OSV *BOLD* SUMMER 2008 SURVEY

DATA REPORT

FINAL

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LIST OF ACRONYMS AND ABBREVIATIONS

µg	microgram(s)
AhR	aryl hydrocarbon receptor
CALUX	Chemical Activated Luciferase Gene Expression
cm	centimeter(s)
CLP	Contract Laboratory Program
COC	chemical of concern
CRQL	contract required quantitation limit
CSL	Washington State Cleanup Screening Levels
DL	detection limit
DMMP	Dredged Material Management Program
DNA	deoxyribonucleic acid
DW	dry weight
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management
ERDC	Engineer Research and Development Center
g	gram(s)
GC/MS	gas chromatograph/mass spectrograph
HPAH	high molecular polycyclic aromatic hydrocarbon
HR	high resolution
IQR	inter-quartile range
KM	Kaplain-Meier
kg	kilogram(s)
LOD	limits of detection
LPAH	low molecular polycyclic aromatic hydrocarbon
Mds	Mahalanobis distances
mg	milligram(s)
MTCA	Model Toxics Control Act
NADA	nondetects and data analysis
NOAA	National Oceanic and Atmospheric Administration
OSV	ocean survey vessel
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PCR	polymerase chain reaction
pg	pictogram(s)
POP	persistent organic pollutant
PS	Puget Sound
PSAMP	Puget Sound Ambient Monitoring Program
QAPP	Quality Assurance Project Plan
QA/QC	quality assurance/quality control
RGS	Reporter Gene System
RSET	Regional Sediment Evaluation Team
SAIC	Science Applications International Corporation
SMS	Washington State Sediment Management Standards
SQS	Washington State Sediment Quality Standards
SVOC	semivolatile organic compound
TEF	toxic equivalent factor
TEQ	toxic equivalent quotient
TOC	total organic carbon
USEPA	U.S. Environmental Protection Agency, Region 10
USACE	U.S. Army Corps of Engineers

1.0 INTRODUCTION

The Dredged Material Management Program (DMMP) agencies (the "Agencies") are reevaluating their procedures for determining the suitability of dredged material for unconfined disposal at designated open-water disposal sites. Specifically, the Agencies are revising guidelines for several persistent organic pollutants (POPs) to reflect current information on the exposure, bioaccumulation, and toxicity of these pollutants. The goal of this reevaluation is to ensure that DMMP guidelines are protective of human health and the environment, support the Puget Sound Initiative's goals for Puget Sound, maintain the viability of the open-water disposal program, and ensure consistency with regulatory requirements. The first POPs under review are the dioxin/furan congeners. A number of alternatives are being considered for developing interpretive guidelines for dioxin/furan congeners.[1] Many of these alternatives rely to some degree on an understanding of background concentrations of dioxins in sediments from the main basin of Puget Sound. Closely related to dioxins are dioxin-like polychlorinated biphenyls (PCBs). While the interpretive guidelines for PCBs are not currently under review, the Agencies anticipate addressing these POPs in the near future.

While the Puget Sound Ambient Monitoring Program (PSAMP) has generated a geographically extensive, long-term sediment data set from sites throughout Puget Sound, they have not routinely analyzed for dioxin/furan congeners and have limited their PCB congener analysis to a subset of the 209 possible congeners. There is little high-resolution dioxin/furan or PCB congener data available for Puget Sound outside of certain Superfund and Model Toxics Control Act (MTCA) cleanup sites. Therefore, it was necessary to conduct a survey of dioxin/furan congeners in Puget Sound in order to provide the background data necessary to evaluate the practical, economic, environmental, and regulatory consequences of the various dioxin/furan guideline alternatives being considered. As PCBs will soon need to be evaluated in a similar manner, background PCB data were also collected.

This report provides the results of a study conducted in the summer of 2008 to measure dioxin/furan and PCB congeners in surface sediments throughout Puget Sound. The study evaluated seventeen (17) 2,3,7,8-chlorine-substituted dioxin/furan and 209 PCB congeners. A full suite of DMMP contaminants of concern (COCs) including semi-volatile organic compounds (SVOCs), polycyclic aromatic hydrocarbons (PAHs), Aroclor PCBs, pesticides, and trace metals were also measured in the sediments collected. These data will be useful for the dredging program as well as other programs focused on sediment contamination in the Puget Sound region. In addition to chemical analysis, dioxin/furan activity was assessed in these sediments using three U.S. Environmental Protection Agency (USEPA)-approved biological-based methods (CALUX, P450RGS/101L, and Procept®).

[1] For more information on interpretive guideline revisions for dioxin, see http://www.nws.usace.army.mil/PublicMenu/Menu.cfm?sitename=DMMO&pagename=Dioxin_Work_Group

2.0 STUDY OBJECTIVES

The DMMP agencies identified the following six objectives to be addressed by this study:

- **Objective 1.** Evaluate whether the concentration distributions of dioxin/furan and PCB congeners appear to be correlated with grain size or total organic carbon (TOC), if possible.
- **Objective 2.** Identify the concentration distributions of dioxin/furan and PCB congeners in existing DMMP reference areas.
- **Objective 3.** Identify the concentration distributions of dioxin/furan and PCB congeners in Puget Sound generally, away from known sources and cleanup sites.
- **Objective 4.** Compare the concentration distributions of dioxin/furan and PCB congeners in existing reference areas to those in Puget Sound (away from known sources and cleanup sites) to determine whether they are statistically different.
- **Objective 5.** Determine the distribution of other chemicals of concern (metals, SVOCs, pesticides) in Puget Sound.
- **Objective 6.** Conduct corroborative testing of three dioxin/furan and PCB congener toxic equivalent quotient (TEQ) assays to determine whether they are well-correlated with standard methods, have low enough detection limits, and are cost-effective.

3.0 SAMPLING AND ANALYSIS

The following sections describe how the sampling design meets the study objectives described in Section 2.0 and provide an overview of the sediment sample collection and analysis. Details of the sampling and analysis protocols are provided in the Work Plan (DMMP 2008), Study Plan (USEPA 2008a), and Quality Assurance Project Plan (QAPP) for the USEPA Ocean Survey Vessel (OSV) *Bold* (USEPA 2008b)[2].

3.1 Overall Design

The study objectives described in Section 2.0 were addressed through the following overall sampling approach:

- **Objective 1** – Grain size and TOC were analyzed at all stations to determine whether there are correlations. The sampling approach is described in Objectives 2 and 3 below.

- **Objective 2** – Five sampling stations were located within each of four existing reference areas, for a total of 20 samples analyzed for dioxin/furan and PCB congeners. The four reference areas that were sampled include Carr Inlet, Holmes Harbor, Dabob Bay, and Samish Bay.

- **Objective 3** – Five sampling stations were located within each of ten strata representing geographic areas of the greater Puget Sound region (including a portion of the Strait of Juan de Fuca, the San Juan Islands, and Hood Canal), for a total of 50 samples analyzed for dioxin/furan and PCB congeners. The ten strata were developed solely for the purpose of distributing the 50 samples throughout the greater Puget Sound area, and the strata boundaries will not be used for decision-making.

- **Objective 4** – The existing reference area distribution described above and the greater Puget Sound distribution described above were compared to determine whether they are statistically different.

- **Objective 5** – Metals, SVOCs, and pesticides were analyzed at all stations to evaluate the concentrations and distribution of these COCs in Puget Sound.

- **Objective 6** – At each station, three assays recently approved by USEPA as Standard Methods were conducted along with dioxin/furan and PCB congener analyses to determine whether these methods have a good correlation with the conventional methods and can achieve low enough detection limits to detect concentrations in the areas sampled. These assays are Method 4425 (101L/P450 Reporter Gene System [RGS]), Method 4430 (Procept®), and Method 4435 (Chemical Activated Luciferase Gene Expression [CALUX]).

3.2 Station Locations

Station locations were selected using a stratified random design. First, urbanized embayments were eliminated from consideration. These included Budd Inlet, Commencement Bay, Elliott Bay, Sinclair and Dyes Inlets, Eagle Harbor, Everett, and Bellingham Bay. Then each of the four existing reference areas was treated as a separate stratum (Dabob Bay, Carr Inlet, Holmes Harbor, and Samish Bay). The remaining area was divided into 10 strata to ensure that the 50 samples would be distributed throughout Puget Sound. The boundaries of these strata were located along obvious geographic features and basins where possible, but are not otherwise significant, as their only purpose was to provide geographic coverage.

[2] Copies of these documents are available on the U.S. Army Corps of Engineers, Seattle District website: http://www.nws.usace.army.mil/PublicMenu/Menu.cfm?sitename=DMMO&pagename=Dioxin_Work_Group

Within each of the 10 greater Puget Sound (PS) strata, Visual Sample Plan (Matzke et al. 2007) was used to generate 20 randomly located stations. Similarly, within each of the existing reference areas, eight randomly located stations were generated. In each stratum, starting with the lowest-numbered station, each station was reviewed for acceptability as follows:

- If the station was too shallow or too deep to be sampled by the USEPA OSV *Bold* (<10 meters or >180 meters), the station was moved due west or due east until a depth of 10–180 meters was reached, whichever direction resulted in a shorter move. If the station could not be relocated without ending up on land, in Canadian waters, or within an urban bay, the station was rejected. Relocated stations were then re-evaluated according to the remaining exclusion criteria.

- If the station was located within 500 meters of an outfall, cleanup site, or other known contaminant source (e.g., the Hood Canal floating bridge), the station was rejected. In the case of cleanup sites and other known contaminated areas, agency staff occasionally used best professional judgment to reject a station outside 500 meters that was nevertheless near enough to contaminated areas or sources to potentially be influenced by them (e.g., two stations northeast of Rayonier and Port Angeles Harbor).

- If the station was located within 250 meters of a detected DMMP screening level exceedance listed in the Washington State Department of Ecology (Ecology)'s Environmental Information Management (EIM) database, the station was rejected. This radius is smaller than the above sites and sources, because this might be a single exceedance of a standard over a small area, and not all data in EIM are as rigorously verified as the source and site information above.

In one case, a station was rejected because it was located in the Tacoma Narrows, in an area where agency staff believed it would not be feasible to maintain a station position and collect the sample.

Any station meeting the above criteria, but located within 2,500 meters of a previously accepted station, was not rejected but was not selected as a primary or backup sampling location to avoid excessive station clustering and provide a representative sample set. It was not always possible to adhere to the 2,500-meter rule in the reference areas (which were much smaller in area than the other strata), but stations were selected to provide the widest possible distribution of sampling points.

Stations that passed all of the above screening criteria were accepted as usable. In each of the Puget Sound strata, starting with the lowest-numbered station, the first five accepted stations were identified as the target sampling stations, and the second five accepted stations were identified as contingency sampling stations, in case any of the five target stations could not be sampled in the field. In all strata, there were sufficient accepted samples to provide five target and five contingency samples. In the existing reference area strata, five target and two to three contingency samples were selected. Five sample splits were also prepared in the field as laboratory duplicates for quality assurance/quality control (QA/QC) purposes.

In addition, the station locations were reviewed against Puget Sound-wide grain size data from EIM to determine whether it was likely that a complete grain size distribution would be sampled. In some areas, it appeared likely that most of the target and backup samples would be either coarse- or fine-grained, and in these strata, one or more contingency samples were identified that could be collected if the first four samples were all coarse- or all fine-grained. Field staff performed wet sieving to roughly determine the grain size of sediments collected from target sampling stations. This information was used to determine whether contingency grain size sampling stations would be substituted for target stations.

A complete list of the samples reviewed in each strata, their acceptance or rejection, and reasons for rejection along with other notes can be found in the Work Plan (DMMP 2008). The locations sampled

during the 2008 survey are shown in Figure 1. The geographic locations for all stations and a detailed summary of field sampling activities can be found in the OSV *Bold* Survey Report (USEPA 2008c).

3.3 Sampling and Analysis Methods

Sediment samples were collected during the period July 31 through August 5, 2008, from the USEPA OSV *Bold*, using a double van Veen sampler. Sampling, decontamination, sample preparation, shipping, analytical, and quality assurance procedures followed for the survey are described in the Survey Plan (USEPA 2008a) and the QAPP for the OSV *Bold* (USEPA 2008b).

A total of 70 surface samples and five duplicate samples were collected from the top 10 to 14 centimeters (cm) of sediment and analyzed for the chemical parameters and assays listed in Table 1. Dioxin/furan and PCB congeners, metals, SVOCs, pesticides, grain size, TOC, and percent solids were analyzed under USEPA's Contract Laboratory Program (CLP), managed by Ginna Grepo-Grove, Project QA Manager, USEPA Region 10. The analytical laboratories are listed in Table 1.

Samples for the dioxin assays (CALUX, 101L, and Procept®) were split in the field and submitted to their respective laboratories; CALUX was analyzed by XDS, while both the 101L and the Procept® samples were analyzed at the U.S. Army Corps of Engineers, Engineer Research and Development Center (USACE-ERDC), with both assays using the same extracts. The Procept® method is a cell-based polymerase chain reaction (PCR) method that rapidly detects the presence of a DNA-bound dioxin receptor in a micro well and is amplified using PCR. The CALUX and 101L methods are based on the ability of dioxin and other dioxin-like compounds to activate the Aryl hydrocarbon receptor (AhR), a chemical responsive deoxyribonucleic acid (DNA) binding protein that is responsible for producing the toxic and chemical effects of these chemicals. Additional information on these assays is provided in the Work Plan (USEPA 2008a).

Figure 1. 2008 OSV *Bold* Sampling Locations and Greater PS Strata

Table 1. Analytical Laboratories for the 2008 OSV *Bold* Survey

Parameter	Method[1]	Analytical Laboratory
Dioxin/Furan Congeners	1613	SGS Laboratories, Wilmington, NC
PCB Congeners	1668	SGS Laboratories, Wilmington, NC
PCB Aroclors	8082	A4 Scientific Inc., The Woodlands, TX
Metals	6020/7471/7740	Bonner Analytical of Hattiesburg, MS
SVOCs	8270	A4 Scientific Inc., The Woodlands, TX
Pesticides	8081	A4 Scientific Inc., The Woodlands, TX
Grain Size	Plumb (1981)[2]	Analytical Resources Inc., Tukwila, WA
TOC	9060	Analytical Resources Inc., Tukwila, WA
Total Solids	PSEP (2003)[3]	Analytical Resources Inc., Tukwila, WA
CALUX Assay	4435	Xenobiotic Detection Systems, Durham, NC
Procept® Assay	4430	U.S. Army Corps of Engineers, Engineer Research and Development Center, Vicksburg, MS
101L Assay	4425	U.S. Army Corps of Engineers, Engineer Research and Development Center, Vicksburg, MS

1 Analytical methods (4000, 6000, 7000, 8000, and 9000 series) are from SW-846, Test Methods for Evaluation Solid Waste Physical/Chemical Methods, U.S. EPA 1986 and updates. http://www.epa.gov/epawaste/hazard/testmethods/index.htm. Method 1613 analytical method from U.S. EPA-821/B-94-005 (1994). Method 1668 analytical method from U.S. EPA-821-R-08-020 (2008).

2 Procedures for Handling and Chemical Analysis of Sediment and Water Samples, Russell H. Plumb, Jr., USEPA/Corps of Engineers, May, 1981.

3 Recommended Protocols for Conventional Sediment Variables in Puget Sound, Puget Sound Estuary Program, March 1986 with minor corrections April 2003.

3.4 Deviations from the Sampling and Analysis Plan

3.4.1 Sample Locations

Two locations were altered in transit. The original AI_8_C_GS was moved north to the AI_20C location when rocky substrate was encountered at what was selected as a fine-grain contingency site. The SJI_11_C_GS sampling site was determined to be navigationally challenging by the Captain, and the alternative site SJI_20_C_GS was placed at the entrance to the East Sound. Both changes were suggested by the Captain and confirmed by the Watch Captain after consulting maps to ensure the new sites met the site selection criteria. Sample location R_Dab_3 was dropped before sampling due to being too shallow and too close to shore to safely sample.

