Remedial Investigation for Sediment Unit and Sawmill Unit

Port Gamble Bay and Mill Site
Port Gamble, WA

FINAL

Prepared by

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2LAET	second lowest apparent effects threshold
µg/kg	micrograms per kilogram
ABS	absorption fraction
AF	adherence factor
AFDW	ash-free dry weight
ARI	Analytical Resources, Inc.
AT	averaging time
BE	Biological Evaluation
BTV	background threshold value
BW	body weight
CAP	cleanup action plan
CDI	chronic daily intake
CF	conversion factor
CoC	chemical of concern
CoPC	chemical of potential concern
CSF	cancer slope factor
CSL	cleanup screening level
cPAHs	carcinogenic polynuclear aromatic hydrocarbons
DNR	Washington Department of Natural Resources
dw	dry weight
ECDF	empirical cumulative distribution function
Ecology	Washington State Department of Ecology
ED	exposure duration
EF	exposure frequency
EIM	Environmental Information Management System
EPA	Environmental Protection Agency
EPC	exposure point concentration
FI	fractional exposure
FLA	former lease area
FLTF	former log transfer facility
FS	feasibility study
HI	hazard index
HPAHs	high molecular weight polynuclear aromatic hydrocarbons
HQ	hazard quotient
IR	ingestion rate
KM	Kaplan-Meier
LAET	lowest apparent effects threshold
LDW	Lower Duwamish Waterway
MDL	method detection limit
MIG	mean individual growth

mg/kg	milligrams per kilogram
MLLW	mean lower low water
MRL	method reporting limit
MTCA	Model Toxics Control Act
ng/kg	nanograms per kilogram
OC	organic carbon
OCDD	octachlorodibenzo-p-dioxin
OCDF	octachlorodibenzofuran
PAHs	polynuclear aromatic hydrocarbons
PCA	principal components analysis
PCBs	polychlorinated biphenyls
PCDDs	polychlorinated dibenzo-p-dioxins
PCDFs	polychlorinated dibenzofurans
pg/g	picograms per gram
PGST	Port Gamble S'Klallam Tribe
PQL	practical quantitation limit
PSEP	Puget Sound Estuary Program
QA-2	quality assurance level 2
QAPP	quality assurance project plan
QA/QC	quality assurance/quality control
RfD	reference dose
RI	remedial investigation
RI/FS	remedial investigation/feasibility study
RL	reporting limit
RME	reasonable maximum exposure
RPD	redox potential discontinuity
RSLs	regional screening levels
SAIC	Science Applications International Corporation
SAP	Sampling and Analysis Plan
SD	standard deviation
SIM	selective ion monitoring
SPI	sediment profile imaging
SQS	sediment quality standard
SMA	sediment management area
SMS	Sediment Management Standards
SRI	supplemental remedial investigation
SVOC	semivolatile organic compound
TCDD	tetrachlorodibenzo-p-dioxin
TEC	toxic equivalency concentration
TEF	toxic equivalency factor
TEQ	toxic equivalency quotient
TOC	total organic carbon
TVS	total volatile solids

UCL	upper confidence limit
UTL	upper tolerance limit
WAC	Washington Administrative Code
WHO	World Health Organization
ww	wet weight

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EXECUTIVE SUMMARY

This report presents the combined results of several remedial investigations performed from 2002 to 2011 by Pope & Talbot, Pope Resources, the Olympic Property Group, and the Washington State Department of Ecology (Ecology) near the former Pope & Talbot Mill and in Port Gamble Bay, Washington. The in-water portions of Port Gamble Bay and the Mill Site are addressed in this document and supporting Appendices A through C, while the Mill Site uplands are addressed in the RI/FS presented in Appendix D. Under Ecology's Toxics Cleanup Program Puget Sound Initiative, Port Gamble Bay is one of seven bays in Puget Sound identified for focused cleanup and restoration.

Port Gamble Bay is located in Kitsap County and encompasses more than 2 square miles of subtidal and shallow intertidal habitat. Pope & Talbot operated a sawmill on the northwest shore of the bay from 1853 to 1995, with log transfer and rafting activities occurring at various locations on the bay. Pope & Talbot leased 72 acres from the Washington Department of Natural Resources from 1970 to 2001 for temporary log storage and transfer purposes. Log rafting ceased in 1995 when the sawmill closed, and Pope & Talbot removed pilings from the leased area in 1996. The log sort yard and ramp operated from 1970 to 1995 and consisted of a dock and pilings on privately owned tidelands and an access road. Three landfills were also located along the western shoreline, some of which received mill waste and some municipal waste. The upland portions of all the landfills and the sediment area of one landfill were cleaned up in 2004 under Ecology's Voluntary Cleanup Program.

The bay and surrounding areas support diverse aquatic and upland habitats, as well as resources for fishing, shellfish harvesting, and many other aquatic uses. The area surrounding the bay remains rural in nature. The Port Gamble S'Klallam Tribal Reservation is located east of the bay, with extensive use of the bay by the tribe for shellfish harvesting, fishing, and other resources.

Current and Former Sources

Based on all of the investigations to date, the likely sources of contamination to Port Gamble Bay are:

- **Wood Waste.** Deposition of wood waste through log rafting, log transfer activities, chip loading, and other sources related to the former mill has resulted in thick deposits of wood chips, bark, and other debris both north and south of the mill site. Smaller amounts of wood debris can be seen at the former lease area and at various locations along the shoreline. In turn, these wood waste deposits generate a variety of breakdown products, including toxic chemicals, resulting in

elevated levels of organic carbon, volatile solids, sulfides, ammonia, resin acids, and phenols in sediments.

- **Creosoted Pilings.** Thousands of creosoted pilings and overwater structures are present near the former mill site and in areas to the south, with varying degrees of structural integrity. These pilings and structures continue to release carcinogenic petroleum hydrocarbons, other chemicals, and wood debris to the aquatic environment.
- **Wood Burning and Hog Fuel Boiler.** Historic burning of large quantities of wood debris at the mill, originally on an uncontained slab and later in a hog fuel boiler, released large amounts of particles into the air. Based on the prevailing winds, much of this material would have settled out on the surrounding soils and in Port Gamble Bay, ultimately settling out into bottom sediments of the bay. Ash was also generated by these wood-burning activities, which may have been deposited in the landfills or in other nearby upland areas. The particles and ash contained petroleum hydrocarbons, dioxins/furans, and potentially metals.
- **Upland Mill Activities.** Other historic industrial activities at the mill may have contributed metals and organic chemicals along the southern and southwestern shoreline of the former mill.
- **Shoreline Debris.** Substantial shoreline debris is present at the former mill site, south along the shoreline in the landfill areas, and continuing further south along the western shoreline. The debris includes asphalted and creosoted materials, bricks, metal scraps, plastics, other landfill waste, and untreated wood. These materials may have contributed some of the chemicals seen in sandier areas along the beach.

Environmental Transport Pathways

Contaminants were transported to and around the bay in the following ways:

- **Currents and Tidal Fluctuations.** As wood deposits continue to break down near the mill through biological and chemical action, finer-grained organic material is produced, which appears to be transported through currents and tidal action to the south-central areas of the bay and deposited there. All of the same wood waste breakdown products observed near the mill are found in this south-central portion of the bay, along with very fine wood particles in the sediments.
- **Concentration of Clay Particles.** Similar transport processes concentrate very fine-grained natural sediments such as clays in the south end of the bay. Metals strongly bind to clay and were found to be highly correlated with the percentage of clay in the sediments. It appears that most metals in the bay are naturally concentrated at the south end of the bay due to deposition of clay particles there. Cadmium levels in the very southeast corner of the bay exceed levels of concern through these natural processes.
- **Aerial Deposition.** Particles containing chemicals from the wood burning activities at the former mill site would have been transported with the prevailing winds and deposited onto the surface of Port Gamble Bay, where currents and tidal fluctuations would have eventually deposited these particles in the south-central areas of the bay.

- **Stormwater Runoff.** Stormwater runoff of contaminants from the former mill site occurred during and after its operation. Based on the investigations conducted, this transport pathway affected mainly intertidal sediments immediately adjacent to the site, primarily to the south and southwest of the former mill.

Ecological and Human Health Risks

- **Ecological Effects.** Detrimental effects to sediment-dwelling organisms have been evaluated through a variety of toxicity tests (laboratory bioassays) over 10 years of studies. Areas to the north and south of the former mill site consistently show toxicity in at least one of the tests used. Smaller areas in the former lease area and in the south-central portion of the bay also show toxicity. The bivalve larval bioassay appears to be the toxicity test that is most sensitive to wood waste breakdown products, and is of considerable concern due to the importance of shellfish reproduction in the bay. In addition, deep deposits of wood waste smother benthic organisms and provide an inhospitable substrate for recolonization, producing an environment largely devoid of sediment-dwelling organisms.
- **Human Health Risks.** Human health risks were calculated for tribal consumption of shellfish and exposure to beach sediments while clamming, scenarios that are also expected to be protective of recreational fishermen and other beach uses. Several chemicals, including arsenic, cadmium, carcinogenic petroleum hydrocarbons, polychlorinated biphenyls, and dioxin/furans have calculated human health risks from seafood consumption that exceed regulatory risk levels, both in Port Gamble Bay and in relatively clean areas of Puget Sound. These risks are associated with consumption of large quantities of shellfish; human health risks associated with use of the beach are below levels of concern.

  The majority of these calculated risks are associated with:

  - Natural geologic concentrations of arsenic,
  - Ubiquitous low-level concentrations of petroleum hydrocarbons and dioxins/furans, and
  - Calculations using the detection limit for undetected compounds.

  Of the remaining contaminants, cadmium and carcinogenic petroleum hydrocarbons exceed Puget Sound natural background concentrations throughout Port Gamble Bay, and dioxin/furan concentrations exceed natural background concentrations over limited areas near the mill site and offshore of the former log transfer facility. These chemicals are considered site-related and will be addressed through the cleanup.

Cleanup Standards

Under the cleanup regulations (Model Toxics Control Act, Chapter 173-340 Washington Administrative Code [WAC] and Sediment Management Standards, Chapter 173-204 WAC), the cleanup standard is set at the highest of:

- Risk-based concentrations (ecological or human health)
- Natural background concentrations
- Practical quantitation limits

Section 8 addresses human health risk, Section 9 presents comparisons of concentrations in sediments and shellfish at the site to natural background concentrations, and Section 11 describes how these are combined with practical quantitation limits to identify contaminants of concern and select site-specific cleanup levels. The following cleanup standards have been selected for Port Gamble Bay:

- **Toxicity due to wood waste breakdown products:** Numeric biological standards based on the results of toxicity tests described in WAC 173-204-320(3). This cleanup standard was set to protect sediment-dwelling organisms, including shellfish.
- **Carcinogenic petroleum hydrocarbons:** 16 micrograms per kilogram (µg/kg) based on the sum of carcinogenic compounds expressed as benzo(a)pyrene equivalents (see Section 8.2.4). This cleanup standard is based on natural background concentrations, which are higher than human health risk-based concentrations.
- **Dioxin/furan TEQ:** 5 nanograms per kilogram (ng/kg), based on the sum of dioxin/furan congeners expressed as 2,3,7,8-tetrachlorodibenzo-p-dioxin equivalents (see Section 8.2.4). This cleanup standard is based on practical quantitation limits, which are higher than both human health risk-based concentrations and natural background concentrations.
- **Cadmium:** 3.0 milligrams per kilogram (mg/kg). This cleanup standard is based on natural background concentrations, which are higher than human health risk-based concentrations.

Site Boundaries and Sediment Management Areas

Sediment management areas (SMAs) were developed to carry forward into the feasibility study for cleanup based on similar characteristics, such as types of contaminants, biological toxicity, geographic contiguity, and hydrologic considerations.

The following SMAs have been defined for Port Gamble Bay (Figure ES-1):

- **Mill Site North.** This SMA encompasses the embayment to the northeast of the former mill, between the jetty and the point. Mill Site North is characterized by deep wood chip deposits, large numbers of creosoted pilings and structures, biological toxicity, and high concentrations of wood waste breakdown chemicals and carcinogenic petroleum hydrocarbons.
- **Mill Site South.** This SMA extends south of the former mill site. This area is characterized by deep deposits of wood chips and bark and also contains significant numbers of pilings and overwater structures. Stations throughout this area are consistently toxic and also have high concentrations of wood waste breakdown chemicals, along with the highest levels of carcinogenic petroleum hydrocarbons in the bay. In addition, areas along the southern shoreline of the former mill have the highest dioxin/furan levels in sediments at the site.

- **Central Bay.** This SMA encompasses four stations showing biological toxicity in the south-central area of the bay that were colocated with elevated levels of wood waste breakdown products.
- **Former Lease Area.** This SMA includes a relatively small area in the former lease area characterized by biological toxicity and wood waste breakdown chemicals.
- **Carcinogenic Petroleum Hydrocarbons.** This large area includes all stations that exceed the cleanup standard for carcinogenic petroleum hydrocarbons in the bay. It also includes a smaller area offshore of the former log transfer facility that slightly exceeds natural background concentrations for dioxins/furans and the station at the southeast corner of the bay that exceeds natural background concentrations for cadmium. This SMA surrounds and includes all the other SMAs, and thus also serves as the site boundary.

SMAs may be refined further in the feasibility study, including subdividing and applying different cleanup alternatives to subareas of an SMA based on environmental benefit, technical feasibility, cost, integration with planned restoration alternatives, and other considerations.

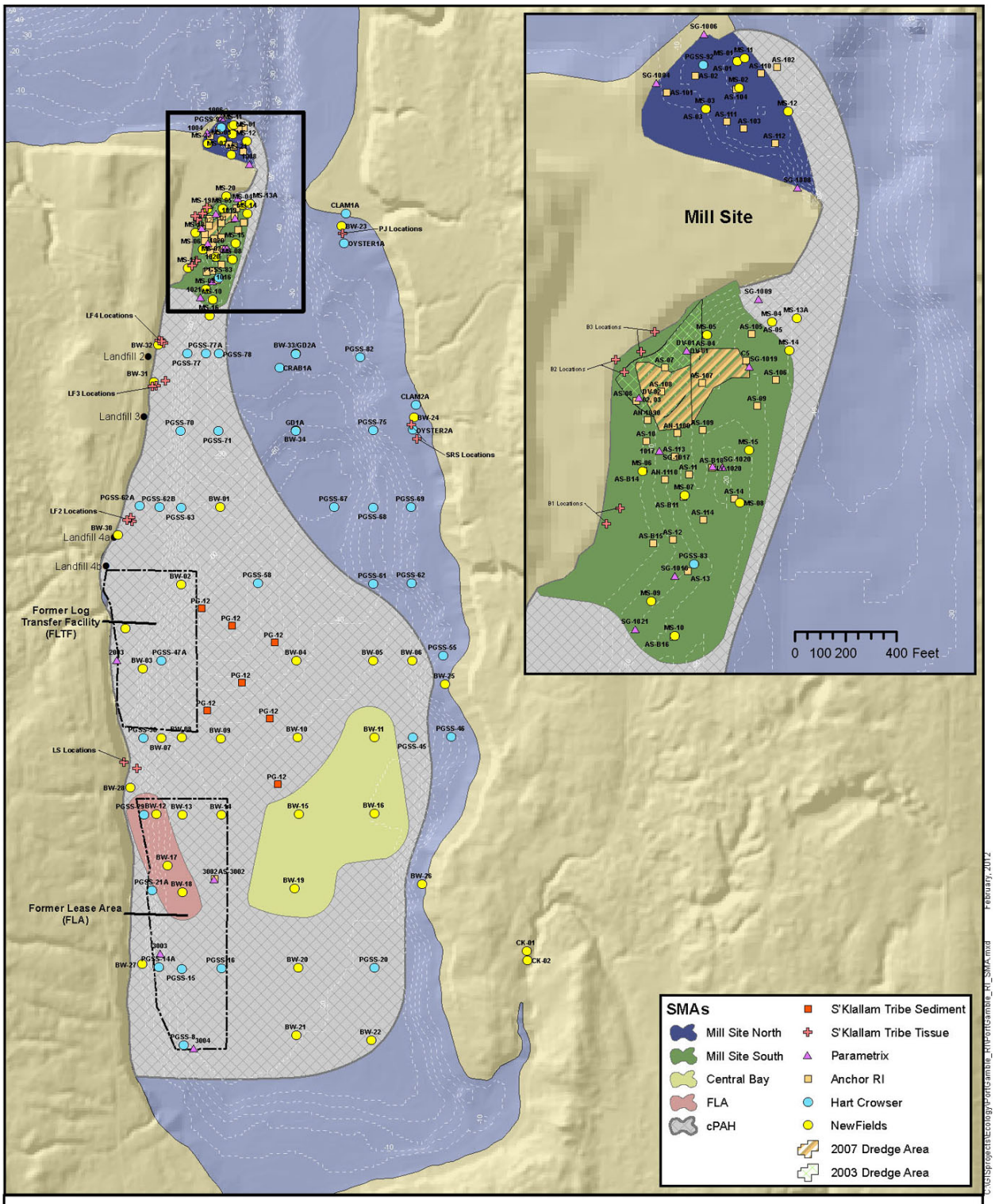

Figure ES-1. Sediment Management Area Boundaries

1.0 INTRODUCTION

This report presents the combined results of several remedial investigations (RIs) performed on behalf of Pope & Talbot, Pope Resources, the Olympic Property Group, and the Washington State Department of Ecology (Ecology) near the former Pope & Talbot Mill and in Port Gamble Bay, Washington (Figure 1-1). The in-water portions of Port Gamble Bay and the Mill Site are addressed in this document and supporting Appendices A through C, while the Mill Site uplands are addressed in the RI/FS presented in Appendix D. Under Ecology's Toxics Cleanup Program Puget Sound Initiative, Port Gamble Bay is one of seven bays in Puget Sound identified for focused cleanup and restoration.

