Control of Toxic Chemicals in Puget Sound

Phase 2: Development of Simple Numerical Models

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Control of toxic chemicals in Puget Sound Phase 2: Development of simple numerical models

The long-term fate and bioaccumulation of polychlorinated biphenyls in Puget Sound

by

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Abstract

This study develops computer prediction tools to predict the concentration of PCBs in water, sediment, and biota of Puget Sound. The tools include a box model that is capable of predicting concentrations of PCBs in two water column layers and a sediment layer for 10 inter-connected basins in Puget Sound. The tools also include a food web bioaccumulation model to predict concentrations of PCBs in the aquatic food web of Puget Sound.

Concentrations of PCBs in sediments and biota were found to be very sensitive to external loading. Considering the wide range of uncertainty in external loading of toxic contaminants, it is possible the mass of PCBs in the aquatic ecosystem of Puget Sound may either increase or decrease over time with current loading levels. The model response to the median estimate of loading suggests that loads may have increased recently, possibly due to increases in loading from nonpoint (diffuse) sources. Limited available biota data possibly corroborate an increasing trend in loading. Concentrations of PCBs appear to be increasing in the large basins and decreasing in the urban bays.

Reduction of external loading is predicted to be effective to reduce future concentrations of PCBs in the water, sediment, and biota of Puget Sound. This would involve implementing comprehensive source control measures and best management practices to reduce contaminants that enter runoff from residential, commercial/industrial, forest, and agricultural watershed areas. Reduction of current loading is recommended to decrease PCB concentrations in sediment and biota from what would otherwise occur.

The modeling framework for quantifying fate, transport, and bioaccumulation of PCBs is adaptable for the evaluation of other toxic contaminants.

Acknowledgements

Several people made generous contributions to this project, including the following:

- Amanda Babson developed and published the original box model of circulation and transport of water in Puget Sound. She also developed the preliminary versions of the software framework for this project which incorporated kinetics and transport of toxic constituents in the water column and sediment.
- Colm Condon applied the food web bioaccumulation model to the Strait of Georgia and created the original version of the software. That version was the basis for the generalized framework and the application to Puget Sound that were developed during this project.
- Bob Johnston compiled data for concentrations of toxic constituents in biota from various sources and provided many valuable insights and ideas.
- Jim West and Sandie O'Neill compiled data for toxic constituents in several species of aquatic biota from the Puget Sound Ambient Monitoring Program[1]. Their publications, public presentations, expertise, and pioneering work provided many valuable interpretations and insights on the status and trends of concentrations in biota in Puget Sound.
- Eric Crecelius provided information and comments related to sedimentation rates.
- John Calambokidis provided data and reports describing trends in contaminant concentrations in Puget Sound harbor seals.
- Alan Mearns provided data describing contaminant concentrations in mussels.
- Callie Meredith developed and applied methods for the calculation of summary statistics for sediment concentration data.
- Valerie Partridge compiled data for concentrations of toxic constituents in sediments.
- Trevor Swanson provided information on the natural history of blackmouth salmon.
- Frank Gobas provided information and comments to help with the development of the food web bioaccumulation modeling framework.
- Dave Serdar provided guidance and advice on methods for summarizing PCB data.
- Dale Norton and Karol Erickson provided management support for this project. Without their enthusiasm and support, this project would not have been possible.

[1] Now called the Puget Sound Assessment and Monitoring Program.

Executive summary

Introduction

The Washington Department of Ecology (Ecology) is working in collaboration with the Puget Sound Partnership and other state and federal agencies to deliver three phases of scientific information related to toxic chemicals that will help jump-start actions to restore Puget Sound. Phases 1 and 2 will determine policy options for an action agenda to reduce and control releases of toxic chemicals. Phase 3 will support implementation of the actions that the Partnership identifies in the action agenda.

The present study is part of Phase 2 of the collaborative effort. This study expands and applies existing numerical models to predict the effects of loading of toxic contaminants on the concentrations of those contaminants in the water, sediment, and biota of Puget Sound.

PCBs were selected for this study because of the relatively abundant data. The tools developed in this study may be applied to other toxic contaminants.

Models

The numerical modeling approach for this project is composed of three parts:

1. **Circulation and transport of water.** A model to predict transport of water between regions of Puget Sound (Figure ES-1) and between surface and deep layers of the water column.

2. **Contaminant fate and transport.** A model to predict water and sediment concentrations of PCBs in response to external loading and internal processes.

3. **Food web bioaccumulation.** A model to predict PCBs in Puget Sound biota in response to water and sediment concentrations.

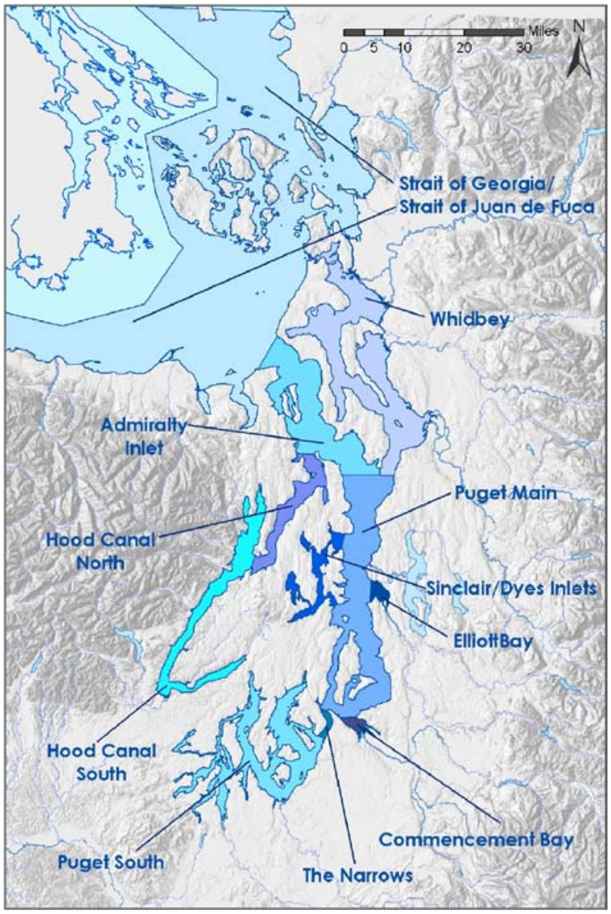

Figure ES-1.
Map of Puget Sound showing the areas represented by Ecology's box model regions.

Major findings

- External loads of PCBs in runoff from watershed areas are the main driver of PCB concentrations in water, sediment, and biota in Puget Sound. Reduced loading of solids from nonpoint sources could lead to significant reduction of PCB loading.

- External loading sources from the watershed account for most of the PCBs entering Puget Sound. These sources are subject to a wide range of uncertainty (median estimate of about 116 Kg/year, with an interquartile range of 27 to 512 Kg/year, in one study; and median estimate of about 285 Kg/year, with an interquartile range of 72 to 1100 Kg/year, in another study). The box model suggests that the plausible range of external loading of PCBs is about 20 to 200 Kg/year to explain the current mass of PCBs stored in the sediments. Uncertainty in the external loading sources from the watershed contributes to a wide range of uncertainty of predicted future concentrations in sediment and biota. A smaller load of PCBs enters from the marine (salt-water) boundary and direct atmospheric deposition.

- External loading of PCBs in runoff from commercial/industrial and residential land covers accounts for about half of the total load of PCBs in one study and more than three-fourths in another study (Figure ES-2). Concentrations of PCBs in runoff from forest areas are considerably lower than concentrations from other land covers (Figure ES-3), but the area of forest land cover (Figure ES-4) is large enough to result in a major source of loading of PCBs. Uncertainty in loading from forest land is a potentially large source of uncertainty in total external loading (Figure ES-5) according to one study.

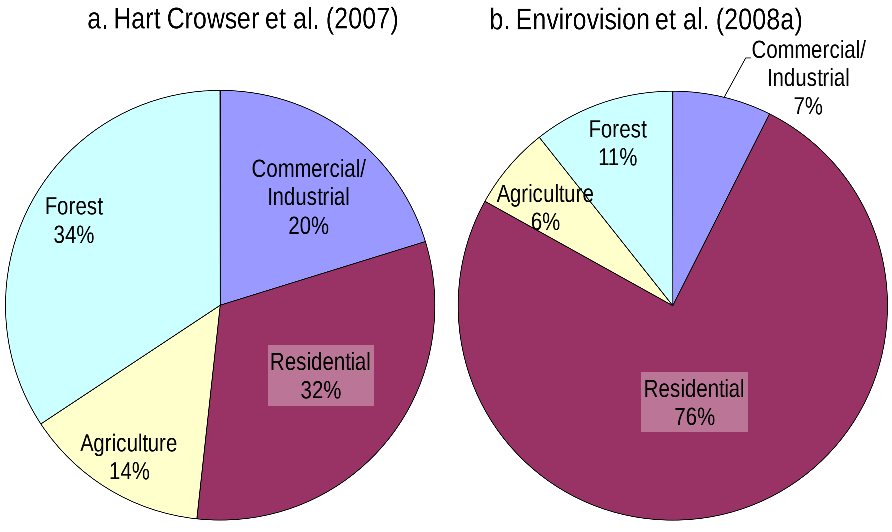

Figure ES-2. Two estimates of the percentage of current total loading of PCBs from each land cover category.

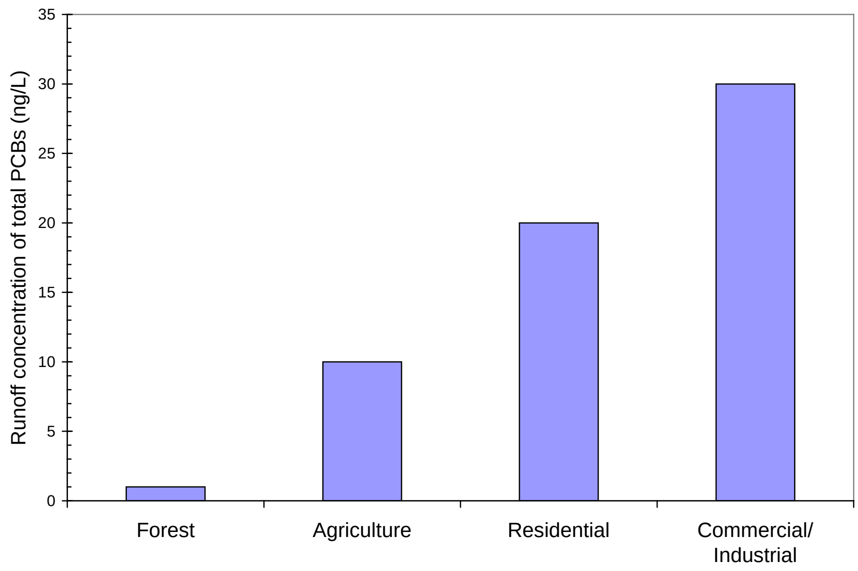

Figure ES-3. Typical runoff concentrations of total PCBs by land cover.

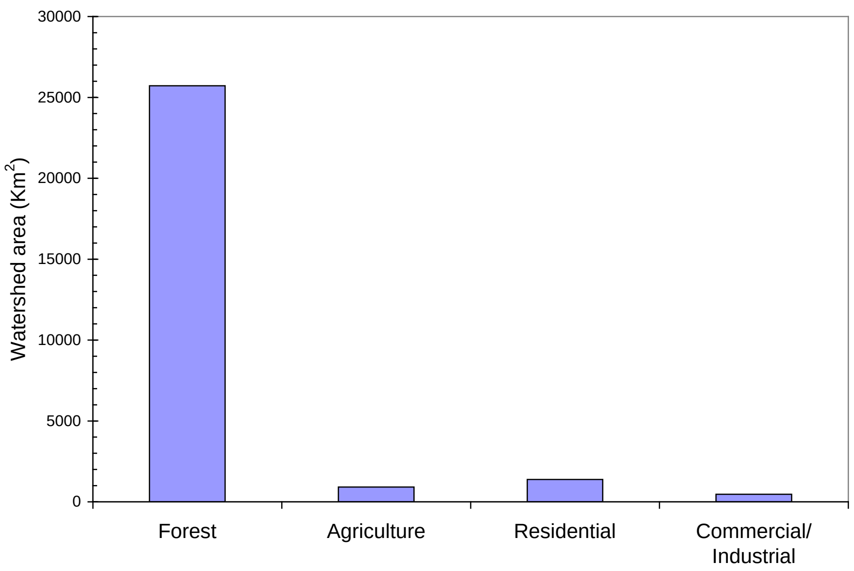

Figure ES-4. Watershed areas of Puget Sound by land cover.

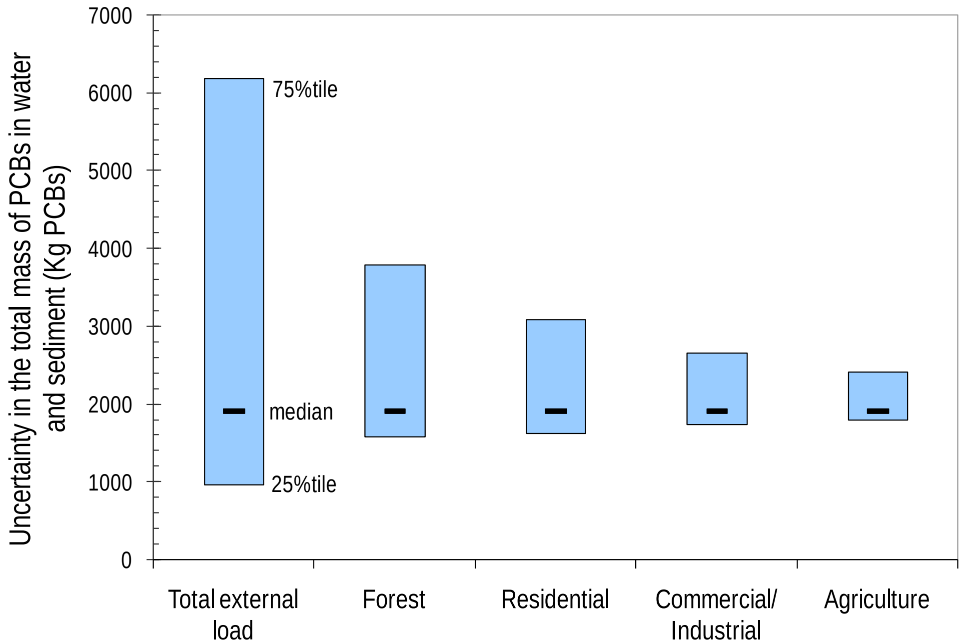

Figure ES-5. Uncertainty in the mass of PCBs in Puget Sound in year 2020 due to external loads using the loading estimates provided by Hart Crowser et al., 2007.

- Current concentrations of PCBs in sediments were found to have little influence on future conditions in the years 2020 to 2050. The total mass of PCBs in the water column and the active sediment (top 10 cm) is predicted to reach approximately the same future value regardless of whether the current condition of sediment is relatively clean or more contaminated. This result is due mainly to the effect of continual burial of sediment and replacement with newly deposited material that is derived from external sources. While burial is a major loss of PCBs from the aquatic food web, contaminated sediment sites still need to be remediated because of the benefits to the nearshore environment and the complex, synergistic effects of multiple contaminants at these sites.

- Burial of deep sediment accounts for the largest loss of PCBs, with loss also due to outflow through the marine boundary, degradation, and volatilization. The model assumes that burial is effective at isolating contaminants from humans and biota throughout Puget Sound. While burial may be effective in deep water, it may not be effective in contaminated sediment sites in the high energy nearshore environment. The nearshore environment has hydrologic, geologic, and biological processes that can disturb contaminated sediments deeper than 10 cm making the sediments bioavailable to the abundant biological community in this environment.

- Approximately 97% of the total mass of PCBs currently in the aquatic ecosystem of Puget Sound is contained in the active sediment layer (top 10 cm), about <1% is stored in the water column, and about <3% is stored in the biota.

- Increases in PCB concentrations in sediment and biota (Figure ES-6) are possible by the year 2020 in the larger basins (South Puget Sound, main basin, Whidbey basin, Hood Canal, and Admiralty Inlet). Increases in water column PCB concentrations are also possible in most basins unless external contaminant loads are reduced. Future concentrations could reach an equilibrium with current external loads in about the year 2050.

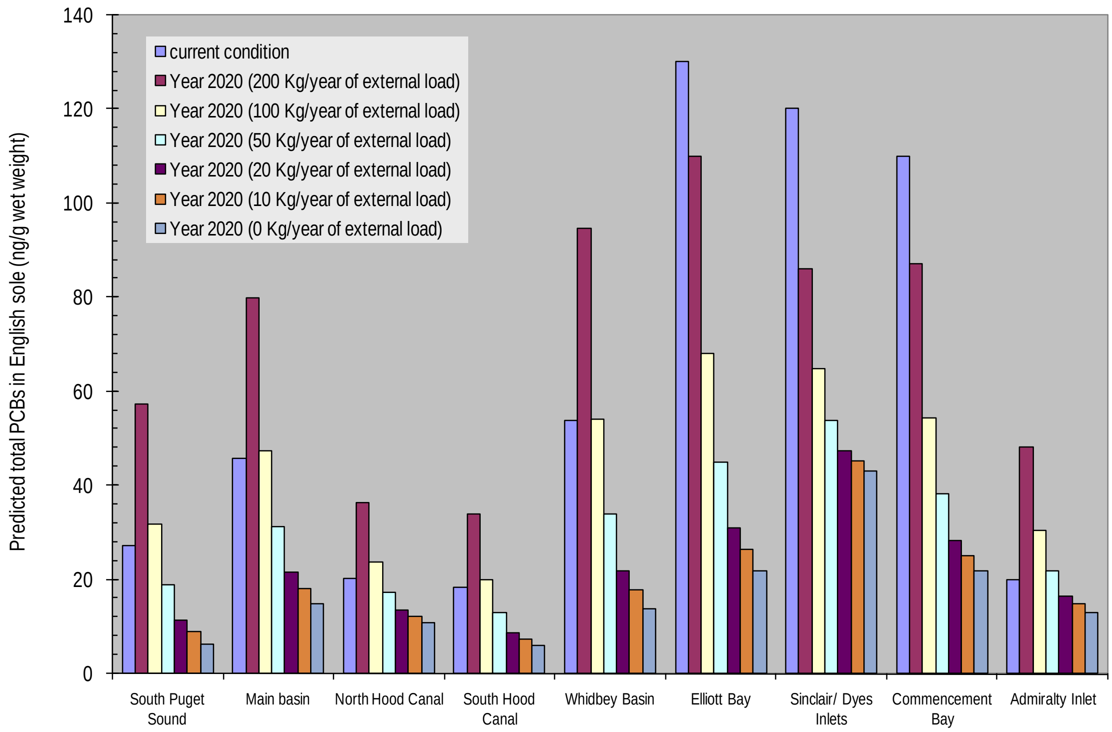

Figure ES-6. Predicted concentrations of PCBs in English sole (whole body) for various alternative scenarios of external loading reduction.

- Decreases in PCB concentrations in sediment and biota (Figure ES-6) are possible by the year 2020 in the urban bays (Sinclair and Dyes Inlets, Elliott Bay, and Commencement Bay). Sediment PCB concentrations in the urban bays could be decreasing due to the combined effect of burial with newly deposited material that is less concentrated than the original source material, and transport of sediment from the urban bays into the adjacent main basin. Concentrations could decrease more depending on whether external loads are reduced.

- Uncertainty in the current (1990s) total mass of PCBs in the water column and active sediment layer of Puget Sound is mainly influenced by the observed variability in current sediment concentrations. The interquartile range of the current mass of PCBs in Puget Sound based on variability of current sediment concentrations is approximately 570 to 3510 Kg of PCBs with a median estimate of 1440 Kg.

- Uncertainty in the predicted future total mass of PCBs in the water column and active sediment layer of Puget Sound is mainly influenced by uncertainty in external loading. The interquartile range of the predicted future mass of PCBs in the year 2020 is approximately

970 to 6190 Kg PCBs with a median estimate of 1920 Kg using loading estimates reported by Hart Crowser et al. (2007).

- Considering the wide range of uncertainty in external contaminant loading, it is possible the mass of PCBs in the aquatic ecosystem of Puget Sound may either increase or decrease over time. The model response to the median estimate of loading suggests that loads may have increased recently, possibly due to increases in loading from nonpoint sources. Limited available biota data possibly corroborate an increasing trend in loading.

Recommendations

The findings of the study suggest the following recommendations:

- **External loads.** We suggest reduction of external contaminant loading to prevent a possible increase, or cause a decrease in PCB concentrations in the sediment and biota of Puget Sound. Methods for reducing external loading of PCBs should be identified and implemented. For example, best management practices to reduce nonpoint loading from developed areas (e.g., commercial/industrial and residential areas) could reduce many pollutants, including PCBs, that are associated with suspended solids in runoff. Data should be collected to improve our estimates of representative PCB concentrations in runoff from forest, residential, commercial/industrial, and agricultural land covers in the watersheds of each region. Studies of sediment cores would also be useful to examine historical trends in sediment concentration of PCBs and other toxic contaminants of concern.

- **Marine boundary.** Data should be collected to describe toxic contaminants in the water column at the marine (salt-water) boundary to improve the accuracy of the model for predicting the distribution of contaminants throughout Puget Sound. Loading of PCBs from the marine boundary is comparable in magnitude to loading from each of the major land covers in the watersheds. Existing field information from the marine boundary is very limited. Additional data should also include other toxic contaminants of concern.

- **Water column toxics.** We recommend additional measurements of toxic contaminants at various locations within Puget Sound. The scarcity of water column data using methods that are capable of detecting the low concentrations that exist is a major data gap. Additional data would improve confidence that the external loading estimates are accurate and the processes describing the transport and fate of PCBs are correctly simulated. The mass of PCBs in the water column is comparable in magnitude with the mass contained in all of the biota of Puget Sound. PCB concentrations in the biota are sensitive to the concentration in the water column due to direct uptake from the water and respiration. Paired data sets of water column and sediment concentrations in contaminated sediment areas are another data gap. In addition to PCBs, other toxic contaminants of concern should be measured.

- **Biota concentrations.** Data gaps exist concerning the concentrations of toxics in various species of biota of the Puget Sound regions, including several trophic layers within the food web. We recommend collection of toxics concentration data in biota to fill in those gaps. Measurements of toxics in whole body samples are preferable if practical, or lipid measurements where it is not practical (e.g., harbor seal pups). These additional data will allow improvement of the model of food web bioaccumulation across all regions of Puget Sound and throughout the entire food web. Tissue data from bottom dwellers and benthic feeders, as well as their prey species, from contaminated sediment sites, will also help to fill the data gap of different exposure scenarios and trophic transfer from sediment to top predators. Paired measurement of concentrations in biota and sediment would also be useful.

- **Other endpoints.** The modeling framework for this project focused on the endpoint of concentrations in sediment, water, and the tissue in biota of the aquatic food web. The model does not address adverse effects to the exposed wildlife. Modeling of other endpoints in nearshore biota, such as reduced fecundity and reduced age to sexual maturity, or other endpoints specific to endocrine disruptors, is also needed.

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Introduction

The Puget Sound Initiative is a collaborative effort by local, tribal, state, and federal governments, business, agricultural and environmental interests, and the public to restore and protect Puget Sound. In 2007, the Washington State Legislature created the Puget Sound Partnership and charged it with leading this effort.

The Washington State Department of Ecology (Ecology) is working with the Partnership and other state and federal agencies to deliver three phases of scientific information related to toxic chemicals that will help jump-start actions to restore Puget Sound (Howard, 2008). Phases 1 and 2 will inform policy options for an action agenda to reduce and control releases of toxic chemicals. Phase 3 will support implementation of the actions that the Partnership identifies in the action agenda.

The present study is part of Phase 2 of the collaborative effort. This study expands and applies existing numerical models to predict the effects of loading of toxic contaminants on the concentrations of those contaminants in the water, sediment, and biota of Puget Sound.

Numerical models of toxic constituents in Puget Sound are needed to allow managers to evaluate the response of environmental concentrations in water, sediment, and biota to various strategies for control of pollutant sources. Models are also effective for illustrating the relative magnitude of sources of pollutant loading to Puget Sound.

The numerical modeling approach for this project is composed of three parts:

1. **Box model of circulation and transport of water.** In this study, we adapt a previously published box model of circulation and transport of water in Puget Sound. This model is capable of predicting seasonal and interannual variations in water residence times and transports and exchanges of water between regions and between the upper and lower layers of the water column.

2. **Mass balance model of contaminant fate and transport.** In this study, we combine a mass balance model of contaminant fate and transport of non-ionic hydrophobic organic contaminants (HOCs) with the box model of circulation. The combined box model and mass balance model is capable of predicting seasonal and interannual variations in concentrations of HOCs in water and sediment in response to external loading and internal processes. Two mass balance modeling tools were developed:

    - The present study integrates a simple process-based, mass-balance model of HOCs with the box model of circulation and transport. This model is capable of simulating a variety of different HOCs, such as polychlorinated biphenyls (PCBs) or polybrominated diphenyl ethers (PBDEs). In the present study, the model is applied to PCBs in Puget Sound to predict concentrations in water and sediment.

- The box model of circulation and transport includes a linkage with the EPA WASP model. The WASP model includes modules for simulation of water column and sediment concentrations of a wide range of contaminants, including non-ionic and ionic organic contaminants, mercury, and other metals. The WASP model was not used during this study, but it is available for use in future modeling studies that may require more complex kinetic processes.

3. **Food web bioaccumulation model.** This study develops a generalized framework for modeling of bioaccumulation of HOCs in aquatic food webs. In this study, we apply the model to PCBs in Puget Sound biota. This model is also capable of simulating food web bioaccumulation of other HOCs (e.g., PBDEs).

Toxic contaminants in Puget Sound can have both acute and chronic effects on humans and the environment and are being addressed on multiple levels (e.g., Gries, 2005). The present modeling approach does not address acute toxicity impacts on a localized level from the most highly contaminated nearshore environments. It is not intended to qualitatively assess the benefits of cleaning up these sensitive nearshore environments nor to make determinations about the amount or type of cleanup that should occur.

PCBs were selected for this study because of the relatively abundant data compared with other toxic contaminants. PCBs are among the most stable organic compounds known, and all PCBs are man-made. Each PCB is composed of chlorine atoms attached to a biphenyl molecule. Different numbers and placements of chlorine atoms form 209 distinct PCB compounds known as congeners. The fate and toxicity of different PCB congeners are determined by the number and placement of chlorine atoms on the biphenyl molecule. Many commercial PCB mixtures combine several congeners together to make new chemical compounds, known by the trade name Aroclor. In this report, the term “total PCBs” is used to represent the sum of all congeners that were measured in a particular sample.

The modeling framework for this project is limited to the endpoint of concentrations of PCBs in sediment, water, and tissue burden in the biota of the aquatic food web. The models do not evaluate other possible PCB impacts such as acute toxicity to the biota in the nearshore environment, or other endpoints that may be impacted such as reduced fecundity and adverse effects to critical habitat values.

Box model of circulation and transport of water

Several modeling studies of Puget Sound have been conducted over the years to simulate circulation and transport of water. The various modeling approaches range from relatively simple box models (e.g., Friebertshauser and Duxbury, 1972; Hamilton et al., 1985; Cokelet et al., 1990), to high-resolution, 3-dimensional hydrodynamic models (e.g., Nairn and Kawase, 2002; Battelle, 2007). The simpler, less computationally expensive box models can be used to explore a wide range of scenarios with sufficient spatial and temporal detail for many kinds of water quality management issues, such as bioaccumulation of contaminants in aquatic food webs.

Babson et al. (2006) developed the most recent and advanced box model for Puget Sound, which is referred to as the "BKM box model" after the initials of the original authors' names. The BKM box model is a prognostic, time-dependent model of circulation in Puget Sound which is capable of predicting seasonal and interannual variations in residence times and interbasin transports.

Amanda Babson upgraded the original BKM box model as part of the current Ecology project. The upgraded box model, which we will refer to as the Ecology box model or psbox.xls, separates additional boxes for Sinclair and Dyes Inlets, Elliott Bay, and Commencement Bay. The Ecology box model also includes an integrated fate and transport model of PCBs as well as linkage with the EPA WASP model. The Ecology box model (psbox.xls) is written in Microsoft Excel's VBA programming language based on a translation from the original MATLAB code. The Excel VBA version was found to produce identical results and is more than 20 times faster than the original MATLAB version.

The Ecology box model divides Puget Sound into ten regions (Figure 1), plus the Strait of Juan de Fuca/Strait of Georgia (SJF/SOG), which represents the model boundary region. The BKM box model originally divided Puget Sound into seven regions that were chosen based on the location of data stations and sills (Figure 2, Babson et al., 2006). The Ecology box model separates three additional regions from the original main basin to represent the relatively more contaminated conditions in the urban bays (Elliott Bay, Commencement Bay, and Sinclair/Dyes Inlets).

Each region is divided vertically to represent the two water column layers defined at different depths for different regions (Table 1). Two-layer estuarine circulation is assumed. Each basin is divided into a surface and deep layer of the water column. The thickness of the surface layer is determined by the depth of no motion, where the tidally averaged velocity crosses zero between an outgoing surface layer and an incoming deep layer (Babson et al., 2006). A schematic diagram of the original BKM box model is presented in Figure 2. The Ecology box model also adds separate boxes for Elliott Bay, Commencement Bay, and Sinclair/Dyes Inlets.

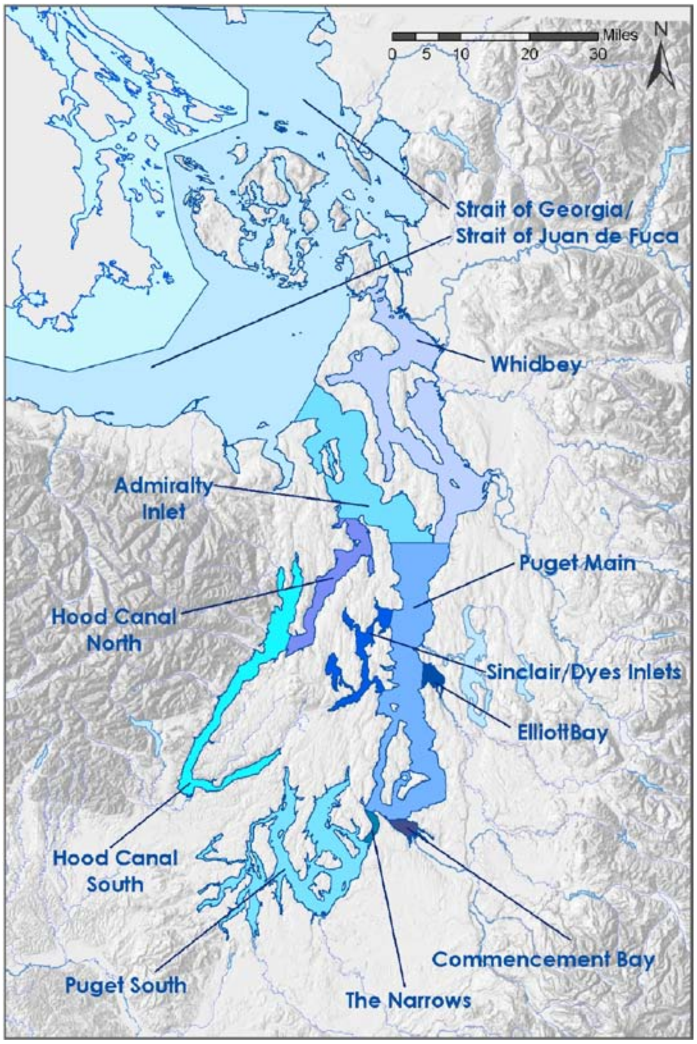

Figure 1. Map of Puget Sound showing the areas of Ecology's box model regions.

Table 1. Depth at which the upper and lower water column is divided for each region of the box model.

Model Region	Depth of upper/lower division (meters)
Admiralty Inlet	37.0
Commencement Bay	20.0
Elliott Bay	40.0
Hood Canal North	19.8
Hood Canal South	13.0
Puget Main	50.2
Puget South	29.9
Sinclair/Dyes Inlet	23.0
The Narrows	21.5
Whidbey	9.1

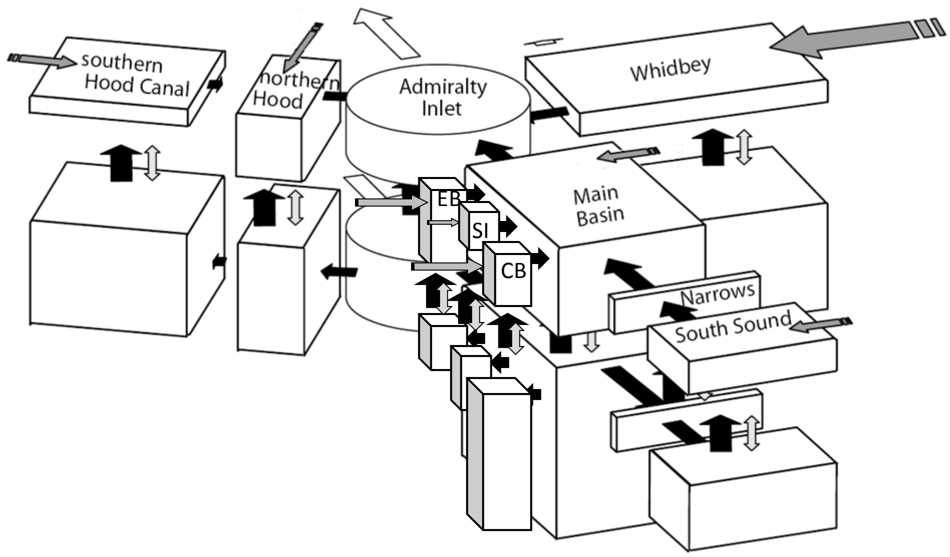

Figure 2. Schematic diagram of the BKM box model of circulation and transport of water in Puget Sound (Babson et al., 2006). Black arrows represent advection, two-way grey arrows represent mixing, grey arrows with dashed ends represent river inputs, and white arrows are outlets to the SJF. Boxes have been *scaled to show relative volumes. Arrows have been scaled to transports within each category*. Rivers are proportional on a log scale. The Admiralty Inlet mixing arrow is shown at 50%. Ecology's box model separates three additional boxes from the main basin to represent the urban bays (EB=Elliott Bay, CB=Commencement Bay, and SI=Sinclair/Dyes Inlets).

Mass balance models of contaminant fate and transport

Ecology's box model (psbox.xls) incorporates a simple mass balance model of fate and transport of HOCs. In this study, we apply the simple mass balance model for the prediction of PCBs. Davis (2004) developed the simple mass balance model of PCBs that was incorporated into the Ecology box model. The Davis PCB model is also applicable to other HOCs (e.g., Oram et al., 2008). With the incorporation of the Davis (2004) model, Ecology's box model is capable of simulating seasonal and interannual variations in each region in response to changes in external loading for concentrations of HOCs in the two water-column layers and an active sediment layer. External loads generally include nonpoint and point sources from the watershed, atmospheric deposition, and marine sources that enter Puget Sound across the open boundary.

The Davis (2004) model accounts for the gains and losses of HOCs from the water column and the sediment. These include the effects of external loads, partitioning of dissolved and particulate forms, volatilization, solids settling, water-to-sediment diffusion, degradation in water, solids resuspension, sediment-to-water diffusion, degradation in sediment, and burial of deep sediments (Figure 3).

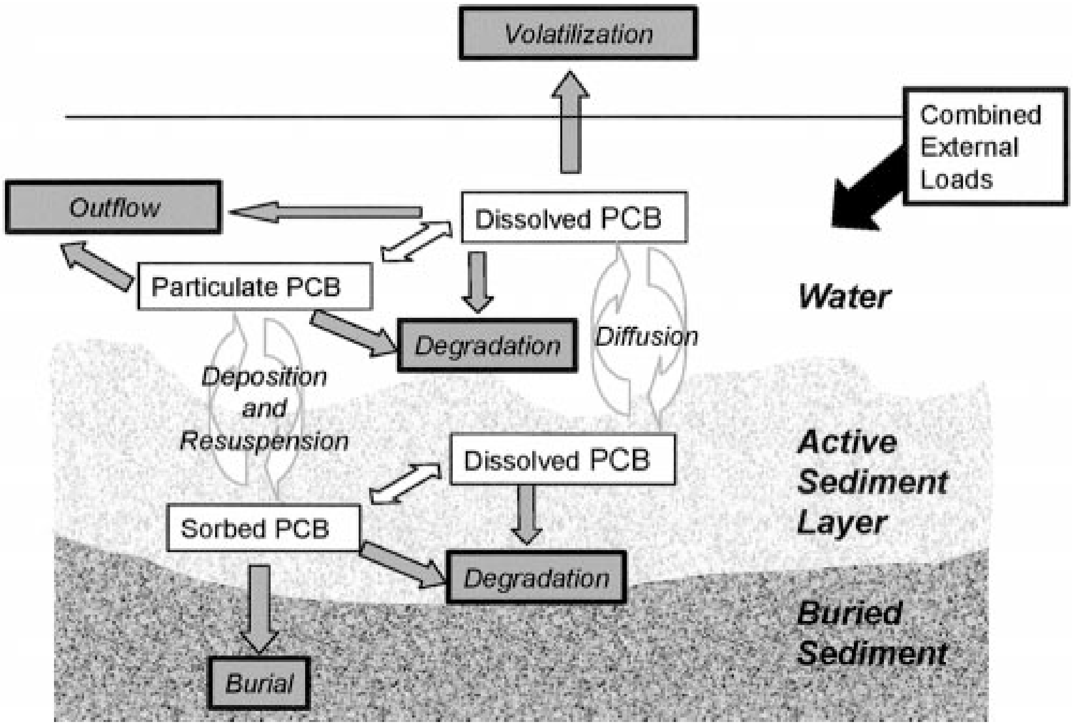

Figure 3. Diagram of PCB fate in the Davis (2004) model that is integrated into the Ecology box model.

Davis (2004) found that PCB concentrations were predicted to change very slowly in response to changes in external loading. This was due to the very small mass of PCBs stored in the water column relative to the mass stored in the active sediment layer because of the low solubility of PCBs and the relative volumes of water and active sediment. High rates of resuspension and deposition of sediments were found to be significant for exchange of material between the water and sediment. The depth of the active sediment layer was found to be one of the most sensitive variables because of the large storage of PCBs in the sediment compared with the water column.

Davis (2004) concluded that the principal value of their model was not in generating precise estimates of sediment and water concentrations, but in showing how the estimates respond to ranges of input values. Using best estimates for all input parameters and assuming no external load of PCBs, the total mass of PCBs in the bay was predicted to decline by about 50% in 20 years. Davis (2004) used the model predictions of trends in sediment concentrations compared with observed trends in biota to estimate the current load of PCBs with the caveat that these loading estimates must be considered preliminary and approximate due to large uncertainties in model inputs. The model results suggested that external loading may prevent sediment PCBs from being reduced below about 50% of their current values over time.

In addition to integrating the Davis (2004) model, the Ecology box model also provides linkage to the EPA WASP model (Wool et al., 2003) through output of an external hydrodynamic linkage file. The WASP model provides modules for simulation of a wide range of contaminants, including non-ionic and ionic organic contaminants, mercury and other metals, as well as conventional water quality variables (e.g., nutrients and dissolved oxygen).

Food web bioaccumulation model

HOCs are known to biomagnify and bioaccumulate in the bodies of aquatic species through the net effect of dietary uptake, respiration, metabolism, and excretion (Arnot and Gobas, 2004). Relatively low concentrations at the base of the food web can result in relatively high concentrations in biota, with increasing concentrations at higher trophic levels, because the rates of elimination of HOCs from an organism are generally lower than the rates of uptake, particularly from diet.

Arnot and Gobas (2004) developed a food web bioaccumulation model for HOCs in aquatic ecosystems. The Arnot and Gobas (2004) model has been applied in the Pacific Northwest in the Strait of Georgia (Condon, 2007) and the Duwamish River (Windward, 2007). King County has also begun an application of the Arnot and Gobas model to a simplified single-box model of PCB bioaccumulation in the entire Puget Sound (Townes-Witzel and Ryan, 2007; Bruce Nairn, King County, personal communication, 2008; Stern et al., 2009).

Condon (2007) applied the model of Arnot and Gobas (2004) to the aquatic food web of the Strait of Georgia. The Condon (2007) model application is the basis of the food web bioaccumulation modeling for Puget Sound for this project. The Condon (2007) model evaluates the concentration of PCBs in the biota at various trophic levels from the fluxes into and out of each organism. This assumes that the concentrations in the biota are at equilibrium with concentrations in the sediment and water (steady-state assumption), considering the following:

- Direct uptake from water
- Uptake from feeding
- Uptake and loss from respiration
- Loss due to metabolism
- Dilution due to growth
- Loss due to diffusion
- Loss due to fecal egestion (excretion)
- Loss due to reproduction and nursing

In order to predict the bioaccumulation of a top predator (e.g., seals), the model evaluates tissue concentrations of toxics in each organism in successive trophic levels. This is done to simulate the bioaccumulation of toxics from sediment, primary producers (e.g., phytoplankton and other plants), secondary producers (e.g., herbivores), to forage species (e.g., carnivores), to top predators (e.g., seals and marine birds).

A diagram of the trophic linkages in the aquatic food web for the Strait of Georgia and Puget Sound is presented in Figure 4 (Condon, 2007). The aquatic food web is focused on three top predators: harbor seals, herons, and cormorants. Harbor seals have a similar diet compared with fish-eating Orcas or killer whales, but they have a much smaller feeding range, which makes them more amenable to prediction of bioaccumulation.

For the application to Puget Sound during this project, all of the species and trophic linkages described by Condon (2007) for the Strait of Georgia were used. Also the following species were added to the aquatic food web based on the availability of concentration data and other studies that have included these (e.g., Windward, 2007; Townes-Witzel and Ryan, 2007. Note that English sole are already included in Condon's original food web):

- Resident Pacific herring
- Resident blackmouth (Chinook) salmon
- Ratfish
- Shiner surfperch
- Staghorn sculpin
- Graceful crab and spot prawn

Ecology's food web bioaccumulation model for this project, named "foodweb.xls", is programmed in Microsoft Excel VBA. It was developed as a generalized modeling framework that can be readily adapted to different waterbodies with different species and food web linkages. It is based on the model theory of Arnot and Gobas (2004) building on the version that was developed by Condon (2007) for the Strait of Georgia, British Columbia.

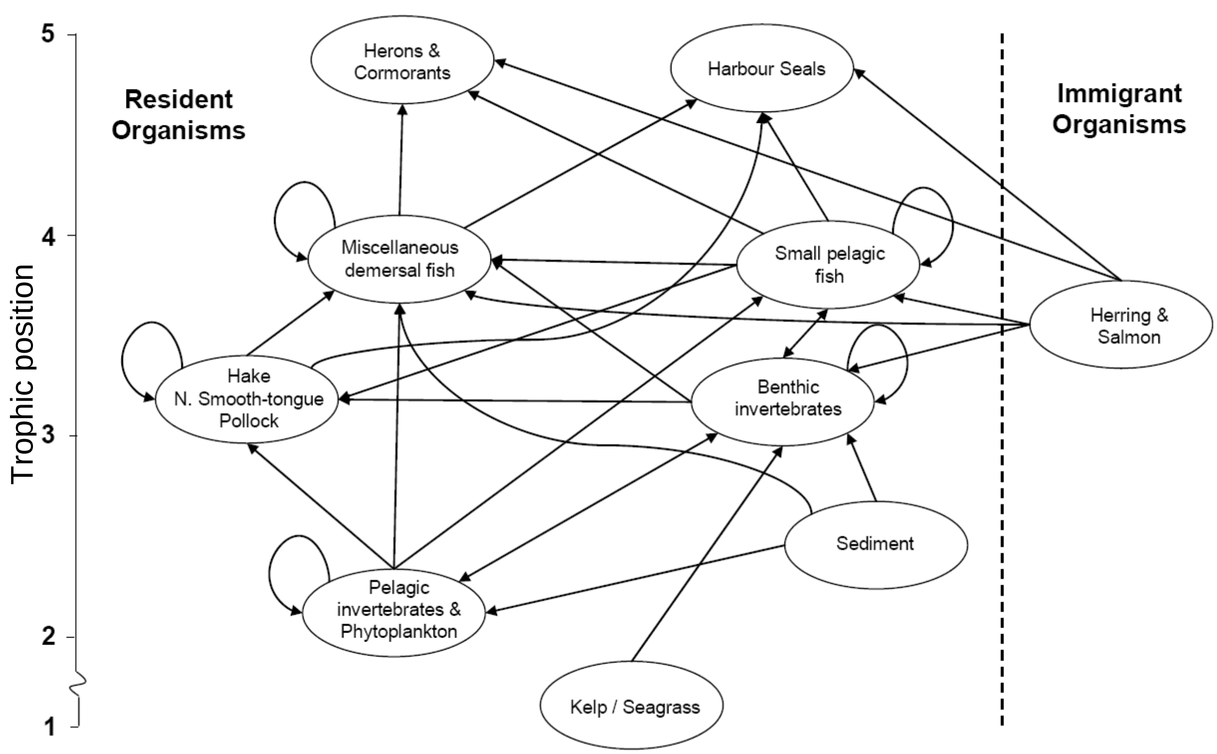

Figure 4. Schematic diagram of trophic linkages for the major feeding groups of concern in the food web bioaccumulation model (after Condon, 2007). Arrows point from prey to predators.

Environmental data

Environmental data serve as input or boundary conditions for application of the fate and transport and food web bioaccumulation models in Puget Sound. Environmental data have not been specifically collected for this study, but numerous studies have collected relevant data that were used in the model. In addition to PCBs, environmental data for other ancillary variables that are necessary for simulation of fate and transport and bioaccumulation of PCBs were also summarized.

This report summarizes the following sediment and water column parameter data collected within the Puget Sound box model regions:

Sediment Data Parameters	**Water Column Data Parameters**
Polychlorinated Biphenyls (PCBs)	Polychlorinated Biphenyls (PCBs)
Percent solids	Total Suspended Solids (TSS)
Total Organic Carbon (TOC)	Total Organic Carbon (TOC)

Other environmental data that were summarized for this project include sediment accumulation rates from Pb-210 studies, and biota concentrations of PCBs.

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Methods

Models

Box model of circulation and transport

The theory for the box model of circulation and transport in psbox.xls is described in detail by Babson et al. (2006). The model equations are based on conservation of mass and salt as well as parameterizations of additional dynamics. The model estimates salinity for each box and transports between boxes, including vertical mixing, and horizontal and vertical advection of water and salt. User instructions for psbox.xls are provided in Appendix A.

PCB fate and transport

The model theory for PCB fate and transport in psbox.xls is explained in detail by Davis (2004). The model estimates inputs and outputs and changes in concentration in water and sediment compartments. Sediments are divided conceptually into an active sediment layer and buried deep sediment. The active sediment layer is the mass of sediment that is actively exchanging PCBs with the water column and the biota of the aquatic food web.

The only modifications to the original Davis (2004) model in psbox.xls were as follows:

- The waterbody is divided into multiple boxes each with two water column layers, with horizontal and vertical exchanges between boxes and layers, instead of the single box with one water column layer that was used by Davis (2004).
- Active sediment areas for each box are divided into two sub-areas (Figure 5) to allow simulation of the transport of sediment from shallower to deeper areas: (1) sediments that are below the surface water layer, and (2) sediments that are below the deep water layer.
- Additional options are provided for estimation of resuspension of bottom sediments.
- An option is provided for calculation of the fraction of dissolved PCB using the equation described by Arnot and Gobas (2004).

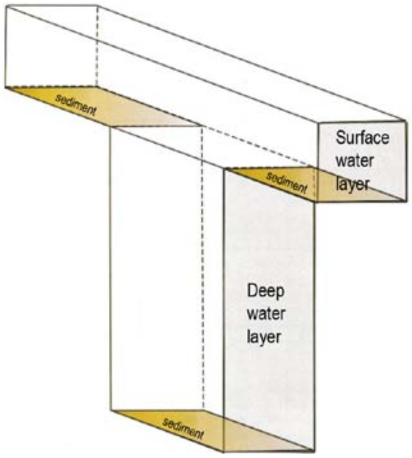

Figure 5. Cross-section of a box showing surface and deep water layers and areas of active sediment.

Davis (2004) calculates sediment solids resuspension (ResFlux in Kg/d) by difference between settling flux (SetFlux in Kg/d) and burial flux (BurFlux in Kg/d) given the inputs for the settling and deep burial parameters on the 'basins' sheet as follows:

SetFlux = 1000 * Cpw * Vss * Saw (eqn 1)
BurFlux = 1000 * Css * Vb * Sas (eqn 2)
ResFlux = SetFlux – BurFlux (eqn 3)

where Cpw = concentration of sediment particles in the water column (Kg/L); Vss = solids settling velocity (m/d); Saw = surface area of the water (m^2); Css = sediment solids concentration (Kg/L); Vb = sediment deep burial velocity (m/d); and Sas = sediment surface area (m^2).

Two additional options were developed for psbox.xls to allow the use of known values of resuspension rates instead of calculating ResFlux by difference while preserving the continuity of the mass of sediment solids that are settled, resuspended, and buried.

Option 1 calculates sediment burial flux (BurFlux in Kg/d) by difference between settling flux (SetFlux in Kg/d) and resuspension flux (ResFlux in Kg/d) given the inputs for the settling and resuspension parameters, including the resuspension velocity (Vrs, m/d) as follows:

SetFlux = 1000 * Cpw * Vss * Saw (eqn 4)
ResFlux = 1000 * Css * Vrs * Sas (eqn 5)
BurFlux = SetFlux – ResFlux (eqn 6)

Option 2 calculates the settling flux (SetFlux in Kg/d) as the sum of burial flux (BurFlux in Kg/d) and resuspension flux (ResFlux in Kg/d), and solves for the settling velocity of solids, given the inputs for the burial and resuspension parameters as follows:

BurFlux = 1000 * Css * Vb * Sas (eqn 7)
ResFlux = 1000 * Css * Vrs * Sas (eqn 8)
SetFlux = BurFlux + ResFlux (eqn 9)
Vss = SetFlux / (1000 * Cpw * Saw) (eqn 10)

The ratio of the freely dissolved water concentration (Cwd) to the total water concentration (Cwt) in the overlying water can be estimated from the following equation (Arnot and Gobas, 2004):

$$C_{wd}/C_{wt} = 1 / (1 + X_{poc}*D_{poc}*\alpha_{poc}*K_{ow} + X_{doc}*D_{doc}*\alpha_{doc}*K_{ow}) \qquad \text{(eqn 11)}$$

X_{poc} and X_{doc} are the concentrations of particulate organic carbon (POC) and dissolved organic carbon (DOC) in the water (Kg/L), which are estimated from measured concentrations. D_{poc} and D_{doc} are the dis-equilibrium factors for POC and DOC partitioning (unitless), which are assumed to be equal to 1 to represent equilibrium partitioning (Arnot and Gobas, 2004). α_{poc} and α_{doc} are the proportionality constants describing the similarity in phase partitioning of POC and DOC in relation to that of octanol. Values of α_{poc} and α_{doc} are assumed to be 0.35 and 0.08, respectively (Arnot and Gobas, 2004), with each value having an uncertainty of approximately plus or minus a factor of 2.5.

Food web bioaccumulation

The theory for the food web bioaccumulation model in foodweb.xls is described in detail in Condon (2007) and Arnot and Gobas (2004). User instructions for foodweb.xls are provided in Appendix B.

Environmental database queries

Environmental data are used as inputs and boundary conditions for the models of fate and transport and food web bioaccumulation. Environmental data were retrieved from Ecology's online Environmental Information Management (EIM) database. EIM contains environmental data collected by multiple entities including (but not limited to) Ecology, in addition to other state agencies, private consultants, counties, and cities and other local governments that are associated with studies related to Ecology.

Additional sediment PCB data collected by the Environmental Monitoring and Assessment Program (EMAP) were also included in PCB data summaries. Washington Coastal EMAP, funded by EPA and jointly conducted by Ecology, NOAA, and EPA, is a large-scale assessment of all of Washington's coastal areas. Annual monitoring has been conducted since 1999. Sediment PCB data, among other toxics, were measured in the Puget Sound area in 2000 and 2004. Results from the 2005-2006 EMAP surveys were not available at the time of this report preparation.

Additional data collected by King County for water column total suspended solids, total organic carbon, and dissolved organic carbon (Curtis DeGaspari, King County, personal communication, 2009) were also included in the project database.

Sediment data

Queries were created to produce sediment data for each parameter listed above to include all data collected in ocean, estuary, intertidal, and subtidal sediment areas of Puget Sound. Queried sediment data were referenced to the different regions of the box model in ArcGIS using a spatial join. Data generated from this query were further filtered and divided into three groups: sediment measurements made in the 0–2 cm, 0-5 cm, and 0-10 cm sediment layer. This was done to characterize data availability at different depths and help inform the decision for the thickness of the active sediment layer in the fate and transport model.

All statistical data summaries are presented for each region, and separately for these three sediment layers (the 0–10 and 0-5 cm data are inclusive of the 0–2 cm data). Sediment percent solids data were also summarized for measurements taken in deeper sediment (10-100 cm) in order to characterize sediment density for deeper sediment. No sediment data were found for "The Narrows" region of the box model.

A list of all PCB data sources (study names), sampling dates, and available PCB congeners can be found in Appendix C. The midpoint of the sample collection dates for sediment data is the late 1990s. The term "current conditions" is sometimes used in this report in reference to sediment and should be interpreted with respect to the range of dates shown in the studies of Appendix C, which is centered approximately in the late 1990s.

Non-detect data

A significant subset of PCB samples (Table 2) was reported as below the detection limit (DL) of the analytical method used to measure the concentration of chemical. The reported values for these non-detect data cannot directly be used for further analysis since they do not represent a quantified concentration.

Numerous substitution methods, where non-detect values are replaced with a substituted value, are available (e.g., Tsanis et al., 1994). These substituted values may then be used in further statistical analysis. For example, the non-detect value could be replaced with a value that is half of the DL. Different substitution methods can bias the results in different ways, so a method that is appropriate for the dataset needed to be selected.

Different substitution methods were tested and analyzed using cumulative frequency distribution (CFD) plots to determine which method was appropriate for the sediment PCB data. The four methods tested, described below, were used to replace non-detect reported values with substituted values:

Method 1: Substitute zero for congener or aroclor values below the DL (<DL) regardless of the DL, but omit from the sample distributions and summary statistics any samples with all congeners or aroclors below the DL.

Method 2: Substitute 0.5DL for values <DL if DL is between 0 – 20 ppb OR substitute 10 ppb for values <DL if DL is greater than or equal to 20 ppb (DL>=20).

Method 3: Substitute 0.5DL for values <DL regardless of the DL.

Method 4: Substitute values that are <DL with the actual DL value regardless of the DL.

Plots illustrating the cumulative frequency distribution (CFD) of PCB concentrations using the above substitution methods can be found in Appendix D for each region of the box model.

Table 2. Summary of sediment PCB data from EIM and EMAP including total number of records and number and percentage of total records with values below the detection limit.

Model Region	Number of data records								
	0 - 2 cm			0 - 5 cm			0 - 10 cm		
	total #	# < DL	% < DL	total #	# < DL	% < DL	total #	# < DL	% < DL
Admiralty	0	--	--	1193	1070	90%	1193	1070	90%
Commencement Bay	768	269	35%	1261	680	54%	1626	916	56%
Elliott Bay	600	481	80%	1576	894	57%	1947	1176	60%
Hood North	0	--	--	971	957	99%	1041	1021	98%
Hood South	0	--	--	1158	1091	94%	1158	1091	94%
Puget Main	1348	1276	95%	3158	2769	88%	3935	3533	90%
Puget South	228	227	100%	2438	2291	94%	2523	2357	93%
The Narrows	0	--	--	0	--	--	0	--	--
Sinclair/Dyes	225	173	77%	2173	1656	76%	2306	1767	77%
SJF/SOG	515	501	97%	6871	6579	96%	7566	7205	95%
Whidbey	273	248	91%	1986	1713	86%	2105	1833	87%
TOTAL	3957	3175	80%	22785	19700	86%	25400	21969	86%

The initial hypothesis was that Method 1 could bias the distribution of results towards a higher concentration since only those values above the detection limit would be included. However, the CFD plots illustrate that Methods 2 – 4, in most cases, have distributions at higher concentrations than Method 1. In general, it appears that the magnitude of the value that is chosen for substitution for non-detects exerts a relatively large influence on the estimated PCB concentration and may bias the estimate towards a higher value than the actual detected values.

Method 1, where non-detect values are substituted with a value of zero, or the sample was omitted altogether if all congeners were reported below detection, was selected as the final substitution method for use in the fate and transport modeling of PCBs for this project. Methods 2, 3, and 4 were rejected because of the observed sensitivity of the sample distribution to the selected substitution value. In general, methods 2, 3, and 4 appear to result in biased estimates of concentrations that are higher than the detected values. Method 1 was determined to be the least biased method, which is important because of the use of sediment concentration data in the food web bioaccumulation model.

Converting sum of aroclors to sum of congeners

The "total PCB" concentration is the sum of all PCB congeners (NOAA, 1993). In this study, the term "total PCB" is used to represent the sum of measured congeners, which are often a subset of the total number of congeners. If aroclors are measured instead of congeners, then the sum of aroclors may overestimate the total PCB concentration because several aroclors may contain some of the same congeners. To estimate the approximate concentration of total PCBs (generally defined as the sum of measured congeners in this project), from the sum of aroclors, we developed a regression relationship with the sum of congeners ($R^2 = 0.96$), which represents the best estimate of the equivalent sum of congeners for a given sum of aroclors (Figure 6). The data in Figure 6 are paired samples where congeners and aroclors were detected.

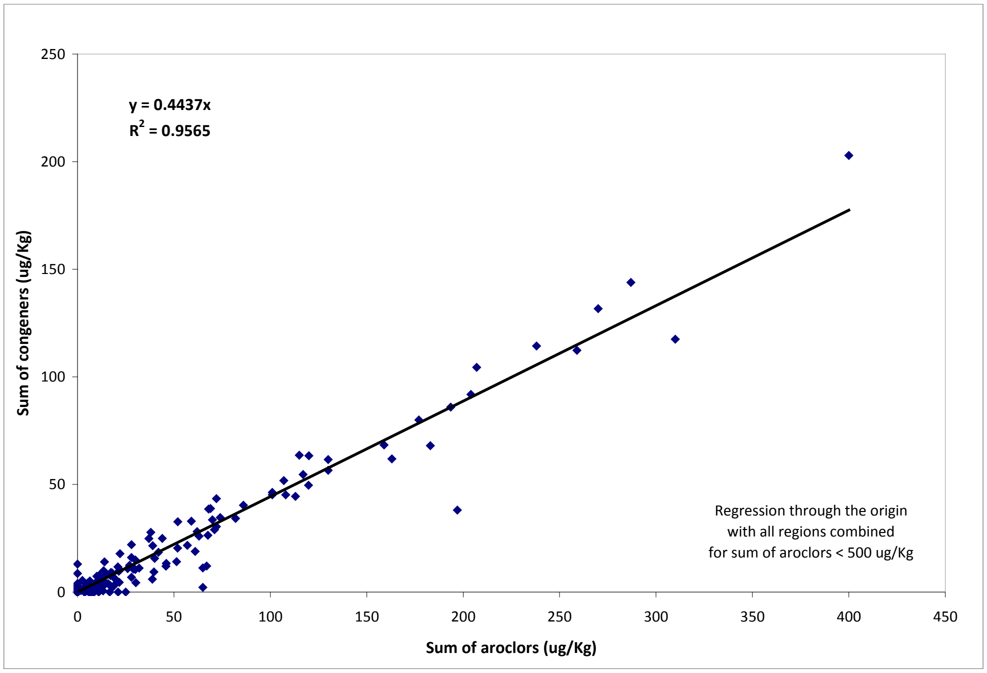

Figure 6. Regression relationship to convert sum of aroclors to sum of measured congeners in the EIM database for sediment samples from Puget Sound.

Most of the sediment PCB congener data were sampled for a subset of up to 22 congeners (Appendix E and F). The GCMS data collected for biota concentrations by PSAMP were sampled for a subset of up to 40 congeners. The average ratio of the sum of 17 of the 22 congeners that overlapped the two methods to the sum of 40 congeners for the GCMS biota data was 63% with a range of 53% to 89%. In other words, 17 of the 22 congeners sampled by EIM represent on average about 63% of the total PCBs that were detected in the 40 congeners sampled by the GCMS method for biota.

These comparisons suggest that the sum of the subset of congeners is likely to underestimate the total PCBs, possibly on the order of less than a factor of 2. While this may be a significant uncertainty, it is relatively small compared with other key model input data. For example, the estimated external load from watershed sources has an interquartile range that spans about a factor of 20.

We decided not to adjust sums of congener subsets to extrapolate to all 209 congeners because of the lack of data for such a conversion, and the possibility that converted data would be subject to about the same degree of uncertainty as unconverted data. Instead we recognize that the use of different subsets of congeners for different data sources is a source of uncertainty in the analysis. Therefore, comparisons between predicted concentrations with observations that use different subsets of congeners should not be expected to agree within better than about a factor of 2.

Water column data

Similar to sediment data, queries were created in EIM to generate water column TSS and TOC data collected in the marine waters of Puget Sound. Queried water column data were referenced to the different regions of the box model in ArcGIS using a spatial join and then divided into 'upper' and 'lower' water column data based on the divisions in Table 1. Data that fell outside the box model regions were excluded.

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Data summaries

External load of polychlorinated biphenyls (PCBs)

Watershed sources

Hart Crowser et al. (2007) presented estimates of loading of PCBs and other toxic chemicals into Puget Sound. Hart Crowser et al. (2007) divided the watershed into sub-basins that contribute to each region of Puget Sound. The watershed areas for each region were further divided into four categories of land cover: forest, residential, commercial/industrial, and agriculture (Figure 7).

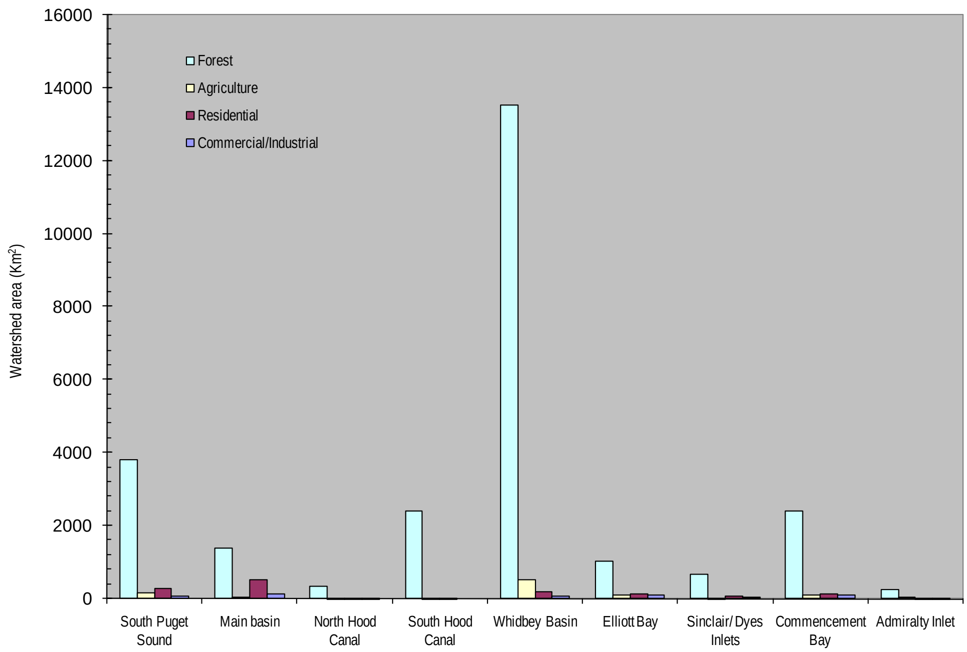

Figure 7. Watershed areas in each basin by land cover in the GIS coverage used by Hart Crowser (2007).

The total flow of runoff from the watershed of each region was based on long-term averages of flow gaging stations with extrapolation proportional to watershed areas to include the ungaged areas. Hart Crowser et al. (2007) determined the flows from each category of land cover within each region by estimating dimensionless relative runoff fractions according to ratios of runoff coefficients that were considered to be typical of each area, and applying these ratios to divide the total flow into the component parts from each land cover. Hart Crowser et al. (2007) then assigned representative concentrations of toxic constituents to the flow from each land cover category based on a summary of literature (Figure 8). The product of the estimated flows and concentrations from each land cover and the summation over all land cover categories resulted in the total loading estimates to each region of Puget Sound.

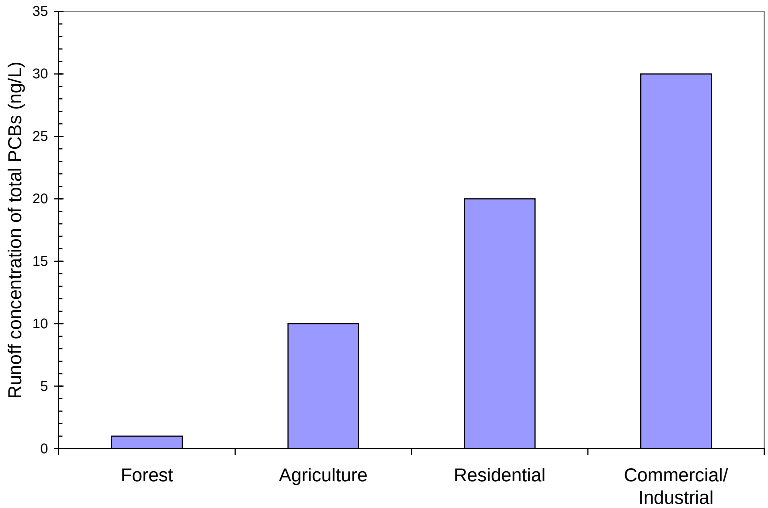

Figure 8. Typical concentrations of total PCBs in runoff.

Envirovision et al. (2008a) recalculated loads from toxic constituents using the same method as Hart Crowser et al. (2007) but with different assumptions for the areas and runoff coefficients of each land cover. For some toxic constituents, but not for PCBs, Envirovision et al. (2008) also calculated separate loading from highways.

A summary of the loading of PCBs from watershed sources is presented in Table 3. Hart Crowser et al. (2007) reported best estimates of median or typical loads (50% probability of exceedance), as well as estimated loads with probabilities of exceedance of 5%, 10%, 25%, 75%, and 95%. For example, if a load is reported to have a probability of exceedance of 25%, then there is an estimated 25% probability that the load could be higher than that value. Envirovision et al. (2008a) also reported loads with the same probabilities of exceedance.

Hart Crowser reported a typical load (50% probability of exceedance) of 116 Kg/year of PCBs, with an interquartile range of 27 to 512 Kg/year (75% and 25% probability of exceedance), for all regions of the Puget Sound box model from watershed sources. The revised loads by Envirovision et al. (2008a) were generally higher, though not significantly different from Hart Crowser et al. (2007) (Table 3), with a typical load (50% probability of exceedance) of 285 Kg/year and an interquartile range of 72 to 1100 Kg/year.

Figure 9 shows the loading and concentration from each land cover category into each of the box model basins. Figure 10 shows the fraction of total PCB loading to Puget Sound that originates from each land cover category that was summarized by Hart Crowser et al. (2007) and Envirovision et al. (2008a). In general, estimates of loading from residential land covers by Envirovision et al. (2008a) were much higher than Hart Crowser et al. (2007) due mainly to the different assumptions about runoff coefficients.

Table 3. Summary of total PCB loading estimates derived from Hart Crowser et al. (2007) and Envirovision et al. (2008 a) in Kg per year.

	South Sound	Main basin	North Hood Canal	South Hood Canal	Whidbey	Elliott Bay	Sinclair/ Dyes Inlet	Commence-ment Bay	Admiralty Inlet	Total
Based on external loading estimates reported by Hart Crowser (2007) (Kg/year):										
TOTAL SURFACE RUNOFF (Kg/year)										
95% exceedance	0.49	0.59	0.020	0.10	1.5	0.31	0.088	0.38	0.056	3.5
75%	3.7	4.2	0.15	1.0	12	2.3	0.64	2.8	0.41	27
50%	15	16	0.66	5.1	54	9.0	2.6	12	1.7	116
25%	64	65	2.9	26	250	37	11	49	7.1	512
5%	520	480	26	280	2300	280	86	410	59	4441
50% EXCEEDANCE LOADS BY LAND COVER (Kg/year)										
Commercial/Industrial (Urban and Non-urban area)	3.3	4.4	0.20	0	6.5	4.0	0.74	4.3	0.25	24
Residential	6.6	11	0.21	0.78	10	3.0	1.3	3.6	0.65	37
Agriculture	1.7	0.25	0.011	0.23	12	0.99	0.081	1.2	0.43	16
Forest	3.4	1.1	0.23	4.1	27	1.1	0.45	2.7	0.38	40
Total	15	16	0.65	5.1	55	9.0	2.6	12	1.7	117
Based on external loading estimates reported by Envirovision et al. (2008a) (Kg/year):										
TOTAL SURFACE RUNOFF (Kg/year)										
95% exceedance	1.5	1.1	0.071	0.44	4.7	0.71	0.30	1.0	0.16	10
75%	10	7.5	0.51	3.4	35	5.0	2.1	7.3	1.1	72
50%	41	29	2.0	14	139	19	8.0	29	4.3	285
25%	160	112	8.0	59	570	75	31	114	17	1147
5%	1162	792	59	499	4471	536	221	834	124	8700
50% EXCEEDANCE LOADS BY LAND COVER (Kg/year)										
Commercial/Industrial (Urban and Non-urban area)	2.9	3.6	0.031	0.12	6.0	4.4	0.66	3.3	0.14	21
Residential	34	25	1.8	10	98	14	7.2	23	3.6	216
Agriculture	1.8	0.15	0.01	0.15	14	0.60	0.032	1.1	0.38	18
Forest	2.1	0.42	0.16	3.6	21	0.55	0.16	1.8	0.24	30
Total	41	29	2.0	14	139	19	8.0	29	4.3	285

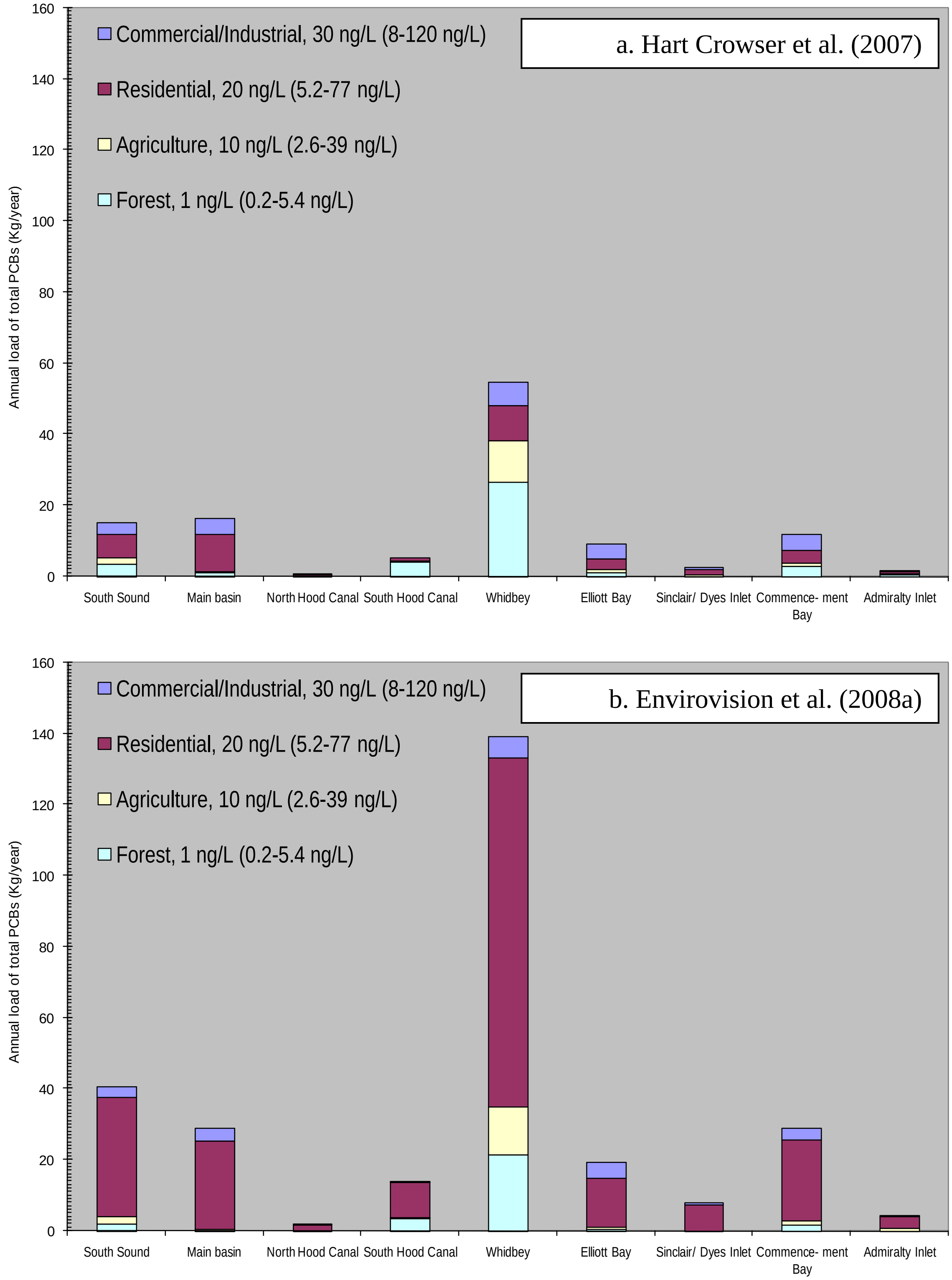

Figure 9. Summary of watershed PCB loads and concentrations by land cover category for each box model basin (typical loads derived from (a.) Hart Crowser et al., 2007 and (b.) Envirovision et al., 2008a). Concentrations shown for each land cover are medians and interquartile ranges.