Upon early completion of collection of the Puget Sound-wide sampling, the Watch Captains, Chief Scientist, and Captain agreed to obtain samples at the Anderson-Ketron Disposal Site to assist in post-disposal monitoring. While these samples were collected on the OSV *Bold*, their analysis was not intended to be associated with the other samples collected on the OSV *Bold* (i.e., they are not part of the reference and main basin sampling plan) and are not included in this data report.

3.4.2 Sampling Procedures

There were several minor deviations during sampling, none of which were likely to impact the quality of resultant data. Additional details are documented in the field logs (Appendix A):

- The PSEP acceptance criteria were not strictly adhered to for some samples. A few samples, particularly in Samish Bay, had possible overpenetration. Others, where rock and cobble were encountered, had minor winnowing.

- Several samples had biota present, which may have impacted sediment chemistry. Large organisms were removed (clams, scallops, echinoderms, large polychaetes, etc.). In the SJI and SJF areas, large rocks covered with biota were also removed.

- The wet sieving analysis procedure was altered at the first sampling site. Only 50 mL of wet sediments were sieved, rather than 100 mL. Wet sieve data were not recorded at R_SAM_3.

- When samples were sent to the various laboratories for analysis, there were insufficient temperature blanks for all the coolers, and bagged ice was used in many coolers instead of blue ice.

3.5 Summary of Quality Assurance Reports

All data collected and analyzed as part of the Puget Sound Sediment PCB and Dioxin Survey underwent a QA/QC validation incorporating specifications outlined in Ecology's QA2 data validation process, the USEPA's Stage 4 Data Validation Electronic and Manual Procedures, and applicable criteria set forth in the USEPA CLP National Functional Guidelines. In addition, the reported analytical data were also qualified based on the professional judgment of the data reviewer.

Based on the results of the QA/QC validations, all data were considered usable as qualified. A summary of the data validations is presented. The full data validation reports are presented in Appendix B.

Dioxin/Furan Congeners

All of the samples were received intact and then frozen by the laboratory. The samples were extracted and analyzed in four batches, all within holding times. Recovery criteria were met in all ongoing precision and recovery samples. OCDD was detected in one method blank. Approximately 23 percent of the total data points were qualified as estimated due to values that were less than the quantitation limits and to interferences. About 0.1 percent of the data were reported as non-detects due to contamination in the blank.

PCB Aroclors and Pesticides

All samples were received intact. Four PCB Aroclor samples were extracted outside the holding time, and one batch of pesticides was analyzed outside the holding time. All samples that exceeded holding time were qualified as estimated. Modifications (noted in Appendix B) were made to the SOW for Method SOM01.2 in order to achieve analytical concentration goals. All of the samples were analyzed in accordance with technical specifications outlined in the modified method SOW. The data, as qualified, are acceptable and can be used for all purposes.

PCB Congeners

All samples were received intact and analyzed within holding times and at the project-required detection limits. Several of the congeners co-eluted and were reported with a laboratory qualifier "C." Trace levels of several PCB congeners were detected in the method blanks and associated samples. Detected congeners at concentrations less than five times the value in their respective method blank(s) were qualified as non-detects, "U." Detections greater than five times the value in the blanks were not qualified. All of the 15,704 data points reviewed were acceptable and can be used for all purposes. Approximately 16 percent of the

total data points were qualified as non-detects due to contamination in the blank or detections with unacceptable mass-ion abundance ratios.

SVOCs

All SVOC samples were received intact and analyzed within holding times. The contract-required quantitation limits (CRQLs) were based on the lowest standard concentration analyzed in the initial calibrations. Detected SVOC compounds in the samples at concentrations less than the CRQLs were qualified as estimated, "J." After all calculations accounted for the amounts extracted, percent moisture, GPC factor, and dilution factor as indicated in the QAPP, some of the CRQLs ended up slightly higher than those required in the method. PAH results from both scan and SIM runs were validated and reported. SIM results were used when noted by the reviewer (Appendix B). The total number of data points evaluated was 6,825. As the result of the data validation, 1.3 percent of those were qualified due to calibration; 1.0 percent were qualified due to failing matrix spikes; 0.4 percent were qualified due to failing surrogates; and 0.03 percent were qualified due to failing internal standards.

Metals

Samples were received and analyzed within holding times. Some metals were found in the method blanks. Most sample concentrations of these metals were greater than five times the blank concentrations and were not qualified. Exceptions were for antimony, cadmium, silver, and mercury. When sample concentrations had less than five times the blank concentrations, these metals were qualified "U." Overall it was noted that several non-detected results for antimony and selenium were erroneously reported as detects or were reported with elevated detection limits. These metals have been correctly qualified "U."

Grain Size/TOC

Only minor issues were noted with the grain size and TOC analysis. All data are acceptable as qualified.

Dioxin Assays

For CALUX analysis, samples NCPS_3, R_HOL_1, R_DAB_7_C, and R_HOL_3 appeared to have leaked slightly into the plastic bag holding the sample containers. No cross contamination was apparent. Samples were extracted and assays conducted within 30 days of receipt. All QA/QC limits were met for this assay (see Appendix C for details). No non-detects were reported for dioxin TEQs. For PCB TEQs, 70 samples were reported as non-detects (limit of detection ranged from 0.1 to 2.72 pg/g TEQ).

Samples for the 101L and Procept® assays were received intact. The samples were extracted within their holding times. Standard reference material was extracted with each batch and for the 101L assay the data fell within historical QC limits; Procept® did not have historical QC comparisons. Two samples were reported as non-detects for the 101L assay (limit of detection [LOD] for 101L was 2.45 pg/g TEQ), and there were no non-detects reported for Procept®.

4.0 RESULTS

This section provides a summary of results for the Puget Sound Sediment PCB and Dioxin Survey. The first section presents an initial evaluation of the overall dioxin/furan and PCB data set, including identification of outliers. The sections that follow present the study results within the context of the Study Objectives (1 through 6) as outlined in Section 2.0.

4.1 Initial Evaluation of Overall Dioxin/Furan and PCB Data Set

TerraStat Consulting Group conducted an initial evaluation of the overall dioxin/furan and PCB data set, including an identification of outliers, following the approach proposed as a result of the Technical Experts' Workshop sponsored by the Regional Sediment Evaluation Team (RSET), DMMP Dioxin Workgroup, and USEPA Region 10 Superfund (Avocet 2008). A description of the graphical displays and statistical methods for the initial evaluation is provided in Section 4.1.1. The evaluation results are provided in Section 4.1.2.

4.1.1 Methods

Graphical Displays

Boxplots (a.k.a. box-and-whisker plots, Figure 2) are used to illustrate the distribution of the data and provide information about the location, spread, and skew of the data. Representing data in this fashion facilitates comparison. Each boxplot has a shaded/colored rectangle that shows the spread of values between the 1st and 3rd quartiles (i.e., the 25th and 75th percentiles). The height of this box is the inter-quartile range (IQR) which is simply the value of the 3rd quartile minus the value of the 1st quartile. The line inside the box indicates the median; the outer brackets (the "whiskers") represent the minimum and maximum values or 1.5 times the IQR from the median, whichever is less. The value of 1.5 times the IQR is somewhat arbitrary but should contain approximately 95 percent of observations from a normal (Gaussian) distribution. Values outside the whiskers are possible extreme values and are shown as single lines.

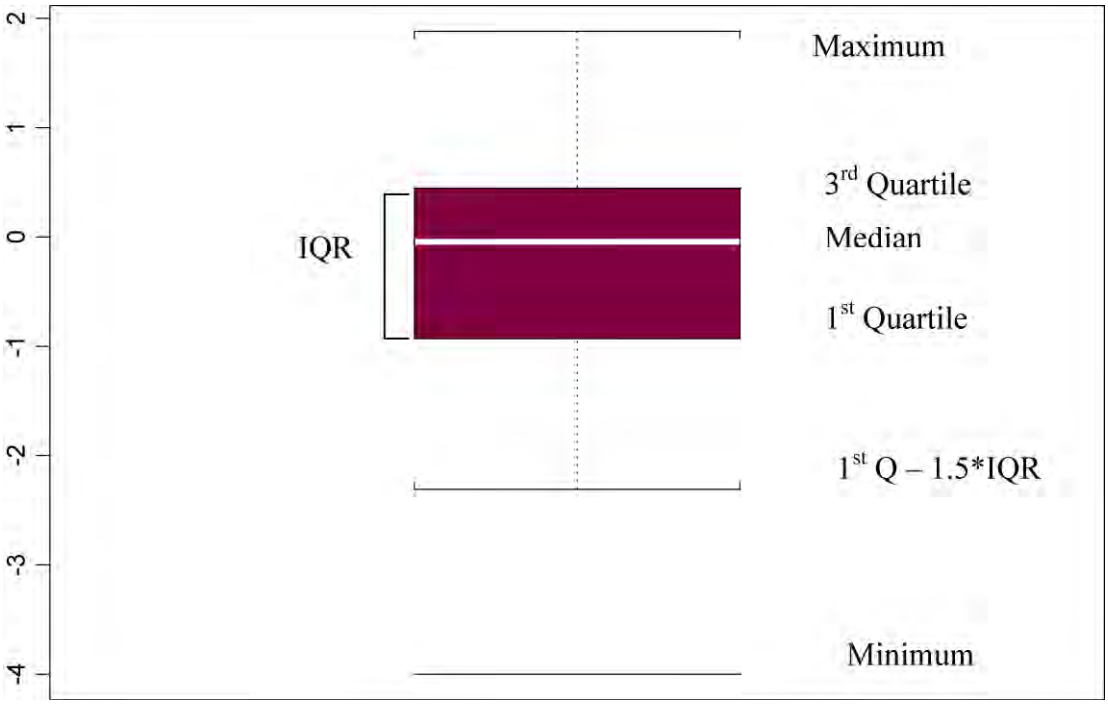


Figure 2. Example Boxplot

Outlier Analysis

"Outliers" are extreme values that are different from the rest of the data. Identification of the extreme values is important to confirm accuracy in reporting, or to identify observations that may be from a different population than the rest of the data.

Two objectives of this study were to describe the chemical characteristics of the ambient and reference area samples. Doing this involved defining the nature of the distribution. Extreme values may identify problem areas, or they may simply be part of the variability in the ambient data. All extreme samples were verified for accuracy, and if correct, summary statistics were calculated both with and without these samples.

A multivariate approach was used to identify extreme values. The approach calculates the distance (known as the Mahalanobis distance[3] [Mds]) between each observation and the "cloud" of remaining observations. An extremely large distance for a given observation indicates that it has a chemical pattern that is different from the other observations. This pattern may differ due to extreme values for individual congeners, or due to higher than expected values for all congeners. The "cloud" of remaining observations is described by robust estimates for location and "scatter" (statistically described as covariance). The robust estimates for location and covariance were calculated using the minimum covariance determinant (mcd) estimators (Rousseeuw and van Driessen 1999; calculated in S-PLUS 2000; Scout 2008 *beta-version*; and R-2.8.0, "robustbase" package), which are not affected by the extreme values that they are intending to detect. Note that this approach does not make allowance for censored data, so non-detects were included at the detection limit. This means that some of the observations with intermediate distances may simply have more detected concentrations than the bulk of the data.

The distributions of robust Mahalanobis distances were evaluated separately for the dioxin/furan congeners, and the PCB congeners. Mahalanobis distances were based on 17 dioxin/furan congeners, and the 11 PCB congeners which had toxic equivalent factors (TEFs). Multivariate Mds were not evaluated for the full suite (209) of PCB congeners because the number of variables must be less than the number of samples (70). Extreme distance values were identified based on the Beta distribution and a very conservative critical value ($p < 0.001$). The distributions of Mds were also evaluated graphically using Quantile-Quantile plots to confirm that the identified extreme samples were indeed unusual from the remainder of the distribution and not just slightly outside the envelope of remaining samples.

Kaplan-Meier Calculations

The Kaplan-Meier (KM) approach is a non-parametric way of estimating summary statistics for right-censored data (i.e., where some values are represented as "greater than" values, such as with survival data where the time-to-failure was not reached). Its application in environmental datasets with left-censored data (i.e., data below the detection limit, represented as "less than" values) is easily done by flipping the data, so that the maximum observed value becomes the minimum value in the flipped data set. In this way, the left censored data become right-censored, and KM methods can be applied (Helsel 2005). The KM approach does not make substitution for non-detects, and can be used for estimating quantiles, means, and variances. The KM quantiles reported for these data were done in S-Plus2000 using the "kaplanMeier" and "censor" functions on the flipped data.

[3] The Mahalanobis distance is similar to Euclidean distance (i.e., the familiar distance measure used to calculate the distance between two points on a line), but is calculated between each point and the robust location estimate, and is divided by the robust covariance estimate.

Calculation of the sum of congeners for each individual sample employed the KM means in an innovative approach based on the mathematical relationship that the Sum = Mean x n (Helsel 2009). The set of 17 dioxin/furan congeners for each sample was evaluated using the KM procedure for left-censored data to estimate the mean of the 17 congeners. This mean was then multiplied by 17 to represent the sum of the 17 congeners. This was done for each sample, separately, for the dioxin/furan congeners as well as the 166 PCB congeners.[4] The same calculations for concentration expressed as TEQs were performed by weighting each concentration by its respective TEF prior to estimation of the mean. The dioxin/furan + PCB TEQ is the sum of the two separate TEQs (i.e., dioxin/furan TEQ + PCB TEQ). The KM means were done in R-2.8.0 using the 'cenfit' and associated functions in the NADA (Nondetects and Data Analysis) package (Lee).

4.1.2 Evaluation Results

The overall data set (n = 70) was evaluated using side-by-side boxplots of sample results by location for the individual dioxin/furan and PCB congeners and homologue groups (Appendix D; Figures D1 – D8), total dioxin/furan (KM sum of 17 congeners[5]) (Figure 3), total PCBs (KM sum of 166 congeners), dioxin/furan TEQ (weighted KM sum of 17 congener[6]), and PCB TEQ (weighted KM sum) (Figure 4). Boxplots excluding extreme values are presented in Figure 5 (individual dioxin/furan congeners and total dioxin/furan) and Figure 6 (dioxin/furan and PCB TEQs). The dry-weight totals and TEQ sums for each sampling location were calculated using a Kaplan-Meier approach (see Section 4.1.1 Methods) (Table 2). Each box in Figures 3 through 6 represents five sampling stations from each of the 14 strata (four reference locations; 10 from the Main Basin). A summary of the dioxin/furan TEQ, PCB TEQ, dioxin/furan/PCB TEQ, and total PCB congeners (all reported in dry weight [dw]) according to area type (reference, greater Puget Sound, and combined) is presented in Tables 3 through 5. These data are also spatially depicted in Figures 7 and 8. The data set has these features:

Dioxin/Furan Congeners

- The overall range of total dioxin/furan concentrations was 0.05 – 11.6 pg/g TEQ with a median value of 0.862 pg/g TEQ (Figure 7; Tables 2 and 5). If extreme values are excluded, the overall median dioxin/furan TEQ value is 0.828 pg/g TEQ.

- The strata that tend to have slightly lower medians and/or smaller ranges for individual congeners are Admiralty Inlet, Straits of Juan de Fuca, San Juan Islands, and North Central Puget Sound.

- The South Sound (SS) stratum has a much greater concentration range than the other areas for most of the individual congeners, homologues, and sums. The two stations exhibiting the higher values are: SS_0 and SS_9_C.

- Other strata with slightly higher ranges than the other areas are Port Susan Possession Sound and South Central Puget Sound.

- The reference area strata generally had similar dioxin concentrations. However, one Carr Inlet station (R_CAR_5) had higher congener concentrations than the other stations from this reference area.