Port Gamble Bay is located in Kitsap County and encompasses more than 2 square miles of subtidal and shallow intertidal habitat just south of the Strait of Juan de Fuca (Figure 1-1). Pope & Talbot operated a sawmill on the northwest shore of the bay from 1853 to 1995, with log transfer and rafting activities occurring at various locations on the bay. Pope & Talbot leased the 72-acre portion of the former lease area (FLA) from the Washington Department of Natural Resources (DNR) from 1970 to 2001 for temporary log storage and transfer purposes (Parametrix 2002). Log rafting ceased in 1995 when the sawmill closed, and Pope & Talbot removed pilings from the leased area in 1996. Log rafting and sawmill activities were not conducted at the former log transfer facility (FLTF) or the FLA after Pope & Talbot removed the pilings in 1996. The FLTF log sort yard and ramp reportedly operated from 1970 to 1995 and consisted of a dock and pilings on privately owned tidelands and an access road (Parametrix 2003). Figure 1-1 also shows several landfills along the western shoreline, some of which received mill waste and some municipal waste.

Log rafting operations resulted in accumulations of wood waste on the bed of Port Gamble Bay near the sawmill. In addition, wood accumulations were suspected at both the FLTF and FLA based on the historic use of these areas (Figure 1-1). Temporary log storage and transfer within the 72-acre portion of the FLA and FLTF were reported from 1970 to 2001 (Parametrix 2002); however, historic log rafting activities also occurred much earlier in this area based on review of aerial photographs. The mill site and associated log transfer and log rafting activities are believed to have been the primary sources of impacts to the bay. Other possible sources of contamination include the former landfills, stormwater outfalls from Highway 101, and surface water drainages in the south and southeast portions of the bay.

The bay and surrounding areas support diverse aquatic and upland habitats, as well as resources for fishing, shellfish harvesting, and many other aquatic uses. The area surrounding the bay remains rural in nature. The Port Gamble S'Klallam Tribal Reservation is located east of the bay, with extensive use of the bay by the tribe for shellfish harvesting, fishing, and other resources.

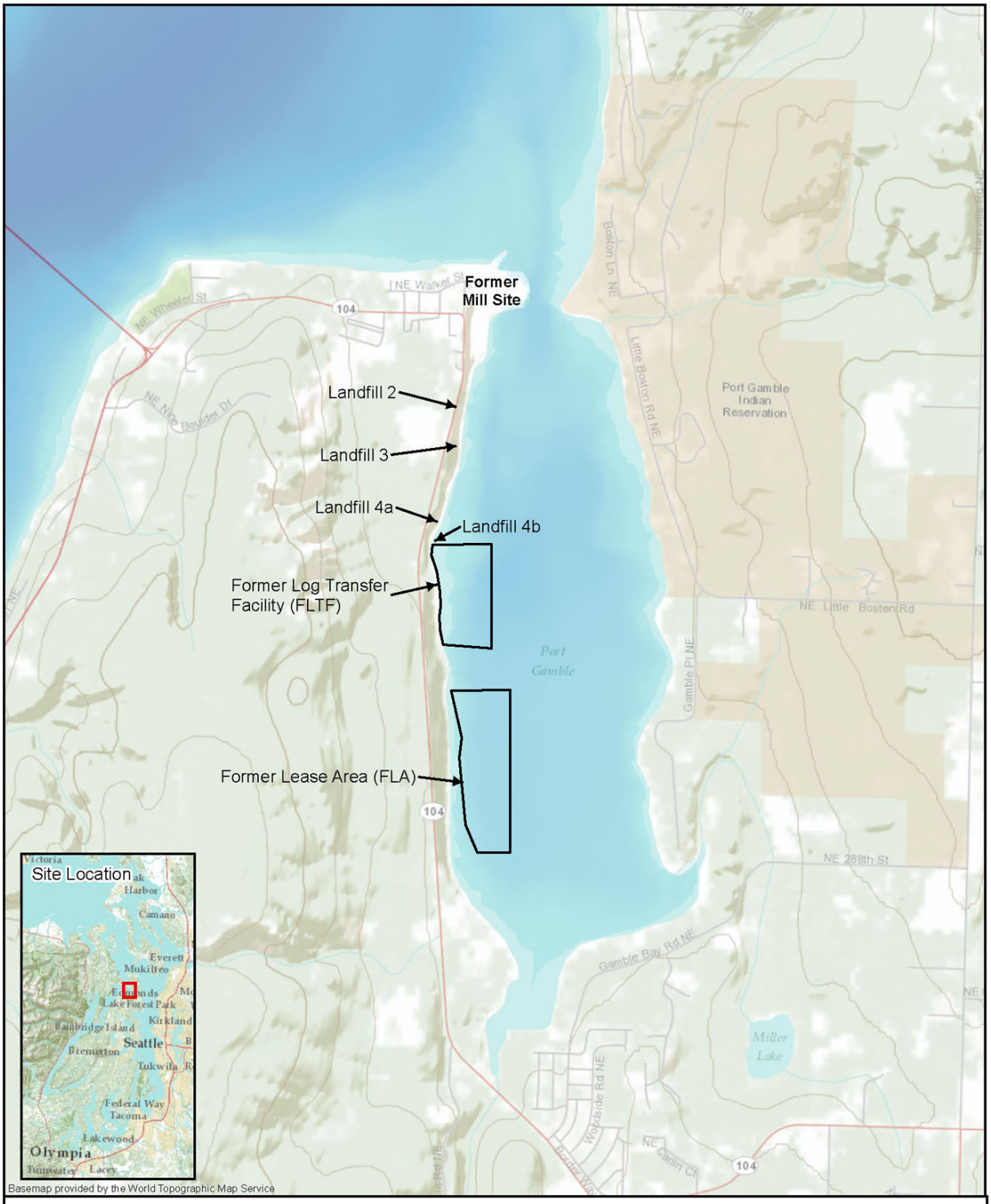

Figure 1-1. Overview of Port Gamble Bay

2.0 SEDIMENT REMEDIAL INVESTIGATIONS AND INTERIM CLEANUP ACTIONS

2.1 Remedial Investigations

As a consultant to Pope & Talbot, Parametrix conducted a series of investigations in Port Gamble Bay from 1999 to 2004 to identify chemical and wood waste impacts from sawmill operations on sediments and biota (Parametrix 2003a). While most of these data have been superseded by more recent investigations, in some areas near the mill these data represent the only information on Sediment Management Standards (SMS) chemicals of concern (CoCs). In areas where no other information is available, these data have been included (see Table 2 and Appendix A for a complete set of historic and current data relied on in this report).

In 2006, Anchor Environmental prepared a report compiling existing data for sediments near the former mill site and proposed a sediment investigation to fill data gaps (Anchor 2006a). A Biological Evaluation (BE) was also prepared (Anchor 2006b) as part of a cooperative interim sediment cleanup action involving approximately 16,500 cubic yards of subtidal sediment, as discussed further below. Much of this previous site investigation work was concentrated on aquatic areas near the sawmill, with only limited delineation of wood waste in other locations such as the FLTF and FLA. The areal and vertical extent of wood waste was not well defined for the purposes of evaluating impacts and potential remediation measures. In addition, chemical and biological quality were sparsely characterized beyond the aquatic areas near the mill. Thus, a complete assessment of impacts to human health and the environment could not be conducted.

Subsequently, Anchor, on behalf of Pope Resources and the Olympic Property Group, and Hart Crowser, on behalf of Ecology, simultaneously conducted RIs and feasibility studies (FS) for what were then termed the Mill Site and Baywide Site, respectively (Anchor 2009, 2010; Hart Crowser 2009, 2010). In addition, the Port Gamble S'Klallam Tribe provided some additional tissue and sediment data in 2010 and 2011 (PGST 2010, 2011). These investigations collectively provided a more complete assessment of impacts to biota near the mill and in other areas of Port Gamble Bay, as well as a preliminary basis on which to evaluate human health risks.

However, certain questions remained to be answered to finalize the RI, including a more complete assessment of other sources to the bay, a thorough evaluation of human health risks, comparison to natural background concentrations and risks, and refinement of biological effects boundaries. The bioassay protocols were refined to better reflect the fine-grained, flocculent nature of the sediments in some areas of the bay and address uncertainties in previous bioassay results. These additional field investigations were conducted by NewFields under contract to Science Applications International Corporation (SAIC) in July 2011. Details of the sampling and bioassay testing protocols are described in NewFields (2011a).

Specific tasks included:

- Collection of surface sediment chemistry samples to provide better delineation of site boundaries at the Mill Site, particularly along the eastern boundary, chip loading area, and areas with substantial pilings.
- Collection of composite sediment and shellfish samples from intertidal areas adjacent to potential upland source areas at the Mill Site to assess possible transport pathways and human health risks.
- Collection of intertidal sediment samples to identify any potential sources of contamination related to upland and/or shoreline activities away from the Mill Site, such as the landfills along the western shoreline, stormwater outfalls, or surface water drainages.
- Collection of surface sediment samples for biological testing using updated test protocols that take into account conditions found in Port Gamble Bay.
- Collection of additional composited crab tissue samples (edible muscle and hepatopancreas) from stations in the southern portion of Port Gamble Bay.
- Comparison of concentrations of bioaccumulative chemicals in sediments and tissues to natural background concentrations in Puget Sound to identify CoCs for human health.
- Development of cleanup standards for human health and ecological CoCs.
- Evaluation of human health and benthic toxicity data to identify areas exceeding the Sediment Quality Standards (SQS) and Cleanup Screening Levels (CSLs) and use of this information to refine the boundaries of the sediment management areas (SMAs).

The primary goal of this investigation was to provide all of the remaining data necessary to evaluate human health and environmental risks throughout Port Gamble Bay sediments to enable completion of the FS and Cleanup Action Plan (CAP) for areas near the mill as well as Port Gamble Bay. The results of this final investigation along with the previously collected data supported combining the entire area into one site; thus, this report addresses both areas near the mill and in the larger Port Gamble Bay.

Anchor, on behalf of Pope Resources and the Olympic Property Group, previously submitted RI and FS Reports for the upland mill site (Anchor 2009, 2010) documenting a substantial amount of interim cleanup of the upland site and the results of soil and groundwater investigations. In addition, in 2011, the Port Gamble S'Klallam Tribe provided analytical results for a number of soil samples showing elevated levels of dioxins/furans in the vicinity of the upland mill site. Ecology will be working with Pope Resources and the Olympic Property Group to address any remaining issues on the upland mill site, including additional investigation of dioxins in soils and to provide closure for work already completed. These upland activities will be conducted separately to allow timely completion of the remedial investigation/feasibility study (RI/FS), CAP, consent decree, and cleanup for Port Gamble Bay.

2.2 Previous Dredging Activities and Interim Remedial Actions

Historic dredging likely occurred episodically near the mill area to maintain navigational depth and access; however, specific information on these events is not available. More recent dredging occurred in 2003 and 2007. In 2003, Pope and Talbot dredged approximately 13,500 cubic yards of sediment and

wood waste from nearshore areas adjacent to the former sawmill. The 2003 dredging occurred over an elevation range of about -12 to -15 feet mean lower low water (MLLW) and was conducted to remove accumulated wood waste that reduced navigation access nearshore.

In 2007, an additional Interim Remedial Action dredging was performed to the east of the 2003 dredging area as a cooperative effort under the Model Toxics Control Act (MTCA) by Ecology, DNR, Pope & Talbot (currently bankrupt), and Pope Resources (Hart Crowser 2008b). Approximately 16,500 cubic yards of sediment and wood waste were removed from nearshore areas adjacent to the former sawmill. The 2007 dredging occurred over an elevation range of about -10 to -28 feet MLLW.

2.3 Known and Potential Sources of Contaminants

A summary of known and potential contaminants and their sources is provided below, which informed the design of the 2011 NewFields RI:

- **Wood waste and related contaminants.** As discussed above, many of the previous investigations and interim actions have focused on wood waste in sediments. Wood waste provides an inappropriate substrate for many benthic and epibenthic organisms to live on or in, and also impacts aquatic plants. In addition, ammonia, sulfides, and other toxic compounds can be generated during breakdown of wood waste in anoxic environments. At Port Gamble Bay, areas with abundant wood waste have elevated sulfides concentrations, but ammonia does not appear to be present at levels of concern. Finally, wood contains many other natural substances that can be present and toxic under certain circumstances, depending on the type of wood, the degree of processing, and environmental conditions. These chemicals include phenols, resin acids, and tannins. Some elevated levels of phenols and resin acids have been observed in areas of Port Gamble Bay with wood waste accumulations.
- **Polynuclear aromatic hydrocarbons (PAHs).** The primary source of PAHs to Port Gamble Bay is believed to be leachate from the thousands of creosoted pilings that are present near the Mill Site and along the northwestern shoreline, and historic burning of waste wood material at the mill over a period of 150 years. Additional sources may include surface water runoff from the mill, from Highway 101, and other paved surfaces; small fuel spills and discharges from vessels (including derelict vessels along the western shoreline); air deposition from combustion of petroleum, including vehicle and vessel exhaust; air deposition from wood stoves and backyard burning of yard waste; and natural background concentrations of PAHs in sediments from natural and regional sources. PAHs can be toxic to benthic organisms at high concentrations, but at the levels found in Port Gamble Bay are primarily of concern to human health due to the carcinogenicity of certain PAHs.
- **Metals.** Arsenic, cadmium, copper, and mercury have been identified as chemicals of potential concern (CoPCs) for human health. Sources of these metals beyond natural background concentrations in the bay are unknown, but could include landfill debris along the western shoreline, ash from the hog fuel boiler at the Mill Site, contributions from drainages to the south and southeast, vessel paints (particularly copper and mercury), and stormwater runoff. Arsenic was found in groundwater at the Mill Site, but is believed to be related to natural geologic

conditions at the site based on multiple soil and groundwater investigations (Anchor 2010). No significant sources of these metals to sediments are known at the Mill Site, although some small areas of upland soils with metals contamination were removed during interim cleanup actions.