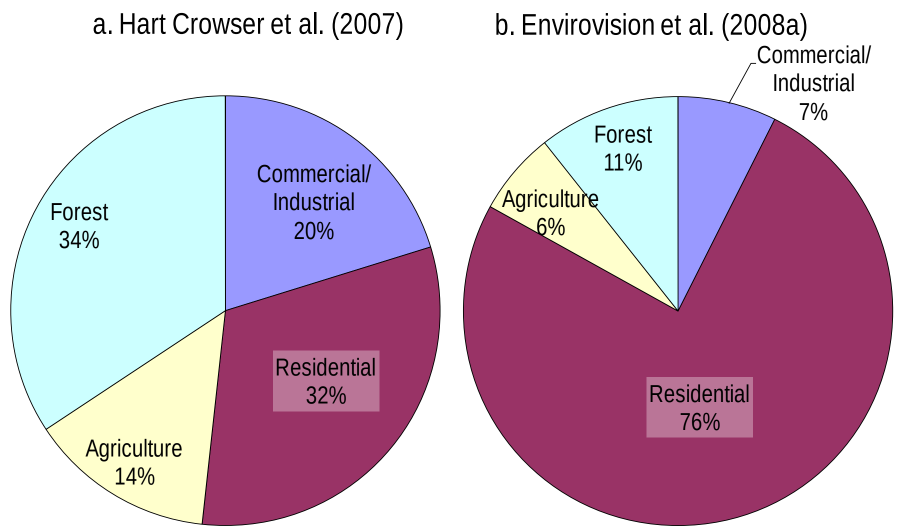

Figure 10. Fraction of the total PCB load to Puget Sound that originates from each land cover category (typical loads derived from (a.) Hart Crowser et al., 2007 and (b.) Envirovision et al., 2008a).

Concentrations of PCBs in runoff from undeveloped forest areas are considerably lower than concentrations from agricultural and commercial/industrial land covers (Figure 8), but the area of forest land cover (Figure 7) is large enough to result in a major source of loading of PCBs.

Recent data collected in the Green River by King County suggests that the concentration of PCBs in runoff from forested areas could be less than 350 pg/L[2], or less than about one-third of the forest loading estimated by Hart Crowser (2007). If the median estimate for forest runoff is assumed to be 350 pg/L instead of the 1 ng/L assumption by Hart Crowser (2007), then the median estimate of total loading would be reduced to about 90 Kg/year instead of 116 Kg/year. This is well within the interquartile range of uncertainty that was reported by Hart Crowser (2007) and Envirovision et al. (2008a). If the runoff from forested areas is assumed to be 175 pg/L (half of the 350 pg/L average in runoff from mixed land covers in the Green River), then the resulting median estimate of total loading would be 84 Kg/year. This is also within the interquartile range of uncertainty that was reported by Hart Crowser et al. (2007) and Envirovision et al. (2008a).

The external loading estimates suggest that nearly half of the total PCB load to Puget Sound enters the Whidbey Basin because it has the largest watershed area and receives the largest river (Skagit River). The main basin and the urban bays (Elliott Bay, Commencement Bay, and Sinclair/Dyes Inlets) together receive about one-third of the total load. Most of the remainder enters South Sound, and a relatively small portion enters Hood Canal and Admiralty Inlet.

Loading of PCBs from municipal and industrial wastewater point source discharges was not estimated due to a scarcity of data (Hart Crowser et al., 2007; Envirovision et al., 2008b).

[2] Personal communication with Bruce Nairn, King County Department of Natural Resources, Seattle, WA.

Loading from flux out of contaminated sediments in urban waterways that are tributary to Puget Sound also are not included in the loading estimates reported by Hart Crowser et al. (2007) or Envirovision et al. (2008a). Modeling studies of the lower Duwamish River estuary by King County suggest that approximately 1 kg/year of PCBs could be contributed to Puget Sound due to flux out of those contaminated sediments[3].

Atmospheric deposition

Hart Crowser et al. (2007) presented a compilation of various estimates of loading of PCBs from atmospheric deposition ranging from about 660 to 8800 ng/m^2/year. Noel (2007) reported results of measurements at two locations in the Strait of Georgia and coastal waters of southern British Columbia (Canada) with an average of 1270 ng/m^2/year, or about 3 Kg/year over the surface area of Puget Sound, for wet and dry deposition of PCBs.

Atmospheric deposition also can be used as a check on the estimates of loading from watershed sources reported by Hart Crowser (2007). If the atmospheric flux of PCBs is considered to be the main source of PCBs in forested areas, then the product of the atmospheric flux and the area of forest land could be considered as an upper bound of the possible PCB loading from forested areas. If atmospheric flux is used to estimate forest loading, then the resulting total loading from all watershed sources is 110 Kg/year, which is well within the interquartile ranges reported by Hart Crowser et al. (2007) and Envirovision et al. (2008a).

Sediment data

Defined below are the summary statistics presented for each parameter's data set:

N	Number of values.	**Median**	Value separating higher half from lower half of all values.
Mean	Arithmetic mean of data set, sum of values divided by number of values.	**75%tile**	Value below which 75% of all values are found.
StdDev	Standard deviation: measure of the spread of values from the mean.	**90%tile**	Value below which 90% of all values are found.
Min	Minimum of all values.	**Max**	Maximum of all values.
10% tile	Value below which 10% of all values are found.	**GeoMean**	Geometric mean: Nth root of the product of N numbers.
25%tile	Value below which 25% of all values are found.	**GeoSD**	Geometric standard deviation: standard deviation of the log (base 10) of values.

Polychlorinated biphenyls (PCBs)

PCB data summaries are organized into 0–2, 0-5, and 0–10 cm groups, using values generated from substitution Method 1. Figure 11 illustrates the sampling locations for these PCB data.

[3] Personal communication with Bruce Nairn, King County Department of Natural Resources, Seattle, WA.

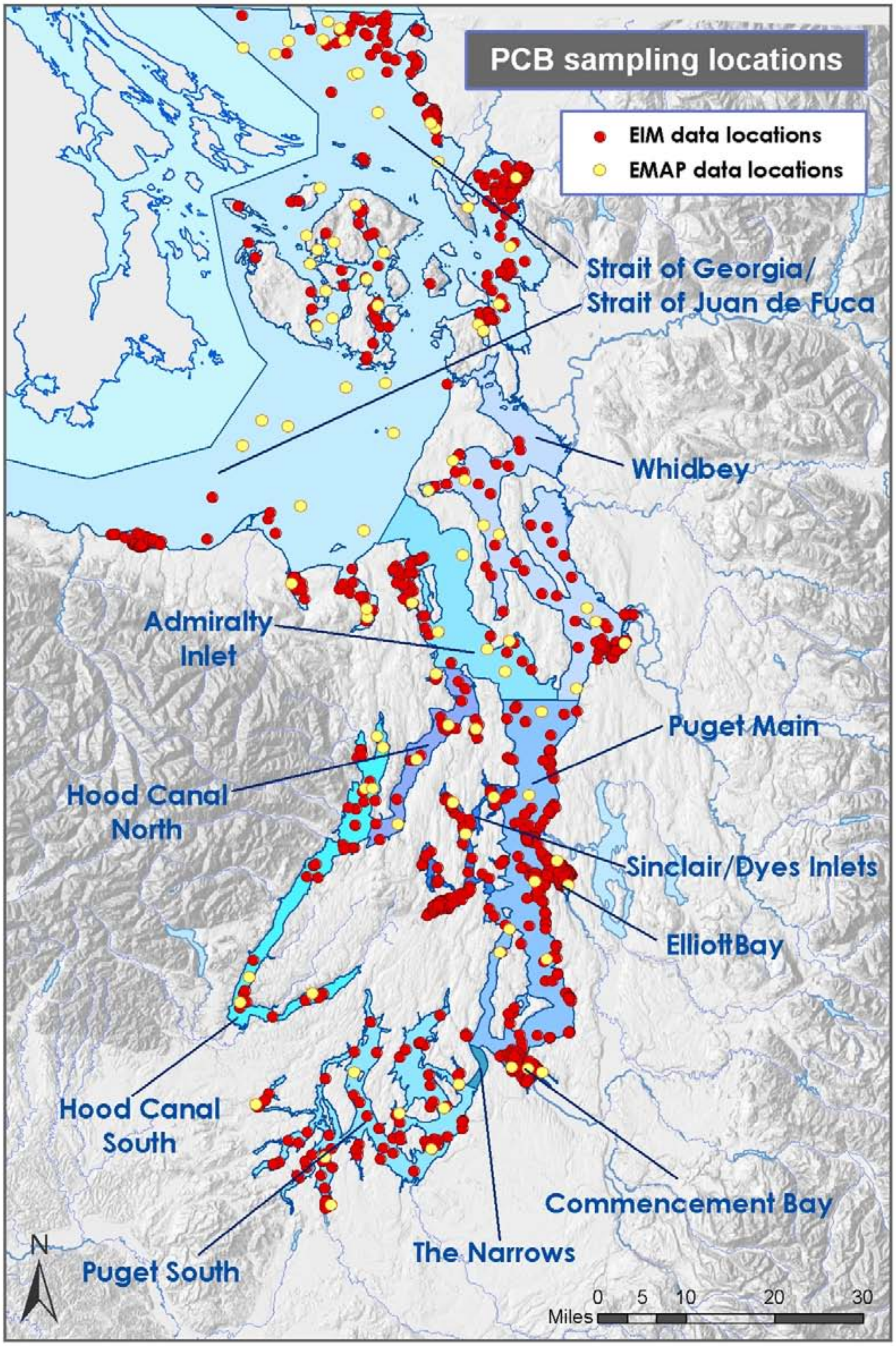

Figure 11. Location of PCB sediment data located within the areas of the box model and used to generate statistical data summaries.

Figure 12 compares median concentrations of total PCBs between three sediment layers. Concentrations in the 0-5 cm and 0-10 cm group appear to be similar in each region. For some regions, the concentrations in the 0-2 cm layer appear to be greater than in the 0-5 or 0-10 cm layers. This finding could possibly be an artifact of different sampling locations in each layer group. For example, 20 data points were found to represent the 0-2 cm sediment layer in Sinclair/Dyes Inlets, whereas there were 141 data points to represent the 0-10 cm layer. Sloan and Gries (2008) found that concentrations of PCBs and some other toxic constituents in the 0-2 cm sediment layer were significantly lower than in the 0-10 cm layer when paired samples were evaluated in Elliott Bay.

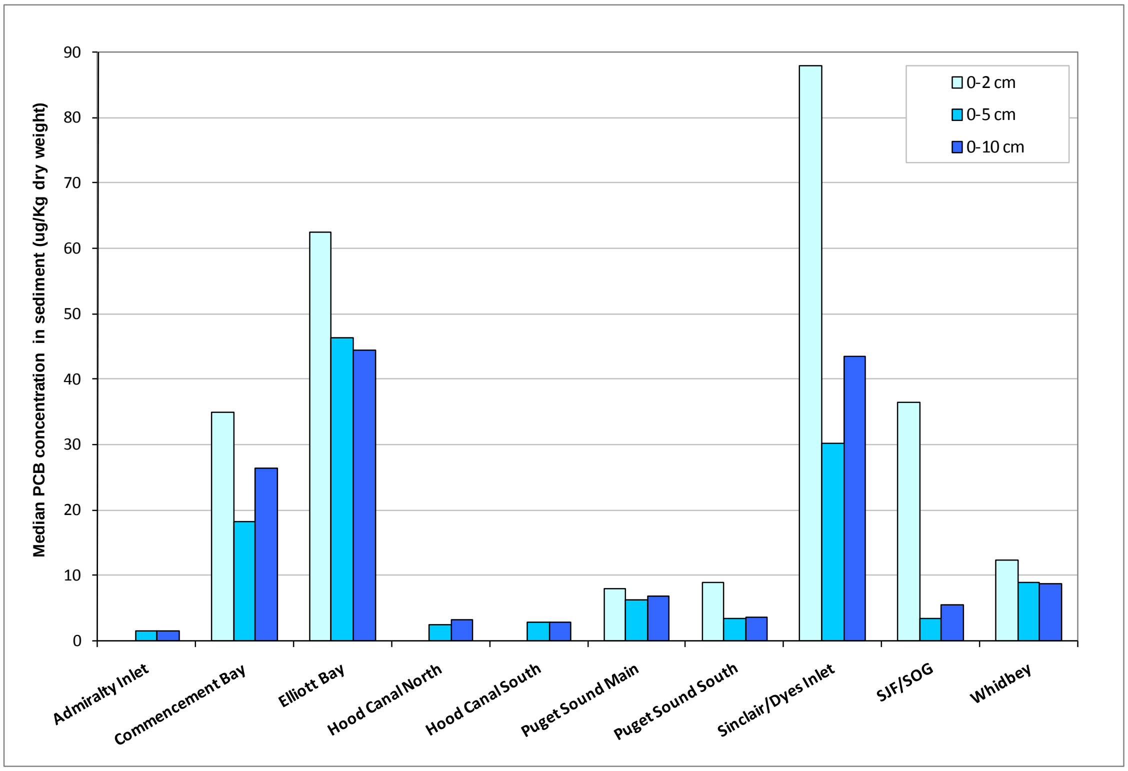

Figure 12. Comparison of median PCB concentrations between the 0-2, 0-5, and 0–10 cm sediment layer for the different regions of the box model.

Figure 13 through Figure 15 show box plots of PCB data for the different regions of the box model. Table 4 presents the summary statistics for this data. Figure 16 and Figure 17 show the fraction of total PCB represented by each congener/aroclor for the two sediment layers using all samples combined. Statistical summaries of individual congeners in the 0-2, 0-5, and 0-10 cm sediment layers, and tables and charts presenting the fraction of total PCBs represented by each congener/aroclor by box model region, can be found in Appendix E and F.

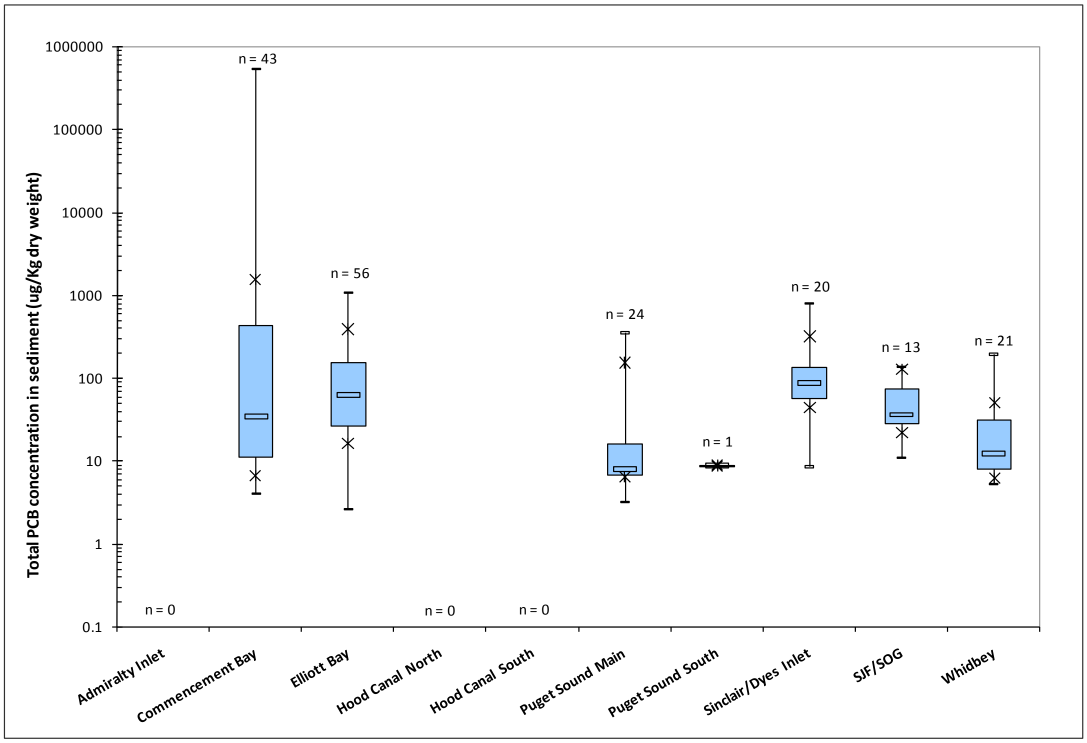

Figure 13. Box plot for total PCB concentration in each region of the box model in the 0–2 cm sediment layer showing the median, maximum, minimum, and 25 and 75 percentiles as well as 10 and 90 percentile (crosses).

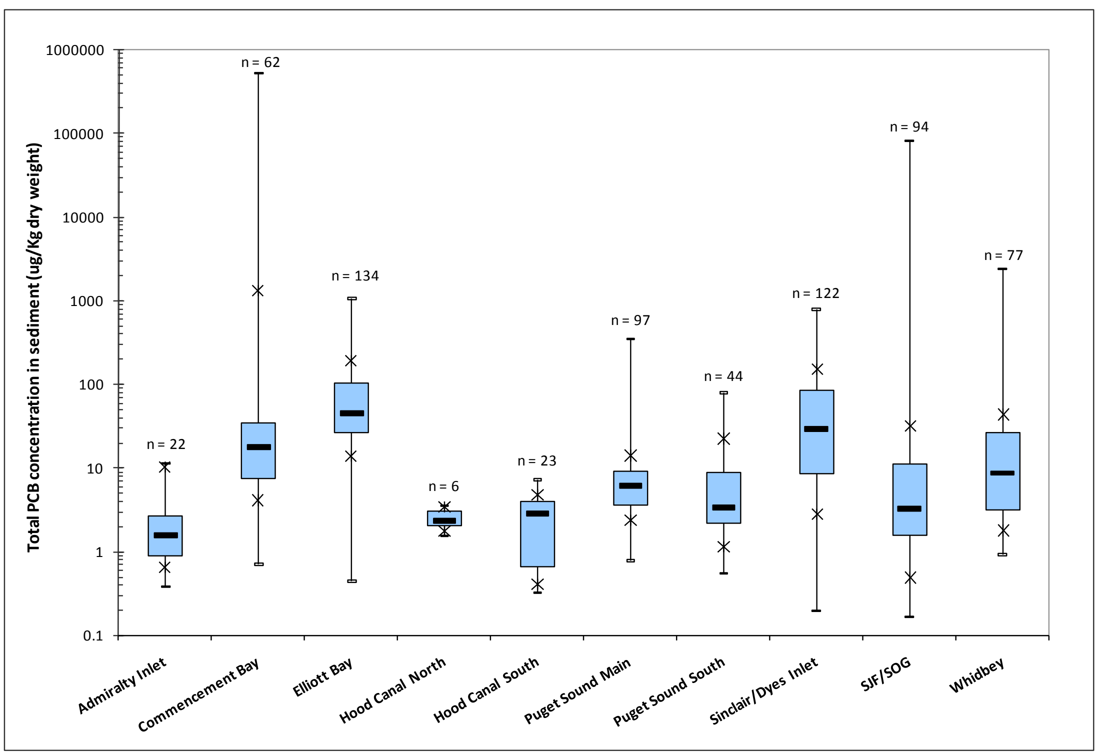

Figure 14. Box plot for total PCB concentration in each region of the box model in the 0–5 cm sediment layer showing the median, maximum, minimum, and 25 and 75 percentiles as well as 10 and 90 percentile (crosses).

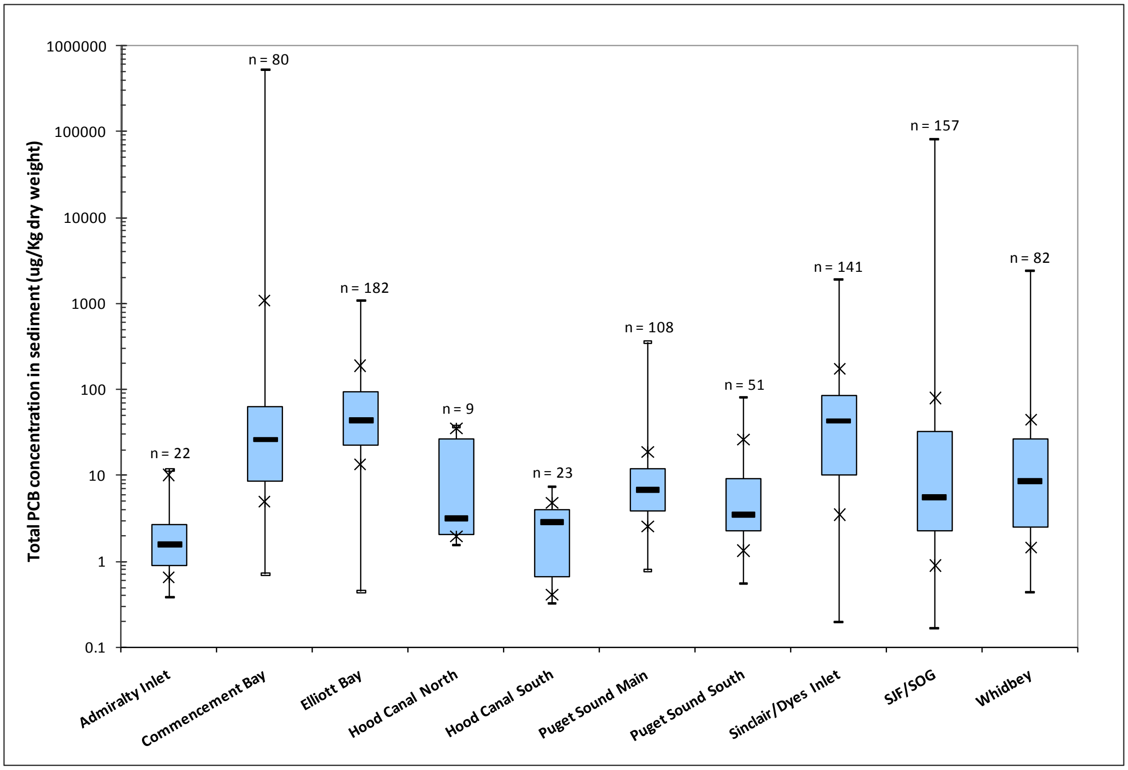

Figure 15. Box plot for total PCB concentration in each region of the box model in the 0–10 cm sediment layer showing the median, maximum, minimum, and 25 and 75 percentiles as well as 10 and 90 percentile (crosses).

Table 4. Statistical data summary of sediment total PCB data (ug/Kg dry weight) in the 0-2, 0-5, and 0-10 cm layer for the different regions of the box model (sum of congeners).

Model Region	N	Mean	StdDev	Min	10%tile	25%tile	Median	75%tile	90%tile	Max	GeoMean	GeoSD
0-2 cm												
Admiralty Inlet	0	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Commencement Bay	43	13110.26	81062.15	4.08	6.67	11.22	34.92	426.50	1562.48	532100	70.30	1.11
Elliott Bay	56	146.76	206.38	2.62	16.29	26.40	62.56	152.08	395.87	1082.63	69.69	0.54
Hood Canal North	0	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Hood Canal South	0	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Puget Sound Main	24	47.97	102.03	3.20	6.48	6.81	7.96	16.02	156.36	356.29	14.56	0.56
Puget Sound South	1	8.87	-----	8.87	8.87	8.87	8.87	8.87	8.87	8.87	8.87	-----
Sinclair/Dyes Inlet	20	147.14	178.69	8.61	44.87	57.68	87.85	133.66	323.10	807.53	91.04	0.45
Strait of Juan de Fuca/Georgia	13	58.88	43.80	11.09	22.36	28.40	36.38	75.43	129.56	137.55	45.24	0.34
Whidbey	21	30.95	46.01	5.32	6.21	7.99	12.42	31.06	51.03	195.23	16.75	0.44
0-5 cm												
Admiralty Inlet	22	2.89	3.46	0.39	0.66	0.90	1.60	2.67	10.20	11.54	1.77	0.41
Commencement Bay	62	9095.40	67538.31	0.72	4.16	7.61	18.14	35.19	1323.00	532100	33.36	1.07
Elliott Bay	134	95.79	144.88	0.45	13.97	26.95	46.31	103.85	191.10	1082.63	50.70	0.49
Hood Canal North	6	2.54	0.80	1.55	1.80	2.04	2.38	3.11	3.44	3.64	2.43	0.14
Hood Canal South	23	2.70	2.14	0.33	0.41	0.67	2.88	4.03	4.82	7.41	1.77	0.45
Puget Sound Main	97	16.68	53.26	0.79	2.39	3.59	6.34	9.32	14.16	356.29	6.51	0.43
Puget Sound South	44	9.28	16.31	0.56	1.17	2.19	3.41	8.84	22.58	81.20	4.21	0.51
Sinclair/Dyes Inlet	122	72.22	115.04	0.20	2.86	8.69	30.17	85.90	153.96	807.53	25.21	0.75
Strait of Juan de Fuca/Georgia	94	896.52	8569.85	0.17	0.49	1.58	3.33	11.09	31.86	83100	4.08	0.81
Whidbey	77	68.28	323.02	0.93	1.81	3.19	8.87	26.40	43.64	2436	9.93	0.64
0-10 cm												
Admiralty Inlet	22	2.89	3.46	0.39	0.66	0.90	1.60	2.67	10.20	11.54	1.77	0.41
Commencement Bay	80	7074.99	59467.34	0.72	4.97	8.55	26.46	63.90	1087.36	532100	35.99	0.98
Elliott Bay	182	92.49	149.98	0.45	13.49	22.85	44.37	93.18	191.19	1082.63	47.31	0.49
Hood Canal North	9	12.64	15.41	1.55	1.94	2.04	3.24	26.62	35.14	37.27	5.77	0.58
Hood Canal South	23	2.70	2.14	0.33	0.41	0.67	2.88	4.03	4.82	7.41	1.77	0.45
Puget Sound Main	108	16.66	50.52	0.79	2.53	3.87	6.86	12.09	18.85	356.29	7.09	0.43
Puget Sound South	51	10.34	17.34	0.56	1.34	2.26	3.55	9.25	26.18	81.20	4.77	0.51
Sinclair/Dyes Inlet	141	103.07	236.02	0.20	3.52	10.21	43.45	85.92	173.04	1903.47	29.99	0.75
Strait of Juan de Fuca/Georgia	157	555.40	6630.16	0.17	0.90	2.28	5.59	32.39	79.87	83100	7.80	0.82
Whidbey	82	64.85	313.23	0.44	1.47	2.49	8.72	26.30	44.94	2436	8.85	0.68

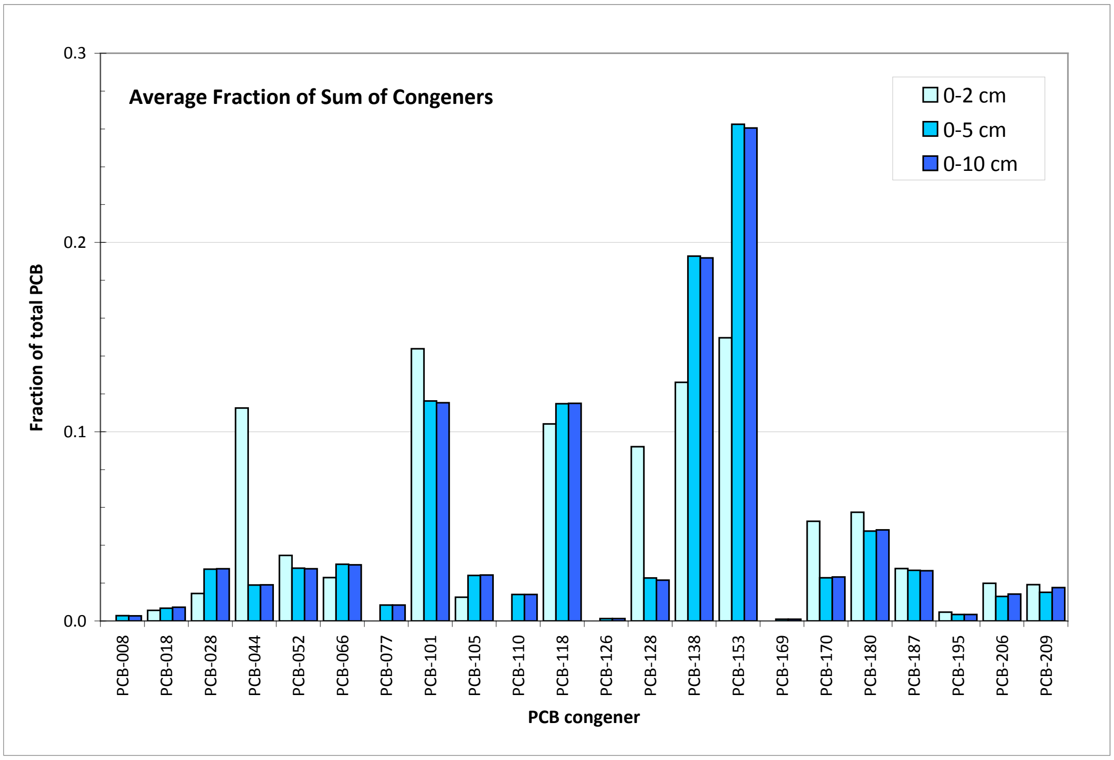

Figure 16. Average fraction of sum of PCB congeners represented by each congener in the 0-2, 0-5, and 0-10 cm sediment layer in all samples combined.

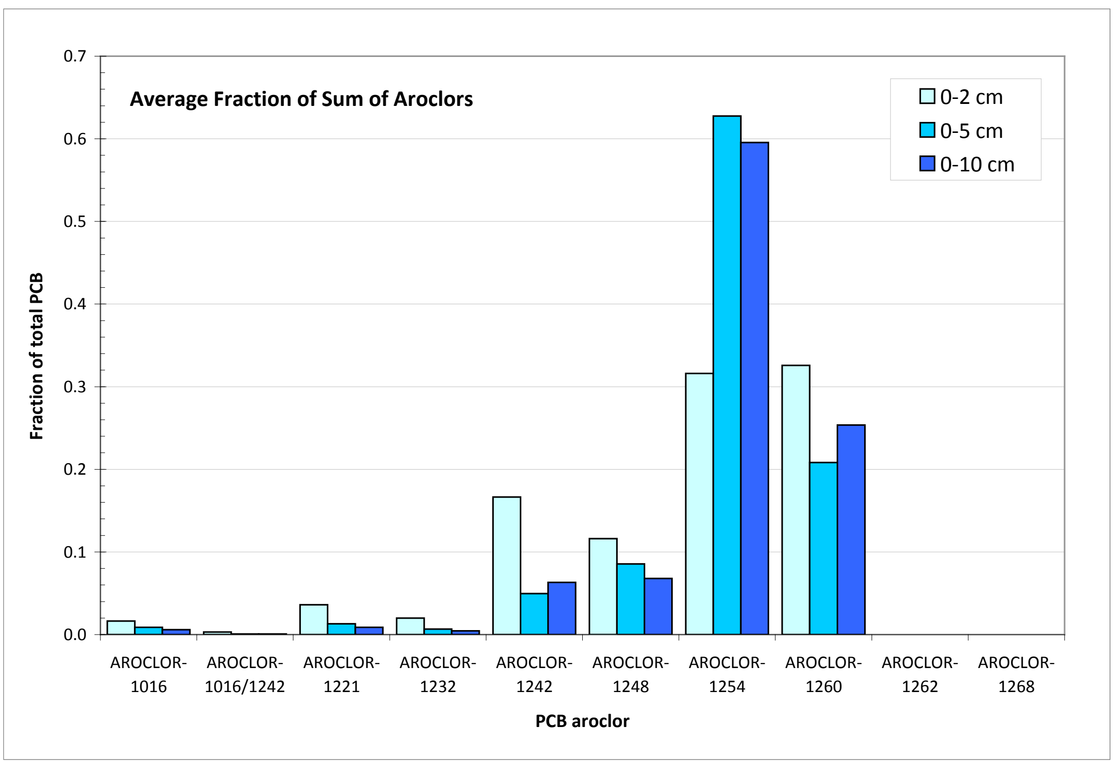

Figure 17. Average fraction of sum of PCB aroclors in the 0-2, 0-5, and 0-10 cm sediment layer in all samples combined.

Percent solids

No sediment percent solids data were found for the 0-2 cm sediment layer. Data from EIM were limited to a few regions of the box model, and most sampling locations were concentrated along the edges of Puget Sound in close proximity to the shorelines (Figure 18). These data may therefore not be representative of sediment throughout the different regions of the box model. Table 5 presents data summaries for the 0-5, 0-10, and 10-100 cm layer.

The measured percent solids (p, percent) was used to estimate the sediment concentration of dry solids (Cs, Kg/L) in units of mass of dry weight of solids per unit volume of sediment, shown in Table 6, using the following equation from Lefkovitz et al. (1997):

$$Cs = (0.1737 * (5.0245 + (EXP(0.0238 * p)))) * (p / 100) \qquad \text{(eqn 11)}$$

Figure 19 presents a comparison of the sediment concentrations of dry solids with water depth from four studies of sedimentation in Puget Sound (METRO, 1984; Carpenter et al., 1985; Lavelle et al., 1986; LOTT, 1998). There is a weak trend of decreasing sediment concentration of dry solids with increasing water depth. The median value is 0.6 Kg/L with an interquartile range of 0.5 to 0.86 Kg/L. Summary statistics for the sediment concentration of dry solids (Kg/L) from 87 cores are as follows:

Number of cores	87
Mean	0.6886
Standard Deviation	0.2461
Minimum	0.3265
25%tile	0.5000
Median	0.6000
75%tile	0.8624
Maximum	1.3750

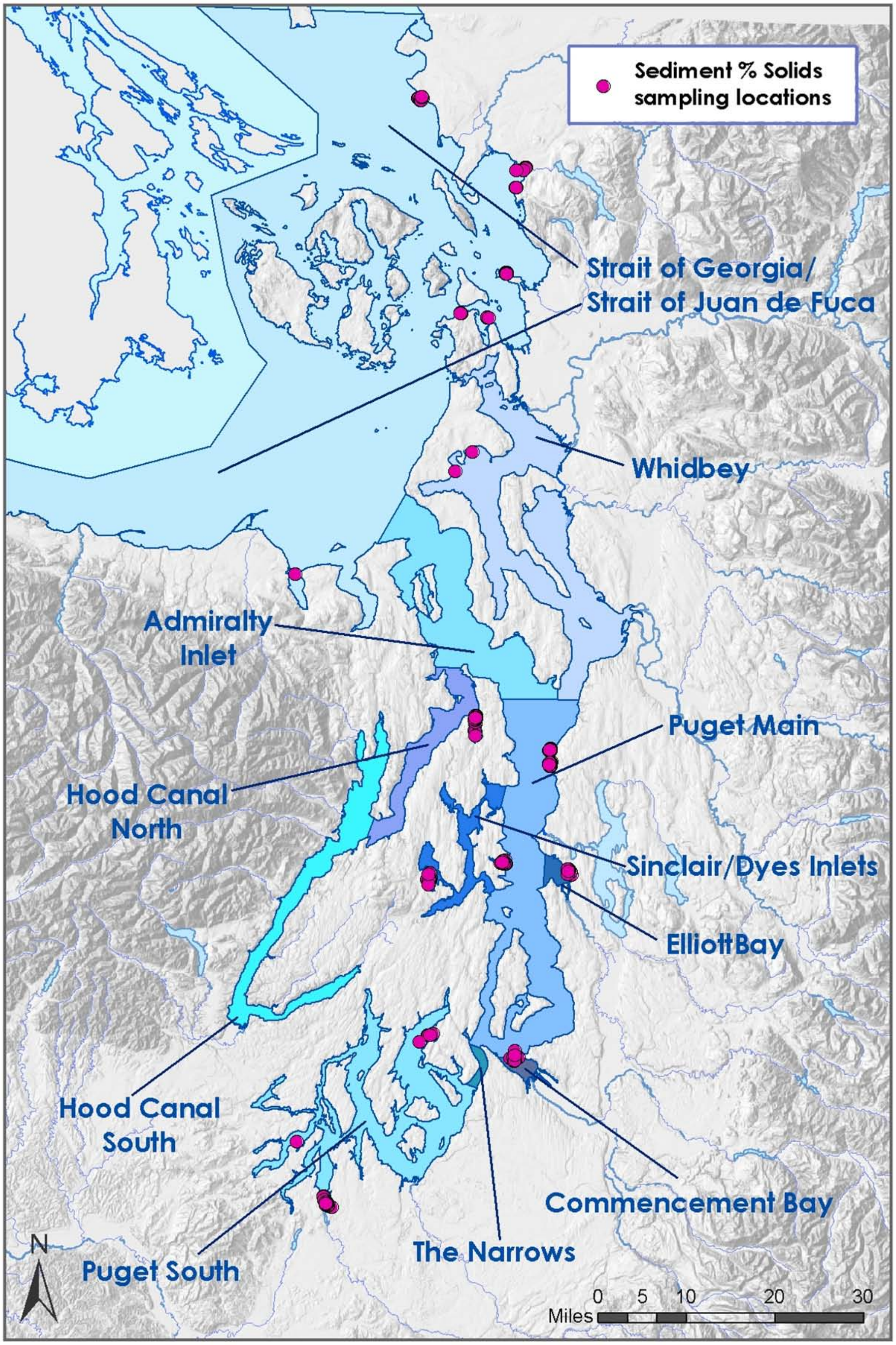

Figure 18. Location of sediment percent solid data within the areas of the box model and used to generate statistical data summaries.

Table 5. Statistical data summary of sediment percent solids data in the 0-5, 0-10, and 10-100 cm layer for the 10 regions of the box model.

Model Region	N	Mean	StdDev	Min	10%tile	25%tile	Median	75%tile	90%tile	Max	GeoMean	GeoSD
0-5 cm												
Admiralty Inlet	0	----	----	----	----	----	----	----	----	----	----	----
Commencement Bay	11	41.22	3.66	38.50	39.00	39.25	39.60	40.65	47.60	49.30	41.08	0.04
Elliott Bay	0	----	----	----	----	----	----	----	----	----	----	----
Hood Canal North	0	----	----	----	----	----	----	----	----	----	----	----
Hood Canal South	0	----	----	----	----	----	----	----	----	----	----	----
Puget Sound Main	21	73.78	13.43	41.60	43.00	75.90	78.60	81.00	82.20	84.40	72.23	0.10
Puget Sound South	5	75.36	7.86	61.80	67.20	75.30	79.40	79.40	80.30	80.90	75.00	0.05
Sinclair/Dyes Inlet	0	----	----	----	----	----	----	----	----	----	----	----
Strait of Juan de Fuca/Georgia	7	59.84	13.59	42.10	46.66	49.90	61.60	67.90	76.18	79.60	58.52	0.10
Whidbey	0	----	----	----	----	----	----	----	----	----	----	----
0-10 cm												
Admiralty Inlet	0	----	----	----	----	----	----	----	----	----	----	----
Commencement Bay	12	40.93	3.63	37.70	38.55	39.08	39.55	40.63	46.91	49.30	40.79	0.04
Elliott Bay	41	65.65	11.25	43.00	56.60	60.00	64.70	72.10	74.40	95.90	64.70	0.08
Hood Canal North	31	52.16	15.23	27.60	35.08	38.45	53.42	66.80	71.81	74.10	49.93	0.13
Hood Canal South	0	----	----	----	----	----	----	----	----	----	----	----
Puget Sound Main	76	74.24	13.72	41.60	52.75	70.40	77.10	82.70	87.51	97.71	72.75	0.09
Puget Sound South	33	40.94	17.85	22.50	27.40	29.50	31.10	50.30	72.92	80.90	37.87	0.17
Sinclair/Dyes Inlet	12	39.54	7.15	32.00	32.38	35.13	36.55	43.30	49.00	54.80	39.00	0.07
Strait of Juan de Fuca/Georgia	53	62.24	13.42	40.11	43.90	49.70	62.23	73.90	79.56	83.30	60.77	0.10
Whidbey	0	----	----	----	----	----	----	----	----	----	----	----
10-100 cm												
Admiralty Inlet	0	----	----	----	----	----	----	----	----	----	----	----
Commencement Bay	0	----	----	----	----	----	----	----	----	----	----	----
Elliott Bay	36	64.28	18.33	23.00	39.40	58.43	66.10	73.00	88.35	96.60	61.08	0.15
Hood Canal North	22	37.10	5.60	29.40	30.75	32.53	36.30	43.08	44.70	46.10	36.70	0.06
Hood Canal South	0	----	----	----	----	----	----	----	----	----	----	----
Puget Sound Main	21	83.40	9.60	66.30	70.00	78.60	82.50	92.10	93.30	93.60	82.84	0.05
Puget Sound South	0	----	----	----	----	----	----	----	----	----	----	----
Sinclair/Dyes Inlet	0	----	----	----	----	----	----	----	----	----	----	----
Strait of Juan de Fuca/Georgia	40	47.88	16.95	25.40	32.55	35.88	39.00	66.08	72.91	85.00	45.26	0.14
Whidbey	8	42.81	8.53	37.30	37.58	38.90	39.95	41.75	49.79	63.30	42.21	0.07

Table 6. Statistical data summary of sediment concentration of dry solids (Kg/L) in the 0-5, 0-10, and 10-100 cm layer for the 10 regions of the box model.

Model Region	N	Mean	StdDev	Min	10%tile	25%tile	Median	75%tile	90%tile	Max	GeoMean	GeoSD
0-5 cm												
Admiralty Inlet	0	----	----	----	----	----	----	----	----	----	----	----
Commencement Bay	11	0.553	0.069	0.503	0.512	0.516	0.522	0.541	0.672	0.707	0.549	0.050
Elliott Bay	0	----	----	----	----	----	----	----	----	----	----	----
Hood Canal North	0	----	----	----	----	----	----	----	----	----	----	----
Hood Canal South	0	----	----	----	----	----	----	----	----	----	----	----
Puget Sound Main	21	1.448	0.383	0.558	0.583	1.465	1.572	1.674	1.727	1.829	1.373	0.163
Puget Sound South	5	1.466	0.270	1.007	1.181	1.442	1.606	1.606	1.644	1.670	1.443	0.091
Sinclair/Dyes Inlet	0	----	----	----	----	----	----	----	----	----	----	----
Strait of Juan de Fuca/Georgia	7	1.003	0.382	0.567	0.656	0.720	1.001	1.200	1.480	1.614	0.943	0.164
Whidbey	0	----	----	----	----	----	----	----	----	----	----	----
0-10 cm												
Admiralty Inlet	0	----	----	----	----	----	----	----	----	----	----	----
Commencement Bay	12	0.548	0.068	0.490	0.504	0.513	0.521	0.540	0.659	0.707	0.544	0.050
Elliott Bay	41	1.164	0.385	0.583	0.872	0.958	1.089	1.326	1.409	2.470	1.110	0.133
Hood Canal North	31	0.823	0.356	0.333	0.447	0.502	0.797	1.152	1.316	1.398	0.747	0.197
Hood Canal South	0	----	----	----	----	----	----	----	----	----	----	----
Puget Sound Main	76	1.480	0.468	0.558	0.783	1.268	1.512	1.750	1.984	2.589	1.392	0.163
Puget Sound South	33	0.612	0.420	0.263	0.331	0.361	0.385	0.728	1.364	1.670	0.515	0.240
Sinclair/Dyes Inlet	12	0.529	0.133	0.398	0.404	0.447	0.471	0.589	0.701	0.829	0.515	0.100
Strait of Juan de Fuca/Georgia	53	1.075	0.382	0.531	0.600	0.716	1.018	1.390	1.612	1.778	1.007	0.161
Whidbey	0	----	----	----	----	----	----	----	----	----	----	----
10-100 cm												
Admiralty Inlet	0	----	----	----	----	----	----	----	----	----	----	----
Commencement Bay	0	----	----	----	----	----	----	----	----	----	----	----
Elliott Bay	36	1.184	0.558	0.270	0.519	0.920	1.131	1.358	2.029	2.515	1.046	0.235
Hood Canal North	22	0.484	0.095	0.359	0.379	0.406	0.466	0.585	0.615	0.642	0.475	0.084
Hood Canal South	0	----	----	----	----	----	----	----	----	----	----	----
Puget Sound Main	21	1.833	0.429	1.137	1.254	1.572	1.741	2.236	2.307	2.325	1.781	0.109
Puget Sound South	0	----	----	----	----	----	----	----	----	----	----	----
Sinclair/Dyes Inlet	0	----	----	----	----	----	----	----	----	----	----	----
Strait of Juan de Fuca/Georgia	40	0.745	0.417	0.302	0.407	0.459	0.512	1.130	1.354	1.858	0.653	0.218
Whidbey	8	0.593	0.188	0.483	0.488	0.510	0.528	0.561	0.736	1.048	0.574	0.110

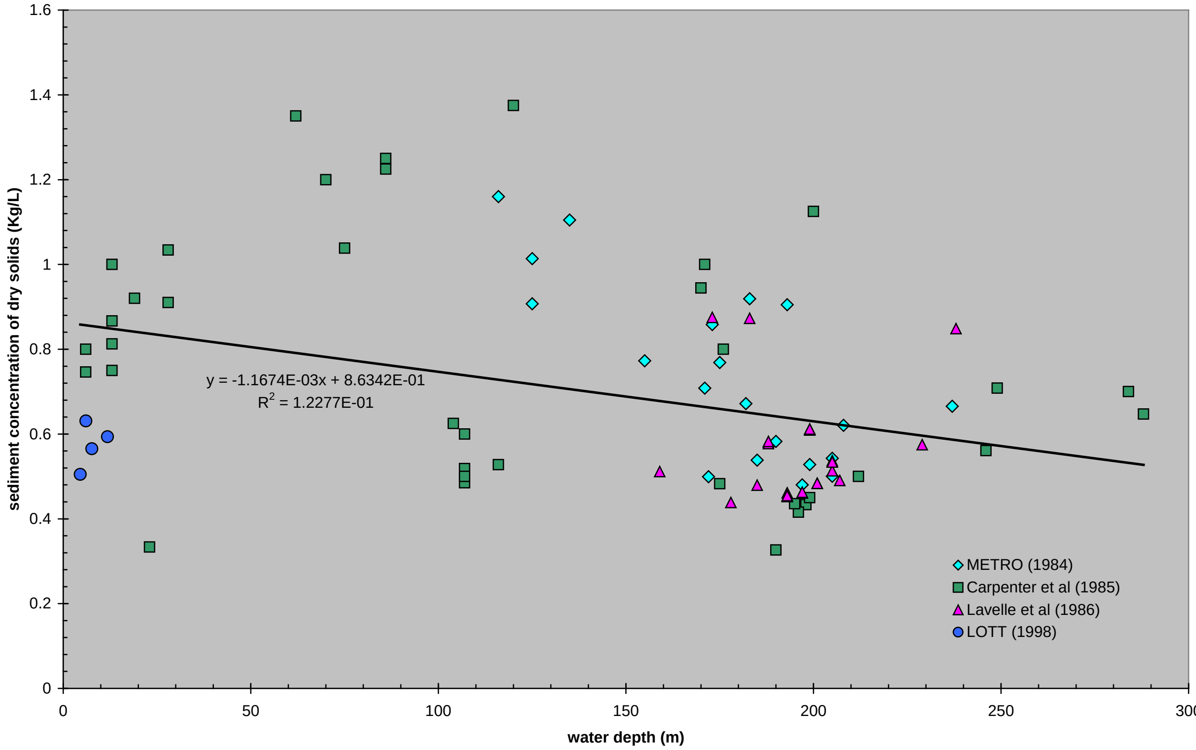

Figure 19. Comparison of the sediment concentration of dry solids in various sedimentation studies of Puget Sound and the relationship with water depth.

Total organic carbon (TOC)

Total organic carbon (TOC) data from EIM were reasonably distributed across the different regions of the box model, but most sampling locations were concentrated along the edges of Puget Sound in close proximity to the shorelines (Figure 20). Table 7 presents TOC data summaries for the 0-2, 0-5, and 0-10 cm sediment layers.

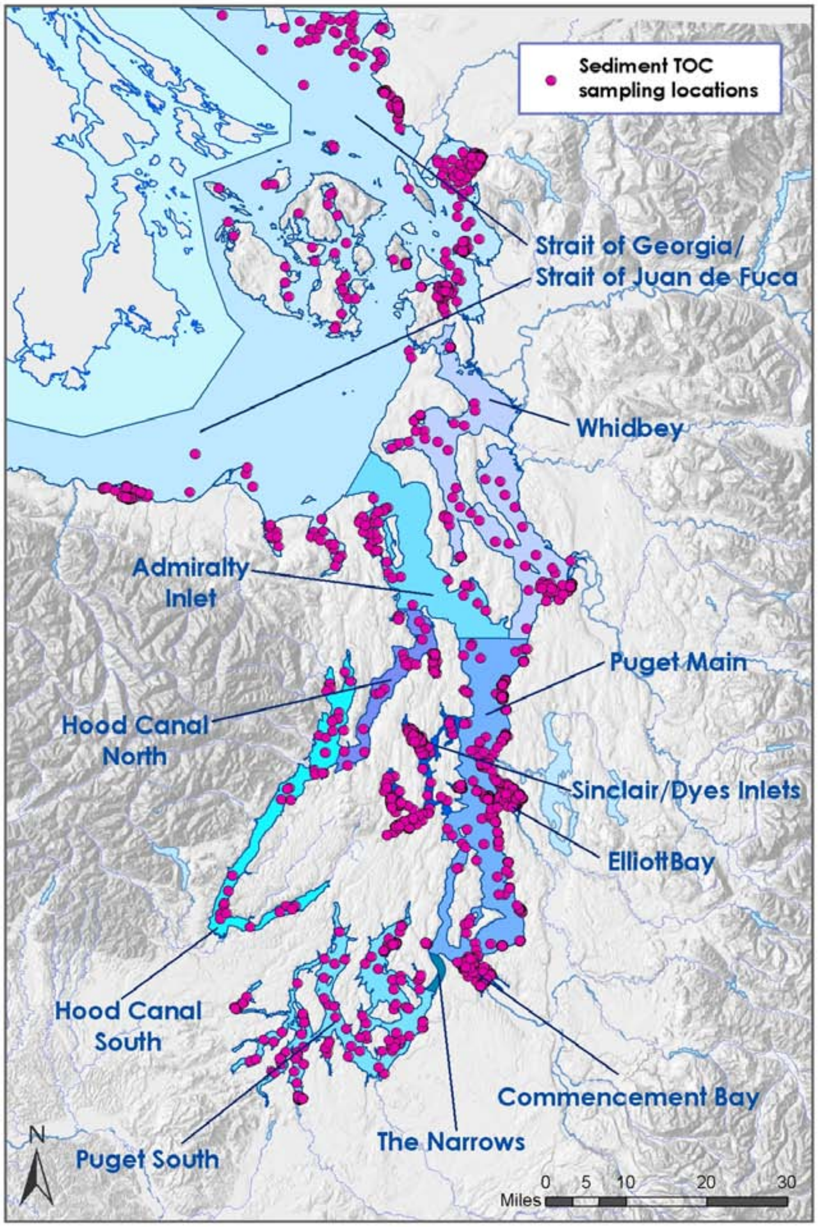

Figure 20. Location of sediment total organic carbon (TOC) data within the areas of the box model and used to generate statistical data summaries.

Table 7. Statistical data summary of sediment percent TOC data in the 0-2, 0-5, and 0-10 cm layer for the 10 regions of the box model.

Model Region	N	Mean	StdDev	Min	10%tile	25%tile	Median	75%tile	90%tile	Max	GeoMean	GeoSD
0-2 cm												
Admiralty Inlet	3	3.73	2.29	1.10	1.86	3.00	4.90	5.05	5.14	5.20	3.04	0.38
Commencement Bay	46	1.30	0.52	0.12	0.54	0.79	1.45	1.60	1.90	2.18	1.15	0.25
Elliott Bay	100	1.41	0.98	0.01	0.16	0.73	1.40	1.99	2.59	5.20	0.98	0.46
Hood Canal North	0	----	----	----	----	----	----	----	----	----	----	----
Hood Canal South	0	----	----	----	----	----	----	----	----	----	----	----
Puget Sound Main	205	0.81	0.88	0.03	0.11	0.18	0.31	1.80	2.22	2.77	0.43	0.51
Puget Sound South	46	1.16	1.00	0.05	0.22	0.37	0.64	2.03	2.50	4.40	0.75	0.45
Sinclair/Dyes Inlet	135	1.62	1.32	0.10	0.50	0.80	1.20	2.30	2.96	10.60	1.24	0.33
Strait of Juan de Fuca/Georgia	189	1.14	1.56	0.00	0.01	0.09	0.78	1.70	2.62	13.00	0.32	0.94
Whidbey	75	3.35	4.62	0.01	0.02	1.40	2.00	3.25	7.12	25.00	0.97	0.98
0-5 cm												
Admiralty Inlet	64	1.24	1.10	0.10	0.22	0.26	1.13	1.85	2.41	5.20	0.79	0.45
Commencement Bay	83	1.41	0.53	0.12	0.64	1.00	1.50	1.80	2.00	2.40	1.28	0.22
Elliott Bay	155	1.36	0.91	0.01	0.18	0.70	1.20	1.90	2.44	5.20	0.98	0.42
Hood Canal North	68	0.67	0.82	0.13	0.18	0.24	0.38	0.64	1.25	4.50	0.45	0.35
Hood Canal South	60	1.84	1.07	0.14	0.22	1.30	2.03	2.45	2.81	4.40	1.32	0.44
Puget Sound Main	431	1.17	0.98	0.03	0.14	0.22	0.85	2.10	2.41	5.76	0.67	0.53
Puget Sound South	314	1.46	1.14	0.05	0.27	0.42	1.10	2.50	3.04	4.40	0.96	0.43
Sinclair/Dyes Inlet	386	1.92	1.29	0.00	0.48	0.90	1.71	2.77	3.50	10.60	1.35	0.57
Strait of Juan de Fuca/Georgia	595	1.40	1.10	0.00	0.15	0.67	1.40	1.90	2.49	13.00	0.82	0.66
Whidbey	211	2.25	3.12	0.01	0.20	1.00	1.50	2.00	5.80	25.00	1.14	0.64
0-10 cm												
Admiralty Inlet	64	1.24	1.10	0.10	0.22	0.26	1.13	1.85	2.41	5.20	0.79	0.45
Commencement Bay	141	1.62	1.16	0.12	0.67	1.00	1.50	1.90	2.30	11.00	1.38	0.25
Elliott Bay	280	1.74	1.15	0.01	0.34	0.90	1.63	2.31	3.01	6.80	1.28	0.41
Hood Canal North	149	3.48	4.61	0.13	0.22	0.35	1.09	5.46	9.27	29.70	1.37	0.64
Hood Canal South	60	1.84	1.07	0.14	0.22	1.30	2.03	2.45	2.81	4.40	1.32	0.44
Puget Sound Main	602	1.00	0.97	0.02	0.10	0.19	0.48	1.90	2.30	6.40	0.51	0.57
Puget Sound South	352	1.47	1.19	0.05	0.28	0.42	0.95	2.50	3.10	4.61	0.96	0.44
Sinclair/Dyes Inlet	402	1.92	1.27	0.00	0.48	0.90	1.73	2.80	3.40	10.60	1.37	0.56
Strait of Juan de Fuca/Georgia	859	1.86	2.52	0.00	0.30	0.72	1.50	2.10	3.13	24.60	1.03	0.61
Whidbey	239	2.11	2.97	0.01	0.20	0.97	1.33	2.00	5.28	25.00	1.07	0.62

Water column data

Polychlorinated biphenyls (PCBs)

Very little data exist on detected concentrations of PCBs in the water column of Puget Sound. Two studies were found by Serdar (2008) that reported detected results of measurements at the picogram per liter (pg/L) levels of concentration that are present in Puget Sound:

- Dangerfield et al. (2007) reported a summary of concentrations in the Strait of Georgia based on measurements at two locations in the southern Strait of Georgia in the near surface and near bottom of the water column. Three samples were collected at each station in different seasons over a one-year period. The reported average concentrations were as follows:
    - 8.5 pg/L in particle-bound PCBs in the near-surface samples.
    - 35 pg/L in dissolved PCBs in the near-surface samples.
    - 12.3 pg/L in particle-bound PCBs in the near-bottom samples.
    - 28 pg/L in dissolved PCBs in the near-bottom samples.
- Mickelson and Williston (2006) reported concentrations measured four times between August and December 2005 at one station in Elliott Bay. The mean and standard deviation of the observed total PCB concentrations at station LTED04 in Elliott Bay was 125 ± 41 pg/L. Reported concentrations of total PCBs at station LTED04 were as follows:
    - 65.6 pg/L on August 22, 2005.
    - 152 pg/L on September 26, 2005.
    - 151 pg/L on November 28, 2005.
    - 131 pg/L on December 19, 2005.

Dangerfield et al. (2007) reported that the dissolved fraction of total PCBs is larger than the particulate-bound PCBs in the marine waters entering Puget Sound. The data of Mickelson and Williston (2006) suggest that in Elliott Bay, and possibly other locations in Puget Sound, the concentrations of PCBs may be much higher than in the marine waters that enter Puget Sound from the Strait of Juan de Fuca.

Total suspended solids (TSS)

Water column TSS data collected by King County were pooled with the EIM data. Summary statistics are provided in Table 8. Sampling locations are shown in Figure 21.

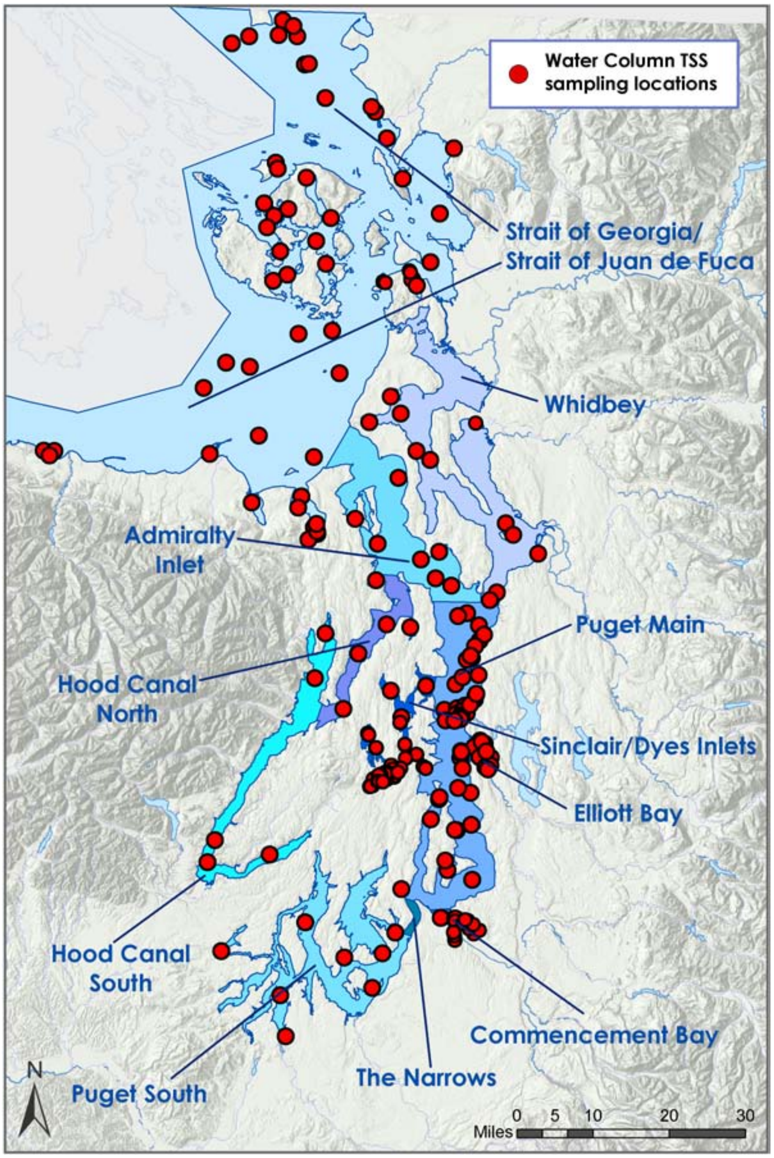

Figure 21. Location of water column total suspended solids (TSS) data within the areas of the box model and used to generate statistical data summaries.

Total and dissolved organic carbon

Water column total organic carbon (TOC) and dissolved organic carbon (DOC) data collected by King County were pooled with the EIM data. Summary statistics are provided in Table 9 and Table 10. Sampling locations for DOC are shown in Figure 22.

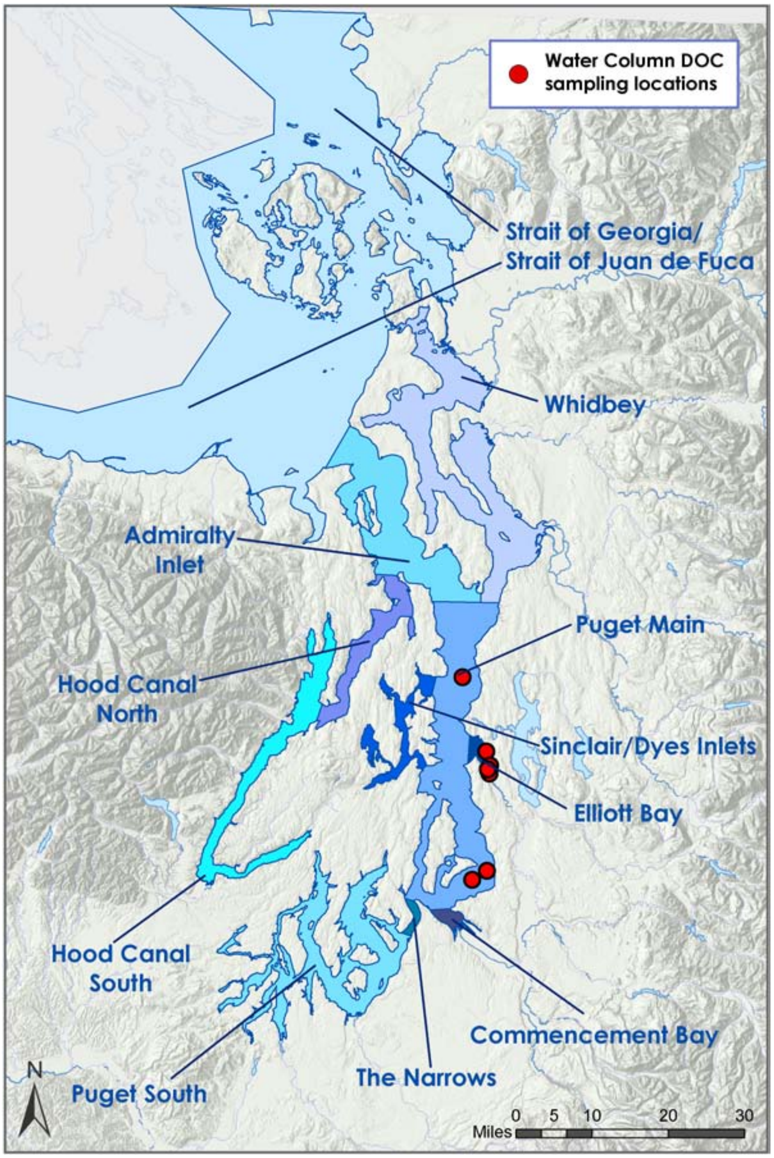

Figure 22. Location of water column DOC data within the areas of the box model and used to generate statistical data summaries.

Table 8. Statistical data summary of TSS concentrations in the upper water column for box model regions.

Model Region	N	Mean	StdDev	Min	10%tile	25%tile	Median	75%tile	90%tile	Max
mg/L TSS in upper water column*										
Admiralty	117	2.99	1.68	0.50	0.89	2.00	2.90	3.60	4.60	9.70
Commencement Bay	6	9.83	11.92	3.00	3.50	4.25	5.50	6.75	20.50	34.00
Elliott Bay	1251	3.71	3.28	0.00	0.81	1.50	2.60	4.55	9.10	20.90
Puget Sound Main	6289	2.88	2.38	0.00	0.90	1.40	2.40	3.60	5.50	64.10
Sinclair/Dyes Inlet	159	2.53	1.89	0.57	1.03	1.29	1.85	3.10	4.60	11.96
Whidbey	29	3.99	1.94	0.80	1.90	2.60	3.60	5.40	6.32	9.40
All regions	7851	3.07	2.56	0.00	1.00	1.50	2.47	3.80	5.90	64.10
mg/L TSS in lower water column*										
Admiralty	86	3.03	1.64	0.00	0.85	1.90	2.80	4.20	5.30	7.20
Elliott Bay	1530	3.55	3.08	0.00	0.90	1.50	3.55	4.29	8.70	20.90
Puget Sound Main	9531	2.91	2.29	0.00	0.90	1.50	2.40	3.70	5.50	64.10
Whidbey	187	2.53	1.38	0.00	0.59	1.60	2.50	3.40	4.40	6.50
All regions	11334	3.00	2.41	0.00	0.90	1.50	2.50	3.70	5.70	64.10

Table 9. Statistical data summary of TOC concentrations in the upper and lower water column for box model regions.

Model Region	N	Mean	StdDev	Min	10%tile	25%tile	Median	75%tile	90%tile	Max	GeoMean	GeoSD
mg/L TOC in upper water column												
Elliott Bay	4	1.76	0.12	1.64	1.66	1.70	1.74	1.80	1.87	1.92	1.76	0.03
Hood Canal South	65	4.97	4.27	1.00	1.00	1.00	4.00	7.00	10.60	17.00	3.36	0.41
Puget Sound Main	16	1.30	0.73	0.85	0.87	0.89	0.93	1.26	1.98	3.68	1.18	0.18
Puget Sound South	103	7.72	9.81	1.00	1.00	2.50	5.00	9.00	14.40	75.00	4.70	0.43
Whidbey	40	5.53	4.09	1.00	2.00	2.00	4.00	8.00	10.00	18.00	4.26	0.33
All regions	228	5.99	7.41	0.85	1.00	1.98	4.00	8.00	11.30	75.00	3.74	0.42
mg/L TOC in lower water column												
Hood Canal South	31	4.87	5.61	1.00	1.00	1.00	4.00	6.50	9.00	30.00	3.09	0.42
Puget Sound South	51	8.67	13.02	1.00	1.00	2.00	5.00	7.00	24.00	79.00	4.73	0.46
Whidbey	38	6.55	7.85	1.00	1.00	2.00	4.00	8.00	12.50	38.00	3.80	0.46
All regions	120	7.02	10.04	1.00	1.00	2.00	4.00	8.00	12.00	79.00	3.95	0.45

Table 10. Statistical data summary of DOC concentrations in the water column for box model regions.

Model Region	N	Mean	StdDev	Min	10%tile	25%tile	Median	75%tile	90%tile	Max	GeoMean	GeoSD
mg/L DOC in upper water column*												
Elliott Bay	4	1.80	0.06	1.73	1.74	1.76	1.80	1.84	1.84	1.85	1.79	0.01
Puget Sound Main	20	1.11	0.41	0.70	0.84	0.88	0.93	1.15	1.76	2.16	1.06	0.14
All regions	24	1.23	0.45	0.70	0.85	0.89	1.06	1.73	1.84	2.16	1.15	0.15

Sediment accumulation, burial, and resuspension

Sediment burial rates, resuspension rates, and the thickness of the active sediment layer are important inputs to the fate and transport model of PCBs. The sediment burial rate, or sedimentation velocity, as well as the thickness of the upper mixed layer of sediment, can be measured from sediment cores. The most common and accurate method of measurement of sediment accumulation is Pb-210 analysis (e.g., Robbins, 1978). Sediment resuspension can be estimated by comparison of measured settling rates from sediment traps with burial rates measured in cores.

Estimates of average sediment accumulation rates from cores are complicated by spatial re-distribution of sediments, or sediment focusing. In addition, the top layer of sediment is vertically mixed by biota through a process called bioturbation.

Focusing of sediment accumulation

Lavelle et al. (1986) observed that the sediment accumulation rates measured in the deep stations along the thalweg of Puget Sound were up to five times greater than the predicted areal-average accumulation rates. They hypothesized that erosion and slumping of submarine sediments were likely to re-distribute sediments and lead to higher accumulation rates in deep areas compared with average accumulation rates across the entire bottom area.

Sediment focusing has long been recognized as an important process of redistribution of fine sediment from shallower to deeper zones of waterbodies (e.g., Likens and Davis, 1975; Hilton, 1985; Blais and Kalff, 1995). In a study of 12 lakes, Blais and Kalff (1995) found that the zone of sediment accumulation was typically less than 50% of the total surface area, and progressively decreased with increase in average bottom slope. Sediments may become resuspended after they are initially deposited and subsequently transported and settled in deeper areas. Sediment focusing may be influenced by mixing depth in the water column, wave and current shear stress, and sediment cohesiveness.

Hakanson (1977) established that sediment will not accumulate on bottom slopes greater than 14 percent, and accumulation will become progressively greater as the slope reduces to about 4 percent. Slopes of greater than about 4% were shown to be transportation zones for redistribution of sediments toward flatter bottom areas. A digital elevation model (DEM) of the bathymetry of Puget Sound (Finlayson, 2005) was used to calculate bottom slopes using ArcGIS (Figure 23). The bottom slopes show the relatively flat trough along the thalweg of Puget Sound where sediment is most likely to accumulate, and the steep side slopes where sediment is likely to be re-distributed toward the deeper trough.

The sediment accumulation zone that is suggested by the occurrence of bottom slopes of less than 4% (Figure 23) is approximately consistent with the areas of muds and sandy muds that were mapped by Roberts, 1979 (Appendix G).

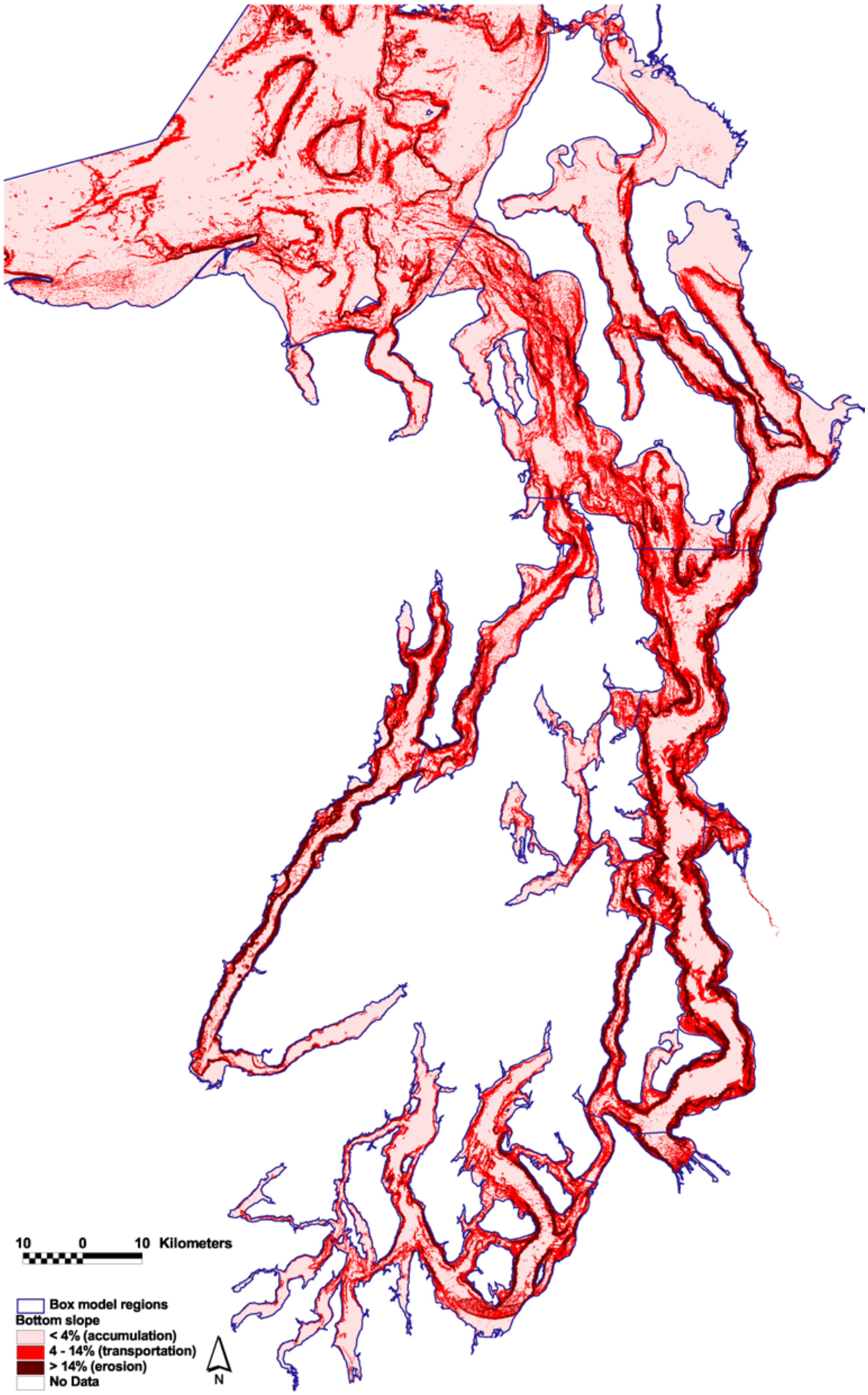

Figure 23. Bottom slopes and zones of sediment accumulation, transport, and erosion in Puget Sound calculated from Finlayson's (2005) DEM.

The ratio of the flatter trough area compared with the total area can be used as an approximation of the focusing factor for accumulation of sediments in the deep zone. Table 11 presents the ratio of the bottom area with slopes less than 4% compared with the total surface area. On average, approximately 55% of the surface area of Puget Sound has bottom slopes less than 4 percent. This ratio corresponds to a focusing factor of approximately 1.8, which is within the range of 1 to 5 that was suggested by Lavelle et al. (1986). This suggests that average sediment accumulation rates measured in cores along the deep thalweg of Puget Sound are probably nearly double the average rate of sediment accumulation for the entire area of Puget Sound.

Table 11. Zones of sediment accumulation in Puget Sound.