[4] The analytical method reported some combinations of PCB congeners (e.g., PCB 129/138/163) as single endpoints. A total of 166 unique PCB congener endpoints were reported, which represents the 209 congeners.
[5] Total dioxin/furan and total PCB congeners in this report are presented as KM sums.
[6] TEQ values for all dioxin/furan and PCB congener HR-GC/MS data were calculated using weighted KM sum (see Section 4.1.1).

- The Samish reference area has the highest median and one of the highest ranges for the lab-reported total dioxins (Total TCDDs, PECDDs, and HXCDDs; but not HPCDDs or the furan sums – see Appendix D; Figures D3 and D4). One of the highest values for total TCDDs outside of South Sound (SS) is found at R_SAM_5 (18.6 pg/g).

- A multivariate review of the 17 individual dioxin/furan congeners involved the calculation of Mahalanobis distances (Mds) (see Section 4.1.1, Methods) for each sample. Inspection of the distribution of Mds found three stations to have extreme distance values indicating different dioxin/furan congener patterns from the remainder of the stations. The Mds were statistically significant (beta distribution, $p<0.001$), and show elevated Mds quite distinct from the rest of the samples (Figure 9). These three stations identified above were also identified as extreme for some of the individual congeners. They are, in decreasing order from the most extreme: R_CAR_5, SS_0, and SS_9_C. The Mahalanobis distances for these three stations were two to three orders of magnitude greater than the other stations. Summary data/statistics excluding these three stations are provided in Figures 5 and 6 and in Table 3-5.

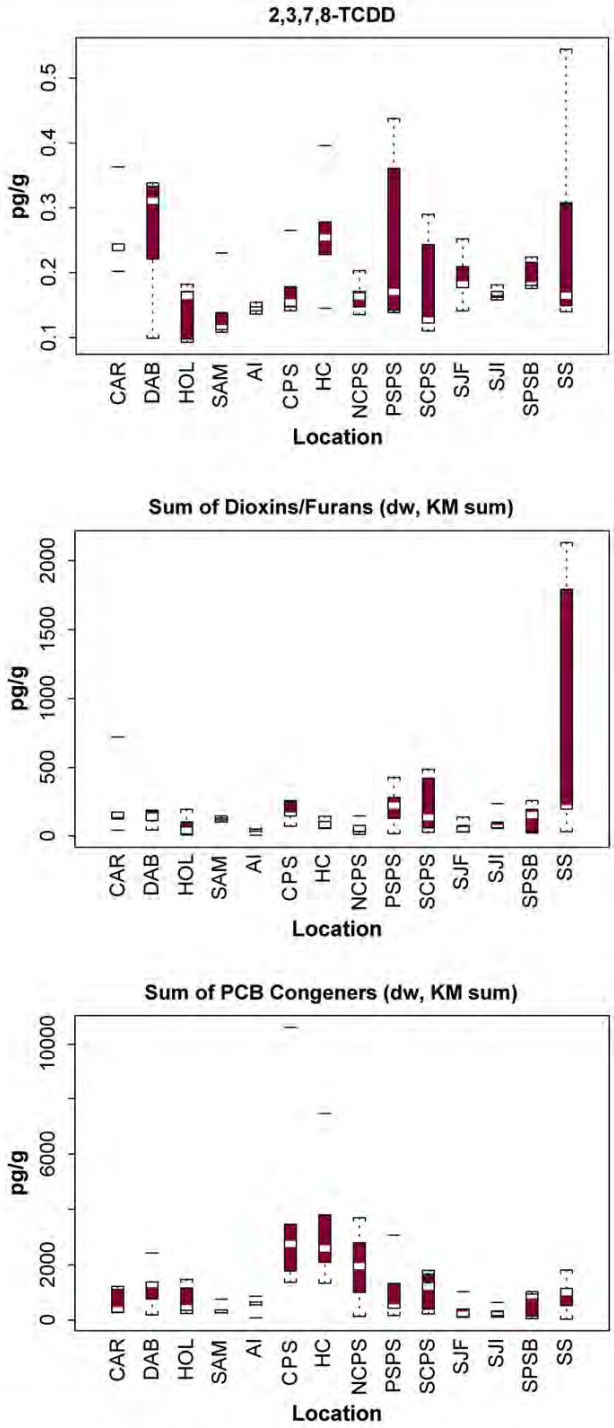


Figure 3. Boxplots for 2,3,7,8-TCDD and Total Dioxin/Furan and PCB Congeners (dry weight, KM sum)

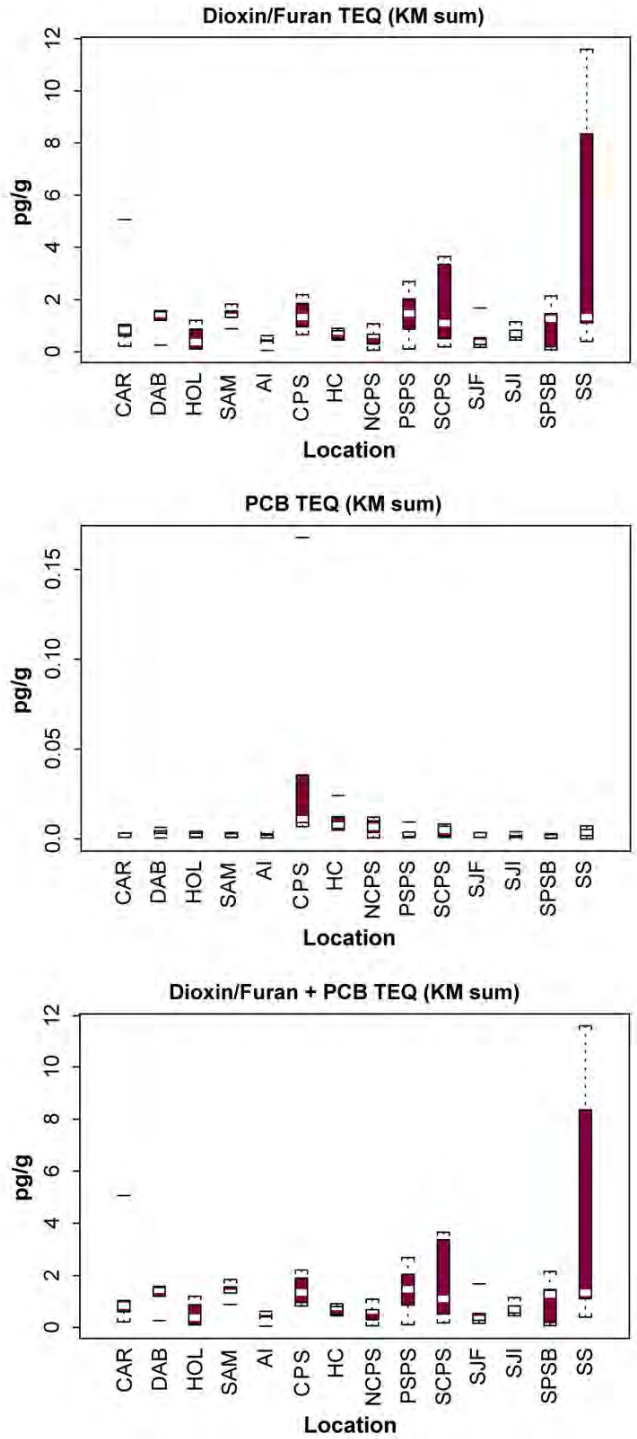
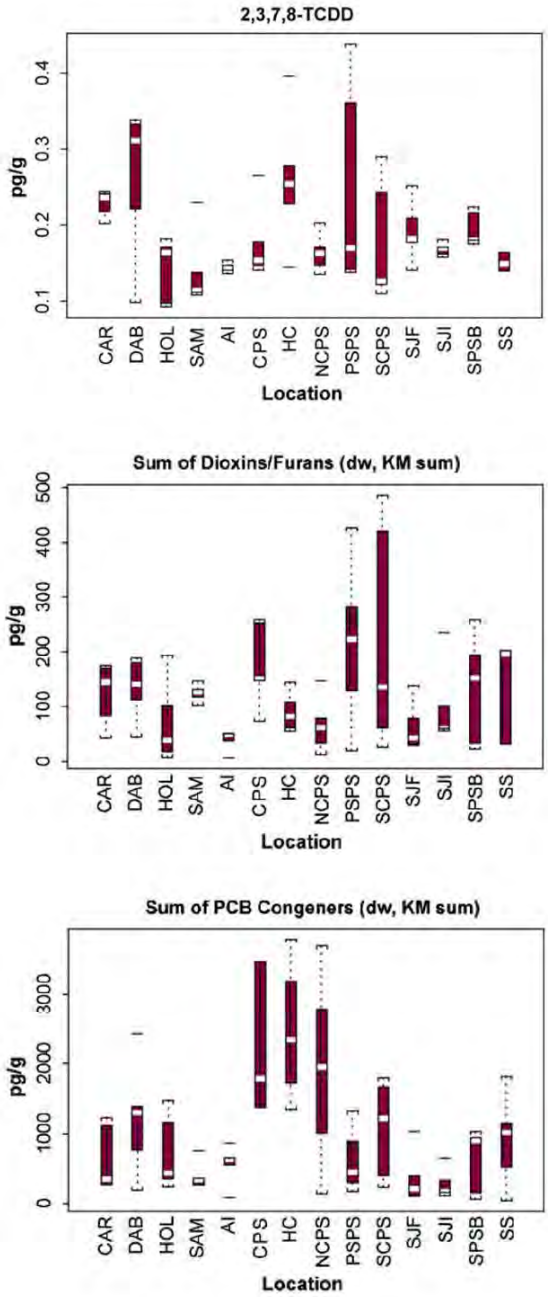
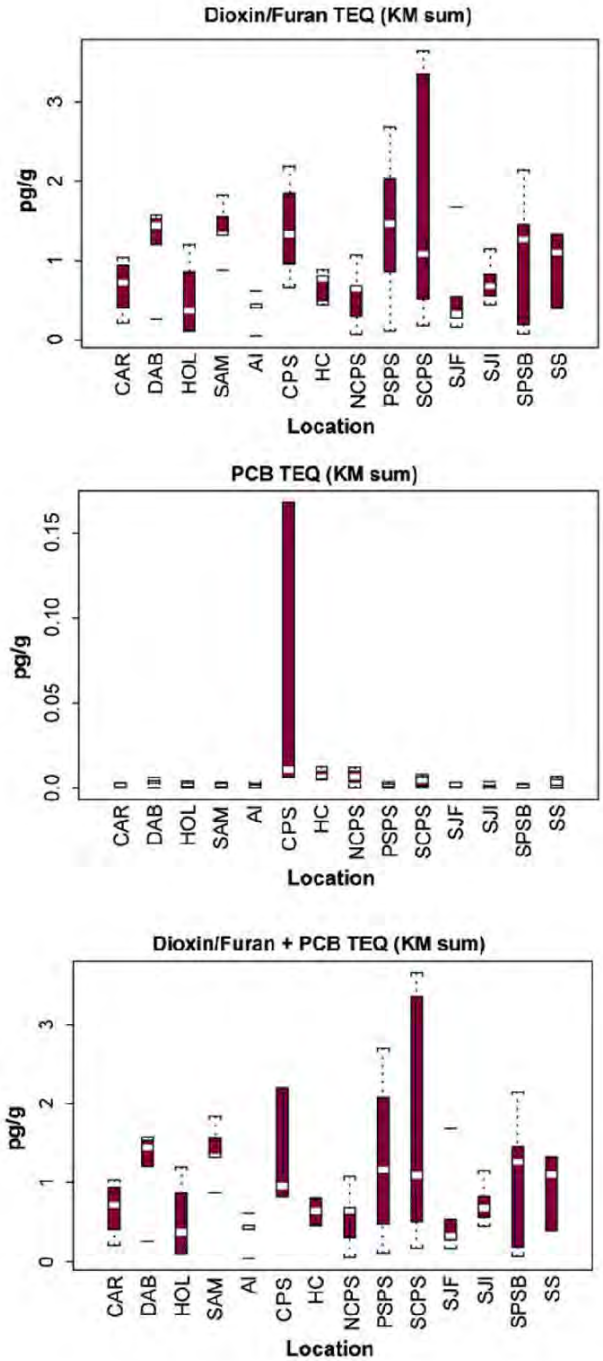


Figure 4. Boxplots for TEQs (weighted KM sum)



Notes:
All boxplots exclude R_CAR_5, SS_0, AND SS_9_C

Figure 5. Boxplots Excluding Extreme Values for 2,3,7,8-TCDD and Total Dioxin/Furan and PCB Congeners (dry weight, KM sum)



Notes:
All boxplots exclude R_CAR_5, SS_0, AND SS_9_C

Figure 6. Boxplots Excluding Extreme Values for TEQs (weighted KM sum)

TerraStat CONSULTING GROUP

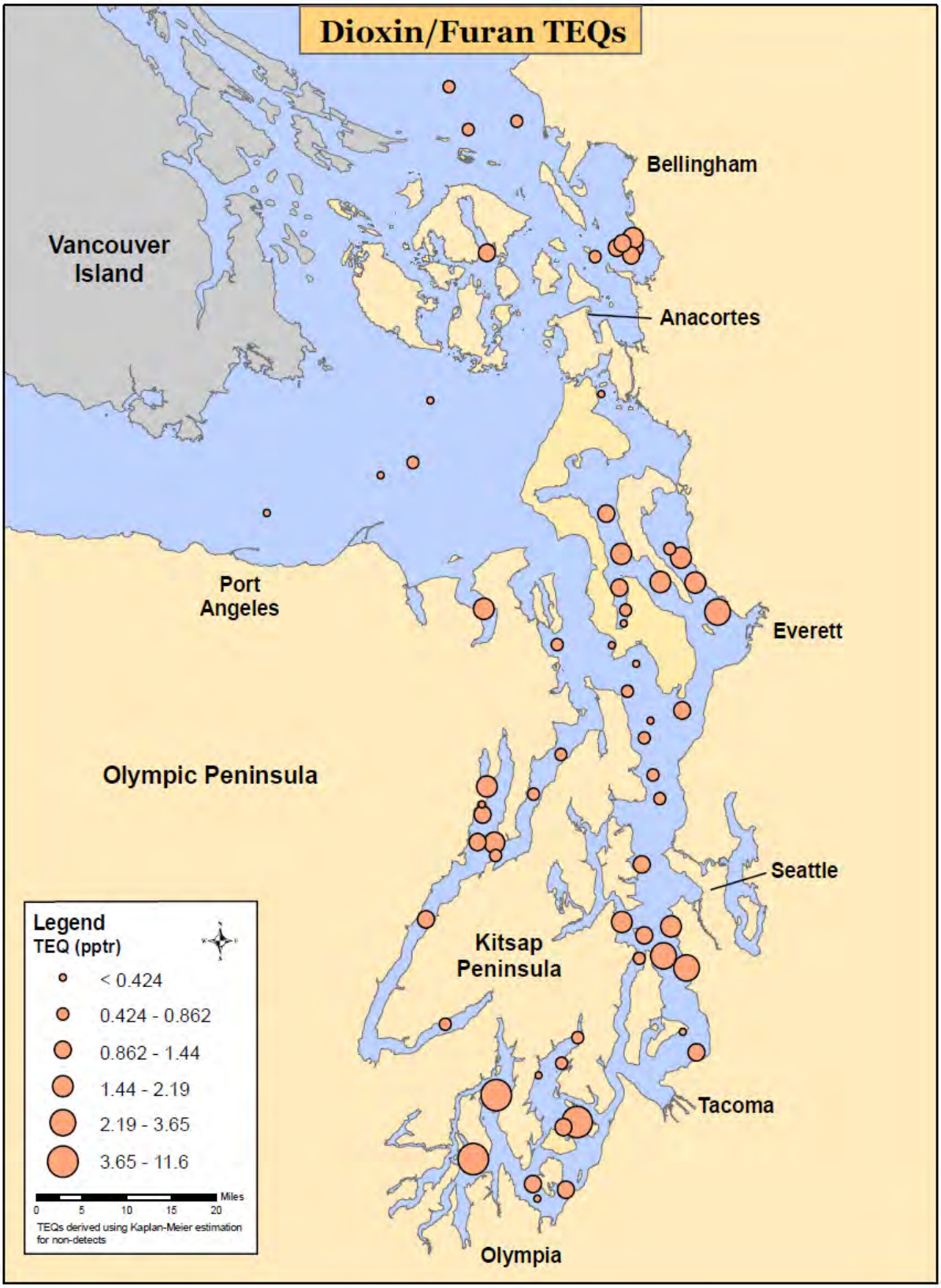


Figure 7. Distribution of Dioxin/Furan TEQs (weighted KM sum)