- **Polychlorinated biphenyls (PCBs).** PCBs have also been identified as potentially of concern for human health. Preliminary statistical analyses suggested that PCB concentrations may be within natural background concentrations; however, previously, there were not enough data to draw a definitive conclusion. In addition, only Aroclor data were available rather than congeners, which are more directly related to human health risk. PCB concentrations in regional sediments are related to global atmospheric deposition. Other sources to Port Gamble Bay sediments could include surface water runoff from several small PCB sources at the Mill Site, contributions from surface water drainages in the southern part of the bay, and landfill debris.
- **Polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans (PCDDs/PCDFs).** PCDDs/PCDFs have also been identified as being of concern for human health. Preliminary statistical analyses suggested that PCDD/PCDF concentrations may be within natural background concentrations; however, there were not enough data to draw a definitive conclusion, especially in areas near the Mill Site. PCDD/PCDF concentrations in regional sediments are related to global atmospheric deposition as well as regional combustion sources and natural sources such as forest fires. Other sources of PCDDs/PCDFs may include surface water runoff and/or atmospheric deposition of particulates from the historic hog fuel boiler at the Mill Site, other local combustion sources including residential sources, and impurities in pentachlorophenol-treated wood.

3.0 SAMPLING AND ANALYSIS SUMMARY

Sampling and testing activities were conducted in general accordance with the protocols established in Ecology's (SMS) (Chapter 173-204 WAC), and Puget Sound Estuary Program (PSEP 1997a, 1997b, and 1997c), as referenced in Ecology's Sediment Sampling and Analysis Plan Appendix (SAPA) (Ecology 2008). The samples collected were acceptable for chemical, physical, and bioassay analysis, except where otherwise noted in Sections 4.0 through 7.0 below.

In addition to the most recent RIs, some data have been included from the historic investigations, as appropriate. These current and historic surveys and the types of data originally collected in each are summarized in Table 3-1. A complete list of the sediment and tissue samples included in the evaluations in this report and associated analyses are presented in Table 3-2. The locations and type of samples collected from each area are listed in Table 3-2 and presented in Figure 3-1, and station coordinates are shown in Table A-1 for all stations used in the RI Report. Complete tables of all data presented and analyzed in this RI Report are provided in Appendix A.

In general, when previous stations were revisited in later investigations, older data were replaced with newer data of the same type. Sediment chemistry data for metals, semivolatile organic compounds (SVOCs), PCBs, and dioxins/furans were used as far back as 2002 for locations where more recent data were not available. Sediment chemistry data for conventionals and sediment bioassay data were used as far back as 2006.

Table 3-1. Summary of Studies Incorporated into the Port Gamble Bay RI Report

			Mill Area[a]		Bay	
Study	**Collection Year**	**Reference**	**Sediment**	**Tissue**	**Sediment**	**Tissue**
NewFields	2011	NewFields 2011b	X	X	X	X
Port Gamble S'Klallam Tribe	2010	PGST 2010		X		X
Port Gamble S'Klallam Tribe	2011	PGST 2011			X	
Hart Crowser	2008	Hart Crowser 2009	X		X	X
Anchor	2006	Anchor 2006a	X		X	
Anchor	2007	Anchor 2009	X			
Anchor	2006	Anchor 2009	X			
Parametrix	2000	Parametrix 2004	X		X	
Parametrix	2002	Parametrix 2004	X			
Parametrix	2003	Parametrix 2004	X			

[a] The Mill Area is represented by the inset area in the figures.

The sections below provide a summary of the investigations previously conducted and interpreted in this RI report. Detailed descriptions of sampling and analysis methods, sample and core logs, chain of custody sheets, laboratory reports, and quality assurance (QA) reports can be found in the original references cited above.

Table 3-2. Samples and Parameters Incorporated into the Port Gamble Bay RI Report

Location ID	NewFields Sample ID[c] /Species	Source	Radiometric Dating	Sieve Samples	Grain Size	Conventionals[b]	Porewater Sulfides/Ammonia	SMS Metals[a]	SVOCs	SIM PAH	Resin Acids (Wood Chemicals)	PCB Aroclors	PCB Congeners	Dioxins/Furan Congeners	% Lipids	Microtox	Amphipod Mortality	Larval Development Bioassay	Juvenile Polychaete Bioassay
Bay Subtidal Samples																			
11092801		PGST 2011			X	X		X	X	X	X	X		X					
11092802		PGST 2011			X	X		X	X	X	X	X		X					
11092803		PGST 2011			X	X		X	X	X	X	X		X					
11092804		PGST 2011			X	X		X	X	X	X	X		X					
11092805		PGST 2011			X	X		X	X	X	X	X		X					
11092806		PGST 2011			X	X		X	X	X	X	X		X					
AS-3002		Anchor 2006a	X		X	X												X	X
AS-3004		Anchor 2006a	X		X	X												X	X
PG11-BW-19-S		NewFields 2011b			X	X	X	X	X			X						X	X
PG11-BW-21-S		NewFields 2011b			X	X	X	X	X			X						X	X
PG11-BW-22-S		NewFields 2011b			X	X		X						X					
PG12		PGST 2011				X		X	X	X	X	X		X					
PGSS- 8		Hart Crowser 2009		X	X	X		X	X		X	X		X		X	X	X	X
PGSS-14A		Hart Crowser 2009		X		X		X	X		X	X				X			
PGSS-15		Hart Crowser 2009		X	X	X		X	X		X	X				X	X	X	X
PGSS-16		Hart Crowser 2009		X	X	X		X	X		X	X				X	X	X	X
PGSS-18	PG11-BW-20-S	Hart Crowser 2009/NewFields 2011b		X	**X**	**X**	**X**	X	X	**X**	X	X		X		X	X	**X**	**X**
PGSS-20		Hart Crowser 2009		X	X	X					X					X	X	X	X
PGSS-21A		Hart Crowser 2009				X		X	X		X	X				X			
PGSS-21B	PG11-BW-17-S	Hart Crowser 2009 /NewFields 2011b		X	**X**	**X**	**X**	X	X	**X**	X	X				X	X	**X**	X
PGSS-22	PG11-BW-18-S	Hart Crowser 2009 /NewFields 2011b		X	**X**	**X**	**X**	X	X	**X**	X	X		X		X	X	**X**	X
PGSS-29		Hart Crowser 2009		X		X		X	X		X	X				X			

Table 3-2. Samples and Parameters Incorporated into the Port Gamble Bay RI Report

Location ID	NewFields Sample ID[c] /Species	Source	Radiometric Dating	Sieve Samples	Grain Size	Conventionals[b]	Porewater Sulfides/Ammonia	SMS Metals[a]	SVOCs	SIM PAH	Resin Acids (Wood Chemicals)	PCB Aroclors	PCB Congeners	Dioxins/Furan Congeners	% Lipids	Microtox	Amphipod Mortality	Larval Development Bioassay	Juvenile Polychaete Bioassay
PGSS-29A	PG11-BW-12-S	Hart Crowser 2009 /NewFields 2011b		X	X	X	X	X	X	X	X	X				X	X	X	X
PGSS-30	PG11-BW-13-S	Hart Crowser 2009 /NewFields 2011b		X	X	X	X	X	X	X	X	X				X	X	X	X
PGSS-31	PG11-BW-14-S	Hart Crowser 2009 /NewFields 2011b		X	X	X	X	X	X	X	X	X				X	X	X	X
PGSS-33	PG11-BW-15-S	Hart Crowser 2009 /NewFields 2011b		X	X	X	X	X		X	X					X	X	X	X
PGSS-35	PG11-BW-16-S	Hart Crowser 2009 /NewFields 2011b		X	X	X	X	X		X	X			X		X	X	X	X
PGSS-38		Hart Crowser 2009		X		X		X	X		X	X				X			
PGSS-38A	PG11-BW-07-S	Hart Crowser 2009 /NewFields 2011b		X	X	X	X	X	X	X	X	X				X	X	X	X
PGSS-39	PG11-BW-08-S	Hart Crowser 2009 /NewFields 2011b		X	X	X	X	X	X	X	X	X				X	X	X	X
PGSS-40	PG11-BW-09-S	Hart Crowser 2009 /NewFields 2011b		X	X	X	X	X	X	X	X	X				X	X	X	X
PGSS-42	PG11-BW-10-S	Hart Crowser 2009 /NewFields 2011b		X	X	X	X	X	X	X	X	X				X	X	X	X
PGSS-44	PG11-BW-11-S	Hart Crowser 2009 /NewFields 2011b		X	X	X	X	X	X	X	X	X				X	X	X	X
PGSS-45		Hart Crowser 2009		X	X	X					X					X	X	X	X
PGSS-46		Hart Crowser 2009		X		X					X					X	X	X	X
PGSS-47	PG11-BW-03-S	Hart Crowser 2009 /NewFields 2011b		X	X	X	X	X	X	X	X	X				X	X	X	X
PGSS-47A		Hart Crowser 2009		X		X		X	X		X	X				X			

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PGSS-51	PG11-BW-04-S	Hart Crowser 2009 /NewFields 2011b		X	**X**	**X**	**X**	**X**	X	**X**	X	X		X		X	X	**X**	X
PGSS-53	PG11-BW-05-S	Hart Crowser 2009 /NewFields 2011b		X	**X**	**X**	**X**	X	X	**X**	X	X				X	X	**X**	X
PGSS-54	PG11-BW-06-S	Hart Crowser 2009 /NewFields 2011b		X	**X**	**X**	**X**	X	X	**X**	X	X				X	X	**X**	X
PGSS-55		Hart Crowser 2009		X		X		X	X		X	X				X			
PGSS-56	PG11-BW-02-S	Hart Crowser 2009 /NewFields 2011b		X	**X**	**X**	**X**	X	X	**X**	X	X				X	X	**X**	X
PGSS-58		Hart Crowser 2009		X	X	X		X	X		X	X				X	X	X	X
PGSS-61		Hart Crowser 2009		X		X					X					X			
PGSS-62		Hart Crowser 2009		X	X	X					X					X	X	X	X
PGSS-62A		Hart Crowser 2009		X		X		X	X		X	X				X			
PGSS-62B		Hart Crowser 2009		X		X		X	X		X	X				X	X	X	X
PGSS-63		Hart Crowser 2009		X	X	X		X	X		X	X				X	X	X	X
PGSS-64	PG11-BW-01-S	Hart Crowser 2009		X	**X**	**X**	**X**	X		**X**	X	X		X		X	X	**X**	X
PGSS-67		Hart Crowser 2009		X	X	X					X					X	X	X	X
PGSS-68		Hart Crowser 2009		X		X					X					X			
PGSS-69		Hart Crowser 2009		X		X		X	X		X	X				X	X	X	X
PGSS-70		Hart Crowser 2009		X		X		X	X		X	X				X			
PGSS-71		Hart Crowser 2009		X		X					X					X			
PGSS-73	PG11-BW-34-S	Hart Crowser 2009 /NewFields 2011b		X	**X**	**X**		**X**	X		X	X		X		X	X	X	X
PGSS-75		Hart Crowser 2009		X	X	X		X	X		X	X		X		X	X	X	X
PGSS-77		Hart Crowser 2009		X		X		X	X		X	X				X			
PGSS-77A		Hart Crowser 2009		X	X	X		X	X		X	X		X		X	X	X	X

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PGSS-78		Hart Crowser 2009		X		X					X					X			
PGSS-80	PG11-BW-33-S	Hart Crowser 2009 /NewFields 2011b		X	**X**	**X**		**X**	X		X	X		X		X			
PGSS-82		Hart Crowser 2009		X		X					X					X			
SG-3002		Parametrix 2004						X	X										
SG-3003		Parametrix 2004						X	X										
SG-3004		Parametrix 2004						X	X										
Mill Area Subtidal Samples																			
AN-1090		Anchor 2009				X													
AN-1100		Anchor 2009				X													
AN-1110		Anchor 2009				X													
AS-01	PG11-MS-01-S	NewFields 2011b			**X**	**X**	**X**										X	**X**	X
AS-02		Anchor 2006a			X	X	X										X	X	X
AS-03	PG11-MS-03-S	NewFields 2011b			**X**	**X**	**X**										X	**X**	X
AS-05	PG11-MS-04-S	NewFields 2011b			**X**	**X**	**X**										X	**X**	**X**
AS-07		Anchor 2006a			X	X	X										X	X	X
AS-08		Anchor 2006a			X	X													
AS-09		Anchor 2006a			X	X	X										X	X	X
AS-10		Anchor 2006a			X	X													
AS-11		Anchor 2006a			X	X													
AS-12		Anchor 2006a			X	X	X												
AS-13		Anchor 2006a			X	X	X										X	X	X
AS-14	PG11-MS-08-S	NewFields 2011b			**X**	**X**	**X**										X	**X**	X
AS-101		Anchor 2009			X	X	X										X	X	X
AS-102		Anchor 2009			X	X	X										X	X	X
AS-103		Anchor 2009			X	X	X												

Table 3-2. Samples and Parameters Incorporated into the Port Gamble Bay RI Report

Location ID	NewFields Sample ID[c] /Species	Source	Radiometric Dating	Sieve Samples	Grain Size	Conventionals[b]	Porewater Sulfides/Ammonia	SMS Metals[a]	SVOCs	SIM PAH	Resin Acids (Wood Chemicals)	PCB Aroclors	PCB Congeners	Dioxins/Furan Congeners	% Lipids	Microtox	Amphipod Mortality	Larval Development Bioassay	Juvenile Polychaete Bioassay
AS-105		Anchor 2009			X	X	X												
AS-106		Anchor 2009			X	X	X										X	X	X
AS-108		Anchor 2009			X	X	X										X	X	X
AS-109		Anchor 2009			X	X	X												
AS-110		Anchor 2009			X	X	X												
AS-111		Anchor 2009			X	X	X												
AS-112		Anchor 2009			X	X	X										X	X	X
AS-113		Anchor 2009			X	X	X										X	X	X
AS-114		Anchor 2009			X	X	X												
AS-B09		Anchor 2009															X	X	
AS-B11	PG11-MS-07-S	NewFields 2011b			**X**	**X**	**X**										X	**X**	
AS-B14	PG11-MS-06-S	NewFields 2011b			**X**	**X**	**X**										X	**X**	
AS-B15		Anchor 2009			X	X	X										X	X	X
AS-B16	PG11-MS-10-S	NewFields 2011b			**X**	**X**	**X**										X	**X**	**X**
AS-B18		Anchor 2009			X	X	X										X	X	X
C5		Anchor 2009				X													
DV-01		Parametrix 2004						X	X	X		X							
DV-02		Parametrix 2004						X	X	X		X							
LY-1020		Parametrix 2004						X				X							
PG11-MS-05-S		NewFields 2011b			X	X	X											X	X
PG11-MS-09-S		NewFields 2011b			X	X	X											X	X
PG11-MS-11-S		NewFields 2011b			X	X		X	X	X	X	X							
PG11-MS-12-S		NewFields 2011b			X	X		X	X	X	X	X							
PG11-MS-13A-S		NewFields 2011b			X	X		X	X	X	X	X							
PG11-MS-14-S		NewFields 2011b			X	X		X	X	X	X	X							
PG11-MS-15-S		NewFields 2011b			X	X		X	X	X	X	X							