Box model number	Region	Total bottom area (m^2)	Bottom area with slope less than 4% (m^2)	Zone of sediment accumulation based on the ratio of areas with slope <4% to total area (fraction of total bottom area)
1	South Puget Sound	4.20E+08	2.35E+08	56%
2	Main Basin	5.83E+08	2.59E+08	44%
3	North Hood Canal	1.37E+08	5.70E+07	42%
4	South Hood Canal	2.41E+08	1.20E+08	50%
5	Whidbey Basin	5.94E+08	4.35E+08	73%
6	The Narrows	1.29E+07	3.54E+06	28%
7	Elliott Bay	2.08E+07	4.67E+06	22%
8	Sinclair/Dyes Inlet	8.99E+07	5.39E+07	60%
9	Commencement Bay	2.05E+07	8.13E+06	40%
10	Admiralty Inlet	4.08E+08	2.13E+08	52%
Total area	--	2.53E+09	1.39E+09	55%

Sediment burial velocities from Pb-210 studies

Several studies have published measurements of sediment accumulation rates in Puget Sound based on analysis of Pb-210 in sediment cores. The most comprehensive and reliable data using the Pb-210 method are presented by Carpenter et al. (1985), METRO (1984), Lavelle et al. (1986), and LOTT (1998). Bloom and Crecelius (1987) also reported on their analysis of the same cores that are collected by METRO (1984). All of these studies analyzed sedimentation velocities in a total of 87 cores at various locations in Puget Sound, mostly in the main basin. Comparisons of the measured sedimentation velocities from each of these studies are presented in Table 12 and Figure 24.

Table 12. Summary of sedimentation velocities (cm/year) measured in Pb-210 studies in Puget Sound.

	METRO (1984)	Carpenter et al. (1985)	Lavelle et al. (1986)	LOTT (1998)	All studies
Number of samples	20	38	25	4	87
Mean (cm/year)	0.98	0.55	1.62	0.94	0.97
Standard deviation	0.58	0.58	0.74	0.75	0.77
Minimum	0.23	0.04	0.53	0.26	0.04
25%tile	0.48	0.17	0.98	0.55	0.30
Median	0.90	0.29	1.52	0.74	0.73
75%tile	1.43	0.71	2.17	1.13	1.48
Maximum	2.03	2.40	3.12	2.00	3.12

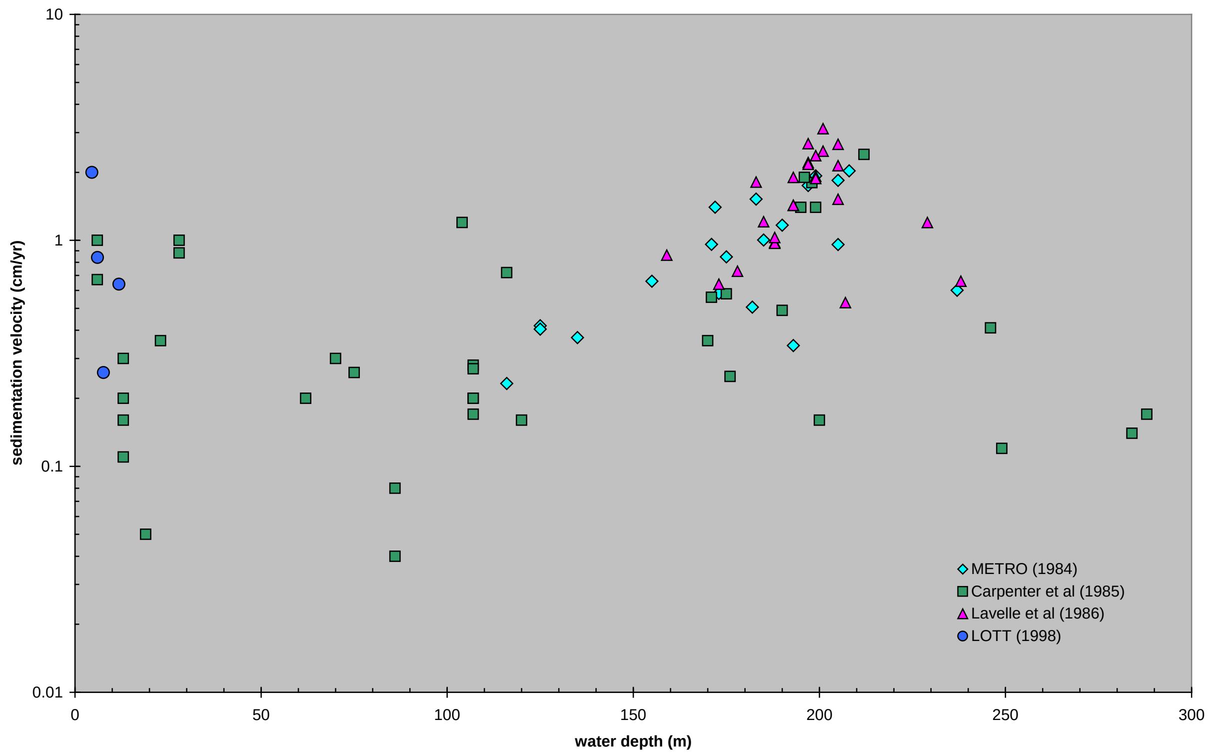

Figure 24. Comparison of measured sedimentation velocities in Pb-210 studies of Puget Sound and their relationship with water depth.

Yake (2001) summarized data from three other studies as follows:

- Schell and Nevissi (1977) reported sedimentation rates of 0.1 to 2 cm/year in Puget Sound, although they did not report station locations.
- Norton and Michelsen (1995) estimated sedimentation velocities in Elliott Bay from 0.1 to 0.72 cm/year, but these data were found to be problematic due to suspected disturbance of sediments at the sampling locations due to dredging.
- Lefkovitz et al. (1997) reported sedimentation velocities of about 1 to 2 cm/year in six cores from the main basin of Puget Sound.

The median and interquartile range of the measured sedimentation velocities for the 87 cores in the four main Pb-210 studies were 0.73 cm/year and 0.30 to 1.48 cm/year, respectively. These summary statistics also are in the same general range as other Pb-210 studies as summarized by Yake (2001).

The U.S. Navy measured sediment burial velocities at various locations in Sinclair and Dyes Inlets using the Pb-210 method and found that the average burial velocity was approximately 0.25 cm/year (Bob Johnston, U.S. Navy, personal communication, 2008).

Because the sediment cores for these measurements were collected from the relatively flat sediment accumulation zone, the measured rates probably over-estimate the average sedimentation rate for the entire area of Puget Sound by nearly a factor of 2. Since the sediment accumulation zone represents approximately 55% of the total area of Puget Sound (Table 11), then the typical sedimentation velocity for the entire area of Puget Sound could be about 55% of the measured rates, or an area-adjusted interquartile range of 0.17 to 0.81 cm/year, and an area-adjusted median of 0.40 cm/year.

Sediment accumulation and resuspension from sediment trap studies

LOTT (1998) reported that more than half of the material collected in sediment traps in Budd Inlet was derived from resuspended material at all times of the year. They reported a range of 47% to 88% of the material in the sediment traps that was estimated to be resuspended, which corresponds to a range of resuspension rates equal to about 1 to 7 times the burial rate.

Norton (1996) reported resuspension estimates for three waterways in Commencement Bay ranging from 60% to 85% of the trapped material, which correspond to resuspension rates of about 2 to 6 times the burial rate.

Boatman et al. (1995) reported a median of 60% and up to 90% of the material in sediment traps at three locations in Elliott Bay was due to resuspension, which corresponds to resuspension rates of up to 9 times the burial rate.

Norton and Barnard (1992) reported an average sediment accumulation rate in sediment traps in Sitcum Waterway of 3.5 g/cm^2/year, with a range of 2.1 to 5.7 g/cm^2/year. Norton and Barnard (1992) translated this into an equivalent sedimentation velocity of 3.7 cm/year, with a range of

2.3 to 5.7 cm/year using estimated density of in-situ sediments. The measured sediment accumulation rates by Norton and Barnard (1992) and Norton (1996) correspond to resuspension rates of approximately 9 times the typical area-averaged burial rate.

Patmont and Crecelius (1991) reported resuspension rates in urban bays ranging from 0.4 to 3.6 g/cm^2/year. Assuming a typical sediment concentration of dry solids of 0.6 g/cm^3, this corresponds to about 0.7 to 6 cm/year of bottom sediment that is resuspended, which is about 2 to 15 times the typical area-averaged burial rate.

Norton (2008, unpublished)[4] has observed sediment accumulation rates that indicate resuspension rates of up to 10 times the area-averaged burial rate in sediment traps in four inlets in southern Puget Sound. Each sediment trap in this study is located at a station with water depth of 60 meters, and the trap is deployed at a depth of 30 meters.

Hedges et al. (1988) deployed sediment traps at depths of 30, 60, and 90 meters at a location 110 meters deep in Hood Canal. Resuspension measured in the deepest trap was found to be nearly double the rate of sediment burial based on direct comparison of measured accumulation rates in sediment traps with a sediment core.

LOTT (1998), Norton (1996), Boatman et al. (1995), and Hedges et al. (1988) may underestimate resuspension because the measured burial rates in sediment cores were directly compared with measured fluxes in the sediment traps without accounting for possible focusing of fine sediments into deeper accumulation zones where the cores were collected.

In summary, the resuspension rates measured in various studies was typically about 2 to 4 times the average burial rate, and can be as high as about 6 to 15 times the average burial rate. Highest rates of resuspension have been observed in locations ranging from relatively shallow urban bays to moderately deep waters of southern Puget Sound. The data from Hood Canal suggest that the deepest basins of Puget Sound may have significant but lower resuspension rates on the order of 2 times the measured burial rate. But resuspension rates in Hood Canal could be as much as about 3 times the average burial rate if focusing of fine sediments is taken into account.

Bioturbation of sediment

Carpenter et al. (1985) found that the thickness of the bioturbated upper layers in sediment cores from the main basin ranged from about 4 to 18 cm. Lavelle et al. (1986) reported that bioturbated upper layers of cores in Puget Sound ranged from about 5 to 40 cm, but that the biological mixing rates were poorly determined.

The median thickness of the upper mixed layer of sediment due to bioturbation was 12 cm, based on 63 cores reported in studies by Carpenter et al. (1985) and Lavelle et al. (1986). The interquartile range of the observed bioturbated upper mixed layer thickness is from 10 to 30 cm.

[4] Personal communication with Dale Norton, Washington State Department of Ecology, Olympia, WA.

Boudreau (1994) found that the thickness of the upper mixed layer due to bioturbation of estuarine and marine sediment was independent of burial velocity. They reported a worldwide mean from 200 cores of 9.8 ± 4.5 cm, and they concluded that the mean value of about 10 cm can be used for sediment modeling with confidence.

Biota concentrations of PCBs

Data describing the concentrations of PCBs in biota are important to test the accuracy of predictive models of food web bioaccumulation. PSAT (2007) presented available data from the Puget Sound Assessment and Monitoring Program (PSAMP) to describe status and trends on concentrations of PCBs and other persistent bioaccumulative toxics (PBTs). Johnston (2007) created a database summary of available PCB data, including data from PSAMP, NOAA mussel watch, and miscellaneous other studies, for demersal fish, invertebrates, and deployed mussels from various studies in Puget Sound (Figure 25). West (Jim West, Washington Department of Fish and Wildlife, personal communication, 2008) also summarized data collected from fish by the Washington Department of Fish and Wildlife. Calambokidis et al. (1999) collected PCB data from harbor seal pups at Gertrude Island in South Puget Sound and other locations in Puget Sound.

Figure 25. Locations of NOAA mussel watch and PSAMP trawl stations (Johnston 2007).

Appendix H lists an inventory of samples that are compiled in the databases by Bob Johnston (U.S. Navy, Bremerton, WA, ENVVEST program), and Jim West (Washington Department of Fish and Wildlife, Olympia, WA). Table 13 presents summary statistics of the concentrations of PCBs measured in whole body samples of various species of biota in Puget Sound.

The term “total PCBs” is used in this report to represent the sum of all measured congeners. Different groups of congeners were measured in different sources of data. For example, the PSAMP GC/MS data are the sum of 40 congeners, and the NOAA Mussel Watch study data compiled by ENVVEST are the sum of 20 congeners. Ecology’s EIM data for sediment concentrations include essentially the same list of congeners as the NOAA Mussel Watch study. The 20 congeners included in the NOAA Mussel Watch and Ecology EIM database account for the majority (about two-thirds) of the sum of the 40 congeners for the PSAMP data.

Table 13. Summary statistics of total PCB concentrations in whole body samples of biota. All units are ng/g wet weight for whole body, sum of measured congeners.

Species	Location	Region	Method (1)	Source (2)	n	mean	stdev	min	25%tile	median	75%tile	max
Blackmouth salmon	Apple Cove Pt	Main basin	GC/MS	PSAMP	48	113	45.1	5.9	79.8	120.0	142.5	190
Chinook salmon	Deschutes River	South Puget Sound	GC/MS	PSAMP	14	51.3	31.9	15.0	35.3	45.5	51.8	150
	Duwamish River	Main basin	GC/MS	PSAMP	25	54.1	37.0	15.0	35.0	43.0	59.0	160
	Fraser/Nimpkish Rivers	Strait of Georgia	GC/MS	PSAMP	13	12.2	5.7	8.1	9.6	11.0	12.0	30.0
	Nisqually River	South Puget Sound	GC/MS	PSAMP	31	50.4	48.8	7.6	23.0	38.0	63.5	280
	Nooksack River	Strait of Georgia	GC/MS	PSAMP	14	50.9	20.6	20.0	31.3	57.5	65.0	86.0
Chum salmon	Apple Cove Pt	Main basin	GC/MS	PSAMP	5	7.3	4.4	4.7	4.8	5.5	6.5	15.0
Coho salmon	Apple Cove Pt	Main basin	GC/MS	PSAMP	2	29.5	2.1	28.0	28.8	29.5	30.3	31.0
	Puget Sound (3)	Main basin	GC/MS	PSAMP	5	15.4	3.4	12.0	14.0	15.0	15.0	21.0
English sole	Commencement Bay	Commencement Bay	sPCBWB	ENVVEST	6	163	89.0	34.6	125	160	198	299
	Elliott Bay	Elliott Bay	sPCBWB	ENVVEST	6	121	96.6	10.6	59.1	95.2	185	263
	Port Gardner	Whidbey basin	sPCBWB	ENVVEST	5	15.1	8.6	5.9	8.2	16.1	17.8	27.7
	Hood Canal	Hood Canal	sPCBWB	ENVVEST	6	11.0	8.2	4.7	6.2	8.4	11.4	27.0
	Nisqually	South Puget Sound	sPCBWB	ENVVEST	6	19.2	7.4	10.2	13.1	20.6	23.6	28.9
	Strait of Georgia	Strait of Georgia	sPCBWB	ENVVEST	6	8.6	6.2	2.5	5.5	7.1	9.2	20.2
	Vendovi Island	Strait of Georgia	sPCBWB	ENVVEST	6	2.4	0.6	1.7	1.9	2.4	2.8	3.1
Graceful crab	Hood Canal	Hood Canal	sPCBWB	ENVVEST	3	3.2	0.8	2.5	2.8	3.0	3.5	4.0
	Nisqually	South Puget Sound	sPCBWB	ENVVEST	6	5.1	1.1	3.3	4.5	5.6	5.9	6.2
	Sinclair Inlet	Sinclair/Dyes Inlets	sPCBWB	ENVVEST	9	43.3	23.5	19.8	28.1	35.1	67.6	83.8
	Vendovi Island	Strait of Georgia	sPCBWB	ENVVEST	3	0.8	0.2	0.6	0.8	0.9	1.0	1.0
Pacific herring (4)	Cherry Pt	Strait of Georgia	GC/MS	PSAMP	3	59.3	8.3	50.0	56.0	62.0	64.0	66.0
	Cherry Pt	Strait of Georgia	HPLC/PDA	PSAMP	20	42.9	12.5	26.0	35.0	41.0	46.5	77.0
	Denman/Hornby	Strait of Georgia	HPLC/PDA	PSAMP	10	18.7	3.8	13.0	15.5	19.0	20.8	24.0
	La Push	--	sum40CBs	O'Neill	3	11.8	2.9	9.4	10.2	11.0	13.0	15.0
	Port Orchard	Sinclair/Dyes Inlets	GC/MS	PSAMP	16	209	63.0	120	160	190	263	330

Species	Location	Region	Method (1)	Source (2)	n	mean	stdev	min	25%tile	median	75%tile	max
	Port Orchard	Sinclair/Dyes Inlets	HPLC/PDA	PSAMP	56	164	46.2	97.0	130	160	183	300
	Port Orchard	Sinclair/Dyes Inlets	sum40CBs	O'Neill	3	140	36.1	110	120	130	155	180
	Quartermaster Harbor	Main basin	HPLC/PDA	PSAMP	10	125	30.4	90.0	103	110	148	170
	Semiahmoo	Strait of Georgia	GC/MS	PSAMP	16	40.1	19.4	20.0	28.0	33.5	46.5	94.0
	Semiahmoo	Strait of Georgia	HPLC/PDA	PSAMP	55	36.2	13.5	17.0	27.5	33.0	39.5	92.0
	Semiahmoo	Strait of Georgia	sum40CBs	O'Neill	3	21.7	4.6	19.0	19.0	19.0	23.0	27.0
	Squaxin Passage	South Puget Sound	GC/MS	PSAMP	10	181	81.9	96.0	120	155	245	320
	Squaxin Passage	South Puget Sound	HPLC/PDA	PSAMP	60	160	47.5	90.0	120	145	190	300
	Squaxin Passage	South Puget Sound	sum40CBs	O'Neill	3	130	10.0	120	125	130	135	140
Mussels	Bellingham Bay	Strait of Georgia	sPCBWB	ENVVEST	3	7.8	1.1	6.7	7.2	7.6	8.3	9.0
	Commencement Bay	Commencement Bay	sPCBWB	ENVVEST	3	12.0	4.1	8.6	9.7	10.9	13.7	16.5
	Elliott Bay	Elliott Bay	sPCBWB	ENVVEST	6	28.4	3.7	23.3	26.0	28.3	31.0	33.1
	Port Orchard marina	Sinclair/Dyes Inlets	sPCBWB	ENVVEST	3	7.3	0.7	6.6	7.0	7.5	7.7	7.9
	Point Roberts	Strait of Georgia	sPCBWB	ENVVEST	3	3.4	1.6	1.9	2.5	3.2	4.2	5.1
	Puget Sound Naval Shipyard	Sinclair/Dyes Inlets	sPCBWB	ENVVEST	3	9.1	1.0	8.0	8.7	9.4	9.6	9.8
	Port Gardner	Whidbey basin	sPCBWB	ENVVEST	3	7.8	2.7	5.7	6.2	6.8	8.8	10.8
	Hood Canal	North Hood Canal	sPCBWB	ENVVEST	3	3.5	0.5	2.9	3.3	3.7	3.8	3.8
	Waterman Point	Sinclair/Dyes Inlets	sPCBWB	ENVVEST	6	10.6	7.5	3.9	4.4	8.3	16.9	20.5
Pink salmon	Skagit	Whidbey basin	GC/MS	PSAMP	5	3.7	1.2	2.5	2.6	3.7	4.2	5.4
Ratfish	Hood Canal	Hood Canal	sPCBWB	ENVVEST	3	29.0	4.8	23.6	27.2	30.8	31.7	32.6
	Nisqually	South Puget Sound	sPCBWB	ENVVEST	3	77.7	23.3	50.8	70.5	90.2	91.1	92.1
	Sinclair Inlet	Sinclair/Dyes Inlets	sPCBWB	ENVVEST	8	230	236	82.6	109	118	244	788
	Strait of Georgia	Strait of Georgia	sPCBWB	ENVVEST	9	19.6	14.6	8.0	9.1	13.2	21.2	49.7
Rock sole	Nisqually	South Puget Sound	sPCBWB	ENVVEST	3	16.2	8.4	7.9	12.0	16.0	20.3	24.7
	Sinclair Inlet	Sinclair/Dyes Inlets	sPCBWB	ENVVEST	3	87.3	37.3	61.2	66.0	70.8	100.4	130
Sand sole	Port Gardner	Whidbey basin	sPCBWB	ENVVEST	3	20.6	6.2	14.7	17.3	20.0	23.5	27.0
	Sinclair Inlet	Sinclair/Dyes Inlets	sPCBWB	ENVVEST	6	47.6	31.5	17.5	30.8	34.2	58.9	103

Species	Location	Region	Method (1)	Source (2)	n	mean	stdev	min	25%tile	median	75%tile	max
Sea cucumber	Sinclair Inlet	Sinclair/Dyes Inlets	sPCBWB	ENVVEST	9	13.0	5.1	6.0	9.1	13.2	15.2	21.5
	Strait of Georgia	Strait of Georgia	sPCBWB	ENVVEST	6	2.5	1.7	1.1	1.3	1.6	3.4	5.2
	Vendovi Island	Strait of Georgia	sPCBWB	ENVVEST	3	0.5	0.2	0.3	0.4	0.4	0.6	0.8
Shiner surfperch	Hood Canal	Hood Canal	sPCBWB	ENVVEST	3	8.4	3.5	4.4	7.3	10.3	10.4	10.5
	Nisqually	South Puget Sound	sPCBWB	ENVVEST	5	25.0	5.0	20.8	23.0	23.0	24.5	33.6
	Sinclair Inlet	Sinclair/Dyes Inlets	sPCBWB	ENVVEST	6	134	17.3	113	119	138	148	152
	Vendovi Island	Strait of Georgia	sPCBWB	ENVVEST	3	5.1	1.7	3.6	4.2	4.8	5.9	7.0
Sockeye salmon	Fraser River	San Juan Islands	GC/MS	PSAMP	5	22.0	11.5	12.0	14.0	15.0	33.0	36.0
Staghorn sculpin	Sinclair Inlet	Sinclair/Dyes Inlets	sPCBWB	ENVVEST	5	45.9	25.2	27.3	27.6	42.7	42.9	88.9
	Strait of Georgia	Strait of Georgia	sPCBWB	ENVVEST	3	5.5	3.1	2.3	4.1	5.9	7.1	8.4
	Vendovi Island	Strait of Georgia	sPCBWB	ENVVEST	3	4.2	1.3	3.1	3.5	3.8	4.7	5.6

(1) GC/MS: the "detailed" method, summing 40 congeners; HPLC/PDA: sum of 15 congeners plus unknowns; sPCBWB: sum of measured congeners on wet wt basis (13-21 congeners); sum18: sum of 18 congeners on wet wt basis; sum40CBs: sum of 40 congeners on wet wt basis.

(2) PSAMP: summary of 1999-2006 data, Puget Sound Assessment and Monitoring Program, Toxics in Biota Component, James E. West, Washington Department of Fish and Wildlife, personal communication;
ENVVEST: compilation of data from 2000-2005 from various sources by Bob Johnston, Marine Environmental Support Office, U.S. Navy, personal communication.
O'Neill: unpublished data from a 2006 study of killer whale prey by WDFW and NOAA Fisheries, Sandie O'Neill, NOAA, personal communication.

(3) River of unknown origin.

(4) For Pacific herring, the location is the name used to identify the spawning stock from which the samples were taken, and each PSAMP sample is a composite of five 2-year to 4-year-old male fish.

English sole

The Washington Department of Fish and Wildlife (WDFW) has documented elevated levels of PCBs in muscle tissue from English sole from urban harbors and bays of Puget Sound, and have shown that PCB accumulation in English sole is strongly correlated to the concentration of PCBs in the sediments where the fish live (PSAT, 2007). In general, the more contaminated the sediments are, the more contaminated the fish, and older fish from contaminated areas had slightly higher PCB concentrations than younger fish.

PCBs in the muscle tissue of English sole have dropped moderately at several locations from the 1970s to the 1990s, particularly in the more contaminated urban bay samples (Figure 26); West and O'Neill, 2007). However there currently appears to be an increasing trend over time since the 1990s, especially in the less urbanized reference areas of central and southern Puget Sound.

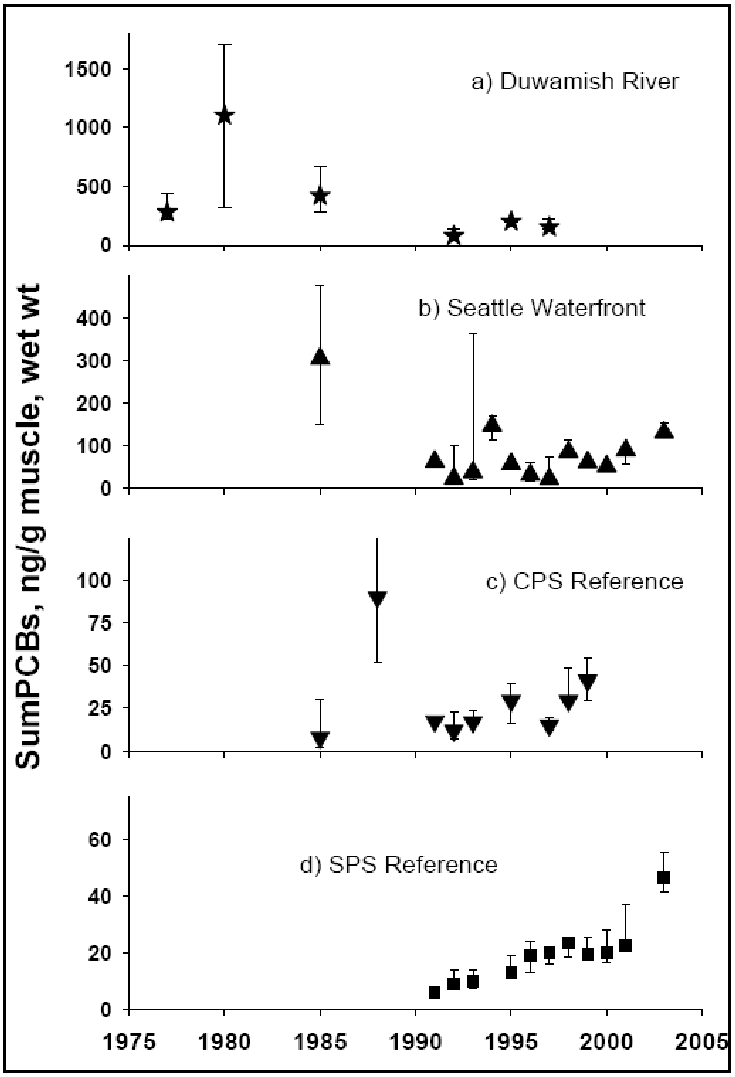

Figure 26. PCBs in English sole from four sampling areas in Puget Sound (medians and interquartile ranges): (a) Duwamish River, (b) Seattle waterfront, (c) Central Puget Sound (CPS) reference, and (d) South Puget Sound (SPS) reference. (West and O'Neill, 2007.)

Rockfish

WDFW has documented the greatest concentrations of PCB in rockfish from Elliott Bay and Sinclair Inlet, with lower concentrations in Commencement Bay and Port Gardner and some areas of the southern portion of the main basin of Puget Sound (Figure 27; PSAT, 2007). PCBs were rarely detected in other areas of Puget Sound.

Average PCB concentration (wet weight, ± 95 percent confidence interval) in three rockfish species from six WDFW Fishery Management Areas in Puget Sound. Sample sizes are indicated in parentheses. Rockfish from three urban bays, Elliott Bay, Sinclair Inlet, and Commencement Bay, had the highest levels. All samples were measured as sum of Aroclors, except Commencement Bay, which was calculated to an Aroclor-equivalent from a congener-based method.
(Source: WDFW)

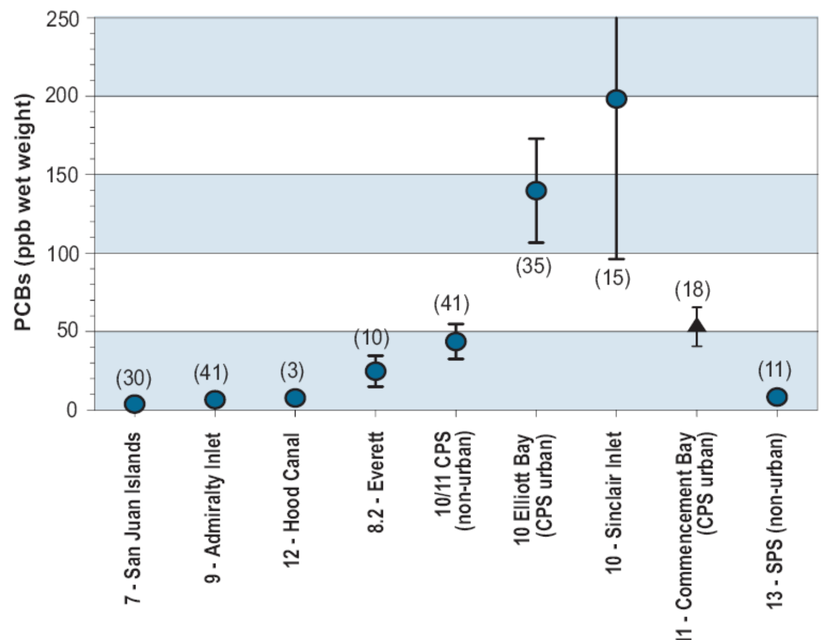

Figure 27. PCBs in rockfish in various management areas of Puget Sound (PSAT, 2007).

Mussels

Data from mussels near Elliott Bay had especially high concentrations of PCBs in the early 1980s (more than 1500 ppb dry weight). These levels have declined in recent years to about 162 ppb dry weight (note that the units for the summary statistics in Table 13 are in wet weight basis based on the compilation by Johnston, 2007) in 2002. This is still about five times the national median of 50 ppb dry weight for PCBs in mussels (PSAT, 2007).

PCBs in mussels at other locations in Puget Sound were about 100 to 200 ppb dry weight in the 1980s and 1990s with possibly lower concentrations suggested in the most recent data. The lowest concentrations of PCBs in mussels were generally found in samples from Washington's outer coast, in northern Puget Sound, and in the Strait of Juan de Fuca (PSAT, 2007).

Pacific herring

PCB concentrations in Pacific herring sampled from locations in the vicinity of Sinclair Inlet (from locations in Port Orchard and Port Madison) and South Puget Sound (Squaxin) from 1999 to 2004 were four to nine times higher than those collected from sites in the Strait of Georgia

(Semiahmoo) (Figure 28; West and O'Neill, 2007; PSAT, 2007). Concentrations do not appear to be changing significantly over time during this period. The concentrations in herring in Puget Sound are comparable to those measured recently in herring from heavily industrialized areas in the Baltic Sea, which has long been considered one of Europe's most contaminated inland seas (PSAT, 2007).

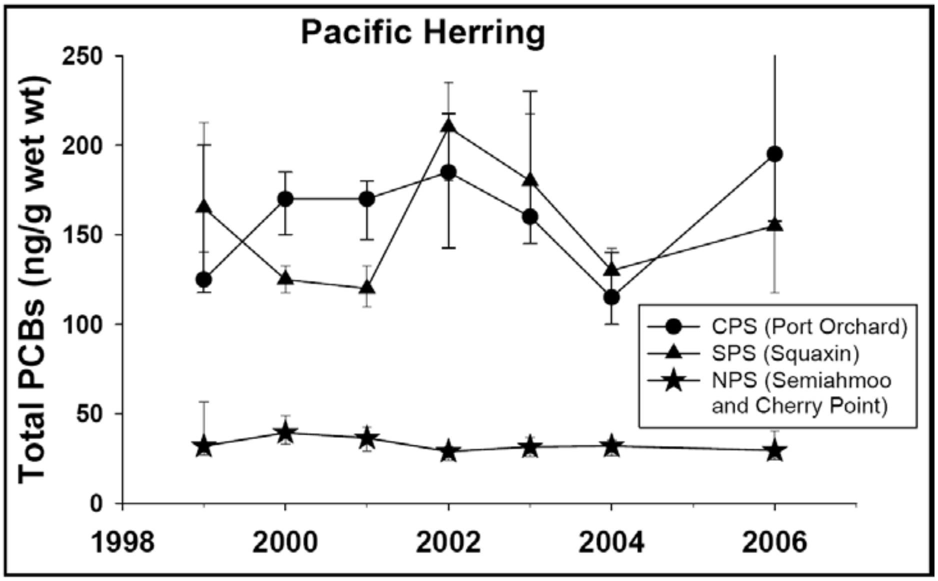

Figure 28. PCBs in Pacific herring in Central Puget Sound (CPS), South Puget Sound (SPS), and North Puget Sound (NPS). (West and O'Neill, 2007.)

Pacific salmon

PCB concentrations in adult Coho salmon returning to spawn appear to be related to the migration distance or residence time in Puget Sound, or possibly increasing proportions of resident Coho salmon with increasing distance from the Pacific Ocean (PSAT, 2007). PCB concentrations in Chinook salmon fillets from Puget Sound are nearly three times higher than other west coast populations (PSAT, 2007).

More than 98% of the final weight of most Pacific salmon is achieved at sea (Quinn, 2005). The concentrations of PCBs in non-resident salmon would therefore most likely be strongly influenced by concentrations of PCBs in prey species that are outside of the Puget Sound food web. However, the finding of elevated concentrations of PCBs in salmon in Puget Sound relative to other west coast populations suggests that a significant portion of the diet could be derived from prey species within Puget Sound.

Resident blackmouth (Chinook) salmon were sampled near Apple Cove Point in the central main basin of Puget Sound by WDFW. The mean and standard deviation of total PCBs (sum of 40 measured congeners) in the whole body of resident blackmouth salmon was 113 ± 45 ng/g wet weight (n=48, sum of 40 congeners). Blackmouth salmon on average have higher concentrations than other Chinook salmon from nearby locations at the Deschutes River (51 ± 32 ng/g wet weight, sum of 40 congeners) and Duwamish River (54 ± 37 ng/g wet weight, sum of 40 congeners).

Blackmouth salmon have lower concentrations than 2-4-year-old male Pacific herring at Port Orchard (209 ± 63 ng/g wet weight, sum of 40 congeners), Quartermaster Harbor (125 ± 30 ng/g wet weight, sum of 15 congeners), and Squaxin (181 ± 82 ng/g wet weight, sum of 40 congeners). Blackmouth salmon also have lower concentrations than Pacific herring that were randomly sampled with respect to age and sex at Port Orchard (140 ± 36 ng/g wet weight, sum of 40 congeners) and Squaxin Passage (130 ± 10 ng/g wet weight, sum of 40 congeners) (Table 13).

Osprey

Nesting osprey in Puget Sound are long-lived, fish-eating migratory birds that frequently return to the same nest sites. PCBs have been measured in osprey eggs from nests near Everett Harbor in the Whidbey Basin and near the Duwamish River. Some organic contaminants in osprey eggs have been shown to biomagnify from fish to an osprey egg by a factor of up to 174-fold (PSAT, 2007).

Harbor seals

A dramatic reduction in PCBs in harbor seals between the 1970s and 1980s was observed by Calambokidis et al. (1999) in data collected from Gertrude Island in South Puget Sound (Figure 29). PCB levels in harbor seal pups at this location appear to have stopped declining in recent years from the 1990s to the present. The mean and standard deviation of the total PCB concentration in blubber of seal pups from all samples (n=57) collected between 1984 through 1997 was reported to be 13.4 ± 8.4 μg/g lipid wet weight.

Orcas

Southern resident orcas in Puget Sound have three times the PCB concentrations compared with northern resident orcas (Figure 30; PSAT, 2007). Both resident orca groups feed mainly on returning salmon in the summer and fall, and are more contaminated with PBTs than other north Pacific resident orca populations. The winter feeding ranges and prey of resident orcas are unknown.

A third population of orcas is transient and occasionally visits Puget Sound. The transient orcas have the highest PCB concentrations (Figure 30). This is probably because the transient population feeds mainly on marine mammals which are a higher trophic level and therefore higher PCB concentration compared with salmon.

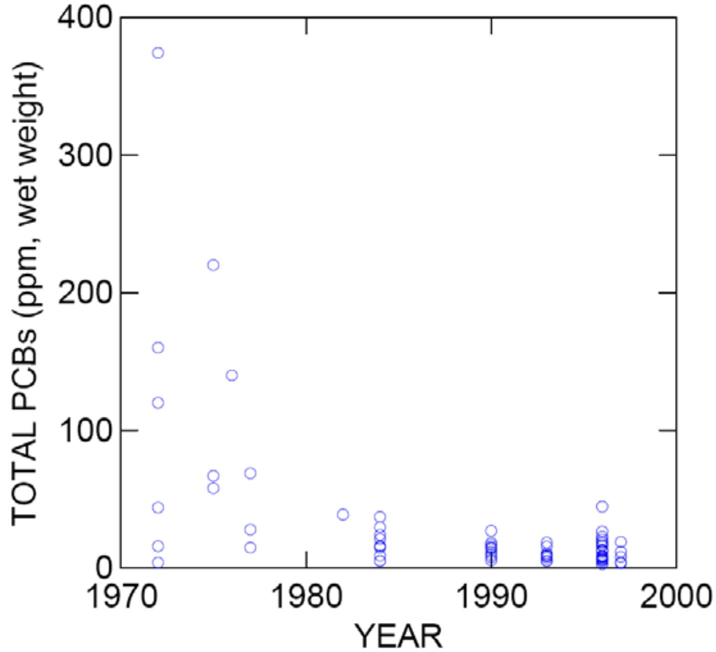

Figure 29. Plot of total PCBs in blubber of harbor seal pups at Gertrude Island in South Puget Sound from 1972 to 1997 (Calambokidis et al., 1999).

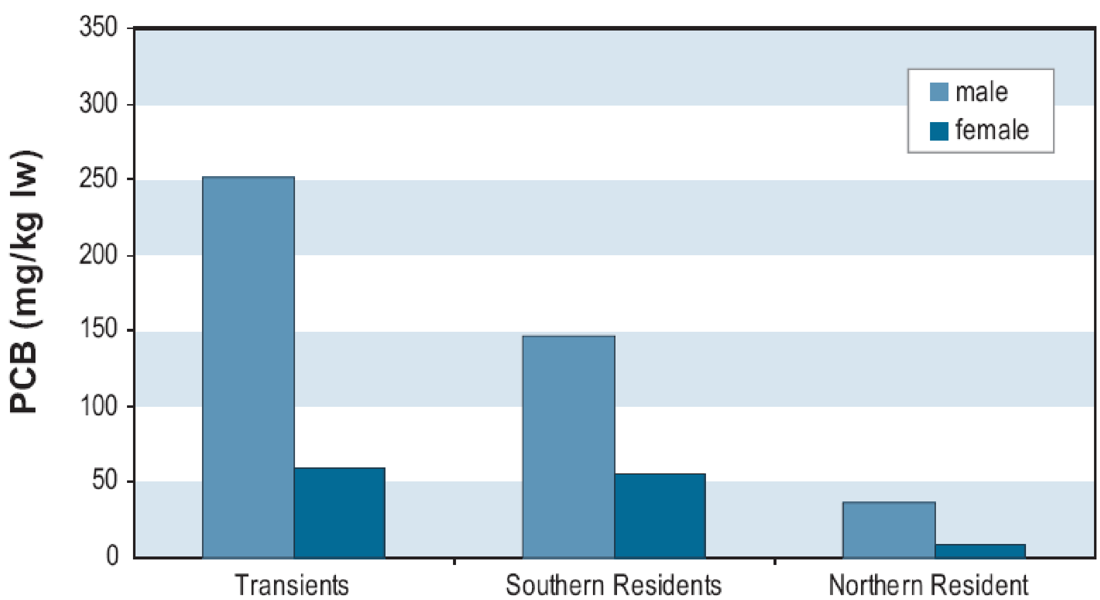

Figure 30. PCBs in lipids of three orca populations in Puget Sound (PSAT, 2007).

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Model results

Box model of PCB fate and transport

Model inputs for the typical condition

The input values for fate and transport modeling using the Davis (2004) model were derived from actual data collected from Puget Sound to the extent possible, and supplemented with default values reported by Davis for model parameters that could not be estimated from observed data. The following values and assumptions were used as the default best estimates of model inputs for the fate and transport model of PCBs [5]:

- **PCB concentrations in the water column at the open boundary**. 43.5 pg/L in the surface water layer and 40.3 pg/L in the deep water layer based on the sum of particulate and dissolved PCB data reported by Dangerfield et al. (2007).
- **Evaporation coefficient for the air side**. 423 m/d (Davis, 2004).
- **Evaporation coefficient for the water side**. 0.649 m/d (Davis, 2004).
- **Initial conditions of PCB in the water**. Assumed to be the same as the open boundary concentration.
- **Initial conditions of PCB in the sediment**. Median concentrations in each region of the box model as shown in Table 4.
- **External load of PCB**. 50% exceedance load derived from Hart Crowser et al. (2007) and shown in Table 3.
- **Atmospheric flux of PCB.** 1270 ng/m^2/year based on the average of two stations in British Columbia, wet and dry deposition, reported by Noel (2007). The estimates by Noel (2007) were considered to be representative because they were based on sampling from the general vicinity of open waters in the Strait of Georgia near Puget Sound and are in the mid-range of reported values summarized by Hart Crowser et al. (2007).
- **Concentration of TSS, TOC, and DOC in the water column.** Median concentrations in each region of the box model as shown in Table 8, Table 9, and Table 10.
- **Thickness of the active sediment layer**: Active sediment thickness of 10 cm was assumed based on the interquartile range of observed sediment cores in Puget Sound and the worldwide mean of 10 cm reported by Boudreau (1994).
- **Concentration of solids in the active sediment layer**. Sediment concentration of dry solids (Cs, Kg/L) was estimated from the following regression equation with water depth (meters) for data from 87 cores in four sedimentation studies in Puget Sound:

  $$Cs = -0.0011674 * depth + 0.86342$$

- **Density of solids.** 1.1 Kg/L in the water column and 2.7 Kg/L in the active sediment layer (Davis, 2004).

[5] Davis (2004) should be consulted for a detailed definition and discussion of the parameters for model kinetics and how the various model inputs are used in the mass balance for PCBs.

- **Sediment burial velocity.** 0.4 cm/year based on the median of 87 Pb-210 cores adjusted for sediment focusing based on the estimated areas of sediment accumulation, except for Sinclair/Dyes Inlets which was assumed to be 0.25 cm/year (Bob Johnston, U.S. Navy, personal communication).
- **Solids resuspension velocity from the active sediment layer.** Two times the burial rate in the active sediment exposed to the deep water layer and four times the burial rate in the active sediment exposed to the surface water layer based on typical values observed in sediment trap studies.
- **Settling flux of solids.** Calculated sum of burial flux and resuspension flux given the inputs for the burial and resuspension parameters.
- **Total organic carbon fraction of dry solids in the active sediment layer.** Regional median concentrations observed in EIM data as shown in Table 7.
- **Density of organic carbon.** 0.9 Kg/L (Davis, 2004).
- **Water/sediment diffusion velocity.** 0.0024 m/day (Davis, 2004).
- **Representative congener for the octanol-water partition coefficient.** PCB congener number 118.
- **Flow-proportional external loads.** The watershed sources of PCBs were assumed to be distributed over time proportional to river flows.

The assumed boundary conditions of river flows and salinity at the open boundary were used as described by Babson et al. (2006). Two simulation periods were examined: 1996-2000, and 1996-2050. The shorter period of 1996-2000 was simulated using actual inter-annual river flow variations to examine the inter-annual variability of predicted concentrations. The longer period of 1996-2050 was simulated by repeating the long-term average hydrograph of river flows and the idealized composite forcing function for salinity at the open boundary for each year of the simulation.

Predicted PCBs in water and sediment for the typical condition

The model predictions presented in this section are intended to represent a typical condition based on the median estimate of external loading and the best estimates for the most likely values of other model inputs. There is a large amount of uncertainty in external loads and other model inputs. The effect of uncertainty on model predictions is discussed in later sections. The results for the typical condition are intended to be preliminary and approximate in consideration of the large uncertainties of model inputs and are not meant to imply a high degree of accuracy.

The predicted concentrations of PCBs in the surface water and active sediment layers during 1997, 1998, and 1999 are presented in Figures 31 and 32. The scarcity of water column PCB data limits the ability to calibrate or confirm the predictions of the fate and transport model. The limited available water column data from Elliott Bay provide the only opportunity to compare predicted and observed concentrations in the water column. The predicted mean and standard deviation of total PCBs in the water column of Elliott Bay is 120 ± 41 pg/L, which compares reasonably well with the observed concentrations of 125 ± 41 pg/L that were reported at a depth of 15 m by Mickelson and Williston (2006).

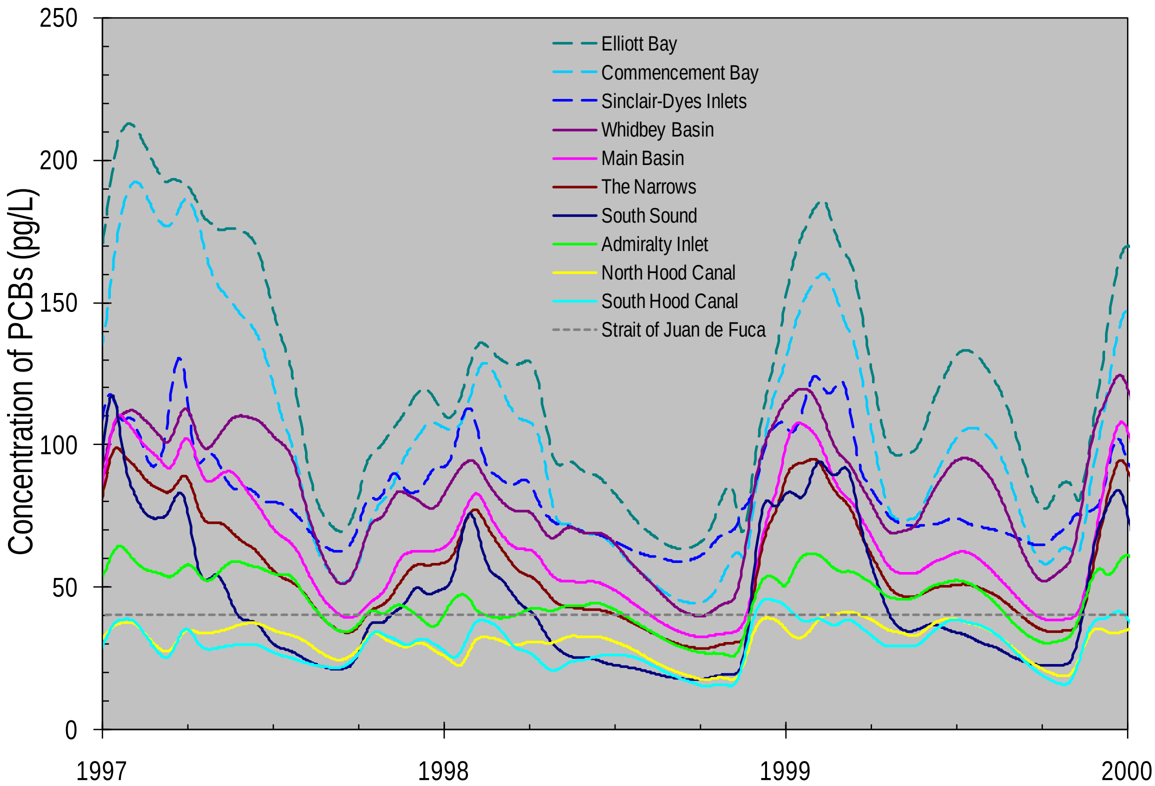

Figure 31. Predicted concentration of PCBs in the water column of each basin during 1997-1999.

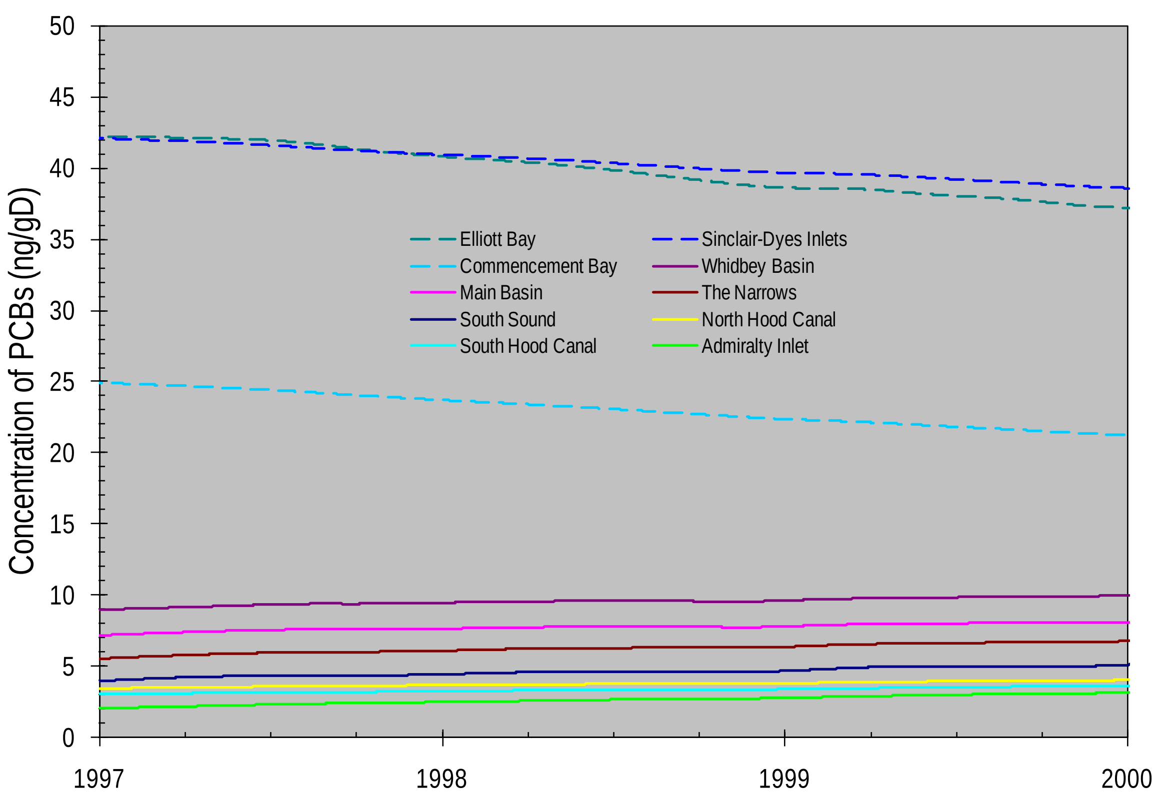

Figure 32. Predicted concentration of PCBs in the active sediment layer of each basin for 1997-1999.

Seasonal variations in total PCBs in the water column are predicted in response to seasonal variations in river flows. The lowest observed concentrations in Elliott Bay also occurred during the dry season (August 2005) and highest concentrations were observed during wetter conditions (September-December 2005).

The long-term simulation through the year 2050 shows that the sediment concentrations in the urban bays (Elliott Bay, Sinclair/Dyes Inlets, and Commencement Bay) are predicted to decrease over time, and the sediment concentrations in the non-urban basins (South Sound, Main Basin, North Hood Canal, South Hood Canal, Whidbey basin, The Narrows, and Admiralty Inlet) are predicted to increase over time (Figure 33).

Practically all of the predicted decrease in total mass of PCBs in the urban bays is explained by loss from deep burial, degradation, and volatilization (Table 14). The model predictions are corroborated by observed trends of significant decreases in sediment PCBs in Elliott Bay between 1998 and 2007 (Partridge et al., 2009). The predicted increase in total mass in the non-urban basins appears to be mainly derived from external loading, including most of the external loading to the urban basins that passes through to the adjacent non-urban basins.

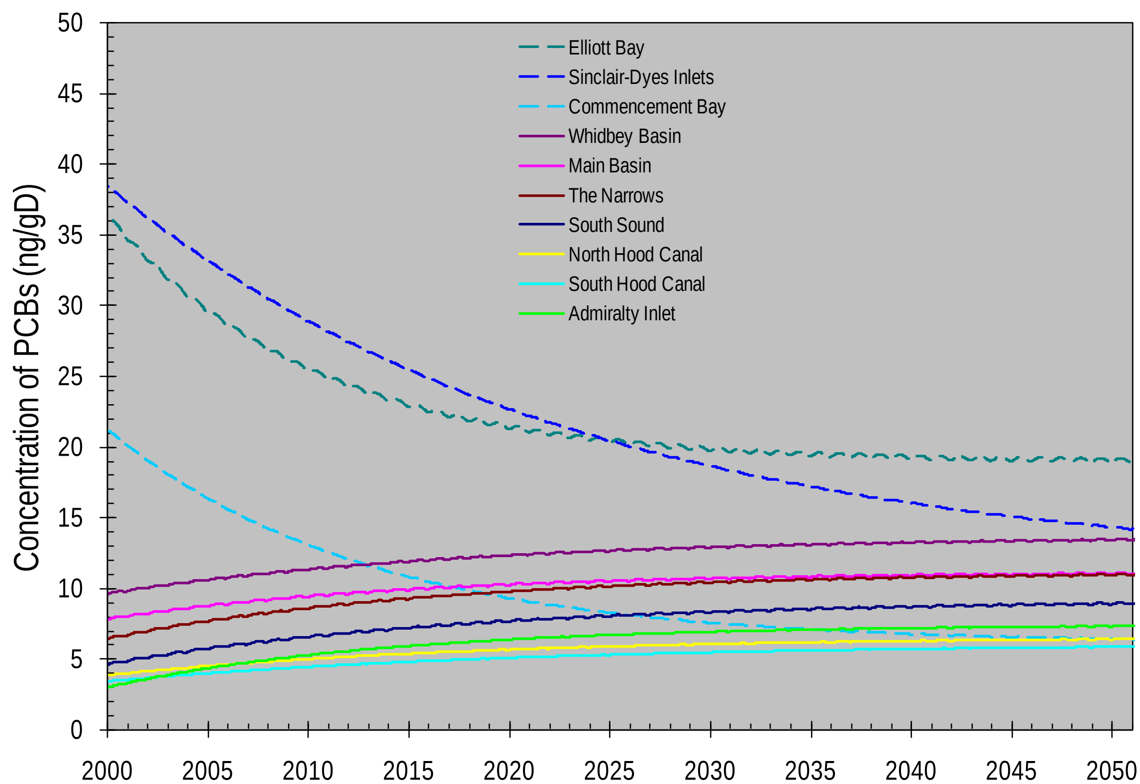

Figure 33. Predicted PCB concentrations in the active sediment layer of each basin for 2000-2050.

Table 14. Summary of predicted changes in mass, and cumulative gains and losses, of total PCBs in non-urban basins and urban bays.

	Non-urban basins (1)	Urban bays (2)	Total
Change in mass of total PCBs stored in the water column and active sediment (positive=increase, negative=decrease) (Kg)			
change from 1996-2020	702	-224	478
change from 1996-2050	876	-292	585
Cumulative gains from external load from the watershed and atmospheric deposition (positive=gain) (Kg)			
gain from 1996-2020	2367	589	2957
gain from 1996-2050	5232	1302	6534
Cumulative loss from deep burial of sediment, degradation, and volatilization (negative=loss) (Kg)			
loss from 1996-2020	-2020	-318	-2338
loss from 1996-2050	-5065	-543	-5608
Net gain-loss through inter-basin transport and ocean boundary exchange (positive=gain, negative=loss) (Kg)			
net gain-loss from 1996-2020	355	-495	-141
net gain-loss from 1996-2050	709	-1050	-341

1) South Sound, Main Basin, North Hood Canal, South Hood Canal, Whidbey Basin, The Narrows, and Admiralty Inlet.
2) Elliott Bay, Sinclair/Dyes Inlets, and Commencement Bay.

Most of the mass of PCBs in the active sediment and water column of Puget Sound appears to be contained in the Whidbey Basin, main basin, and South Puget Sound (Figure 34). The urban bays (Elliott Bay, Commencement Bay, and Sinclair-Dyes Inlets) have higher sediment concentrations, but together they account for only about 30% of the total mass of PCBs in Puget Sound, and over time they are expected to represent a decreasing fraction of the total (Figure 34). However, a larger fraction of the PCBs in the urban bays may be more bioavailable compared with the larger basins due to the preferred feeding ranges of biota and the greater proportion of shallow areas.

The total mass of PCBs stored in the active sediment layer and water column at the start of the simulation was estimated to be approximately 1440 Kg[6]. The total mass is predicted to increase over time to about 1920 Kg by the year 2020, and reach a steady state of approximately 2030 Kg of PCBs by the year 2050. The predicted increasing trend in the total mass of PCBs that is accessible to biota in Puget Sound may be corroborated by the possibility that concentrations in biota for some species may be increasing in recent years after the initial decline between the 1970s and 1980s (West and O'Neill, 2007).

[6] The initial total mass of PCBs in the active sediment layer of Puget Sound was estimated as the sum across all basins of the product of the current median sediment concentrations in the surface 10 cm of sediment multiplied by the total mass of dry solids in the volume of the active sediment layer. This was estimated as the product of the solids concentration and the volume of the active sediment layer in each basin, where the volume was estimated as the product of surface area and thickness of the active sediment layer.

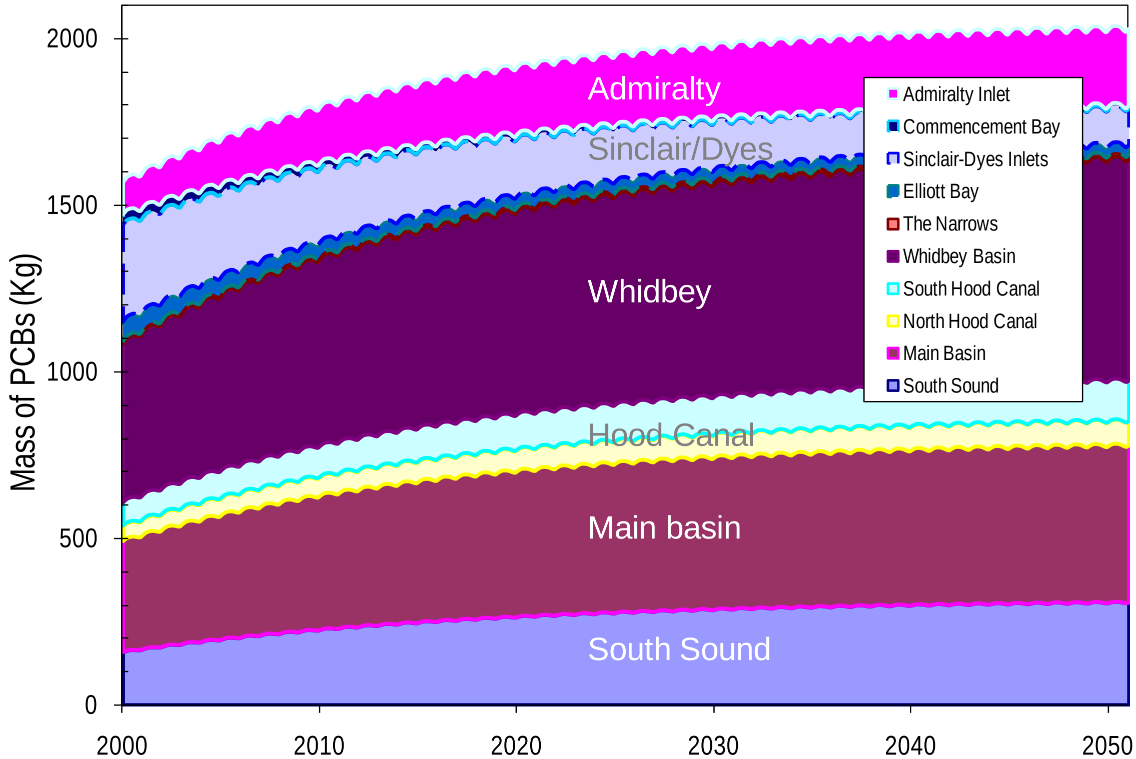

Figure 34. Total predicted mass of PCBs in the water column and active sediment layers of each basin from 2000-2050.

A preliminary first-cut estimate of the total mass of PCBs stored in the biomass of biota in Puget Sound is probably less than about 40 Kg (O'Neill and West, 2007), or on the order of about <3% of the total mass of PCBs in water, active sediment, and biota combined (Table 15). The total mass of PCBs in the active sediment layer (approximately 1440 Kg) accounts for about 97% of the total. The mass of PCBs in the water column (approximately 10 Kg) is only about <1% of the total, but it is comparable in magnitude to the mass in biota (<40 Kg).

Table 15. Comparison of the estimated current active sediment, water, and biotic mass of PCBs in Puget Sound.

		Mass of PCBs (Kg)	Percent of total
PCBs in the active sediment and water	Active sediment layer (top 10 cm) (1)	1440	97%
	Water column (2)	10	<1%
Biotic mass of PCBs (3)		<40	<3%
Total mass of active sediment, water column, and biotic PCBs (4)		1490	100%

(1) Based on an active sediment layer thickness of 10 cm and median PCB concentrations in each region.
(2) Based on predicted average PCB concentrations in the water column during 1997, 1998, and 1999.
(3) Source: O'Neill and West, 2007.
(4) Assume biotic mass of 40 Kg PCBs.

The cumulative mass of PCBs entering Puget Sound from all sources over time is presented in Figure 35. PCBs enter Puget Sound from three main sources as follows:

1. **Watershed.** Approximately 116 Kg/year of PCBs enter Puget Sound from watershed sources based in the 50% exceedance load derived from Hart Crowser et al. (2007). There is a large uncertainty in the loading from watershed sources (e.g., interquartile range of about 27 to 512 Kg/year reported by Hart Crowser et al. 2007).
2. **Open boundary.** Approximately 24 Kg/year of PCBs enter Puget Sound through transport of dissolved and particulate PCBs in the water from the Strait of Juan de Fuca into Admiralty Inlet based on the observed concentrations reported by Dangerfield et al. (2007) and the water transports calculated in the box model of Babson et al. (2006).
3. **Atmospheric deposition.** About 3 Kg/year of PCBs enter Puget Sound from atmospheric deposition based on the deposition fluxes reported by Noel (2007) applied to the surface area of Puget Sound.

The cumulative mass of PCBs that leave the active sediment layer and water column of Puget Sound from all losses over time is presented in Figure 36. Cumulative losses of PCBs through the year 2050 are predicted to be less than cumulative sources, with the difference accounting for a predicted increase in storage over time. PCBs are predicted to be lost from potential access to the biota in Puget Sound through four main pathways as follows:

1. **Sediment burial.** Approximately 72 Kg/year of PCBs are estimated to be buried to deep sediments.
2. **Open boundary.** About 30 Kg/year of PCBs are estimated to leave Puget Sound through the open boundary to the Strait of Juan de Fuca through transport of dissolved and particulate PCBs in the water.
3. **Degradation.** About 23 Kg/year of PCBs are predicted to be lost due to degradation.
4. **Volatilization.** About 7 Kg/year of PCBs are predicted to be lost to the atmosphere through volatilization across the water surface.

The sources and losses listed above are the estimated averages from 1996-2050, assuming the annual average rate of loading from sources remains constant. The total rate of loading from all sources currently exceeds the total rate of losses. This is consistent with the prediction that the total mass of PCBs may be increasing over time, and suggests that the loading may have increased recently. If the sources and losses were at equilibrium, then the total rate of loading from sources would equal the total rate of losses, and the total mass of PCBs in the active sediment layer and water column of Puget Sound would remain constant.

The rate of loss is dependent on the rate of loading from sources. For example, if sources change, then the concentration in the water column will change, and the rate of loss from transport to the ocean will change until the total losses are at equilibrium with total sources. Also, as the sediment concentrations change, the rate of loss from burial of sediment will change until equilibrium.

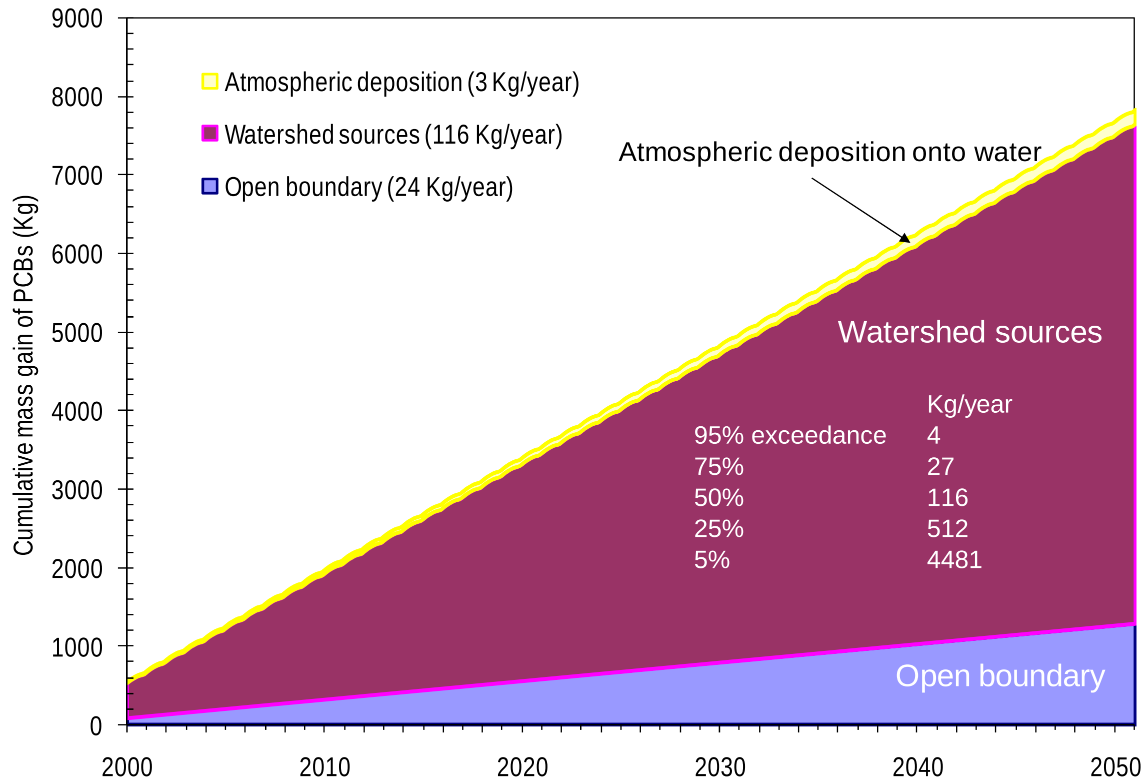

Figure 35. Cumulative mass influx of PCBs into Puget Sound from all sources.

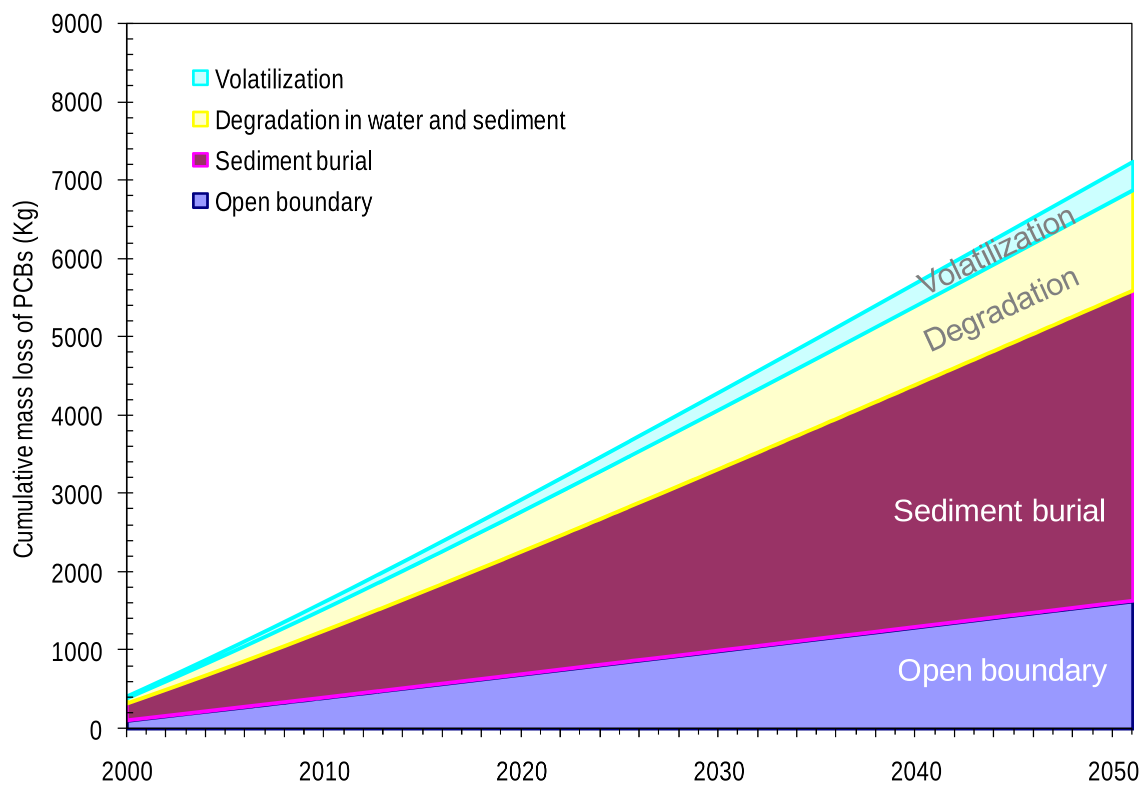

Figure 36. Cumulative mass outflux of PCBs out of Puget Sound from all losses.

Sensitivity and uncertainty analysis of model inputs

Uncertainty in many of the important model inputs is expected to result in uncertainty in the predicted PCBs in Puget Sound. The predicted concentrations of PCBs in water, sediment, and biota are expected to be uncertain due to the uncertainty in the most sensitive input variables. Key model inputs were selected to evaluate the effect of their uncertainty on the predicted total mass of PCBs in the water and sediment as follows (Table 16 and Figure 37):

- External loads of PCBs from watershed sources.
- Initial concentration of PCBs in the active sediment layer.
- Sediment burial velocity.
- Sediment resuspension velocity.
- Active sediment layer thickness.
- Octanol-water partition coefficient.
- Henry's law constant.
- Degradation rate of PCBs.
- Total suspended solids in the water column.
- Dissolved organic carbon in the water column.
- Salinity in the Strait of Juan de Fuca.
- Concentration of PCBs in the Strait of Juan de Fuca.

The low and high values from the interquartile range of estimated values were used as input to the model to evaluate the sensitivity and uncertainty in predicted PCBs due to uncertainty in external loads, initial sediment concentrations, and sediment burial velocities. To evaluate the uncertainty of predicted PCBs due to uncertainty in each input, all of the other model inputs were held at their default median best estimate values as described in the model inputs section, and the low or high estimates were substituted one at a time for each of the evaluated inputs. The predicted total mass of PCBs in the active sediment layer and water column of Puget Sound was evaluated for the low and high estimates of each model input. The basis for the low and high values for each variable in the sensitivity analysis is presented in Table 16.

Uncertainty in watershed sources is predicted to result in the largest uncertainty in model predictions of future PCBs (Figure 37a). Predicted concentrations of PCBs in Elliott Bay using the 50% exceedance loads (120 ± 41 pg/L) were similar to the observed values in Elliott Bay (125 ± 41 pg/L). In contrast, predicted concentrations in Elliott Bay using the 25% exceedance load (310 ± 120 pg/L) or 75% exceedance load (53 ± 7 pg/L) were much higher or lower than the observed concentrations in Elliott Bay. This suggests that the median (50% exceedance) loading estimate may be close to the actual load, and uncertainty may be overstated by Hart Crowser et al. (2007), especially at the high end. However, these results show that the predicted mass of PCBs in Puget Sound is very sensitive to external loading sources. Since about 97% of the mass of PCBs in the aquatic ecosystem of Puget Sound is stored in the active sediment layer, this result suggests that the external loading sources exert a large influence on the content of PCBs in the sediment.

Table 16. Results of the sensitivity analysis to predict the total mass of PCBs in the water and active sediment (Kg).

Sensitivity scenario	Current Condition	Year 2020	Year 2050	Basis of low or high estimate
External loading estimated using values from Hart Crowser et al. (2007) (1)				
Median best estimates for all inputs	1440	1920	2030	
Total external load at low estimate	"	967	809	75% probability of exceedance
Total external load at high estimate	"	6190	7500	25% probability of exceedance
Loading from forest land at low estimate	"	1580	1600	75% probability of exceedance
Loading from forest land at high estimate	"	3790	4420	25% probability of exceedance
Loading from residential land at low estimate	"	1630	1660	75% probability of exceedance
Loading from residential land at high estimate	"	3090	3530	25% probability of exceedance
Loading from commercial/industrial land at low estimate	"	1740	1800	75% probability of exceedance
Loading from commercial/industrial land at high estimate	"	2660	2980	25% probability of exceedance
Loading from agricultural land at low estimate	"	1800	1880	75% probability of exceedance
Loading from agricultural land at high estimate	"	2420	2670	25% probability of exceedance
Total external loading reduced by 50%	"	1300	1230	NA
Total external loading reduced by 75%	"	985	832	NA
Total external loading reduced by 90%	"	797	592	NA
Initial sediment PCBs at low estimate	568	1670	1980	initial sediment PCBs at 25%tile
Initial sediment PCBs at high estimate	3510	2480	2150	initial sediment PCBs at 75%tile
Thickness of active sediment layer at low estimate	726	1130	1160	0.5 cm thickness
Thickness of active sediment layer at high estimate	2880	3190	3310	20 cm thickness
Sediment burial velocity at low estimate	1440	2130	2480	25%tile
Sediment burial velocity at high estimate	"	1330	1320	75%tile
Sediment resuspension velocity at low estimate	"	1790	1860	2x burial in shallow, 1x burial in deep sediments
Sediment resuspension velocity at high estimate	"	2060	2210	8x burial in shallow, 4x burial in deep sediments
Octanol-water partitioning coefficient at low estimate	"	1580	1590	25%tile Log Kow = 6.28
Octanol-water partitioning coefficient at high estimate	"	2140	2310	75%tile Log Kow = 7.3

Sensitivity scenario	Current Condition	Year 2020	Year 2050	Basis of low or high estimate
Henry's law constant at low estimate	"	1990	2120	25%tile Kh = 0.325
Henry's law constant at high estimate	"	1840	1920	75%tile Kh = 19.1
Degradation rate for PCBs at low estimate	"	2220	2490	degradation half-life of 560 years
Degradation rate for PCBs at high estimate	"	698	683	degradation half-life of 5.6 years
Total suspended solids at low estimate	"	2140	2320	25%tile
Total suspended solids at high estimate	"	1780	1850	75%tile
Dissolved organic carbon at low estimate	"	1900	2000	25%tile
Dissolved organic carbon at high estimate	"	2020	2160	75%tile
Salinity in the Strait of Juan de Fuca at low estimate	"	1930	2040	best estimate minus 1 psu
Salinity in the Strait of Juan de Fuca at high estimate	"	1920	2030	best estimate plus 1 psu
PCBs in the Strait of Juan de Fuca at low estimate	"	1810	1880	best estimate divided by 2
PCBs in the Strait of Juan de Fuca at high estimate	"	2160	2330	best estimate multiplied by 2
External loading estimated using values from Envirovision et al. (2008) (2)				
Median best estimates for all inputs	1440	3760	4390	
Total external load at low estimate	"	1450	1430	75% probability of exceedance
Total external load at high estimate	"	13100	16300	25% probability of exceedance

(1) Median best estimates for all inputs is the baseline. Other scenarios listed below it adjust one input variable at a time to lower or higher estimates for comparison.
(2) Same as (1) except that the estimates of external loading of PCBs are from Envirovision et al. (2008) instead of Hart Crowser et al. (2007).