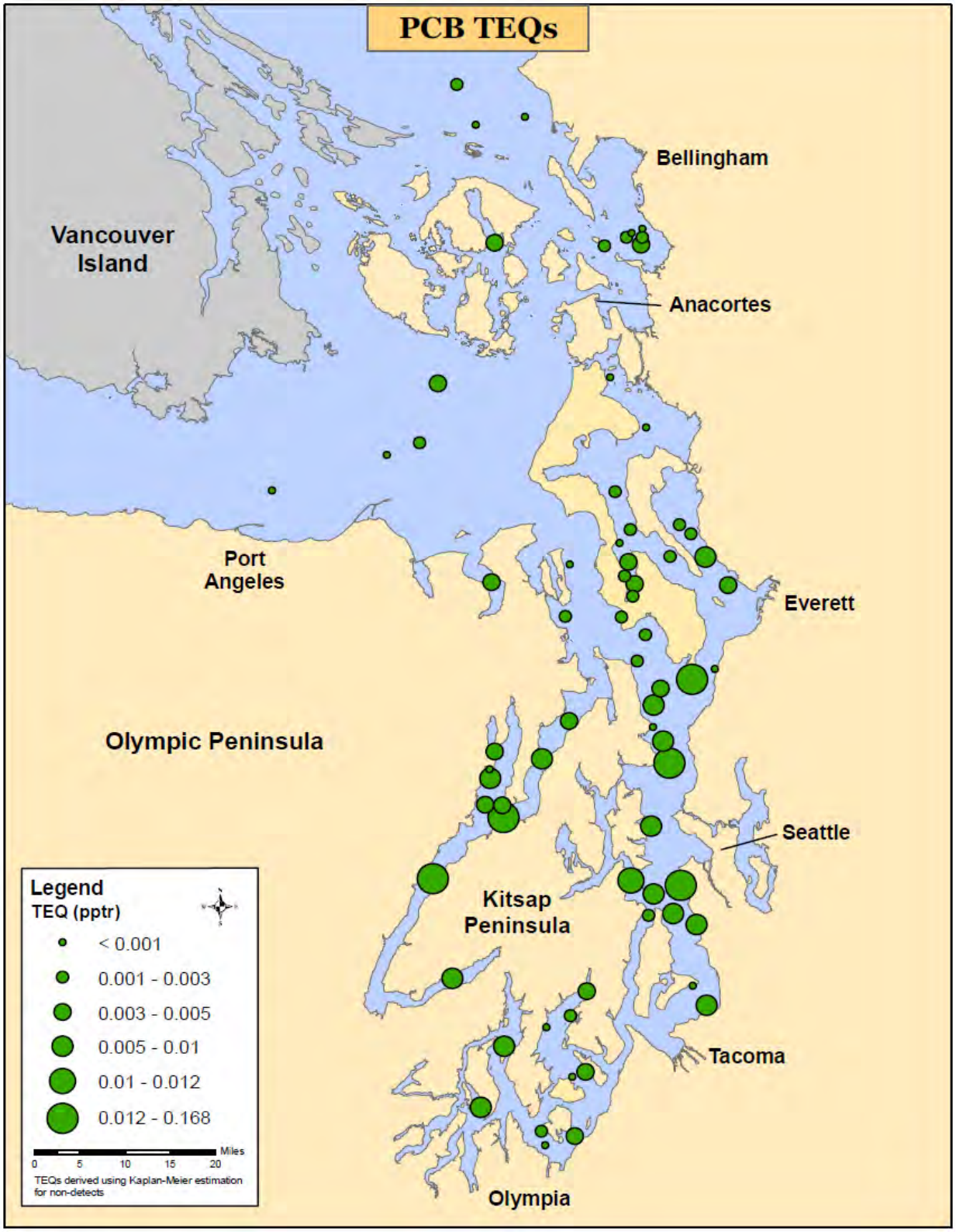
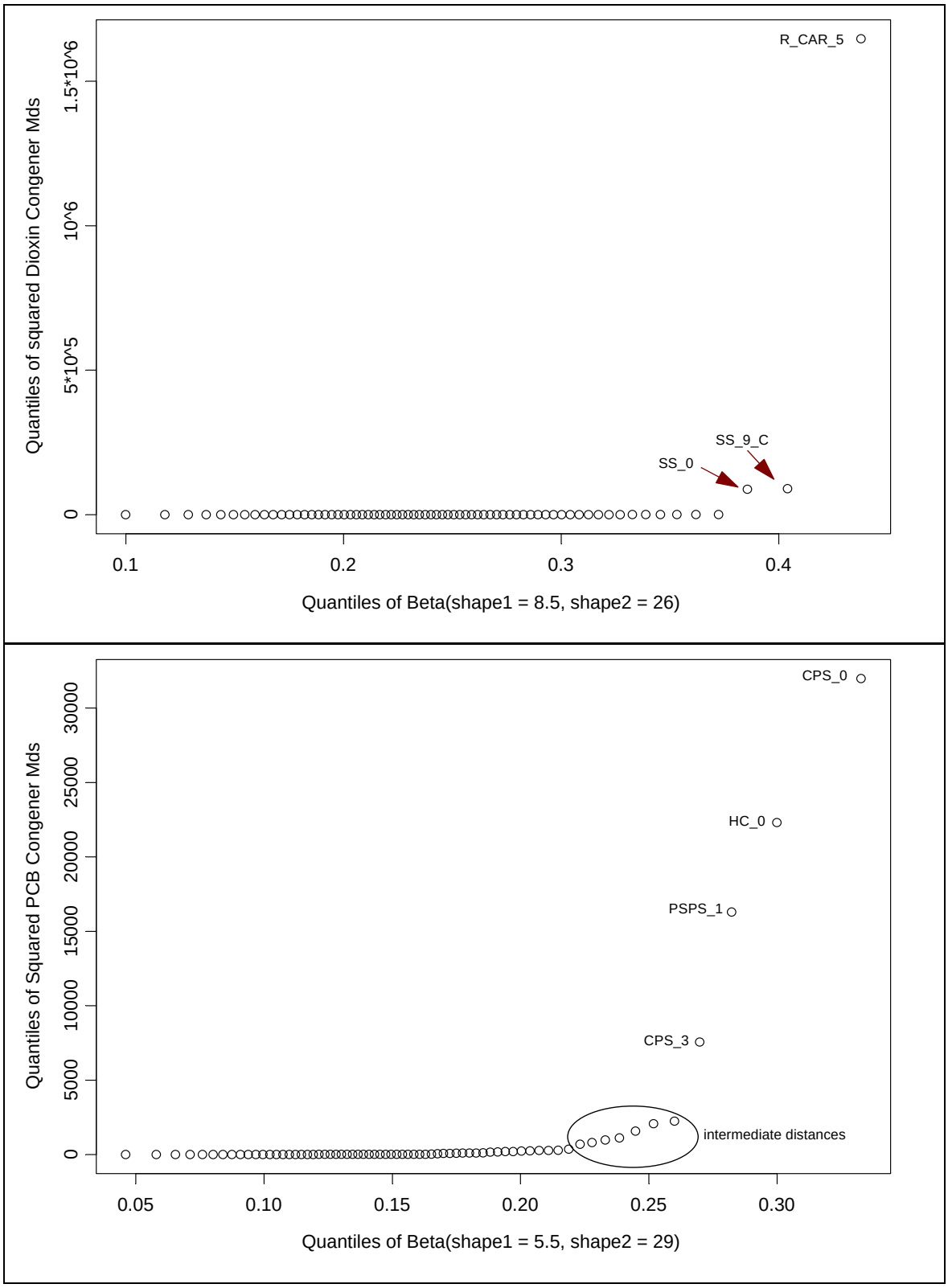


Figure 8. Distribution of PCB TEQs (weighted KM sum)



Note: Extreme values are identified by Sample ID.

Figure 9. Quantile-Quantile Plots for the Squared Mahalanobis Distance Values Calculated on All 70 Samples for the 17 Dioxin Congeners and the 11 PCB Congeners with TEFs

Table 2. Dioxin/Furan and PCB Congener Dry Weight Sums and TEQs by Location Using Kaplan-Meier Approach

Sample ID	Total Dioxin/ Furan (pg/g dw)	Dioxin/Furan TEQ (pg/g)	Sum of PCB Congeners (pg/g dw)	# detected congeners included in sum	PCB TEQ (pg/g)	Dioxin + PCB TEQ (pg/g)
AI_1	37.1	0.424	554	69	2.33E-03	0.426
AI_11_C	5.82	0.0473	82.4	34	5.92E-04	0.048
AI_13_C	51.3	0.453	635	67	2.78E-03	0.455
AI_20_C_GS	48.5	0.619	867	92	2.94E-03	0.622
AI_5_C	50.5	0.407	651	80	2.11E-03	0.409
CPS_0	254	1.85	10603	115	3.56E-02	1.889
CPS_1	259	2.19	3472	117	1.11E-02	2.200
CPS_3	148	1.33	2757	115	9.15E-03	1.341
CPS_4	149	0.948	1784	100	6.93E-03	0.955
CPS_5	72.7	0.655	1369	101	1.68E-01	0.823
HC_0	108	0.886	7465	107	2.42E-02	0.910
HC_1	61.0	0.803	1341	94	4.84E-03	0.808
HC_2	145	0.774	2589	89	5.91E-03	0.780
HC_3	55.0	0.443	2084	91	7.35E-03	0.451
HC_6	82.1	0.493	3792	110	1.24E-02	0.506
NCPS_0	78.4	0.646	2790	94	9.98E-03	0.656
NCPS_1	12.8	0.0634	141	43	5.97E-04	0.064
NCPS_2	147	1.07	3698	111	1.22E-02	1.081
NCPS_3	61.9	0.676	1954	78	6.75E-03	0.682
NCPS_4	33.4	0.298	1005	86	3.71E-03	0.301
PSPS_1	282	2.03	3071	102	9.37E-03	2.042
PSPS_2	426	2.69	1329	80	3.78E-03	2.692
PSPS_3	129	0.862	430	44	1.71E-03	0.863
PSPS_8	19.0	0.105	172	33	6.60E-04	0.105
PSPS_9	223	1.46	461	50	1.28E-03	1.465
R_CAR_0	126	0.598	355	73	1.30E-03	0.599
R_CAR_1	164	1.04	285	63	7.82E-04	1.041
R_CAR_4	176	0.839	1224	83	3.37E-03	0.842
R_CAR_5	721	5.06	1112	78	3.12E-03	5.068
R_CAR_6_C	42.4	0.210	272	54	9.18E-04	0.211
R_DAB_0	45.2	0.257	188	48	4.97E-04	0.257
R_DAB_1	141	1.58	1382	88	3.25E-03	1.581
R_DAB_2	181	1.44	765	69	4.44E-03	1.447

Sample ID	Total Dioxin/ Furan (pg/g dw)	Dioxin/Furan TEQ (pg/g)	Sum of PCB Congeners (pg/g dw)	# detected congeners included in sum	PCB TEQ (pg/g)	Dioxin + PCB TEQ (pg/g)
R_DAB_5	189	1.53	1299	85	3.89E-03	1.535
R_DAB_7_C	112	1.20	2425	101	6.50E-03	1.208
R_HOL_0	17.7	0.120	353	68	1.12E-03	0.122
R_HOL_1	39.1	0.373	434	69	1.88E-03	0.374
R_HOL_3	7.96	0.100	234	71	7.34E-04	0.101
R_HOL_4	194	1.20	1165	80	3.27E-03	1.202
R_HOL_7	103	0.863	1478	87	4.29E-03	0.867
R_SAM_0	103	1.32	346	32	3.73E-03	1.324
R_SAM_1	131	1.56	272	42	1.03E-03	1.562
R_SAM_3	127	1.32	361	44	1.11E-03	1.326
R_SAM_4	117	0.878	265	27	7.63E-04	0.878
R_SAM_5	147	1.83	754	49	2.93E-03	1.834
SCPS_1	421	3.35	1664	82	7.10E-03	3.361
SCPS_10_C	136	1.09	1215	76	5.10E-03	1.094
SCPS_2	60.3	0.509	408	58	1.45E-03	0.510
SCPS_3	26.4	0.177	229	36	9.28E-04	0.178
SCPS_5	485	3.65	1799	80	8.35E-03	3.658
SJF_10_C	32.1	0.323	104	20	3.56E-03	0.327
SJF_12_C_GS	139	1.68	1030	54	3.60E-03	1.681
SJF_2	43.1	0.275	132	41	8.01E-04	0.276
SJF_3	29.5	0.163	210	54	9.88E-04	0.164
SJF_9_C	77.7	0.536	401	67	1.65E-03	0.537
SJI_0	102	0.677	333	52	1.30E-03	0.678
SJI_1	60.4	0.828	168	41	8.95E-04	0.829
SJI_20_C_GS	235	1.15	644	65	3.97E-03	1.154
SJI_3	55.3	0.445	163	35	1.79E-03	0.447
SJI_8_C	59.6	0.556	114	38	8.16E-04	0.557
SPSB_0	194	1.46	940	70	1.88E-03	1.459
SPSB_1	153	1.27	902	70	2.34E-03	1.267
SPSB_2	258	2.15	1030	65	2.90E-03	2.150
SPSB_3	33.5	0.191	153	35	4.20E-04	0.192
SPSB_8_C	22.0	0.0727	59.3	18	2.38E-04	0.073
SS_0	1791	8.35	1149	64	5.27E-03	8.355
SS_1	31.7	0.393	38.5	16	0.00E+00	0.393

Sample ID	Total Dioxin/ Furan (pg/g dw)	Dioxin/Furan TEQ (pg/g)	Sum of PCB Congeners (pg/g dw)	# detected congeners included in sum	PCB TEQ (pg/g)	Dioxin + PCB TEQ (pg/g)
SS_2	202	1.33	518	71	1.87E-03	1.333
SS_8_C	196	1.10	1015	84	3.50E-03	1.107
SS_9_C	2131	11.6	1813	76	7.21E-03	11.609

TEQs calculated in R using cenfit() function
dw = dry weight

PCBs

- The overall range of total PCBs based on congeners was 38.5 – 10,600 pg/g with a median value of 765 pg/g (Tables 2 and 5). If extreme values are excluded, the median total PCB concentration is 651 pg/g.

- The overall range of PCB TEQ was 0 – 0.17 pg/g TEQ with a median value of 0.003 pg/g TEQ (Figure 8; Tables 2 and 5). The median value does not change when extreme values are excluded.

- Total PCBs and PCB TEQs were slightly elevated in CPS, HC, and NCPS areas. These areas had the highest median values and ranges among all areas.

- CPS_5 had the highest value for the PCB TEQ (0.17 pg/g TEQ; Figure 4). This was driven by the detected concentration of PCB-126 (1.63 pg/g) and the relatively high TEF of 0.1 associated with this congener. This sample had the only detected concentration for PCB-126 in the dataset.