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PG11-MS-16-S		NewFields 2011b			X	X		X	X	X	X	X							
PGSS-83		Hart Crowser 2009				X		X	X		X	X							
PGSS-92		Hart Crowser 2009			X	X		X	X		X	X		X			X	X	X
SG-1016		Parametrix 2004						X	X										
SG-1017		Parametrix 2004						X	X										
SG-1019		Parametrix 2004						X	X										
SG-1020		Parametrix 2004						X	X										
SG-1021		Parametrix 2004						X	X										
Bay Intertidal and Creek Samples																			
PG11-BW-23-S		NewFields 2011b			X	X		X	X	X			X	X					
PG11-BW-24-S		NewFields 2011b			X	X		X	X	X			X	X					
PG11-BW-25-S		NewFields 2011b			X	X		X	X	X			X	X					
PG11-BW-26-S		NewFields 2011b			X	X		X	X	X			X	X					
PG11-BW-27-S		NewFields 2011b			X	X		X	X	X			X	X					
PG11-BW-28-S		NewFields 2011b			X	X		X	X	X			X	X					
PG11-BW-29-S		NewFields 2011b			X	X		X	X	X			X	X					
PG11-BW-30-S		NewFields 2011b			X	X		X	X	X			X	X					
PG11-BW-31-S		NewFields 2011b			X	X		X	X	X			X	X					
PG11-BW-32-S		NewFields 2011b			X	X		X	X	X			X	X					
PG11-CK-01-S		NewFields 2011b			X	X		X	X	X			X	X					
PG11-CK-02-S		NewFields 2011b			X	X		X	X	X			X	X					
PG11-CK-03-S		NewFields 2011b			X	X		X	X	X			X	X					
PG11-CK-04-S		NewFields 2011b			X	X		X	X	X			X	X					
SG-2003		Parametrix 2004						X	X										
Mill Area Intertidal Samples																			
PG11-MS-17-S		NewFields 2011b			X	X		X		X			X	X					

Table 3-2. Samples and Parameters Incorporated into the Port Gamble Bay RI Report

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PG11-MS-18-S		NewFields 2011b			X	X		X		X			X	X					
PG11-MS-19-S		NewFields 2011b			X	X		X		X			X	X					
PG11-MS-20-S		NewFields 2011b			X	X		X		X			X	X					
PG11-MS-21-S		NewFields 2011b			X	X		X		X			X	X					
PG11-MS-22-S		NewFields 2011b			X	X		X		X			X	X					
SG-1004		Parametrix 2004						X	X										
SG-1006		Parametrix 2004						X	X										
SG-1008		Parametrix 2004						X	X										
SG-1009		Parametrix 2004						X	X										
Bioassay Reference Samples																			
CR-20W		Hart Crowser 2009			X	X										X	X		
CR-23Mod		Hart Crowser 2009			X	X										X	X		
MSMP 43		Hart Crowser 2009			X	X										X	X		
PG11-CI-01-S		NewFields 2011b			X	X	X											X	X
PG11-CI-02-S		NewFields 2011b			X	X	X											X	X
PG11-CI-03-S		NewFields 2011b			X	X	X											X	X
Bay Tissue Samples																			
Clam #1A	Littleneck Clam	Hart Crowser 2009						X		X		X	X	X	X				
Clam 2A	Littleneck Clam	Hart Crowser 2009						X		X		X	X	X	X				
Crab 1-A Muscle Tissue	Dungeness Crab	Hart Crowser 2009						X		X		X	X	X	X				
Crab 1-A Pan2 (Hepatopancreas)	Dungeness Crab	Hart Crowser 2009						X		X		X	X	X	X				
GD Station #1A (PGSS-73)	Geoduck	Hart Crowser 2009						X		X		X	X	X	X				

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GD Station #2A (PGSS-80)	Geoduck	Hart Crowser 2009						X		X		X	X	X	X				
LF2_C_PGST_100429	Cockle	PGST 2010						X		X		X			X				
LF2_LN_PGST_100429	Littleneck Clam	PGST 2010						X		X		X			X				
LF2_M_PGST_100429	Manila Clam	PGST 2010						X		X		X			X				
LF2_O_PGST_100429	Oysters	PGST 2010						X		X		X			X				
LF3_C_PGST_100429	Cockle	PGST 2010						X		X		X			X				
LF3_LN_PGST_100429	Littleneck Clam	PGST 2010						X		X		X			X				
LF3_M_PGST_100429	Manila Clam	PGST 2010						X		X		X			X				
LF4_C_PGST_100429	Cockle	PGST 2010						X		X		X			X				
LF4_LN_PGST_100429	Littleneck Clam	PGST 2010						X		X		X			X				
LF4_M_PGST_100429	Manila Clam	PGST 2010						X		X		X			X				
LF4_O_PGST_100429	Oyster	PGST 2010						X		X		X			X				
LS_C_PGST_100429	Cockle	PGST 2010						X		X		X			X				
LS_LN_PGST_100429	Littleneck Clam	PGST 2010						X		X		X			X				
LS_M_PGST_100429	Manila Clams	PGST 2010						X		X		X			X				
LS_O_PGST_100429	Oyster	PGST 2010						X		X		X			X				
Oyster #1A	Oyster	Hart Crowser 2009						X		X		X	X	X	X				
Oyster #2A	Oyster	Hart Crowser 2009						X		X		X	X	X	X				
PG11-BW-04-DCH-R1	Dungeness Crab	NewFields 2011b						X		X			X	X	X				
PG11-BW-04-DCH-R2	Dungeness Crab	NewFields 2011b						X		X			X	X	X				
PG11-BW-04-DCM-R1	Dungeness Crab	NewFields 2011b						X		X			X	X	X				
PG11-BW-04-DCM-R2	Dungeness Crab	NewFields 2011b						X		X			X	X	X				
PG11-BW-30-LN	Littleneck Clam	NewFields 2011b						X		X			X	X	X				
PG11-BW-31-LN	Littleneck Clam	NewFields 2011b						X		X			X	X	X				
PG11-BW-32-LN	Littleneck Clam	NewFields 2011b						X		X			X	X	X				

Table 3-2. Samples and Parameters Incorporated into the Port Gamble Bay RI Report

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PJ_O_PGST_100429	Oyster	PGST 2010						X		X		X			X				
SRS_C_PGST_100429	Oyster	PGST 2010						X		X		X			X				
SRS_O_PGST_100429	Oyster	PGST 2010						X		X		X			X				
Mill Area Tissue Samples																			
B1_C_PGST_100429	Cockle	PGST 2010						X		X		X			X				
B1_LN_PGST_100429	Littleneck Clam	PGST 2010						X		X		X			X				
B1_O_PGST_100429	Oysters	PGST 2010						X		X		X			X				
B2_C_PGST_100429	Cockle	PGST 2010						X		X		X			X				
B2_O_PGST_100429	Oysters	PGST 2010						X		X		X			X				
B3_C_PGST_100429	Cockle	PGST 2010						X		X		X			X				
B3_O_PGST_100429	Oysters	PGST 2010						X		X		X			X				
PG11-MS-17-LN	Littleneck Clam	NewFields 2011b						X		X			X	X	X				
PG11-MS-18-LN	Littleneck Clam	NewFields 2011b						X		X			X	X	X				
PG11-MS-19-LN	Littleneck Clam	NewFields 2011b						X		X			X	X	X				
PG11-MS-20-LN	Littleneck Clam	NewFields 2011b						X		X			X	X	X				
PG11-MS-21-LN	Littleneck Clam	NewFields 2011b						X		X			X	X	X				
PG11-MS-22-LN	Littleneck Clam	NewFields 2011b						X		X			X	X	X				

[a] Metals analysis include the SMS Metals: arsenic, cadmium, chromium, copper, lead, mercury, silver, and zinc.

[b] Conventionals include total organic carbon (TOC), total volatile solids (TVS), total solids, ammonia, and total sulfides.

[c] NewFields sample ID applies to samples collected at the same location as the previous Hart Crowser study.

X -Results from NewFields (2011b) replace or supplement previous data at this location.

SIM = selective ion monitoring, SVOC = semivolatile organic compound

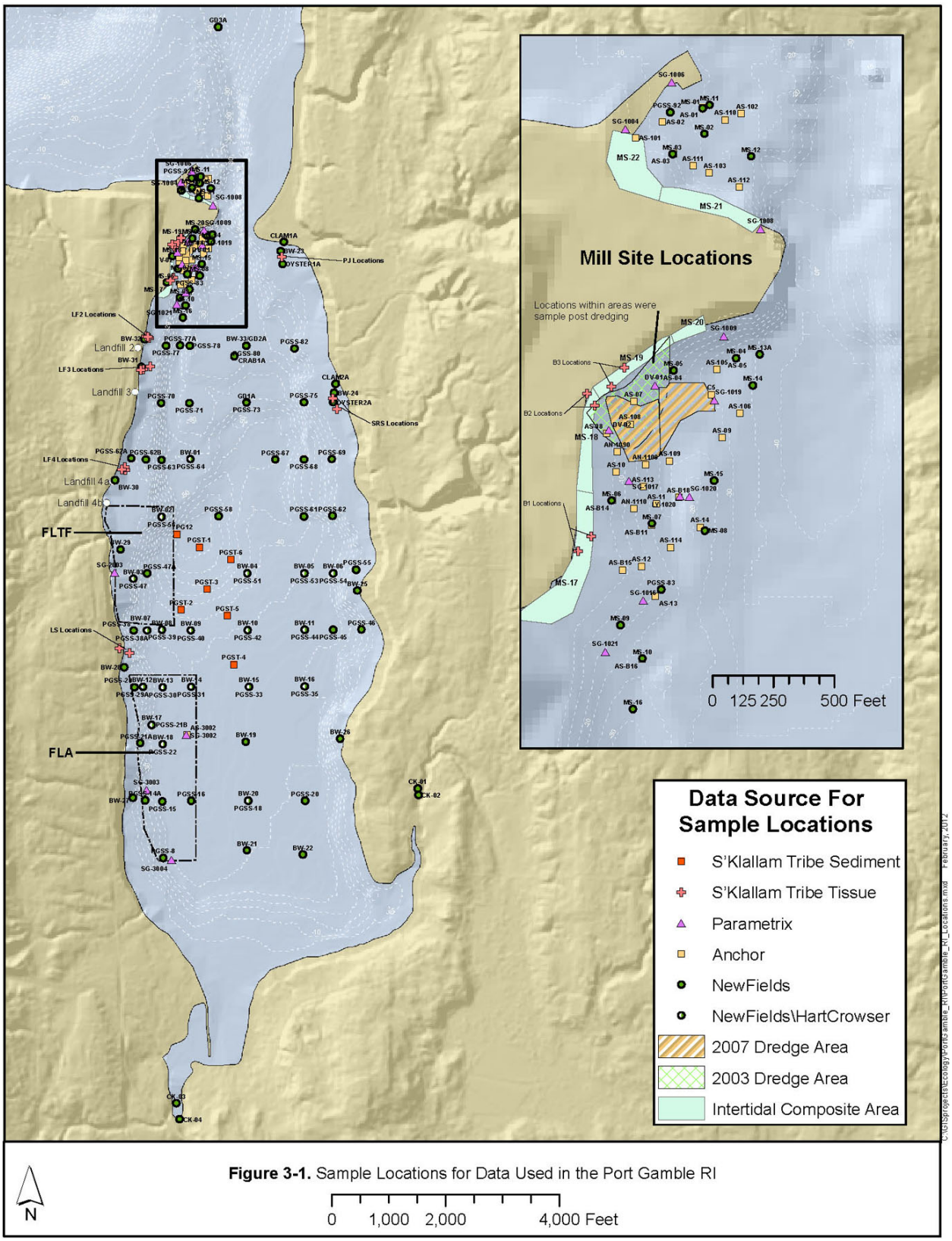

Figure 3-1. Sample Locations for Data Used in the Port Gamble RI

3.1 Sediment Profile Imaging/Plan View Images

During the Hart Crowser 2008 RI, sediment profile images (SPI) were collected from 120 subtidal locations in Port Gamble Bay and outside the mouth of the bay by SAIC of Bothell, Washington, under subcontract to Hart Crowser. Plan view (surface) photographs were collected at the majority of the locations. Samples were collected along multiple transects. Several locations were added to the original proposed locations along the shore of the bay to better delineate transitional areas and boundaries of potentially impacted sediments.

Three SPI images up to 20 cm (~8 in) depth were collected at each location. Plan view images of the surface (20 × 30 cm^2) were attempted at each location. Both SPI and plan view images were evaluated for the presence of wood waste and benthic organisms. The SPI report and SPI data are provided in Hart Crowser (2009) and interpreted in Section 4.

3.2 Sieved Samples

During the Hart Crowser 2008 RI, field staff performed sieving of subsamples to determine whether wood waste that was too small to be otherwise observed in bulk sediment was present. Six cores and 51 surface sediment samples were sieved using 0.5-mm and/or 1.0-mm sieves. Eight- to 16-oz jars of homogenized sediment were washed through the sieves and the amount of fine wood was visually estimated. Macrofauna and large polychaete tubes were removed from the sieve samples to facilitate more accurate estimate of wood waste volumes. The sieved samples were stored in ziplock bags and transported to Analytical Resources, Inc. (ARI) for archiving. The sieved samples were subsequently weighed, transferred to glass jars, and preserved with isopropyl alcohol. The preserved samples were then shipped to Ecology for additional microscopic examination.

3.3 Sediment Cores

During the Hart Crowser 2008 RI, 38 sediment cores were collected from subtidal locations within Port Gamble Bay to investigate the possible presence of wood waste and evaluate the types of subsurface sediments present. Twenty core locations were selected based on SPI image interpretation (six within the FLA/FLTF). Eighteen additional core locations were selected during sampling (four within the FLA/FLTF). Ten of the cores were collected in the FLA and FLTF since, based on historical log rafting practices, those were the areas of primary concern for wood waste. Each core was photographed and visually examined in general accordance with ASTM D 2488, Standard Practice for the Classification of Soils (Visual-Manual Procedure). Core logs and representative photographs are included in Hart Crowser (2009).

Two sediment core samples, 22B and 51B, were selected for radiometric dating. Radiometric dating was performed to determine sedimentation rates within the bay. Sedimentation rates were used to estimate the amount of deposition since mill operations began and to evaluate whether natural recovery is a viable cleanup alternative. Analysis was performed by Battelle Marine Sciences Laboratory in Sequim, Washington. Cores were subsectioned into 80 2-cm-thick sections and selected samples were analyzed for ^{210}Pb and ^{137}Cs.

One sediment core (42) was selected for chemical analysis. Four sub-samples (0–0.5 ft, 1.5–2 ft, 3.5–4 ft, and 6.5–7 ft) were individually homogenized, placed in designated containers, and submitted to ARI of Tukwila, Washington, for analysis of grain size and conventional parameters.

3.4 Subtidal Surface Sediments

3.4.1 Parametrix 2002/2003 Investigations

Three surface sediment grab samples in the northwestern part of the bay and eight surface sediment grab samples collected near the mill were included in this RI Report, as these locations were not resampled in any of the subsequent investigations. Data for SMS metals and SVOCs from these samples were included in the data set for this RI Report to provide better spatial coverage for these analytes. Details of all of the sampling and analyses conducted during these investigations can be found in Parametrix (2004).

3.4.2 Anchor 2006 Mill RI

Data from 11 surface sediment grabs collected near the mill in 2006 were included in this RI Report. All of these samples were analyzed for conventionals and grain size, and four of these samples were also submitted for porewater sulfides and ammonia. In addition, these 11 samples were subjected to a full suite of bioassay tests, including amphipod 10-day mortality with *Eohaustorius estuarius*, larval abnormality and mortality with *Dendraster excentricus*, and the juvenile polychaete growth test with *Neanthes arenaceodentata.* Complete results of this investigation can be found in Anchor (2006a).