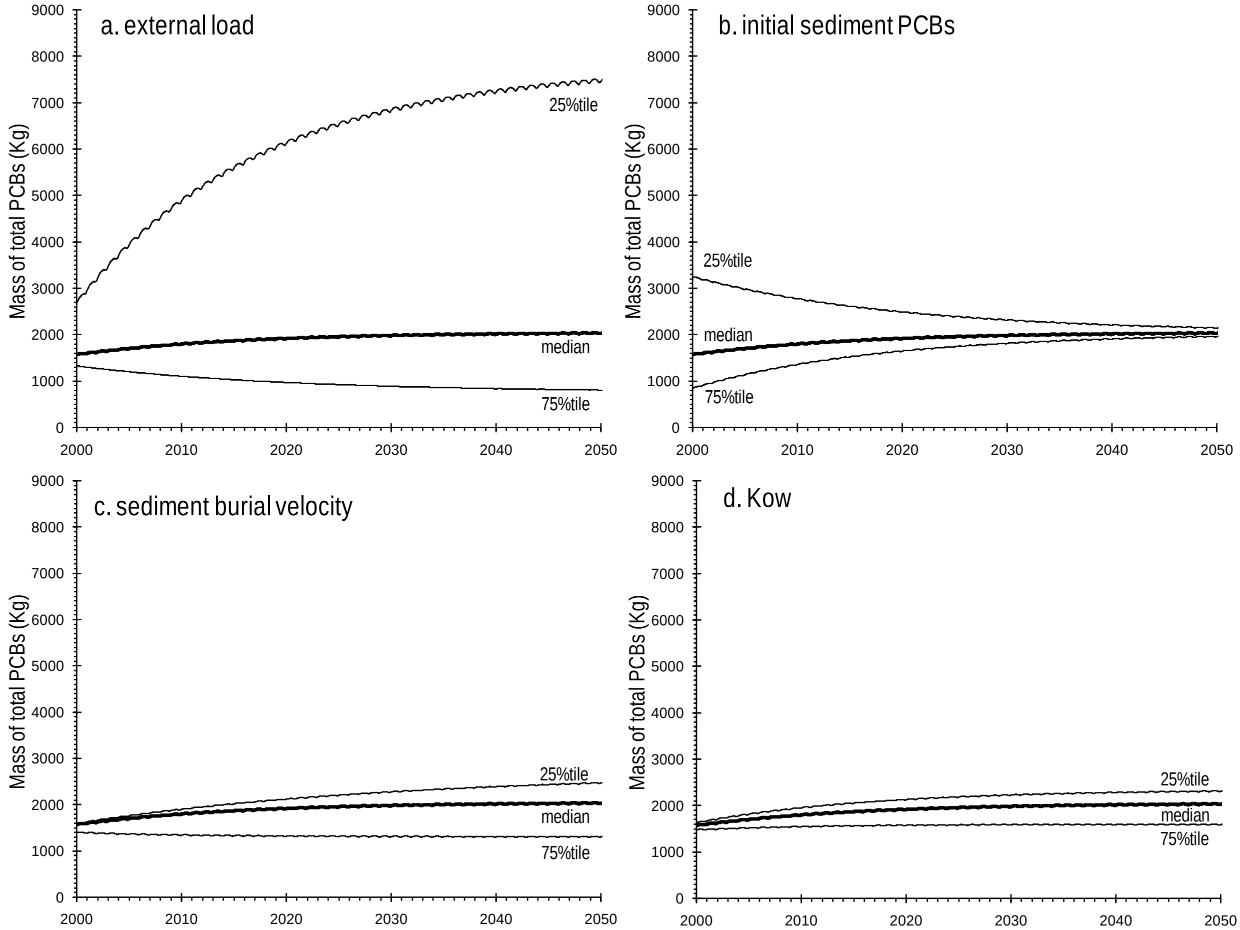

Figure 37. Uncertainty in the predicted total mass of PCBs in the active sediment and water column of Puget Sound due to uncertainty in: (a) external loading sources of PCBs from the watershed; (b) initial concentration of PCBs in the active sediment layer; (c) sediment burial velocity; and (d) octanol-water partition coefficient (Kow).

Uncertainty in loading from forest land cover contributed the most to total uncertainty due to external loading (Figure 38), followed by uncertainty in loading from residential, commercial/ industrial, and agricultural land covers using loading estimates reported by Hart Crowser et al. (2007). The interquartile range of the external loads by year 2020 corresponds to a range of the total mass of PCBs in the active sediment and water column of Puget Sound of approximately 970 to 6190 Kg with a median of about 1920 Kg. By year 2050, this range corresponds to an approximate steady-state range of 810 to 7500 Kg with a median of about 2030 Kg.

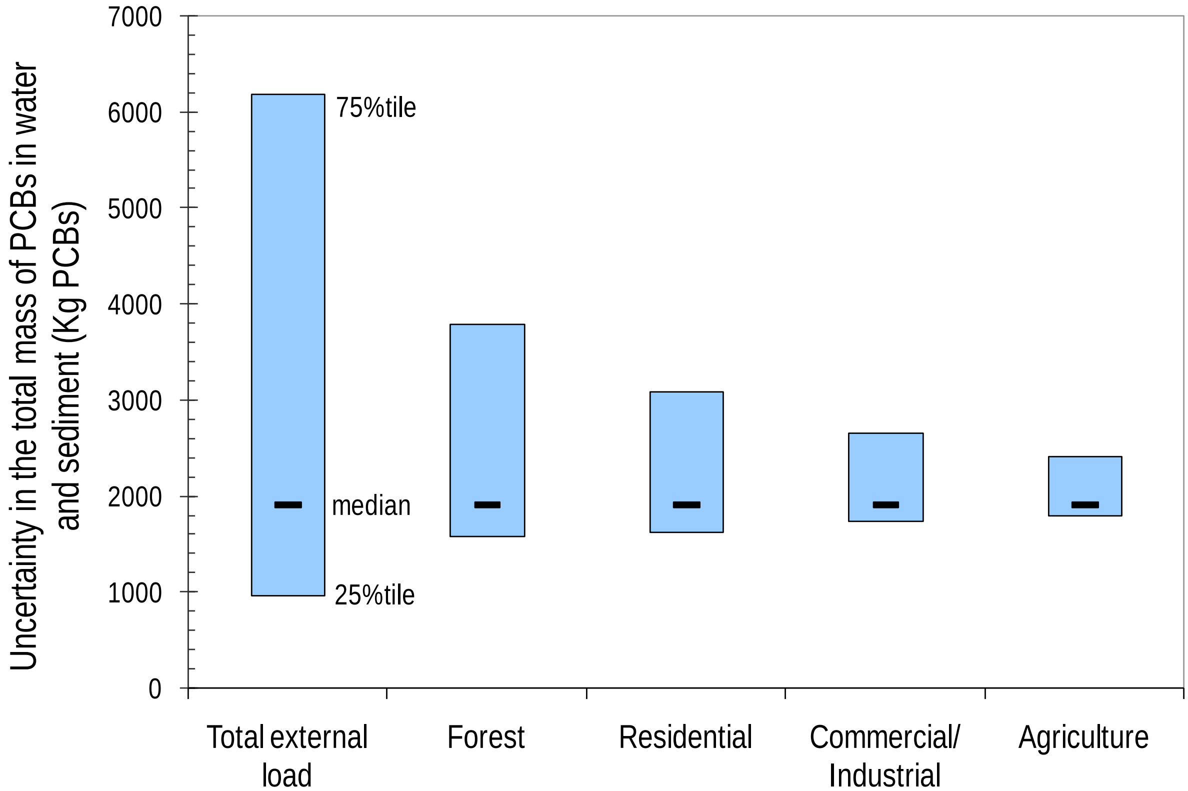

Figure 38. Uncertainty in the total mass of PCBs in the water column and active sediment layer in the year 2020 due to variability of total external loading and the components of forest, residential, commercial/industrial, and agricultural runoff using loading estimates provided by Hart Crowser et al., 2007.

Uncertainty in the initial concentrations of PCBs in sediment does not have a significant effect on the predicted steady-state mass of PCBs by the year 2050 (Figure 37b). The total mass of PCBs in Puget Sound in the future at steady state is predicted to converge on approximately the same value regardless of whether the current condition (defined in this project as the 1990s) of sediment is relatively clean or more contaminated. This result is most likely due to the effect of continuous burial of sediments over time. Variability in the initial sediment concentrations mainly influences the current condition of Puget Sound and is not a major factor for determining the total PCBs in the future.

The interquartile range of the initial sediment concentrations corresponds to a range of the current (1990s) total mass of PCBs in the active sediment and water column of Puget Sound of approximately 570 to 3510 Kg, with a median of about 1440 Kg (Figure 37b). Uncertainty in the current sediment concentrations of PCBs represents the actual variability of the sediment conditions as determined from a relatively large number of samples.

Uncertainty in the sediment burial velocity has a negligible effect on current conditions, but has an increasingly large effect on predicted PCBs over time (Figure 37c). Sediment burial velocity appears to contribute less to model uncertainty than external loading (Figure 37a).

Uncertainty due to the range of octanol-water partition coefficients has a relatively small effect on uncertainty in PCBs over the range of values that represent most of the PCBs in Puget Sound (Figure 37d) compared with the other model inputs.

Sensitivity to external loading

The predicted response of PCBs in Puget Sound to hypothetical scenarios of external loading sources was evaluated (Figure 39). Each of these scenarios was evaluated at their default best estimates of current conditions, with the exception of external loads from watershed sources which were assumed to be various hypothetical amounts, and the initial concentration of PCBs in the sediments which was assumed to be zero. These hypothetical scenarios are not intended to imply that loading will be constant over time. Actual external loading may be increasing or decreasing over time. For example, increases in nonpoint sources due to watershed changes with population growth may increase loading over time. Conversely, load reduction strategies may lead to decreasing loads over time as best management practices are implemented.

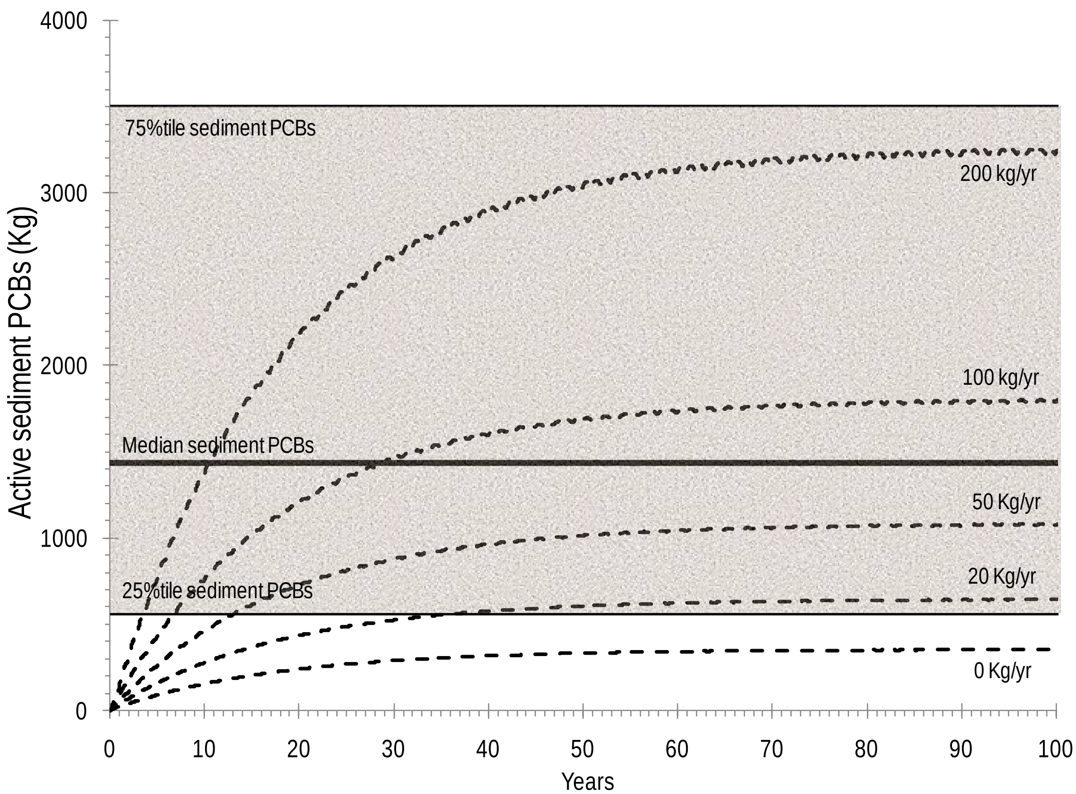

Figure 39. Predicted response of the total mass of PCBs in the active sediment layer for various external watershed loads of PCBs assuming initial sediment concentration of zero.

The model was used to estimate a plausible range of external loading of PCBs that would result in the buildup of a predicted mass of PCBs in the active sediment layer that is consistent with the observed interquartile range of sediment concentrations (Figure 39). The concentration of PCBs at the ocean boundary and loading from atmospheric deposition were assumed to occur at the median best estimates described previously. If the initial concentrations of PCBs in the sediments are assumed to be zero, and a watershed load is assumed to be constant for a long period of time, then the model will eventually reach a hypothetical "steady-state" build-up of the mass of PCBs in the active sediment layer.

When the external loading from watershed sources is assumed to be zero, the long-term build-up of PCBs in the active sediment layer approaches about 360 Kg due to loading from atmospheric deposition and the ocean boundary. Atmospheric deposition supports a long-term build-up of about 50 Kg of PCBs in the sediment, and the ocean boundary supports build-up of about 310 Kg of PCBs. In other words, the total mass of PCBs in the aquatic ecosystem of Puget Sound probably could not be reduced much below about 400 Kg because of the buildup that is sustained by inputs from the ocean boundary and atmospheric deposition.

The plausible range of external loading from watershed sources that corresponds to the observed mass of PCBs, as represented by the observed interquartile range of sediment concentrations, appears to be about 20 to 200 Kg/year, with the median possibly in the range of about 50 to 100 Kg/year. The plausible range of 20 to 200 Kg/year of external loading of PCBs overlaps the lower end of the other reported interquartile ranges of estimated watershed loading of 27 to 512 Kg/year (Hart Crowser et al., 2007) and 72 to 1100 Kg/year (Envirovision et al., 2008). The plausible range of 20 to 200 Kg/year of external loading represents all potential sources other than atmospheric deposition and ocean boundary loading (e.g., nonpoint sources, point sources, flux from contaminated sediments in tributary urban waterways).

External loading is a strong driver of the magnitude of the long-term future mass of PCBs in Puget Sound (Figure 39). This result is consistent with a similar finding by Davis (2004) in San Francisco Bay. The current total mass of PCBs in Puget Sound appears to be nearly at equilibrium with external loading of about 50 to 100 Kg/year, which is about 50% less than the median estimate by Hart Crowser et al. (2007) and about 75% less than the median estimate by Envirovision et al. (2008), which suggests one of the following possibilities:

- **External loading from the watershed may be over-estimated.** The actual external load to Puget Sound may be approximately 50% to 75% less than the 50% exceedance probability from Hart Crowser et al. (2007) and Envirovision et al. (2008). The confidence interval for the loading estimates suggests that current loading of PCBs could be this low. Considering the wide range of uncertainty, it is possible that the total mass of PCBs in the aquatic ecosystem of Puget Sound may be in equilibrium with current loading or possibly decreasing over time.
- **External loading may be increasing.** External loading in recent years may have increased approximately 50%, after the dramatic reductions that were observed in biota between the 1970s and 1980s (Calambokidis et al., 1999). This is consistent with the possibility that concentrations of PCBs in some species may be increasing since about 1990[7]. Nonpoint

[7] West and O'Neill (2007) evaluated long-term trends in PCBs in English sole, Pacific herring, and Coho salmon. None of these three fish species exhibited a decline in PCBs over the past 15 years. This finding is consistent with the lack of declining trends in the most recent data from the Great Lakes (e.g. Hickey et al., 2006). PCBs in English sole in reference areas of South Puget Sound and the main basin appear to be significantly increasing starting in about 1990. West and O'Neill hypothesized that the possible increasing trend and lack of a declining trend in Puget Sound could be due to internal recycling of the mass of PCBs in biota. Changes in external loading of PCBs could explain the observed trends in biota concentrations.

loading may be increasing due to changes in watershed sources with more than a 50% increase in population since 1980 (PSRC, 2007).

- **Sediment PCBs may be under-estimated.** The total mass of PCBs in the volume of the active sediment layer may be under-estimated by the median concentrations from the observed sediment data. The total mass estimated by sediment concentrations between the median and the 75%tile of the observed data are approximately at equilibrium with the current external loads (Figure 37b).
- **Sediment burial loss of PCBs may be under-estimated.** The loss of PCBs due to sediment burial may be under-estimated by the median burial velocity. The total mass of PCBs is approximately at equilibrium with the 75%tile of sediment burial velocity (Figure 37c).

The model sensitivity to various external loads of PCBs suggests that efforts to reduce external loading should be considered to manage concentrations in the water, sediment, and biota. Since a large fraction of the estimated external loading appears to come from nonpoint sources, and a large fraction is in the particulate form, then efforts to reduce the loading of solids from watershed sources could lead to significant reductions of PCBs in Puget Sound. Loading estimates from point sources are not available to compare with nonpoint sources.

Sensitivity to the initial sediment concentration of PCBs

The long-term future mass of PCBs in the water column and active sediment layer of Puget Sound is not sensitive to the current concentrations of PCBs in the sediment (Figure 37b). This finding is consistent with similar results by Davis (2004) in San Francisco Bay. The total mass of PCBs in Puget Sound in the future at steady state is predicted to converge on approximately the same value regardless of whether the current condition of sediment is relatively clean or contaminated.

This result is due to the effect of continuous burial of sediments over time. Variability in the initial sediment concentrations mainly influences the current condition of Puget Sound and is not a major factor for determining the total mass of PCBs that is accessible to the food web in the future. While burial is a major loss of PCBs from the aquatic food web, contaminated sediment sites require cleanup (e.g., Gries, 2005) because of the benefits to the nearshore environment. These benefits include reclaiming and restoring habitat function; reducing acute and chronic toxicity impacts to the benthic community from single contaminants such as PCBs or synergistic effects from a mixture of contaminants; decreasing contaminant exposure to biota in the nearshore environment and humans on a local, community level; and protecting and restoring local shellfish populations.

The predicted concentrations of PCBs in the water column (volume-weighted average of surface and deep water layers) and the active sediment layer of each basin for the year 2020 for different alternative scenarios of external loading reduction (relative to the median estimate by Hart Crowser et al., 2007) are presented in Figure 40 and Figure 41.

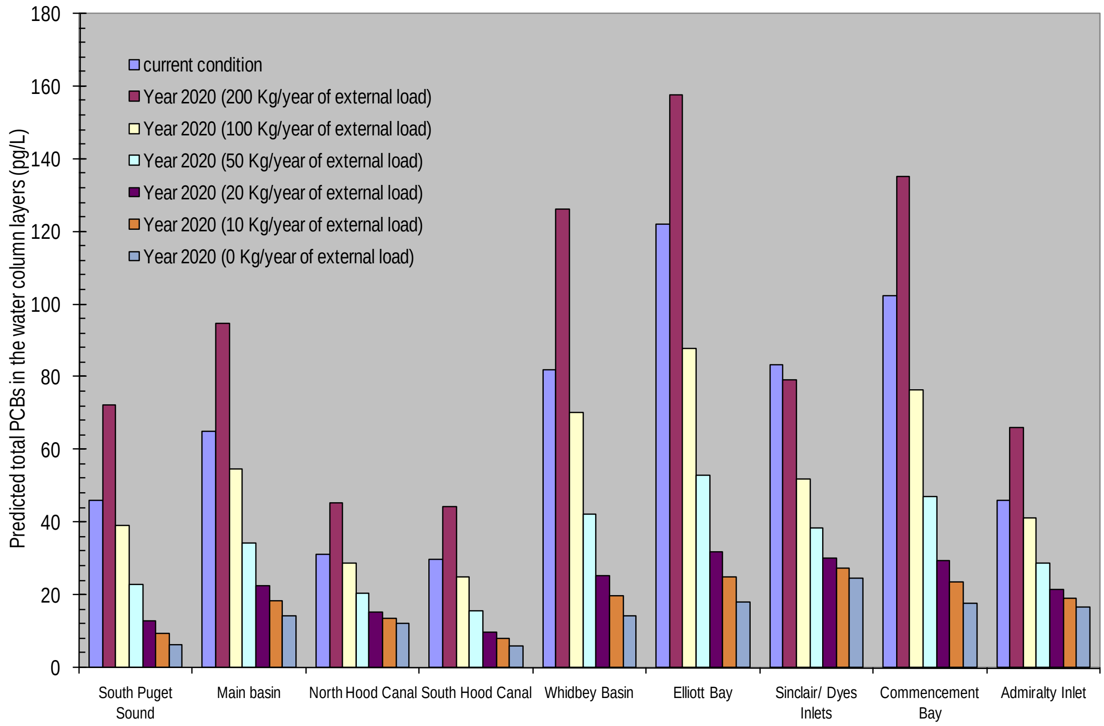

Figure 40. Predicted concentrations of PCBs in the volume-weighted average water column of Puget Sound for the year 2020 for alternative scenarios of reduction of external loading.

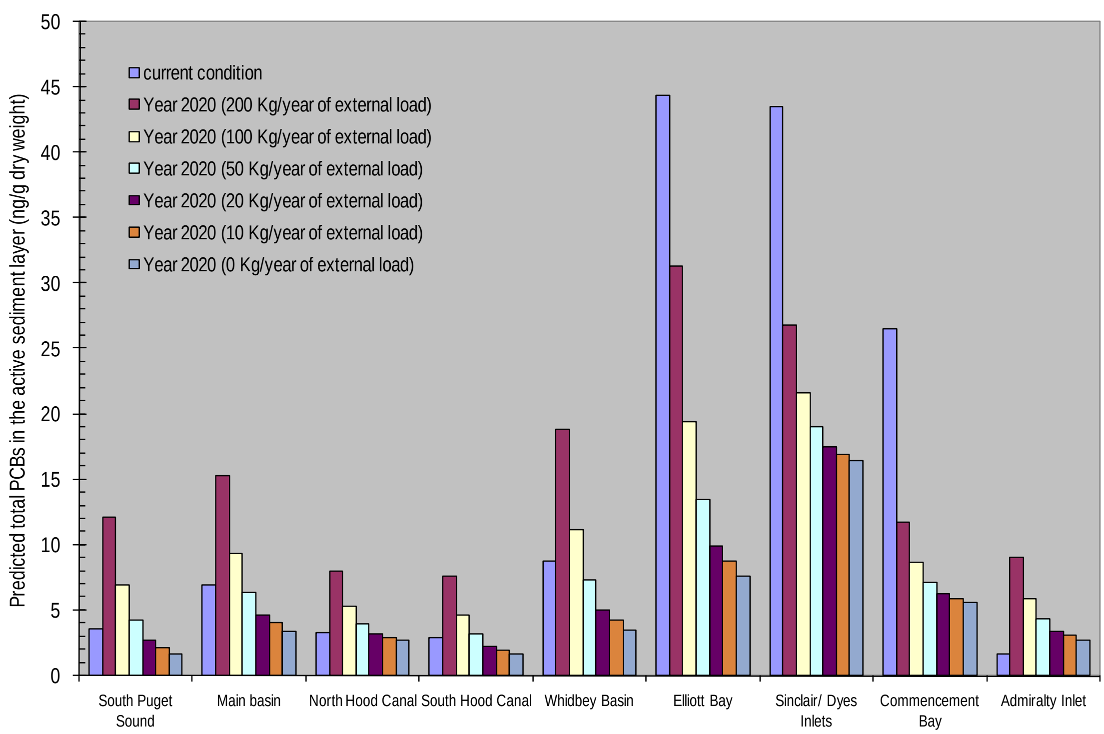

Figure 41. Predicted concentrations of PCBs in the active sediment layer of Puget Sound for the year 2020 for alternative scenarios of reduction of external loading.

Food web bioaccumulation of PCBs

Model inputs

For the application to Puget Sound during this project, all of the species and trophic linkages that were described by Condon (2007) for the Strait of Georgia were used. Also the following species were added to the aquatic food web based on the availability of concentration data in biota and other studies that have included these species (e.g., Windward, 2007; and Townes-Witzel and Ryan, 2007):

- Resident Pacific herring
- Resident blackmouth salmon
- Ratfish
- Shiner surfperch
- Staghorn sculpin
- Graceful crab
- Spot prawn

Appendix I presents the inputs used for various parameters of the food web bioaccumulation model. The diet fractions of various prey species and parameter values for the digestion efficiency of lipids and non-lipid organic matter were determined using a genetic algorithm (Charbonneau and Knapp, 1995; Charbonneau, 2002) for blackmouth salmon, shiner surfperch, staghorn sculpin, English sole, and graceful crab. Resident Pacific herring diet and digestion efficiencies were assumed to be the same as those reported by Windward (2007). Spot prawns were assumed to have the same diet and digestion efficiencies as those reported by Townes-Witzel and Ryan (2007). All of the other model input values for biological and chemical parameters were the same as those described by Condon (2007) with the exception of the following changes:

- Current conditions of sediment PCBs were estimated based on the median of observed data in each region as presented in earlier sections. Current and future water column concentrations of PCBs, and future sediment concentrations of PCBs, were based on those predicted by the box model of Puget Sound presented above (psbox.xls).
- Concentrations of dissolved organic carbon, particulate organic carbon, organic carbon content of the active sediment layer, and total suspended solids were the median values for each box model region as presented in Tables 7 through 10.
- Twenty congeners were simulated with input of Kow and Koa specific to each of the following: 8, 18, 28, 44, 52, 66, 77, 101, 105, 118, 126, 128, 138, 153, 170, 180, 187, 195, 206, and 209.
- Pacific herring prey for all predators were assumed to be resident.

Predicted PCBs in biota compared with observed data

Table 17 presents a comparison of predicted and observed concentrations of PCBs in various species at various locations. Model bias was estimated by the ratio of predicted to observed mean concentrations. For example, a value of 0.5 indicates that the model prediction is half of the observed mean value, and a value of 2 indicates that the model prediction is twice the observed mean value.

Predicted and observed PCB concentrations (whole body sum of congeners) for all species in the food web in all regions are presented in Figures 42 to 50. The predicted concentrations of each species in each region are based on the assumption that the entire diet is composed of prey from within the same region. This may lead to possible over-estimates or under-estimates of concentrations for mobile species if they obtain a significant portion of their diet from other regions which are more or less contaminated with PCBs. The predicted concentrations for each species should be considered as a hypothetical condition based on the assumption that all of the prey for a given species comes from a particular region.

The overall geometric mean of the model bias across all species at all locations was 1.4, which indicates that on average the model predictions were about 40% higher than the observed mean values. Predictions were within a factor of 2 of the observed data for all species across all locations, which is considered to be reasonable agreement and similar in model performance compared with results reported by Arnot and Gobas (2004), Condon (2007), and Windward (2007).

Model predictions were generally within a factor of 2 compared with observed mean values for each species in each region of Puget Sound, with the following exceptions:

- Pacific herring in Sinclair/Dyes Inlets was predicted, based on the concentration of PCBs in the active sediment and water column in Sinclair/Dyes Inlets, to be about two to three times higher than the observed mean value, but within a factor of 2 of predictions based on sediment and water column PCBs in the adjacent main basin. This result suggests that the Pacific herring that were sampled from Sinclair Inlet may forage outside of Sinclair Inlet in relatively cleaner areas of the main basin.

- English sole sampled in Port Gardner were predicted, based on the concentration of PCBs in the active sediment and water column in the Whidbey basin, to be about three to four times the concentration that was observed. The other four locations with English sole observations were predicted to be within a factor of 2 of the observed mean value. In general the model was within a factor of 2 for the areas with highest and lowest concentrations of PCBs observed in English sole.

- Mussels sampled from Waterman Point were predicted, based on the concentration of PCBs in the active sediment and water column in Sinclair/Dyes Inlets, to be about two to three times higher than observed values. Mussel predictions from the main basin were within a factor of 2 of the observed mean values at Waterman Point, which suggests that the main basin may be more representative of the PCBs in water and sediment that these mussels are exposed to. Waterman Point is at the entrance of Sinclair Inlet and may be more similar to the conditions in the adjacent main basin than the average conditions within Sinclair/Dyes Inlets.

- Mussels sampled from the Port Orchard marina were predicted, based on the concentration of PCBs in the active sediment and water column in Sinclair/Dyes Inlets, to be about three times higher than observed mean values. The concentration of PCBs in the active sediment and water column at the Port Orchard marina location also may be more similar to the main basin than the average conditions within Sinclair and Dyes Inlets.

Blackmouth salmon results were found to raise some questions about major prey species in their diet. Two alternative diets were evaluated for blackmouth salmon as follows:

- A diet consisting of krill, resident pelagic fish (herring-size and smaller), and non-resident Pacific herring with an assumed concentration similar to the immigrant herring in the Strait of Georgia (Condon, 2007). For this diet, the genetic algorithm found an optimum diet fraction of 15% krill, 9% resident pelagic fish, and 76% non-resident herring to provide a close match of the predicted and observed concentrations of PCBs in blackmouth salmon.
- A diet consisting of krill and resident pelagic fish (herring-size and smaller). For this diet, the genetic algorithm found an optimum diet fraction of 96% krill and 4% resident pelagic fish to provide a close match of the predicted and observed concentrations of PCBs in blackmouth salmon.

The results for resident blackmouth salmon suggest the following possibilities:

- If their prey consist of mostly small pelagic fish (herring size and smaller), then their prey may be mostly non-resident fish with significantly lower concentrations than the resident Pacific herring in Puget Sound. Observed concentrations of PCBs in resident Pacific herring are generally higher than the observed concentrations in resident blackmouth salmon at nearby regions. Other small pelagic fish were predicted to have concentrations similar to Pacific herring. If blackmouth salmon were feeding mainly on herring and other small pelagic fish, then the blackmouth salmon should be expected to bioaccumulate and exhibit higher concentrations of PCBs than these prey species, which was not the case.
- Alternatively, the prey for resident blackmouth salmon as they grow and mature may consist mostly of resident organisms at a lower trophic level such as krill. Krill are known to comprise a portion of the diet for salmon (e.g., the color or salmon flesh varies from almost white to deep red depending on the richness of their krill diet). Krill are not generally thought to be the major prey for mature Puget Sound blackmouth salmon, but krill may be a larger portion of the diet for smaller immature fish, and therefore a substantial source of the ultimate biomass of the mature fish.

Both of the estimated diets for resident blackmouth salmon were able to predict the observed concentrations of PCBs equally well. This finding suggests that more research is needed to examine the actual diet at various stages of the blackmouth salmon life cycle and the origin of pelagic fish prey if these are a significant portion of their diet.

Table 17. Comparison of observed and predicted concentrations of total PCBs in biota (sum of measured congeners).

Species	Sample location	Model region for comparison with observed data	Observed concentration (mean ± sd)			Predicted concentration	Units	Model bias (1)	Calibration location? (2)
Harbor seal pups	Gertrude Island	South Puget Sound	13400	±	8400	19100	ng/g lipid	1.4	
Pacific herring	Quartermaster Harbor	Main basin	125	±	30	194	ng/g wet wt	1.6	
	Squaxin (PSAMP)	South Puget Sound	181	±	82	121	"	0.7	
	Squaxin (O'Neill)	South Puget Sound	130	±	10	121	"	0.9	
	Port Orchard (PSAMP)	Sinclair/Dyes Inlets	209	±	63	363	"	1.7	
	Port Orchard (O'Neill)	Sinclair/Dyes Inlets	140	±	36	363	"	2.6	
	Port Orchard (O'Neill)	Main basin		"		194	"	1.4	
Blackmouth salmon	Apple Cove Pt	Main basin	113	±	45	123	"	1.1	Yes
Ratfish	Hood Canal	North Hood Canal	29	±	5	40.4	"	1.4	
	Nisqually	South Puget Sound	78	±	23	54.0	"	0.7	
	Sinclair Inlet	Sinclair/Dyes Inlets	230	±	236	249	"	1.1	Yes
English sole	Commencement Bay	Commencement Bay	163	±	89	111	"	0.7	
	Elliott Bay	Elliott Bay	121	±	97	133	"	1.1	
	Port Gardner	Whidbey basin	15	±	9	53.7	"	3.5	
	Hood Canal	North Hood Canal	11	±	8	20.1	"	1.8	
	Nisqually	South Puget Sound	19	±	7	27.1	"	1.4	Yes
Shiner surfperch	Hood Canal	North Hood Canal	8.4	±	3.5	24.4	"	2.9	
	Nisqually	South Puget Sound	25.0	±	5.0	33.2	"	1.3	
	Sinclair Inlet	Sinclair/Dyes Inlets	134.2	±	17.3	139	"	1.0	Yes
Staghorn sculpin	Sinclair Inlet	Sinclair/Dyes Inlets	45.9	±	25.2	39.5	"	0.9	Yes
Graceful crab	Hood Canal	North Hood Canal	3.2	±	0.8	5.9	"	1.9	
	Nisqually	South Puget Sound	5.1	±	1.1	7.9	"	1.5	
	Sinclair Inlet	Sinclair/Dyes Inlets	43.3	±	23.5	34.8	"	0.8	Yes
Mussels	Commencement Bay	Commencement Bay	12.0	±	4.1	22.9	"	1.9	
	Elliott Bay	Elliott Bay	28.4	±	3.7	26.5	"	0.9	
	Port Orchard marina	Sinclair/Dyes Inlets	7.3	±	0.7	23.3	"	3.2	
	Port Gardner	Whidbey basin	7.8	±	2.7	10.4	"	1.3	
	Hood Canal	North Hood Canal	3.5	±	0.5	4.15		1.2	

Species	Sample location	Model region for comparison with observed data	Observed concentration (mean ± sd)			Predicted concentration	Units	Model bias (1)	Calibration location? (2)
	Waterman Point	Sinclair Inlet	10.6	±	7.5	23.2	"	2.2	
	Waterman Point	Main basin		"		13.9	"	1.3	
Overall geometric mean model bias of all species and locations:								1.4	

(1) Model bias is the ratio of predicted to observed concentrations. For example, if the predicted concentration is 150 ng/g, and the observed concentration is 100 ng/g, then the model bias equals 1.5.

(2) "Yes" indicates that a genetic algorithm was used for this species at this location to determine the optimum parameter values for the dietary uptake efficiency of lipids and non-lipid organic material as well as the diet matrix for prey species, and other locations for this species used the same parameter and diet values as the calibration location. Diets and parameter values for harbor seal pups and mussels were from Condon, 2007, and for Pacific herring were from Townes-Witzel and Ryan, 2007.

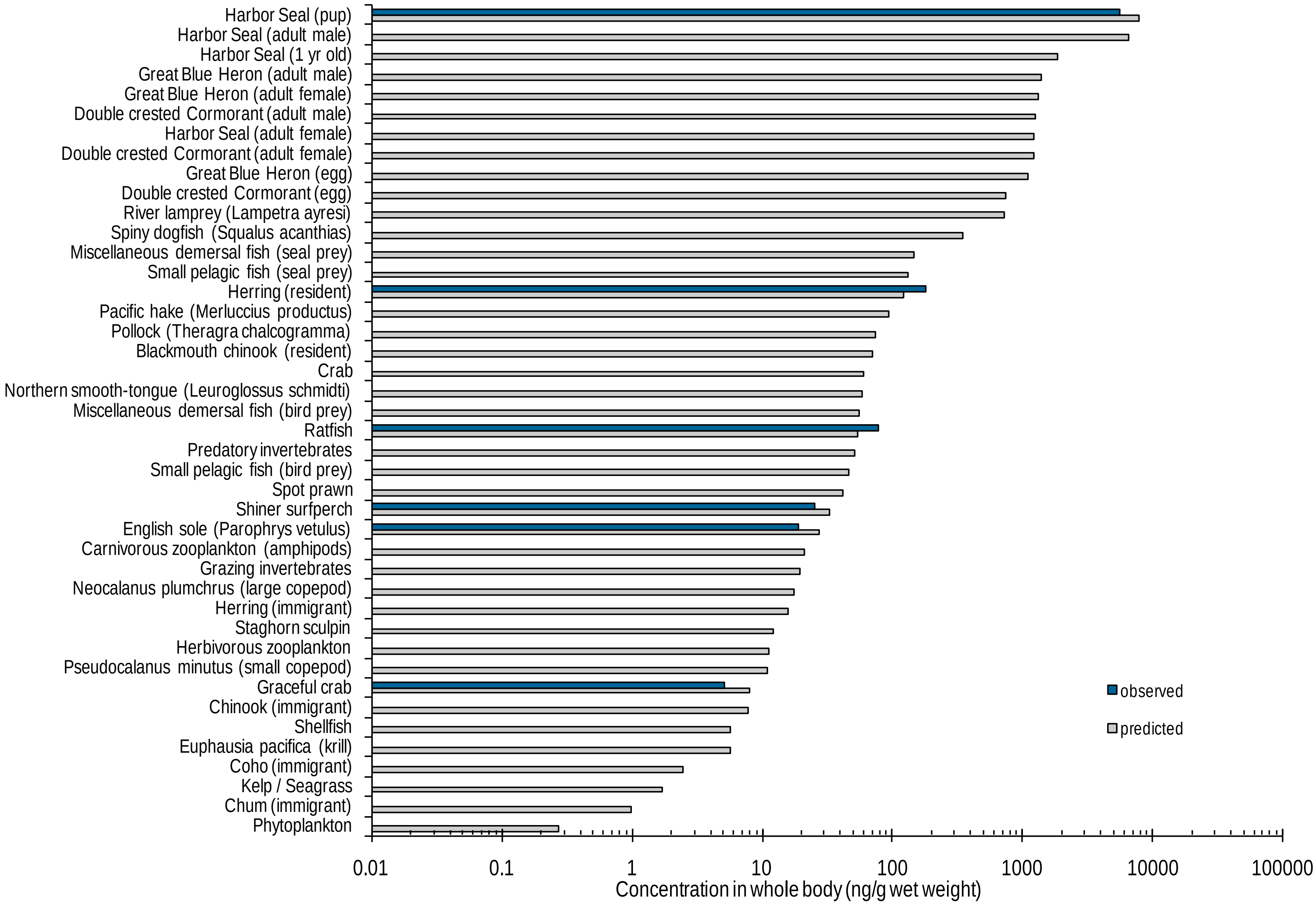

Figure 42. Predicted and observed PCBs in biota in South Puget Sound (whole body, sum of congeners).

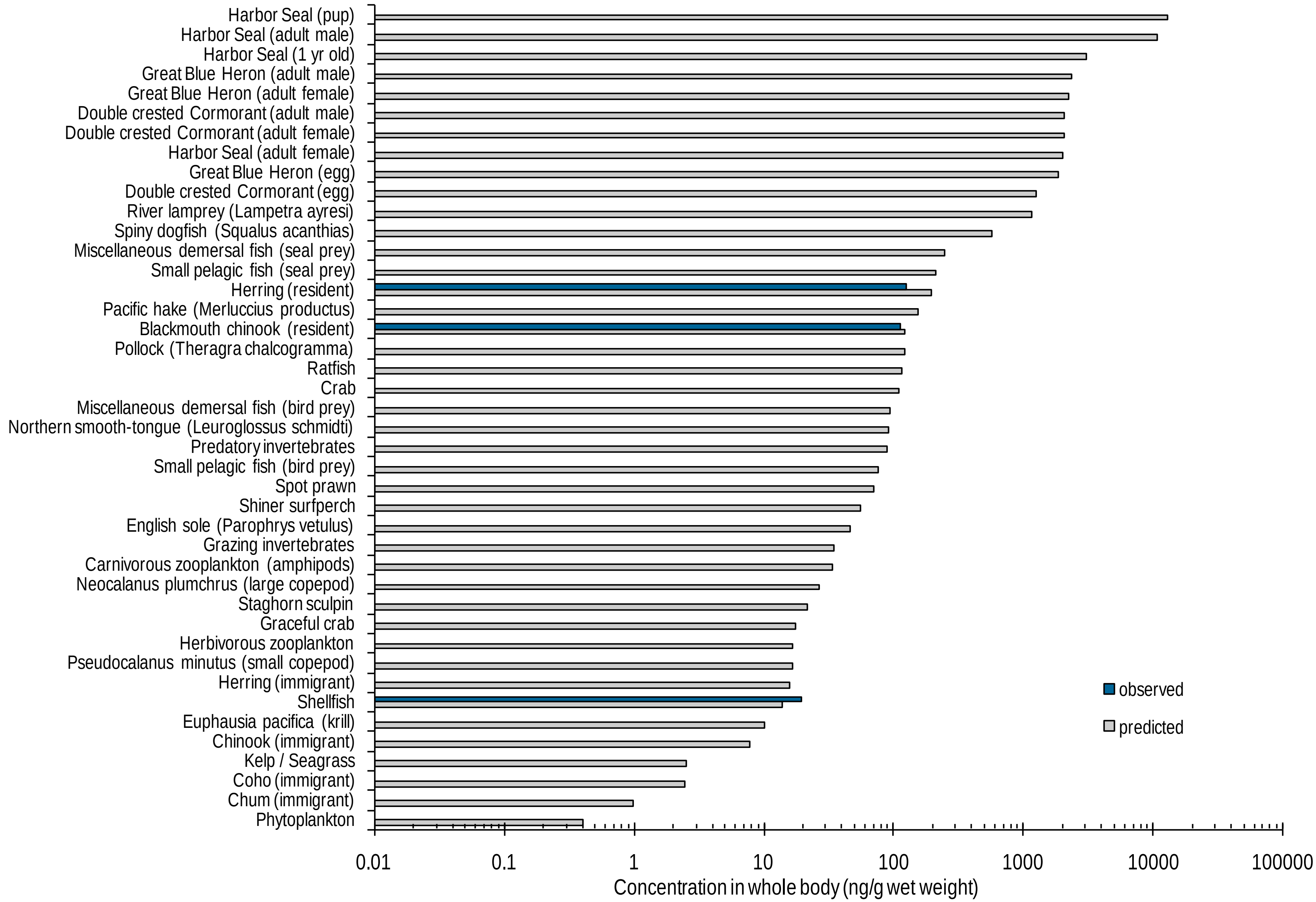

Figure 43. Predicted and observed PCBs in biota in the main basin of Puget Sound (whole body, sum of congeners).

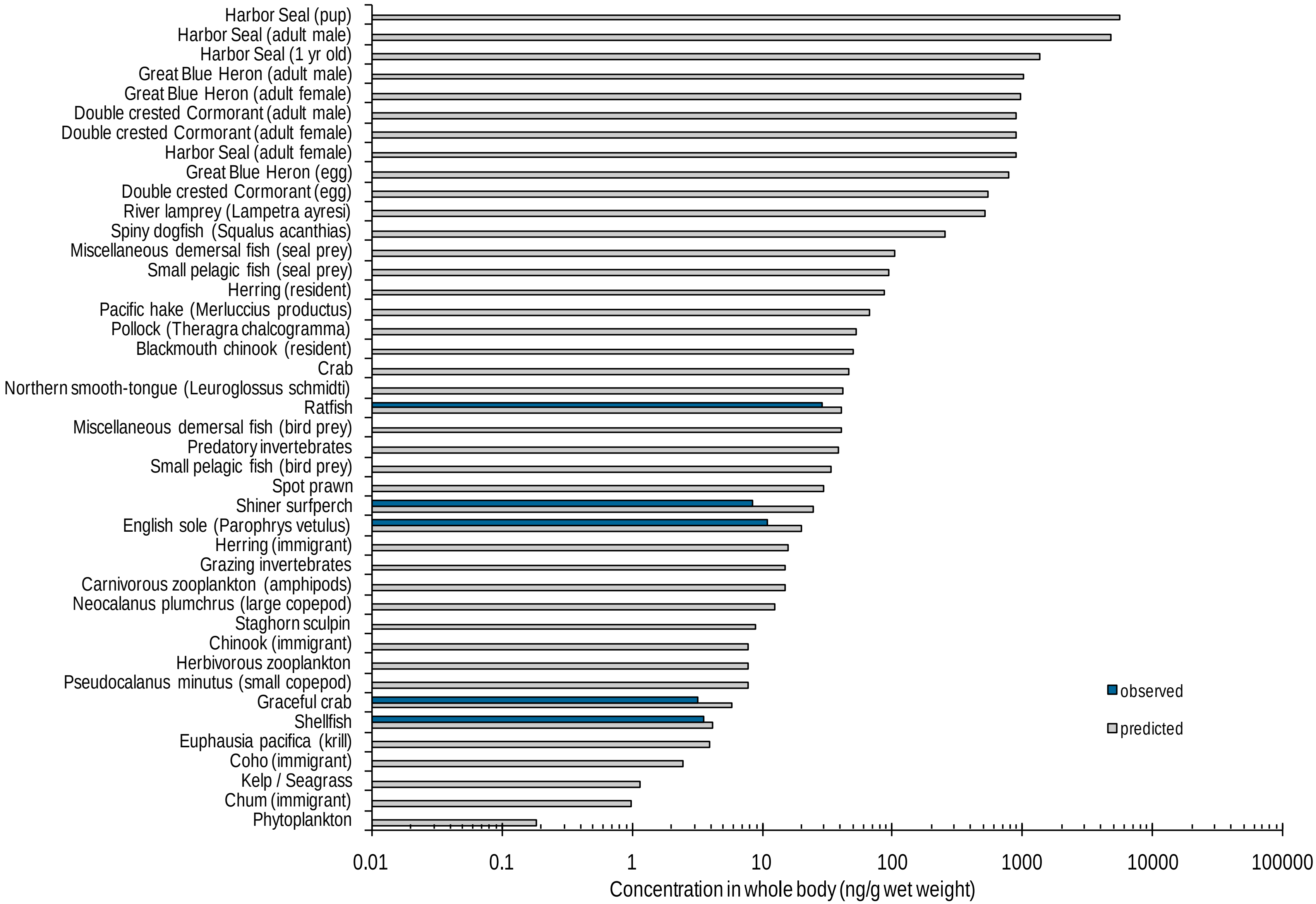

Figure 44. Predicted and observed PCBs in biota in North Hood Canal (whole body, sum of congeners).

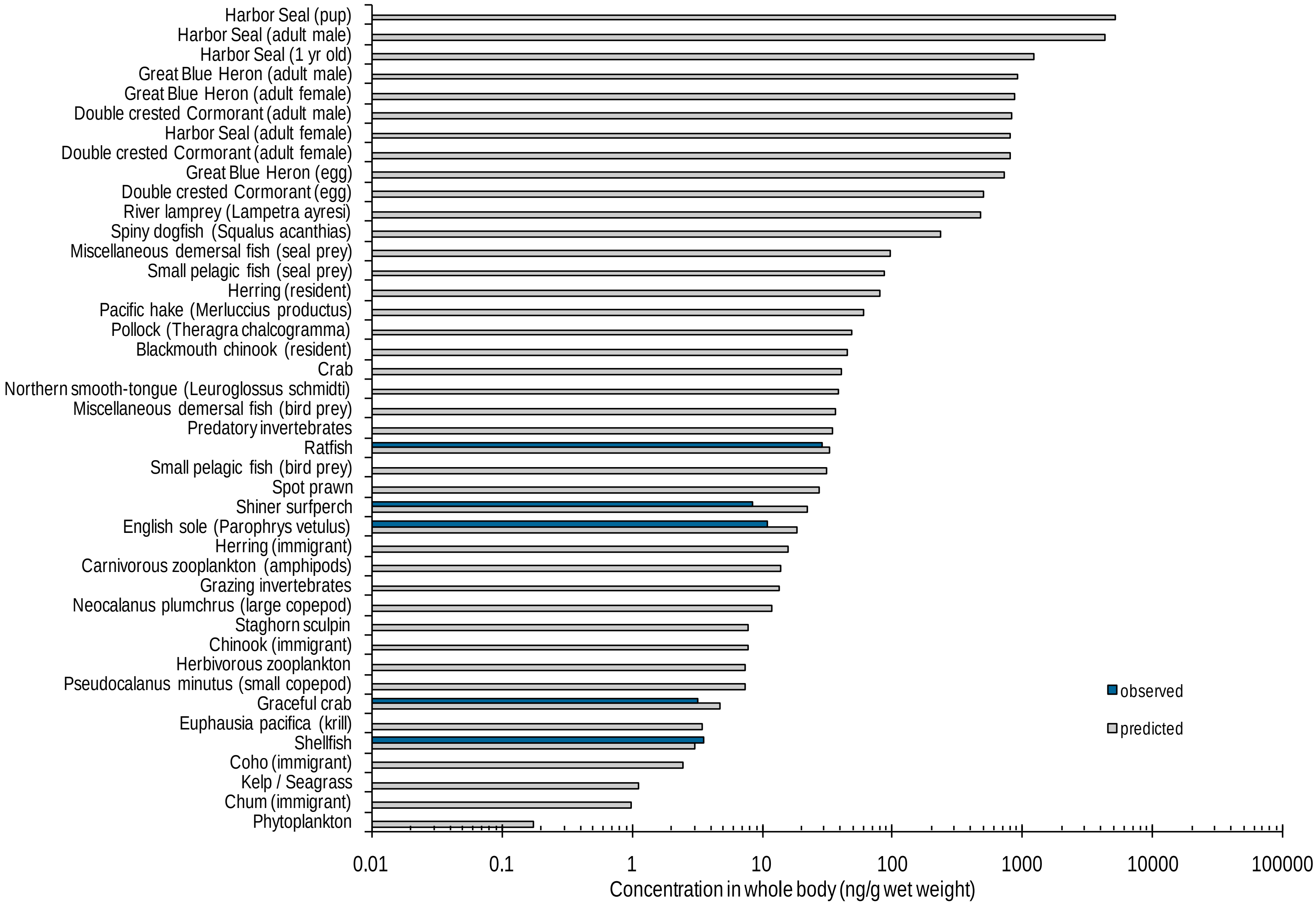

Figure 45. Predicted PCBs in biota in South Hood Canal (whole body, sum of congeners).

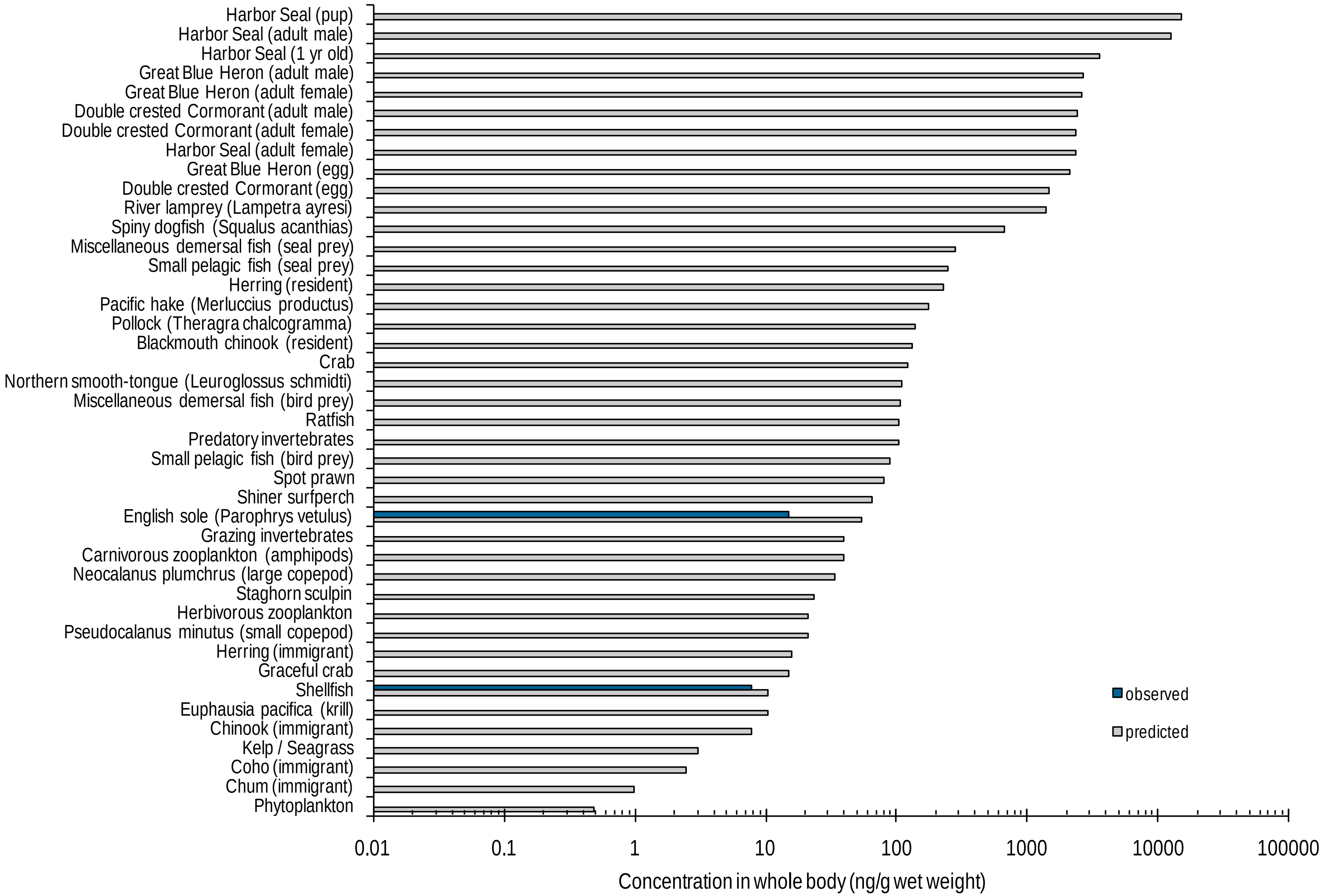

Figure 46. Predicted and observed PCBs in biota in the Whidbey basin (whole body, sum of congeners).

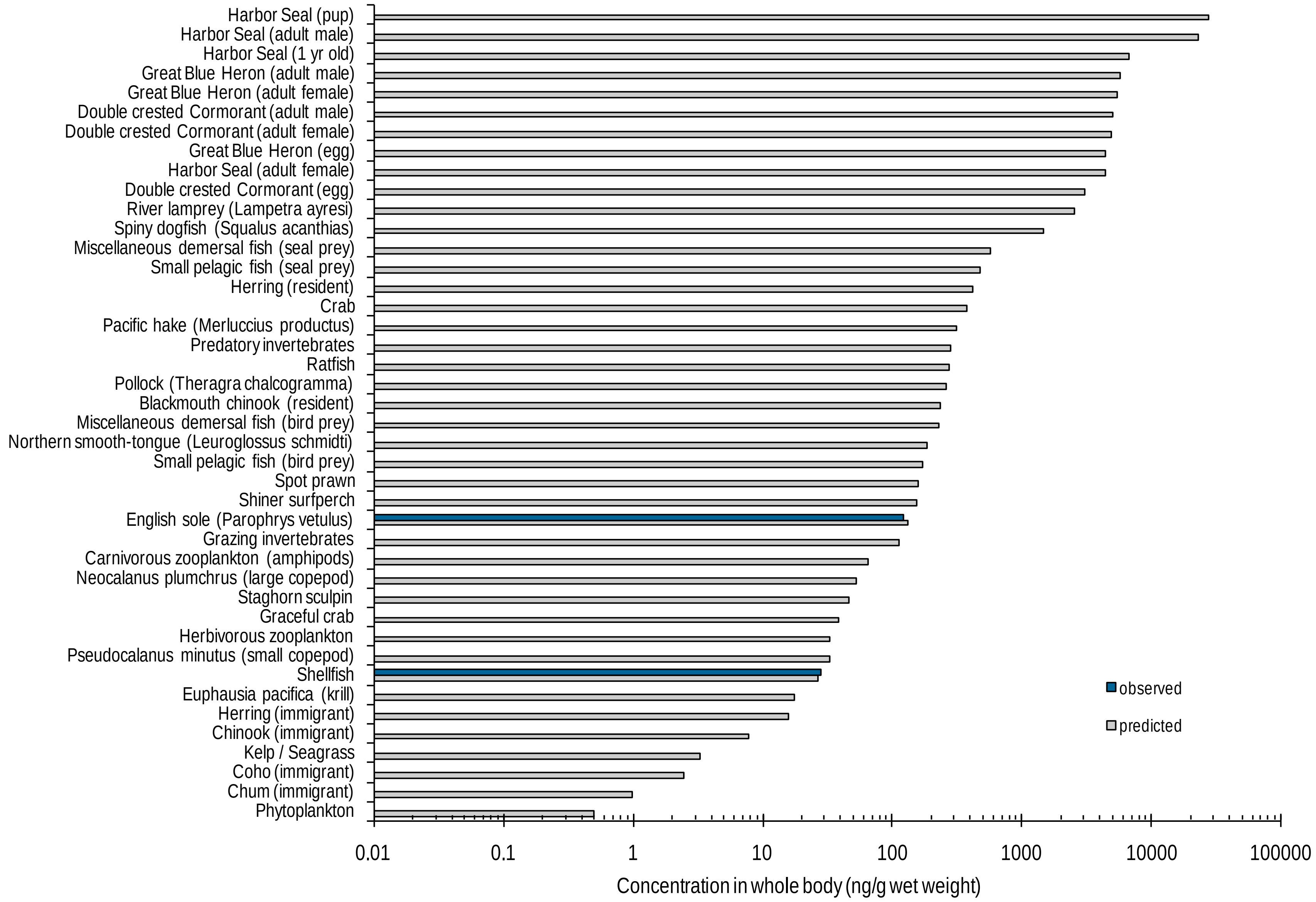

Figure 47. Predicted and observed PCBs in biota in Elliott Bay (whole body, sum of congeners).

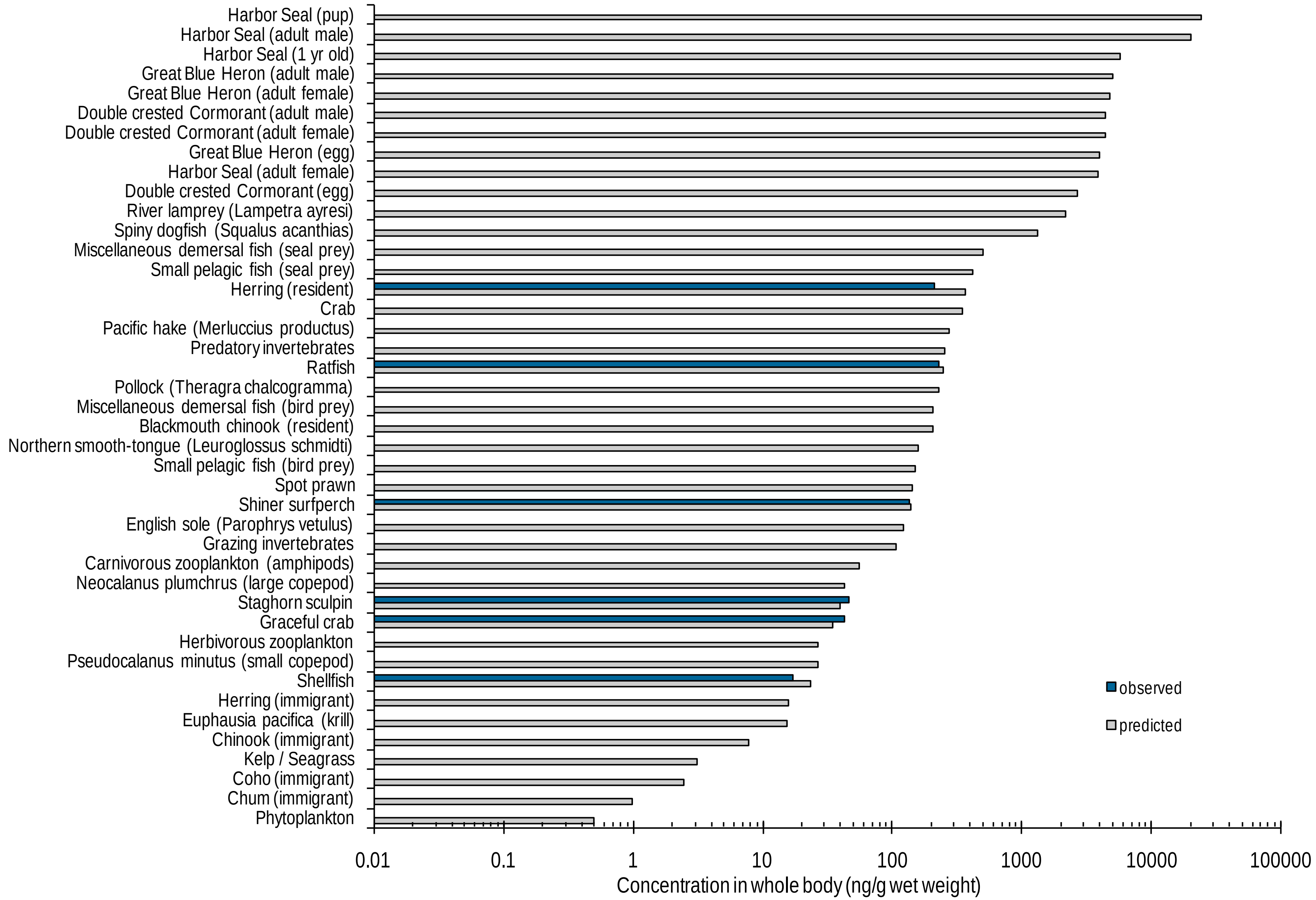

Figure 48. Predicted and observed PCBs in biota in Sinclair/Dyes Inlets (whole body, sum of congeners).

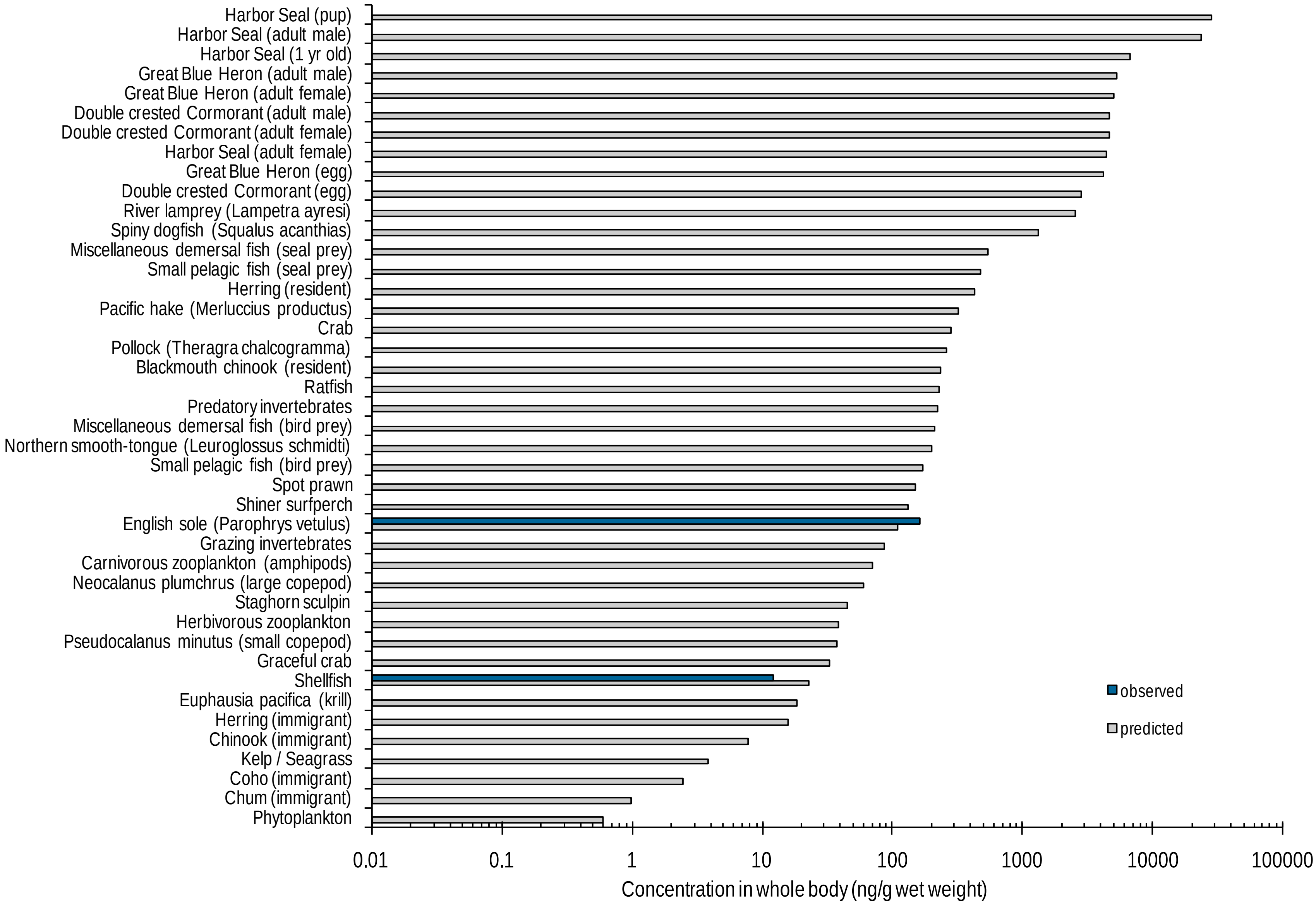

Figure 49. Predicted and observed PCBs in biota in Commencement Bay (whole body, sum of congeners).

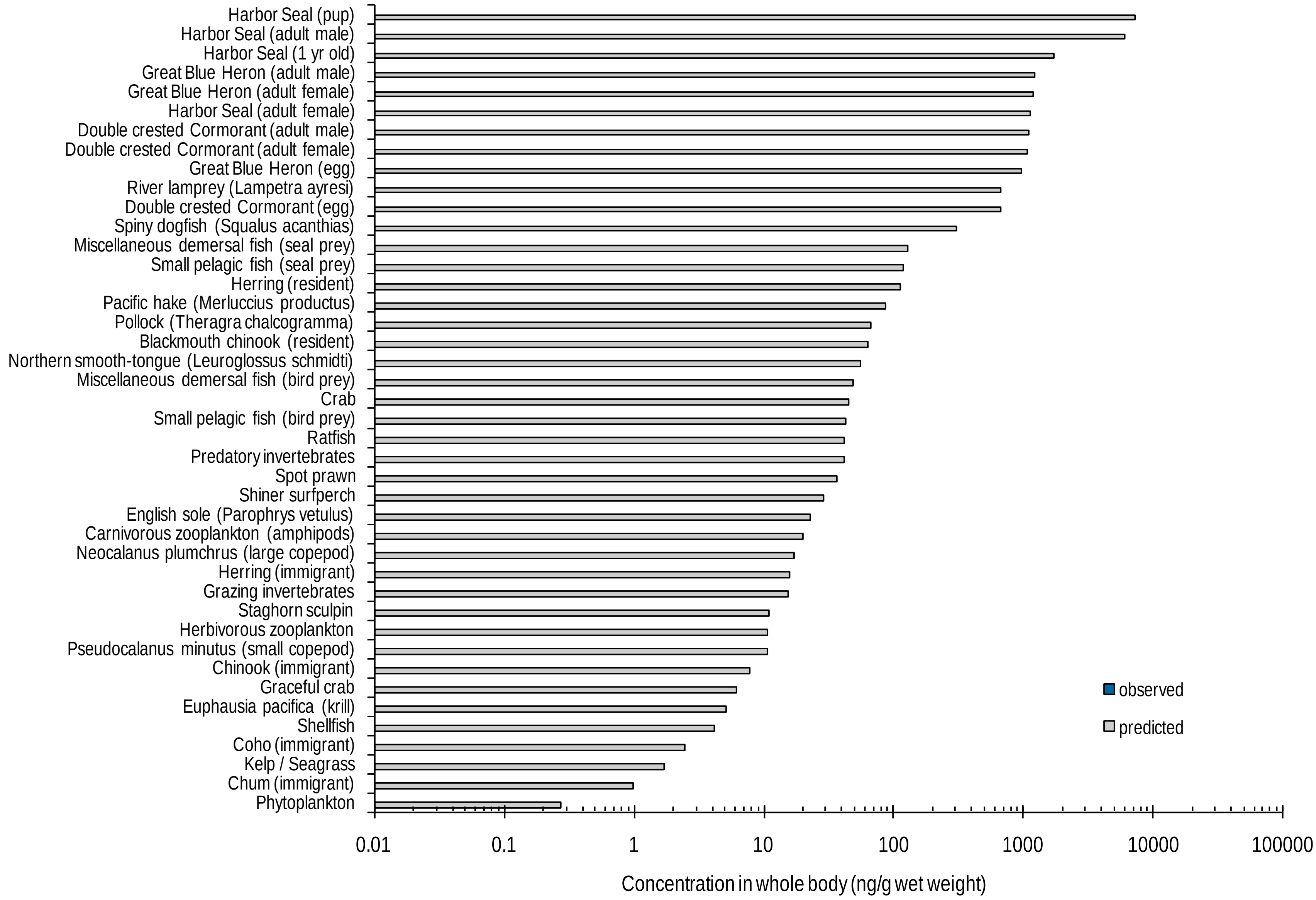

Figure 50. Predicted PCBs in biota in Admiralty Inlet (whole body, sum of congeners).

Predicted PCBs in biota for scenarios of external loading of PCBs

Table 18 and Figures 51 to 56 present predicted concentrations in selected biota comparing current conditions with alternative scenarios of external loading of PCBs. These comparisons are intended to provide information about the sensitivity of concentrations in biota to possible changes in external loading. Current conditions for this analysis are considered to be representative of sediment and biota concentrations that were measured in the 1990s. The future condition was predicted for the year 2020 using the predicted concentrations in sediment and water using the box model of fate and transport that was described previously. External loading scenarios included the plausible range of current external loading of PCBs of from 200 to 20 kg/year, in addition to further hypothetical reduced loading of 10 and 0 Kg/year.

In the larger basins of South Puget Sound, the main basin, and the Whidbey basin, the concentrations of PCBs in biota are predicted to increase significantly by the year 2020 if the external loading of PCBs is greater than 50 to 100 Kg/year. If external loads are about 50 to 100 Kg/year, then the concentrations in biota by the year 2020 are predicted to be approximately the same as the current condition. External loading of less than 50 Kg/year is predicted to result in decreasing concentrations in biota in these larger basins. The predicted trend of potential increases in concentrations of PCBs in English sole at the mid to upper end of the plausible range of loading is similar in magnitude to the observed increasing trend in South Puget Sound (Figures 26 and 54).

In the urban bays, Elliott Bay, Sinclair/Dyes Inlets, and Commencement Bay, concentrations in biota are predicted to decrease over time for all external loads in the range of 0 to 200 Kg/year. This finding suggests that historical external loading to the urban bays was probably much greater than current loading. Sediment concentrations in the urban bays appear to be decreasing due to the combined effect of burial with newly deposited material that is less concentrated than the original source material, and transport of sediment from the urban bays into the adjacent main basin. The magnitude of the decrease in concentrations in biota in the urban bays is predicted to be largest for the lowest values of external loading.

Concentrations of PCBs in biota in Hood Canal and Admiralty Inlet are predicted to be the lowest of all regions and change the least, although the same general pattern was predicted for increases at the highest levels of external loading and decreases with lower levels of external loading.

Table 18. Predicted concentrations of PCBs in water, sediment, and selected biota of Puget Sound for alternative scenarios of external loading from the watershed.