- A multivariate review of the 11 individual PCB congeners which had TEFs (PCB-156/157 was reported as a single congener) revealed extreme Mahalanobis distances for stations CPS_0, HC_0, PSPS_1, and CPS_3. The Mds for these samples were statistically significant (beta distribution, $p<0.001$), and show elevated Mds distinct from the rest of the samples (Figure 9 [bottom]). Summary data/statistics excluding these four stations are provided in Figures 5 and 6 and in Table 3-5. Two additional samples (NCPS_0 and CPS_1) had statistically significant Mds (beta distribution, $p<0.001$) but were part of a larger group of samples from all areas of the Sound with intermediate distance values (Figure 9 [bottom]). Sample CPS_5 (a univariate extreme value for the PCB TEQ, Figure 4) was not identified as a multivariate outlier because the concentrations themselves were not particularly elevated; the sample only appeared unusual when multiplied by the TEF. The stations with extreme values for total PCBs were CPS_0 (10,600 pg/g) and HC_0 (7,460 pg/g).

- For PCBs, there were a number of samples that showed intermediate Mds from the rest of the data (Figure 9 [bottom]), and these were from all areas of the Sound. The overall distribution of Mds is quite skewed, and the long tail of the Mds distribution is smooth up until the break separating the four extreme samples identified above. This reveals the non-homogeneity of the congener patterns across the entire data set. The areas with the most consistent congener patterns and lower median Mds were CAR, HOL, SAM, SI, SPSD, and SJI; the areas exhibiting more variable congener patterns as illustrated by the larger Mds were CPS, NCPS, SCPS, HC, DAB and SPSB (Figure 10). Overall, the concentrations of PCBs were very low (the 95th percentile of total PCBs was 3.7 µg/kg; Table 3 and Figure 4).

Table 3. Reference Population Dioxin/Furan and PCB Congener Summary Statistics (pg/g) Including and Excluding Extremes

Group	Chemical[1]	n	Number Censored	Min. all data	Min. detected data	Max. all data	Max. detected data	25th percentile	50th percentile	75th percentile	90th percentile	95th percentile
Reference	Sum of Dioxin/Furan (KM sum)	20	0	7.96	7.96	721	721	103	127	176	194	721
Reference	Dioxin/Furan TEQ (weighted KM sum)	20	0	0.1	0.1	5.07	5.07	0.598	1.2	1.53	1.83	5.06
Reference	Sum of PCB Congeners (KM sum)	20	0	188	188	2420	2420	285	434	1220	1480	2420
Reference	PCB TEQ (weighted KM sum)	20	0	0	0	0.007	0.007	0.001	0.00293	0.00373	0.00444	0.0065
Reference	Dioxin/Furan + PCB TEQ (weighted KM sum)	20	0	0.101	0.101	5.07	5.07	0.599	1.2	1.53	1.83	5.07
Excluding Extremes	Sum of Dioxin/Furan (KM sum)	19	0	7.96	7.96	194	194	45.2	126	164	189	194
Excluding Extremes	Dioxin/Furan TEQ (weighted KM sum)	19	0	0.100	0.1	1.83	1.83	0.373	1.04	1.44	1.58	1.83
Excluding Extremes	Sum of PCB Congeners (KM sum)	20	0	188	188	2420	2420	285	434	1220	1480	2420
Excluding Extremes	PCB TEQ (weighted KM sum)	20	0	0	0	0.007	0.007	0.00103	0.00293	0.00373	0.00444	0.0065
Excluding Extremes	Dioxin/Furan + PCB TEQ (weighted KM sum)	19	0	0.101	0.101	1.83	1.83	0.374	1.04	1.45	1.58	1.83

1 Dry weight (dw) sums and TEQs were calculated using the Kaplan-Meier approach (see text for details)

Samples excluded from the dioxin endpoints: R_CAR_5 (reference)

Samples excluded from the PCB endpoints: None

Table 4. Greater PS Population Dioxin/Furan and PCB Congener Summary Statistics (pg/g) Including and Excluding Extremes

Group	Chemical[1]	n	Number Censored	Min. all data	Min. detected data	Max. all data	Max. detected data	25th percentile	50th percentile	75th percentile	90th percentile	95th percentile
Greater PS	Sum of Dioxin/Furan (KM sum)	50	0	5.82	5.82	2130	2130	48.5	82.1	196	421	485
Greater PS	Dioxin/Furan TEQ (weighted KM sum)	50	0	0.047	0.047	11.6	11.6	0.424	0.774	1.33	2.69	3.65
Greater PS	Sum of PCB Congeners (KM sum)	50	0	38.5	38.5	10600	10600	229	940	1800	3470	3790
Greater PS	PCB TEQ (weighted KM sum)	50	0	0	0	0.168	0.168	0.001	0.0035	0.0071	0.0122	0.0242
Greater PS	Dioxin/Furan + PCB TEQ (weighted KM sum)	50	0	0.048	0.048	11.6	11.6	0.426	0.808	1.34	2.69	3.66
Excluding Extremes	Sum of Dioxin/Furan (KM sum)	48	0	5.82	5.82	485	485	48.5	78.4	194	259	421
Excluding Extremes	Dioxin/Furan TEQ (weighted KM sum)	48	0	0.0473	0.0473	3.65	3.65	0.424	0.677	1.33	2.15	2.69
Excluding Extremes	Sum of PCB Congeners (KM sum)	46	0	38.5	38.5	3790	3790	210	870	1370	2590.00	3470
Excluding Extremes	PCB TEQ (weighted KM sum)	46	0	0	0	0.168	0.168	0.00128	0.0029	0.00591	0.0100	0.01221
Excluding Extremes	Dioxin/Furan + PCB TEQ (weighted KM sum)	44	0	0.0479	0.0479	3.66	3.66	0.409	0.678	1.15	2.15	2.69

1 Dry weight (dw) sums and TEQs were calculated using the Kaplan-Meier approach (see text for details)

Samples excluded from the dioxin endpoints: SS_0 and SS_9_C (ambient)

Samples excluded from the PCB endpoints: CPS_0, CPS_3, HC_0, PSPS_1 (all ambient)

Table 5. Combined Population Dioxin/Furan and PCB Congener Summary Statistics (pg/g) Including and Excluding Extremes

Group	Chemical[1]	n	Number Censored	Min. all data	Min. detected data	Max. all data	Max. detected data	25th percentile	50th percentile	75th percentile	90th percentile	95th percentile
Combined	Sum of Dioxin/Furan (KM sum)	70	0	5.82	5.82	2130	2130	48.5	112	181	282	485
Combined	Dioxin/Furan TEQ (weighted KM sum)	70	0	0.047	0.047	11.6	11.6	0.424	0.862	1.44	2.19	3.65
Combined	Sum of PCB Congeners (KM sum)	70	0	38.5	38.5	10600	10600	272	765	1380	2790	3700
Combined	PCB TEQ (weighted KM sum)	70	0	0	0	0.168	0.168	0.001	0.00294	0.00527	0.00998	0.0124
Combined	Dioxin/Furan + PCB TEQ (weighted KM sum)	70	0	0.048	0.048	11.6	11.6	0.426	0.863	1.45	2.2	3.66
Excluding Extremes	Sum of Dioxin/Furan (KM sum)	67	0	5.82	5.82	485	485	45.2	103	164	254	282
Excluding Extremes	Dioxin/Furan TEQ (weighted KM sum)	67	0	0.0473	0.0473	3.65	3.65	0.407	0.828	1.33	1.85	2.19
Excluding Extremes	Sum of PCB Congeners (KM sum)	66	0	38.5	38.5	3790	3790	272	651	1330	2080	2790
Excluding Extremes	PCB TEQ (weighted KM sum)	66	0	0	0	0.168	0.168	0.00103	0.0029	0.00444	0.00735	0.01106
Excluding Extremes	Dioxin/Furan + PCB TEQ (weighted KM sum)	63	0	0.0479	0.0479	3.66	3.66	0.393	0.808	1.32	1.68	2.2

1 Dry weight (dw) sums and TEQs were calculated using the Kaplan-Meier approach (see text for details)

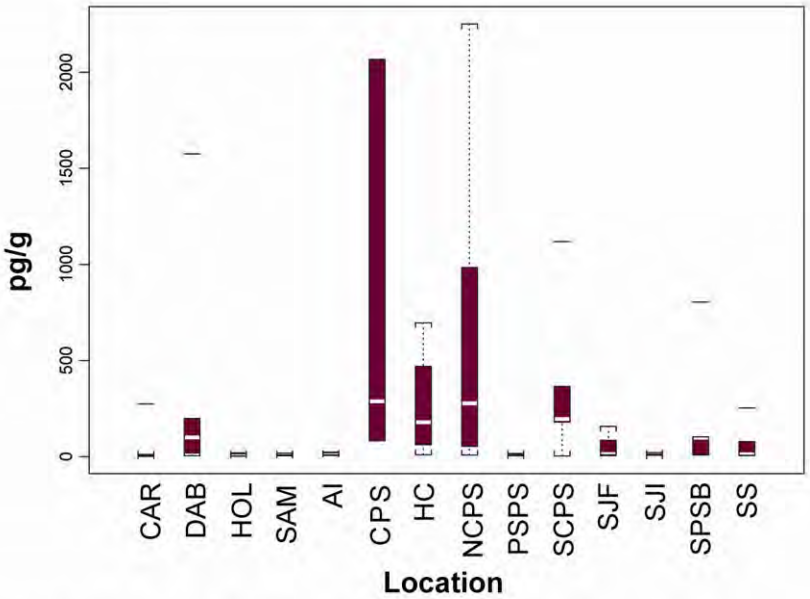
Samples excluded from the dioxin endpoints: R_CAR_5 (reference); SS_0 and SS_9_C (ambient)

Samples excluded from the PCB endpoints: CPS_0, CPS_3, HC_0, PSPS_1 (all ambient)

4.1.3 Outlier/Extreme Samples

As described in detail above, the samples identified as outliers/extremes are as follows:

- For dioxin/furan: R_CAR_5 (Carr Inlet), SS_0, and SS_9_C (South Sound).
- For PCBs: CPS_0 (Central Puget Sound), HC_0 (Hood Canal), PSPS_1 (Port Susan Possession Sound), and CPS_3 (Central Puget Sound).



Note the four extreme stations identified on Figure 7 (bottom) were removed from this plot to provide a scale that allowed greater differentiation among the remaining samples.

Figure 10. Box Plot for PCBs by Location of the Squared Mahalanobis Distances

4.2 Objective 1. Evaluation of TOC and Grain Size Correlations

4.2.1 Wet Sieve Versus Conventional Grain Size Analyses

The modified wet sieving process provided an excellent field evaluation of sediment grain sizes. Comparison of conventional analysis for fines and the wet sieving method resulted in an r^2 of 0.87, with only one sample (from Dabob Bay) that was an outlier (R_DAB_2) (Figure 11).

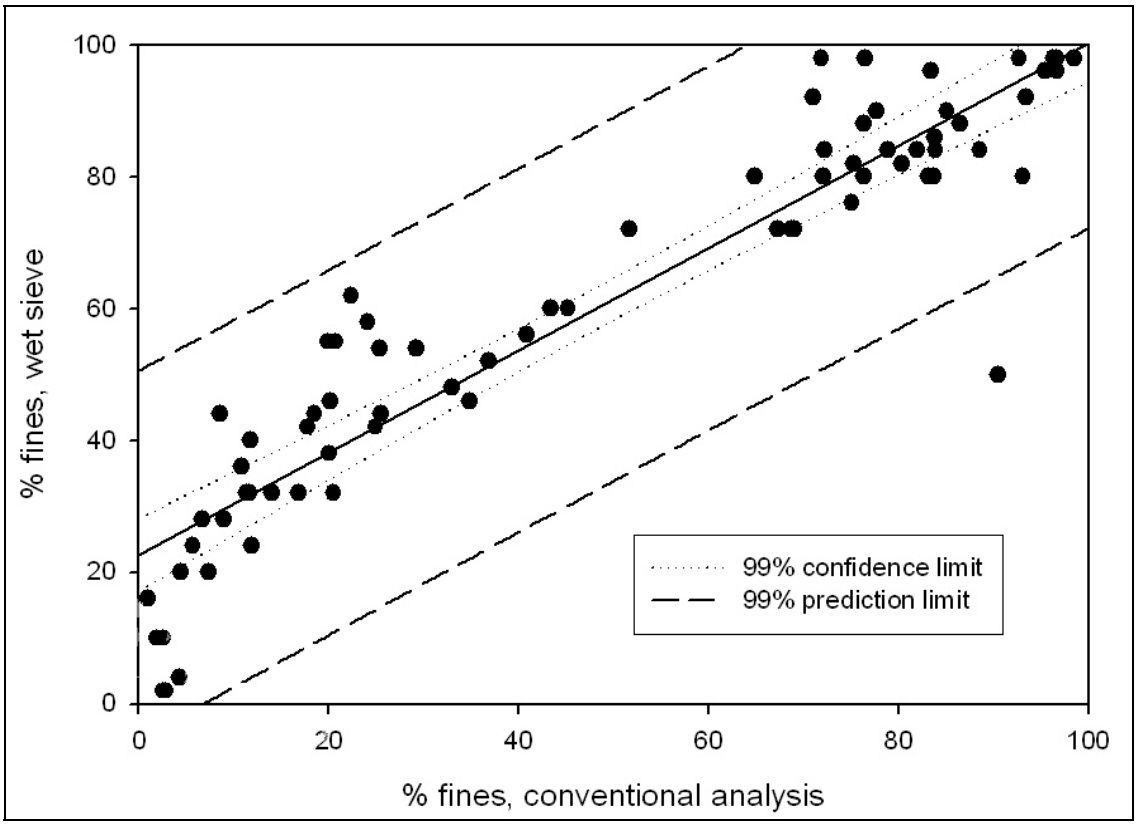


Figure 11. Comparison of Conventional Fines Analysis with Wet Sieving

4.2.2 Regional Differences in TOC and Grain Size

The site selection process successfully resulted in a wide range of grain sizes within each stratum of the Sound, except in the Admiralty Inlet (AI) stratum (Figure 12). Analysis of grain size across the different strata indicates that only the AI stratum was significantly different than the rest of the groups, having lower fines content (ANOVA, p=0.02). Significant differences in percent TOC were not observed in the various strata (Figure 13).