3.4.3 Anchor 2008 Supplemental Mill RI

Data from 18 surface sediment grabs collected near the mill in 2008 were included in this RI Report. All of these samples were submitted for conventionals analysis, and 14 of the samples were also submitted for grain size and porewater sulfides and ammonia analysis. Fourteen stations were also subjected to a full suite of bioassay tests, including amphipod 10-day mortality with *Eohaustorius estuarius*, larval abnormality and mortality with *Dendraster excentricus*, and the Microtox test. Complete results of this investigation can be found in Anchor (2009).

3.4.4 Hart Crowser 2008 RI

Fifty surface sediment grab samples were collected from subtidal locations within Port Gamble Bay and two sediment grab samples were collected outside Port Gamble Bay. Of these, 33 were colocated with core locations (nine within the FLA/FLTF). Three samples were collected at the same location as organisms collected for tissue analysis and two samples were colocated with the radiometric dating cores. Eighteen of the sediment grab sample locations were within the FLA and FLTF. In addition, three Carr Inlet reference samples were collected.

Sediment from these samples were submitted to ARI for analysis of conventional parameters and SMS chemicals. Analysis for conventional chemicals and resin acids was conducted on 52 sediment samples. Chemical analysis of SVOCs, polychlorinated biphenyls (PCBs), and SMS metals was conducted on 40

samples. Grain size analysis was performed on 32 sediment samples. Analysis for conventional chemicals and grain size was performed on the three reference sediment samples for bioassay testing.

Microtox 100% porewater testing was initially performed on a wide distribution of 52 stations and three reference stations to assess its utility as a screening tool for wood waste sites. Microtox testing was conducted by Nautilus Environmental of Tacoma, Washington. In addition, a full suite of bioassay toxicity testing for SMS decision-making purposes was performed on 32 surface sediment samples from the bay and three reference samples collected from Carr Inlet. The acute tests conducted included the 10-day amphipod survival test using *Eohaustorius estuarius and* the larval development test using *Mytilus galloprovincialis*. The chronic test conducted was the 20-day polychaete survival and growth test using *Neanthes arenaceodentata.* These bioassay samples were submitted to Northwestern Aquatic Sciences of Newport, Oregon for analysis.

3.4.5 Port Gamble S'Klallam Tribe 2010 Investigation

Seven surface sediment grab samples were collected from subtidal locations offshore of the FLTF in west-central Port Gamble Bay. Sediments from these samples were submitted to ARI for analysis of SMS metals, SVOCs, selected ion monitoring (SIM) PAHs, resin acids, PCB Aroclors, conventionals, and grain size. Sediments from these samples were also submitted to Axys for analysis of dioxin/furan congeners.

3.4.6 NewFields 2011 RI

Twenty-three surface sediment samples were collected from subtidal locations within Port Gamble Bay and three surface sediment samples were collected from Carr Inlet as reference samples. Most of these stations were colocated with stations sampled in the Hart Crowser 2008 RI. Three new stations (BW-22, 33, and 34) were added to provide additional chemistry in central and southern areas of the bay that were not previously sampled, and two of the sample locations (BW-19 and 21) had not previously had bioassays conducted.

All surface sediment samples were submitted for sediment conventional analyses, porewater sulfides and ammonia, and analysis of PAHs by the SIM method to obtain lower detection limits than in 2008. In addition, full SMS chemistry (metals, SVOCs, and PCB Aroclors) was analyzed at the two new bioassay stations, metals were analyzed at 5 additional stations in the center of the bay, and dioxins/furans were analyzed at three stations in the south/southeast area of the bay. Reference sediments from Carr Inlet, collected to support the bioassay testing, were submitted for sediment conventionals and porewater ammonia and sulfides.

Twenty-one samples from the bay and six reference samples from Carr Inlet were submitted for the larval development test using *Mytilus galloprovincialis.* Larval bioassays were run using the standard protocol as well as a recently developed protocol that minimizes entrainment of larvae due to fine-grained flocculent sediments such as are found in Port Gamble Bay. Both endpoints can be determined in the same samples and were run as a side-by-side comparison (see NewFields 2011a for details of the protocols). To test the new method, samples were selected from among the 2008 RI stations that

passed SQS, stations that failed SQS, and stations that failed CSL, as well as two new bioassay stations for added spatial coverage.

In addition, the 20-day polychaete survival and growth test was rerun at seven stations within the bay as well as on three reference samples from Carr Inlet. This protocol has also been revised in line with national guidance to use the ash-free dry weight (AFDW) endpoint, which reduces variability in the biomass endpoint caused by sediment in the gut. This revised protocol can also be found in NewFields (2011a). Both sets of bioassays were conducted at NewFields, Port Gamble, Washington.

3.5 Intertidal Surface Sediments

3.5.1 Parametrix 2002/2003 Investigations

Five intertidal sampling stations near the mill were included in this RI Report, as these locations were not resampled in any of the subsequent investigations. Data for SMS metals and SVOCs from these samples were included in the data set for this RI Report to provide better spatial coverage for these analytes. Details of all of the sampling and analyses conducted during these investigations can be found in Parametrix (2004).

3.5.2 NewFields 2011 RI

During the NewFields 2011 RI, 14 intertidal sediment samples were collected from areas around the perimeter of the bay to evaluate potential sources of contamination to the bay and human health risks from exposure to intertidal sediments. Six samples were located along the western shoreline, and the northern three of these were colocated with tissue (clam) samples. Four samples were located along the eastern shoreline, and two samples each were located in creek drainages to the south and southeast of the bay.

Intertidal samples from 11 of the locations were collected during low tide using a stainless steel spoon or scoop. Composite samples were collected at intertidal stations BW-30, BW-31, and BW-32. All intertidal sediment samples and the intertidal creek samples were submitted for analysis of sediment conventionals, SMS metals and SVOCs, SIM PAHs, PCB congeners, and dioxin/furan congeners.

3.6 Biota

3.6.1 Hart Crowser 2008 RI

Biota sample locations were selected based on known areas where the Port Gamble S'Klallam Tribe collects shellfish for consumption and sale. Biota samples were collected by the Port Gamble S'Klallam Tribe Natural Resources Department using divers, traps, and hand collection. Proposed sample coordinates were provided to the tribe, and actual sample collection coordinates are listed in Hart Crowser (2009). The following organisms were collected:

- Geoducks (35 individuals) were collected at three subtidal sample locations near locations 73 and 80 (Geoduck 1 and 2, respectively), and location Geoduck 3. Three specimens were composited to obtain a single sample for each location. The skins on the necks of the geoducks were removed and archived. The gut ball was included in the meat composite.
- A crab trap was placed overnight to collect Dungeness crabs (8 collected) near location 80. All crabs were composited into a single sample, with muscle meat and hepatopancreas composited separately.
- Two oyster samples (45 total) and two littleneck clam samples (60 total) were hand collected from intertidal sample locations near locations 76 and 87. Oyster samples were composited from 15 oysters and clam samples were composited from approximately 30 individual clams.

In total, three geoduck samples, two oyster samples, two clam samples, and one crab sample (muscle tissue and hepatopancreas analyzed separately) were analyzed for percent lipids, metals, PCBs, and dioxins/furans to determine chemical concentrations in shellfish harvested for Tribal consumption and commercial sale.

3.6.2 Port Gamble S'Klallam Tribe 2010 Shellfish Sampling

In 2010, the Port Gamble S'Klallam Tribe conducted additional shellfish sampling at a variety of sites around Port Gamble Bay, including:

- Three samples of cockles, three samples of littleneck clams, three samples of manila clams, and two samples of oysters near the former landfills along the northwestern shoreline.
- One sample each of cockles, littleneck clams, manila clams, and oysters near the FLTF.
- One sample each of cockles and oysters near the south end of the Port Gamble S'Klallam Tribe reservation on the eastern shoreline.
- One sample of oysters at Point Julia as a reference sample.
- One sample each of cockles, manila clams, and oysters at a reference site outside the bay.

Oyster samples were composited from 15 oysters and clam samples were composited from approximately 30 individual clams. Samples were collected and composited by the Port Gamble S'Klallam Tribe and submitted to ARI for chemical analysis. In total, five cockle samples, four littleneck clam samples, four manila clam samples, and five oyster samples were collected from within the bay. All were submitted for analysis of percent lipids, metals, high molecular weight polynuclear aromatic hydrocarbons (HPAHs), and PCBs.

3.6.3 NewFields 2011 RI

Additional biota samples were collected to supplement the tissue data collected above, as follows:

- Native littleneck clam tissues (*Protothaca staminea*) were collected at three intertidal locations (BW-30, 31, and 32) along the northwestern portion of Port Gamble Bay, southwest of the former mill site. At each location, one to four individual clams were collected from ten discrete subsample stations (seven for BW-30). All clams from each subsample were then combined into one analytical composite sample per location. Clams were hand collected from each sampling location and were colocated with intertidal surface sediment samples.
- Two composite samples of Dungeness crab (*Cancer magister*) each consisting of six individuals were collected at BW-04 using a crab pot. Crab sampling was also attempted at BW-20, but no crabs were collected at that location.

Clam samples were depurated for 12 to 24 hours and then shucked to generate three analytical composites of 21, 28, and 38 individuals for stations BW-30, BW-31, and BW-32, respectively. Crab muscle tissue and hepatopancreas were composited as two separate analytical samples. After compositing, crab and clam samples were submitted to ARI and Axys for chemical analyses. Three intertidal clam samples collected from the northwestern shoreline of the bay and one crab sample were submitted for tissue analysis. Clam samples were analyzed for percent lipids, SMS SVOCs and metals, SIM PAHs, PCB congeners, and dioxin/furan congeners. The crab sample was analyzed for SMS metals, SIM PAHs, PCB congeners, and dioxin/furan congeners.

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4.0 SEDIMENT PHYSICAL CHARACTERISTICS AND OBSERVATIONS

Surface sediment samples and sediment cores were photographed, and visual observations and soil descriptions were documented in core logs presented in Hart Crowser (2009). Visual sample descriptions of surface sediment grabs and laboratory grain size reports are presented in Hart Crowser (2009) and NewFields (2011b).

4.1 Grain Size

The baywide distribution of sediment grain size ranged from very soft, clayey silt in low energy areas to very dense, coarse sand in high-energy areas of the bay near the Port Gamble Bay entrance. Baywide evaluation of sediment grain size is based on all available data including SPI images, surface sediment grab samples, and vibracores, and is shown in terms of percent fines in Figure 4-1. The complete grain size distribution is reported for each station in Appendix A.

In the southern and central portions of the bay, sediments generally consist of very soft, clayey silt (85–95% fines), indicating a low energy depositional environment. Sediments near the shoreline along the edges of the bay consist of silty sand to sandy silt in the shallow subtidal zones and transition to slightly silty sand to fine sand in the intertidal zones, indicating higher energy due to current and wave activity. Sediments near and within the northern bay entrance contained a higher proportion of coarse sand or gravel, reflecting the presence of strong tidal currents.

The laboratory also noted that 13 samples contained shells or shell hash, and/or organic matter or wood waste (PGSS-16, PGSS-21B, PGSS-29A, PGSS-38A, PGSS-39, PGSS-47, PGSS-51, PGSS-53, PGSS-56, PGSS-62, PGSS-73, PGSS-75, and PGSS-92). The shells or shell hash and/or organic material or wood waste were not removed prior to the grain size analysis.

4.2 Apparent Redox Potential Discontinuity

The apparent redox potential discontinuity (RPD) depth indicates the depth of oxygenation in the upper sediment column and generally reflects the degree of biogenic sediment mixing. As interpreted by SPI images, the distribution of mean apparent RPD depths in Port Gamble Bay ranged from 0.0 cm at station PG88 near the former mill site to a high of 5.53 cm at station PG19 in the fine-grained southern portion of the bay (Hart Crowser 2010, Figure 16). The mean apparent RPD depth for Port Gamble Bay was 2.77 cm. Relatively shallow apparent RPD depths (less than 2.0 cm) were generally measured in areas close to shore. At station 88 near the former mill site, SPI images show accumulation of wood chips on the sediment surface (Hart Crowser 2009). The deepest RPD depths (about 3–5 cm) were measured in fine-grained sediments present in the southern portion of the bay. At nine locations in the southern bay, the apparent RPD depth could not be measured due to over-penetration by the camera prism. However, apparent RPD depths at these locations are likely similar to surrounding RPD measurements.

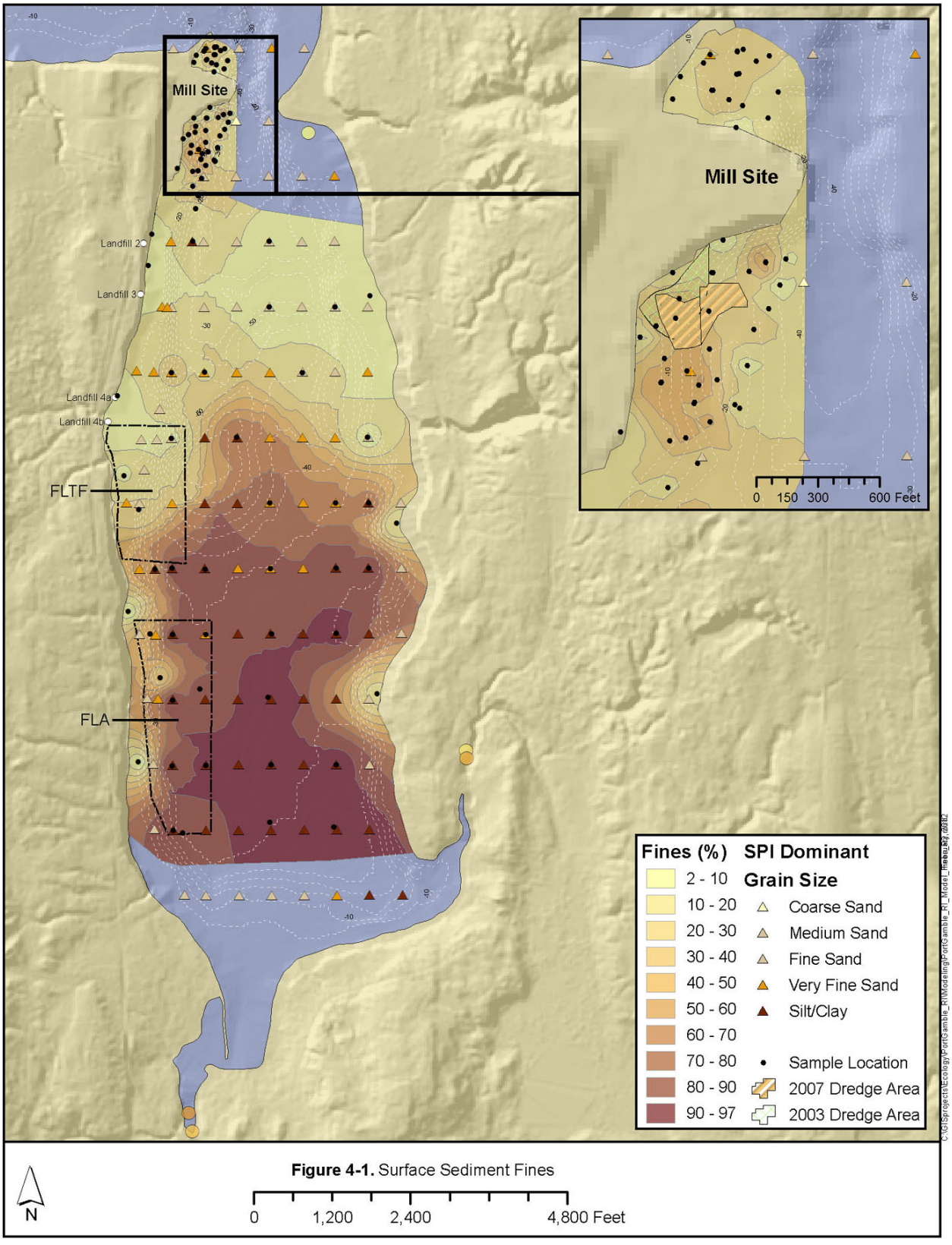

Figure 4-1. Surface Sediment Fines

4.3 Radiometric Dating Results

Sediment core dating makes use of radioisotopes ^{210}Pb and ^{137}Cs. ^{210}Pb is formed by the decay of gaseous ^{222}Rn, has a half-life of 22.3 years, and binds strongly to sediment. Dates are determined by the decrease in ^{210}Pb activity in subsurface sediments. ^{137}Cs owes its presence in the atmosphere to anthropogenic thermonuclear activities. ^{137}Cs deposition began around 1952 and peaked around 1963–1964. The sediment depth interval exhibiting ^{137}Cs activity should correspond to a ^{210}Pb-derived date between approximately 1952 and 1965.