Species	South Puget Sound	Main basin	North Hood Canal	South Hood Canal	Whidbey Basin	Elliott Bay	Sinclair/ Dyes Inlets	Commence-ment Bay	Admiralty Inlet
Current concentrations of PCBs									
Water column average (pg/L)	45.9	64.8	31.1	29.8	82.1	122	83.3	102	45.8
Sediment (ng/g dry weight)	3.55	6.86	3.24	2.88	8.72	44.4	43.5	26.5	1.60
Harbor seal pup (ng/g lipid)	19000	31000	14000	13000	37000	68000	59000	68000	15000
Pacific herring (ng/g wet wt)	120	190	86	80	230	420	360	420	97
Blackmouth salmon (ng/g wet wt)	70	120	50	45	130	230	200	240	55
Ratfish (ng/g wet wt)	54	120	40	33	100	280	250	230	37
Shiner surfperch (ng/g wet wt)	33	55	24	22	66	150	140	130	25
English sole (ng/g wet wt)	27	46	20	18	54	130	120	110	20
Staghorn sculpin (ng/g wet wt)	12	22	8.8	7.9	23	46	39	45	9.5
Graceful crab (ng/g wet wt)	7.9	17	5.9	4.7	15	39	35	33	5.4
Shellfish (ng/g wet wt)	5.6	14	4.1	3.1	10	27	23	23	3.7
Predicted year 2020 concentrations of PCBs with external loading from watershed sources of 200 Kg/year									
Water column average (pg/L)	72.3	94.6	45.3	44.2	126	158	79.2	135	66.0
Sediment (ng/g dry weight)	12.1	15.2	7.92	7.56	18.8	31.3	26.8	11.7	9.04
Harbor seal pup (ng/g lipid)	36000	52000	23000	21000	61000	65000	46000	62000	31000
Pacific herring (ng/g wet wt)	220	320	140	130	380	410	290	390	200
Blackmouth salmon (ng/g wet wt)	130	210	83	74	220	230	160	220	110
Ratfish (ng/g wet wt)	130	220	77	63	190	230	170	170	98
Shiner surfperch (ng/g wet wt)	68	94	43	41	110	130	100	110	58
English sole (ng/g wet wt)	57	80	36	34	95	110	86	87	48
Staghorn sculpin (ng/g wet wt)	24	37	15	13	40	43	30	40	20
Graceful crab (ng/g wet wt)	18	33	11	8.9	27	33	24	25	14
Shellfish (ng/g wet wt)	14	27	8.1	5.8	19	22	16	17	10
Predicted year 2020 concentrations of PCBs with external loading from watershed sources of 100 Kg/year									
Water column average (pg/L)	39.2	54.4	28.6	25.0	70.1	87.7	51.9	76.4	41.2
Sediment (ng/g dry weight)	6.88	9.32	5.29	4.61	11.1	19.4	21.6	8.65	5.89
Harbor seal pup (ng/g lipid)	20000	30000	15000	12000	35000	38000	33000	38000	20000

Species	South Puget Sound	Main basin	North Hood Canal	South Hood Canal	Whidbey Basin	Elliott Bay	Sinclair/ Dyes Inlets	Commence-ment Bay	Admiralty Inlet
Pacific herring (ng/g wet wt)	120	180	91	77	220	240	200	240	120
Blackmouth salmon (ng/g wet wt)	73	120	53	43	120	130	110	130	72
Ratfish (ng/g wet wt)	70	130	51	37	110	140	130	110	63
Shiner surfperch (ng/g wet wt)	38	56	28	24	65	80	75	67	37
English sole (ng/g wet wt)	32	47	24	20	54	68	65	54	30
Staghorn sculpin (ng/g wet wt)	13	22	9.7	7.8	22	25	22	24	13
Graceful crab (ng/g wet wt)	10	20	7.4	5.3	16	20	18	16	9.2
Shellfish (ng/g wet wt)	7.6	16	5.3	3.4	11	13	12	11	6.5
Predicted year 2020 concentrations of PCBs with external loading from watershed sources of 50 Kg/year									
Water column average (pg/L)	22.7	34.4	20.3	15.5	42.1	52.8	38.3	47.0	28.8
Sediment (ng/g dry weight)	4.25	6.36	3.97	3.13	7.29	13.5	19.0	7.12	4.31
Harbor seal pup (ng/g lipid)	12000	20000	11000	7800	21000	24000	27000	25000	14000
Pacific herring (ng/g wet wt)	72	120	65	49	130	150	160	160	87
Blackmouth salmon (ng/g wet wt)	43	80	38	27	76	85	91	90	51
Ratfish (ng/g wet wt)	42	88	37	24	69	91	110	76	45
Shiner surfperch (ng/g wet wt)	22	37	20	15	41	52	62	46	26
English sole (ng/g wet wt)	19	31	17	13	34	45	54	38	22
Staghorn sculpin (ng/g wet wt)	7.8	14	7.0	5.0	14	16	18	16	9.1
Graceful crab (ng/g wet wt)	6.2	13	5.4	3.4	10	13	15	11	6.6
Shellfish (ng/g wet wt)	4.6	11	3.9	2.2	6.9	8.8	10	7.7	4.7
Predicted year 2020 concentrations of PCBs with external loading from watershed sources of 20 Kg/year									
Water column average (pg/L)	12.8	22.3	15.3	9.75	25.4	31.9	30.1	29.4	21.4
Sediment (ng/g dry weight)	2.68	4.59	3.19	2.24	4.98	9.91	17.5	6.20	3.37
Harbor seal pup (ng/g lipid)	6800	13000	8100	5100	13000	16000	23000	18000	11000
Pacific herring (ng/g wet wt)	42	80	50	32	83	100	140	110	66
Blackmouth salmon (ng/g wet wt)	25	55	30	18	48	56	78	63	38
Ratfish (ng/g wet wt)	26	62	29	16	44	64	98	57	34
Shiner surfperch (ng/g wet wt)	13	25	16	10	26	36	54	34	20
English sole (ng/g wet wt)	11	21	13	8.7	22	31	47	28	16
Staghorn sculpin (ng/g wet wt)	4.6	9.8	5.4	3.3	8.8	11	15	12	6.9
Graceful crab (ng/g wet wt)	3.7	9.4	4.2	2.3	6.4	9.0	14	8.3	5.0

Species	South Puget Sound	Main basin	North Hood Canal	South Hood Canal	Whidbey Basin	Elliott Bay	Sinclair/ Dyes Inlets	Commence-ment Bay	Admiralty Inlet
Shellfish (ng/g wet wt)	2.8	7.8	3.1	1.5	4.5	6.1	9.1	5.8	3.6
Predicted year 2020 concentrations of PCBs with external loading from watershed sources of 10 Kg/year									
Water column average (pg/L)	9.44	18.3	13.6	7.84	19.8	24.9	27.4	23.5	18.9
Sediment (ng/g dry weight)	2.15	4.00	2.92	1.95	4.21	8.73	16.9	5.89	3.05
Harbor seal pup (ng/g lipid)	5200	11000	7300	4200	11000	14000	21000	16000	9400
Pacific herring (ng/g wet wt)	32	67	45	26	67	84	130	96	59
Blackmouth salmon (ng/g wet wt)	19	46	27	15	38	47	73	54	34
Ratfish (ng/g wet wt)	20	53	26	14	36	55	94	51	31
Shiner surfperch (ng/g wet wt)	10	21	14	8.6	21	30	51	30	18
English sole (ng/g wet wt)	8.7	18	12	7.3	18	26	45	25	15
Staghorn sculpin (ng/g wet wt)	3.5	8.3	4.9	2.7	7.0	9.2	14	10	6.2
Graceful crab (ng/g wet wt)	2.9	8.0	3.8	1.9	5.3	7.7	13	7.4	4.5
Shellfish (ng/g wet wt)	2.2	6.7	2.8	1.3	3.7	5.3	8.8	5.2	3.2
Predicted year 2020 concentrations of PCBs with external loading from watershed sources of 0 Kg/year									
Water column average (pg/L)	6.14	14.3	11.9	5.93	14.2	17.9	24.7	17.7	16.4
Sediment (ng/g dry weight)	1.63	3.41	2.66	1.65	3.44	7.54	16.4	5.58	2.74
Harbor seal pup (ng/g lipid)	3600	9100	6500	3300	8100	11000	20000	13000	8200
Pacific herring (ng/g wet wt)	22	54	40	21	50	67	120	80	51
Blackmouth salmon (ng/g wet wt)	13	37	24	11	29	37	68	45	30
Ratfish (ng/g wet wt)	14	44	24	11	28	45	90	45	27
Shiner surfperch (ng/g wet wt)	7.2	17	13	6.9	16	25	49	26	16
English sole (ng/g wet wt)	6.2	15	11	5.9	14	22	43	22	13
Staghorn sculpin (ng/g wet wt)	2.5	6.8	4.3	2.1	5.3	7.4	13	8.7	5.4
Graceful crab (ng/g wet wt)	2.1	6.7	3.4	1.6	4.1	6.4	12	6.5	4.0
Shellfish (ng/g wet wt)	1.6	5.6	2.5	1.0	2.9	4.4	8.4	4.5	2.8

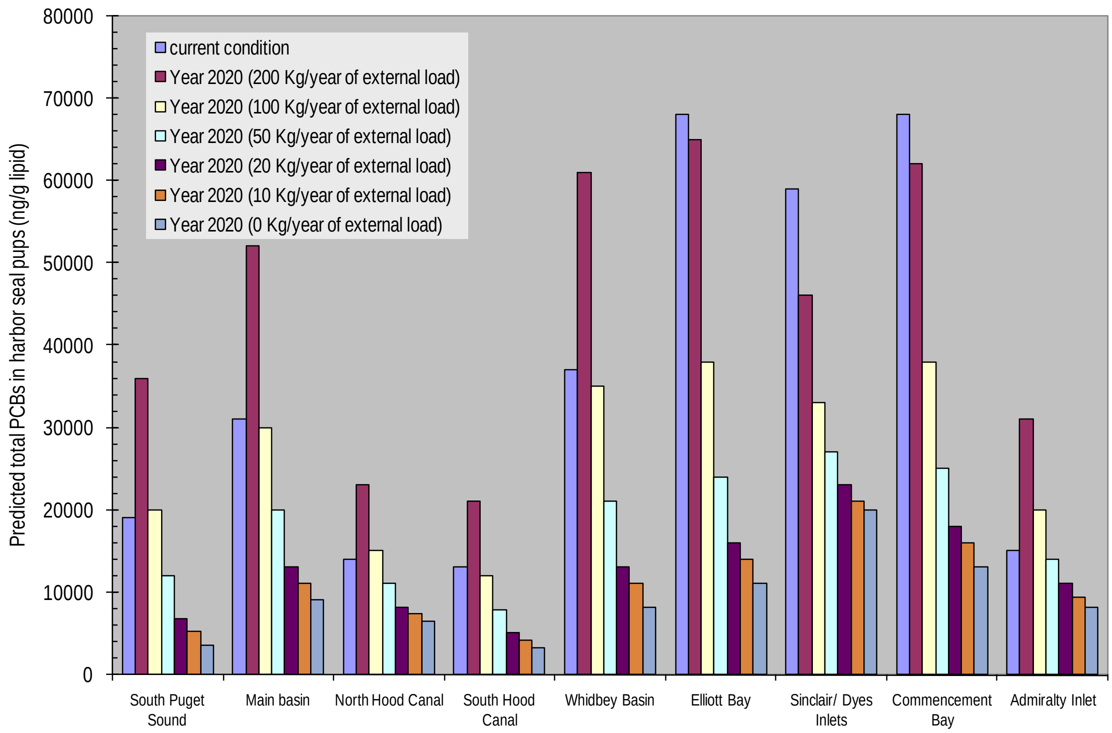

Figure 51. Predicted concentrations of PCBs in lipids of harbor seal pups for various alternative scenarios of external loading.

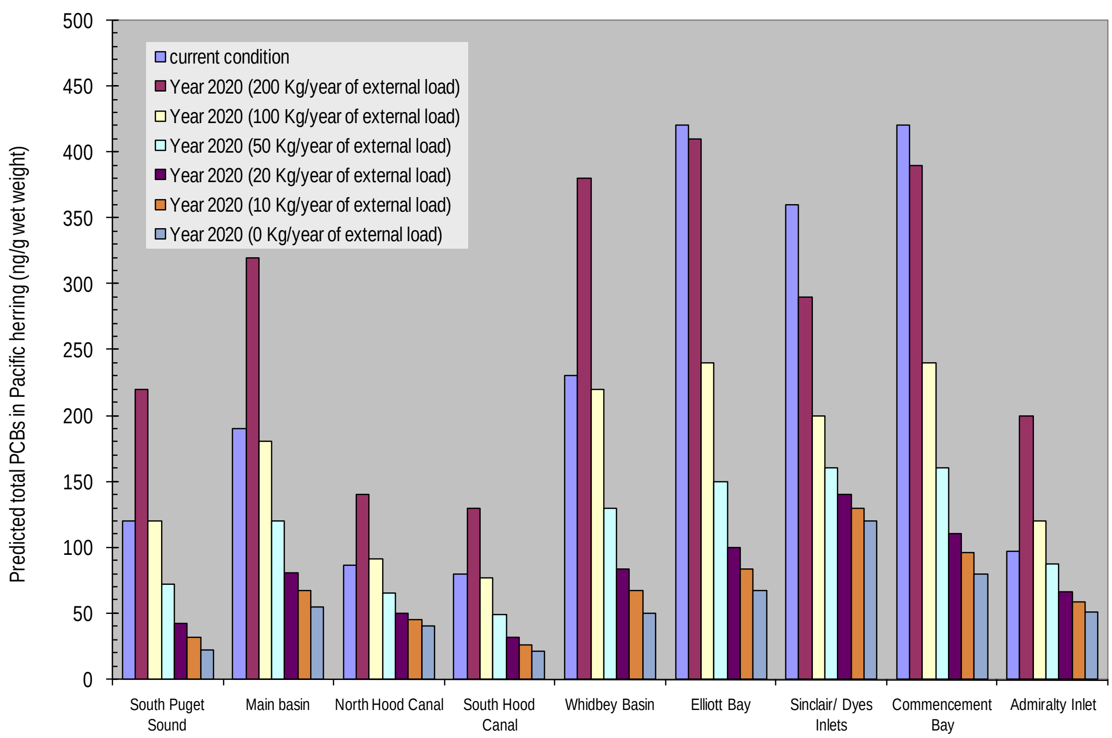

Figure 52. Predicted concentrations of PCBs in whole bodies of Pacific herring for various alternative scenarios of external loading.

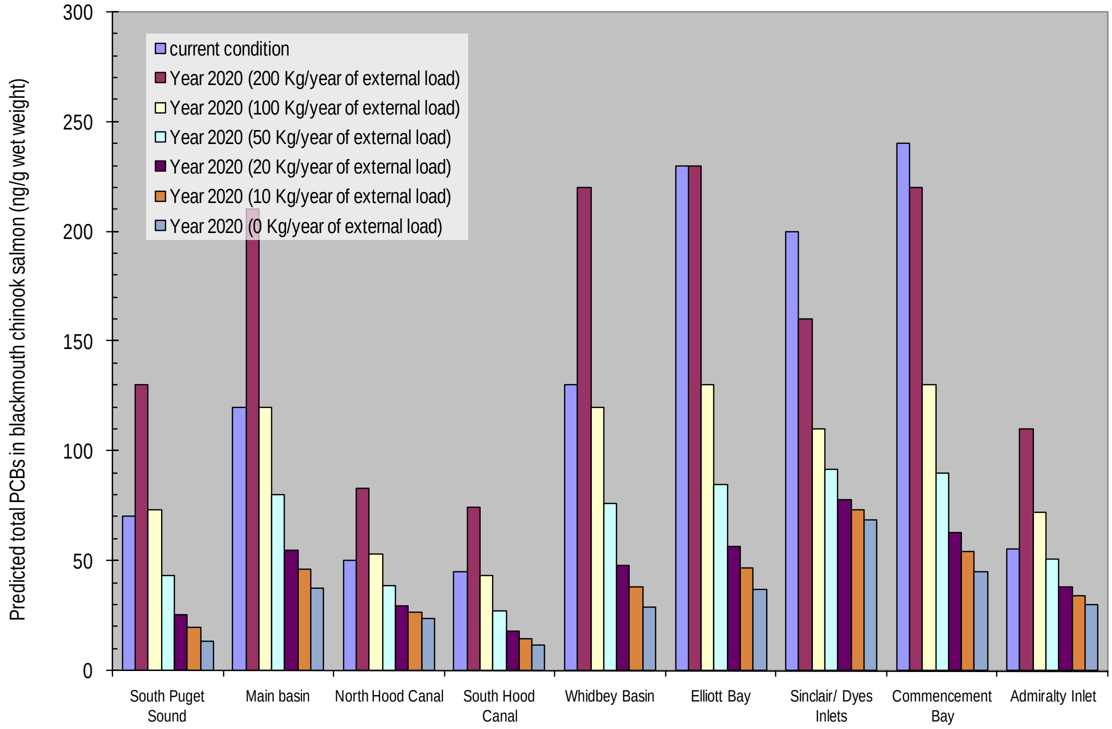

Figure 53. Predicted concentrations of PCBs in whole bodies of blackmouth salmon for various alternative scenarios of external loading.

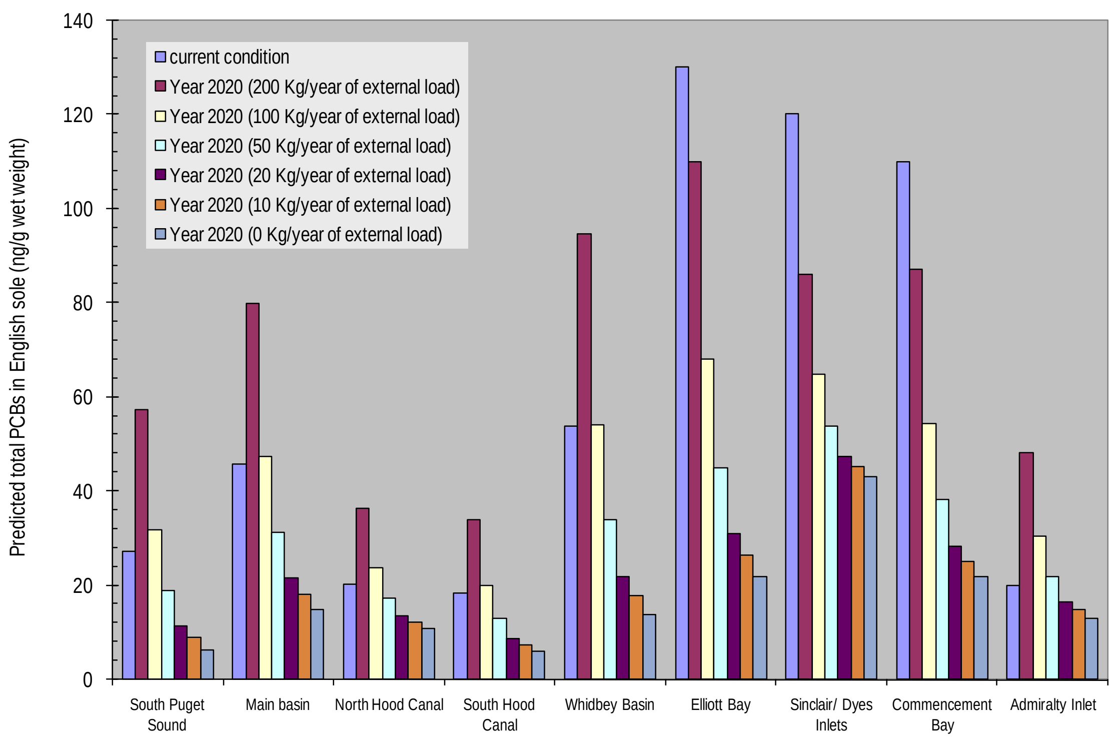

Figure 54. Predicted concentrations of PCBs in whole bodies of English sole for various alternative scenarios of external loading.

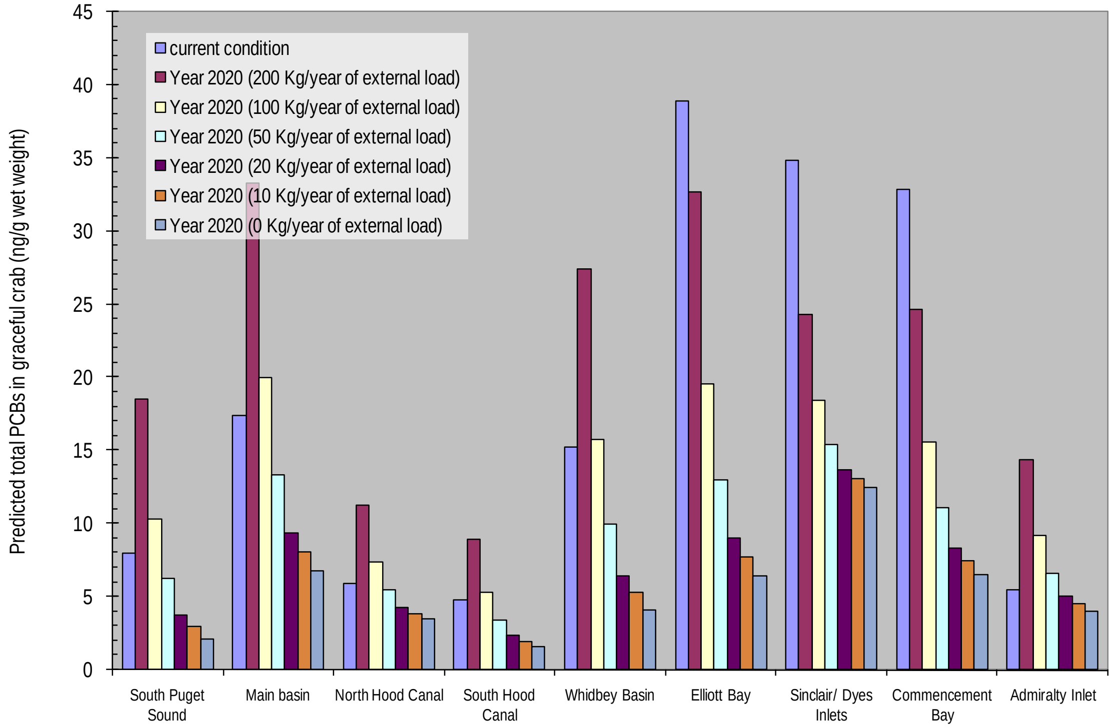

Figure 55. Predicted concentrations of PCBs in whole bodies of graceful crab for various alternative scenarios of external loading.

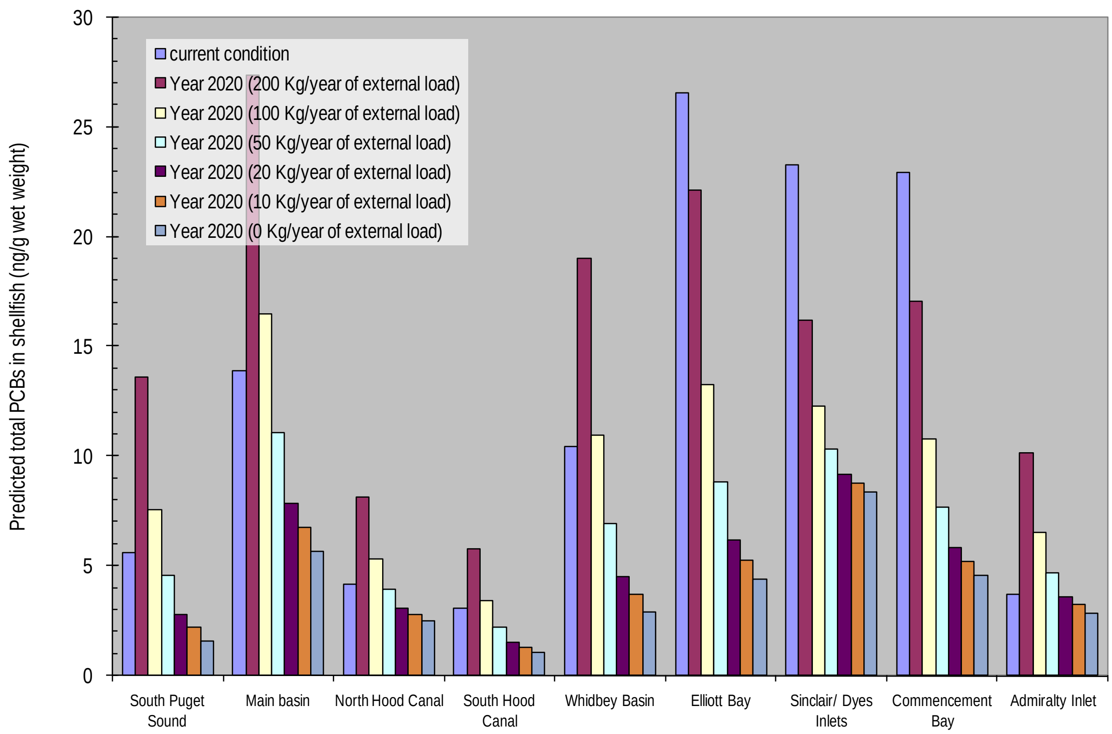

Figure 56. Predicted concentrations of PCBs in whole bodies of shellfish (excluding the shell) for various alternative scenarios of external loading.

Conclusions

The following conclusions may be drawn from this study:

- External loads of PCBs in runoff from watershed areas are the main driver of concentrations in water, sediment, and biota in Puget Sound. Reductions in external loading were predicted to be effective for reducing future concentrations of PCBs in the water column, sediment, and biota. Reduced loading of solids from nonpoint sources could lead to significant reduction of PCB loading.

- External loading sources from the watershed account for most of the PCBs entering Puget Sound. These sources are subject to a wide range of uncertainty (median estimate of about 116 Kg/year, with an interquartile range of 27 to 512 Kg/year in one study; and median estimate of about 285 Kg/year, with an interquartile range of 72 to 1100 Kg/year in another study). The box model suggests that the plausible range of external loading of PCBs is about 20 to 200 Kg/year to explain the current mass of PCBs stored in the sediments. Uncertainty in the external loading sources from the watershed contributes to a wide range of uncertainty of predicted future concentrations in sediment and biota. A smaller load of PCBs enters from the marine boundary and direct atmospheric deposition.

- External loading of PCBs in runoff from commercial/industrial and residential land covers accounts for about half of the total load of PCBs in one study and more than three-fourths in another study. Concentrations of PCBs in runoff from forest areas are considerably lower than concentrations from other land covers, but the area of forest land cover is large enough to result in a potentially major source of loading of PCBs.

- Current concentrations of PCBs in sediments were found to have little influence on future conditions in the years 2020 to 2050. The total mass of PCBs in the water column and the active sediment (top 10 cm) is predicted to reach approximately the same future value regardless of whether the current condition of sediment is relatively clean or more contaminated. This result is due mainly to the effect of continual burial of sediment and replacement with newly deposited material that is derived from external sources.

  While burial is a major loss of PCBs from the aquatic food web, contaminated sediment sites require cleanup because of the benefits to the nearshore environment. These benefits include reclaiming and restoring habitat function; reducing acute and chronic toxicity impacts to the benthic community from single contaminants such as PCBs or synergistic effects from a mixture of contaminants; decreasing contaminant exposure to biota in the nearshore environment and humans on a local, community level; and protecting and restoring local shellfish populations.

- Burial of deep sediment accounts for the largest loss of PCBs, with loss also due to outflow through the marine boundary, degradation, and volatilization. The model assumes that burial is effective at isolating contaminants from humans and biota throughout Puget Sound. While burial may be successful in deep water, it would not apply to contaminated sediment sites in the high energy nearshore environment. The nearshore environment has hydrologic, geologic, and biological processes that can disturb contaminated sediments deeper than 10 cm, making them bioavailable to the abundant biological community in this environment.

- Approximately 97% of the total mass of PCBs currently in the aquatic ecosystem of Puget Sound is predicted to be contained in the active sediment layer, about <1% is stored in the water column, and about <3% is stored in the biota.

- Increases in sediment and biota concentrations of PCBs are possible by the year 2020 in the larger basins (South Puget Sound, main basin, Whidbey basin, Hood Canal, and Admiralty Inlet). Increases in water column concentrations are also possible in most basins unless external loads are reduced. Future concentrations are predicted to reach a steady state with current external loads in about the year 2050.

- Decreases in sediment and biota concentrations of PCBs are possible by the year 2020 in the urban bays (Sinclair and Dyes Inlets, Elliott Bay, and Commencement Bay). Sediment concentrations in the urban bays appear to be decreasing due to the combined effect of burial with newly deposited material that is less concentrated than the original source material, and transport of sediment from the urban bays into the adjacent main basin. Concentrations would decrease more depending on weather external loads are reduced.

- The total mass of PCBs stored in the active sediment layer and water column during the 1990s was estimated to be about 1440 Kg. It could increase over time and reach approximately 1920 Kg by the year 2020 and reach a steady state of approximately 2030 Kg of PCBs by the year 2050. For comparison, a preliminary estimate suggested by other researchers for the total mass of PCBs in all of the biota of Puget Sound could be less than 40 Kg. These estimates should be considered preliminary and approximate, especially considering the large uncertainties in sediment concentrations and external loading.

- Uncertainty in the current (1990s) total mass of PCBs in the water column and active sediment layer of Puget Sound is mainly influenced by the observed variability in current sediment concentrations. The interquartile range of the current mass of PCBs in Puget Sound based on variability of current sediment concentrations is approximately 570 to 3510 Kg of PCBs with a median estimate of 1440 Kg.

- Uncertainty in the predicted future total mass of PCBs in the water column and active sediment layer of Puget Sound is mainly influenced by uncertainty in external loading. The interquartile range of the predicted future mass of PCBs at steady state in the year 2020 is approximately 970 to 6190 Kg PCBs with a median estimate of 1920 Kg using estimates of external loading reported by Hart Crowser et al. (2007).

- Although the uncertainty in external loading is large, the limited available water column data suggest a fairly close match between predicted and observed conditions, which suggests that the median estimates for external loading are plausible. The scarcity of data to describe concentrations of PCBs in the water column for confirmation of the model predictions is a relatively large data gap.

- Most of the mass of PCBs stored in the active sediment and water column appears to be contained in the large basins (Whidbey basin, main basin, and South Puget Sound). Over time, the large basins are predicted to account for an increasing fraction of the total mass of PCBs as their sediment concentrations increase. The predicted increase in total mass of PCBs in the non-urban basins appears to be derived mainly from external loading sources.

- The food web bioaccumulation model was found to represent measured concentrations in biota with reasonable accuracy. The overall geometric mean of the model bias across all species at all locations was 1.4, which indicates that on average the model predictions were about 40% higher than the observed mean values. This is generally similar in performance compared with studies in other waterbodies.

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Recommendations

This study suggests the following recommendations:

- **External loads.** Reduction of external loading is suggested to prevent a possible increase, or cause a decrease in PCB concentrations in Puget Sound. Methods for reducing external loading of PCBs should be identified and implemented. For example, best management practices to reduce nonpoint loading from developed areas (e.g., commercial/industrial and residential areas) could reduce many pollutants, including PCBs that are associated with suspended solids in runoff.

  Improvements in our understanding and quantification of external loads will lead to significant improvement in the uncertainty of the model. Data collection to improve characterization of loading in runoff from forest and residential land could reduce uncertainty of the external loading the most, although loading from commercial/industrial and agricultural land covers also contribute to uncertainty in loading from the watersheds of each region. Studies of sediment cores would also be useful to examine historical trends in sediment concentration of PCBs and other toxic contaminants of concern.

- **Marine boundary.** Existing data from the marine boundary were very limited. Therefore, we recommend that more data be collected to improve the accuracy of the model for predicting the distribution of contaminants throughout Puget Sound. Modeling results indicate that the loading of toxics from the marine boundary of Puget Sound has a large influence on concentrations throughout Puget Sound. Loading from the marine boundary is comparable in magnitude to loading from each of the major land covers in the watersheds.

  The marine boundary for this study was defined as the Straits of Georgia and Juan de Fuca. Canadian investigators are separately conducting analyses of toxics fate and transport and food web bioaccumulation in the Strait of Georgia.

  Samples should be collected from the surface and deep layers of the water column. In addition to dissolved and particulate PCBs, other toxic contaminants of concern should also be measured.

- **Water column toxics.** The concentrations of PCBs and other toxics in the water column within various regions of Puget Sound are not well known due to very limited data. While the total mass of PCBs in the water column represents only about <1% of the total contained in the active sediment, water, and biota, it is comparable in magnitude with the mass contained in all of the biota of Puget Sound. Concentrations in the biota are sensitive to the concentration in the water column due to direct uptake from the water and respiration.

  The scarcity of water column data using methods that are capable of detecting the low concentrations that exist is also a major data gap for confirmation of the model to improve confidence that the external loading estimates are accurate and the kinetic processes are correctly simulated. We recommend additional measurements of toxics at various locations within Puget Sound to provide the data necessary to calibrate and confirm the model.

Samples should be collected from the surface and deep layers of the water column. In addition to dissolved and particulate PCBs, other toxic contaminants of concern should be measured (dissolved and particulate forms for contaminants that partition with solids), as well as total suspended solids, dissolved organic carbon, particulate organic carbon, temperature, salinity, dissolved oxygen, and pH. Paired data sets of water column and sediment concentrations in contaminated sediment areas are another data gap.

- **Biota concentrations.** Data gaps exist concerning the concentrations of toxics in various species of biota of the Puget Sound regions, including several trophic layers within the food web. We recommend collection of toxics concentration data in biota to fill in those gaps. Measurements of toxics in whole body samples are preferable if practical, or lipid measurements where it is not practical (e.g., harbor seal pups). These additional data will allow improvement of the model of food web bioaccumulation across all regions of Puget Sound and throughout the entire food web. Tissue burden data from bottom dwellers and benthic feeders, as well as their prey species, from contaminated sediment sites, as well as paired measurement of sediment concentrations, will also help to fill the data gap of different exposure scenarios and trophic transfer from sediment to top predators.

- **Modeling of other toxic contaminants.** The modeling framework developed during this study should be used to evaluate the fate, transport, and bioaccumulation of other toxic constituents that have been identified to be of concern in Puget Sound.

- **Other endpoints.** The modeling framework for this project focused on the endpoint of concentrations in sediment, water, and the tissue in biota of the aquatic food web. The model does not address adverse effects to the exposed wildlife. Modeling of other endpoints in nearshore biota, such as reduced fecundity and reduced age to sexual maturity, or other endpoints specific to endocrine disruptors, is also needed.

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Appendices

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Appendix A. User's guide for the Puget Sound box model (psbox.xls)

The most recent and advanced box model for Puget Sound was developed by Babson et al. (2006), and it is referred to as the "BKM box model" after the initials of the original authors names. The BKM box model is a prognostic, time-dependent model of circulation in Puget Sound which is capable of predicting seasonal and interannual variations in residence times and interbasin transports.

The original BKM box model was upgraded by Amanda Babson as part of the current Ecology project. The upgraded box model, which we will refer to as the "Ecology box model" or "psbox.xls", separates additional boxes for Sinclair/Dyes Inlets, Elliott Bay, and Commencement Bay. The Ecology box model also includes an integrated fate and transport model of PCBs as well as linkage with the EPA WASP model. The Ecology box model is written in Microsoft Excel's Visual Basic for Applications (VBA) programming language based on a translation from the original MATLAB code. The VBA version was found to produce identical results and is more than 20 times faster compared with the original MATLAB version.

The Ecology box model divides Puget Sound into 10 regions (Figure 1), plus the Strait of Juan de Fuca/Strait of Georgia (SJF/SOG) which represents the model boundary region. Each region is further divided vertically to represent the two water-column layers defined at different depths for different regions.

The Ecology box model was integrated with a simple mass balance model of fate and transport of HOCs and applied for prediction of PCBs. Davis (2004) developed the simple mass balance model of PCBs that was incorporated into the Ecology box model. The Davis PCB model is also applicable to other HOCs. With the incorporation of the Davis (2004) model, Ecology's box model is capable of simulating seasonal and interannual variations in each region in response to changes in external loading for concentrations of HOCs in the two water-column layers and an active sediment layer.

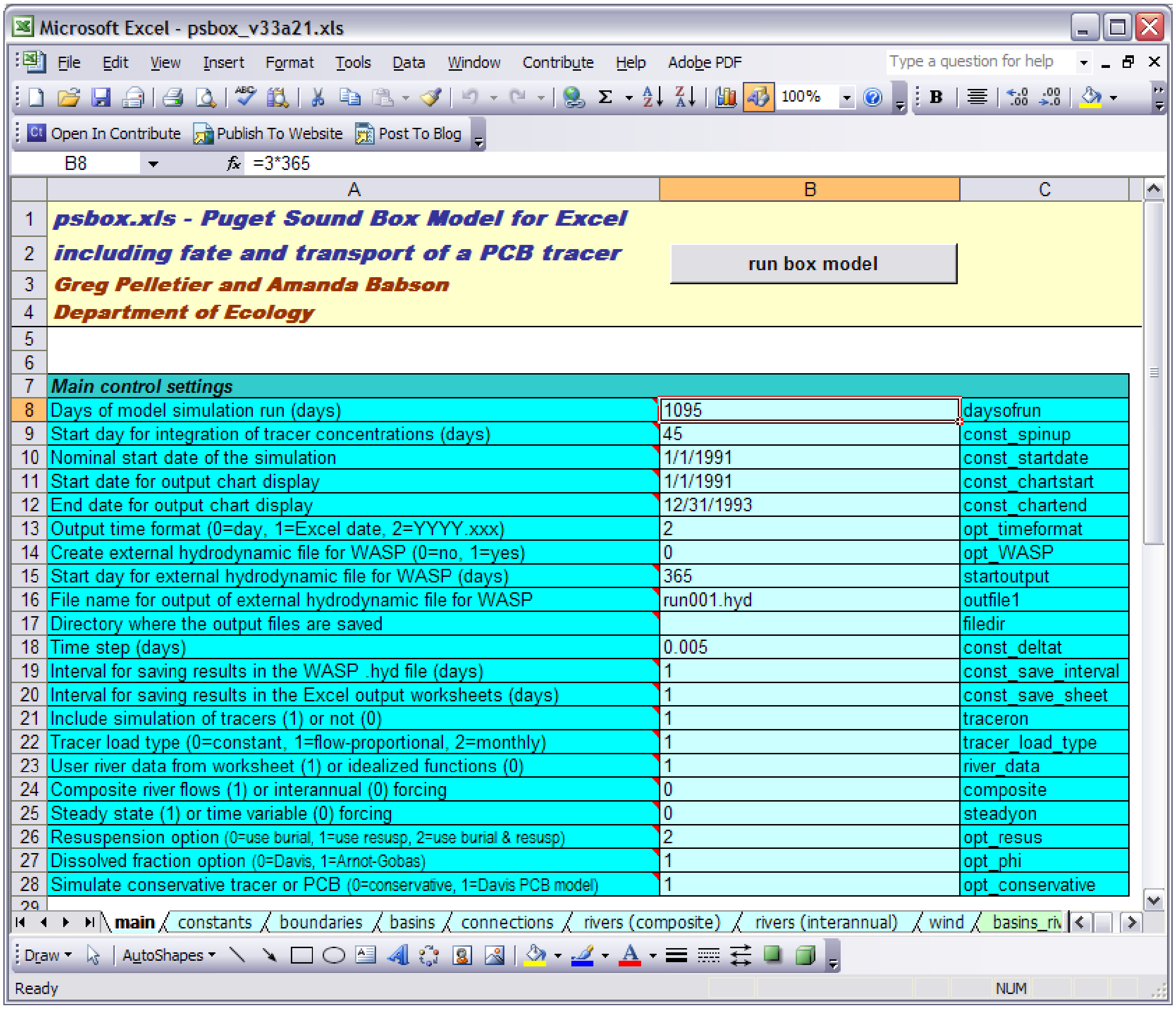
The computer code used to implement the calculations for the Puget Sound box model is written in VBA. Excel worksheets serve as the user interface for entering input data and viewing output results.

For the macros to run properly, the macro security settings in Excel should be set to low or medium. To check the macro security settings, use the Excel menu Tools>Macro>Security and select low or medium security. This version was written in Excel 2003 (Excel version 11.0) and may not be compatible with some earlier versions of Excel.

Color is used to signify whether information is to be input by the user or output by the program:

- **Pale Blue** designates variable and parameter values that are to be entered by the user.
- **Pale Green** designates output values generated by psbox.xls.
- **Dark solid colors** are used for labels and should not be changed.

Each worksheet has a button that is labeled "run box model" as shown in Figure A1. Clicking on this button from any worksheet will run the model. When the model runs, it reads the input values that are entered in the blue cells from the input sheets and stores the model results in the green cells in the output sheets. Input worksheets are color-coded with light blue tabs, output worksheets are color-coded with green tabs, and charts are color-coded with dark blue tabs.



	A	B	C
1	***psbox.xls - Puget Sound Box Model for Excel***		
2	***including fate and transport of a PCB tracer***	run box model	
3	***Greg Pelletier and Amanda Babson***		
4	***Department of Ecology***		
5			
6			
7	***Main control settings***		
8	Days of model simulation run (days)	1095	daysofrun
9	Start day for integration of tracer concentrations (days)	45	const_spinup
10	Nominal start date of the simulation	1/1/1991	const_startdate
11	Start date for output chart display	1/1/1991	const_chartstart
12	End date for output chart display	12/31/1993	const_chartend
13	Output time format (0=day, 1=Excel date, 2=YYYY.xxx)	2	opt_timeformat
14	Create external hydrodynamic file for WASP (0=no, 1=yes)	0	opt_WASP
15	Start day for external hydrodynamic file for WASP (days)	365	startoutput
16	File name for output of external hydrodynamic file for WASP	run001.hyd	outfile1
17	Directory where the output files are saved		filedir
18	Time step (days)	0.005	const_deltat
19	Interval for saving results in the WASP .hyd file (days)	1	const_save_interval
20	Interval for saving results in the Excel output worksheets (days)	1	const_save_sheet
21	Include simulation of tracers (1) or not (0)	1	traceron
22	Tracer load type (0=constant, 1=flow-proportional, 2=monthly)	1	tracer_load_type
23	User river data from worksheet (1) or idealized functions (0)	1	river_data
24	Composite river flows (1) or interannual (0) forcing	0	composite
25	Steady state (1) or time variable (0) forcing	0	steadyon
26	Resuspension option (0=use burial, 1=use resusp, 2=use burial & resusp)	2	opt_resus
27	Dissolved fraction option (0=Davis, 1=Arnot-Gobas)	1	opt_phi
28	Simulate conservative tracer or PCB (0=conservative, 1=Davis PCB model)	1	opt_conservative

Figure A1. The 'main' input worksheet in psbox.xls

The following worksheets are inputs and outputs:

- Input worksheets:
    - Main – general model control.
    - Constants – constants and parameters that apply to all basins.
    - Boundaries – properties of the open boundaries.
    - Basins – properties of each basin.
    - Connections – properties of each connection between basins.

- Rivers (composite) - Input of river flows (used only if using river data from worksheet and composite river flows are selected on 'main' sheet). Days 1-365 are repeated for all years of the simulation.
- Rivers (interannual) - Input of river flows (used only if using river data from worksheet and interannual river flows are selected on 'main' sheet).
- Wind – wind speed for each basin.

- Output worksheets and charts:
  - Basins_rivers – river flows for each basin.
  - Boundaries_out – boundary conditions.
  - Transport (1) – horizontal volume transports through each basin connection in the surface layer.
  - Transport (2) – horizontal volume transports through each basin connection in the deep layer.
  - Transport_vert – vertical advective volume transports between the deep and surface layers in each basin.
  - Basins_Kv – effective eddy diffusivity in each basin.
  - Basins_mixing – bulk vertical diffusive mixing transport between deep and surface layers in each basin.
  - Basins_resusp_velocity – resuspension velocity of the bulk sediment (shown if opt_resus =0 on the 'main' sheet).
  - Basins_burial_velocity – burial velocity of the bulk sediment (shown if opt_resus=1 on the 'main' sheet).
  - Basins_salt (1) – salinity in the surface layer of each basin.
  - Basins_salt (2) –salinity in the deep layer of each basin.
  - Basins_tracers (1) – tracer concentration (e.g. PCB) in the surface layer of each basin.
  - Basins_tracers (2) – tracer concentration (e.g. PCB) in the deep layer of each basin.
  - Basins_tracers (3) – tracer concentration (e.g. PCB) in the sediment layer of each basin.
- Charts of model results:
  - Chart_basins_rivers – chart of river flows in each basin.
  - Chart_transport (1) – chart of volume transports between surface layers through each basin connection.
  - Chart_transport (2) – chart of volume transports between deep layers through each basin connection.
  - Chart_transport_vert – chart of vertical volume transports between deep and surface layers in each basin.
  - Chart_basins_Kv – chart of vertical eddy diffusivity in each basin
  - Chart_basins_mixing – chart of diffusive volume transport between deep and surface layers in each basin.
  - Chart_basins_resusp_vel – chart of resuspension velocity of the bulk sediment (shown if opt_resus =0 on the 'main' sheet).
  - Chart_basins_burial_vel – chart of burial velocity of the bulk sediment (shown if opt_resus=1 on the 'main' sheet).
  - Chart_salt (1) – chart of salinity in the surface layer of each basin.

- Chart_salt (2) – chart of salinity in the deep layer of each basin.
- Chart_tracers (1) – chart of the tracer (e.g. PCB concentration) in the surface layer of each basin.
- Chart_tracers (2) – chart of the tracer (e.g. PCB concentration) in the deep layer of each basin.
- Chart_tracers (3) – chart of the tracer (e.g. PCB concentration) in the sediment layer of each basin.

Detailed instructions or information about required inputs in the input worksheets are provided with Excel comments, indicated by red triangles in the upper right corner of the worksheet cells (Figure A2). To view the comments in Excel, hover the cursor over the cell with the comment indicator.

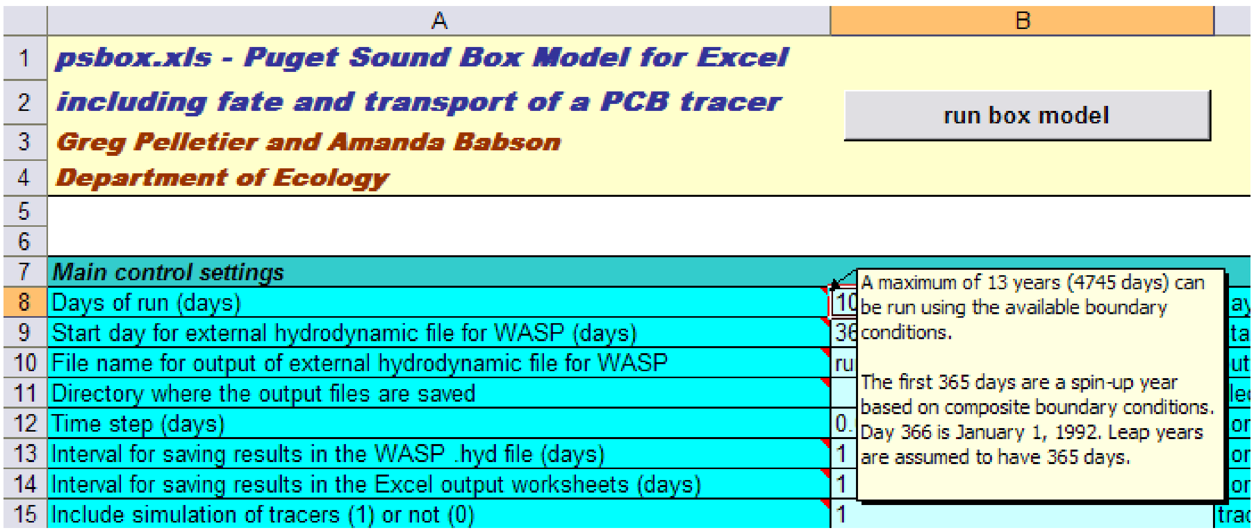


Figure A2. An example of a comment to explain an input value in the 'main' input worksheet in psbox.xls

References

Babson, A.L., M. Kawase, and P. MacCready. 2006. Seasonal and interannual variability in the circulation of Puget Sound, Washington: a box model study. Atmosphere-Ocean 44(1)2006, 29-45.

Davis, J.A. 2003. The long term fate of PCBs in San Francisco Bay. RMP Technical Report: SFEI Contribution 47. San Francisco Bay Estuary Institute, Oakland, CA.

Davis, J.A. 2004. The long term fate of polychlorinated biphenyls in San Francisco Bay (USA). Environmental Toxicology and Chemistry, Vol. 23, No. 10, pp. 2396-2409.

Appendix B. User's guide for the food web bioaccumulation model (foodweb.xls)

This Excel/VBA program is a generalized modeling framework based on the model theory of Arnot and Gobas (2004). The present version builds on the model application that was developed by Condon (2007) for the Strait of Georgia, British Columbia. The present version is a generalized framework with the goal that the user is not required to do any editing of the VBA code or any spreadsheet formulas to adapt the model to different waterbodies with different food webs with more or fewer species in any trophic level.

In addition to making the program generalized, the following new features are included:

- Calculation of goodness-of-fit with different methods including the ratio of max(pred, obs)/min(pred, obs), chi-square, and relative difference. Calculation of 'model bias' as defined in Arnot and Gobas (2004) is also included.

- Calculation of predicted values for the sum of all congeners, and for the sum of only the observed congeners for better matching of predicted and observed data where the observed data are from a subset of all of the congeners that are being simulated.

- Input of water column total concentrations for use with eqn 2 and 4 of Arnot and Gobas (2004) as an option to Colm's default method of estimating water column dissolved concentration as a function of the sediment concentration.

- Calculation of the bioaccumulation factor (BAF) as ng/g wet weight in biota per ng/mL water column total concentration, as well as biota-sediment accumulation factor (BSAF) as ng/g wet weight in biota per ng/g dry weight in sediment.

- Automatic creation of charts of the comparisons of predicted and observed BAF and BSAF for all observed data.

- An optional genetic algorithm to automatically find the optimum values of parameters to provide the best possible goodness-of-fit. An example application of the genetic algorithm is set up and described in the 'pikaia' sheet to find optimal dietary uptake efficiencies of lipids and non-lipid organic matter.

The computer code used to implement the calculations for the food web bioaccumulation model is written in Visual Basic for Applications (VBA). Excel worksheets serve as the user interface for entering input data and viewing output results.

For the macros to run properly, the macro security settings in Excel should be set to low or medium. To check the macro security settings use the Excel menu Tools>Macro>Security and select low or medium security. This version was written in Excel 2003 (Excel version 11.0) and may not be compatible with some earlier versions of Excel.

Colors of worksheet cells are used to signify whether information is to be input by the user or output by the program:

- **Pale Blue** designates variable and parameter values that are to be entered by the user.
- **Pale Yellow** designates data that the user enters. These data are then displayed on graphs generated by foodweb.xls for comparison with predicted values and also for calculation of goodness-of-fit statistics.
- **Pale Green** designates output values generated by foodweb.xls.
- **Dark solid colors** are used for labels and should not be changed.

Each worksheet has a button that is labeled “Run the model” as shown in Figure B1. Clicking on this button from any worksheet will run the model. When the model runs, it reads the input values that are entered in the blue cells from the input sheets and stores the model results in the green cells in the output sheets. Input worksheets are color-coded with light blue tabs, observed data worksheets are color-coded with yellow tabs, output worksheets are color-coded with green tabs, and charts of model predictions are color-coded with dark blue tabs.

Detailed instructions or information about required inputs in the input worksheets are provided with Excel comments, indicated by red triangles in the upper right corner of the worksheet cells (Figure B2). To view the comments in Excel, hover the cursor over the cell with the comment indicator.

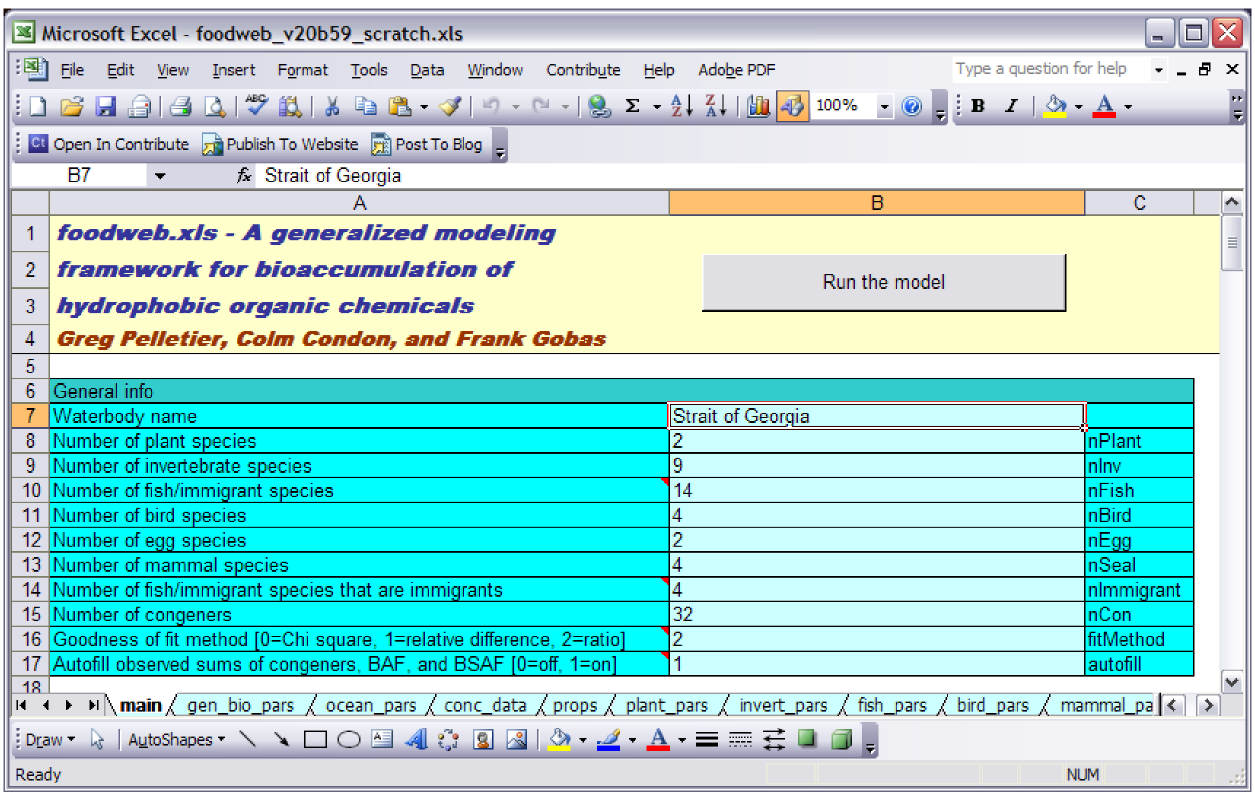


Figure B1. The ‘main’ input worksheet in foodweb.xls.

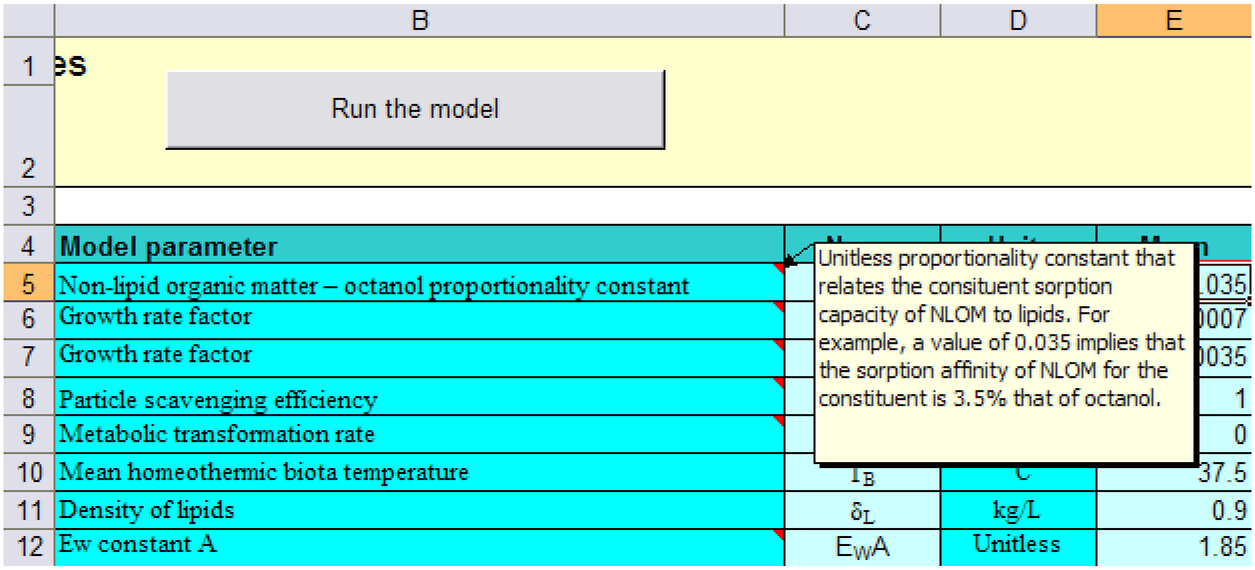


Figure B2. An example of a comment to explain an input value in the ‘gen_bio_pars’ input worksheet in foodweb.xls

The following worksheets are inputs, observed data, and outputs:

- Input worksheets
  - Main – general model control.
  - Gen_bio_pars – general biological parameters.
  - Ocean_bars – environmental parameters.
  - Conc_data – constituent concentration data for boundary conditions (sediment, water, and immigrant organisms).
  - Props – chemical properties of congeners.
  - Plant_pars – plant parameters.
  - Invert_pars – invertebrate parameters.
  - Fish_pars – fish parameters.
  - Bird_pars – bird parameters.
  - Mammal_pars – mammal parameters.
  - Foodweb – feeding relationships between predators and prey.
- Observed data worksheets
  - Obs_conc – observed concentrations in biota (ng/g wet weight), sediment (ng/g dry weight), water (ng/mL), and air (ng/mL).
  - Obs_lnconc – observed lipid normalized concentrations (ng/g lipid).
  - Obs_baf – observed bioaccumulation factors (ng/g wet weight in biota per ng/mL water column total concentration).
  - Obs_bsaf – observed biota-sediment accumulation factors (ng/g wet weight in biota per ng/g dry weight sediment total concentration).

- Output worksheets
  - Pred_conc – predicted concentrations in biota (ng/g wet weight), sediment (ng/g dry weight), water (ng/mL), and air (ng/mL).
  - Pred_lnconc – predicted lipid normalized concentrations (ng/g lipid).
  - Pred_baf – predicted bioaccumulation factors (ng/g wet weight in biota per ng/mL water column total concentration).
  - Pred_bsaf – predicted biota-sediment accumulation factors (ng/g wet weight in biota per ng/g dry weight sediment total concentration).
  - Fit_conc – goodness-of-fit values comparing observed and predicted concentrations in biota, active sediment, and water column.
  - Fit_lnconc – goodness-of-fit values comparing observed and predicted concentrations in lipid-normalized biota.
  - Fit_baf – goodness-of-fit values comparing observed and predicted bioaccumulation factors.
  - Fit_bsaf – goodness-of-fit values comparing observed and predicted biota-sediment accumulation factors.
  - Sorted_results – predicted biota concentrations, BAF, and BSAF sorted by concentration and also showing the model bias compared with observed data.
- Charts of predictions and comparisons with observed data
  - Chart_sort_baf (all) – comparison of predicted and observed BAF for sums of all congeners.
  - Chart_sort_baf (obs) – comparison of predicted and observed BAF for sums of congeners with observed data.
  - Chart_sort_bsaf (all) – comparison of predicted and observed BSAF for sums of all congeners.
  - Chart_sort_bsaf (obs) – comparison of predicted and observed BSAF for sums of congeners with observed data.
  - Chart_bsaf (i) – comparison of observed and predicted concentrations for each congener in each organism (i) with observed data.

User instructions

The required inputs are in the light blue colored cells in the sheets with light blue tabs. The model outputs are in the light green colored cells. Observed data are entered in sheets with yellow tabs in yellow cells. In some cases, some output cells (light green cells) may be present in sheets for input data or observed data.

Charts of predicted and observed bioaccumulation factors (BAF defined as ng/g wet weight in biota per ng/mL water concentration total) and biota-sediment accumulation factor (BSAF defined as ng/g wet weight in biota per ng/g dry weight in sediment) are in the sheets with dark blue tabs.

Optional scratch sheets and cells for intermediate calculations by the user are shown with gray colored cells or tabs. The user may add as many sheets as needed for any additional calculations (e.g. to derive the required inputs, calculate goodness-of-fit. Data below or to the right of the colored cell areas are scratch data or extra notes that are not required to run the program.

Do not insert or delete any rows or columns in, above, or to the left of the colored ranges of any sheets with light blue or light green tabs except where noted (the foodweb sheet).

Do not change the names of any of the input/output sheets with tabs that are colored light blue or light green.

To run the model, click on the button named "Run the model" after entering all of the required inputs in the light blue cells.

Genetic algorithm

A genetic algorithm is also provided in the sheet named pikaia (light orange tabs). The use of the genetic algorithm is not required to run the food web bioaccumulation model. The genetic algorithm is provided as an optional tool for the user. The genetic algorithm may be configured by the user to automatically optimize rate parameters instead of manual adjustment of rate parameters to improve the goodness-of-fit. Instructions for use of the pikaia genetic algorithm are provided in the cell comments and at the bottom of the pikaia sheet. The pikaia genetic algorithm is set up to optimize for the dietary absorption efficiency of lipids and non-lipid organic material as an example to illustrate how it can be integrated with the food web model to find the optimum values for any input parameters.

The genetic algorithm is set up to find the optimum values of the dietary absorption efficiencies of lipids and non-lipid organic matter. When the user clicks on the 'run pikaia' button, the genetic algorithm will attempt to solve for a set of parameter values that will result in the closest possible match between predicted and observed BSAF by maximizing the reciprocal of the geometric mean over all biota of the ratios of max(BSAFpred, BSAFobs) to min(BSAFpred, BSAFobs), where BSAFpred is the predicted BSAF for the sum all measured congeners, and BSAFobs is the observed BSAF for the sum all measured congeners. The reciprocal is used for the fitness function in this example because the genetic algorithm maximizes the fitness value. The notes below provide more information on how to use the genetic algorithm in general.

The following steps are a quick guide to the general use the pikaia genetic algorithm with the food web bioaccumulation model:

1. Select the parameters to optimize and input the parameter ranges. Decide which model parameters that you want to optimize. Enter the parameter names and the possible minimum and maximum values in rows 20-22 of this pikaia sheet starting in column B. For example, if the dietary absorption efficiency of lipids for zooplankton is the first parameter being optimized, and the optimum value is between 0.5 and 1, then enter 0.5 and 1 in cells B21 and B22.

2. Create a fitness function. Calculate a goodness-of-fit statistic (fitness) for the model results. Enter a reference to where the fitness value is calculated in cell B26 in this pikaia sheet. The only requirement for the fitness function is that it must increase as the goodness-of-fit improves. In this example, the equation "=1/fit_conc!AP50" is entered in cell B26 to use the reciprocal of the geometric mean over all biota of the ratios of max(BSAFpred, BSAFobs) to

min(BSAFpred, BSAFobs), where BSAFpred is the predicted BSAF for the sum of all measured congeners, and BSAFobs is the observed BSAF for the sum of all measured congeners.

3. Link the required model inputs to the pikaia optimum values using cell references. Enter cell references in the required input cells of the food web model input sheets. The input cells for the parameters being optimized must refer to the output solution from the pikaia genetic algorithm. For example, if the dietary absorption efficiency of lipids for zooplankton is the first parameter being optimized, then pikaia will write the optimum value in cell B31 of the pikaia sheet, and the formula "=pikaia!B31" should be entered in cell E13 of the gen_bio_pars sheet.

4. Set the general control parameters for pikaia. The default controls in cell B5-B16 will be adequate in most cases. The number of generations (cell B7) may be increased to 100 if the fitness is still improving after 50 generations. A different random seed (cell B5) can be used to find a different optimum solution.

5. Run the genetic algorithm by clicking on the 'run pikaia' button. The program may take several hours to run depending on the speed of your computer and number of individuals in the population (cell B6) and the number of generations (cell B7). After the program is finished, the food web model will be calculated with the final optimum set of parameters. The improvement in the goodness-of-fit during the evolution may be inspected in the 'output generations' sheet (filter by rank, with rank=1 representing the parameter set with the best fit for each generation).

References

Arnot, J.A. and F.A. Gobas, 2004. A food web bioaccumulation model for organic chemicals in aquatic ecosystems. Environmental Toxicology and Chemistry. 23 (10) 2342-2355.

Condon, C.D. 2007. Development, evaluation, and application of a food web bioaccumulation model for PCBs in the Strait of Georgia, British Columbia. A project submitted in partial fulfillment of the requirements for the degree of Master of Resource Management. Simon Fraser University.

Appendix C. Data sources for PCB data summaries

Table C-1. List of studies/data sources used in generating sediment PCB data summaries.

Study Id	Study Name	Start Date	End Date*
Environmental Information Management (EIM) database			
53ACSO96	King County's NPDES CSO Subtidal Sed	10/16/1996	
63ACSO97	NPDES 63rd Ave CSO Baseline Study, 1997	10/14/1997	
AK_CSO97	NPDES Alaska CSO Baseline Study	10/14/1997	
ALKI9497	NPDES Alki Subtidal Monitoring 1994-1997	7/29/1996	10/16/1997
AR-94-02	NRDA Sed. Svy of Comm & Elliott Bays	5/27/1994	6/8/1994
ARCOCP00	Arco Cherry Point NPDES Characterization	10/3/2000	10/5/2000
BCWTAC95	Boise Cascades West Tacoma Mill Baseline	9/28/1995	
BN_SF_HV	BN_SF RR Harborview Park Investigation	8/17/2005	
BPCP06	RETEC BP Cherry Point 2006	9/22/2006	9/25/2006
BREMTP98	98 Bremerton WTP NPDES Sed. Monitoring Report	4/28/1998	
BRTCSO97	NPDES Barton CSO Baseline Study	10/15/1997	
BUDD98	BUDD INLET	6/9/1998	6/10/1998
CARKEK00	Carkeek Park Outfall Monitoring	10/12/2000	
CENKIT99	Central Kitsap WWTP NPDES monitoring	1/5/1999	1/6/1999
CHAMBR95	Chambers Creek WWTP Marine Sediment Monitoring	11/6/1995	
CHEVPW04	Chevron Point Wells Supplemental Study	5/12/2004	
CHEVPW94	Chevron Pt Wells NPDES Baseline	4/20/1994	
CHEVRN02	Chevron Whatcom Crk Bellingham	10/24/2002	
COLMAN94	Colman Dock - South Area, Seattle, WA	10/15/1993	
CONOCO04	ConocoPhillips NPDES Permit Support	6/9/2004	
CPSD9497	Ambient Subtidal Monitoring 1994-1997	10/17/1996	10/16/1997
DAISPA99	Daishowa-Port Angeles NPDES Monitoring	4/26/1999	4/28/1999
DENN9496	Denny Way Cap Monitoring 1994-96	8/6/1996	9/10/1996
EDMDUNOC	City of Edmonds Unocal Study	9/6/2000	9/12/2000
EHPMAR95	U.S. Navy Everett Rec. Marina Sed. Monitoring	11/15/1994	
EVTWE494	Weyerhaeuser Everett, WA	3/29/1994	3/30/1994
GPBASE93	GP Baseline Sed. Character., '93 NPDES	9/9/1993	9/10/1993
HIRIPH2	Harbor Island Phase II RI	9/26/1991	10/31/1991
HYLE9496	Hylebos Waterway PRD Event 1A, 1B & 1C	6/27/1994	12/20/1995
INTLCO99	Intalco Sediment Investigation	9/21/1999	9/24/1999
KEYPORT	The Navy's Keyport RI Report	6/10/1991	
KEYPRT92	Navy/Keyport Final RI Report of 10/25/93	6/10/1991	
KINGST02	Kitsap County Outfall	10/17/2001	
KITSAP03	Kitsap Transit/Sidney Landing Investigation	3/4/2003	
LAK99	Lakehaven Utility District NPDES	8/11/1999	8/13/1999
LAKOTA05	Lakota Sediment Sampling	12/22/2005	
LOTT_96	LOTT 1996 NPDES Sed. Monitoring Report	5/29/1996	5/31/1996
MAGCSO96	NPDES Magnolia CSO Baseline Study, 1996	10/16/1996	
MIDWAY06	Midway Sewer District Sed Sampling	6/27/2006	6/30/2006
MIDWAY95	MIDWAY BASELINE	4/3/1995	4/6/1995
MONCB191	2003 Tiered-Full Monitoring in Com Bay	7/2/2003	7/7/2003
MURCSO97	NPDES CSO Subtidal Sediments, 1997	10/14/1997	10/15/1997
NB_CSO96	Magnolia, North Beach, 53rd Street CSO's	10/15/1996	

Study Id	Study Name	Start Date	End Date*
Environmental Information Management (EIM) database			
OVRA99	Olympic View Restoration in Commencement	1/11/1999	6/20/1999
P&T_MILL	Pope_and_Talbot_Mill_Site_Sediment	6/27/2002	
P53MON93	Metro QA Review of P53-55 Capping Data	5/18/1993	5/21/1993
P53MON96	Pier 53 Cap Monitoring 1996	8/12/1996	
P66CAP	PIER66 SEDIMENT CAP/CENTRAL WATERFRONT	3/23/2004	3/26/2004
PA_STP04	Port Angeles NPDES Sediment Analysis	9/23/2003	6/21/2004
PA_STP96	1996 City of Port Angeles NPDES Report	10/1/1996	10/2/1996
PIER_D93	U.S. Navy Pier D Supplemental Sampling	8/10/1993	8/13/1993
PIER_D95	U.S. Navy Pier D Long-Term Area Monitor	12/17/1994	3/7/1995
POLARIS	Crowley Marine Services Base Sed Samp	12/4/2001	
POSTPT96	Seattle, Port of, Terminal 5, DY97	4/29/1996	5/1/1996
PSAMP_HP	Puget Sound Assessment and Monitoring Program's Historical Sediment	4/1/1989	4/10/1995
PSAMP_LT	Puget Sound Assessment and Monitoring Program's Long-Term Temporal	3/19/1989	4/25/2005
PSAMP_SP	Puget Sound Assessment and Monitoring Program's (PSAMP) Spatial/Temporal	6/3/2002	6/15/2006
PSAMPNOA	A Cooperative Agreement with the PSAMP	6/2/1997	6/30/1999
PSDDA_00	Elliott Bay Full Monitoring	6/29/2000	
PSDDA_01	Full Monitoring of Commencement Bay	7/30/2001	8/14/2001
PSDDA_02	Tiered-Partial Monitoring of Elliott Bay	7/2/2002	7/8/2002
PSDDA_95	Commencement Bay Full Monitoring	6/13/1995	6/19/1995
PSDDA1	PSDDA Phase I Survey of Disposal Sites	5/13/1988	6/8/1988
PSDDA2	PSDDA Phase 2 Survey of Disposal Sites	4/24/1989	5/1/1989
PSNS90	Puget Snd Naval Shipyard Site Inspec. 90	11/29/1990	12/12/1990
RAYONR05	Former Rayonier Mill Site	8/6/2002	8/29/2002
RED99	Lakehaven Utility District NPDES	8/16/1999	8/17/1999
REDONDO	Redondo Sediment Sampling	12/21/2005	
RENT01	NPDES Renton (South Plant) Subtidal 2001	11/5/2001	11/8/2001
RENT9497	NPDES Renton Subtidal Monitoring 1994-97	10/7/1996	10/13/1997
RENT99	NPDES Renton Subtidal Monitoring 1999	10/12/1999	10/14/1999
RICH9496	Richmond Beach IT Monitoring 1994-96	7/29/1996	
SCOTT95	Scott Paper Co. Baseline Sediment Survey	5/1/1995	5/9/1995
SIMPSON	Simpson NPDES Sediment Analysis 2004	3/10/2004	
SINCLET	Lower Sinclair Inlet Sediment PCB Study	11/16/1999	11/17/1999
STPAUL93	St. Paul Waterway Area Remedial Action	6/14/1993	7/19/1993
SWSSD96	Southwest Suburban Sewer District	8/28/1996	8/29/1996
TESORO01	TESORO SEDIMENT CHEMISTRY	12/20/2001	
THFOSS94	Thea Foss & Wheeler-Osgood W'way Round 1	8/20/1994	
TPPS3AB	TPPS Phase III A & B	3/4/1981	10/1/1982
WHATRI96	Whatcom Waterway 1996 RI Report	9/3/1996	9/10/1996
WLDCFT01	WELDCRAFT SUPP. SEDIMENT INVESTIGATION	11/21/2000	
WP1&2_96	West Point EBO Baseline Study Phase 1	2/1/1996	9/25/1996
WPNT00	NPDES West Pt Subtidal Monitoring 2000	10/4/2000	10/11/2000
WPNT9497	West Point Subtidal NPDES Monit. 1994-97	7/18/1994	7/22/1997
WPNT98	1998 West Point Outfall Sediment Data	11/17/1998	3/5/1999
Environmental Monitoring and Assessment Program			
EMAP 2000		2000	
EMAP 2004		2004	

* Studies with no end date only monitored for a single day

Table C-2. List of all PCB congeners for which data were available.

PCB-008
PCB-018
PCB-028
PCB-044
PCB-052
PCB-066
PCB-077
PCB-101
PCB-105
PCB-110*
PCB-118
PCB-126
PCB-128
PCB-138
PCB-153
PCB-169*
PCB-170
PCB-180
PCB-187
PCB-195
PCB-206
PCB-209

*these congeners are in addition to the 20 congeners that are sampled per NOAA (1993).

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Appendix D. Cumulative frequency distribution plots

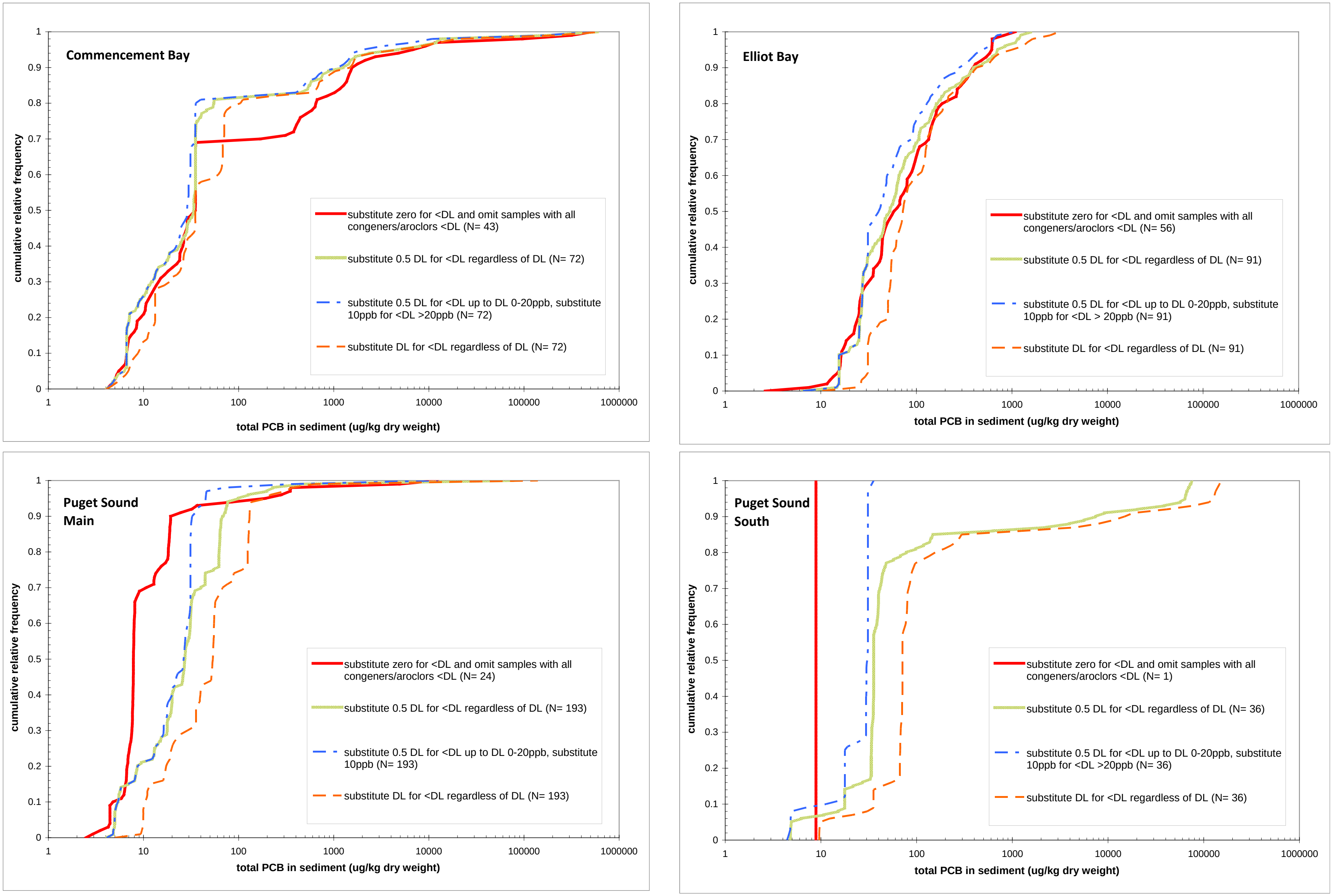


Figure D-1. CFD plots, by region, of total PCB in the 0-2 cm sediment layer, using four different substitution methods to replace non-detect values.