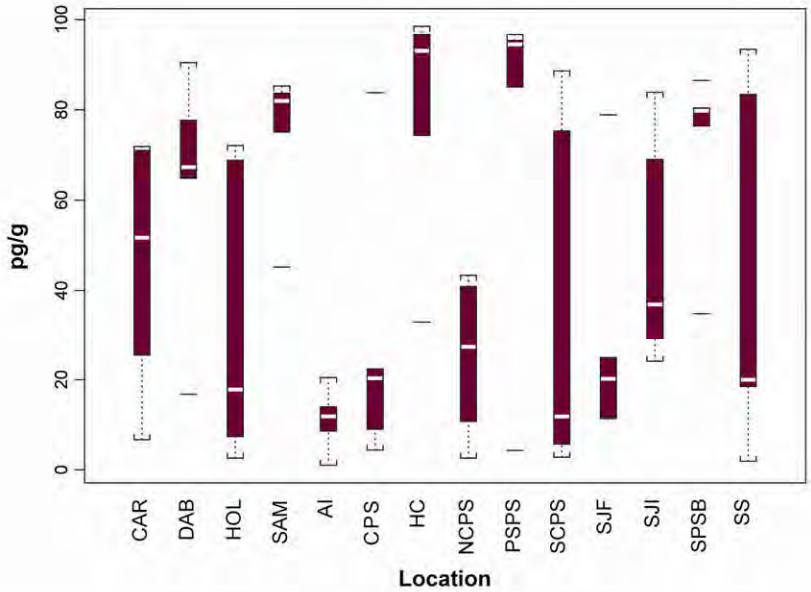


Figure 12. Percent Fines

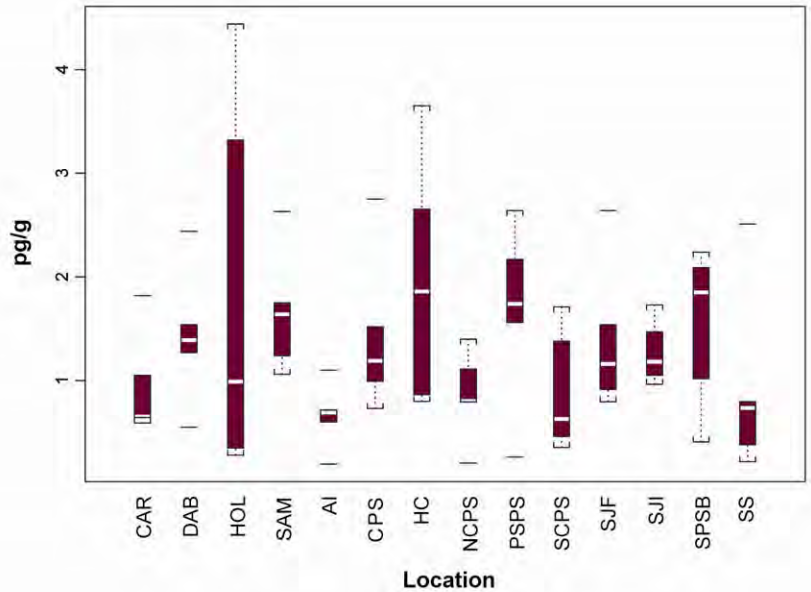


Figure 13. Percent TOC

4.2.3 Relationship of Grain Size and TOC with Chemical Parameters

No trends were observed between organics and grain size or total organic carbon (TOC); PCBs and dioxin/furan congeners were evaluated for relationships with grain size and TOC due to their being the focus of this study. Pyrene was also evaluated as a representative SVOC as it was detected in more samples than other SVOCs. For all three organics, r^2 was less than 0.2 for percent fines and less than 0.05 for percent TOC. Due to these poor relationships, percent TOC and percent fines were not considered as co-factors when analyzing dioxin/furan and PCB trends in the Sound.

Detected concentrations of selected trace metals (arsenic, chromium, copper, lead, nickel, and zinc) were also evaluated for correlations with grain size and TOC. Linear regression analysis resulted in r^2 of 0.2 to 0.52; better trends were observed with percent fines (increasing metals concentrations with increasing percent fines), where r^2 ranged from 0.4 to as high as 0.75 (zinc).

4.3 Objective 2. Characterize Reference Populations

For the 20 reference area samples combined, basic summary statistics were estimated for total dioxin/furan, total PCBs, dioxin/furan TEQ, PCB TEQ, and the dioxin/furan + PCB TEQ (sum of the 2 TEQs). These statistics were calculated both with and without the extreme samples identified in Section 4.1 and are reported in Table 3. Summary statistics for individual dioxin/furan/PCB congeners and dioxin/furan homologue groups are provided in Appendix D (Table D–1).

As described in Section 4.1, the dioxin/furan TEQ at station R_CAR_5 (5.06 pg/g TEQ) was highest in the reference population, but was considered an outlier/extreme sample. Excluding this sample, the median dioxin/furan TEQ for all of the reference samples slightly decreases from 1.2 pg/g TEQ to 1.04 pg/g TEQ, while the 95th percentile is reduced from 5.06 pg/g TEQ to 1.83 pg/g TEQ. Specifically for Carr Inlet, the median dioxin/furan TEQ is 0.718 pg/g TEQ. The median TEQs in the other three reference areas (Dabob Bay, Holmes Harbor, and Samish Bay) are 1.44, 0.373, and 1.32 pg/g TEQ, respectively.

The median PCB TEQ for all of the reference samples is 2.93E-03 TEQ. The 95th percentile is 6.50E-03 pg/g TEQ. The median PCB TEQ for each of the reference areas is 1.30E-03, 3.89E-03, 1.88E-03, and 1.11E-03 pg/g TEQ, respectively (see Appendix D; Table D–1).

4.4 Objective 3. Characterize Puget Sound-wide Populations

For the combined 50 samples from greater PS strata, basic summary statistics were estimated for total dioxin/furan, total PCBs, dioxin/furan TEQ, PCB TEQ, and the dioxin/furan + PCB TEQ. These statistics were calculated both with and without the extreme samples identified in Section 4.1 and are reported in Table 4. Summary statistics for individual dioxin/furan/PCB congeners and dioxin/furan homologue groups are provided in Appendix D (Table D–2).

Excluding the extreme samples identified in Section 4.1 for dioxin/furan and PCBs, the median dioxin/furan TEQ for all of the greater PS samples is 0.677 pg/g TEQ, with a range of 0.0473 to 3.65 pg/g TEQ. The 95th percentile is 2.69 pg/g TEQ. The median PCB TEQ for all of the greater PS samples is 2.90E-03 pg/g TEQ. The 95th percentile is 1.22E-02 pg/g TEQ. Summaries of dioxin/furan and PCB TEQs by location are provided in Appendix D (Table D–2).

4.5 Objective 4. Compare Distributions of Reference Areas and Puget Sound-wide Populations

The Mann-Whitney-Wilcoxon rank sum test was used to test the null hypothesis that the two distributions (Reference Areas and greater Puget Sound population) come from a single population. The test uses ranks, so is robust to the presence of the extreme values. However, the test was run for each of the five composite endpoints (sums or TEQs) both with and without the extreme values. None of the comparisons were statistically significant, and thus the null hypothesis was accepted. Results of the Mann-Whitney-Wilcoxon tests are reported in Table 6. The combined summary statistics for the Reference Area and greater Puget Sound populations are reported in Table 5 (for both all data and excluding extremes).

Table 6. Results of Mann-Whitney Comparison Between Reference and Greater PS for DW Sum and TEQ Endpoints

Group	Endpoint	Sample sizes	p-value
All Samples	Sum of Dioxin/Furan (KM sum)	20 vs. 50	0.76
	Dioxin/Furan TEQ (weighted KM sum)	20 vs. 50	0.46
	Sum of PCB Congeners (KM sum)	20 vs. 50	0.37
	PCB TEQ (weighted KM sum)	20 vs. 50	0.10
	Dioxin/Furan + PCB TEQ (weighted KM sum)	20 vs. 50	0.46
Exclude extremes	Sum of Dioxin/Furan (KM sum)	19 vs. 48	0.79
	Dioxin/Furan TEQ (weighted KM sum)	19 vs. 48	0.47
	Sum of PCB Congeners (KM sum)	20 vs. 46	0.69
	PCB TEQ (weighted KM sum)	20 vs. 46	0.24
	Dioxin/Furan + PCB TEQ (weighted KM sum)	19 vs. 44	0.26

4.6 Objective 5. Distributions of Other Chemicals in Puget Sound

This section provides basic summary statistics for the other chemicals of concern analyzed and detected in both the Reference Areas and Puget Sound-wide populations as part of the OVS *Bold* survey. The chemical groups included metals, SVOCs, Aroclor PCBs, and pesticides (Appendix E). However, it was beyond the scope of this study to analyze this data using the KM approach or conduct a statistical comparison of the chemicals between the Reference Areas and Puget Sound-wide populations.

4.6.1 Metals

Antimony was the only metal not detected in any of the samples (Table 7). Selenium was detected in 37 percent of the samples, mercury in 59 percent, cadmium in 67 percent, and silver in 74 percent. All other metals were detected in every sample. All concentrations were below the Washington State Sediment Management Standards (Washington Administrative Code [WAC] Chapter 173-204) Sediment Quality Standards (SQS) and Cleanup Screening Level (CSL) criteria.

Zinc had the highest concentrations, with a median of 51.4 mg/kg. Chromium and nickel were the next highest, with medians of 26.2 and 25.2 mg/kg respectively. Of the frequently detected metals, mercury and silver had the lowest concentrations.

The spatial distribution of Mercury is shown in Figure 14. Detected concentrations ranged from 0.031 mg/kg at SS_2 to 0.26 mg/kg at R_CAR_4. By area, the lowest average concentrations were measured at Admiralty Inlet, San Juan Islands, and Strait of Juan de Fuca. Saratoga Passage and Skagit Bay, Port Susan and Possession Sound, and Carr Inlet had the highest average concentrations by area.

Table 7. Percent Detected and Percentiles for Metals

Analyte (mg/kg DW)	Percent Detected	SMS		Percentiles				
		SQS	CSL	25th	50th	75th	90th	95th
Antimony	0	--	--	DL	DL	DL	DL	DL
Arsenic	100	57	93	3.6	6.0	8.6	11.0	13.6
Cadmium	67	5.1	6.7	DL	DL	0.4	0.7	0.9
Chromium	100	260	270	18.9	26.2	38.5	54.6	67.6
Copper	100	390	390	9.4	15.7	31.2	40.3	49.9
Lead	100	450	530	5.0	7.7	13.3	17.6	21.6
Mercury	59	0.41	0.59	DL	DL	0.1	0.2	0.2
Nickel	100	--	--	19.4	25.2	30.7	49.6	55.2
Selenium	37	--	--	DL	DL	DL	1.0	1.2
Silver	74	6.1	6.1	DL	DL	0.2	0.2	0.3
Zinc	100	410	960	32.5	51.4	78.2	92.4	94.6

DL = Percentile value is under the value for the maximum reported detection limit.

SMS = Sediment Management Standards (WAC Chapter 173-204)

SQS = Sediment Quality Standards

CSL = Cleanup Screening Levels

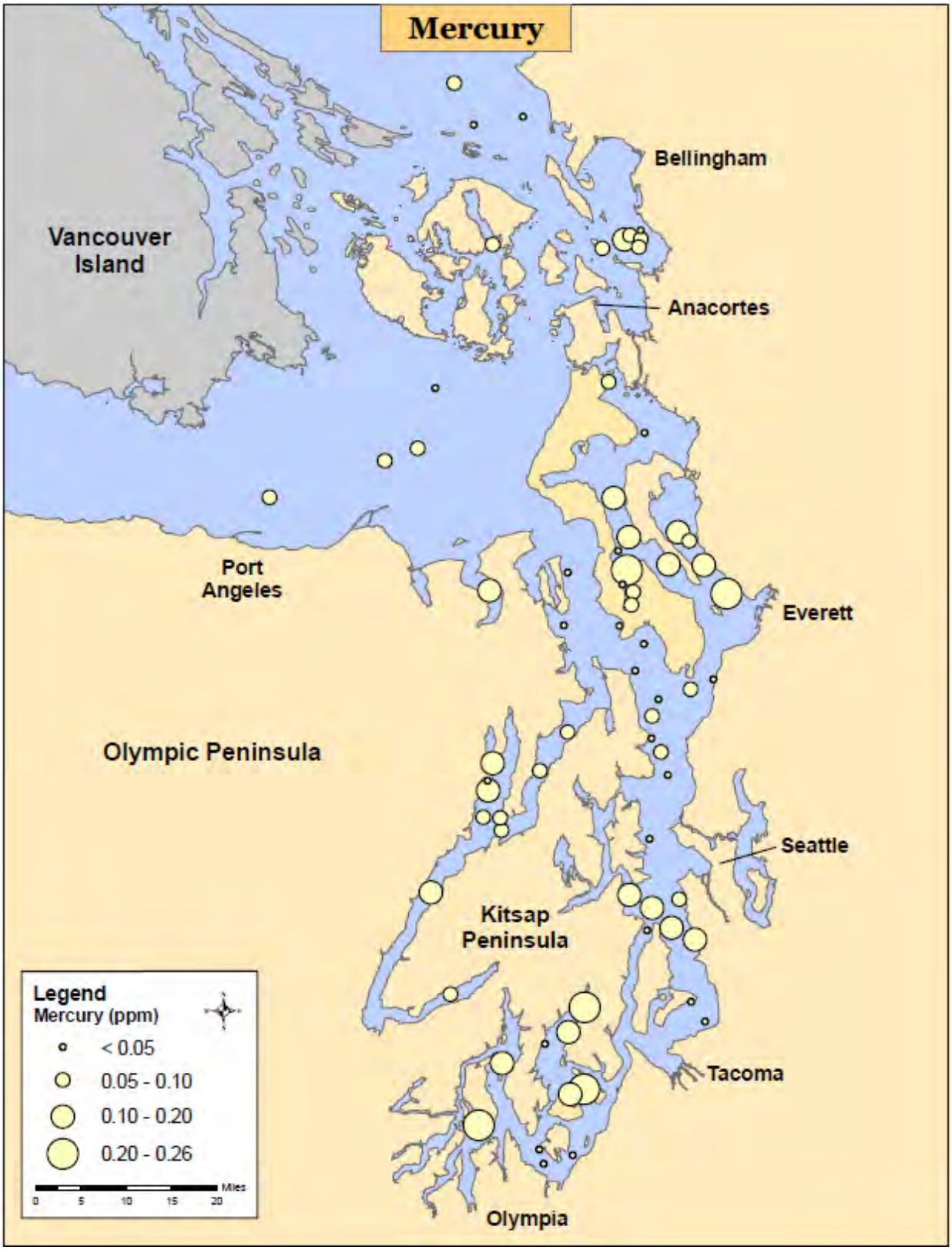


Figure 14. Spatial Distribution of Mercury in Reference and Greater PS Populations

4.6.2 SVOCs

Percentile concentrations calculated for the detected SVOCs are listed in Table 8. Undetected concentrations were included in the calculation of the percentiles. In cases where the percentile is within the range of the detection limit, the DL is reported.

PAHs were the most frequently detected SVOC, with high molecular weight PAHs (HPAHs) being detected more frequently than low molecular weight PAHs (LPAHs) (Table 8). A significant source of PAH in Puget Sound sediments is the combustion of petroleum products, particularly car exhaust (Partridge et al. 2005). All detected PAH compounds were below SQS and CSL criteria. Frequency of detection for LPAH ranged from 0 percent for acenaphthlyene and fluorene to 74 percent of samples for phenanthrene. All other LPAH were detected in less than 40 percent of samples. Frequency of detection for HPAH ranged from 4 percent for dibenz(a,h)anthracene to 89 percent for pyrene. Indeno(1,2,3)pyrene and benzo(g,h,i)perylene were detected in 27 percent and 34 percent of samples, respectively. All other HPAH were detected in greater than 50 percent of samples.

LPAH and HPAH were calculated as a sum concentration by adding all detected PAHs (2-methylnaphthalene was not included for LPAH). When all PAHs were undetected, the highest detection limit was used as to represent the sum (LPAH or HPAH) and given a "U" qualifier. LPAH were present in 74 percent of samples, and HPAH in 94 percent. The 95th percentiles for LPAH and HPAH were 14.7 µg/kg and 116.2 µg/kg, respectively (Table 8).

Figures 15 and 16 show the spatial distribution of LPAH and HPAH concentrations in Puget Sound. The concentration ranges represented in Figures 15 and 16 are equivalent to the percentiles listed in Table 8. For example, the largest circles in both figures represent the 95th percentile concentration and above. For both LPAH and HPAH, stations CPS_0, NCPS_3, SCPS_1, and SCPS_3 had the highest concentrations. South central, central, and north central Puget Sound locations also had the highest concentrations when averaged by area. The lowest average HPAH concentrations were found at Admiralty Inlet, Dabob Bay, and Strait of Juan de Fuca. Several areas had low average concentrations of LPAH due to frequent non-detected compounds.

Chlorinated aromatic compounds were not detected in any samples. Benzaldehyde was the only miscellaneous extractable compound detected, and it was found in only three samples. Of the phthalates, only bis(2-ethylhexyl)phthalate was detected. It was found at concentrations of 45, 71, 320, and 3,800 µg/kg in samples R_HOL_0, R_DAB_7_C, SS_9_C, and SS_0, respectively (see Appendix E). There are no percentile values for bis(2-ethylhexyl)phthalate due to the low number of detections (Table 8). However, when normalized to TOC, samples SS_9_C (84.2 mg/kg TOC) and SS_0 (151.4 mg/kg TOC) exceed the CSL criteria of 78 mg/kg TOC.