Two sediment cores (locations 22 and 51) were submitted to Battelle for radiometric dating. Figure 4-2 presents calculated year versus depth of sediment. Based on ^{210}Pb dating results at both core locations, a sediment depth of approximately 50–55 cm (1.6–1.8 feet) would correspond to the year 1853, when sawmill operations began.

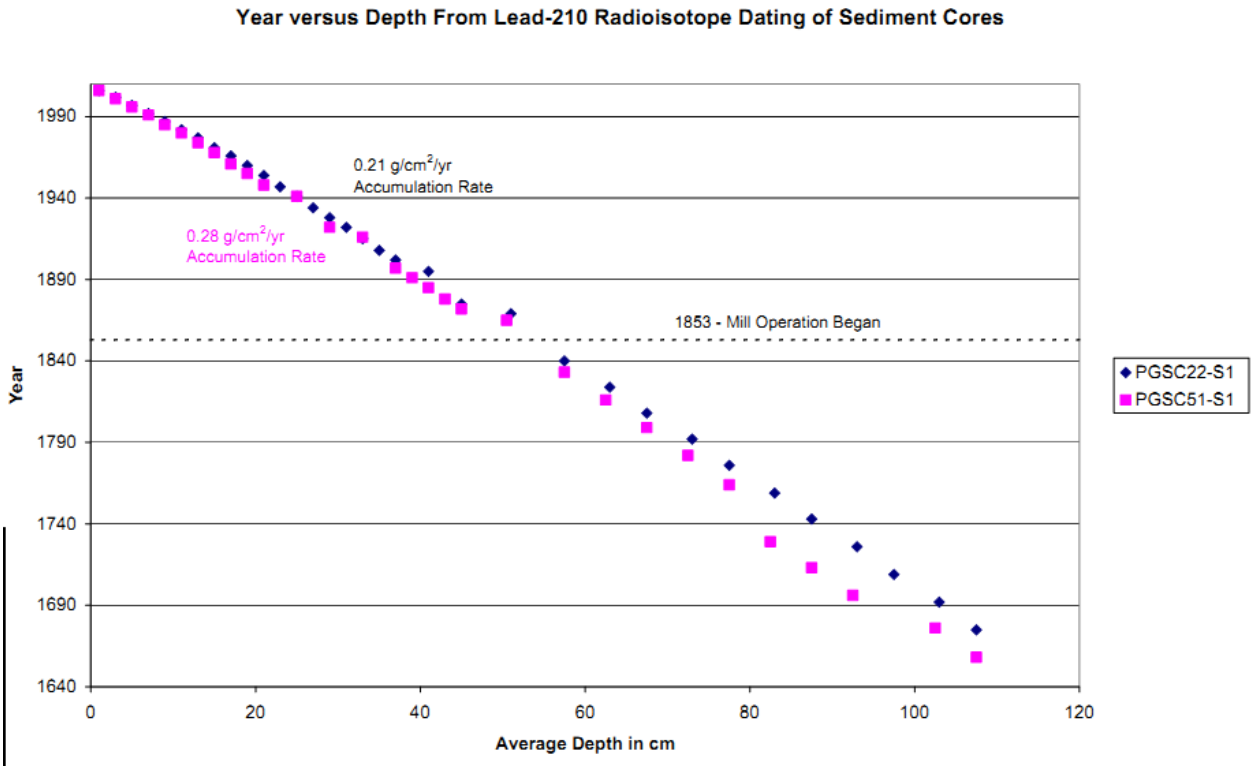

Figure 4-2. ^{210}Pb Radioisotope Dating Results (Source: Hart Crowser 2009)

^{210}Pb dating at location 22, toward the shore in the FLA, indicates an overall sediment accumulation rate of 0.21 g/cm^2-yr. Sediment accumulation rates cannot be calculated for shallower, more recent sediments due to surface mixing or for deeper, older sediment due to constant radioactivity levels from migration of radon from the earth. This accumulation rate corresponds to a sedimentation rate of 0.22–0.26 cm/year in sediment deeper than 60 cm and 0.43–0.48 cm/year in shallow (0–10 cm) sediment. This decrease in apparent sedimentation with depth may be due to consolidation and increased density of deeper sediments. The mixed layer at core location 22, as deduced from the ^{210}Pb data, appears to be

from 0–14 cm depth. ^{210}Pb derived dates corresponding to the ^{137}Cs maximum peak ranged from 1947 to 1960. Assuming that sediment mixing or diffusion of cesium occurred, the dates estimated from ^{137}Cs analysis demonstrate reasonable agreement with the ^{210}Pb results.

For location 51, located in the center of Port Gamble Bay, the results of ^{210}Pb dating indicate a sedimentation rate of 0.28 g/cm^2-yr. This accumulation rate corresponds to a sedimentation rate of 0.31–0.33 cm/year in sediment deeper than 30 cm and 0.40–0.44 cm/year in shallow (0–10 cm) sediment. There was no apparent mixed layer in this core. ^{210}Pb-derived dates corresponding to the ^{137}Cs maximum peak ranged from 1955 to the present. The radiometric dating report and supporting data are presented in Hart Crowser (2009).

4.4 Distribution and Estimated Percentage of Wood Waste

SPI images, surface sediment grab samples, sediment core samples, and Ecology wet sieve samples from each location within the Port Gamble grid were observed for the presence of wood waste. Identification of wood waste was based on visual interpretation of SPI photographs and field interpretations and is subjective. For purposes of this report, wood waste included bark, wood chips, and wood particles, as well as terrestrial wood debris (i.e., twigs and pinecones). The baywide distribution of wood waste is presented in Figure 4-3 and the estimated percentage of wood waste for sediment samples are summarized in Table 4-1. Figure 4-3 presents combined near-surface and subsurface distribution based on SPI, plan view analysis, vibracores, and surface sediment samples.

Surface sediment grab samples and sediment core samples were evaluated in the field for the presence of wood waste. While wood waste was widely distributed, less than 5% by volume was estimated at most locations (Table 3). Greater amounts of bark material (visual estimates of up to about 50%) were generally observed at the base of the slope around the FLTF and FLA areas where historic log rafting and transfer occurred.

Wet sieving was also performed on samples from the upper 10 cm of sediment from 51 surface sediment samples and 6 sediment core samples using 0.5 mm and/or 1.0 mm sieves to determine whether wood waste that was too small to be observed in bulk sediment, was present. Sub-samples from the upper 10 cm of sediment contained approximately 5% by volume fine wood and wood fragments that were not otherwise visually obvious in the bulk sediment.

Wood waste was identified in:

- Either the plan view or SPI images in 28 of the 120 subtidal locations (approximately 23%).
- Eight of the 52 subtidal surface sediment sample locations (approximately 15%).
- Thirty of the 38 subtidal sediment core samples (approximately 79%).
- All of the 51 wet sieve surface sediment samples and the six wet sieve sediment core samples (100% of samples contained fine wood material).

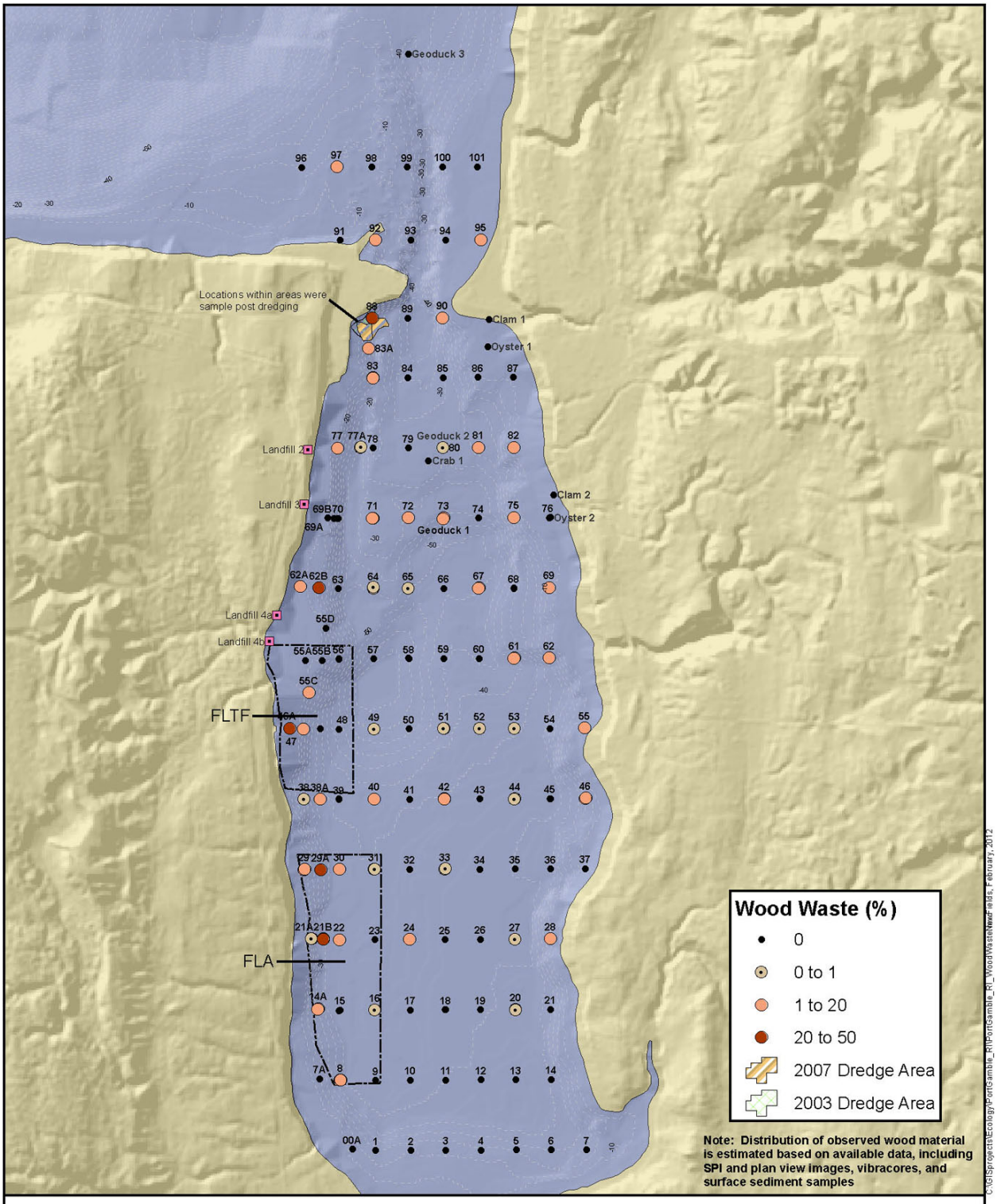

Figure 4-3. Observed Near-Surface and Subsurface Wood Waste

Wood waste was observed with the highest accumulations (15–50% cover) near the former sawmill operations at the mouth of the bay and nearshore within the FLA/FLTF. In many cases, these relatively high accumulations consisted of a single piece of wood. In contrast, wood waste was observed in trace accumulations (1–7%) in the northern and central portions of the bay.

Table 4-1. Wood Waste Observations in Surface Grabs and Subsurface Sediment Cores

Location ID	Estimated Percentage	Depth Beneath Sediment Surface (ft)			Notes
SPI Plan View					
47	1%	0			Leaf litter, stick upper right
SPI Image					
14A	2%	0.66			Wood waste (particles)
20	1%	0.66			Wood waste (particles)
21B	5%	0.66			Wood waste (particles)
24	2%	0.66			Wood waste (particles)
27	1%	0.66			Wood waste (particles)
28	7%	0.66			Wood waste (particles)
29A	50%	0.66			Large piece of wood waste on surface
30	3%	0.66			Wood waste (particles)
38	1%	0.66			Wood waste (particles)
46A	25%	0.66			Wood waste on surface
52	1%	0.66			Wood waste (particles)
55	1%	0.66			Wood waste (particles)
55C	2%	0.66			Wood waste (particles)
62	5%	0.66			Wood waste (particles), twig
62A	2%	0.66			Wood waste (particles)
62B	30%	0.66			Large piece of wood waste on surface
67	1%	0.66			Wood waste (particles)
71	2%	0.66			Wood waste (particles)
72	2%	0.66			Wood waste (particles)
73	15%	0.66			Large piece of wood waste on surface
81	3%	0.66			Wood waste (particles)
83A	20%	0.66			Large piece of wood waste on surface
88	30%	0.66			Large piece of wood waste on surface, leaves
90	5%	0.66			Wood chips 1 cm
92	15%	0.66			Wood waste (particles)
95	5%	0.66			Wood waste (particles)
97	2%	0.66			Wood waste (particles)
Sediment Core Samples					
8	5%	0 to 0.5	0.5 to 2.0		Wood waste (bark, wood chips)
16	1%	1	4.5		Bark piece, twig
22	5%	0 to 1			Wood waste (bark)
29	20%	0.5 to 1.6			Wood waste (bark, wood chips)
31	1%	3			Bark piece
33	1%	3.5			Twig
38A	20%	0 to 2.2			Wood waste (bark, wood chips)
40	5%	0 to 0.5	1.0 to 1.5		Wood waste (wood chips)
42	5%	0 to 0.5	1.5 to 2.0	6.5 to 7	Wood waste (bark, wood chips), twig and pine cone

Table 4-1. Wood Waste Observations in Surface Grabs and Subsurface Sediment Cores

Location ID	Estimated Percentage	Depth Beneath Sediment Surface (ft)			Notes
44	1%	0 to 0.5			Wood waste (bark, wood chips), twigs
46	2%	0 to 0.5	2		Wood waste (bark, wood chips)
47	20%	0 to 1			Wood waste (bark)
49	1%	2.3 to 2.5	7		Wood waste (bark)
51	1%	3.7	5.5	6.5	Wood waste (bark)
53	1%	1.5 to 2			Wood waste (wood chips)
55	20%	1.2 to 2.0	2.2		Wood waste (bark, wood chips)
61	5%	0 to 1.1	2.6		Wood waste (wood chips), twig
62	1%	0 to 0.3			Wood waste
62B	5%	0.5	1		Wood waste (bark, wood chips)
64	1%	1.5	2.2		Wood waste
65	1%	1.5 to 2			Wood waste (wood chips)
67	5%	0.30	1.3 to 2.1	3.7 to 6.4	Wood waste (bark, wood chips), twigs
69	5%	1.3 to 1.8			Wood waste (bark, wood chips), twigs
71	5%	0 to 0.5	0.5 to 1		Wood waste (bark, wood chips)
73	20%	0 to 0.5	1	2	Wood waste (bark, wood chips)
75	20%	0.4	1.5		Wood waste (bark, wood chips)
77	15%	0 to 0.5	0.5 to 1		Wood waste (bark, wood chips)
78	1%	0			Wood waste (bark, wood chips)
80	1%	0	0 to 0.5		Wood waste (bark)
82	2%	0 to 0.5	1.3 to 1.6		Wood waste (bark, wood chips)
Surface Sediment Samples					
21A	1%	0.66			Twig
21B	25-50%	0.66			Wood waste (bark)
29A	5%	0.66			Wood waste (bark, wood chips), twig
38A	5%	0.66			Wood waste (bark)
61	1%	0.66			Twig
73	5%	0.66			Wood waste (bark, wood chips)
83	5%	0.66			Wood waste (bark)
92	5%	0.66			Wood waste (bark, wood chips)

Source: Hart Crowser 2009

A summary of the SPI observations and interpretation relative to the presence of near-surface wood waste is presented in SAIC's SPI Survey Report in Hart Crowser (2009) and in Figure 4-3. Identification of sawdust and wood chips in SPI images was based on visual interpretation of photographs and is subjective. Wood waste was identified in either the plan view or SPI images in 28 of the 120 subtidal locations (approximately 23%).