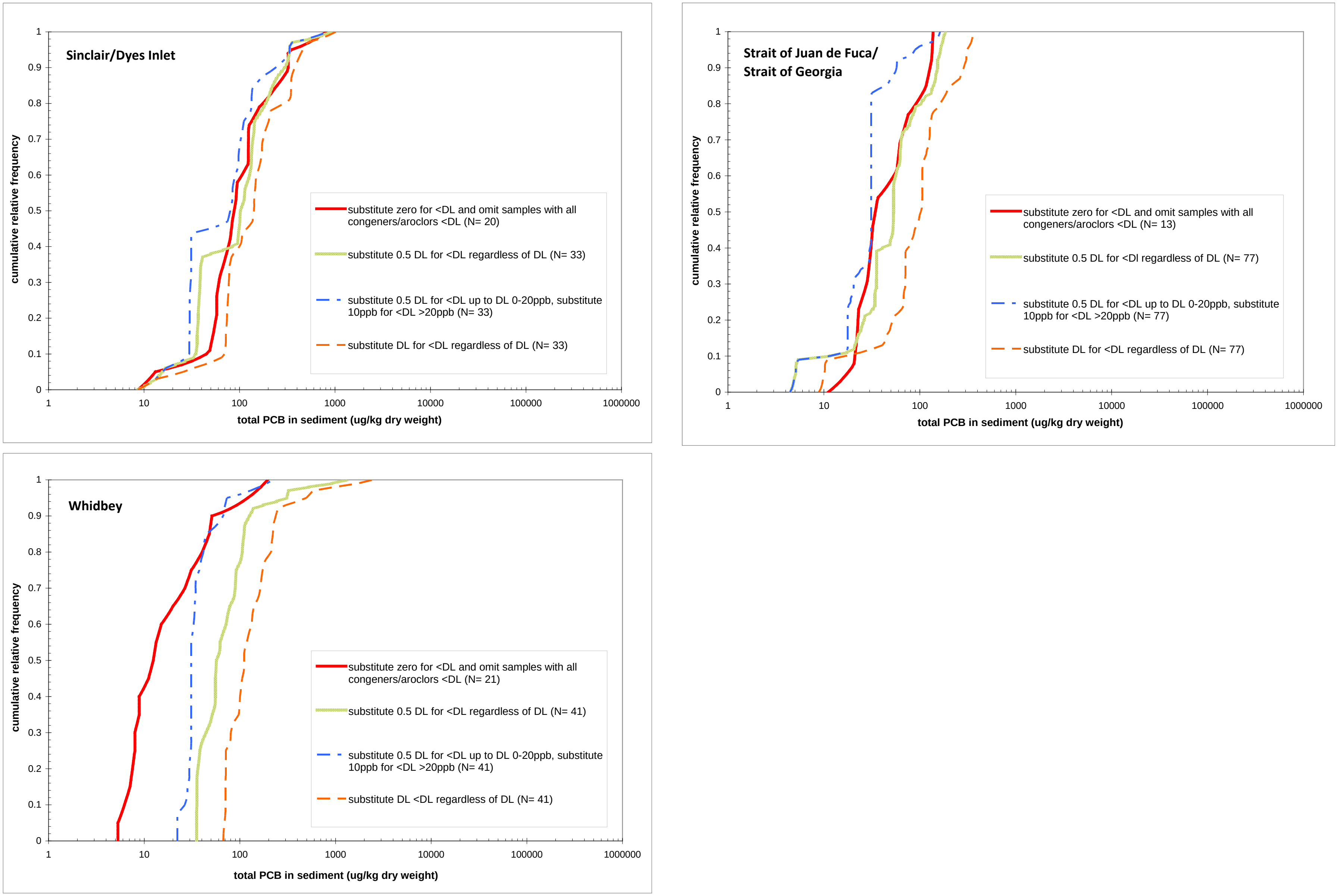


Figure D-2. CFD plots, by region, of total PCB in the 0-2 cm sediment layer, using four different substitution methods to replace non-detect values.

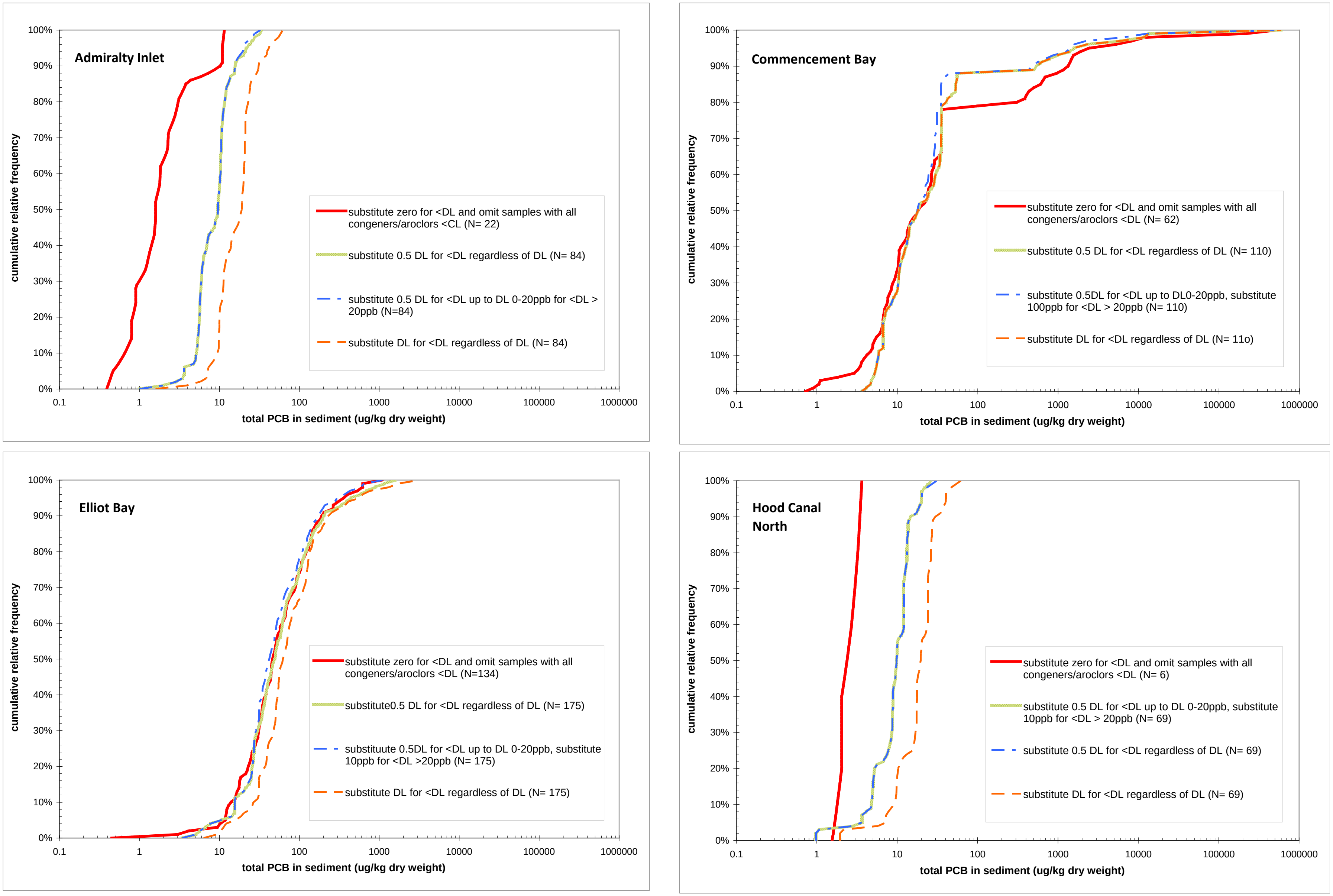


Figure D-3. CFD plots, by region, of total PCB in the 0-5 cm sediment layer, using four different substitution methods to replace non-detect values.

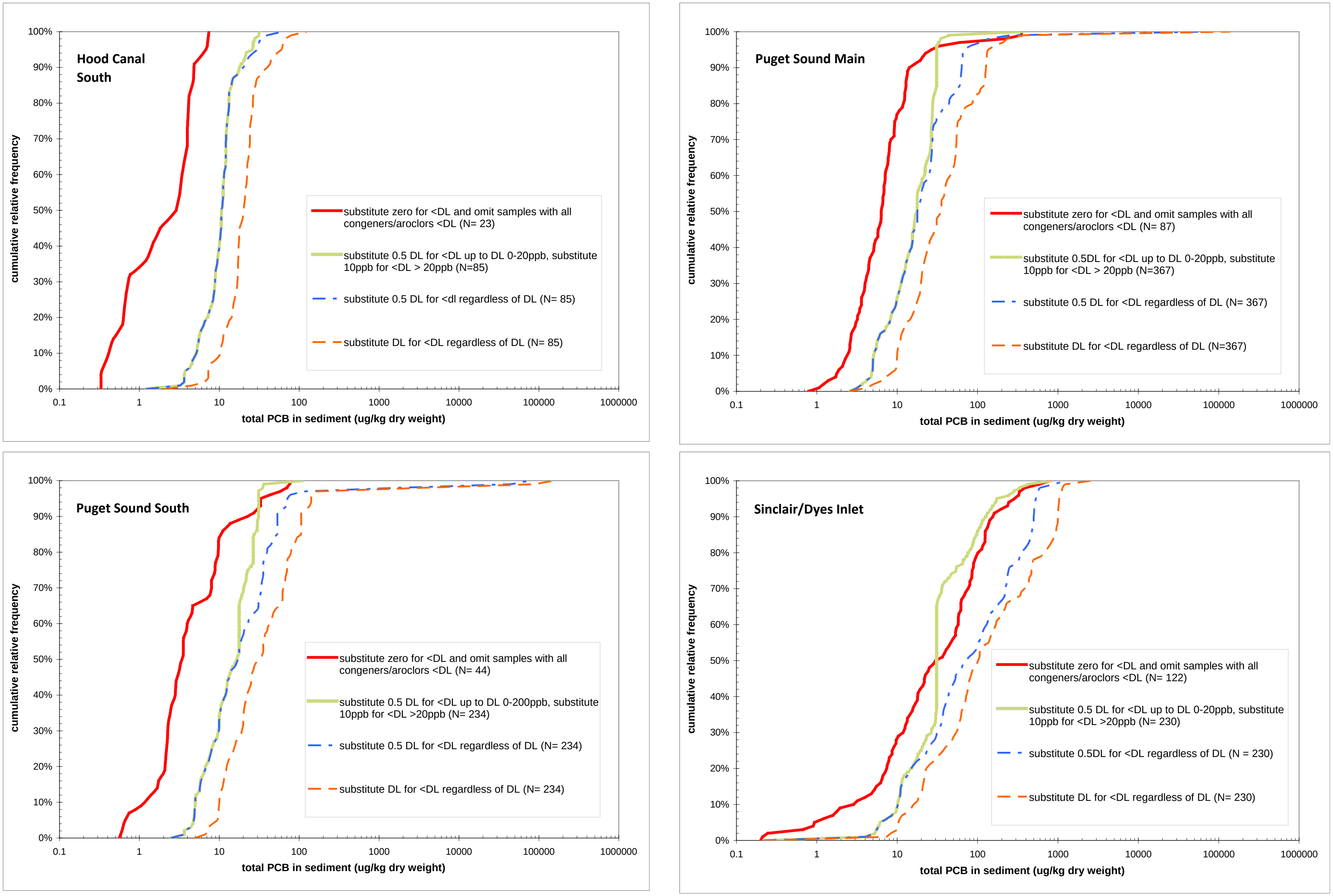
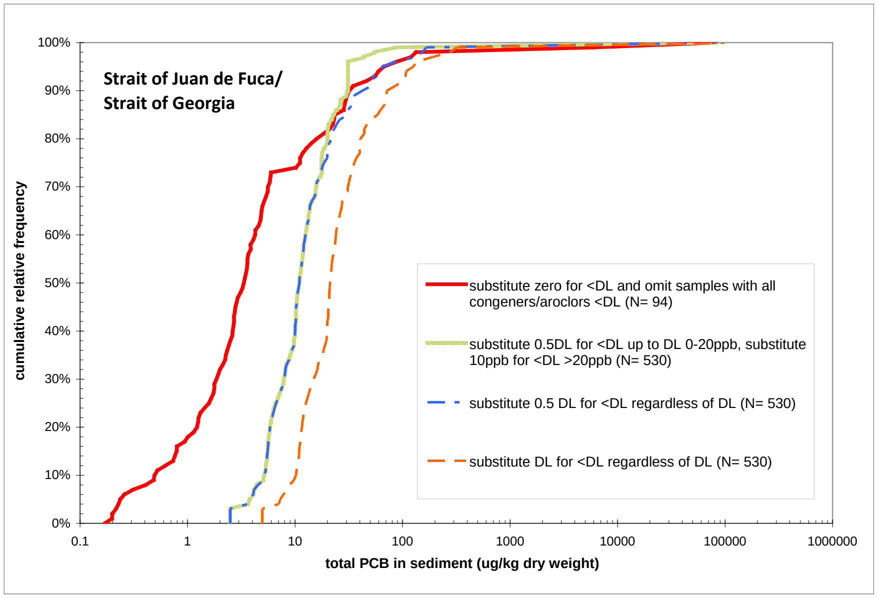


Figure D-4. CFD plots, by region, of total PCB in the 0-5 cm sediment layer, using four different substitution methods to replace non-detect values.



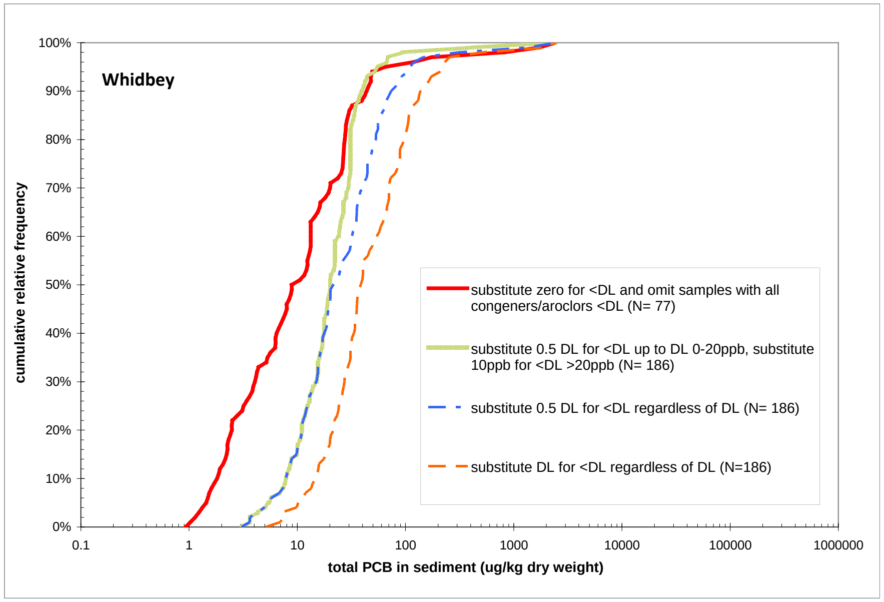


Figure D-5. CFD plots, by region, of total PCB in the 0-5 cm sediment layer, using four different substitution methods to replace non-detect values.

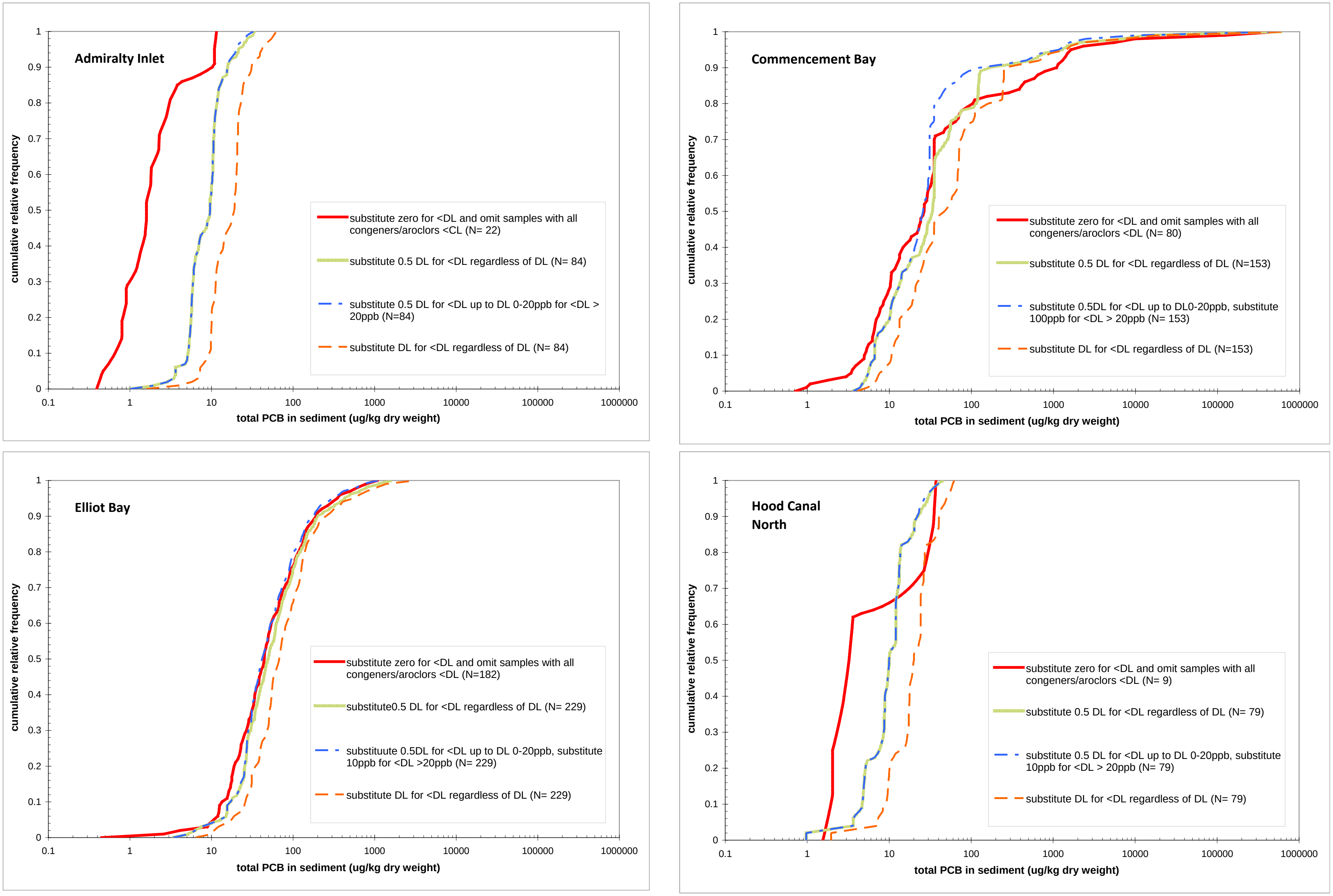


Figure D-6. CFD plots, by region, of total PCB in the 0-10 cm sediment layer, using four different substitution methods to replace non-detect values.

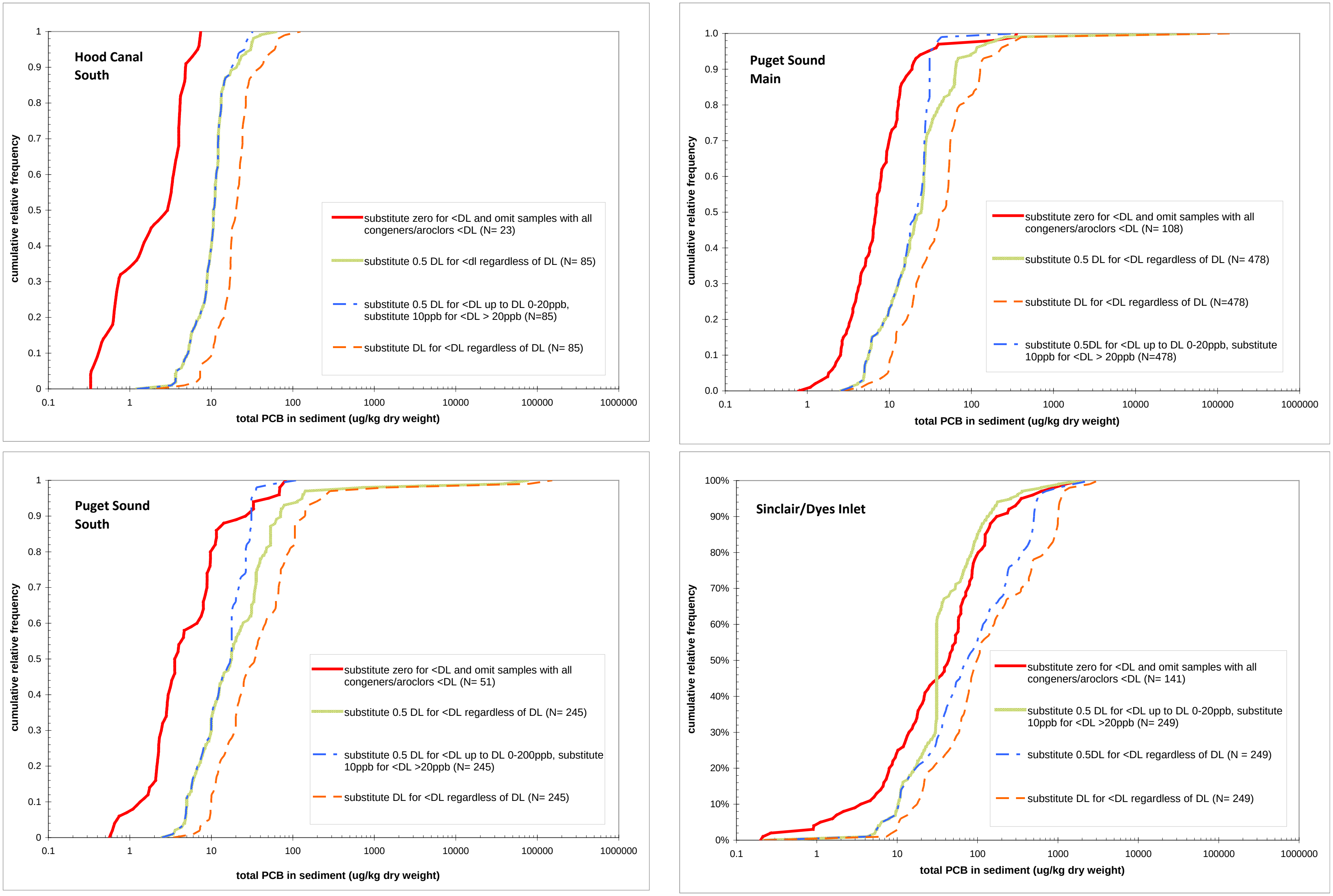
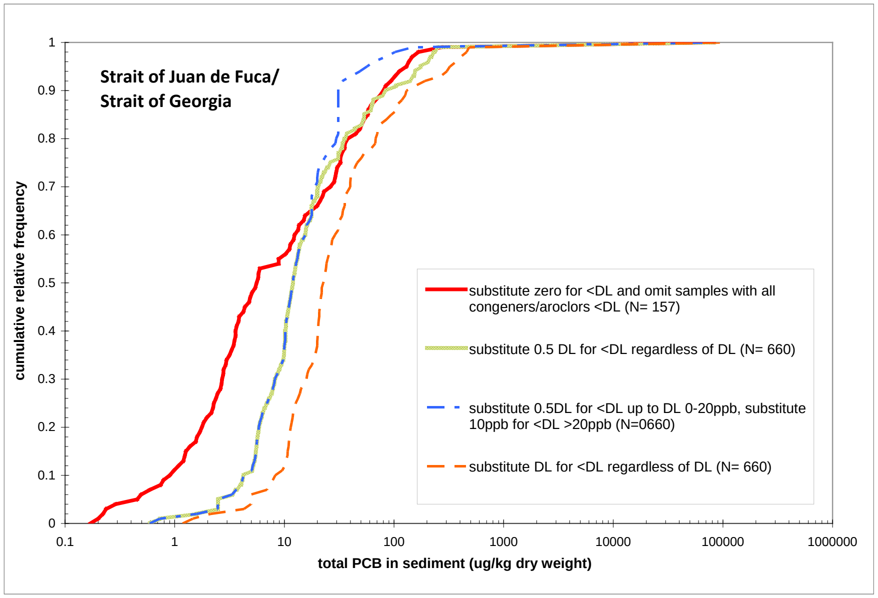


Figure D-7. CFD plots, by region, of total PCB in the 0-10 cm sediment layer, using four different substitution methods to replace non-detect values.



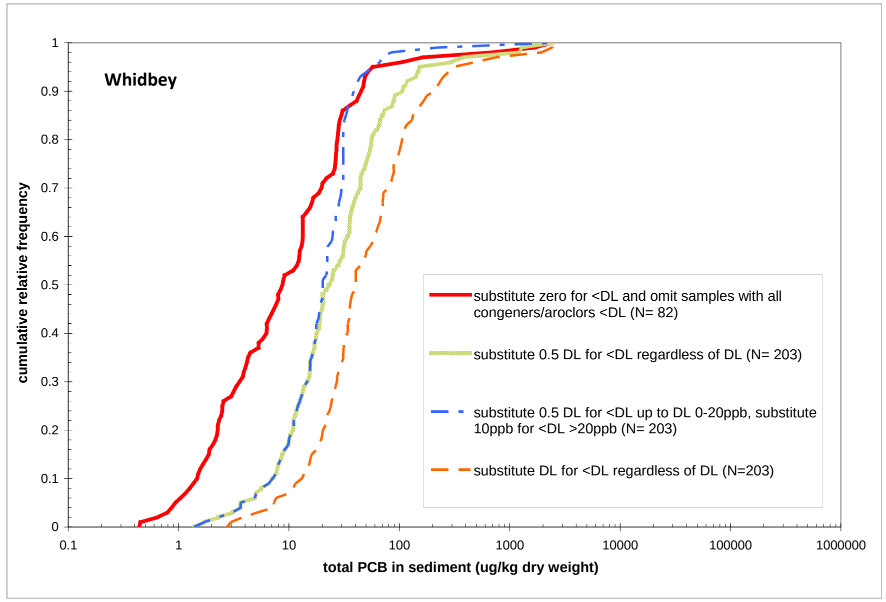


Figure D-8. CFD plots, by region, of total PCB in the 0-10 cm sediment layer, using four different substitution methods to replace non-detect values.

Appendix E. Summary statistics for individual PCB congeners/ aroclors

Table E-1. Summary statistics for individual PCB congeners and aroclors in the 0-2 cm sediment layer.

Congener/aroclor	N	Mean	StdDev	Min	10%tile	25%tile	Median	75%tile	90%tile	Max	Geomean	GeoSD
Commencement Bay												
PCB-008	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-018	10	0.50	0.41	0.21	0.22	0.28	0.31	0.48	1.13	1.40	0.87	3782.36
PCB-028	21	72.45	192.54	0.14	0.18	0.20	0.34	0.90	130.00	738	3.25	3934.85
PCB-044	31	3510.45	19023.14	0.44	0.51	0.60	0.90	40.00	500.00	106000	5.17	4194.60
PCB-052	28	49.34	90.03	0.28	0.32	0.47	1.00	40.25	189.80	315	3.62	3766.23
PCB-066	26	3235.92	16269.48	0.11	0.25	0.37	0.95	20.00	123.50	83000	3.02	3766.23
PCB-077	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-101	31	780.32	3782.36	0.46	0.57	0.71	1.70	40.00	117.00	21000	3.03	3764.37
PCB-105	25	869.07	4194.60	0.07	0.08	0.12	0.37	20.00	193.80	21000	1.29	10924.22
PCB-110	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-118	31	709.29	3766.23	0.24	0.40	0.46	1.70	41.50	140.00	21000	5.24	275.18
PCB-126	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-128	31	723.48	3765.50	0.24	0.37	0.69	6.00	40.50	120.00	21000	6.36	11881.86
PCB-138	30	743.54	3827.55	0.20	0.40	0.69	1.95	40.00	133.00	21000	6.69	3610.64
PCB-153	31	2725.95	14917.04	0.45	0.54	0.91	2.40	41.50	255.00	83100	8.03	3960.61
PCB-169	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-170	22	104.59	275.18	0.13	0.27	0.45	1.15	41.00	127.90	1090	5.23	3714.12
PCB-180	31	3054.52	15969.74	0.24	0.35	0.55	1.60	40.50	140.00	89000	5.74	0.05
PCB-187	28	834.44	4149.38	0.18	0.33	0.47	1.43	41.25	245.10	22000	3.39	0.00
PCB-195	9	141.12	383.77	0.05	0.07	0.10	0.17	0.37	319.20	1160	1.73	5.20
PCB-206	22	1167.83	4693.88	0.05	0.11	0.19	0.41	32.68	459.40	22000	2.77	5.53
PCB-209	26	886.25	4307.59	0.09	0.14	0.24	1.65	35.00	236.50	22000	4.16	5.53
AROCLOR-1016	9	9.80	0.05	9.70	9.78	9.80	9.80	9.80	9.82	9.90	9.80	11.85
AROCLOR-1016/1242	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1221	9	20.00	0.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	14.07	0.05
AROCLOR-1232	9	9.90	0.05	9.80	9.88	9.90	9.90	9.90	9.92	10.00	10.56	-------
AROCLOR-1242	10	12.31	7.62	9.80	9.89	9.90	9.90	9.90	12.40	34.00	10.56	-------
AROCLOR-1248	9	9.90	0.05	9.80	9.88	9.90	9.90	9.90	9.92	10.00	11.45	95417.95
AROCLOR-1254	11	16.28	15.70	9.80	9.90	9.90	9.90	9.95	30.00	60.00	11.45	81062.15
AROCLOR-1260	9	9.90	0.05	9.80	9.88	9.90	9.90	9.90	9.92	10.00	9.90	24.29
AROCLOR-1262	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1268	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
Elliott Bay												
PCB-008	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-018	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-028	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-044	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-052	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-066	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-077	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-101	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-105	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-110	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-118	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-126	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-128	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-138	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-153	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------

Congener/aroclor	N	Mean	StdDev	Min	10%tile	25%tile	Median	75%tile	90%tile	Max	Geomean	GeoSD
PCB-169	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-170	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-180	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-187	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-195	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-206	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-209	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1016	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1016/1242	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1221	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1232	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1242	5	36.00	20.74	20.00	20.00	20.00	30.00	40.00	58.00	70.00	32.01	0.23
AROCLOR-1248	8	144.30	135.71	3.00	30.30	52.50	78.50	244.77	336.00	350.00	75.74	0.67
AROCLOR-1254	52	230.24	369.80	3.70	26.05	40.00	82.50	195.00	750.00	1700.00	99.18	0.55
AROCLOR-1260	54	96.59	119.14	2.20	17.30	30.00	47.50	100.00	195.64	500.00	54.48	0.48
AROCLOR-1262	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1268	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
Puget Sound Main												
PCB-008	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-018	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-028	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-044	1	0.42	-------	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	-------
PCB-052	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-066	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-077	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-101	1	0.67	-------	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.28
PCB-105	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-110	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-118	1	0.44	-------	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	-------
PCB-126	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-128	1	0.16	-------	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	-------
PCB-138	1	0.56	-------	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	-------
PCB-153	1	0.65	-------	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	-------
PCB-169	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-170	1	0.18	-------	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	-------
PCB-180	1	0.12	-------	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	-------
PCB-187	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-195	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-206	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-209	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1016	3	112.33	4.16	109.00	109.40	110.00	111.00	114.00	115.80	117.00	112.28	0.02
AROCLOR-1016/1242	1	17.00	-------	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	-------
AROCLOR-1221	3	112.33	4.16	109.00	109.40	110.00	111.00	114.00	115.80	117.00	112.28	0.02
AROCLOR-1232	3	112.33	4.16	109.00	109.40	110.00	111.00	114.00	115.80	117.00	112.28	0.02
AROCLOR-1242	5	72.92	54.74	1.59	11.35	26.00	109.00	111.00	114.60	117.00	35.77	0.80
AROCLOR-1248	9	37.70	44.98	1.59	5.81	7.52	17.00	42.46	112.20	117.00	18.00	0.61
AROCLOR-1254	21	23.28	31.95	5.91	8.28	8.71	9.90	17.67	72.00	111.00	14.26	0.37
AROCLOR-1260	19	19.29	33.17	5.88	6.18	6.63	7.48	9.85	36.20	117.00	10.46	0.38
AROCLOR-1262	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1268	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
Puget Sound South												
PCB-008	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-018	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-028	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-044	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------

Congener/aroclor	N	Mean	StdDev	Min	10%tile	25%tile	Median	75%tile	90%tile	Max	Geomean	GeoSD
PCB-052	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-066	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-077	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-101	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-105	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-110	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-118	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-126	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-128	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-138	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-153	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-169	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-170	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-180	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-187	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-195	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-206	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-209	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1016	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1016/1242	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1221	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1232	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1242	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1248	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1254	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1260	1	20.00	-------	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	-------
AROCLOR-1262	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1268	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
Sinclair/Dyes Inlet												
PCB-008	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-018	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-028	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-044	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-052	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-066	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-077	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-101	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-105	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-110	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-118	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-126	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-128	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-138	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-153	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-169	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-170	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-180	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-187	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-195	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-206	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-209	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1016	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1016/1242	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1221	5	75.20	70.58	28.00	33.20	41.00	51.00	56.00	142.40	200.00	57.99	0.32
AROCLOR-1232	1	300.00	-------	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	-------

Congener/aroclor	N	Mean	StdDev	Min	10%tile	25%tile	Median	75%tile	90%tile	Max	Geomean	GeoSD
AROCLOR-1242	11	56.63	71.22	3.70	7.20	26.50	36.00	49.50	87.00	260.00	32.85	0.50
AROCLOR-1248	5	42.18	35.40	3.70	5.10	7.20	49.00	71.00	76.40	80.00	23.66	0.62
AROCLOR-1254	11	236.59	368.63	7.50	10.00	57.00	92.00	165.00	670.00	1200.00	91.78	0.66
AROCLOR-1260	19	132.65	102.30	4.50	38.76	89.00	110.00	150.00	216.00	440.00	90.45	0.49
AROCLOR-1262	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1268	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
Strait of Juan de Fuca/Georgia												
PCB-008	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-018	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-028	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-044	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-052	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-066	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-077	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-101	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-105	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-110	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-118	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-126	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-128	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-138	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-153	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-169	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-170	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-180	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-187	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-195	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-206	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-209	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1016	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1016/1242	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1221	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1232	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1242	11	145.82	101.42	50.00	52.00	59.50	130.00	215.00	300.00	310.00	115.75	0.31
AROCLOR-1248	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1254	3	40.33	24.85	25.00	25.40	26.00	27.00	48.00	60.60	69.00	35.98	0.25
AROCLOR-1260	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1262	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1268	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
Whidbey												
PCB-008	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-018	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-028	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-044	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-052	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-066	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-077	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-101	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-105	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-110	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-118	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-126	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-128	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-138	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-153	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------

Congener/aroclor	N	Mean	StdDev	Min	10%tile	25%tile	Median	75%tile	90%tile	Max	Geomean	GeoSD
PCB-169	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-170	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-180	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-187	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-195	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-206	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-209	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1016	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1016/1242	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1221	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1232	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1242	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1248	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1254	16	65.63	109.59	12.00	15.00	17.75	24.50	43.00	140.50	440.00	33.85	0.44
AROCLOR-1260	9	46.11	26.51	12.00	18.40	21.00	45.00	70.00	76.40	82.00	38.26	0.30
AROCLOR-1262	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1268	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------

* These PCB congeners are have been selected by Mussel Watch Project.
N = number.
StdDev = standard deviation.
Min = minimum.
Max = maximum.
Geomean = geometric mean.

Table E-2. Summary statistics for individual PCB congeners and aroclors in the 0-5 cm sediment layer.

Congener/aroclor	N	Mean	StdDev	Min	10%tile	25%tile	Median	75%tile	90%tile	Max	Geomean	GeoSD
Admiralty Inlet												
PCB-008	1	0.16	-------	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	-------
PCB-018	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-028	9	0.17	0.05	0.11	0.12	0.15	0.15	0.18	0.24	0.25	0.16	0.12
PCB-044	5	0.33	0.24	0.14	0.15	0.16	0.17	0.59	0.59	0.59	0.27	0.32
PCB-052	5	0.60	0.55	0.18	0.19	0.20	0.21	1.20	1.20	1.20	0.40	0.43
PCB-066	7	0.17	0.04	0.11	0.13	0.15	0.16	0.21	0.21	0.21	0.17	0.11
PCB-077	0	------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-101	14	0.52	0.76	0.13	0.14	0.17	0.21	0.30	1.73	2.30	0.29	0.40
PCB-105	7	0.51	0.61	0.12	0.13	0.14	0.15	0.80	1.40	1.40	0.28	0.48
PCB-110	10	0.21	0.08	0.12	0.12	0.15	0.18	0.27	0.33	0.34	0.19	0.17
PCB-118	15	0.46	0.45	0.12	0.15	0.20	0.28	0.49	1.13	1.50	0.33	0.33
PCB-126	0	------	------	------	------	------	------	------	------	------	------	------
PCB-128	0	------	------	------	------	------	------	------	------	------	------	------
PCB-138	16	0.51	0.70	0.14	0.18	0.19	0.23	0.41	1.38	2.30	0.32	0.37
PCB-153	17	0.42	0.45	0.14	0.19	0.20	0.26	0.33	0.92	1.60	0.31	0.30
PCB-169	0	------	------	------	------	------	------	------	------	------	------	------
PCB-170	0	------	------	------	------	------	------	------	------	------	------	------
PCB-180	4	0.16	0.04	0.11	0.12	0.13	0.16	0.19	0.20	0.21	0.16	0.12
PCB-187	3	0.19	0.05	0.14	0.15	0.16	0.18	0.21	0.23	0.24	0.18	0.12
PCB-195	0	------	------	------	------	------	------	------	------	------	------	------
PCB-206	1	0.25	------	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	------
PCB-209	3	0.24	0.14	0.11	0.13	0.17	0.23	0.31	0.35	0.38	0.21	0.27
AROCLOR-1016	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1016/1242	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1221	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1232	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1242	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1248	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1254	5	8.44	9.91	2.70	3.06	3.60	3.60	6.30	18.12	26	5.64	0.39
AROCLOR-1260	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1262	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1268	0	------	------	------	------	------	------	------	------	------	------	------
Commencement Bay												
PCB-008	1	1.20	-------	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	-------
PCB-018	10	0.50	0.41	0.21	0.22	0.28	0.31	0.48	1.13	1.40	0.40	0.28
PCB-028	22	69.17	188.53	0.14	0.18	0.21	0.34	0.86	128.10	738	1.20	1.21
PCB-044	33	3297.73	18438.70	0.44	0.50	0.56	0.89	40.00	422.20	106000	5.33	1.32
PCB-052	34	40.74	83.59	0.28	0.33	0.53	0.80	40.00	149.90	315	3.05	1.06
PCB-066	27	3116.09	15965.68	0.11	0.25	0.38	0.92	20.00	122.20	83000	2.82	1.34
PCB-077	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-101	39	620.49	3375.79	0.31	0.55	0.73	1.40	20.00	57.00	21000	4.17	1.08
PCB-105	26	835.68	4113.38	0.07	0.08	0.13	0.37	15.20	181.00	21000	1.27	1.43
PCB-110	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-118	36	610.94	3495.68	0.24	0.39	0.47	1.50	40.25	128.50	21000	4.15	1.15
PCB-126	1	1.20	-------	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	-------
PCB-128	32	700.90	3706.47	0.24	0.39	0.69	5.15	40.25	119.70	21000	6.78	1.16
PCB-138	40	557.93	3316.58	0.20	0.45	0.66	1.40	20.00	110.10	21000	3.58	1.09
PCB-153	42	2012.28	12817.50	0.41	0.52	0.75	1.45	40.00	127.90	83100	4.52	1.14
PCB-169	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-170	25	92.10	259.71	0.13	0.28	0.49	0.77	41.00	121.60	1090	3.36	1.20
PCB-180	36	2630.41	14823.84	0.24	0.40	0.55	0.97	40.00	124.50	89000	4.58	1.30
PCB-187	32	730.24	3882.55	0.18	0.35	0.52	0.95	41.00	229.60	22000	4.32	1.25
PCB-195	9	141.12	383.77	0.05	0.07	0.10	0.17	0.37	319.20	1160	0.75	1.56
PCB-206	25	1027.82	4407.74	0.05	0.11	0.20	1.00	4.70	349.60	22000	2.21	1.52

Congener/aroclor	N	Mean	StdDev	Min	10%tile	25%tile	Median	75%tile	90%tile	Max	Geomean	GeoSD
PCB-209	31	743.48	3946.18	0.09	0.15	0.30	1.40	15.00	111.00	22000	2.55	1.29
AROCLOR-1016	10	11.82	6.39	9.70	9.79	9.80	9.80	9.80	11.91	30	10.96	0.15
AROCLOR-1016/1242	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1221	9	20.00	0.00	20.00	20.00	20.00	20.00	20.00	20.00	20	20.00	0.00
AROCLOR-1232	9	9.90	0.05	9.80	9.88	9.90	9.90	9.90	9.92	10	9.90	0.00
AROCLOR-1242	11	13.92	8.98	9.80	9.90	9.90	9.90	9.95	30.00	34	12.25	0.21
AROCLOR-1248	12	9.34	1.24	6.00	7.78	9.70	9.90	9.90	9.90	10	9.25	0.07
AROCLOR-1254	18	15.23	12.91	7.10	9.23	9.90	9.90	11.00	27.90	60	12.59	0.24
AROCLOR-1260	15	10.42	1.91	6.20	9.84	9.90	9.90	10.50	12.60	15	10.25	0.08
AROCLOR-1262	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1268	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
Elliott Bay												
PCB-008	6	0.51	0.32	0.25	0.27	0.29	0.35	0.71	0.91	1.00	0.44	0.25
PCB-018	18	1.04	0.75	0.21	0.39	0.55	0.79	1.33	1.94	3	0.83	0.30
PCB-028	22	2.47	1.31	0.27	1.20	1.43	2.15	3.38	4.08	6	2.09	0.29
PCB-044	25	1.41	0.78	0.49	0.64	0.70	1.40	1.90	2.46	3	1.21	0.25
PCB-052	29	2.46	1.67	0.12	1.07	1.50	2.00	3.40	4.74	7	1.87	0.39
PCB-066	26	2.17	2.09	0.16	0.77	1.03	1.50	2.68	3.60	11	1.57	0.38
PCB-077	1	7.50	-------	7.50	7.50	7.50	7.50	7.50	7.50	8	7.50	-------
PCB-101	27	6.84	4.88	0.32	1.54	3.85	5.20	10.40	13.40	19	4.83	0.44
PCB-105	29	4.13	2.97	0.18	1.54	2.40	3.30	5.90	8.46	13	3.11	0.37
PCB-110	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-118	28	5.63	4.89	0.29	2.25	3.13	4.55	5.48	9.60	24	4.20	0.36
PCB-126	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-128	28	2.24	1.85	0.45	0.77	0.90	1.65	2.93	3.80	8	1.71	0.32
PCB-138	30	9.87	8.15	0.23	2.98	5.15	7.10	11.75	21.10	36	6.80	0.45
PCB-153	30	7.80	6.09	0.11	2.11	4.23	6.05	8.75	18.10	24	5.34	0.47
PCB-169	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-170	29	3.63	3.03	0.32	0.95	1.90	2.60	3.90	9.32	11	2.64	0.36
PCB-180	30	5.85	5.50	0.11	1.19	2.53	3.95	5.93	15.10	21	3.74	0.47
PCB-187	29	3.58	3.05	0.31	0.86	1.80	2.50	4.00	8.48	12	2.57	0.37
PCB-195	24	0.80	0.62	0.12	0.27	0.40	0.59	0.92	1.84	2	0.61	0.34
PCB-206	24	1.10	1.05	0.11	0.30	0.46	0.74	1.18	2.27	5	0.77	0.38
PCB-209	24	1.01	0.78	0.20	0.34	0.52	0.73	1.23	2.00	3	0.78	0.32
AROCLOR-1016	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1016/1242	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1221	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1232	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1242	9	33.33	18.71	10.00	18.00	20.00	30.00	40.00	54.00	70	28.75	0.26
AROCLOR-1248	10	122.74	128.50	3.00	12.00	45.50	67.00	183.02	332.00	350	62.04	0.64
AROCLOR-1254	98	152.36	283.39	3.50	23.70	35.00	68.00	130.00	305.00	1700	69.85	0.50
AROCLOR-1260	99	85.98	98.87	2.20	14.80	29.50	49.00	100.00	190.00	500	52.52	0.44
AROCLOR-1262	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1268	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
Hood Canal North												
PCB-008	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-018	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-028	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-044	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-052	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-066	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-077	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-101	3	0.59	0.01	0.59	0.59	0.59	0.59	0.60	0.60	0.60	0.59	0.00
PCB-105	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-110	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-118	1	0.65	-------	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	-------
PCB-126	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------

Congener/aroclor	N	Mean	StdDev	Min	10%tile	25%tile	Median	75%tile	90%tile	Max	Geomean	GeoSD
PCB-128	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-138	3	0.72	0.03	0.70	0.70	0.70	0.70	0.73	0.74	0.75	0.72	0.02
PCB-153	3	0.74	0.02	0.71	0.72	0.73	0.75	0.75	0.75	0.75	0.74	0.01
PCB-169	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-170	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-180	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-187	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-195	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-206	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-209	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1016	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1016/1242	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1221	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1232	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1242	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1248	1	4.00	-------	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	-------
AROCLOR-1254	3	5.00	2.02	3.50	3.64	3.85	4.20	5.75	6.68	7.30	4.75	0.17
AROCLOR-1260	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1262	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1268	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
Hood Canal South												
PCB-008	0	------	------	------	------	------	------	------	------	------	------	------
PCB-018	0	------	------	------	------	------	------	------	------	------	------	------
PCB-028	2	0.25	0.00	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.00
PCB-044	0	------	------	------	------	------	------	------	------	------	------	------
PCB-052	0	------	------	------	------	------	------	------	------	------	------	------
PCB-066	2	0.19	0.00	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.00
PCB-077	0	------	------	------	------	------	------	------	------	------	------	------
PCB-101	2	0.20	0.00	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.00
PCB-105	0	------	------	------	------	------	------	------	------	------	------	------
PCB-110	3	0.22	0.05	0.16	0.18	0.21	0.25	0.25	0.25	0.25	0.22	0.11
PCB-118	6	0.26	0.09	0.17	0.17	0.18	0.25	0.35	0.36	0.36	0.25	0.16
PCB-126	0	------	------	------	------	------	------	------	------	------	------	------
PCB-128	0	------	------	------	------	------	------	------	------	------	------	------
PCB-138	11	0.38	0.26	0.12	0.17	0.21	0.26	0.57	0.79	0.79	0.31	0.29
PCB-153	12	0.42	0.29	0.16	0.16	0.21	0.26	0.75	0.83	0.84	0.34	0.29
PCB-169	0	------	------	------	------	------	------	------	------	------	------	------
PCB-170	2	0.18	0.00	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.00
PCB-180	2	0.64	0.00	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.00
PCB-187	2	0.28	0.00	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.00
PCB-195	0	------	------	------	------	------	------	------	------	------	------	------
PCB-206	0	------	------	------	------	------	------	------	------	------	------	------
PCB-209	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1016	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1016/1242	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1221	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1232	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1242	2	4.15	1.06	3.40	3.55	3.78	4.15	4.53	4.75	4.90	4.08	0.11
AROCLOR-1248	8	3.70	0.67	2.80	3.01	3.18	3.75	4.05	4.38	4.80	3.65	0.08
AROCLOR-1254	11	5.15	1.08	3.40	3.70	4.50	5.20	5.85	6.60	6.70	5.04	0.10
AROCLOR-1260	2	5.90	0.99	5.20	5.34	5.55	5.90	6.25	6.46	6.60	5.86	0.07
AROCLOR-1262	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1268	0	------	------	------	------	------	------	------	------	------	------	------
Puget Sound Main												
PCB-008	2	0.70	0.71	0.19	0.29	0.44	0.70	0.95	1.10	1.20	0.48	0.57
PCB-018	6	0.61	0.29	0.14	0.31	0.50	0.66	0.74	0.88	1.00	0.53	0.30
PCB-028	10	0.51	0.21	0.09	0.31	0.38	0.52	0.65	0.76	0.80	0.44	0.27

Congener/aroclor	N	Mean	StdDev	Min	10%tile	25%tile	Median	75%tile	90%tile	Max	Geomean	GeoSD
PCB-044	8	0.55	0.24	0.27	0.29	0.39	0.50	0.72	0.86	0.89	0.50	0.19
PCB-052	13	0.59	0.23	0.27	0.33	0.47	0.49	0.74	0.92	0.97	0.54	0.18
PCB-066	14	0.52	0.22	0.10	0.34	0.43	0.46	0.67	0.78	0.97	0.47	0.23
PCB-077	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-101	22	0.74	0.48	0.07	0.45	0.48	0.66	0.77	1.19	2.40	0.62	0.30
PCB-105	8	0.45	0.17	0.25	0.31	0.34	0.41	0.51	0.62	0.78	0.42	0.15
PCB-110	1	0.75	-------	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	-------
PCB-118	21	0.75	0.49	0.10	0.44	0.46	0.58	0.89	1.20	2.30	0.63	0.27
PCB-126	1	1.40	-------	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	-------
PCB-128	14	0.44	0.22	0.07	0.18	0.33	0.43	0.58	0.72	0.84	0.38	0.29
PCB-138	23	0.95	0.85	0.23	0.39	0.56	0.63	1.10	1.44	4.50	0.77	0.27
PCB-153	26	1.01	0.85	0.15	0.51	0.57	0.76	1.20	1.50	4.70	0.82	0.27
PCB-169	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-170	14	0.59	0.42	0.07	0.23	0.41	0.49	0.66	0.91	1.80	0.47	0.33
PCB-180	18	0.71	0.72	0.11	0.26	0.41	0.54	0.76	1.03	3.40	0.53	0.33
PCB-187	10	0.75	0.56	0.40	0.44	0.48	0.60	0.71	0.92	2.30	0.65	0.21
PCB-195	6	0.34	0.14	0.12	0.21	0.31	0.33	0.42	0.48	0.51	0.31	0.22
PCB-206	12	0.47	0.32	0.08	0.21	0.26	0.38	0.59	0.89	1.20	0.38	0.31
PCB-209	6	0.84	0.81	0.21	0.22	0.23	0.44	1.44	1.85	2.00	0.54	0.45
AROCLOR-1016	3	112.33	4.16	109.00	109.40	110	111	114	115.80	117	112.28	0.02
AROCLOR-1016/1242	1	17.00	-------	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	-------
AROCLOR-1221	3	112.33	4.16	109	109.40	110	111	114	115.80	117	112.28	0.02
AROCLOR-1232	3	112.33	4.16	109	109.40	110	111	114	115.80	117	112.28	0.02
AROCLOR-1242	6	61.47	56.43	1.59	2.90	9.65	67.50	110.50	114.00	117	25.03	0.81
AROCLOR-1248	10	35.03	43.24	1.59	6.34	8.12	14.00	38.34	111.60	117	17.13	0.58
AROCLOR-1254	63	14.59	19.72	4.00	5.80	6.75	9.00	13.80	20.76	111	10.53	0.29
AROCLOR-1260	44	13.90	22.57	4.50	5.13	6.21	7.48	11.19	17.10	117	9.24	0.30
AROCLOR-1262	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1268	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
Puget Sound South												
PCB-008	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-018	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-028	3	0.36	0.14	0.20	0.25	0.32	0.44	0.44	0.44	0.44	0.34	0.20
PCB-044	3	6.20	3.64	2.00	3.26	5.15	8.30	8.30	8.30	8.30	5.16	0.36
PCB-052	5	1.71	1.35	0.60	0.61	0.63	1.70	1.70	3.03	3.92	1.34	0.34
PCB-066	2	0.80	0.00	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.00
PCB-077	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-101	15	1.81	2.64	0.36	0.47	0.58	0.72	1.40	3.90	10.40	1.04	0.42
PCB-105	5	1.40	1.15	0.60	0.61	0.62	1.20	1.20	2.52	3.40	1.13	0.31
PCB-110	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-118	18	1.52	2.34	0.35	0.40	0.50	0.69	0.89	3.60	10.00	0.88	0.39
PCB-126	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-128	4	1.54	1.27	0.55	0.72	0.96	1.10	1.68	2.72	3.41	1.23	0.33
PCB-138	17	1.89	2.94	0.40	0.44	0.57	0.81	1.02	4.40	12.20	1.05	0.41
PCB-153	20	1.48	2.08	0.44	0.50	0.63	0.74	1.13	3.30	9.61	0.98	0.34
PCB-169	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-170	4	1.20	1.05	0.43	0.54	0.71	0.80	1.29	2.17	2.75	0.93	0.34
PCB-180	8	1.11	1.41	0.20	0.28	0.32	0.49	1.30	2.24	4.43	0.65	0.45
PCB-187	5	1.03	1.13	0.20	0.30	0.45	0.75	0.75	2.11	3.02	0.69	0.43
PCB-195	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-206	4	1.26	1.10	0.52	0.60	0.73	0.80	1.33	2.27	2.90	0.99	0.32
PCB-209	3	0.43	0.12	0.29	0.33	0.40	0.50	0.50	0.50	0.50	0.42	0.14
AROCLOR-1016	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1016/1242	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1221	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1232	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1242	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------

Congener/aroclor	N	Mean	StdDev	Min	10%tile	25%tile	Median	75%tile	90%tile	Max	Geomean	GeoSD
AROCLOR-1248	2	6.25	1.06	5.50	5.65	5.88	6.25	6.63	6.85	7.00	6.20	0.07
AROCLOR-1254	20	18.71	29.87	5.10	5.20	6.38	9.25	18.75	24.30	139	11.52	0.36
AROCLOR-1260	8	14.76	12.72	5.30	6.14	7.18	10.45	15.50	27.20	44	11.66	0.30
AROCLOR-1262	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1268	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
Sinclair/Dyes Inlet												
PCB-008	3	0.71	0.03	0.69	0.69	0.70	0.71	0.73	0.73	0.74	0.71	0.02
PCB-018	7	0.73	0.24	0.39	0.41	0.54	0.87	0.92	0.94	0.96	0.69	0.17
PCB-028	14	1.03	0.94	0.16	0.40	0.50	0.79	1.33	1.40	4.00	0.78	0.33
PCB-044	16	1.06	0.72	0.24	0.37	0.59	0.86	1.25	2.35	2.40	0.85	0.30
PCB-052	19	1.68	1.43	0.43	0.51	0.58	1.30	1.95	4.44	4.80	1.24	0.35
PCB-066	21	1.17	0.72	0.39	0.42	0.65	1.00	1.50	2.50	2.70	0.98	0.27
PCB-077	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-101	26	3.17	3.32	0.15	0.34	0.66	1.50	5.38	7.75	12.00	1.60	0.57
PCB-105	21	1.65	1.28	0.13	0.52	0.82	1.10	2.20	3.10	5.70	1.23	0.37
PCB-110	4	8.63	3.37	4.80	5.79	7.28	8.35	9.70	11.68	13.00	8.12	0.18
PCB-118	27	3.10	3.31	0.21	0.36	0.62	1.80	5.25	6.92	14.00	1.68	0.52
PCB-126	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-128	20	1.36	0.82	0.39	0.47	0.72	1.15	2.03	2.21	3.50	1.13	0.28
PCB-138	20	3.62	4.14	0.25	0.40	0.95	2.05	4.95	9.73	16.00	1.97	0.52
PCB-153	31	3.98	4.50	0.20	0.28	0.51	1.60	7.15	10.00	14.00	1.73	0.62
PCB-169	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-170	22	2.03	1.75	0.13	0.39	0.69	1.35	3.18	3.69	5.90	1.32	0.45
PCB-180	21	3.16	3.02	0.32	0.34	0.54	2.30	5.80	7.30	10.00	1.72	0.54
PCB-187	19	2.76	1.75	0.18	0.42	0.82	2.80	4.25	4.38	5.30	1.90	0.46
PCB-195	5	1.06	0.81	0.54	0.61	0.71	0.71	0.85	1.84	2.50	0.90	0.26
PCB-206	20	1.66	1.63	0.27	0.29	0.56	1.30	2.43	2.91	7.40	1.13	0.40
PCB-209	15	1.82	1.29	0.35	0.53	0.81	1.70	2.25	3.70	4.60	1.41	0.34
AROCLOR-1016	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1016/1242	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1221	5	75.20	70.58	28.00	33.20	41.00	51	56	142.40	200	57.99	0.32
AROCLOR-1232	1	300	-------	300	300	300	300	300	300	300	300	-------
AROCLOR-1242	15	44.41	63.81	3.70	7.08	7.65	36	45	72.20	260	23.68	0.50
AROCLOR-1248	5	42.18	35.40	3.70	5.10	7.20	49	71	76.40	80	23.66	0.62
AROCLOR-1254	66	190.22	282.27	2.50	11.50	17.00	83	215	545.00	1400	68.84	0.68
AROCLOR-1260	52	76.70	83.29	2.70	6.04	20.25	48	113	158.00	440	41.48	0.55
AROCLOR-1262	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1268	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
Strait of Juan de Fuca/Strait of Georgia												
PCB-008	1	0.22	-------	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	-------
PCB-018	3	0.40	0.21	0.21	0.24	0.29	0.37	0.50	0.58	0.63	0.37	0.24
PCB-028	12	0.34	0.35	0.10	0.11	0.13	0.17	0.48	0.60	1.30	0.24	0.37
PCB-044	4	0.16	0.04	0.11	0.12	0.14	0.16	0.18	0.19	0.20	0.15	0.11
PCB-052	12	0.48	0.57	0.14	0.15	0.16	0.22	0.39	1.52	1.70	0.30	0.40
PCB-066	9	0.31	0.24	0.11	0.11	0.13	0.26	0.30	0.59	0.86	0.25	0.30
PCB-077	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-101	27	0.55	0.61	0.12	0.14	0.17	0.37	0.57	1.24	2.40	0.36	0.38
PCB-105	7	0.20	0.13	0.10	0.11	0.11	0.18	0.21	0.31	0.47	0.17	0.24
PCB-110	11	0.40	0.17	0.11	0.17	0.26	0.44	0.52	0.58	0.61	0.35	0.25
PCB-118	25	0.51	0.63	0.10	0.12	0.21	0.32	0.44	0.90	2.60	0.33	0.36
PCB-126	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-128	3	0.24	0.13	0.10	0.13	0.18	0.26	0.31	0.34	0.36	0.21	0.29
PCB-138	28	0.69	0.78	0.11	0.11	0.15	0.31	0.78	2.26	2.60	0.40	0.46
PCB-153	38	0.71	0.91	0.11	0.13	0.20	0.29	0.97	1.66	3.70	0.41	0.44
PCB-169	1	1.20	-------	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	-------
PCB-170	10	0.65	0.67	0.11	0.12	0.36	0.40	0.54	1.57	2.20	0.43	0.41
PCB-180	17	0.93	1.30	0.12	0.15	0.19	0.68	0.83	2.06	4.90	0.49	0.48

Congener/aroclor	N	Mean	StdDev	Min	10%tile	25%tile	Median	75%tile	90%tile	Max	Geomean	GeoSD
PCB-187	11	0.59	0.78	0.10	0.13	0.16	0.30	0.39	1.70	2.50	0.33	0.44
PCB-195	2	0.61	0.43	0.30	0.36	0.45	0.61	0.76	0.85	0.91	0.52	0.34
PCB-206	2	1.29	0.73	0.77	0.87	1.03	1.29	1.54	1.70	1.80	1.18	0.26
PCB-209	3	27700.30	47977.55	0.12	0.25	0.45	0.77	41550.39	66480.15	83100	19.73	3.16
AROCLOR-1016	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1016/1242	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1221	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1232	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1242	14	124.10	102.14	6.00	20.18	52.75	96.50	162.50	288.00	310	77.18	0.53
AROCLOR-1248	12	10.08	8.70	3.70	5.00	5.90	6.85	7.95	26.01	29	8.04	0.27
AROCLOR-1254	26	13.36	15.57	3.20	3.85	4.05	5.65	19.25	31.50	69	8.43	0.39
AROCLOR-1260	14	10.39	12.37	1.80	2.35	3.70	6.65	8.80	23.79	46	6.71	0.39
AROCLOR-1262	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1268	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
Whidbey												
PCB-008	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-018	2	7.60	10.47	0.19	1.67	3.89	7.60	11.30	13.52	15	1.69	1.34
PCB-028	10	7.17	18.22	0.09	0.76	1.03	1.65	2.13	7.88	59	1.62	0.68
PCB-044	7	6.01	12.34	1.10	1.22	1.30	1.40	1.50	14.56	34	2.13	0.53
PCB-052	13	10.72	32.84	0.49	0.54	1.20	1.90	1.90	3.08	120	1.97	0.59
PCB-066	19	4.27	14.03	0.16	0.24	0.34	0.73	1.40	3.00	62	0.86	0.61
PCB-077	12	0.63	0.47	0.21	0.32	0.37	0.50	0.70	0.79	2	0.53	0.25
PCB-101	23	6.86	24.71	0.25	0.29	0.37	0.73	3.50	4.04	120	1.26	0.64
PCB-105	7	1.47	0.59	0.27	0.83	1.35	1.70	1.80	1.94	2	1.27	0.31
PCB-110	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-118	18	15.22	56.11	0.37	0.38	0.79	2.25	3.13	4.10	240	1.97	0.64
PCB-126	2	1.30	0.00	1.30	1.30	1.30	1.30	1.30	1.30	1	1.30	0.00
PCB-128	6	4.31	7.71	0.09	0.59	1.13	1.30	1.93	11.05	20	1.38	0.75
PCB-138	24	15.16	64.95	0.13	0.35	0.49	1.25	3.50	3.80	320	1.51	0.67
PCB-153	26	15.79	72.26	0.06	0.27	0.50	1.09	2.85	3.15	370	1.23	0.70
PCB-169	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-170	8	24.78	66.76	0.09	0.71	0.99	1.05	1.63	59.03	190	1.68	0.93
PCB-180	13	28.48	96.61	0.18	0.68	1.40	1.70	1.90	4.30	350	2.04	0.75
PCB-187	9	19.86	56.31	0.18	0.71	0.96	1.00	1.10	36.16	170	1.61	0.82
PCB-195	1	260	-------	260	260	260	260	260	260	260	260	-------
PCB-206	1	94	-------	94	94	94	94	94	94	94	94	-------
PCB-209	1	12.00	-------	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	-------
AROCLOR-1016	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1016/1242	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1221	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1232	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1242	3	9.17	2.08	6.90	7.44	8.25	9.60	10.30	10.72	11.00	9.00	0.10
AROCLOR-1248	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1254	40	36.76	72.90	3.30	5.02	7.68	18.00	33.25	52.00	440	18.28	0.46
AROCLOR-1260	23	183.99	701.50	4.70	13.40	20.50	30.00	59.00	80.60	3400	36.96	0.53
AROCLOR-1262	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
AROCLOR-1268	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------

* These PCB congeners are have been selected by Mussel Watch Project.
N = number.
StdDev = standard deviation.
Min = minimum.
Max = maximum.
Geomean = geometric mean.

Table E-3. Summary statistics for individual PCB congeners and aroclors in the 0-10cm sediment layer.