Phenol was detected in 63 percent of the samples and 10 of the 70 samples exceeded the SQS. Phenol at one station (HC_2) equaled the CSL. 4-methylphenol was detected in 50 percent of the samples, with one station (R_SAM_3) exceeding the CSL (the CSL is equal to the SQS for 4-methylphenol) (Table 8). Detected phenol concentrations ranged from 30 to 1,200 µg/kg, and detected 4-methylphenol concentrations ranged from 27 to 790 µg/kg. Phenol in sediments are not expected to persist in the environment and can come from anthropogenic sources (e.g., industrial and chemical manufacturing) and natural sources such as the byproduct from natural degradation of organic materials (e.g., leaf litter, pine needles, seafood products) (SAIC 2005). Elevated phenol concentrations and long-term temporal variability are not uncommon in Puget Sound sediments. A joint study between Ecology and the National Oceanic and Atmospheric Administration (NOAA) conducted between 1997 and 1997 in Puget Sound measured phenol concentrations that exceeded the SQS in 45 of 305 samples (15 percent) and exceeded the CSL in 22 of 305

samples (7 percent) (Long et al. 2003). Most of these elevated concentrations occurred in northern Puget Sound (from the U.S./Canada border to Possession Sound).

The spatial distributions for phenol and 4-methylphenol are shown in Figures 17 and 18. As with PAH, the symbol sizes match the percentiles from Table 8, with the largest circle representing the 95th percentile (820 µg/kg for phenol, and 425 µg/kg for 4-methylphenol). The median concentration for phenol was 100.5 µg/kg. The median concentration for 4-methylphenol was below the detection limit. Figures 17 and 18 show a cluster of high phenol and 4-methylphenol concentrations in Samish Bay. When averaged by area, Samish Bay has the highest concentrations for both compounds, followed by Holmes Harbor, Hood Canal, and North Central Puget Sound. Saratoga Passage and Skagit Bay, Dabob Bay, and Strait of Juan de Fuca consistently had some of the lowest concentrations.

Table 8. Percent Detection and Percentiles for SVOCs

Analyte (µg/kg)	Percent Detected	Percentiles				
		25th	50th	75th	90th	95th
LPAH in µg/kg DW						
Naphthalene	27%	DL	DL	DL	DL	DL
Acenaphthene	1%	DL	DL	DL	DL	DL
Phenanthrene	74%	DL	DL	4.9	7.9	10.5
Anthracene	14%	DL	DL	DL	DL	DL
2-Methylnaphthalene	37%	DL	DL	DL	DL	DL
Total LPAH*	74%	DL	DL	6.4	10.9	14.7
HPAH in µg/kg DW						
Fluoranthene	87%	DL	5.2	9.5	12.1	19.6
Pyrene	89%	DL	5.0	8.4	12.1	17.0
Benzo(a)anthracene	57%	DL	DL	4.4	6.2	11.1
Chrysene	64%	DL	DL	4.8	6.9	11.1
Benzo(b)fluoranthene	77%	DL	5.6	11.0	16.4	25.7
Benzo(k)fluoranthene	77%	DL	DL	4.9	8.8	12.2
Benzo(a)pyrene	59%	DL	DL	5.0	10.1	15.0
Indeno(1,2,3-cd)pyrene	27%	DL	DL	DL	4.8	5.8
Dibenz(a,h)anthracene	4%	DL	DL	DL	DL	DL
Benzo(g,h,i)perylene	34%	DL	DL	DL	5.0	5.7
Total HPAH*	94%	8.4	29.5	52.8	75.1	116.2
Phthalate Esters in µg/kg DW						
bis(2-Ethylhexyl)phthalate	6%	DL	DL	DL	DL	DL
Phenols in µg/kg DW						
Phenol	63%	DL	100.5	270	484	820
4-Methylphenol	50%	DL	DL	114.8	302	425
Pentachlorophenol	3%	DL	DL	DL	DL	DL
Miscellaneous Extractables in µg/kg DW						
Benzaldehyde	4%	DL	DL	DL	DL	DL

DL = Percentile value is under the value for the maximum reported detection limit.
SMS listed chemicals not included in this table were not detected in any samples.

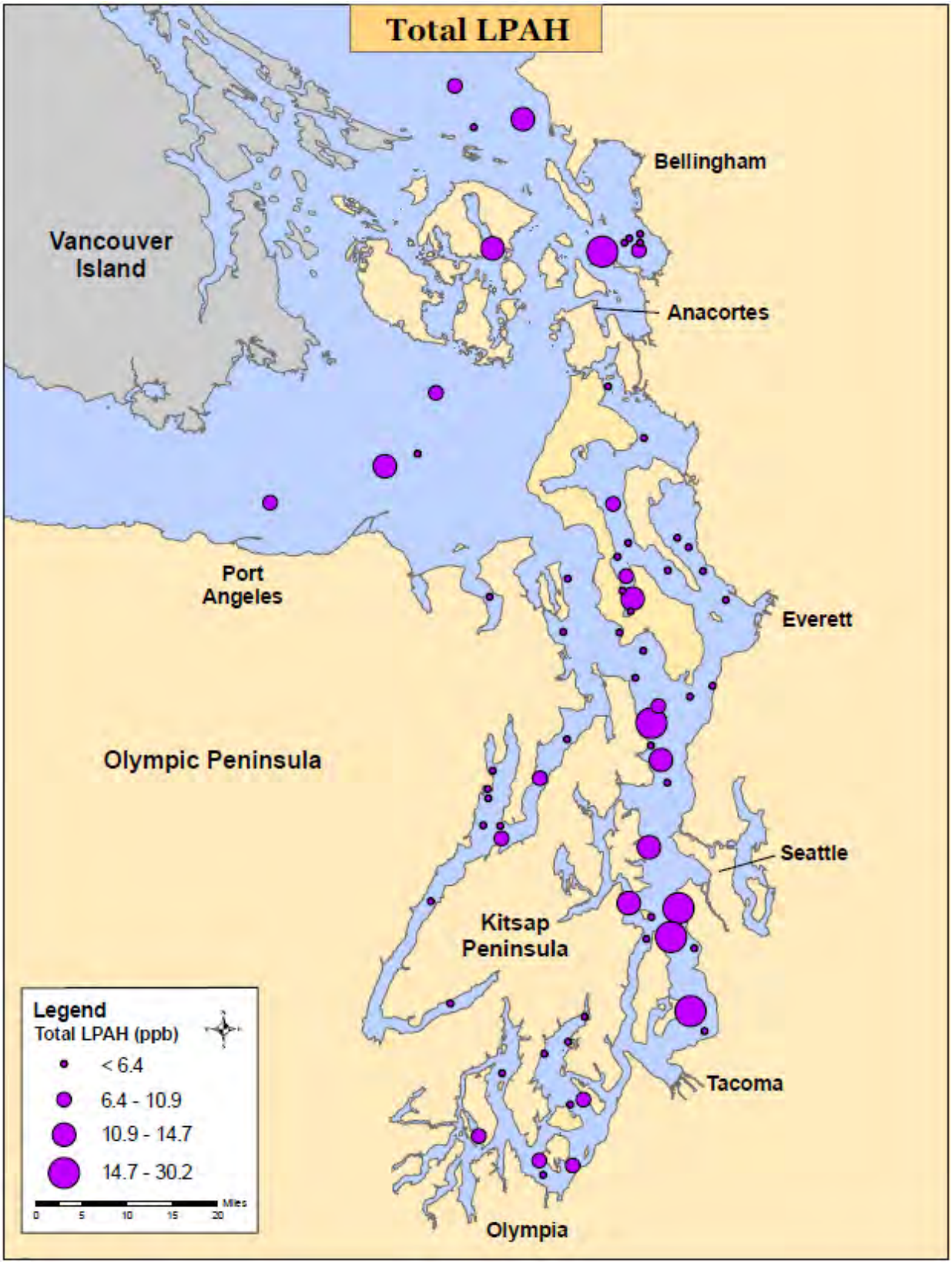


Figure 15. Spatial Distribution of LPAH in Reference and Greater PS Populations

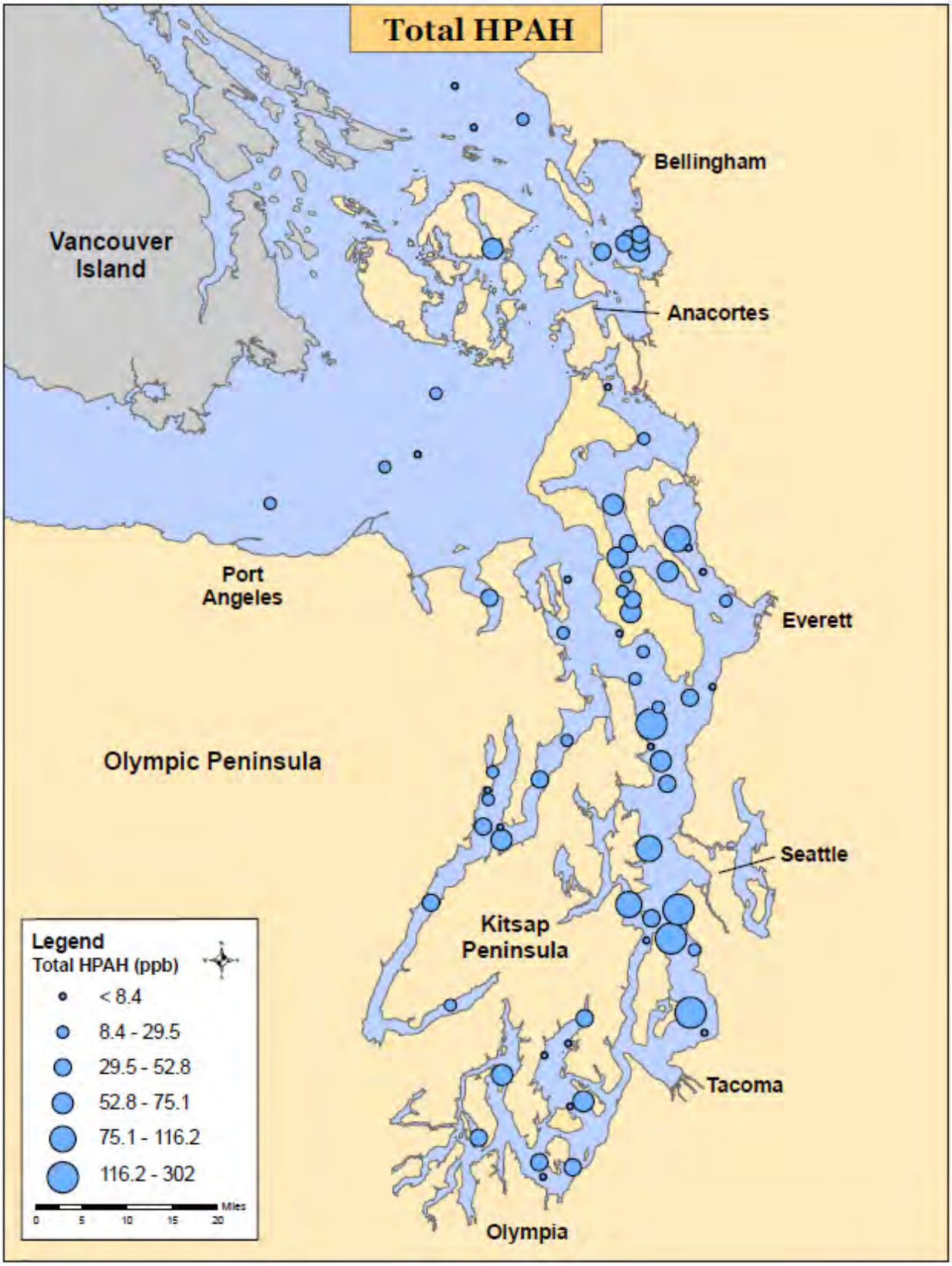


Figure 16. Spatial Distribution of HPAH in Reference and Greater PS Populations

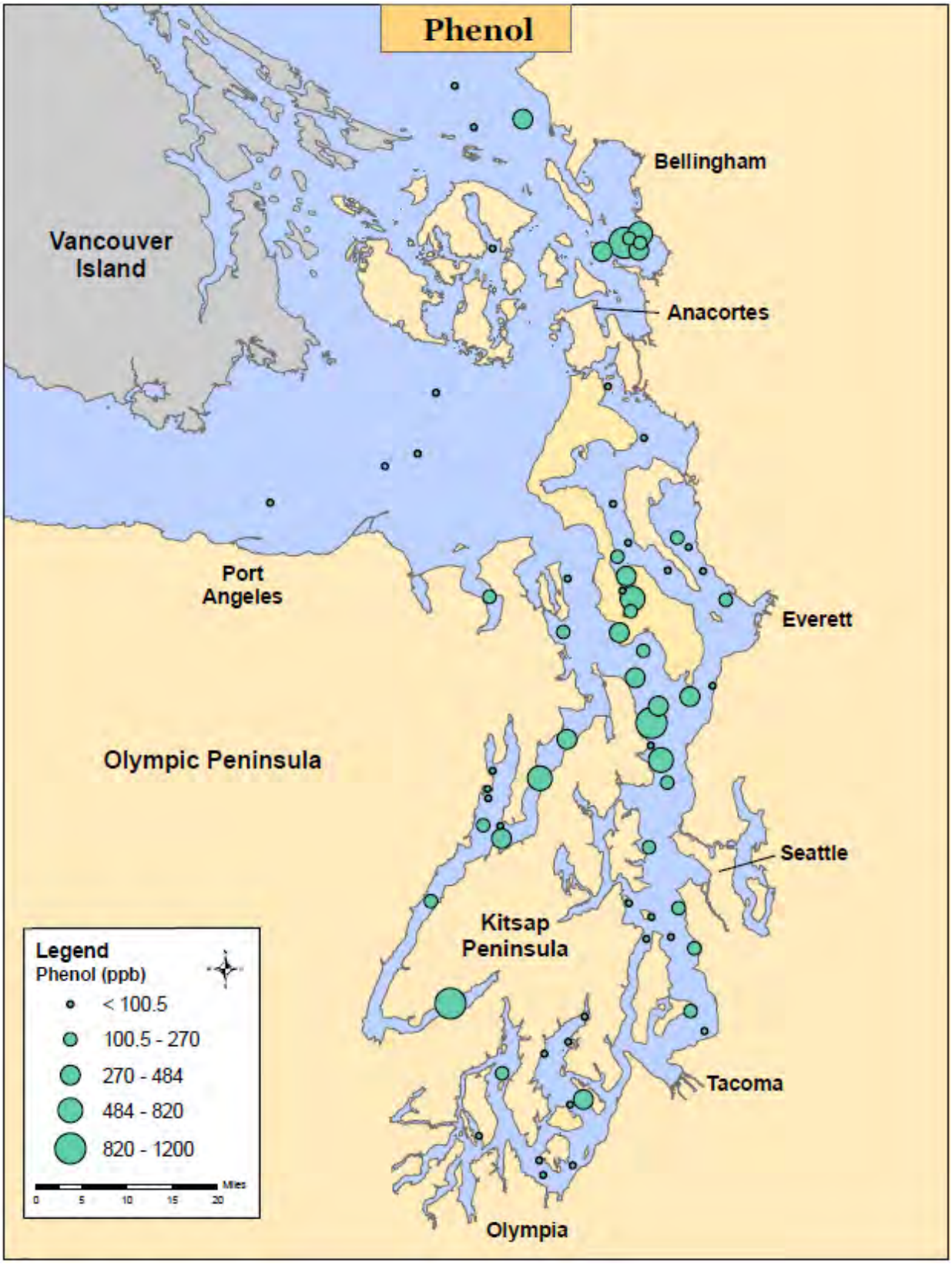


Figure 17. Spatial Distribution of Phenol in Reference and Greater PS Populations