4.5 Distribution of Benthic Organisms

Marine biological organisms, including macroalgae and invertebrates, were identified at most of the locations. Marine animals, macroalgae, or burrows were identified at 89% of the locations, based on reviews of the SPI and plan view images and sediment core and grab sample observations.

4.5.1 Marine Organisms

The majority of organisms were observed and identified in the sediment surface grab samples. Small fish were present in four grab samples. Sipunculids (peanut worms) were present at the bottom of three grab samples at approximately 1 ft below mudline. Other worms, including polychaetes, nemerteans, and worm tubes were identified in 37 grab samples. Cnidarians, including sea whips, sea pens, and a sea anemone, were identified in four grab samples. Arthropods, including shrimp, crabs, and barnacles were identified in 12 grab samples. Mollusks, including clams, a nudibranch, a limpet, and a piece of geoduck siphon, were present in eight grab samples. Shells, shell fragments, and shell hash were recorded in 32 grab samples. Echinoderms, including a sea cucumber and brittle stars, were observed in two grab samples, while sand dollars were identified in photographic images. Additionally, a tunicate (sea squirt) was caught on the Young grab sampler frame (Hart Crowser 2009).

The distribution of benthic organisms generally followed the bottom substrate type and grain size distribution in Port Gamble Bay. Geoducks and other organisms favoring sandy bottom conditions were generally present in shoreline areas and the northern half of the bay. Infaunal deposit-feeding organisms associated with fine-grained, unconsolidated soft bottom classifications were generally observed in the southern end of the bay.

Infaunal transitional organisms, including shallow-dwelling bivalves or tube-dwelling amphipods, were also observed in the middle portion of the bay, where the transition from fine-grain unconsolidated sediments to more consolidated sandy sediments occurs. Infaunal high energy organisms, including tubicolous and surface-dwelling polychaetes, were observed in the northern portion of the bay, where hard sandy consolidated sediments with higher bottom current energy are present.

Several locations in Port Gamble Bay also exhibited the presence of eelgrass (*Zostera* sp.) and other macrofauna such as sea pens (*Ptilosarcus gurneyi*) and sea whips (order Pennatulacea). Intact eelgrass beds were observed in locations north of the bay entrance (94, 97, 98, and 100), and just south of the entrance along the eastern shore (locations 82, 86, and 87). Eelgrass detritus (i.e., decomposing eelgrass blades, loose strands) was observed at locations 54 and 88. Sea pens and sea whips were observed at several locations in the northern portions of Port Gamble Bay. These organisms are known to position themselves in the path of currents in order to ensure a steady supply of food (e.g., plankton).

4.5.2 Benthic Habitat Type

The benthic habitat classifications in Port Gamble Bay generally followed the grain size major mode distribution measured from SPI images (Hart Crowser 2009). The greatest number of locations consisted of a hard, fine sandy bottom. Medium sandy hard bottom and medium sandy hard bottom with gravel were observed at 4% and 2% of the locations, respectively. The two stations with sandy hard bottom and gravel were located within the entrance channel to Port Gamble Bay. Hard sandy bottom classifications were generally found in shoreline areas and the northern half of Port Gamble Bay. One location within the entrance channel to the bay (location 89) consisted of a hard rock or gravel bottom. Location 88, near the former mill site, did not have a benthic habitat classification due to the high accumulations of wood debris on the sediment surface.

The second most predominant habitat classification (33%) was an unconsolidated soft bottom with very soft silts/clays. Silty unconsolidated soft bottom and sandy/silty unconsolidated soft bottom were also observed at 11% and 7% of the locations, respectively. The unconsolidated soft bottom classification was predominant in the southern reaches of Port Gamble Bay (Hart Crowser 2009).

4.5.3 Infaunal Successional Stage

The majority of infaunal successional stages observed in SPI images collected in Port Gamble Bay were Stage I (65%). Stage I infauna are typically the first organisms to colonize the sediment surface. These opportunistic organisms may include small, tubicolous, surface-dwelling polychaetes.

Stage III or Stage I on III comprised 31% of SPI locations, mainly associated with the more sandy substrate in the northern half of the bay. Stage III is a high-order successional stage consisting of long-lived, infaunal deposit-feeding organisms. Stage III invertebrates may feed at depth in a head-down orientation and create distinctive feeding voids visible in SPI images. Stage I taxa can persist in these areas, as they are opportunistic feeders, and are commonly associated with a Stage III community (Rhoads and Germano 1986).

Infaunal successional stage was indeterminate at five locations (4%) due to camera prism overpenetration or the presence of abundant wood debris.

In sandy substrates, such as the areas along the shoreline and the northern portion of Port Gamble Bay, the climax communities consisted primarily of surface dwellers (e.g., amphipods) that reside in the upper 1 cm of the sediment, as well as filter feeders including clams and geoducks not observed in the SPI images. These community types are classified as Stage I communities and are reflective of an area influenced by physical factors and the presence of a sandy substrate.

A higher order successional stage would typically be assigned to a climax community in a depositional environment consisting of a silt/clay substrate, such as areas in southern Port Gamble Bay. Localized feeding of large, deep-burrowing infauna (Stage III taxa) in these depositional environments result in distinctive excavations called feeding voids. Location 18 provides a representative example of feeding voids visible in southern Port Gamble Bay (Hart Crowser 2009).

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5.0 SEDIMENT CHEMISTRY RESULTS

This section presents analytical results for all of the sediment samples listed in Table 3-1. The various data sets from 2002–2011 have been combined for a more comprehensive interpretation. Both intertidal and subtidal chemistry are discussed and presented together in the following sections and on the figures. Complete data tables for all sediment samples are presented in Appendix A.

Results of the sediment chemical analysis were compared to applicable SMS marine criteria, including SQS and CSL thresholds, as described in WAC 173-204-320 and WAC 173-204-520. The marine SQS and dry weight (dw) equivalent lowest apparent effects threshold (LAET) numerical chemical concentration criteria define the degree of sediment quality that is expected to cause no adverse effects to biological resources in marine sediments. At concentrations at or below the CSL or dry weight equivalent second lowest apparent effects threshold (2LAET), effects to biota are expected to be minor. CSL and 2LAET represent the upper bound of minor adverse effects and above these concentrations, effects are anticipated to be significant.

5.1 Data Quality Review Summary

Overall, the data quality objectives, as set forth in Hart Crowser (2008a) and NewFields (2011a), were achieved, and these recent data are acceptable for use, as qualified. For some analytes, the two RIs had different data quality objectives; specifically, the supplemental RI had lower method detection limits/ method reporting limits (MDLs/MRLs) for several analytes to facilitate natural background comparisons and human health evaluations.

During the Hart Crowser 2008 RI, 22 non-detected sample results for neoabietic acid were rejected during the quality assurance/quality control (QA/QC). Results for other chemicals associated with wood waste were acceptable, so there is no significant impact to the data. Results for several analytes were qualified as estimated concentrations based on minor exceedances of quality control criteria. For some samples, reporting limits (RLs) for chlorinated benzenes, hexachlorobutadiene, butylbenzylphthalate, phenol, and 2,4-dimethylphenol were above SQS and/or dry weight equivalent criteria. When analytes were present, the laboratory reported estimated results to the MDLs, which were below the SQS and dry weight criteria for all analytes. Detailed chemical data quality review and chemical laboratory certificates of analysis are presented in Hart Crowser (2009).

All sediment and tissue samples in the NewFields (2011b) supplemental RI were submitted to EcoChem Inc., Seattle, Washington, for a level quality assurance level 2 (QA-2) validation (Environmental Protection Agency [EPA] Stage 3/4). The data were reviewed using guidance and quality control criteria documented in the *Combined Sampling and Analysis Plan (SAP) and Quality Assurance Project Plan (QAPP)* (NewFields 2011a) and the USEPA National Functional Guidelines. For some samples, detection limits for hexachlorobenzene, 1,2,4-trichlorobenzene, and hexachlorobutadiene were above the SQS criteria. Porewater ammonia and sulfides were analyzed as part of the NewFields supplemental RI following the procedures described in the SAP (NewFields 2011a). Porewater results did not undergo independent data validation. Detailed chemical data quality review and chemical laboratory certificates of analysis are presented in NewFields (2011b).

Sediment and tissue data collected by the Port Gamble S'Klallam Tribe were independently validated by Ecochem, Inc. Holding times were exceeded for mercury and the conventional parameters. QA results for earlier surveys can be found in the respective RI Reports listed in Table 3-1.

5.2 Conventional Parameters

Total organic carbon (TOC) concentrations in subtidal surface sediment samples ranged from 0.327–5.04% in the bay, with concentrations ranging up to 12.8% near the mill in areas of high wood waste (Table 5-1, Figure 5-1). TOC concentrations in the 10 intertidal sediment samples around Port Gamble Bay were generally low at <1%, while in the four creek samples to the south and southwest, TOC ranged from 2.41–8.19%. Aside from wood-impacted areas near the mill, TOC was generally lower in the northern half of the bay where currents are higher and was highest in the south-central part of the bay and in the FLA.

Total volatile solids (TVS) concentrations ranged from 0.46–20.06% in the bay, and similar to TOC, ranged up to higher levels near the mill, with a maximum of 44%. In the intertidal samples around Port Gamble Bay, TVS ranged from 0.56–1.95%, while in creek samples it was much higher, ranging from 4.49–18.04%. TVS followed a similar pattern overall to TOC, with high concentrations in the south-central portion of the bay.

Another indicator of the presence of organic loading such as wood waste and the overall availability of organic matter contained in sediment is the TVS/TOC ratio. Typical, unimpacted marine sediment has a TVS/TOC ratio <2 (personal communication, Jack Word, NewFields). Conversely, ratios >2 are often indicative of labile organic matter such as wood waste that is available for chemical or microbial breakdown. This often results in anaerobic conditions and elevated concentrations of sulfides. TVS/TOC ratios for Port Gamble Bay sediment samples are presented in Figure 5-2. Samples containing the highest TVS/TOC ratio are located toward the center of the bay where sediments are flocculent and fine-grained, as well as south of the former mill. This south-central part of the bay appears to be a location where fine-grained organic matter has come to be located through tidal and current action, and coincides with areas of bioassay exceedances (see Section 7).

Total sulfide concentrations in the bay ranged from 0.05U to 1,060 mg/kg, with the highest concentrations generally in the south-central part of the bay (Figure 5-3). Higher concentrations up to 3,220 mg/kg are found in areas near the former mill. Intertidal samples also ranged widely, from 1.13U to 418 mg/kg. The highest intertidal concentrations were at the FLTF and in the creek samples. Elevated sulfide concentrations are due to microbial decomposition of excess organic matter, are indicative of organic-rich anaerobic sediment, and may be associated with low oxygen. Samples containing the highest sulfide concentrations are located toward the central portion of the bay and within the FLTF and FLA, generally colocated with visual wood waste presence and locations with higher TVS/TOC ratios.

Table 5-1. Summary of Sediment Conventionals Results

	Port Gamble Bay Samples						Mill Area Samples					
	Samples	**Detects**	**Minimum**	**Maximum**	**Mean**	**90th %ile**	**Samples**	**Detects**	**Minimum**	**Maximum**	**Mean**	**90th %ile**
Subtidal Samples												
Conventionals in %												
Preserved Total Solids	52	52	23.1	80.3	52.7	77.4	18	18	28.1	73	52	71.9
Total Organic Carbon	61	61	0.327	5.04	2.52	3.94	45	45	0.27	12.8	3.79	7.73
Total Solids	61	61	27.2	84.2	51.1	75.6	45	45	33.8	84	53.5	74.1
Total Volatile Solids	61	61	0.46	20.06	6.45	10.6	44	44	0.74	44.1	12.2	26.1
Conventionals in mg/kg												
Sulfide	52	52	1.44	1060	307	838	18	18	2.96	3220	571	1290
N-Ammonia	59	59	2.75	53.6	18.2	39.9	18	18	2.87	105.1	26	60.4
Intertidal Samples												
Conventionals in %												
Preserved Total Solids	14	14	45.3	83.9	69.2	79.9	6	6	74.00	83.2	79.1	82.9
Total Organic Carbon	14	14	0.254	8.19	1.85	5.21	6	6	0.24	4.78	1.26	2.82
Total Solids	14	14	39	86.6	71.7	83.9	6	6	76.70	86.73	82.3	86
Total Volatile Solids	14	14	0.56	18.04	3.09	5.87	6	6	0.61	3.17	1.36	2.28
Conventionals in mg/kg												
Sulfide	14	11	1.13	418	99.7	280	6	6	1.25	288	79	191
N-Ammonia	14	14	3.3	22.8	9.15	15.4	6	6	1.03	22.2	5.88	13.5

Non-detects included in descriptive statistics.