Congener/aroclor	N	Mean	StdDev	Min	10%tile	25%tile	Median	75%tile	90%tile	Max	Geomean	GeoSD
Admiralty Inlet												
PCB-008	1	0.16	-------	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	-------
PCB-018	0	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-028	9	0.17	0.05	0.11	0.12	0.15	0.15	0.18	0.24	0.25	0.16	0.12
PCB-044	5	0.33	0.24	0.14	0.15	0.16	0.17	0.59	0.59	0.59	0.27	0.32
PCB-052	5	0.60	0.55	0.18	0.19	0.20	0.21	1.20	1.20	1.20	0.40	0.43
PCB-066	7	0.17	0.04	0.11	0.13	0.15	0.16	0.21	0.21	0.21	0.17	0.11
PCB-077	0	------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
PCB-101	14	0.52	0.76	0.13	0.14	0.17	0.21	0.30	1.73	2.30	0.29	0.40
PCB-105	7	0.51	0.61	0.12	0.13	0.14	0.15	0.80	1.40	1.40	0.28	0.48
PCB-110	10	0.21	0.08	0.12	0.12	0.15	0.18	0.27	0.33	0.34	0.19	0.17
PCB-118	15	0.46	0.45	0.12	0.15	0.20	0.28	0.49	1.13	1.50	0.33	0.33
PCB-126	0	------	------	------	------	------	------	------	------	------	------	------
PCB-128	0	------	------	------	------	------	------	------	------	------	------	------
PCB-138	16	0.51	0.70	0.14	0.18	0.19	0.23	0.41	1.38	2.30	0.32	0.37
PCB-153	17	0.42	0.45	0.14	0.19	0.20	0.26	0.33	0.92	1.60	0.31	0.30
PCB-169	0	------	------	------	------	------	------	------	------	------	------	------
PCB-170	0	------	------	------	------	------	------	------	------	------	------	------
PCB-180	4	0.16	0.04	0.11	0.12	0.13	0.16	0.19	0.20	0.21	0.16	0.12
PCB-187	3	0.19	0.05	0.14	0.15	0.16	0.18	0.21	0.23	0.24	0.18	0.12
PCB-195	0	------	------	------	------	------	------	------	------	------	------	------
PCB-206	1	0.25	------	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	------
PCB-209	3	0.24	0.14	0.11	0.13	0.17	0.23	0.31	0.35	0.38	0.21	0.27
AROCLOR-1016	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1016/1242	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1221	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1232	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1242	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1248	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1254	5	8.44	9.91	2.70	3.06	3.60	3.60	6.30	18.12	26	5.64	0.39
AROCLOR-1260	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1262	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1268	0	------	------	------	------	------	------	------	------	------	------	------
Commencement Bay												
PCB-008	1	1.20	------	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	------
PCB-018	17	1.82	1.92	0.21	0.26	0.29	1.10	2.60	4.86	5.70	0.96	0.53
PCB-028	29	52.92	165.89	0.14	0.18	0.29	0.48	2.30	114.80	738	1.28	1.06
PCB-044	40	2721.06	16750.24	0.44	0.51	0.65	1.30	25.00	149.90	106000	4.60	1.20
PCB-052	41	34.20	77.32	0.28	0.34	0.54	1.00	20.00	117.00	315	2.87	0.97
PCB-066	33	2549.89	14442.86	0.00	0.22	0.39	0.92	6.00	99.60	83000	------	------
PCB-077	0	------	------	------	------	------	------	------	------	------	------	------
PCB-101	46	526.63	3110.22	0.31	0.60	0.82	1.85	17.50	41.50	21000	4.06	1.00
PCB-105	33	658.93	3652.17	0.07	0.08	0.20	0.68	5.00	101.60	21000	1.38	1.28
PCB-110	0	------	------	------	------	------	------	------	------	------	------	------
PCB-118	43	513.16	3198.99	0.24	0.40	0.65	2.20	35.50	107.60	21000	4.44	1.07
PCB-126	1	1.20	------	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	------
PCB-128	38	590.39	3402.50	0.24	0.46	0.66	1.70	35.00	117.90	21000	4.98	1.11
PCB-138	46	485.94	3093.28	0.20	0.47	0.69	1.75	18.00	75.00	21000	3.77	1.02
PCB-153	48	1761.47	11990.21	0.41	0.53	0.87	1.70	25.00	115.30	83100	4.64	1.06
PCB-169	0	------	------	------	------	------	------	------	------	------	------	------
PCB-170	32	72.29	231.66	0.13	0.29	0.54	0.97	25.00	102.30	1090	2.75	1.07
PCB-180	43	2203.73	13567.63	0.24	0.45	0.62	1.70	20.00	95.60	89000	4.97	1.20
PCB-187	39	599.66	3518.15	0.18	0.37	0.62	1.90	40.00	135.80	22000	3.92	1.14
PCB-195	15	85.15	298.65	0.05	0.09	0.14	0.62	1.30	66.20	1160	0.88	1.19
PCB-206	32	805.11	3901.80	0.05	0.11	0.27	1.40	11.25	128.10	22000	2.86	1.37

Congener/aroclor	N	Mean	StdDev	Min	10%tile	25%tile	Median	75%tile	90%tile	Max	Geomean	GeoSD
PCB-209	38	609.88	3564.75	0.09	0.15	0.38	2.05	22.25	62.70	22000	3.47	1.21
AROCLOR-1016	10	11.82	6.39	9.70	9.79	9.80	9.80	9.80	11.91	30	10.96	0.15
AROCLOR-1016/1242	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1221	9	20.00	0.00	20.00	20.00	20.00	20.00	20.00	20.00	20	20.00	0.00
AROCLOR-1232	9	9.90	0.05	9.80	9.88	9.90	9.90	9.90	9.92	10	9.90	0.00
AROCLOR-1242	11	13.92	8.98	9.80	9.90	9.90	9.90	9.95	30.00	34	12.25	0.21
AROCLOR-1248	12	9.34	1.24	6.00	7.78	9.70	9.90	9.90	9.90	10	9.25	0.07
AROCLOR-1254	27	114.15	496.96	7.10	9.86	9.90	11.00	27.50	35.60	2600	18.62	0.50
AROCLOR-1260	22	34.01	52.03	6.20	9.90	9.90	10.50	34.00	91.20	230	18.46	0.43
AROCLOR-1262	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1268	0	------	------	------	------	------	------	------	------	------	------	------
Elliott Bay												
PCB-008	6	0.51	0.32	0.25	0.27	0.29	0.35	0.71	0.91	1.00	0.44	0.25
PCB-018	18	1.04	0.75	0.21	0.39	0.55	0.79	1.33	1.94	3	0.83	0.30
PCB-028	22	2.47	1.31	0.27	1.20	1.43	2.15	3.38	4.08	6	2.09	0.29
PCB-044	25	1.41	0.78	0.49	0.64	0.70	1.40	1.90	2.46	3	1.21	0.25
PCB-052	29	2.46	1.67	0.12	1.07	1.50	2.00	3.40	4.74	7	1.87	0.39
PCB-066	26	2.17	2.09	0.16	0.77	1.03	1.50	2.68	3.60	11	1.57	0.38
PCB-077	1	7.50	------	7.50	7.50	7.50	7.50	7.50	7.50	8	7.50	------
PCB-101	27	6.84	4.88	0.32	1.54	3.85	5.20	10.40	13.40	19	4.83	0.44
PCB-105	29	4.13	2.97	0.18	1.54	2.40	3.30	5.90	8.46	13	3.11	0.37
PCB-110	0	------	------	------	------	------	------	------	------	------	------	------
PCB-118	28	5.63	4.89	0.29	2.25	3.13	4.55	5.48	9.60	24	4.20	0.36
PCB-126	0	------	------	------	------	------	------	------	------	------	------	------
PCB-128	28	2.24	1.85	0.45	0.77	0.90	1.65	2.93	3.80	8	1.71	0.32
PCB-138	30	9.87	8.15	0.23	2.98	5.15	7.10	11.75	21.10	36	6.80	0.45
PCB-153	30	7.80	6.09	0.11	2.11	4.23	6.05	8.75	18.10	24	5.34	0.47
PCB-169	0	------	------	------	------	------	------	------	------	------	------	------
PCB-170	29	3.63	3.03	0.32	0.95	1.90	2.60	3.90	9.32	11	2.64	0.36
PCB-180	30	5.85	5.50	0.11	1.19	2.53	3.95	5.93	15.10	21	3.74	0.47
PCB-187	29	3.58	3.05	0.31	0.86	1.80	2.50	4.00	8.48	12	2.57	0.37
PCB-195	24	0.80	0.62	0.12	0.27	0.40	0.59	0.92	1.84	2	0.61	0.34
PCB-206	24	1.10	1.05	0.11	0.30	0.46	0.74	1.18	2.27	5	0.77	0.38
PCB-209	24	1.01	0.78	0.20	0.34	0.52	0.73	1.23	2.00	3	0.78	0.32
AROCLOR-1016	1	19.00	------	19.00	19.00	19.00	19.00	19.00	19.00	19	19.00	------
AROCLOR-1016/1242	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1221	2	19.50	0.71	19.00	19.10	19.25	19.50	19.75	19.90	20	19.49	0.02
AROCLOR-1232	1	20.00	------	20.00	20.00	20.00	20.00	20.00	20.00	20	20.00	------
AROCLOR-1242	10	32.00	18.14	10.00	19.00	20.00	25.00	40.00	52.00	70	27.73	0.25
AROCLOR-1248	22	87.46	109.62	3.00	7.45	12.25	40.50	81.00	273.64	350	38.05	0.62
AROCLOR-1254	127	152.46	289.48	3.50	18.00	32.00	68.00	135.00	298.00	1700	67.39	0.52
AROCLOR-1260	142	86.58	109.65	2.20	15.10	28.25	49.50	100.00	190.00	850	52.38	0.44
AROCLOR-1262	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1268	0	------	------	------	------	------	------	------	------	------	------	------
Hood Canal North												
PCB-008	0	------	------	------	------	------	------	------	------	------	------	------
PCB-018	0	------	------	------	------	------	------	------	------	------	------	------
PCB-028	0	------	------	------	------	------	------	------	------	------	------	------
PCB-044	0	------	------	------	------	------	------	------	------	------	------	------
PCB-052	0	------	------	------	------	------	------	------	------	------	------	------
PCB-066	0	------	------	------	------	------	------	------	------	------	------	------
PCB-077	0	------	------	------	------	------	------	------	------	------	------	------
PCB-101	3	0.59	0.01	0.59	0.59	0.59	0.59	0.60	0.60	0.60	0.59	0.00
PCB-105	0	------	------	------	------	------	------	------	------	------	------	------
PCB-110	0	------	------	------	------	------	------	------	------	------	------	------
PCB-118	1	0.65	------	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	------
PCB-126	0	------	------	------	------	------	------	------	------	------	------	------

Congener/aroclor	N	Mean	StdDev	Min	10%tile	25%tile	Median	75%tile	90%tile	Max	Geomean	GeoSD
PCB-128	0	------	------	------	------	------	------	------	------	------	------	------
PCB-138	3	0.72	0.03	0.70	0.70	0.70	0.70	0.73	0.74	0.75	0.72	0.02
PCB-153	3	0.74	0.02	0.71	0.72	0.73	0.75	0.75	0.75	0.75	0.74	0.01
PCB-169	0	------	------	------	------	------	------	------	------	------	------	------
PCB-170	0	------	------	------	------	------	------	------	------	------	------	------
PCB-180	0	------	------	------	------	------	------	------	------	------	------	------
PCB-187	0	------	------	------	------	------	------	------	------	------	------	------
PCB-195	0	------	------	------	------	------	------	------	------	------	------	------
PCB-206	0	------	------	------	------	------	------	------	------	------	------	------
PCB-209	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1016	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1016/1242	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1221	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1232	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1242	2	43.50	12.02	35.00	36.70	39.25	43.50	47.75	50.30	52.00	42.66	0.12
AROCLOR-1248	1	4.00	------	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	------
AROCLOR-1254	4	18.00	26.05	3.50	3.71	4.03	5.75	19.73	42.09	57.00	8.84	0.56
AROCLOR-1260	3	26.00	5.57	21.00	21.80	23.00	25.00	28.50	30.60	32.00	25.61	0.09
AROCLOR-1262	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1268	0	------	------	------	------	------	------	------	------	------	------	------
Hood Canal South												
PCB-008	0	------	------	------	------	------	------	------	------	------	------	------
PCB-018	0	------	------	------	------	------	------	------	------	------	------	------
PCB-028	2	0.25	0.00	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.00
PCB-044	0	------	------	------	------	------	------	------	------	------	------	------
PCB-052	0	------	------	------	------	------	------	------	------	------	------	------
PCB-066	2	0.19	0.00	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.00
PCB-077	0	------	------	------	------	------	------	------	------	------	------	------
PCB-101	2	0.20	0.00	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.00
PCB-105	0	------	------	------	------	------	------	------	------	------	------	------
PCB-110	3	0.22	0.05	0.16	0.18	0.21	0.25	0.25	0.25	0.25	0.22	0.11
PCB-118	6	0.26	0.09	0.17	0.17	0.18	0.25	0.35	0.36	0.36	0.25	0.16
PCB-126	0	------	------	------	------	------	------	------	------	------	------	------
PCB-128	0	------	------	------	------	------	------	------	------	------	------	------
PCB-138	11	0.38	0.26	0.12	0.17	0.21	0.26	0.57	0.79	0.79	0.31	0.29
PCB-153	12	0.42	0.29	0.16	0.16	0.21	0.26	0.75	0.83	0.84	0.34	0.29
PCB-169	0	------	------	------	------	------	------	------	------	------	------	------
PCB-170	2	0.18	0.00	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.00
PCB-180	2	0.64	0.00	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.00
PCB-187	2	0.28	0.00	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.00
PCB-195	0	------	------	------	------	------	------	------	------	------	------	------
PCB-206	0	------	------	------	------	------	------	------	------	------	------	------
PCB-209	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1016	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1016/1242	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1221	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1232	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1242	2	4.15	1.06	3.40	3.55	3.78	4.15	4.53	4.75	4.90	4.08	0.11
AROCLOR-1248	8	3.70	0.67	2.80	3.01	3.18	3.75	4.05	4.38	4.80	3.65	0.08
AROCLOR-1254	11	5.15	1.08	3.40	3.70	4.50	5.20	5.85	6.60	6.70	5.04	0.10
AROCLOR-1260	2	5.90	0.99	5.20	5.34	5.55	5.90	6.25	6.46	6.60	5.86	0.07
AROCLOR-1262	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1268	0	------	------	------	------	------	------	------	------	------	------	------
Puget Sound Main												
PCB-008	2	0.70	0.71	0.19	0.29	0.44	0.70	0.95	1.10	1.20	0.48	0.57
PCB-018	6	0.61	0.29	0.14	0.31	0.50	0.66	0.74	0.88	1.00	0.53	0.30
PCB-028	10	0.51	0.21	0.09	0.31	0.38	0.52	0.65	0.76	0.80	0.44	0.27

Congener/aroclor	N	Mean	StdDev	Min	10%tile	25%tile	Median	75%tile	90%tile	Max	Geomean	GeoSD
PCB-044	8	0.55	0.24	0.27	0.29	0.39	0.50	0.72	0.86	0.89	0.50	0.19
PCB-052	13	0.59	0.23	0.27	0.33	0.47	0.49	0.74	0.92	0.97	0.54	0.18
PCB-066	14	0.52	0.22	0.10	0.34	0.43	0.46	0.67	0.78	0.97	0.47	0.23
PCB-077	0	------	------	------	------	------	------	------	------	------	------	------
PCB-101	22	0.74	0.48	0.07	0.45	0.48	0.66	0.77	1.19	2.40	0.62	0.30
PCB-105	8	0.45	0.17	0.25	0.31	0.34	0.41	0.51	0.62	0.78	0.42	0.15
PCB-110	1	0.75	------	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	------
PCB-118	21	0.75	0.49	0.10	0.44	0.46	0.58	0.89	1.20	2.30	0.63	0.27
PCB-126	1	1.40	------	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	------
PCB-128	14	0.44	0.22	0.07	0.18	0.33	0.43	0.58	0.72	0.84	0.38	0.29
PCB-138	23	0.95	0.85	0.23	0.39	0.56	0.63	1.10	1.44	4.50	0.77	0.27
PCB-153	26	1.01	0.85	0.15	0.51	0.57	0.76	1.20	1.50	4.70	0.82	0.27
PCB-169	0	------	------	------	------	------	------	------	------	------	------	------
PCB-170	14	0.59	0.42	0.07	0.23	0.41	0.49	0.66	0.91	1.80	0.47	0.33
PCB-180	18	0.71	0.72	0.11	0.26	0.41	0.54	0.76	1.03	3.40	0.53	0.33
PCB-187	10	0.75	0.56	0.40	0.44	0.48	0.60	0.71	0.92	2.30	0.65	0.21
PCB-195	6	0.34	0.14	0.12	0.21	0.31	0.33	0.42	0.48	0.51	0.31	0.22
PCB-206	12	0.47	0.32	0.08	0.21	0.26	0.38	0.59	0.89	1.20	0.38	0.31
PCB-209	6	0.84	0.81	0.21	0.22	0.23	0.44	1.44	1.85	2.00	0.54	0.45
AROCLOR-1016	3	112.33	4.16	109.00	109.40	110	111	114	115.80	117	112.28	0.02
AROCLOR-1016/1242	1	17.00	------	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	------
AROCLOR-1221	3	112.33	4.16	109	109.40	110	111	114	115.80	117	112.28	0.02
AROCLOR-1232	3	112.33	4.16	109	109.40	110	111	114	115.80	117	112.28	0.02
AROCLOR-1242	6	61.47	56.43	1.59	2.90	9.65	67.50	110.50	114.00	117	25.03	0.81
AROCLOR-1248	12	34.40	39.44	1.59	6.93	9.31	18.50	42.47	104.15	117	18.72	0.53
AROCLOR-1254	72	16.22	19.07	4.00	5.80	7.15	9.86	17.75	27.60	111	11.84	0.30
AROCLOR-1260	46	15.44	23.67	4.50	5.15	6.23	7.55	12.00	25.05	117	9.90	0.33
AROCLOR-1262	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1268	0	------	------	------	------	------	------	------	------	------	------	------
Puget Sound South												
PCB-008	0	------	------	------	------	------	------	------	------	------	------	------
PCB-018	0	------	------	------	------	------	------	------	------	------	------	------
PCB-028	4	0.32	0.14	0.18	0.19	0.20	0.32	0.44	0.44	0.44	0.29	0.21
PCB-044	4	4.78	4.11	0.53	0.97	1.63	5.15	8.30	8.30	8.30	2.92	0.57
PCB-052	6	1.46	1.36	0.18	0.39	0.61	1.17	1.70	2.81	3.92	0.96	0.47
PCB-066	2	0.80	0.00	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.00
PCB-077	0	------	------	------	------	------	------	------	------	------	------	------
PCB-101	16	1.71	2.58	0.20	0.41	0.56	0.69	1.24	3.90	10.40	0.93	0.44
PCB-105	6	1.20	1.15	0.16	0.38	0.61	0.91	1.20	2.30	3.40	0.81	0.44
PCB-110	0	------	------	------	------	------	------	------	------	------	------	------
PCB-118	19	1.45	2.29	0.25	0.38	0.45	0.69	0.88	3.60	10.00	0.83	0.40
PCB-126	0	------	------	------	------	------	------	------	------	------	------	------
PCB-128	5	1.25	1.28	0.08	0.27	0.55	1.10	1.10	2.49	3.41	0.71	0.61
PCB-138	18	1.80	2.87	0.34	0.43	0.56	0.78	1.02	4.40	12.20	0.99	0.42
PCB-153	21	1.42	2.05	0.31	0.50	0.61	0.74	1.10	3.30	9.61	0.93	0.35
PCB-169	0	------	------	------	------	------	------	------	------	------	------	------
PCB-170	5	1.05	0.97	0.43	0.44	0.46	0.80	0.80	1.97	2.75	0.81	0.32
PCB-180	9	1.00	1.36	0.16	0.19	0.32	0.32	1.30	1.93	4.43	0.56	0.47
PCB-187	5	1.03	1.13	0.20	0.30	0.45	0.75	0.75	2.11	3.02	0.69	0.43
PCB-195	0	------	------	------	------	------	------	------	------	------	------	------
PCB-206	5	1.03	1.09	0.11	0.27	0.52	0.80	0.80	2.06	2.90	0.64	0.51
PCB-209	3	0.43	0.12	0.29	0.33	0.40	0.50	0.50	0.50	0.50	0.42	0.14
AROCLOR-1016	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1016/1242	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1221	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1232	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1242	1	88.00	------	88.00	88.00	88.00	88.00	88.00	88.00	88	88.00	------

Congener/aroclor	N	Mean	StdDev	Min	10%tile	25%tile	Median	75%tile	90%tile	Max	Geomean	GeoSD
AROCLOR-1248	2	6.25	1.06	5.50	5.65	5.88	6.25	6.63	6.85	7.00	6.20	0.07
AROCLOR-1254	26	21.08	27.83	5.10	5.45	8.00	10.50	21.75	35.50	139	13.81	0.36
AROCLOR-1260	8	14.76	12.72	5.30	6.14	7.18	10.45	15.50	27.20	44	11.66	0.30
AROCLOR-1262	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1268	0	------	------	------	------	------	------	------	------	------	------	------
Sinclair/Dyes Inlet												
PCB-008	3	0.71	0.03	0.69	0.69	0.70	0.71	0.73	0.73	0.74	0.71	0.02
PCB-018	7	0.73	0.24	0.39	0.41	0.54	0.87	0.92	0.94	0.96	0.69	0.17
PCB-028	14	1.03	0.94	0.16	0.40	0.50	0.79	1.33	1.40	4.00	0.78	0.33
PCB-044	16	1.06	0.72	0.24	0.37	0.59	0.86	1.25	2.35	2.40	0.85	0.30
PCB-052	19	1.68	1.43	0.43	0.51	0.58	1.30	1.95	4.44	4.80	1.24	0.35
PCB-066	21	1.17	0.72	0.39	0.42	0.65	1.00	1.50	2.50	2.70	0.98	0.27
PCB-077	0	------	------	------	------	------	------	------	------	------	------	------
PCB-101	26	3.17	3.32	0.15	0.34	0.66	1.50	5.38	7.75	12.00	1.60	0.57
PCB-105	21	1.65	1.28	0.13	0.52	0.82	1.10	2.20	3.10	5.70	1.23	0.37
PCB-110	4	8.63	3.37	4.80	5.79	7.28	8.35	9.70	11.68	13.00	8.12	0.18
PCB-118	27	3.10	3.31	0.21	0.36	0.62	1.80	5.25	6.92	14.00	1.68	0.52
PCB-126	0	------	------	------	------	------	------	------	------	------	------	------
PCB-128	20	1.36	0.82	0.39	0.47	0.72	1.15	2.03	2.21	3.50	1.13	0.28
PCB-138	20	3.62	4.14	0.25	0.40	0.95	2.05	4.95	9.73	16.00	1.97	0.52
PCB-153	31	3.98	4.50	0.20	0.28	0.51	1.60	7.15	10.00	14.00	1.73	0.62
PCB-169	0	------	------	------	------	------	------	------	------	------	------	------
PCB-170	22	2.03	1.75	0.13	0.39	0.69	1.35	3.18	3.69	5.90	1.32	0.45
PCB-180	21	3.16	3.02	0.32	0.34	0.54	2.30	5.80	7.30	10.00	1.72	0.54
PCB-187	19	2.76	1.75	0.18	0.42	0.82	2.80	4.25	4.38	5.30	1.90	0.46
PCB-195	5	1.06	0.81	0.54	0.61	0.71	0.71	0.85	1.84	2.50	0.90	0.26
PCB-206	20	1.66	1.63	0.27	0.29	0.56	1.30	2.43	2.91	7.40	1.13	0.40
PCB-209	15	1.82	1.29	0.35	0.53	0.81	1.70	2.25	3.70	4.60	1.41	0.34
AROCLOR-1016	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1016/1242	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1221	5	75.20	70.58	28.00	33.20	41.00	51	56	142.40	200	57.99	0.32
AROCLOR-1232	1	300	------	300	300	300	300	300	300	300	300	------
AROCLOR-1242	15	44.41	63.81	3.70	7.08	7.65	36	45	72.20	260	23.68	0.50
AROCLOR-1248	5	42.18	35.40	3.70	5.10	7.20	49	71	76.40	80	23.66	0.62
AROCLOR-1254	85	287.74	656.47	2.50	14.00	19.00	64	200	662.00	4290	75.72	0.70
AROCLOR-1260	67	74.32	74.40	2.70	9.28	22.00	57	100	134.00	440	45.08	0.50
AROCLOR-1262	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1268	0	------	------	------	------	------	------	------	------	------	------	------
Strait of Juan de Fuca/Strait of Georgia												
PCB-008	1	0.22	------	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	------
PCB-018	3	0.40	0.21	0.21	0.24	0.29	0.37	0.50	0.58	0.63	0.37	0.24
PCB-028	12	0.34	0.35	0.10	0.11	0.13	0.17	0.48	0.60	1.30	0.24	0.37
PCB-044	4	0.16	0.04	0.11	0.12	0.14	0.16	0.18	0.19	0.20	0.15	0.11
PCB-052	12	0.48	0.57	0.14	0.15	0.16	0.22	0.39	1.52	1.70	0.30	0.40
PCB-066	9	0.31	0.24	0.11	0.11	0.13	0.26	0.30	0.59	0.86	0.25	0.30
PCB-077	0	------	------	------	------	------	------	------	------	------	------	------
PCB-101	27	0.55	0.61	0.12	0.14	0.17	0.37	0.57	1.24	2.40	0.36	0.38
PCB-105	7	0.20	0.13	0.10	0.11	0.11	0.18	0.21	0.31	0.47	0.17	0.24
PCB-110	11	0.40	0.17	0.11	0.17	0.26	0.44	0.52	0.58	0.61	0.35	0.25
PCB-118	25	0.51	0.63	0.10	0.12	0.21	0.32	0.44	0.90	2.60	0.33	0.36
PCB-126	0	------	------	------	------	------	------	------	------	------	------	------
PCB-128	3	0.24	0.13	0.10	0.13	0.18	0.26	0.31	0.34	0.36	0.21	0.29
PCB-138	28	0.69	0.78	0.11	0.11	0.15	0.31	0.78	2.26	2.60	0.40	0.46
PCB-153	38	0.71	0.91	0.11	0.13	0.20	0.29	0.97	1.66	3.70	0.41	0.44
PCB-169	1	1.20	------	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	------
PCB-170	10	0.65	0.67	0.11	0.12	0.36	0.40	0.54	1.57	2.20	0.43	0.41
PCB-180	17	0.93	1.30	0.12	0.15	0.19	0.68	0.83	2.06	4.90	0.49	0.48

Congener/aroclor	N	Mean	StdDev	Min	10%tile	25%tile	Median	75%tile	90%tile	Max	Geomean	GeoSD
PCB-187	11	0.59	0.78	0.10	0.13	0.16	0.30	0.39	1.70	2.50	0.33	0.44
PCB-195	2	0.61	0.43	0.30	0.36	0.45	0.61	0.76	0.85	0.91	0.52	0.34
PCB-206	2	1.29	0.73	0.77	0.87	1.03	1.29	1.54	1.70	1.80	1.18	0.26
PCB-209	3	27700.30	47977.55	0.12	0.25	0.45	0.77	41550.39	66480.15	83100	19.73	3.16
AROCLOR-1016	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1016/1242	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1221	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1232	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1242	27	117.16	100.80	6.00	26.60	49.50	73.00	155.00	276.00	380	77.48	0.45
AROCLOR-1248	14	52.21	155.01	3.70	5.20	6.00	7.40	17.03	28.70	590	11.67	0.56
AROCLOR-1254	40	58.85	114.26	3.20	3.89	4.53	9.00	63.00	192.00	640	17.59	0.66
AROCLOR-1260	54	49.91	56.16	1.80	2.76	6.48	27.00	92.00	137.00	230	21.80	0.63
AROCLOR-1262	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1268	0	------	------	------	------	------	------	------	------	------	------	------
Whidbey												
PCB-008	0	------	------	------	------	------	------	------	------	------	------	------
PCB-018	2	7.60	10.47	0.19	1.67	3.89	7.60	11.30	13.52	15	1.69	1.34
PCB-028	10	7.17	18.22	0.09	0.76	1.03	1.65	2.13	7.88	59	1.62	0.68
PCB-044	7	6.01	12.34	1.10	1.22	1.30	1.40	1.50	14.56	34	2.13	0.53
PCB-052	13	10.72	32.84	0.49	0.54	1.20	1.90	1.90	3.08	120	1.97	0.59
PCB-066	19	4.27	14.03	0.16	0.24	0.34	0.73	1.40	3.00	62	0.86	0.61
PCB-077	12	0.63	0.47	0.21	0.32	0.37	0.50	0.70	0.79	2	0.53	0.25
PCB-101	23	6.86	24.71	0.25	0.29	0.37	0.73	3.50	4.04	120	1.26	0.64
PCB-105	7	1.47	0.59	0.27	0.83	1.35	1.70	1.80	1.94	2	1.27	0.31
PCB-110	0	------	------	------	------	------	------	------	------	------	------	------
PCB-118	18	15.22	56.11	0.37	0.38	0.79	2.25	3.13	4.10	240	1.97	0.64
PCB-126	2	1.30	0.00	1.30	1.30	1.30	1.30	1.30	1.30	1	1.30	0.00
PCB-128	6	4.31	7.71	0.09	0.59	1.13	1.30	1.93	11.05	20	1.38	0.75
PCB-138	24	15.16	64.95	0.13	0.35	0.49	1.25	3.50	3.80	320	1.51	0.67
PCB-153	26	15.79	72.26	0.06	0.27	0.50	1.09	2.85	3.15	370	1.23	0.70
PCB-169	0	------	------	------	------	------	------	------	------	------	------	------
PCB-170	8	24.78	66.76	0.09	0.71	0.99	1.05	1.63	59.03	190	1.68	0.93
PCB-180	13	28.48	96.61	0.18	0.68	1.40	1.70	1.90	4.30	350	2.04	0.75
PCB-187	9	19.86	56.31	0.18	0.71	0.96	1.00	1.10	36.16	170	1.61	0.82
PCB-195	1	260	------	260	260	260	260	260	260	260	260	------
PCB-206	1	94	------	94	94	94	94	94	94	94	94	------
PCB-209	1	12.00	------	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	------
AROCLOR-1016	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1016/1242	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1221	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1232	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1242	3	9.17	2.08	6.90	7.44	8.25	9.60	10.30	10.72	11.00	9.00	0.10
AROCLOR-1248	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1254	45	35.69	70.86	0.99	3.42	6.90	18.00	33.00	62.00	440	15.14	0.56
AROCLOR-1260	23	183.99	701.50	4.70	13.40	20.50	30.00	59.00	80.60	3400	36.96	0.53
AROCLOR-1262	0	------	------	------	------	------	------	------	------	------	------	------
AROCLOR-1268	0	------	------	------	------	------	------	------	------	------	------	------

* These PCB congeners are have been selected by Mussel Watch Project.
N = number.
StdDev = standard deviation.
Min = minimum.
Max = maximum.
Geomean = geometric mean.

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Appendix F. Average fraction of sum of PCB congeners/aroclors

Table F-1. Average fraction of sum of PCB congeners/aroclors represented by each PCB congener/aroclor by box model region in the 0-2 cm sediment layer.

Congener/aroclor	Admiralty Inlet	Commencement Bay	Elliott Bay	Hood Canal North	Hood Canal South	Puget Sound Main	Puget Sound South	Sinclair/ Dyes Inlet	Strait of Juan de Fuca/Georgia	Whidbey	All regions averaged
PCB CONGENER											
PCB-008	-----	0.000	-----	-----	-----	0.000	-----	-----	-----	-----	**0.000**
PCB-018	-----	0.011	-----	-----	-----	0.000	-----	-----	-----	-----	**0.006**
PCB-028	-----	0.029	-----	-----	-----	0.000	-----	-----	-----	-----	**0.015**
PCB-044	-----	0.094	-----	-----	-----	0.131	-----	-----	-----	-----	**0.113**
PCB-052	-----	0.069	-----	-----	-----	0.000	-----	-----	-----	-----	**0.035**
PCB-066	-----	0.046	-----	-----	-----	0.000	-----	-----	-----	-----	**0.023**
PCB-077	-----	0.000	-----	-----	-----	0.000	-----	-----	-----	-----	**0.000**
PCB-101	-----	0.078	-----	-----	-----	0.209	-----	-----	-----	-----	**0.144**
PCB-105	-----	0.025	-----	-----	-----	0.000	-----	-----	-----	-----	**0.013**
PCB-110	-----	0.000	-----	-----	-----	0.000	-----	-----	-----	-----	**0.000**
PCB-118	-----	0.071	-----	-----	-----	0.138	-----	-----	-----	-----	**0.104**
PCB-126	-----	0.000	-----	-----	-----	0.000	-----	-----	-----	-----	**0.000**
PCB-128	-----	0.134	-----	-----	-----	0.050	-----	-----	-----	-----	**0.092**
PCB-138	-----	0.077	-----	-----	-----	0.175	-----	-----	-----	-----	**0.126**
PCB-153	-----	0.096	-----	-----	-----	0.203	-----	-----	-----	-----	**0.150**
PCB-169	-----	0.000	-----	-----	-----	0.000	-----	-----	-----	-----	**0.000**
PCB-170	-----	0.049	-----	-----	-----	0.056	-----	-----	-----	-----	**0.053**
PCB-180	-----	0.077	-----	-----	-----	0.038	-----	-----	-----	-----	**0.057**
PCB-187	-----	0.055	-----	-----	-----	0.000	-----	-----	-----	-----	**0.028**
PCB-195	-----	0.009	-----	-----	-----	0.000	-----	-----	-----	-----	**0.005**
PCB-206	-----	0.040	-----	-----	-----	0.000	-----	-----	-----	-----	**0.020**
PCB-209	-----	0.038	-----	-----	-----	0.000	-----	-----	-----	-----	**0.019**
PCB AROCLOR											
AROCLOR-1016	-----	0.093	0.000	-----	-----	0.023	0.000	0.000	0.000	0.000	**0.016**
AROCLOR-1016/1242	-----	0.000	0.000	-----	-----	0.022	0.000	0.000	0.000	0.000	**0.003**
AROCLOR-1221	-----	0.189	0.000	-----	-----	0.023	0.000	0.040	0.000	0.000	**0.036**
AROCLOR-1232	-----	0.094	0.016	-----	-----	0.023	0.000	0.008	0.000	0.000	**0.020**
AROCLOR-1242	-----	0.177	0.032	-----	-----	0.040	0.000	0.096	0.821	0.000	**0.166**
AROCLOR-1248	-----	0.094	0.540	-----	-----	0.117	0.000	0.062	0.000	0.000	**0.116**
AROCLOR-1254	-----	0.260	0.413	-----	-----	0.463	0.000	0.224	0.179	0.674	**0.316**
AROCLOR-1260	-----	0.094	0.000	-----	-----	0.291	1.000	0.570	0.000	0.326	**0.326**
AROCLOR-1262	-----	0.000	0.000	-----	-----	0.000	0.000	0.000	0.000	0.000	**0.000**
AROCLOR-1268	-----	0.000	0.000	-----	-----	0.000	0.000	0.000	0.000	0.000	**0.000**

Table F-2. Average fraction of sum of PCB congeners/aroclors represented by each PCB congener/aroclor by box model region in the 0-5 cm sediment layer.

Congener/aroclor	Admiralty Inlet	Commencement Bay	Elliott Bay	Hood Canal North	Hood Canal South	Puget Sound Main	Puget Sound South	Sinclair/Dyes Inlet	Strait of Juan de Fuca/Georgia	Whidbey	All regions averaged
PCB CONGENER											
PCB-008	0.005	0.010	0.002	0.000	0.000	0.007	0.000	0.001	0.004	0.000	**0.003**
PCB-018	0.000	0.008	0.011	0.000	0.000	0.015	0.000	0.010	0.016	0.006	**0.007**
PCB-028	0.046	0.022	0.031	0.000	0.010	0.024	0.005	0.022	0.092	0.020	**0.027**
PCB-044	0.016	0.073	0.020	0.000	0.000	0.022	0.023	0.020	0.005	0.012	**0.019**
PCB-052	0.025	0.065	0.043	0.000	0.000	0.034	0.015	0.032	0.022	0.044	**0.028**
PCB-066	0.037	0.035	0.031	0.000	0.008	0.040	0.002	0.033	0.035	0.079	**0.030**
PCB-077	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.082	**0.008**
PCB-101	0.121	0.096	0.100	0.267	0.008	0.103	0.145	0.089	0.098	0.136	**0.116**
PCB-105	0.032	0.020	0.066	0.000	0.000	0.017	0.032	0.038	0.018	0.017	**0.024**
PCB-110	0.075	0.000	0.000	0.000	0.021	0.003	0.000	0.013	0.027	0.000	**0.014**
PCB-118	0.181	0.067	0.088	0.080	0.104	0.127	0.176	0.117	0.097	0.111	**0.115**
PCB-126	0.000	0.003	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.004	**0.001**
PCB-128	0.000	0.100	0.037	0.000	0.000	0.032	0.007	0.035	0.008	0.008	**0.023**
PCB-138	0.203	0.113	0.179	0.321	0.355	0.179	0.183	0.084	0.121	0.190	**0.193**
PCB-153	0.214	0.142	0.138	0.332	0.447	0.216	0.353	0.288	0.288	0.207	**0.262**
PCB-169	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.000	**0.001**
PCB-170	0.000	0.039	0.057	0.000	0.008	0.036	0.006	0.047	0.020	0.016	**0.023**
PCB-180	0.013	0.070	0.100	0.000	0.027	0.058	0.035	0.059	0.068	0.045	**0.048**
PCB-187	0.013	0.048	0.056	0.000	0.012	0.036	0.010	0.054	0.023	0.017	**0.027**
PCB-195	0.000	0.007	0.011	0.000	0.000	0.007	0.000	0.003	0.002	0.004	**0.003**
PCB-206	0.004	0.037	0.015	0.000	0.000	0.023	0.006	0.031	0.011	0.001	**0.013**
PCB-209	0.015	0.044	0.014	0.000	0.000	0.016	0.002	0.024	0.035	0.000	**0.015**
PCB AROCLOR											
AROCLOR-1016	0.000	0.081	0.000	0.000	0.000	0.007	0.000	0.000	0.000	0.000	**0.009**
AROCLOR-1016/1242	0.000	0.000	0.000	0.000	0.000	0.007	0.000	0.000	0.000	0.000	**0.001**
AROCLOR-1221	0.000	0.113	0.000	0.000	0.000	0.007	0.000	0.009	0.000	0.000	**0.013**
AROCLOR-1232	0.000	0.056	0.000	0.000	0.000	0.007	0.000	0.002	0.000	0.000	**0.007**
AROCLOR-1242	0.000	0.131	0.013	0.000	0.046	0.015	0.000	0.023	0.259	0.009	**0.050**
AROCLOR-1248	0.000	0.085	0.021	0.163	0.311	0.045	0.031	0.014	0.186	0.000	**0.085**
AROCLOR-1254	1.000	0.349	0.516	0.837	0.577	0.599	0.800	0.562	0.370	0.666	**0.628**
AROCLOR-1260	0.000	0.185	0.450	0.000	0.066	0.312	0.170	0.391	0.184	0.325	**0.208**
AROCLOR-1262	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	**0.000**
AROCLOR-1268	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	**0.000**

Table F-3. Average fraction of sum of PCB congeners/aroclors represented by each PCB congener/aroclor by box model region in the 0-10 cm sediment layer.

Congener/aroclor	Admiralty Inlet	Commencement Bay	Elliott Bay	Hood Canal North	Hood Canal South	Puget Sound Main	Puget Sound South	Sinclair/Dyes Inlet	Strait of Juan de Fuca/Georgia	Whidbey	All regions averaged
PCB CONGENER											
PCB-008	0.005	0.009	0.002	0.000	0.000	0.007	0.000	0.001	0.004	0.000	**0.003**
PCB-018	0.000	0.014	0.011	0.000	0.000	0.015	0.000	0.010	0.016	0.006	**0.007**
PCB-028	0.046	0.022	0.031	0.000	0.010	0.024	0.008	0.022	0.092	0.020	**0.028**
PCB-044	0.016	0.067	0.020	0.000	0.000	0.022	0.030	0.020	0.005	0.012	**0.019**
PCB-052	0.025	0.060	0.043	0.000	0.000	0.034	0.017	0.032	0.022	0.044	**0.028**
PCB-066	0.037	0.032	0.031	0.000	0.008	0.040	0.002	0.033	0.035	0.079	**0.030**
PCB-077	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.082	**0.008**
PCB-101	0.121	0.090	0.100	0.267	0.008	0.103	0.141	0.089	0.098	0.136	**0.115**
PCB-105	0.032	0.021	0.066	0.000	0.000	0.017	0.033	0.038	0.018	0.017	**0.024**
PCB-110	0.075	0.000	0.000	0.000	0.021	0.003	0.000	0.013	0.027	0.000	**0.014**
PCB-118	0.181	0.073	0.088	0.080	0.104	0.127	0.173	0.117	0.097	0.111	**0.115**
PCB-126	0.000	0.003	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.004	**0.001**
PCB-128	0.000	0.088	0.037	0.000	0.000	0.032	0.008	0.035	0.008	0.008	**0.022**
PCB-138	0.203	0.106	0.179	0.321	0.355	0.179	0.180	0.084	0.121	0.190	**0.192**
PCB-153	0.214	0.132	0.138	0.332	0.447	0.216	0.342	0.288	0.288	0.207	**0.260**
PCB-169	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.000	**0.001**
PCB-170	0.000	0.037	0.057	0.000	0.008	0.036	0.012	0.047	0.020	0.016	**0.023**
PCB-180	0.013	0.076	0.100	0.000	0.027	0.058	0.036	0.059	0.068	0.045	**0.048**
PCB-187	0.013	0.047	0.056	0.000	0.012	0.036	0.009	0.054	0.023	0.017	**0.027**
PCB-195	0.000	0.008	0.011	0.000	0.000	0.007	0.000	0.003	0.002	0.004	**0.003**
PCB-206	0.004	0.048	0.015	0.000	0.000	0.023	0.007	0.031	0.011	0.001	**0.014**
PCB-209	0.015	0.069	0.014	0.000	0.000	0.016	0.002	0.024	0.035	0.000	**0.018**
PCB AROCLOR											
AROCLOR-1016	0.000	0.052	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.000	**0.006**
AROCLOR-1016/1242	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.000	**0.001**
AROCLOR-1221	0.000	0.073	0.001	0.000	0.000	0.006	0.000	0.007	0.000	0.000	**0.009**
AROCLOR-1232	0.000	0.036	0.001	0.000	0.000	0.006	0.000	0.001	0.000	0.000	**0.004**
AROCLOR-1242	0.000	0.085	0.009	0.200	0.046	0.013	0.021	0.019	0.230	0.008	**0.063**
AROCLOR-1248	0.000	0.055	0.039	0.081	0.311	0.057	0.024	0.011	0.101	0.000	**0.068**
AROCLOR-1254	1.000	0.419	0.465	0.540	0.577	0.613	0.823	0.559	0.264	0.695	**0.596**
AROCLOR-1260	0.000	0.280	0.484	0.178	0.066	0.292	0.132	0.401	0.405	0.296	**0.254**
AROCLOR-1262	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	**0.000**
AROCLOR-1268	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	**0.000**

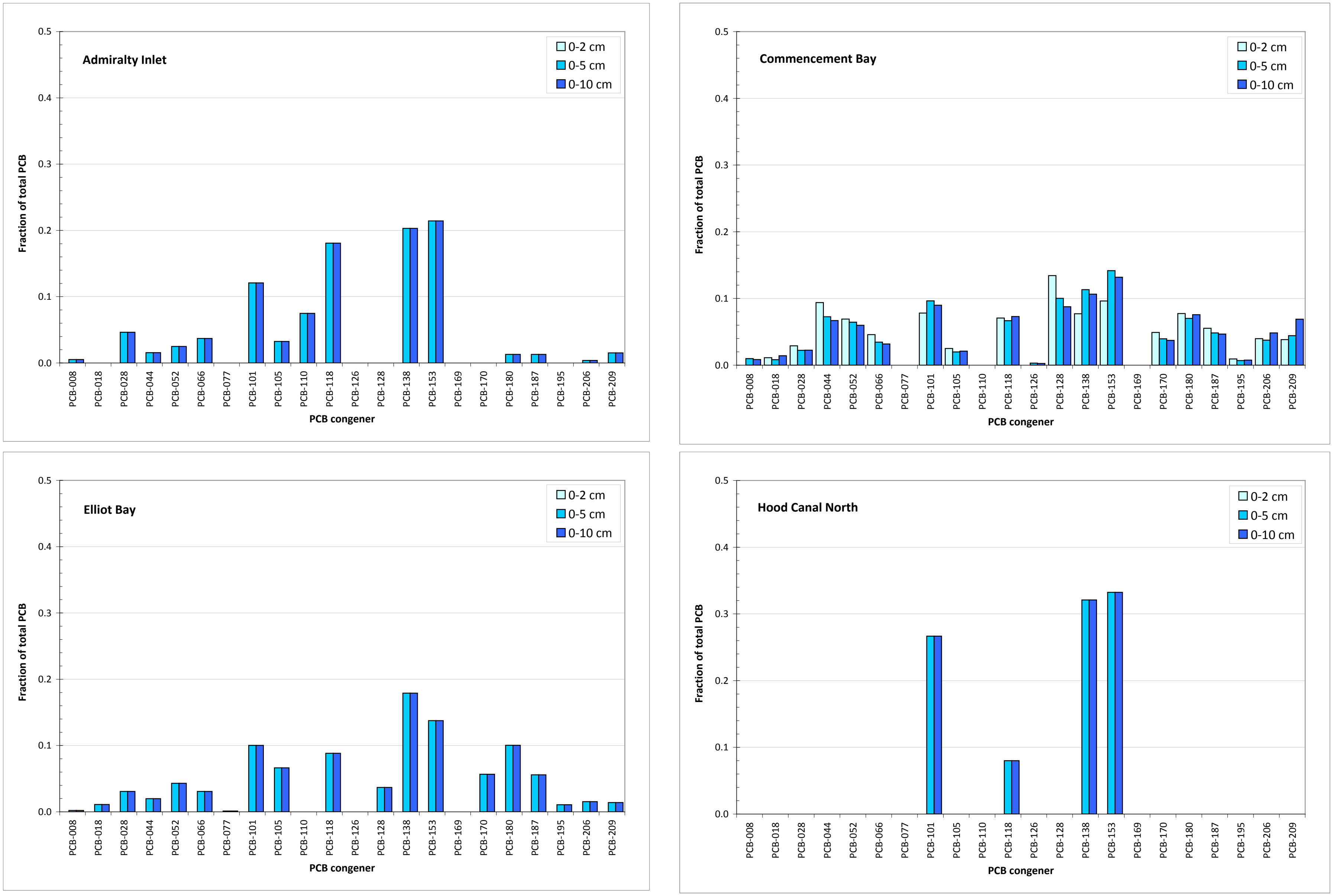


Figure F-1. Average fraction of sum of PCB congeners represented by each congener in the 0-2, 0-5, and 0-10 cm sediment layer for different regions of the box model

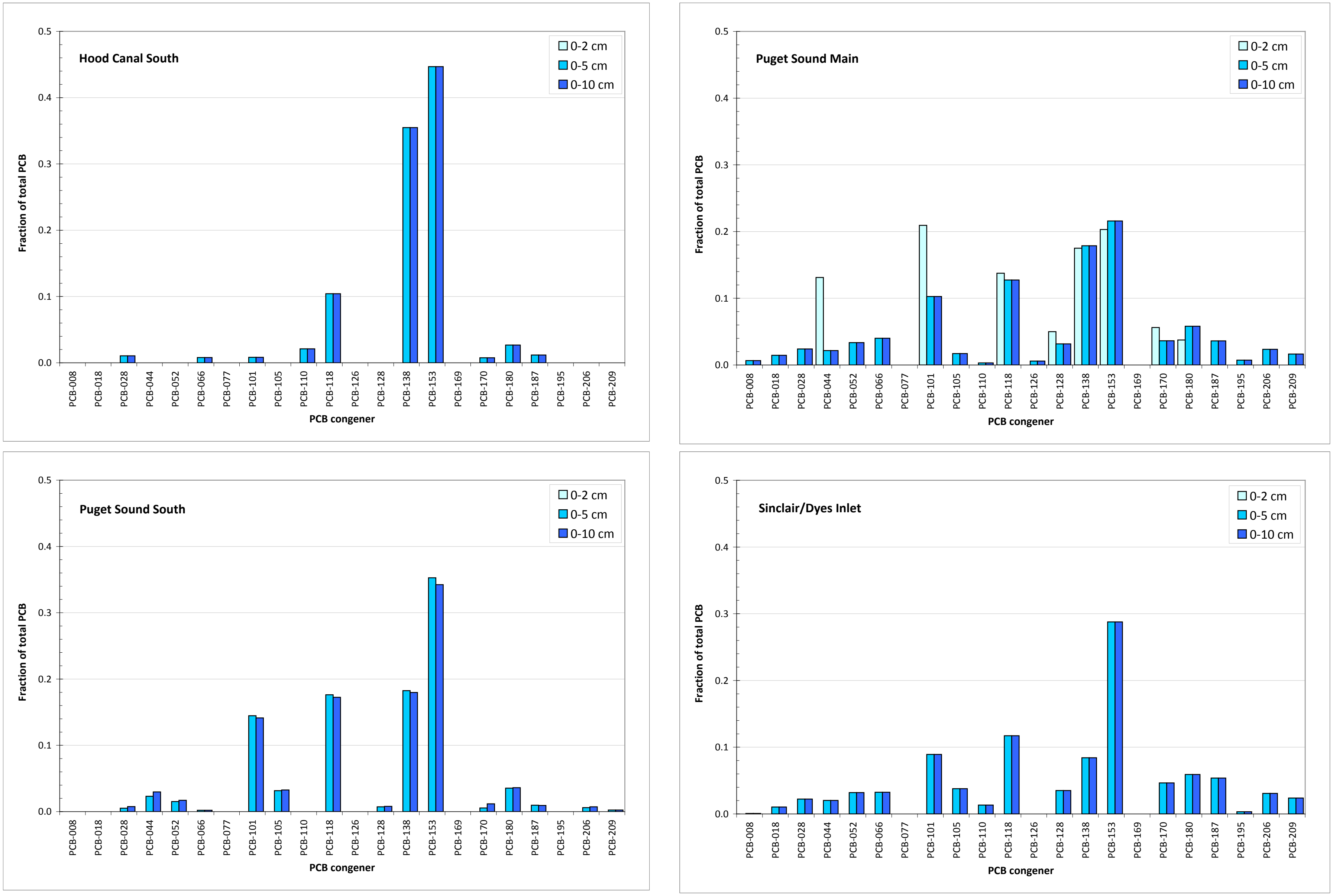
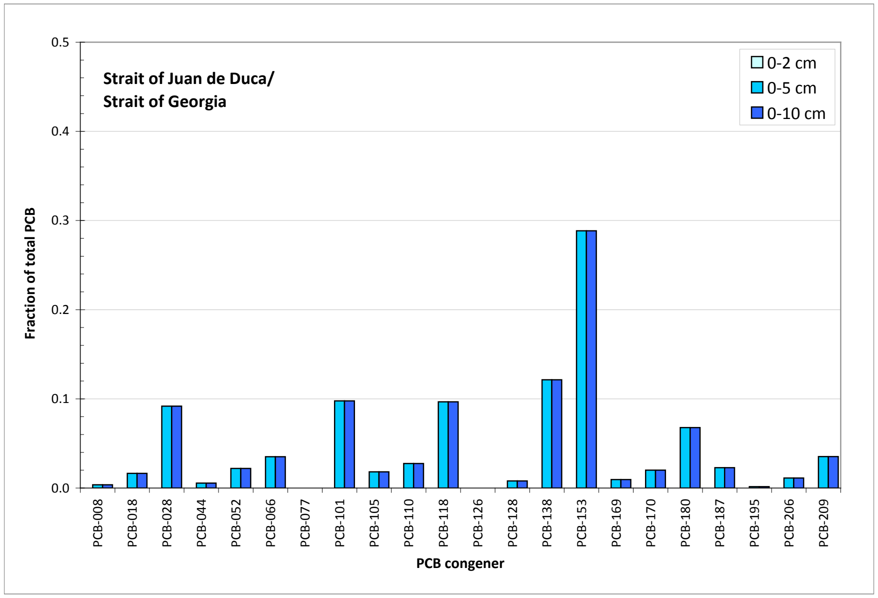


Figure F-2. Average fraction of sum of PCB congeners represented by each congener in the 0-2, 0-5, and 0-10 cm sediment layer for different regions of the box model



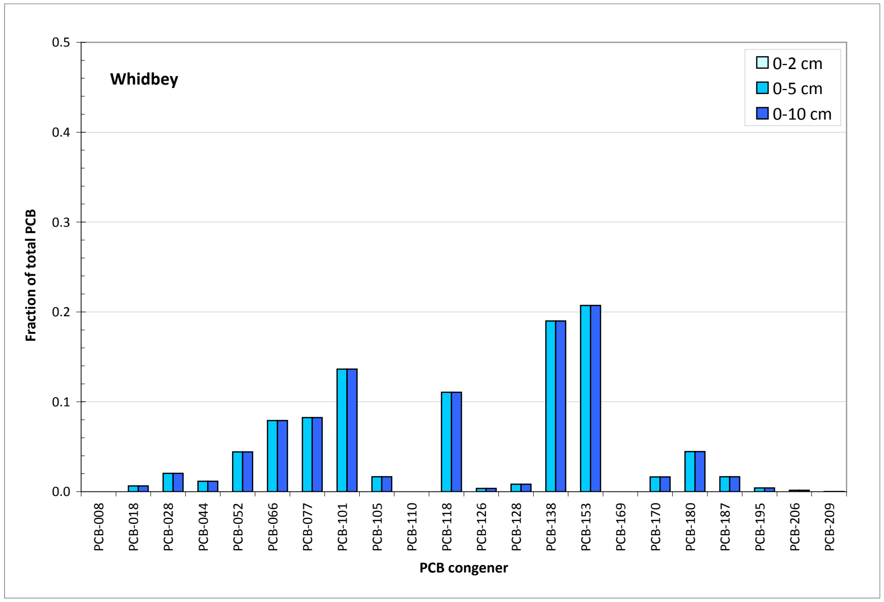


Figure F-3. Average fraction of sum of PCB congeners represented by each congener in the 0-2, 0-5, and 0-10 cm sediment layer for different regions of the box model

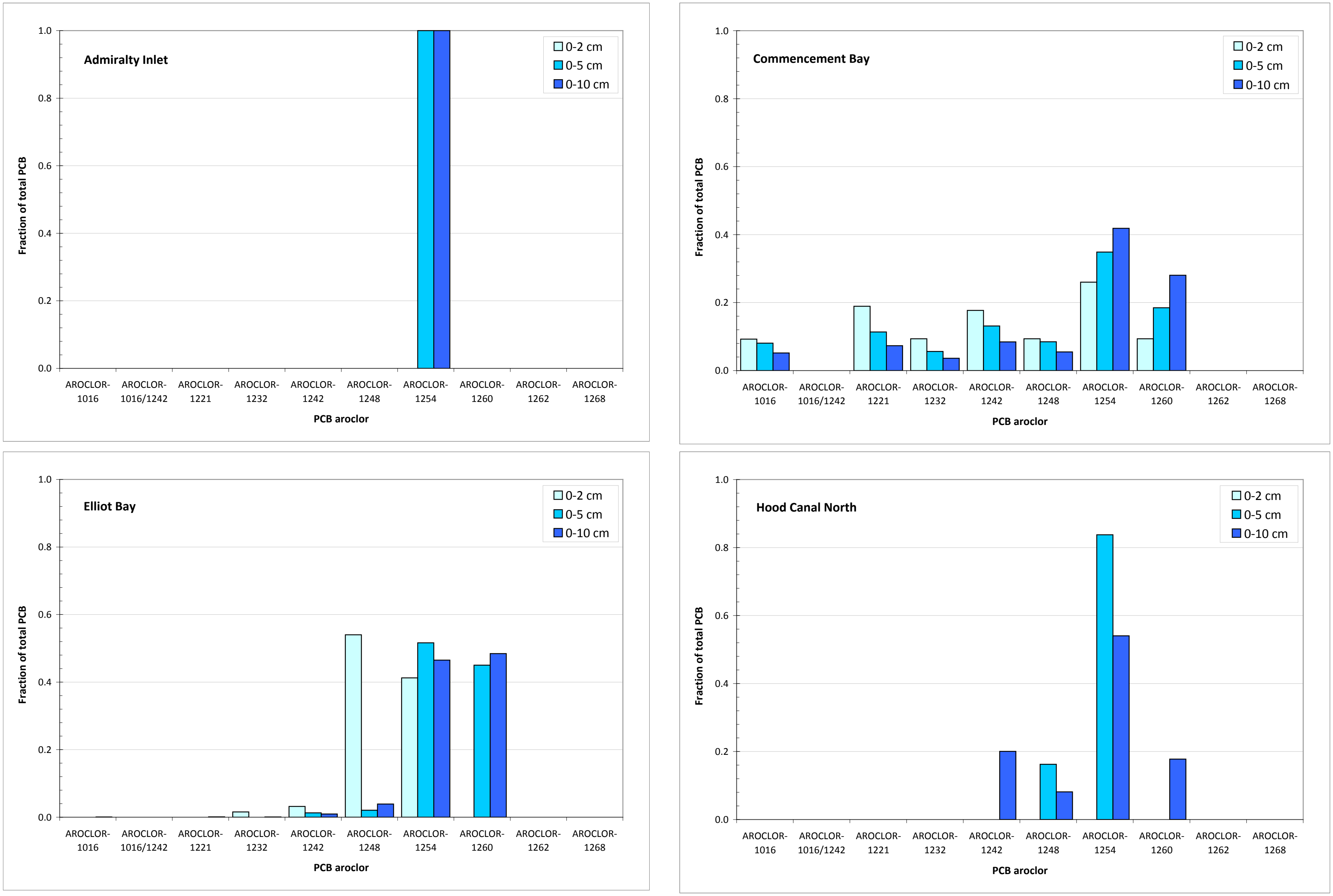


Figure F-4. Average fraction of sum of PCB aroclors represented each aroclor in the 0-2, 0-5, and 0-10 cm sediment layer for different regions of the box model

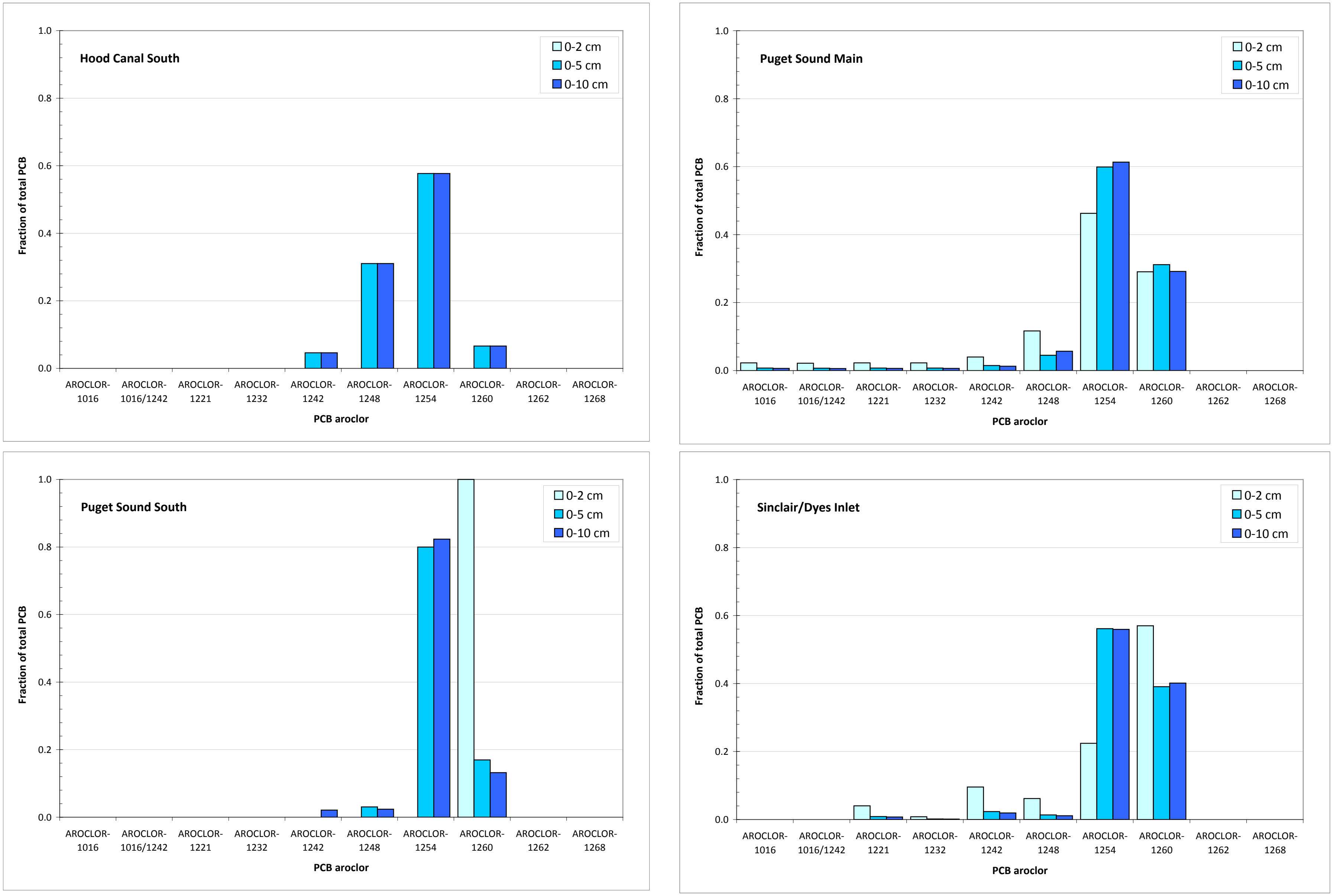


Figure F-5. Average fraction of sum of PCB aroclors represented each aroclor in the 0-2, 0-5, and 0-10 cm sediment layer for different regions of the box model

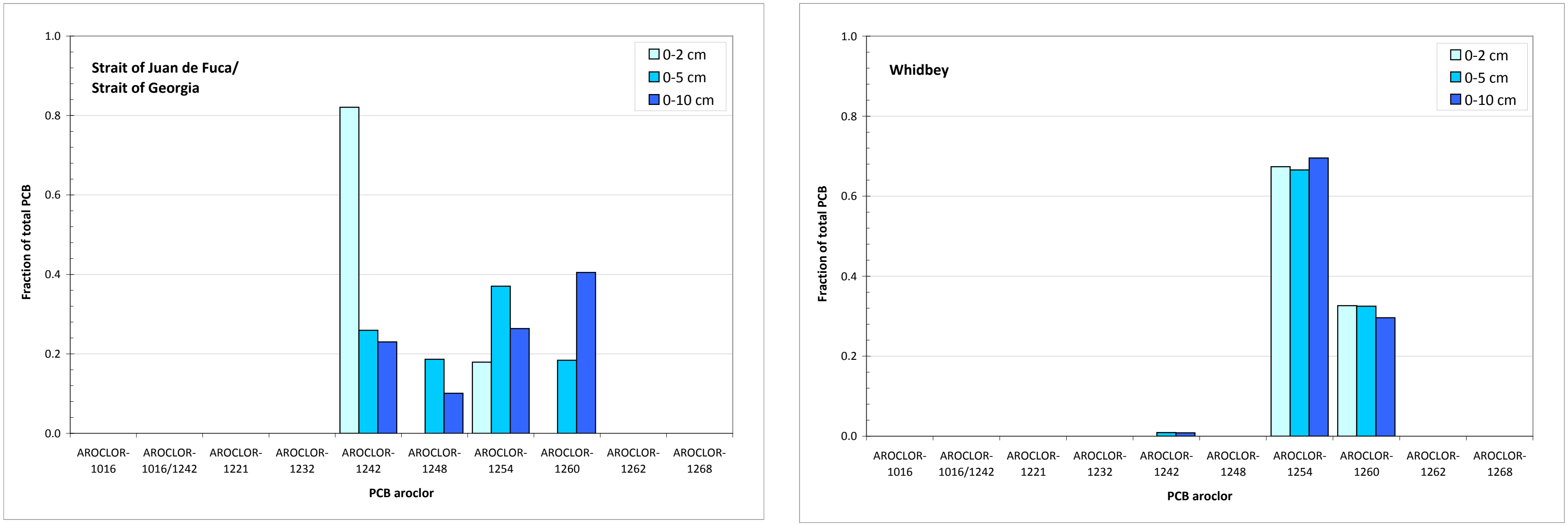


Figure F-6. Average fraction of sum of PCB aroclors represented each aroclor in the 0-2, 0-5, and 0-10 cm sediment layer for different regions of the box model

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Appendix G. Puget Sound sediment charts by Roberts (1979).

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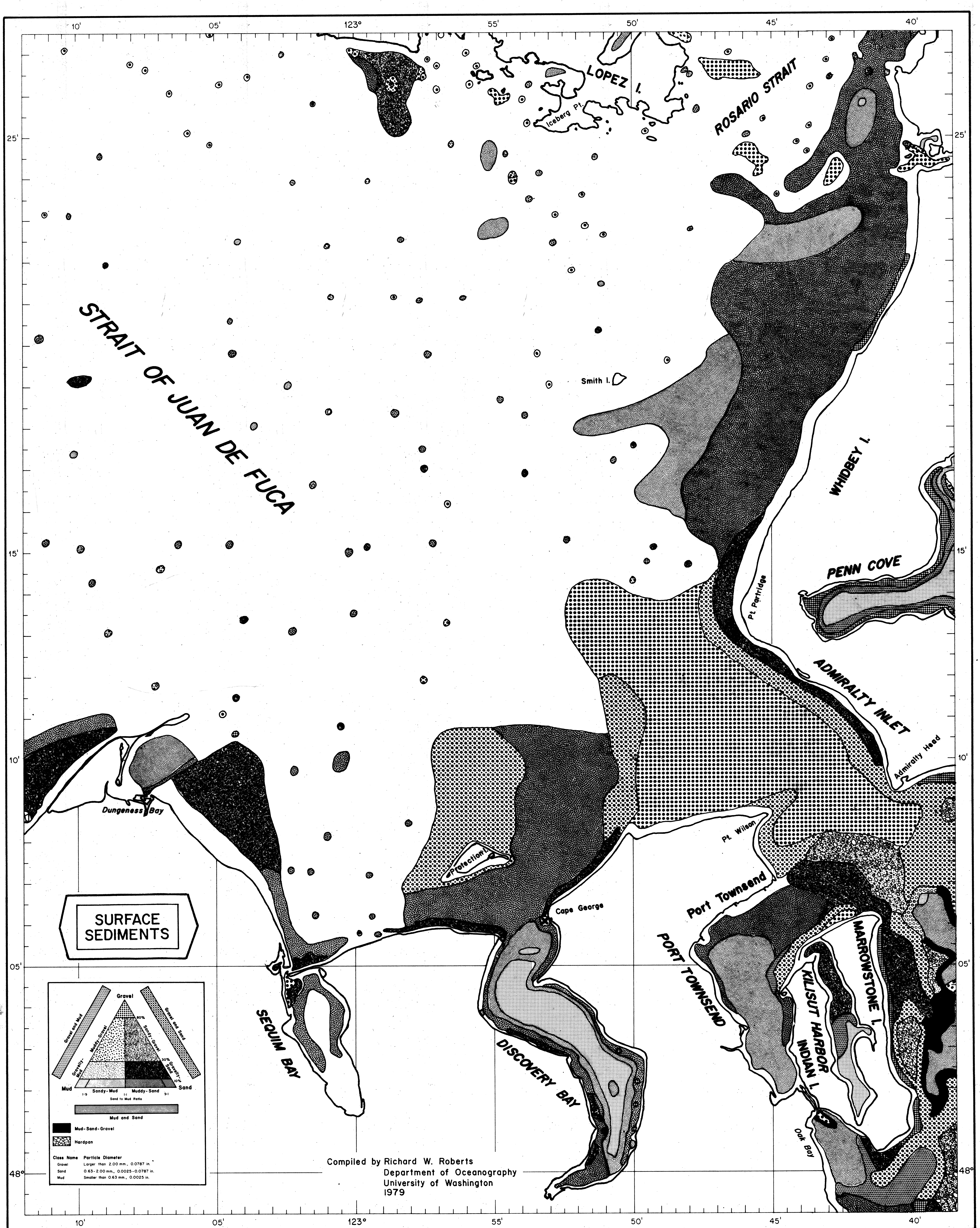
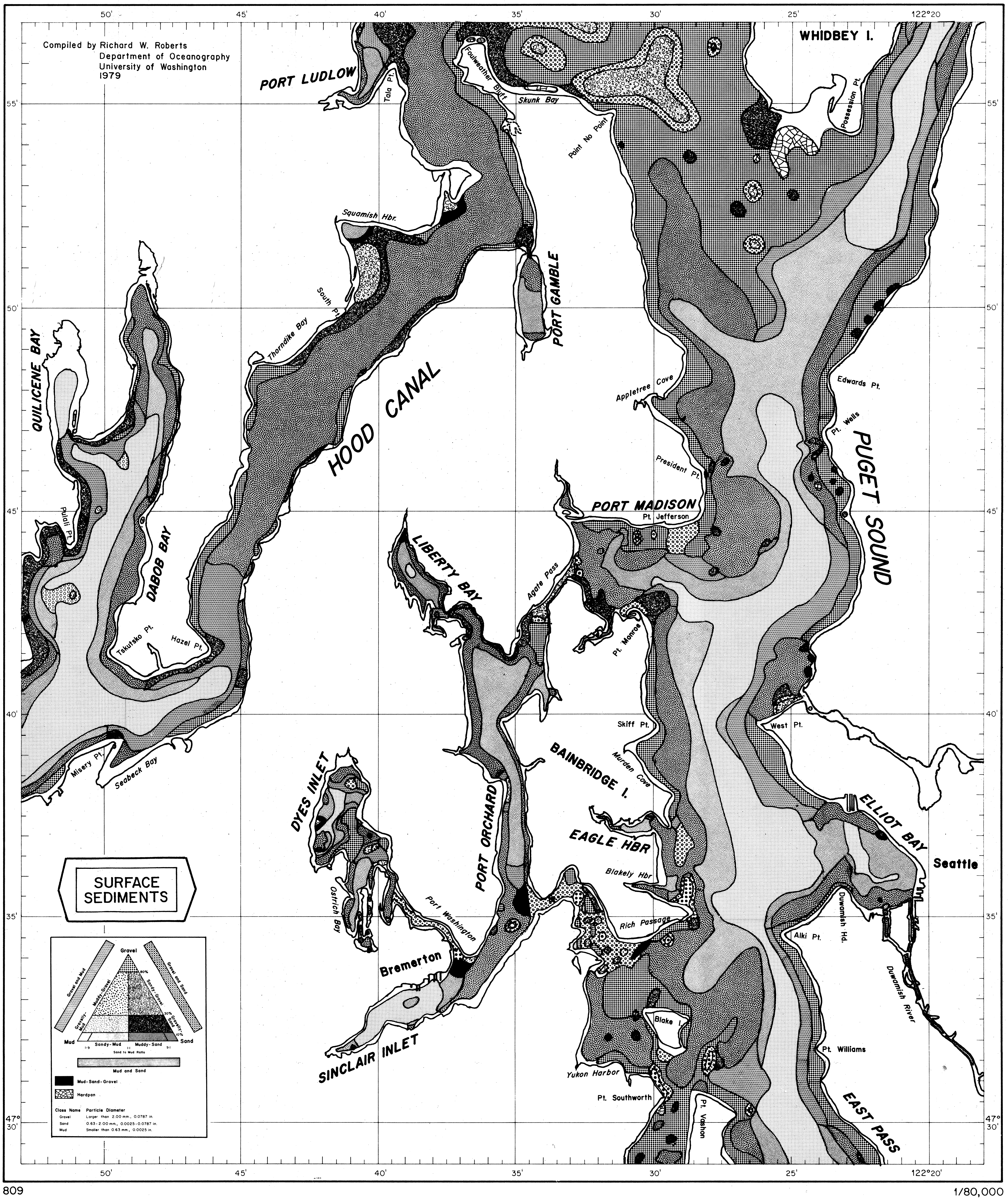
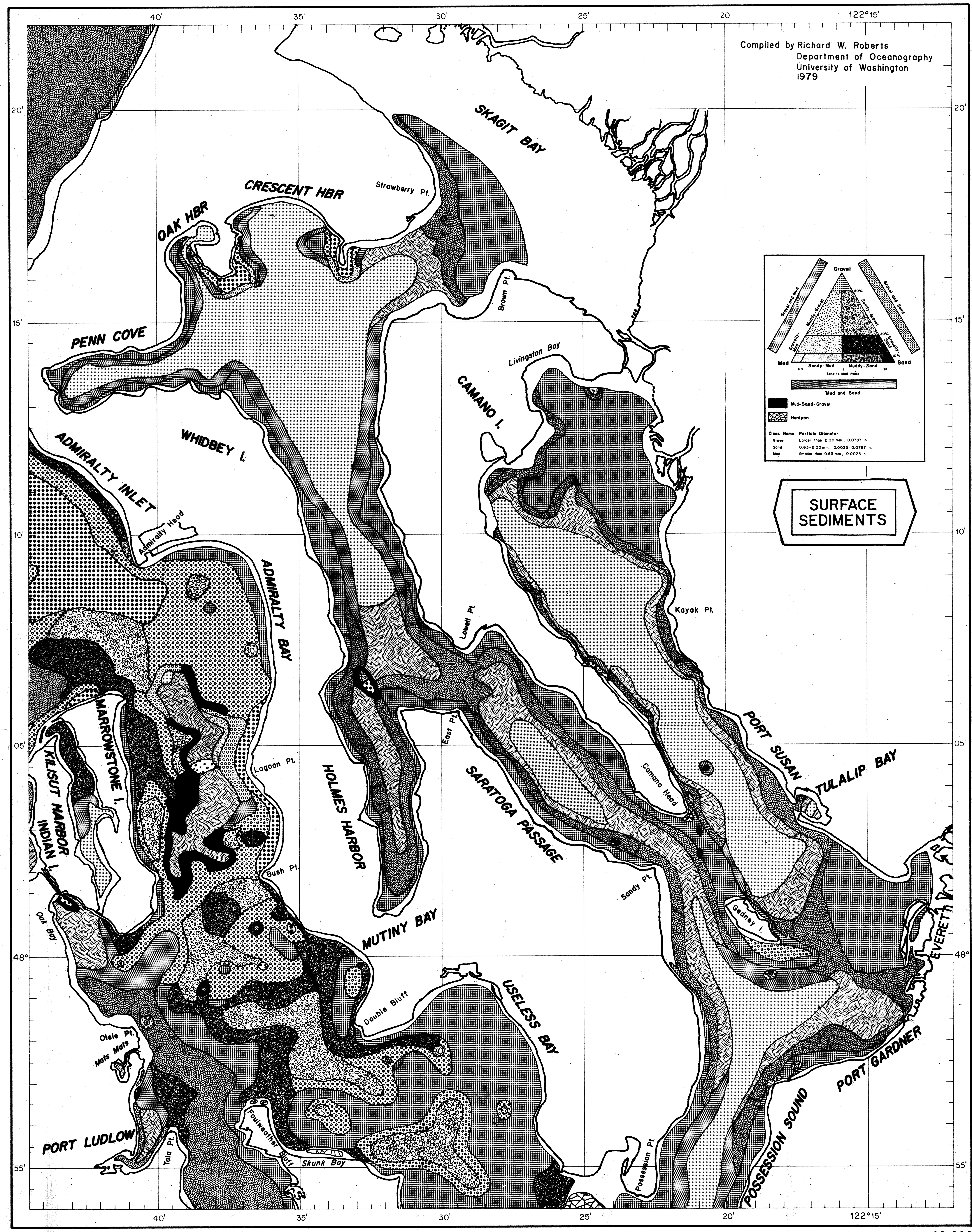

SURFACE SEDIMENTS
STRAIT OF JUAN DE FUCA
LOPEZ I.
Iceberg Pt.
ROSARIO STRAIT
Smith I.
WHIDBEY I.
PENN COVE
Pt. Partridge
ADMIRALTY INLET
Admiralty Head
Dungeness Bay
Protection I.
Cape George
Pt. Wilson
Port Townsend
PORT TOWNSEND
MARROWSTONE I.
KILISUT HARBOR
INDIAN I.
Oak Bay
SEQUIM BAY
DISCOVERY BAY
Gravel
Gravel and Mud
Gravel and Sand
Muddy-Gravel
Sandy-Gravel
80%
30%
10%
Gravelly-Mud
Gravelly-Sand
Mud
Sand
Sandy-Mud
Muddy-Sand
1:9
1:1
9:1
Sand to Mud Ratio
Mud and Sand
Mud-Sand-Gravel
Hardpan
Class Name Particle Diameter
Gravel Larger than 2.00 mm., 0.0787 in.
Sand 0.63-2.00 mm., 0.0025-0.0787 in.
Mud Smaller than 0.63 mm., 0.0025 in.
Compiled by Richard W. Roberts
Department of Oceanography
University of Washington
1979
10'
05'
123°
55'
50'
45'
40'
25'
15'
48°

807

1/80,000



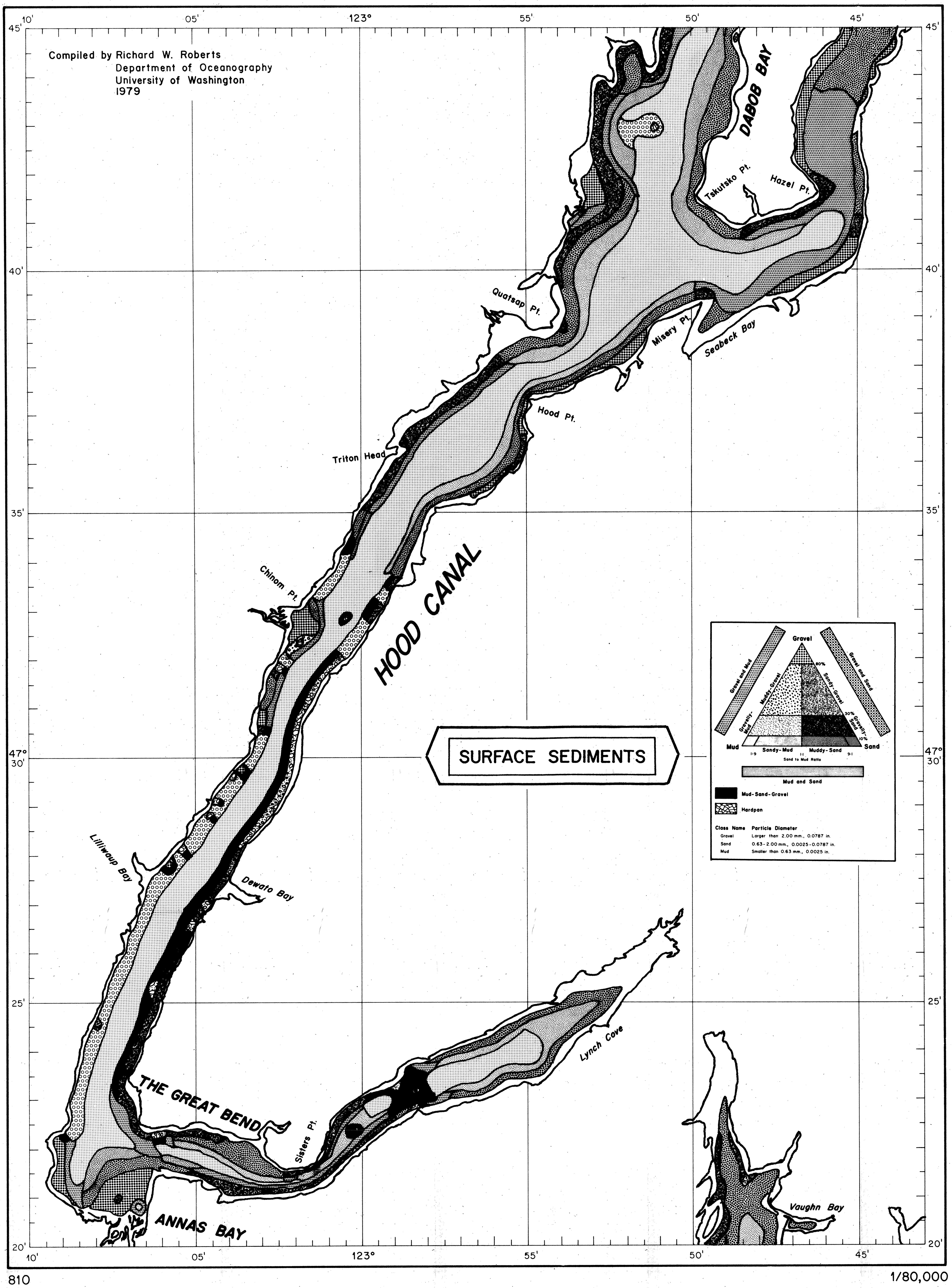
Compiled by Richard W. Roberts
Department of Oceanography
University of Washington
1979
SURFACE SEDIMENTS
Gravel
Gravel and Mud
Gravel and Sand
Muddy-Gravel
Sandy-Gravel
80%
30%
10%
Gravelly-Mud
Gravelly-Sand
Mud
Sand
Sandy-Mud
Muddy-Sand
1:9
1:1
9:1
Sand to Mud Ratio
Mud and Sand
Mud-Sand-Gravel
Hardpan
Class Name Particle Diameter
Gravel Larger than 2.00 mm., 0.0787 in.
Sand 0.63-2.00 mm., 0.0025-0.0787 in.
Mud Smaller than 0.63 mm., 0.0025 in.
50'
45'
40'
35'
30'
25'
122°20'
55'
50'
45'
40'
35'
47° 30'
WHIDBEY I.
PORT LUDLOW
Tala Pt.
Foulweather Bluff
Skunk Bay
Point No Point
Possession Pt.
Squamish Hbr.
South Pt.
Thorndike Bay
PORT GAMBLE
HOOD CANAL
QUILCENE BAY
DABOB BAY
Pulali Pt.
Tskutsko Pt.
Hazel Pt.
Misery Pt.
Seabeck Bay
Appletree Cove
President Pt.
Edwards Pt.
Pt. Wells
PUGET SOUND
PORT MADISON
Pt. Jefferson
LIBERTY BAY
Agate Pass
Pt. Monroe
Skiff Pt.
West Pt.
BAINBRIDGE I.
Murden Cove
ELLIOT BAY
Seattle
EAGLE HBR
Blakely Hbr
Rich Passage
DYES INLET
Ostrich Bay
Port Washington
PORT ORCHARD
Bremerton
SINCLAIR INLET
Alki Pt.
Duwamish Hd.
Duwamish River
Blake I.
Pt. Williams
Yukon Harbor
Pt. Southworth
Pt. Vashon
EAST PASS
809
1/80,000