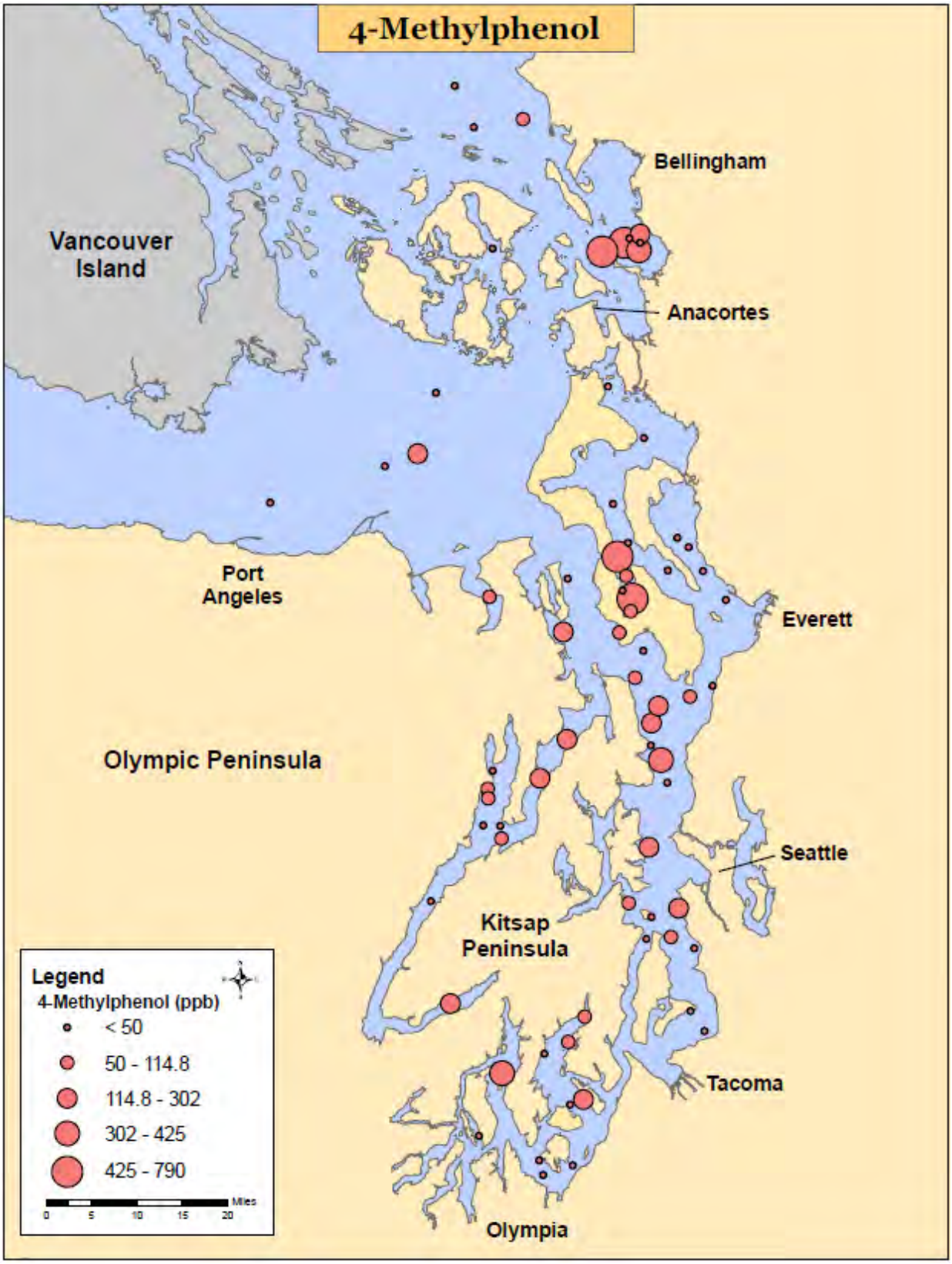


Figure 18. Spatial Distribution of 4-Methylphenol in Reference and Greater PS Populations

4.6.3 PCB Aroclors

PCB Aroclor 1268 was detected in six samples, three of which were qualified "J." Three of the six samples were from Carr Inlet, two from Holmes Harbor, and one from South Sound. Concentrations in these samples ranged from 2.1 µg/kg to 31 µg/kg. All other PCB Aroclors were undetected.

4.6.4 Pesticides

Analysis for 28 pesticides and pesticide degradation products was conducted (see Table 2 of the QAPP; USEPA 2008b). No pesticide compounds were detected.

4.7 Objective 6. Evaluation of the Performance of the Assays vs. Standard Methods

The CALUX assay was conducted by Xenobiotics Detection Systems, while both the 101L and Procept® assays were performed at the USACE-ERDC laboratory. Results are summarized in Tables 9 and 10. In the original scope of work for this study, one objective was to correlate these assays with high-resolution gas chromatograph/mass spectrograph (HR-GC/MS) data. Both the CALUX and the 101L assays outperformed the Procept® assay at these low concentrations, although correlations with HR-GC/MS were poor for all assays (r^2 = 0.327, 0.029, and less than 0.001, respectively). It is difficult to evaluate the assay performance based on the OSV *Bold* data set alone due to very low environmental concentrations in the base data set.

Another factor that may be contributing to the poor relationships between HR-GC/MS and the assays is sample heterogeneity. Extracts generated for chemical analyses cannot be split and sent to the assay labs due to the addition of internal standards for HR-GMCS chemical analysis that might interfere with the assays. Therefore, chemistry and the dioxin assays were conducted on separate sediment aliquots sent to the three analytical laboratories (fixed lab for HR-GCMS, Xenobiotics Detection Systems, and USACE-ERDC) and extracted at those labs. The issue of sample heterogeneity is best illustrated by the HR-GC/MS results from samples split in the field to create blind laboratory duplicates. While three of the five split samples were reasonably close to each other, two of the field splits returned very different values; HC_2 field splits were 0.77 and 3.33 pg/g TEQ, and PSPS_1 field splits were 0.95 and 2.04 pg/g TEQ (Table 11). Since HR-GC/MS, CALUX, and the 101L plus Procept® assays were conducted on three separate extracts (101L and Procept® were taken from the same extract), the sample heterogeneity is likely to have negatively affected relationships between the assays and the HR-GC/MS.

Our assessment of the utility of these assays for evaluating dredged material is incomplete at this time but is in progress under a separate program funded by USACE and USEPA. In order to evaluate the potential of the various assays for the evaluation of dredged sediments, more data are being considered that include a wider TEQ concentration range. The outcome of this analysis will be published in a separate report.

Table 9. Summary of Dioxin Assay Data, with HRGCMS Data for Comparison (pg/g TEQ)

Sample ID	HR-GC/MS	101L	CALUX	Procept®
AI_20_C_GS	0.62	3.3	4.58	16
AI_1	0.42	9.8	4.00	24
AI_11_C	0.04	2.2 J	1.07	21
AI_13_C	0.45	6.2	3.24	52
AI_5_C	0.41	4.4	1.33	50
CPS_0	1.85	8.9	11.53	184
CPS_1	2.19	4.8	2.60	95
CPS_3	1.33	5.2	4.18	94
CPS_4	0.95	16.6	4.45	140
CPS_5	0.65	4.9	3.83	96
HC_0	0.89	9.0	7.06	162
HC_1	0.80	5.0	6.12	7
HC_2	0.77	7.6	8.54	4
HC_3	0.44	7.1	8.77	36
HC_6	0.49	4.7	11.94	28
NCPS_0	0.65	10.2	5.33	0
NCPS_1	0.08	5.5	1.15	48
NCPS_2	1.07	3.0	5.35	31
NCPS_3	0.67	4.5	6.17	0
NCPS_4	0.30	22.6	4.96	37
PSPS_8	0.10	4.1	1.96	55
PSPS_9	1.46	6.5	12.28	104
PSPS_1	2.04	4.3	7.16	69
PSPS_2	2.69	4.8	10.80	2
PSPS_3	0.86	3.0	10.29	2
R_SAM_0	1.32	4.7	7.58	39
R_SAM_1	1.56	5.0	7.33	73
R_SAM_3	1.32	3.1	4.68	54
R_SAM_4	0.88	6.6	11.13	84
R_SAM_5	1.84	4.9	12.33	19
R_CAR_0	0.60	4.3	3.04	6
R_CAR_1	0.99	4.2	3.09	0
R_CAR_4	0.84	3.8	4.53	42
R_CAR_5	5.07	7.4	6.32	0
R_CAR_6_C	0.21	7.8	2.70	25
R_DAB_0	0.26	3.5	1.52	40

Sample ID	HR-GC/MS	101L	CALUX	Procept®
R_DAB_1	1.58	5.1	10.40	47
R_DAB_2	1.44	5.3	9.12	33
R_DAB_5	1.53	7.8	11.53	48
R_DAB_7_C	1.20	4.6	4.14	73
R_HOL_0	0.12	3.2	1.66	44
R_HOL_1	0.37	5.1	0.98	30
R_HOL_3	0.10	4.2	0.73	40
R_HOL_4	1.20	7.2	11.11	41
R_HOL_7	0.86	8.9	8.87	13
SCPS_1	3.35	8.6	8.44	28
SCPS_10_C	1.09	2.5	5.59	19
SCPS_2	0.51	3.3	3.55	71
SCPS_3	0.18	2.6	0.99	38
SCPS_5	3.66	12.5	16.99	83
SJF_10_C	0.32	4.4	1.50	40
SJF_12_C_GS	1.68	4.6	9.17	50
SJF_2	0.28	2.4	3.70	23
SJF_3	0.16	3.0	1.65	15
SJF_9_C	0.54	3.4	2.01	25
SJI_0	0.68	3.9	4.11	38
SJI_1	0.83	3.4	2.38	22
SJI_20_C_GS	1.04	8.0	3.82	16
SJI_3	0.45	5.1	1.46	36
SJI_8_C	0.56	3.8	1.58	23
SPSB_0	1.46	5.4	9.68	34
SPSB_1	1.26	10.6	5.80	49
SPSB_2	2.14	5.4	8.50	41
SPSB_3	0.19	3.8	1.14	35
SPSB_8_C	0.07	0.9 J	0.41	1
SS_0	8.35	5.9	12.91	28
SS_1	0.39	2.5	0.34	13
SS_2	1.33	3.3	2.23	20
SS_8_C	1.10	2.7	3.42	36
SS_9_C	11.59	7.5	14.63	4

J Reported value was below the detection limit but showed a response in the assay

Table 10. Statistical summary of the dioxin assay data, with HRGCMS for comparison (pg/g TEQ)

Endpoint	Mean	Minimum	Maximum	Q1	Median	Q3	Distribution	Adjusted Mean	90%UTL
HRGCMS	1.268	0.044	11.594	0.419	0.85	1.447	Lognormal	1.307	3.349
101L	5.636	0.893	22.613	3.464	4.779	7.125	Lognormal	1.598	10.59
CALUX	5.678	0.34	16.99	2.175	4.555	8.795	Lognormal	1.418	12.28
Procept®	41.37	-0.14	184.39	19.04	35.8	49.75	Nonparametric	41.37	95.88

Values are in pg/g TEQ.

"Adjusted means" are corrected for the data distribution.

Table 11. Results of Laboratory Duplicate Analyses (pg/g TEQ)

Station ID	HRGCMS	101L	CALUX	Procept®
CPS_3	1.33	5.23	4.18	94.19
CPS_3	1.55	4.59	4.07	60.91
HC_2	0.77	7.59	8.54	4.20
HC_2	3.33	8.40	7.05	136.77
NCPS_2	1.07	2.96	5.35	31.15
NCPS_2	0.92	3.38	2.03	52.91
PSPS_1	2.04	4.31	7.16	68.92
PSPS_1	0.95	5.86	6.82	75.02
SPSB_0	1.46	5.41	9.68	33.54
SPSB_0	1.57	5.79	5.36	56.26

5.0 SUMMARY AND CONCLUSIONS

Objective 1. Evaluate whether the concentration distributions appear to be correlated with grain size or TOC if possible.

- Organic contaminants (such as dioxin/furan congeners, PCBs, and PAHs) did not correlate with either percent TOC or percent fines. Although it may be expected that such hydrophobic compounds would associate with organic matter, the relationship is not present at the low concentrations of dioxin/furan congeners, PCBs, and PAHs measured in these samples. Due to the lack of correlation with either TOC or percent fines, these factors were not considered as co-factors when analyzing dioxin/furan and PCB trends in the Puget Sound region.

- Metals had weak correlations with TOC, and somewhat better correlations with percent fines.

Objective 2. Identify the concentration distributions of dioxin/furan/PCB congeners in the existing DMMP reference areas.

- In the reference areas, dioxin/furan TEQs ranged from 0.1 to 5.07 pg/g TEQ.

- The TEQ contribution from dioxin-like PCBs in the reference areas was extremely low, ranging from 0 to 0.168 pg/g TEQ.

- Outliers/extreme concentrations were found in the Carr Inlet stratum for dioxin/furan TEQs,

Objective 3. Identify the concentration distributions of dioxin/furan/PCB congeners in Puget Sound (away from known sources of contamination and cleanup sites).

- In the greater Puget Sound dataset (excluding reference areas), dioxin/furan TEQ ranged from 0.047 to 11.6 pg/g TEQ.

- PCB TEQs ranged from 0 to 0.168 pg/g TEQ. In general, PCBs were shown to contribute very little to total TEQs.

- Although these differences were not statistically significant, concentrations of dioxin/furan/PCB congeners in Admiralty Inlet, the San Juan Islands and the Straits of Juan de Fuca appeared lower than in the other subgroups.

- Outliers/extreme concentrations were found in the South Sound stratum for dioxin/furan TEQs, and in the Central Puget Sound, Hood Canal and Port Susan Possession Sound strata for PCB TEQs.

Objective 4. Compare the concentration distributions in the existing reference areas to general concentrations in Puget Sound away from known sources and cleanup sites to determine whether they are statistically different.

- There were no statistical differences in dioxin/furan or PCB TEQs between the reference areas and the greater Puget Sound dataset.

Objective 5. Determine the distribution of other chemicals of concern (metals, SVOCs, pesticides) in Puget Sound.

- The 95th percentile concentrations of all metals were below the SMS SQS values:
  - Antimony was not detected in any samples.
  - Cadmium, mercury, selenium, and silver were detected in some samples.
  - Arsenic, chromium, copper, lead, nickel, and zinc were detected in all samples.
- SVOCs, except phenols, were low.
  - The 95th percentile concentrations of LPAHs and HPAHs were below SQS, with the total PAH sum of the 95th percentiles being 131 µg/kg.
  - Bis(2-ethylhexyl)phthalate was detected in only 6 percent of the samples, all below SQS.
  - Phenol was detected in 63 percent of the samples, with 10 of the 70 samples being above the SQS. Concentrations at one station (HC_2) equaled the CSL.
  - 4-methylphenol was detected in 50 percent of the samples, with one station (R_SAM_3) being above the CSL (the CSL is equal to the SQS for 4-methylphenol).
- No pesticides were detected in the samples.

Objective 6. Conduct corroborative testing of two dioxin/furan and PCB congener TEQ assays to determine whether they are well-correlated with standard methods, have low enough detection limits, and are cost-effective.

- The determination of utility of these assays for evaluating dredged material is incomplete at this time but is in progress under a separate program funded by USACE and USEPA. In order to evaluate the potential of the various assays for the evaluation of dredged sediments, more data are being considered, which include a wider TEQ concentration range.
- The outcome of this analysis will be published in a separate report.[7]

[7] This report and other project updates will be posted on the U.S. Army Corps of Engineers, Seattle District: http://www.nws.usace.army.mil/PublicMenu/Menu.cfm?sitename=DMMO&pagename=Dioxin_Work_Group

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