perylene				82.0	12 - 110	58
Chrysene				107.3	47 - 95	42
Dibenzo(a,h)anthracene				11.6	8 - 25	19
Fluoranthene				152.9	75 - 160	80
Indeno(1,2,3-c,d)pyrene				80.4	20 - 88	49
Pyrene				179.7	75 - 150	92
Total Benzofluoranthenes				197.3	93 - 180	121