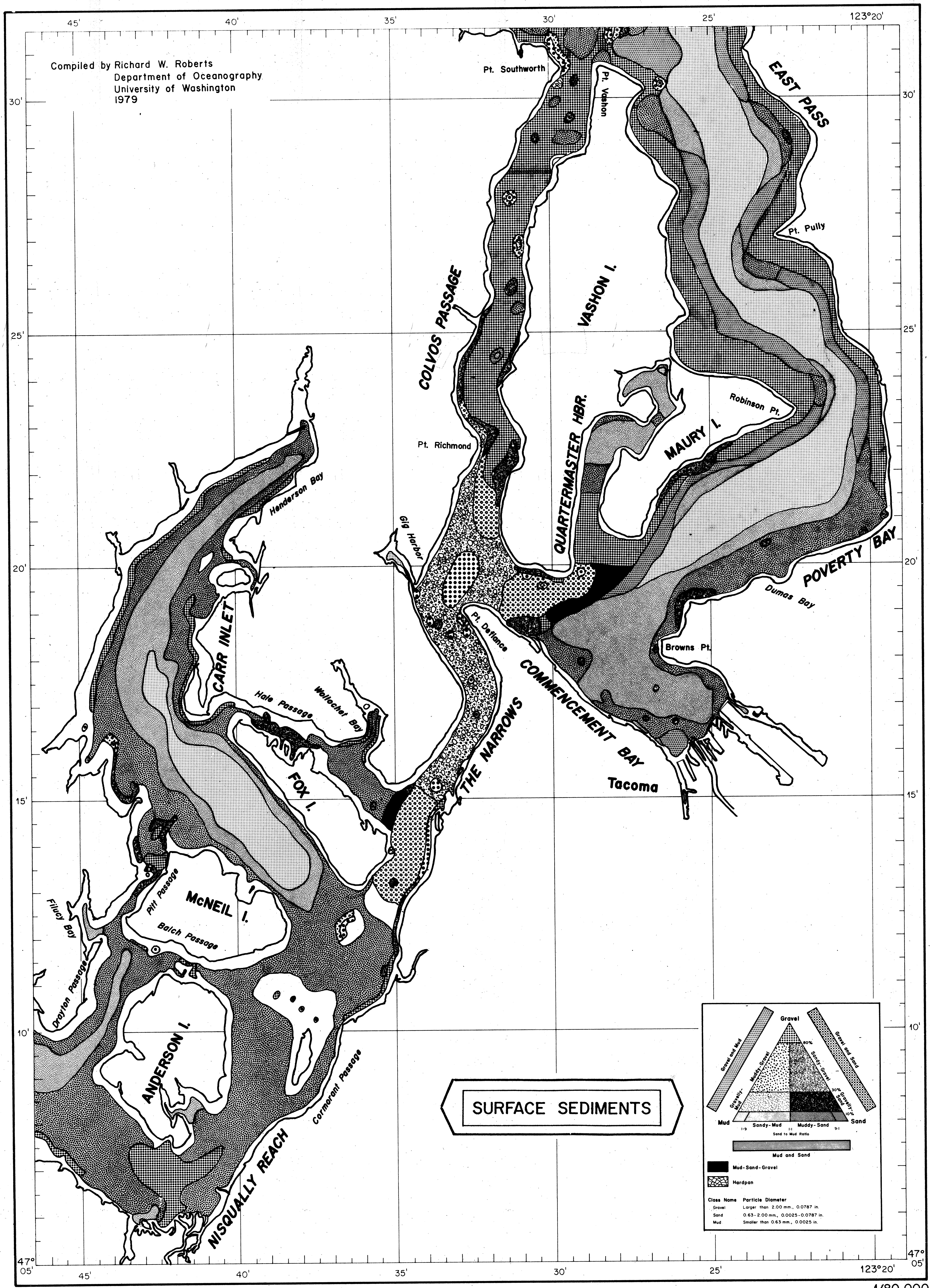


Compiled by Richard W. Roberts
Department of Oceanography
University of Washington
1979
SURFACE SEDIMENTS
Gravel
Gravel and Mud
Gravel and Sand
80%
Muddy-Gravel
Sandy-Gravel
30%
Gravelly-Mud
Gravelly-Sand
10%
Mud
Sand
Sandy-Mud
Muddy-Sand
1:9
1:1
9:1
Sand to Mud Ratio
Mud and Sand
Mud-Sand-Gravel
Hardpan
Class Name Particle Diameter
Gravel Larger than 2.00 mm., 0.0787 in.
Sand 0.63-2.00 mm., 0.0025-0.0787 in.
Mud Smaller than 0.63 mm., 0.0025 in.
40'
35'
30'
25'
20'
122°15'
20'
15'
10'
05'
48°
55'
SKAGIT BAY
CRESCENT HBR
Strawberry Pt.
OAK HBR
PENN COVE
Brown Pt.
Livingston Bay
CAMANO I.
WHIDBEY I.
ADMIRALTY INLET
Admiralty Head
ADMIRALTY BAY
Kayak Pt.
Lowell Pt.
MARROWSTONE I.
KILISUT HARBOR
INDIAN I.
Lagoon Pt.
HOLMES HARBOR
East Pt.
SARATOGA PASSAGE
Camano Head
PORT SUSAN
TULALIP BAY
Bush Pt.
Sandy Pt.
Gedney I.
Oak Bay
MUTINY BAY
EVERETT
Double Bluff
USELESS BAY
Olele Pt.
Mats Mats
PORT GARDNER
PORT LUDLOW
Tala Pt.
Foulweather Bluff
Skunk Bay
Possession Pt.
POSSESSION SOUND

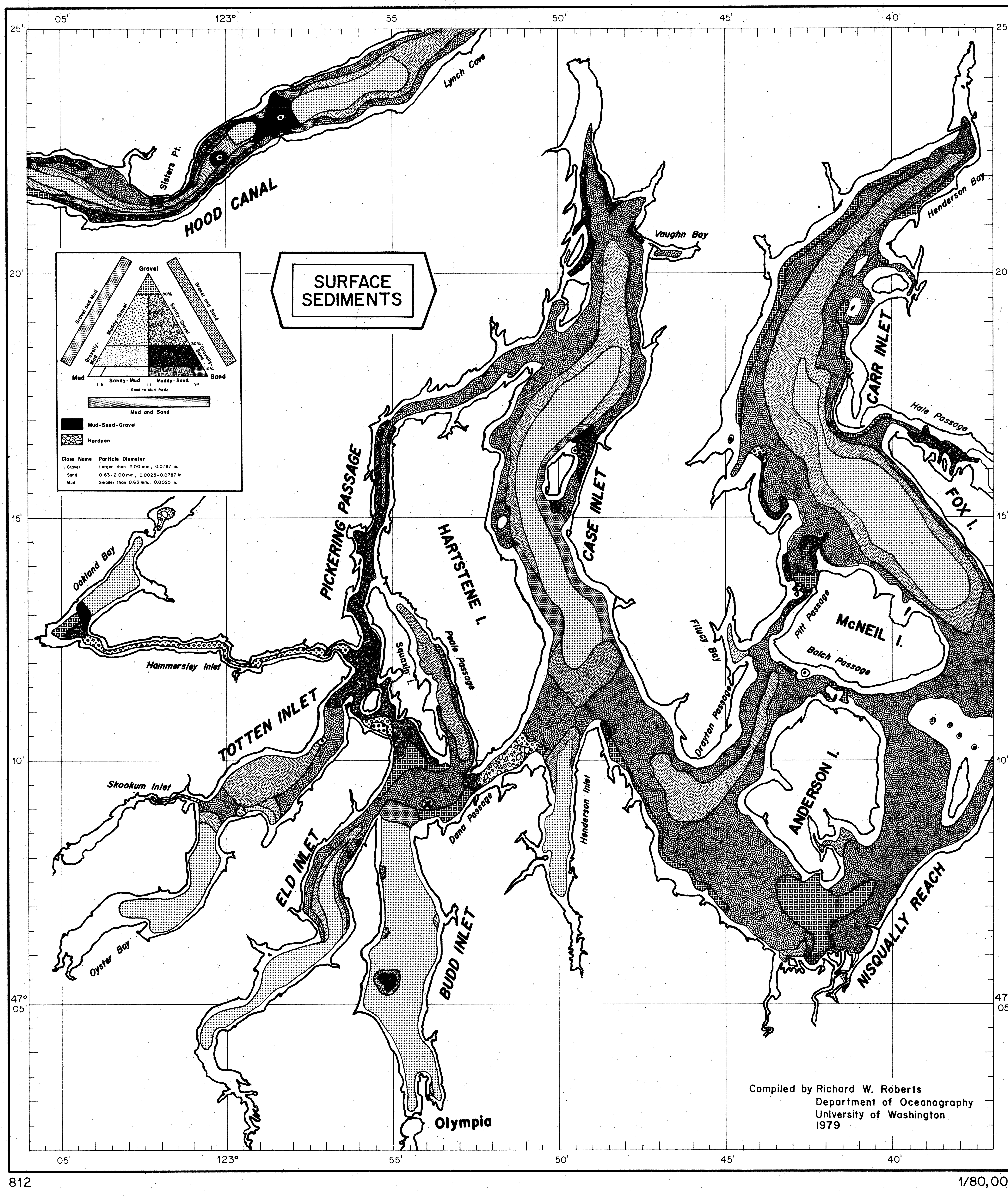
808

1/80,000


SURFACE SEDIMENTS
Compiled by Richard W. Roberts
Department of Oceanography
University of Washington
1979
HOOD CANAL
DABOB BAY
Tskutsko Pt.
Hazel Pt.
Quatsap Pt.
Misery Pt.
Seabeck Bay
Hood Pt.
Triton Head
Chinom Pt.
Lilliwaup Bay
Dewato Bay
THE GREAT BEND
Sisters Pt.
Lynch Cove
ANNAS BAY
Vaughn Bay
10'
05'
123°
55'
50'
45'
40'
35'
47°
30'
25'
20'
Gravel
Gravel and Mud
Gravel and Sand
80%
Muddy-Gravel
Sandy-Gravel
30%
Gravelly-Mud
Gravelly-Sand
10%
Mud
Sandy-Mud
Muddy-Sand
Sand
1:9
1:1
9:1
Sand to Mud Ratio
Mud and Sand
Mud-Sand-Gravel
Hardpan
Class Name Particle Diameter
Gravel Larger than 2.00 mm., 0.0787 in.
Sand 0.63 - 2.00 mm., 0.0025 - 0.0787 in.
Mud Smaller than 0.63 mm., 0.0025 in.
810
1/80,000



Compiled by Richard W. Roberts
Department of Oceanography
University of Washington
1979
SURFACE SEDIMENTS
EAST PASS
Pt. Southworth
Pt. Vashon
Pt. Pully
VASHON I.
COLVOS PASSAGE
QUARTERMASTER HBR.
MAURY I.
Robinson Pt.
Pt. Richmond
Gig Harbor
Pt. Defiance
POVERTY BAY
Dumas Bay
Browns Pt.
COMMENCEMENT BAY
Tacoma
THE NARROWS
Henderson Bay
CARR INLET
Hale Passage
Wollochet Bay
FOX I.
McNEIL I.
Pitt Passage
Balch Passage
Filucy Bay
Drayton Passage
ANDERSON I.
Cormorant Passage
NISQUALLY REACH
Gravel
Gravel and Mud
Gravel and Sand
Muddy-Gravel
Sandy-Gravel
Gravelly-Mud
Gravelly-Sand
Mud
Sand
Sandy-Mud
Muddy-Sand
Sand to Mud Ratio
Mud and Sand
Mud-Sand-Gravel
Hardpan
Class Name
Particle Diameter
Gravel
Larger than 2.00 mm., 0.0787 in.
Sand
0.63-2.00 mm., 0.0025-0.0787 in.
Mud
Smaller than 0.63 mm., 0.0025 in.
123°20'
47° 05'
811
1/80,000

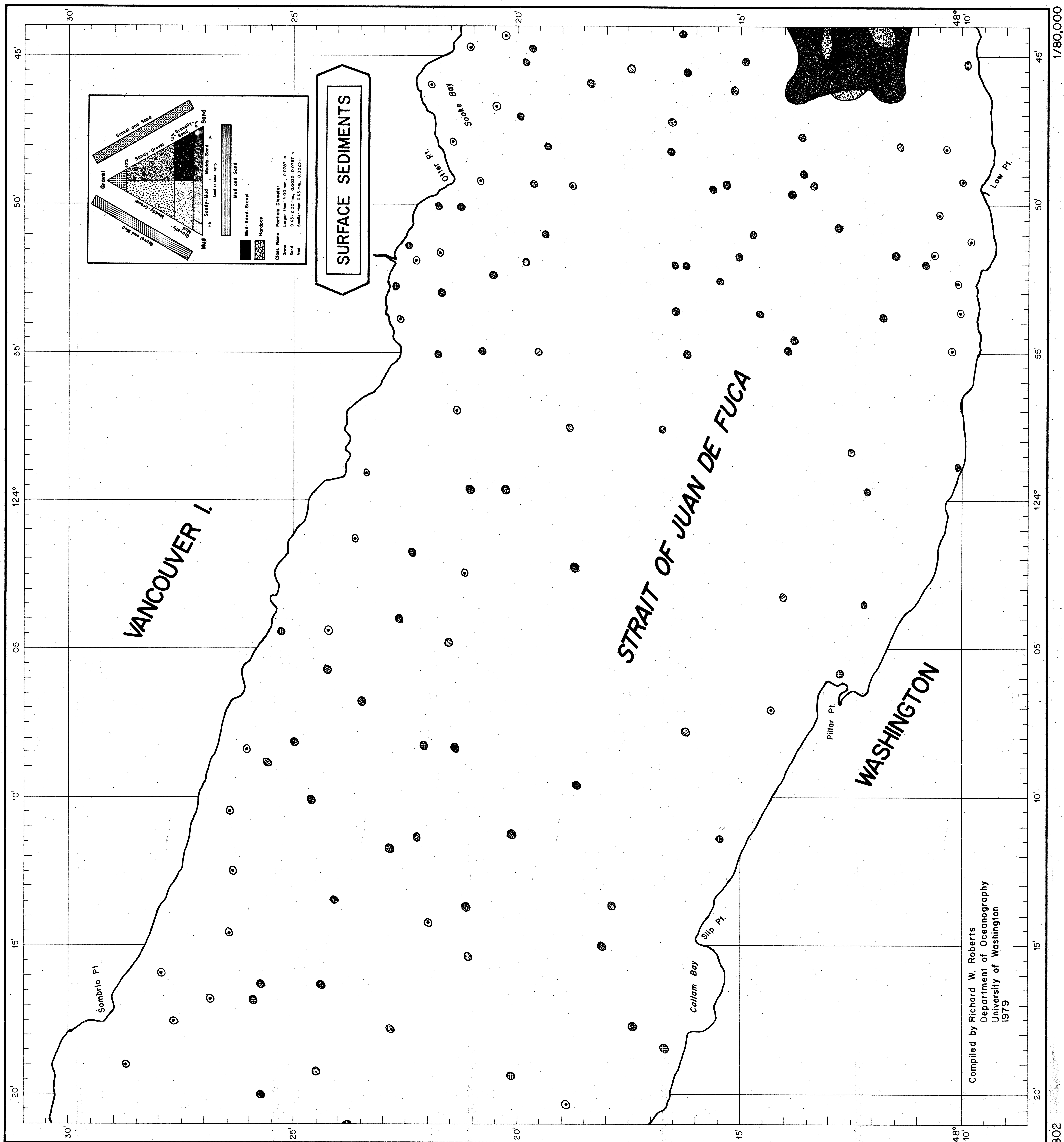

SURFACE SEDIMENTS
HOOD CANAL
Lynch Cove
Sisters Pt.
Vaughn Bay
Henderson Bay
CARR INLET
Hale Passage
FOX I.
CASE INLET
PICKERING PASSAGE
HARTSTENE I.
Oakland Bay
Hammersley Inlet
Squaxin I.
Peale Passage
Filucy Bay
Pitt Passage
McNEIL I.
Balch Passage
Drayton Passage
TOTTEN INLET
Skookum Inlet
Dana Passage
Henderson Inlet
ANDERSON I.
ELD INLET
BUDD INLET
NISQUALLY REACH
Oyster Bay
Olympia
Gravel
Sand
Mud
Gravel and Mud
Gravel and Sand
Muddy-Gravel
Sandy-Gravel
Gravelly-Mud
Gravelly-Sand
80%
30%
10%
Sandy-Mud
Muddy-Sand
1:9
1:1
9:1
Sand to Mud Ratio
Mud and Sand
Mud-Sand-Gravel
Hardpan
Class Name Particle Diameter
Gravel Larger than 2.00 mm., 0.0787 in.
Sand 0.63-2.00 mm., 0.0025-0.0787 in.
Mud Smaller than 0.63 mm., 0.0025 in.
05'
123°
55'
50'
45'
40'
25'
20'
15'
10'
47° 05'
Compiled by Richard W. Roberts
Department of Oceanography
University of Washington
1979

812 1/80,000

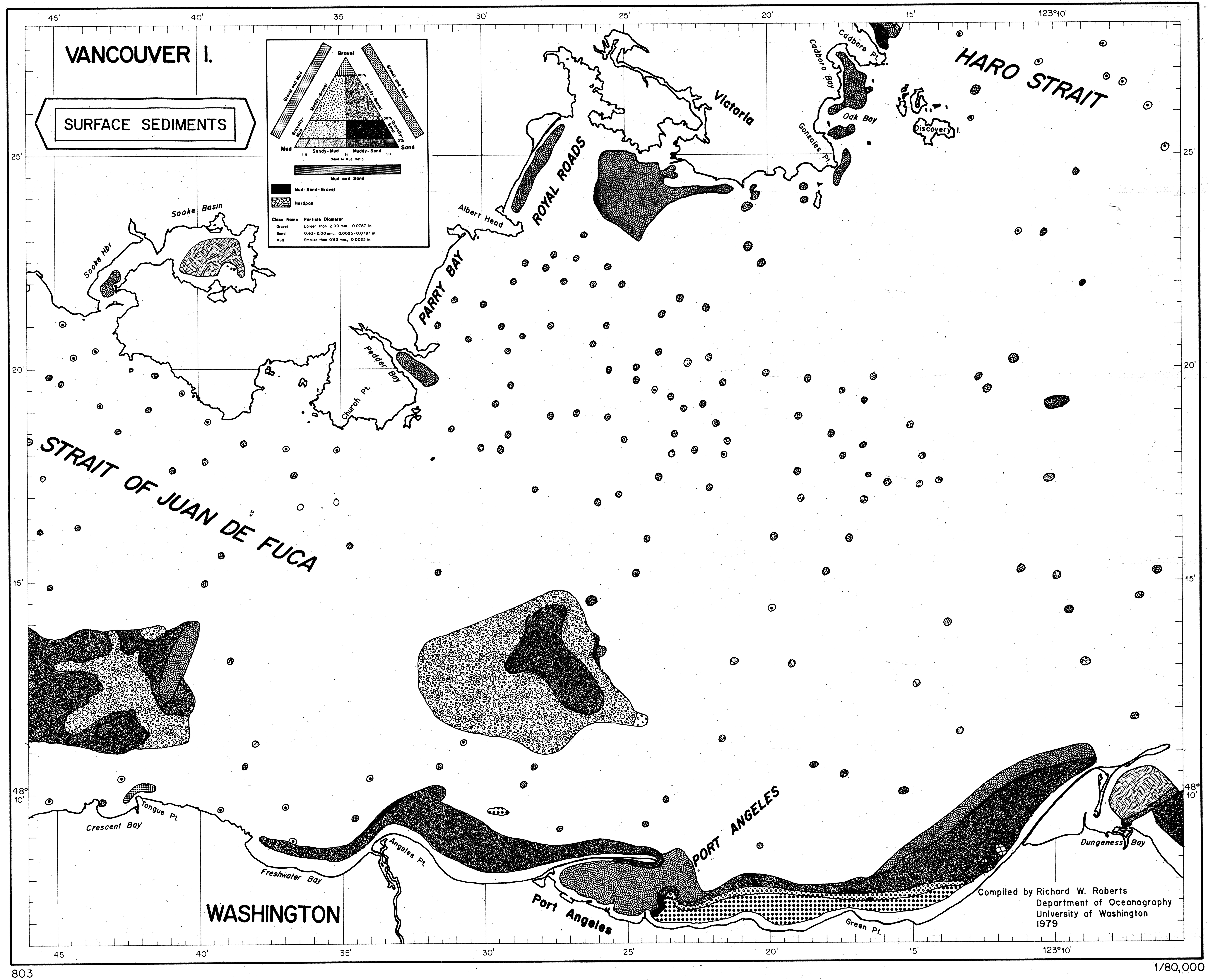

VANCOUVER I.
Bonilla Pt.
PORT SAN JUAN
STRAIT OF JUAN DE FUCA
Cape Flattery
NEAH BAY
WASHINGTON
Kydaka Pt.
Gravel
Gravel and Mud
Gravel and Sand
Muddy-Gravel
Sandy-Gravel
80%
30%
10%
Gravelly-Mud
Gravelly-Sand
Mud
Sand
Sandy-Mud
Muddy-Sand
1:9
1:1
9:1
Sand to Mud Ratio
Mud and Sand
Mud-Sand-Gravel
Hardpan
Class Name Particle Diameter
Gravel Larger than 2.00 mm., 0.0787 in.
Sand 0.63-2.00 mm., 0.0025-0.0787 in.
Mud Smaller than 0.63 mm., 0.0025 in.
SURFACE SEDIMENTS
Compiled by Richard W. Roberts
Department of Oceanography
University of Washington
1979

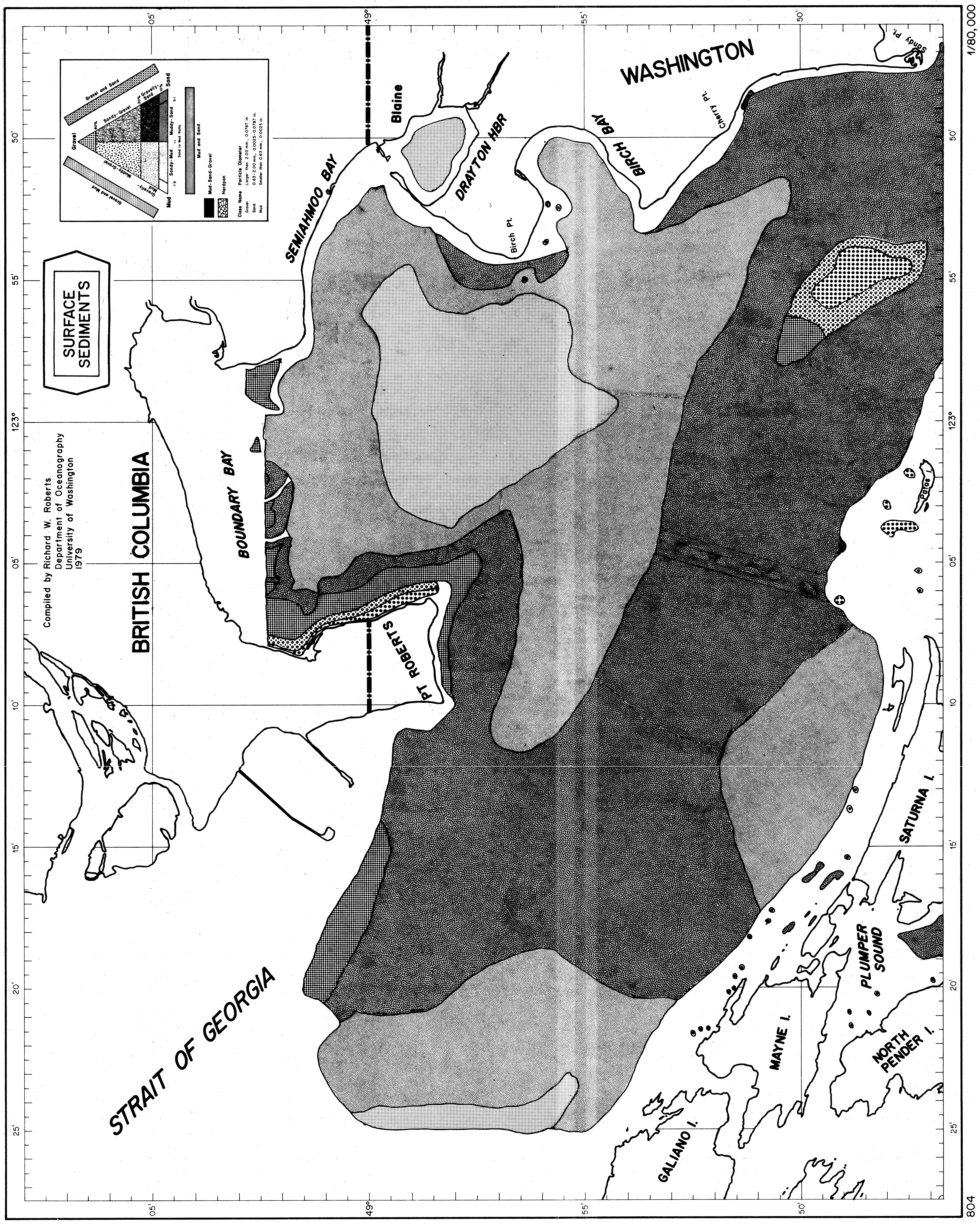
801

1/80,000

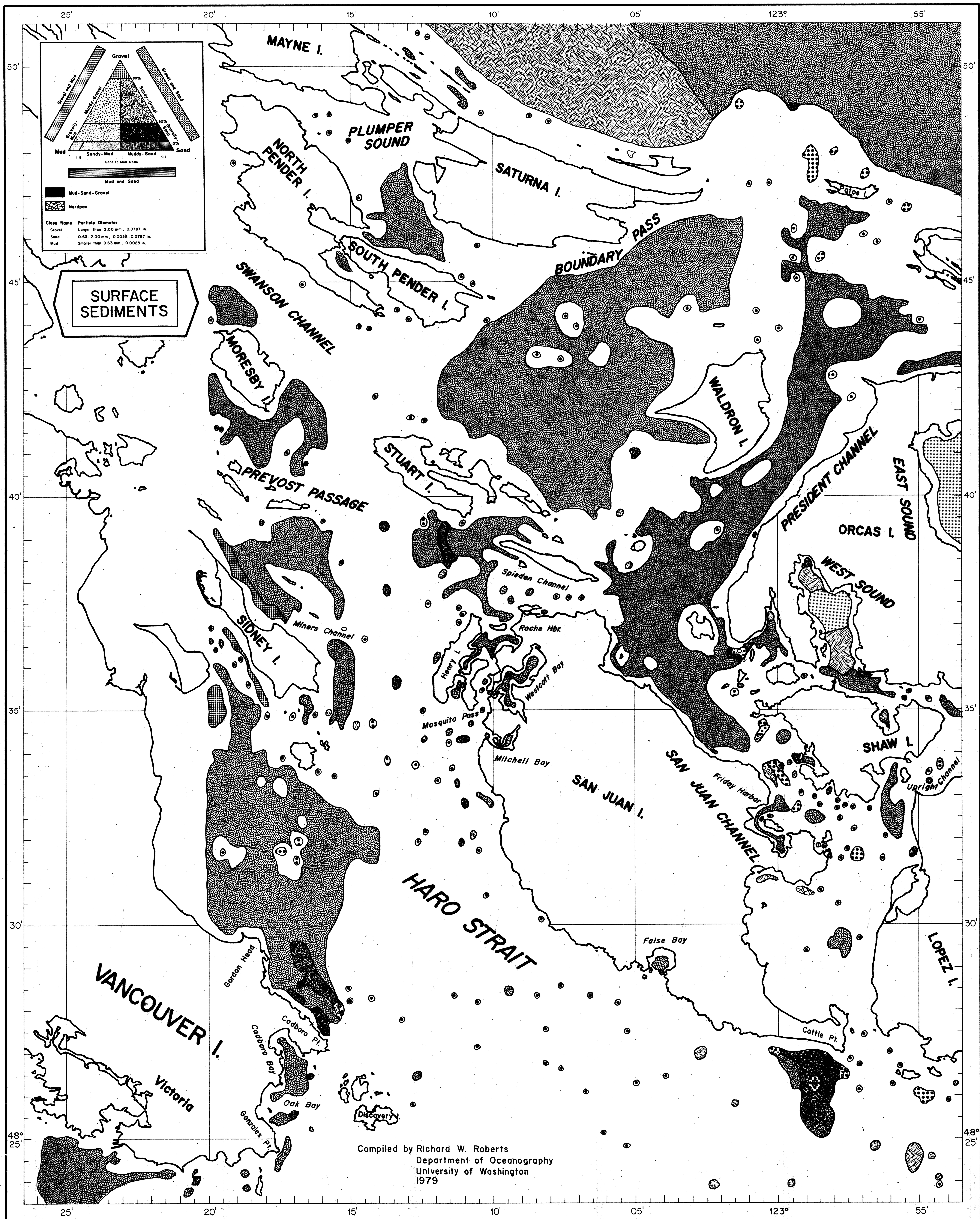


SURFACE SEDIMENTS
STRAIT OF JUAN DE FUCA
VANCOUVER I.
WASHINGTON
Otter Pt.
Sooke Bay
Low Pt.
Pillar Pt.
Slip Pt.
Callam Bay
Sombrio Pt.
Gravel
Sand
Mud
Gravel and Sand
Gravel and Mud
Sandy-Gravel
Muddy-Gravel
Gravelly-Sand
Gravelly-Mud
Muddy-Sand
Sandy-Mud
80%
30%
10%
1:9
1:1
9:1
Sand to Mud Ratio
Mud and Sand
Mud-Sand-Gravel
Hardpan
Class Name Particle Diameter
Gravel Larger than 2.00 mm., 0.0787 in.
Sand 0.63-2.00 mm., 0.0025-0.0787 in.
Mud Smaller than 0.63 mm., 0.0025 in.
Compiled by Richard W. Roberts
Department of Oceanography
University of Washington
1979
1/80,000
802
48° 10'
45'
50'
55'
124°
05'
10'
15'
20'
30'
25'


VANCOUVER I.
SURFACE SEDIMENTS
Gravel
Gravel and Mud
Gravel and Sand
Muddy-Gravel
Sandy-Gravel
Gravelly-Mud
Gravelly-Sand
Mud
Sand
Sandy-Mud
Muddy-Sand
Sand to Mud Ratio
Mud and Sand
Mud-Sand-Gravel
Hardpan
Class Name Particle Diameter
Gravel Larger than 2.00 mm., 0.0787 in.
Sand 0.63-2.00 mm., 0.0025-0.0787 in.
Mud Smaller than 0.63 mm., 0.0025 in.
HARO STRAIT
Cadboro Pt.
Cadboro Bay
Oak Bay
Discovery I.
Gonzales Pt.
Victoria
ROYAL ROADS
Albert Head
PARRY BAY
Pedder Bay
Church Pt.
Sooke Basin
Sooke Hbr
STRAIT OF JUAN DE FUCA
Tongue Pt.
Crescent Bay
Freshwater Bay
Angeles Pt.
WASHINGTON
PORT ANGELES
Port Angeles
Green Pt.
Dungeness Bay
Compiled by Richard W. Roberts
Department of Oceanography
University of Washington
1979
123°10'
48° 10'
803
1/80,000



SURFACE SEDIMENTS
Compiled by Richard W. Roberts
Department of Oceanography
University of Washington
1979
Gravel and Sand
Sandy-Gravel
Gravelly-Sand
Sand
Gravel
Muddy-Sand
Sandy-Mud
Mud
Gravel and Mud
Mud and Sand
Mud-Sand-Gravel
Hardpan
BRITISH COLUMBIA
WASHINGTON
Blaine
SEMIAHMOO BAY
DRAYTON HBR
BIRCH BAY
Birch Pt.
Cherry Pt.
Sandy Pt.
BOUNDARY BAY
PT ROBERTS
STRAIT OF GEORGIA
Patos I.
SATURNA I.
PLUMPER SOUND
MAYNE I.
NORTH PENDER I.
GALIANO I.
1/80,000
804



SURFACE SEDIMENTS
Gravel
Gravel and Mud
Gravel and Sand
Muddy-Gravel
Sandy-Gravel
80%
30%
10%
Gravelly-Mud
Gravelly-Sand
Mud
Sand
Sandy-Mud
Muddy-Sand
1:9
1:1
9:1
Sand to Mud Ratio
Mud and Sand
Mud-Sand-Gravel
Hardpan
Class Name Particle Diameter
Gravel Larger than 2.00 mm., 0.0787 in.
Sand 0.63-2.00 mm., 0.0025-0.0787 in.
Mud Smaller than 0.63 mm., 0.0025 in.
MAYNE I.
PLUMPER SOUND
NORTH PENDER I.
SATURNA I.
Patos I.
BOUNDARY PASS
SOUTH PENDER I.
SWANSON CHANNEL
MORESBY I.
WALDRON I.
PRESIDENT CHANNEL
EAST SOUND
STUART I.
PREVOST PASSAGE
ORCAS I.
WEST SOUND
Spieden Channel
Miners Channel
Roche Hbr.
SIDNEY I.
Henry I.
Westcott Bay
Mosquito Pass
Mitchell Bay
SHAW I.
SAN JUAN I.
Friday Harbor
SAN JUAN CHANNEL
Upright Channel
HARO STRAIT
False Bay
LOPEZ I.
Gordon Head
VANCOUVER I.
Cadboro Pt.
Cadboro Bay
Cattle Pt.
Victoria
Oak Bay
Discovery I.
Gonzales Pt.
Compiled by Richard W. Roberts
Department of Oceanography
University of Washington
1979
25'
20'
15'
10'
05'
123°
55'
50'
45'
40'
35'
30'
48° 25'

805 1/80,000


SURFACE
SEDIMENTS
Gravel
Gravel and Mud
Gravel and Sand
Muddy-Gravel
Sandy-Gravel
80%
30%
10%
Gravelly-Mud
Gravelly-Sand
Mud
Sand
Sandy-Mud
Muddy-Sand
1:9
1:1
9:1
Sand to Mud Ratio
Mud and Sand
Mud-Sand-Gravel
Hardpan
Class Name Particle Diameter
Gravel Larger than 2.00 mm., 0.0787 in.
Sand 0.63-2.00 mm., 0.0025-0.0787 in.
Mud Smaller than 0.63 mm., 0.0025 in.
Compiled by Richard W. Roberts
Department of Oceanography
University of Washington
1979
STRAIT OF GEORGIA
LUMMI BAY
Bellingham
BELLINGHAM BAY
Hale Passage
LUMMI I.
EAST SOUND
ORCAS I.
Sinclair I.
CYPRESS I.
Bellingham Channel
GUEMES I.
Guemes Channel
Samish I.
PADILLA BAY
Harney Channel
SHAW I.
Upright Channel
BLAKELY I.
Thatcher Pass
DECATUR I.
LOPEZ SOUND
LOPEZ I.
San Juan Channel
ROSARIO STRAIT
Anacortes
Fidalgo Bay
March Pt.
Burrows Bay
FIDALGO I.
Mud Bay
Iceberg Pt.
Deception Pass
Cornet Bay
Similk Bay
WHIDBEY I.
55'
50'
45'
40'
35'
30'
122°25'
45'
40'
35'
30'
48°
25'
806
1/80,000

Appendix H. Inventory of data for concentrations of PCBs in biota.

Table H-1. Inventory of locations and species in Jim West's biota PCB database.

Basin	Location	Category	Species	Sample matrix
Central Puget Sound	COMMBAY	fish	Brown	muscle
Central Puget Sound	ELLTBAY	fish	Brown	muscle
Central Puget Sound	SCLINLET	fish	Brown	muscle
Central Puget Sound	DUWAMISH	fish	Chinook	whole body
Central Puget Sound	APPLCVPT	fish	Chum	whole body
Central Puget Sound	AGATEPAS	fish	Coho	muscle
Central Puget Sound	DUWAMISH	fish	Coho	muscle
Central Puget Sound	WALLACER	fish	Coho	muscle
Central Puget Sound	ELLTBAY	fish	Copper	muscle
Central Puget Sound	COMMBAY	fish	English	muscle
Central Puget Sound	EGLHARBR	fish	English	muscle
Central Puget Sound	ELLTBAY	fish	English	muscle
Central Puget Sound	SCLINLET	fish	English	muscle
Central Puget Sound	PTORCHRD	fish	Herring	whole
Central Puget Sound	QTRMASTR	fish	Herring	whole
Central Puget Sound	ELLTBAY	fish	Lingcod	muscle
Central Puget Sound	COMMBAY	fish	Quillback	muscle
Central Puget Sound	ELLTBAY	fish	Quillback	muscle
Central Puget Sound	COLVOSP	fish	Sixgill	muscle
Central Puget Sound	APPLCVPT	fish	TH	whole body
Hood Canal	HDCANAL	fish	English	muscle
MIX	PSMIXED01	fish	Coho	whole
San Juan Islands	NOOKSACK	fish	Chinook	whole/muscle
San Juan Islands	NOOKSACK	fish	Coho	muscle
San Juan Islands	VENDOVI	fish	English	muscle
San Juan Islands	FRASER	fish	Sockeye	whole body
Strait of Georgia	FRASERNIMP	fish	Chinook	whole body
Strait of Georgia	STRTGEOR	fish	English	muscle
Strait of Georgia	CHERYPNT	fish	Herring	whole body
Strait of Georgia	DENMANHB	fish	Herring	whole body
Strait of Georgia	SEMIAMOO	fish	Herring	whole
South Puget Sound	DESCHUTE	fish	Chinook	whole body
South Puget Sound	NISQUALY	fish	Chinook	whole/muscle
South Puget Sound	DESCHUTE	fish	Coho	muscle
South Puget Sound	MINTERCR	fish	Coho	muscle
South Puget Sound	NISQUALY	fish	Coho	muscle
South Puget Sound	SOUTHSOUND	fish	Coho	muscle
South Puget Sound	NISQUALY	fish	English	muscle
South Puget Sound	SQUAXIN	fish	Herring	whole
Whidbey Basin	SKAGIT	fish	Coho	muscle
Whidbey Basin	PTGARDNR	fish	Copper	muscle
Whidbey Basin	PTGARDNR	fish	English	muscle
Whidbey Basin	SKAGIT	fish	Pink	whole

Table H-2. Summary of locations and species in Bob Johnston's biota PCB database

Location	Category	Species	Sample matrix
Bellingham Bay	invert	Mytilus sp. (mussel)	whole body
Commencement Bay	invert	Mytilus sp. (mussel)	whole body
Commencement Bay	fish	English Sole	whole body/muscle
Elliot Bay	invert	Mytilus sp. (mussel)	whole body
Elliot Bay	fish	English Sole	whole body/muscle
Everett (Port Gardener)	fish	English Sole	whole body
Hood Canal	invert	Graceful Crab	whole body
Hood Canal	fish	English Sole	whole body/muscle
Hood Canal	fish	Ratfish	whole body
Hood Canal	fish	Shinner Surfperch	whole body
Nisqually	invert	Graceful Crab	whole body
Nisqually	fish	Shinner Surfperch	whole body
Nisqually	fish	Rock Sole	whole body
Nisqually	fish	English Sole	whole body/muscle
Nisqually	fish	Ratfish	whole body
Nisqually	fish	Shinner Surfperch	whole body
Ostrich Bay	invert	Mytilus sp. (mussel)	whole body
PO marina/passage	invert	Mytilus sp. (mussel)	whole body
Point Roberts	invert	Mytilus sp. (mussel)	whole body
Port Gardner	fish	Sand Sole	whole body
Port Gardner	fish	English Sole	muscle
PSNS	invert	Mytilus sp. (mussel)	whole body
Puget Sound	invert	Mytilus sp. (mussel)	whole body
Ross Point	invert	Mytilus sp. (mussel)	whole body
Sinclair Inlet	invert	Mytilus sp. (mussel)	whole body
Sinclair Inlet	invert	Sea Cucumber	whole body
Sinclair Inlet	invert	Graceful Crab	whole body
Sinclair Inlet	fish	English Sole	whole body/muscle
Sinclair Inlet	fish	Ratfish	whole body
Sinclair Inlet	fish	Sand Sole	whole body
Sinclair Inlet	fish	Shinner Surfperch	whole body
Sinclair Inlet	fish	Rock Sole	whole body
Sinclair Inlet	fish	Staghorn Sculpin	whole body
Strait of Georgia	invert	Sea Cucumber	whole body
Strait of Georgia	fish	Staghorn Sculpin	whole body
Strait of Georgia	fish	English Sole	whole body/muscle
Strait of Georgia	fish	English Sole	whole body
Strait of Georgia	fish	Ratfish	whole body
Vendovi	invert	Graceful Crab	whole body
Vendovi	invert	Sea Cucumber	whole body
Vendovi	fish	Staghorn Sculpin	whole body
Vendovi	fish	Shinner Surfperch	whole body
Vendovi	fish	English Sole	whole body/muscle
Waterman Point	invert	Mytilus sp. (mussel)	whole body

Appendix I. Inputs for the food web bioaccumulation model (foodweb.xls).

'main' sheet (e.g. for South Puget Sound):

Waterbody name	South Puget Sound	
Number of plant species	2	nPlant
Number of invertebrate species	11	nInv
Number of fish/immigrant species	19	nFish
Number of bird species	4	nBird
Number of egg species	2	nEgg
Number of mammal species	4	nSeal
Number of fish/immigrant species that are immigrants	4	nImmigrant

'gen_bio_pars' sheet:

Group of organisms	Model parameter	Name	Units	Value
All	Non-lipid organic matter – octanol proportionality constant	b	Unitless	0.035
Fish	Growth rate factor	GRFF	Unitless	0.0007
Invertebrates	Growth rate factor	GRFI	Unitless	0.00035
Scavengers	Particle scavenging efficiency	s	Unitless	1
Poikilotherms/Homeotherms	Metabolic transformation rate	kMp	d-1	0
Homeotherms	Mean homeothermic biota temperature	TB	°C	37.5
Homeotherms	Density of lipids		kg/L	0.9
Poikilotherms	Ew constant A	EWA	Unitless	1.85

'ocean_pars' sheet:

Model parameter	Name	Units	Value
Concentration of particulate organic carbon in water	Xpoc	kg/L	0.00E+00
Concentration of dissolved organic carbon in water	Xdoc	kg/L	1.00E-06
Concentration of suspended solids	Vss	kg/L	2.40E-06
Mean annual water temperature	Tw	oC	9.5
Mean annual air temperature	Ta	oC	10.3
Salinity	PSU	g/kg	30
Density of organic carbon in sediment	dOCS	kg/L	0.9
Organic carbon content of sediment	OCS	unitless	0.0095
Dissolved oxygen concentration @ 90% saturation	Cox	mg O2/L	7.5
Setschenow proportionality constant	S_PC	L/cm3	0.0018
Ideal gas law constant (Rgaslaw)	RGL	Pa.m3/mol.K	8.314
Absolute temperature	Tabs	K	273.16
Molar concentration of seawater @ 35 ppt	MCS	mol/L	0.5
Organic carbon burial rate	OCBR	gC/cm2/yr	0.011
Primary production rate of organic carbon	PPR	gC/cm2/yr	0.552
Disequilibrium factor for POC partitioning in water column	Dpoc	unitless	1
Disequilibrium factor for DOC partitioning in water column	Ddoc	unitless	1
Proportionality constant for phase partitioning of POC	alphaPOC	unitless	0.35
Proportionality constant for phase partitioning of POC	alphaDOC	unitless	0.08

‘conc_data’ sheet (e.g. sediment/water data are for South Puget Sound, other basins vary):

				Immigrant 1	Immigrant 2	Immigrant 3	Immigrant 4
Congener rank order	Congener name	Sediment concenration ng/g (dw)	Water column total concentration ng/ml	Herring ng/g (ww)	Chum ng/g (ww)	Coho ng/g (ww)	Chinook ng/g (ww)
1	PCB 8	9.73E-03	1.26E-07	9.68E-03	2.18E-03	8.87E-03	8.01E-03
2	18	2.62E-02	3.38E-07	4.22E-02	1.58E-02	3.74E-02	3.26E-02
3	28	1.01E-01	1.30E-06	3.96E-01	7.65E-02	1.84E-01	2.41E-01
4	44	6.83E-02	8.83E-07	4.87E-01	5.12E-02	1.25E-01	2.56E-01
5	52	9.93E-02	1.28E-06	7.10E-01	8.53E-02	2.34E-01	4.17E-01
6	66	1.07E-01	1.38E-06	3.92E-01	3.77E-02	9.27E-02	2.40E-01
7	77	2.97E-02	3.84E-07	8.38E-01	9.81E-02	2.59E-01	5.35E-01
8	101	4.15E-01	5.36E-06	1.77E+00	1.20E-01	3.27E-01	9.73E-01
9	105	8.74E-02	1.13E-06	5.41E-01	2.28E-02	6.51E-02	2.21E-01
10	118	4.16E-01	5.38E-06	1.43E+00	6.52E-02	1.94E-01	6.08E-01
11	126	4.32E-03	5.58E-08	3.35E-01	1.38E-02	2.88E-02	1.51E-01
12	128	7.68E-02	9.92E-07	3.35E-01	1.38E-02	2.88E-02	1.51E-01
13	138	6.92E-01	8.94E-06	2.82E+00	1.26E-01	3.14E-01	1.28E+00
14	153	9.40E-01	1.21E-05	3.30E+00	1.57E-01	4.11E-01	1.57E+00
15	170	8.31E-02	1.07E-06	2.80E-01	1.12E-02	1.46E-02	1.31E-01
16	180	1.73E-01	2.23E-06	8.43E-01	3.36E-02	5.47E-02	4.08E-01
17	187	9.54E-02	1.23E-06	9.88E-01	4.42E-02	8.00E-02	4.68E-01
18	195	1.23E-02	1.59E-07	1.12E-01	3.41E-03	5.13E-03	5.66E-02
19	206	5.08E-02	6.56E-07	5.09E-02	1.44E-03	2.34E-03	2.40E-02
20	209	6.37E-02	8.23E-07	2.48E-02	9.18E-04	2.28E-03	1.30E-02

‘props’ sheet:

Congener name	Molecular weight g/mol	LeBas molar volume cm^3/mol	Log Kow fw @ 9.5°C Unitless	Log Kow fw @ 9.5 SD Unitless	Log Kow fw @ 37.5°C Unitless	Log Koa @ 10.3°C Unitless	Log Koa @ 37.5°C Unitless	kM_spec(1) Metabolic rate (cormorant) d^-1	kM_spec(2) Metabolic rate (heron) d^-1	kM_spec(3) Metabolic rate (male seals) d^-1	kM_spec(4) Metabolic rate (female seals) d^-1
PCB 8	223.1	226.4	5.19		5.1	7.68	6.59	0.00E+00	0.00E+00	2.25E-02	2.25E-02
18	257.5	247.4	5.37		5.27	7.93	6.82	0.00E+00	0.00E+00	1.47E-02	1.47E-02
28	257.5	247.4	5.8		5.7	8.61	7.44	3.50E-02	8.00E-03	2.29E-02	2.29E-02
44	292	268.4	5.88		5.78	9.18	7.96	0.00E+00	0.00E+00	3.65E-03	3.65E-03
52	292	268.4	5.97		5.87	8.81	7.62	0.00E+00	0.00E+00	0.00E+00	0.00E+00
66	292	268.4	6.33		6.23	9.87	8.58	3.12E-02	1.00E-02	2.00E-01	2.00E-01
77	292	278.9	6.5		6.39	9.86	8.91				
101	326.4	289.4	6.52		6.41	9.85	8.56	1.15E-01	9.43E-02	2.66E-03	2.66E-03
105	326.4	289.4	6.79		6.68	10.72	9.36	1.20E-02	4.90E-03	2.66E-02	2.66E-02
118	326.4	289.4	6.88		6.77	10.43	9.09	6.80E-03	8.50E-04	3.03E-02	3.03E-02
126	326.4	299.9	7.03		6.92	10.47	9.78				
128	360.9	310.4	6.87		6.77	10.5	9.16	1.15E-02	2.68E-03	7.80E-03	7.80E-03
138	360.9	310.4	6.96		6.86	10.61	9.26	5.20E-03	1.89E-03	2.25E-03	2.25E-03
153	360.9	310.4	7.05		6.95	10.55	9.2	0.00E+00	0.00E+00	0.00E+00	0.00E+00
170	395.3	331.4	7.4		7.3	11.3	9.89	3.00E-03	3.50E-04	0.00E+00	0.00E+00
180	395.3	331.4	7.49		7.39	11.58	10.14	0.00E+00	0.00E+00	0.00E+00	0.00E+00
187	395.3	331.4	7.3		7.2	11.11	9.71	4.40E-02	0.00E+00	6.61E-04	6.61E-04
195	429.8	352.4	7.72		7.6	11.8	10.45				
206	464.2	373.4	8.2		8.11	12.5	10.98	0.00E+00	0.00E+00	0.00E+00	0.00E+00
209	498.7	394.4	8.27		8.2	13.8	12.16	0.00E+00	0.00E+00	0.00E+00	0.00E+00

‘plant_pars’ sheet:

			Plant 1	Plant 2
			Phytoplankton	Kelp / Seagrass
Model parameter	Name	Units	Value	Value
Wet weight of the organism	WB	kg	0	0
Lipid fraction in plant	vLB	Unitless	0.0009	0.0008
Non-lipid organic carbon fraction in plant	vNB	Unitless	0.0006	0.06
Water fraction in plant	vWB	Unitless	0.9985	0.9372
Growth rate constant	kG	d-1	1.25E-01	1.25E-01
Aqueous phase resistance constant	AP	Unitless	6.00E-05	6.00E-05
Organic phase resistance constant	BP	Unitless	5.50E+00	5.50E+00

‘invert_pars’ sheet:

			Inv 1	Inv 2	Inv 3	Inv 4	Inv 5	Inv 6	Inv 7	Inv 8	Inv 9	Inv 10	Inv 11
		name:	Herb- ivorous zoo plankton	Neo- calanus plumchrus (large copepod)	Pseudo- calanus minutus (small copepod)	Shellfish	Crab	Grazing invert- ebrates	Carn- ivorous zoo plankton (amphi- pods)	Eu- phausia pacifica (krill)	Predatory invert- ebrates	Spot prawn	Graceful crab
Model parameter	Name	Units											
Wet weight of the organism	WB	kg	7.10E-08	4.54E-06	8.84E-08	8.06E-03	5.37E-01	5.00E-02	3.23E-07	4.03E-05	1.00E+00	3.70E-04	1.65E-01
Lipid fraction in biota	vLB	Unitless	4.00E-02	1.20E-01	4.00E-02	1.00E-02	3.00E-02	2.00E-02	4.00E-02	2.00E-02	2.00E-02	1.50E-02	1.12E-02
Non-lipid organic matter fraction in biota	vNB	Unitless	1.50E-01	6.00E-02	1.50E-01	1.90E-01	1.70E-01	1.90E-01	1.30E-01	1.60E-01	1.80E-01	2.40E-01	1.50E-01
Water fraction in biota	vWB	Unitless	8.10E-01	8.10E-01	8.10E-01	8.00E-01	8.00E-01	8.00E-01	8.30E-01	8.30E-01	8.00E-01	7.40E-01	8.40E-01
Dietary absorption efficiency of lipid	eL	Unitless	7.20E-01	7.20E-01	7.20E-01	7.50E-01	7.50E-01	7.50E-01	7.20E-01	7.50E-01	7.50E-01	7.50E-01	3.01E-01
Dietary absorption efficiency of non-lipid organic matter	eN	Unitless	7.20E-01	7.20E-01	7.20E-01	7.50E-01	7.50E-01	7.50E-01	7.20E-01	7.50E-01	7.50E-01	7.50E-01	3.10E-01
Dietary absorption efficiency of water	eW	Unitless	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01
Fraction of respiration that involves sediment pore water	mP	Unitless	0.00E+00	0.00E+00	0.00E+00	2.00E-01	2.00E-01	2.00E-01	5.00E-02	5.00E-02	2.00E-01	2.00E-01	2.00E-01
ED constant A	EDA	Unitless	8.50E-08	8.50E-08	8.50E-08	8.50E-08	8.50E-08	8.50E-08	8.50E-08	8.50E-08	8.50E-08	8.50E-08	8.50E-08
ED constant B	EDB	Unitless	2	2	2	2	2	2	2	2	2	2	2
Filter feeders *Yes" or "No":			Yes	Yes	Yes	Yes	No	No	No	Yes	No	No	No

‘fish_pars’ sheet:

			Fish 1	Fish 2	Fish 3	Fish 4	Fish 5	Fish 6
		name:	Herring (non- resident)	Small pelagic fish (seal prey)	Small pelagic fish (bird prey)	River lamprey (Lampetra ayresi)	Miscellane ous demersal fish (seal prey)	Miscellane ous demersal fish (bird prey)
Model parameter	Name	Units						
Wet weight of the organism	WB	kg	5.95E-02	4.49E-02	4.92E-03	1.43E-02	1.81E-01	4.72E-03
Lipid fraction in biota	vLB	Unitless	4.99E-02	3.86E-02	1.53E-02	1.25E-01	2.51E-02	1.63E-02
Non-lipid organic matter fraction in biota	vNB	Unitless	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01
Water fraction in biota	vWB	Unitless	7.50E-01	7.61E-01	7.85E-01	6.75E-01	7.75E-01	7.84E-01
Dietary absorption efficiency of lipid	eL	Unitless	9.00E-01	9.00E-01	9.00E-01	9.00E-01	9.00E-01	9.00E-01
Dietary absorption efficiency of non-lipid organic matter	eN	Unitless	5.00E-01	5.00E-01	5.00E-01	5.00E-01	5.00E-01	5.00E-01
Dietary absorption efficiency of water	eW	Unitless	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01
Fraction of respiration that involves sediment pore water	mP	Unitless	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-02	5.00E-02
ED constant A	EDA	Unitless	8.50E-08	8.50E-08	8.50E-08	8.50E-08	8.50E-08	8.50E-08
ED constant B	EDB	Unitless	2	2	2	2	2	2
Is this fish/immigrant group an immigrant (Yes or No)?			Yes	No	No	No	No	No
Immigrant index number for 'conc_data' if immigrant:			1					

			Fish 7	Fish 8	Fish 9	Fish 10	Fish 11	Fish 12
		name:	Chum (non- resident)	Coho (non- resident)	Chinook (non- resident)	Pacific hake (Merlucciu s productus)	Spiny dogfish (Squalus acanthias)	Pollock (Theragra chalcogra mma)
Model parameter	Name	Units						
Wet weight of the organism	WB	kg	3.96E+00	3.50E+00	3.63E+00	3.74E-01	2.00E+00	7.97E-02
Lipid fraction in biota	vLB	Unitless	4.83E-02	6.39E-02	5.43E-02	5.20E-02	1.00E-01	2.16E-02
Non-lipid organic matter fraction in biota	vNB	Unitless	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01
Water fraction in biota	vWB	Unitless	7.52E-01	7.36E-01	7.46E-01	7.48E-01	7.00E-01	7.78E-01
Dietary absorption efficiency of lipid	eL	Unitless	9.00E-01	9.00E-01	9.00E-01	9.00E-01	9.00E-01	9.00E-01
Dietary absorption efficiency of non-lipid organic matter	eN	Unitless	5.00E-01	5.00E-01	5.00E-01	5.00E-01	5.00E-01	5.00E-01
Dietary absorption efficiency of water	eW	Unitless	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01
Fraction of respiration that involves sediment pore water	mP	Unitless	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ED constant A	EDA	Unitless	8.50E-08	8.50E-08	8.50E-08	8.50E-08	8.50E-08	8.50E-08
ED constant B	EDB	Unitless	2	2	2	2	2	2
Is this fish/immigrant group an immigrant (Yes or No)?			Yes	Yes	Yes	No	No	No
Immigrant index number for 'conc_data' if immigrant:			2	3	4			

			Fish 13	Fish 14	Fish 15	Fish 16	Fish 17	Fish 18	Fish 19
		name:	Northern smooth- tongue (Leuroglos sus schmidti)	English sole (Parophrys vetulus)	Herring (resident)	Blackmout h chinook (resident)	Ratfish	Shiner surfperch	Staghorn sculpin
Model parameter	Name	Units							
Wet weight of the organism	WB	kg	7.50E-04	7.40E-02	5.95E-02	3.63E+00	7.50E-01	1.88E-01	7.52E-02
Lipid fraction in biota	vLB	Unitless	4.99E-02	2.00E-02	6.50E-02	1.10E-01	1.20E-01	4.62E-02	2.12E-02
Non-lipid organic matter fraction in biota	vNB	Unitless	2.00E-01	2.00E-01	2.00E-01	2.00E-01	1.80E-01	2.14E-01	1.90E-01
Water fraction in biota	vWB	Unitless	7.50E-01	7.80E-01	7.35E-01	6.90E-01	7.00E-01	7.40E-01	7.89E-01
Dietary absorption efficiency of lipid	eL	Unitless	9.00E-01	5.05E-01	9.00E-01	6.51E-01	3.07E-01	3.01E-01	3.11E-01
Dietary absorption efficiency of non-lipid organic matter	eN	Unitless	5.00E-01	5.08E-01	5.00E-01	6.62E-01	3.06E-01	3.26E-01	3.14E-01
Dietary absorption efficiency of water	eW	Unitless	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01
Fraction of respiration that involves sediment pore water	mP	Unitless	0.00E+00	5.00E-02	0.00E+00	0.00E+00	5.00E-02	0.00E+00	0.00E+00
ED constant A	EDA	Unitless	8.50E-08	8.50E-08	8.50E-08	8.50E-08	8.50E-08	8.50E-08	8.50E-08
ED constant B	EDB	Unitless	2	2	2	2	2	2	2
Is this fish/immigrant group an immigrant (Yes or No)?			No	No	No	No	No	No	No

'bird_pars' sheet:

			Bird 1	Bird 2	Bird 3	Bird 4
Adult Birds		name:	Double crested Cormorant (adult male)	Double crested Cormorant (adult female)	Great Blue Heron (adult male)	Great Blue Heron (adult female)
Input parameters for adult birds	Name	Units	Mean	Mean	Mean	Mean
Wet weight of the organism	WB	kg	2.50E+00	2.40E+00	2.58E+00	2.20E+00
Lipid fraction in biota	vLB	Unitless	7.50E-02	7.50E-02	7.50E-02	7.50E-02
Non-lipid organic matter fraction in biota	vNB	Unitless	2.00E-01	2.00E-01	2.00E-01	2.00E-01
Water fraction in biota	vWB	Unitless	7.25E-01	7.25E-01	7.25E-01	7.25E-01
Dietary absorption efficiency of lipid	eL	Unitless	9.50E-01	9.50E-01	9.50E-01	9.50E-01
Dietary absorption efficiency of non-lipid organic matter	eN	Unitless	7.50E-01	7.50E-01	7.50E-01	7.50E-01
Dietary absorption efficiency of water	eW	Unitless	8.50E-01	8.50E-01	8.50E-01	8.50E-01
Lung uptake efficiency	Ea	Unitless	7.00E-01	7.00E-01	7.00E-01	7.00E-01
Growth rate constant	kG	d-1	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Activity Factor	AF	Unitless	3.00E+00	3.00E+00	3.00E+00	3.00E+00
ED constant A	EDA	Unitless	3.00E-09	3.00E-09	3.00E-09	3.00E-09
ED constant B	EDB	Unitless	1.04E+00	1.04E+00	1.04E+00	1.04E+00
Male or Female?			Male	Female	Male	Female
Species-specific metabolic transformation index from 'props':			1	1	2	2
Bird type ('Cormorant' or 'Heron')			Cormorant	Cormorant	Heron	Heron

			Egg 1	Egg 2
Eggs		name:	Double crested Cormorant (egg)	Great Blue Heron (egg)
Input parameters for eggs	Name	Units	Mean	Mean
No. clutches per year	NCY	clut/yr	1	1
No. eggs per clutch	NEC	eggs	4	4
Wet weight of egg	WE	kg	4.49E-02	7.10E-02
Lipid content of egg	vLE	Unitless	0.046	0.063
NLOM content of egg	vNE	Unitless	0.115	0.12
Water content of egg	vWE	Unitless	0.839	0.817
What is the id number of the adult female bird that laid the egg?	EggsBird	Unitless	2	4

'mammal_pars' sheet:

		name:	Seal 1 Harbor Seal (adult male)	Seal 2 Harbor Seal (adult female)	Seal 3 Harbor Seal (1 yr old)	Seal 4 Harbor Seal (pup)
Model parameter	Name	Units				
Wet weight of the organism	WB	kg	8.70E+01	6.48E+01	3.33E+01	2.39E+01
Lipid fraction in biota	vLB	Unitless	4.30E-01	1.50E-01	1.20E-01	4.10E-01
Non-lipid organic matter fraction in biota	vNB	Unitless	2.00E-01	2.00E-01	2.50E-01	1.50E-01
Water fraction in biota	vWB	Unitless	3.70E-01	6.50E-01	6.40E-01	4.40E-01
Dietary absorption efficiency of lipid	eL	Unitless	9.70E-01	9.70E-01	9.70E-01	9.70E-01
Dietary absorption efficiency of non-lipid organic matter	eN	Unitless	7.50E-01	7.50E-01	7.50E-01	7.50E-01
Dietary absorption efficiency of water	eW	Unitless	8.50E-01	8.50E-01	8.50E-01	8.50E-01
Lung uptake efficiency	Ea	Unitless	7.00E-01	7.00E-01	7.00E-01	7.00E-01
Growth rate constant	kG	d-1	7.50E-05	1.00E-05	1.00E-03	2.50E-02
Activity Factor	AF	Unitless	2.50E+00	2.50E+00	2.50E+00	1.50E+00
ED constant A	EDA	Unitless	1.00E-09	1.00E-09	1.00E-09	1.00E-09
ED constant B	EDB	Unitless	1.03E+00	1.03E+00	1.03E+00	1.03E+00
Does this mammal group represent pups (Yes or No)?			No	No	No	Yes
If this group represents pups, which mammal number is the mother?						2
Male or Female?			Male	Female	Male	Male
Species-specific metabolic transformation index on 'props':			3	4	3	3
Coefficient k for Gd = kGd * Wb			0.07	0.11	0.08	0.06

Additional seal parameters	Name	Units	Mean
Proportion of population reproducing	PR	Unitless	0.9
Weight of fetus	WF	kg	11.2
Lipid content of fetus	vLF	Unitless	0.11
NLOM content of fetus	vNF	Unitless	0.2
Water content of fetus	vWF	Unitless	0.69
Lipid content of milk	vLM	Unitless	0.49
NLOM content of milk	vNM	Unitless	0.12
Water content of milk	vWM	Unitless	0.39

‘foodweb’ sheet (part 1 of 2):

		Prey:	Sediment / Detritus	Plant 1 Phyto-plankton	Plant 2 Kelp / Seagrass	Inv 1 Herb-ivorous zoo-plankton	Inv 2 Neo-calanus plum-chrus (large copepod)	Inv 3 Pseudo-calanus minutus (small copepod)	Inv 4 Shellfish	Inv 5 Crab	Inv 6 Grazing invert-ebrates	Inv 7 Carn-ivorous zoo-plankton (amphipods)	Inv 8 Euph-ausia pacifica (krill)	Inv 9 Predatory invert-ebrates	Inv 10 Spot prawn	Inv 11 Graceful crab
		Sediment / Detritus														
		Predator:														
Plant	1	Phytoplankton														
Plant	2	Kelp / Seagrass														
Inv	1	Herbivorous zooplankton	0.3	0.7												
Inv	2	Neocalanus plumchrus (large copepod)	0.3	0.7												
Inv	3	Pseudocalanus minutus (small copepod)	0.3	0.7												
Inv	4	Shellfish	0.21	0.579	0.1	0.03	0.05	0.02	0.01	0.001						
Inv	5	Crab	0.438	0.002	0.1	0.06	0.02	0.02	0.15	0.01	0.2					
Inv	6	Grazing invertebrates	0.374	0.176	0.3	0.05	0.05	0.05								
Inv	7	Carnivorous zooplankton (amphipods)	0.05			0.359	0.404	0.102	0.03	0.002	0.003	0.05				
Inv	8	Euphausia pacifica (krill)	0.14	0.809		0.05			0.001							
Inv	9	Predatory invertebrates	0.5			0.065	0.05	0.05	0.055	0.01	0.1		0.111	0.036		
Inv	10	Spot prawn									0.3	0.7				
Inv	11	Graceful crab	0.098			0.077			0.758		0.046	0.02				
Fish	1	Herring (non-resident)														
Fish	2	Small pelagic fish (seal prey)		0.005		0.1	0.15	0.07	0.03	0.01	0.05	0.264	0.15	0.05		
Fish	3	Small pelagic fish (bird prey)		0.005		0.1	0.151	0.07	0.03	0.01	0.05	0.264	0.17	0.05		
Fish	4	River lamprey (Lampetra ayresi)														
Fish	5	Miscellaneous demersal fish (seal prey)	0.1	0.005		0.04	0.051	0.05	0.172		0.09	0.154	0.1	0.04		
Fish	6	Miscellaneous demersal fish (bird prey)	0.1	0.005		0.058	0.051	0.05	0.172		0.09	0.154	0.13	0.04		
Fish	7	Chum (non-resident)														
Fish	8	Coho (non-resident)														
Fish	9	Chinook (non-resident)														
Fish	10	Pacific hake (Merluccius productus)		0.005		0.02	0.02	0.01	0.03	0.001		0.163	0.7	0.005		
Fish	11	Spiny dogfish (Squalus acanthias)				0.01	0.01	0.01	0.05	0.01	0.15	0.11	0.08	0.235		
Fish	12	Pollock (Theragra chalcogramma)		0.01		0.01	0.03	0.02	0.001			0.09	0.668	0.05		
Fish	13	Northern smooth-tongue (Leuroglossus schmidti)		0.02		0.31	0.3	0.15	0.001		0.056	0.05	0.102			
Fish	14	English sole (Parophrys vetulus)	0.121	0.157		0.159					0.41	0.153				
Fish	15	Herring (resident)				0.4					0.1	0.4			0.1	
Fish	16	Blackmouth chinook (resident)											0.963			
Fish	17	Ratfish	0.007						0.586		0.153					0.252
Fish	18	Shiner surfperch	0.267			0.245					0.248	0.24				
Fish	19	Staghorn sculpin	0.018			0.47					0.001	0.024				0.476
Bird	1	Double crested Cormorant (adult male)														
Bird	2	Double crested Cormorant (adult female)														
Bird	3	Great Blue Heron (adult male)														
Bird	4	Great Blue Heron (adult female)														
Seal	1	Harbor Seal (adult male)														
Seal	2	Harbor Seal (adult female)														
Seal	3	Harbor Seal (1 yr old)														
Seal	4	Harbor Seal (pup)														

‘foodweb’ sheet (part 2 of 2):

		Prey:	Fish 1 Pacific herring (non-resident)	Fish 2 Small pelagic fish (seal prey)	Fish 3 Small pelagic fish (bird prey)	Fish 4 River lamprey (Lampetra ayresi)	Fish 5 Miscellaneous demersal fish (seal prey)	Fish 6 Miscellaneous demersal fish (bird prey)	Fish 7 Chum (non-resident)	Fish 8 Coho (non-resident)	Fish 9 Chinook (non-resident)	Fish 10 Pacific hake (Merluccius productus)	Fish 11 Spiny dogfish (Squalus acanthias)	Fish 12 Pollock (Theragra chalcogramma)	Fish 13 Northern smooth-tongue (Leuroglossus schmidti)	Fish 14 English sole (Parophrys vetulus)	Fish 15 Pacific herring (resident)	Seal mother's milk
		Sediment / Detritus																
		Predator:																
Plant	1	Phytoplankton																
Plant	2	Kelp / Seagrass																
Inv	1	Herbivorous zooplankton																
Inv	2	Neocalanus plumchrus (large copepod)																
Inv	3	Pseudocalanus minutus (small copepod)																
Inv	4	Shellfish																
Inv	5	Crab																
Inv	6	Grazing invertebrates																
Inv	7	Carnivorous zooplankton (amphipods)																
Inv	8	Euphausia pacifica (krill)																
Inv	9	Predatory invertebrates	0.022	0.001														
Inv	10	Spot prawn																
Inv	11	Graceful crab						0.001										
Fish	1	Herring (non-resident)																
Fish	2	Small pelagic fish (seal prey)	0.02	0.1					0.001									
Fish	3	Small pelagic fish (bird prey)			0.1													
Fish	4	River lamprey (Lampetra ayresi)	0.64	0.199					0.053	0.051	0.051	0.001		0.005				
Fish	5	Miscellaneous demersal fish (seal prey)	0.03	0.05			0.1		0.001	0.004	0.003	0.01						
Fish	6	Miscellaneous demersal fish (bird prey)			0.05			0.1										
Fish	7	Chum (non-resident)																
Fish	8	Coho (non-resident)																
Fish	9	Chinook (non-resident)																
Fish	10	Pacific hake (Merluccius productus)		0.04					0.001	0.001	0.001			0.002	0.001			
Fish	11	Spiny dogfish (Squalus acanthias)	0.02	0.042		0.005	0.01		0.055	0.07	0.07	0.056	0.005	0.001		0.001		
Fish	12	Pollock (Theragra chalcogramma)	0.05	0.01								0.01		0.001	0.05			
Fish	13	Northern smooth-tongue (Leuroglossus schmidti)		0.01								0.001						
Fish	14	English sole (Parophrys vetulus)																
Fish	15	Herring (resident)																
Fish	16	Blackmouth chinook (resident)		0.012	0.025													
Fish	17	Ratfish						0.002										
Fish	18	Shiner surfperch																
Fish	19	Staghorn sculpin			0.011													
Bird	1	Double crested Cormorant (adult male)	0.027		0.057			0.916										
Bird	2	Double crested Cormorant (adult female)	0.027		0.057			0.916										
Bird	3	Great Blue Heron (adult male)			0.109			0.891										
Bird	4	Great Blue Heron (adult female)			0.109			0.891										
Seal	1	Harbor Seal (adult male)	0.231	0.1			0.175		0.01	0.008	0.005	0.464	0.001	0.006				
Seal	2	Harbor Seal (adult female)	0.231	0.1			0.175		0.01	0.008	0.005	0.464	0.001	0.006				
Seal	3	Harbor Seal (1 yr old)	0.231	0.1			0.175		0.01	0.008	0.005	0.464	0.001	0.006				
Seal	4	Harbor Seal (pup)																1

Appendix J. Glossary, acronyms, and abbreviations

Bathymetry: Measure of underwater depth of a waterbody.

Benthic: The benthic zone is the ecological region at the lowest level of a body of water such as an ocean or a lake, including the sediment surface and some sub-surface layers.

Best management practices (BMPs): Physical, structural, and/or operational practices that, when used singularly or in combination, prevent or reduce pollutant discharges.

Bioaccumulative pollutants: Pollutants that build up in the food chain.

Biota: Flora (plants) and fauna (animals).

Bioturbation: The displacement and mixing of sediment particles by benthic fauna (animals) or flora (plants).

Box model: A computer prediction tool to simulate the movement of water and pollutants within Puget Sound.

Congener: In chemistry, congeners are related chemicals. For example, polychlorinated biphenyls (PCB) are a group of 209 related chemicals that are called congeners.

Fecundity: A measure of fertility, such as sperm count or egg count or the number of live offspring produced by an organism. The state of being fertile or capable of producing offspring. The quality of something that causes or assists healthy growth. The number of offspring produced by an organism in its lifetime.

Geometric mean: The geometric mean, in mathematics, is a type of mean or average, which indicates the central tendency or typical value of a set of numbers. It is similar to the arithmetic mean, which is what most people think of with the word "average," except that instead of adding the set of numbers and then dividing the sum by the count of numbers in the set, n, the numbers are multiplied and then the nth root of the resulting product is taken.

Loading: The input of pollutants into a waterbody.

Nonpoint source: Pollution that enters any waters of the state from any dispersed land-based or water-based activities, including but not limited to atmospheric deposition, surface water runoff from agricultural lands, urban areas, or forest lands, subsurface or underground sources, or discharges from boats or marine vessels not otherwise regulated under the National Pollutant Discharge Elimination System Program. Generally, any unconfined and diffuse source of contamination. Legally, any source of water pollution that does not meet the legal definition of “point source” in section 502(14) of the Clean Water Act.

Point source: Sources of pollution that discharge at a specific location from pipes, outfalls, and conveyance channels to a surface water. Examples of point source discharges include municipal wastewater treatment plants, municipal stormwater systems, industrial waste treatment facilities, and construction sites that clear more than 5 acres of land.

Standard deviation: Measure of the variability or spread of values in a data set.

Thalweg: The deepest or fastest moving portion of a channel.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

Acronyms and Abbreviations

BKM	Babson, Kawase, and MacCready
CFD	Cumulative frequency distribution
CSO	Combined sewer overflow
DEM	Digital elevation model
DL	Detection limit
DOC	Dissolved organic carbon
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
EMAP	Environmental Monitoring and Assessment Program
EPA	U.S. Environmental Protection Agency
GCMS	Gas chromatography-mass spectrometry
HOC	Hydrophobic organic contaminants
Invert	Invertebrate
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
Pb-210	Lead 210
PBDE	Polybrominated diphenyl ethers
PBT	Persistent bioaccumulative toxics
PCB	Polychlorinated biphenyls
PSAMP	Puget Sound Assessment and Monitoring Program
PSNS	Puget Sound Naval Shipyard
Psbox.xls	Ecology's computer prediction tool for the box model
SJF/SOG	Strait of Juan de Fuca / Strait of Georgia
TOC	Total organic carbon
TSS	Total suspended solids
WASP	Water Analysis Simulation Program
WDFW	Washington Department of Fish and Wildlife
wt	weight
WWTP	Wastewater treatment plant

Units of measurement

µg	microgram
cm	centimeter
g	gram
Kg	kilogram
L	liter
m/d	meters per day
ng	nanogram
pg	picogram
ppb	parts per billion