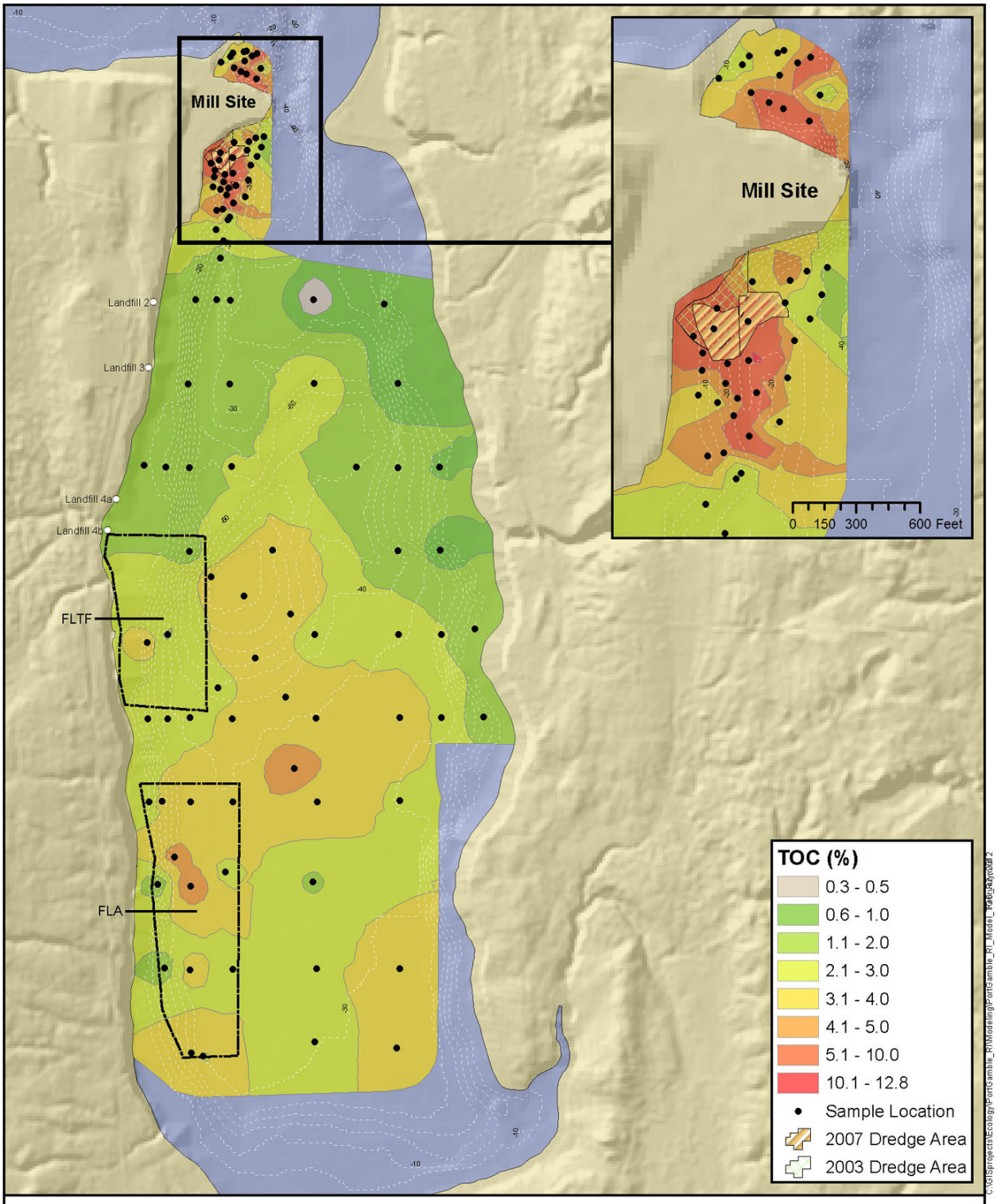


Figure 5-1. Surface Sediment Total Organic Carbon

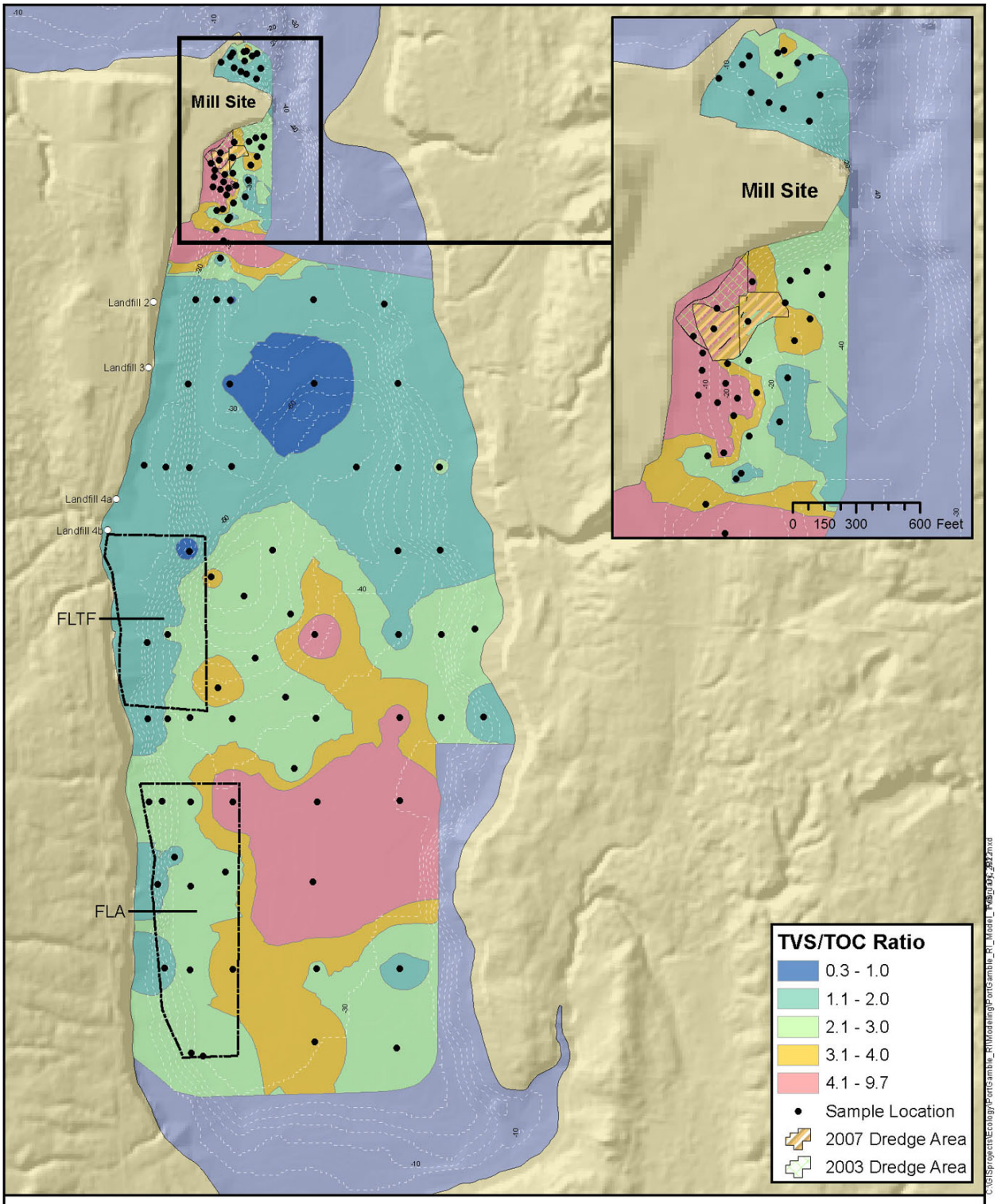


Figure 5-2. Surface Sediment TVS/TOC Ratio

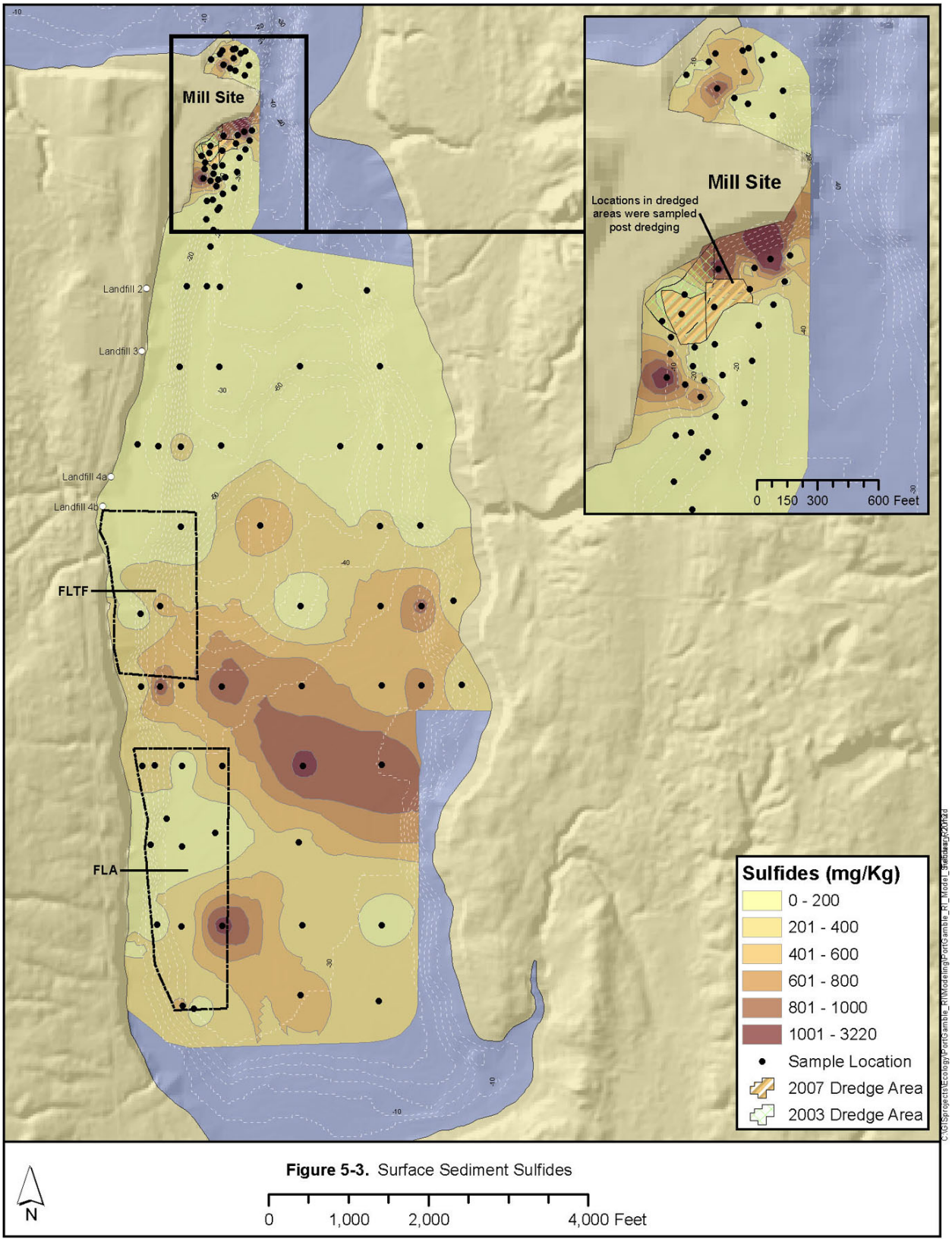


Figure 5-3. Surface Sediment Sulfides

Porewater sulfides are shown in Figure 5-4, and are generally considered the more bioavailable fraction of sulfides. In general, high concentrations of porewater sulfides up to 93.9 mg/L are located in the northern embayment near the former mill site and along the shoreline south of the former mill site. Porewater sulfides in surface sediments in these areas may be related to tidal pumping through wood waste deposits that continually generates sulfides through microbial breakdown processes (Anchor 2010). The elevated sulfide concentrations in the south end of the bay may be due to microbial breakdown of naturally occurring organic matter because they are not colocated with other wood waste indicators.

Ammonia concentrations in the bay ranged from 2.75–53.6 mg/kg, with the highest concentrations in the south-central portion of the bay and near the eastern boundary of the FLA. Stations near the former mill ranged up to 105 mg/kg. Intertidal ammonia concentrations were generally quite low, ranging from 3.3–22.8 mg/kg. Elevated ammonia concentrations are also indicative of organic-rich, anaerobic sediment and may be associated with low oxygen due to degradation of wood waste, even though wood itself contains very little nitrogen. While these levels of ammonia are not believed to be high enough to cause toxicity alone, samples containing the highest ammonia concentrations are generally colocated with sulfides, visual wood waste presence, and higher TVS/TOC (Figure 5-5).

5.3 Fatty and Resin Acids

Both fatty acids (oleic and linoleic) and resin acids (abietic acids, pimaric acids, and palustric acid) were analyzed (Table 5-2). These two classes of compounds help identify the presence of wood waste, and resin acids have been associated with toxicity in runoff from log sort yards and in wood waste deposits. The distribution of resin acids in subtidal sediment samples is shown in Figure 5-6. These compounds were not analyzed in intertidal sediments.

Oleic acid was detected in every sample at concentrations ranging from 370–8,400 µg/kg. Linoleic acid was detected in 28 of 51 samples analyzed at concentrations ranging from 110–830 µg/kg. Resin acids were detected in 18 of 51 samples analyzed. Total detected resin acid concentrations ranged from 110–4,880 µg/kg. Higher concentrations of fatty acids and resin acids appeared to be somewhat correlated, although fatty acids were more widely distributed throughout the bay. The highest concentrations of oleic and linoleic acid were found in samples collected from the FLTF, immediately north of the FTLF, and east of the FTLF throughout the width of the bay to the opposite shore. The highest concentrations of resin acids were found in the same locations.

Oleic and linoleic acids also naturally occur in blue-green algae (Ikawa 2004), although typical concentration ranges were not reported. Douglas Fir also contains oleic and linoleic acid (Foster et al. 1980). Reported fatty acid concentrations in Douglas Fir are approximately 100 mg/kg based on analysis of the ether-extractable fraction of wood, with oleic acid comprising 20–30% of the total and linoleic acid comprising 6–10% of the total fatty acids.

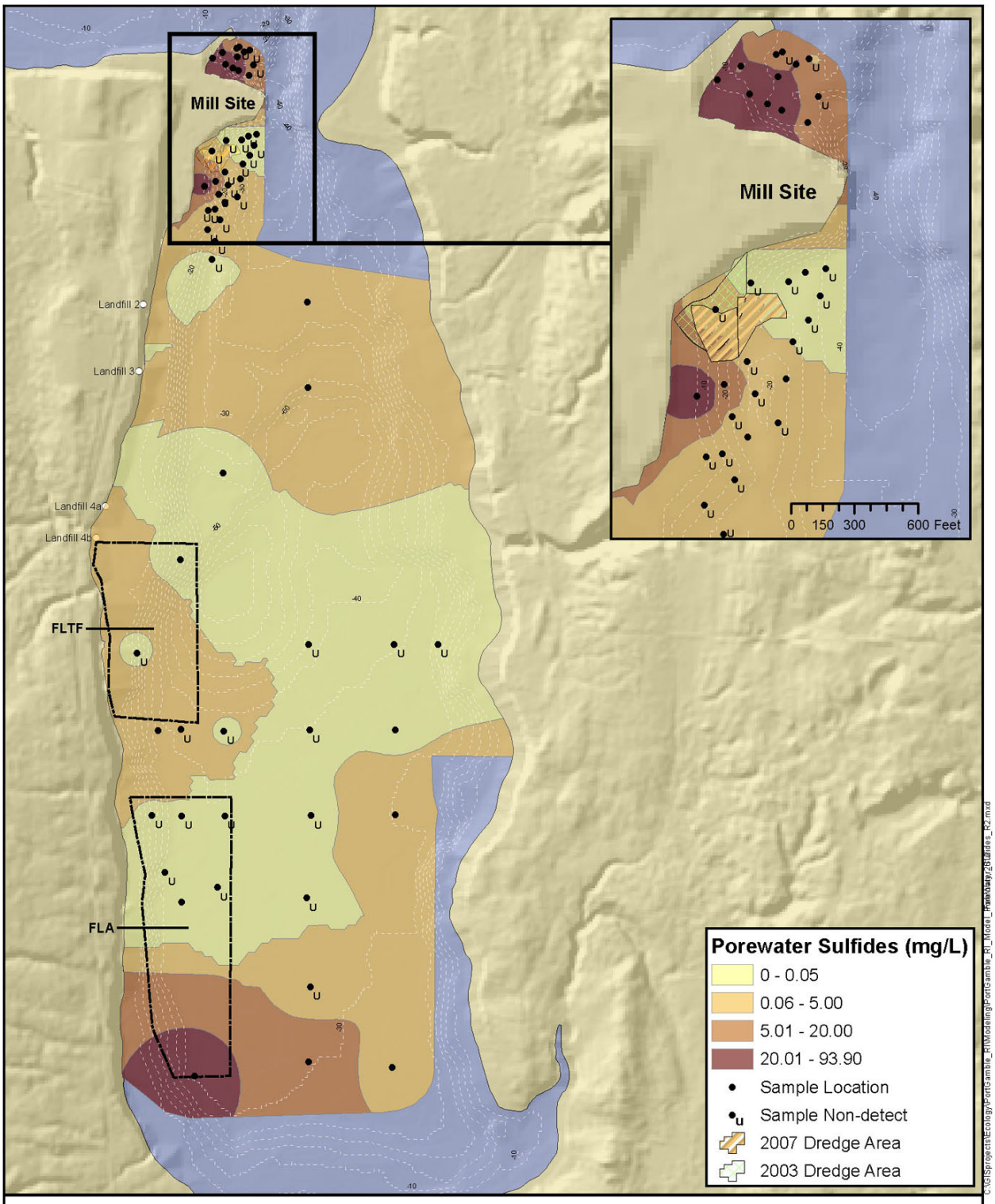


Figure 5-4. Surface Sediment Porewater Sulfides

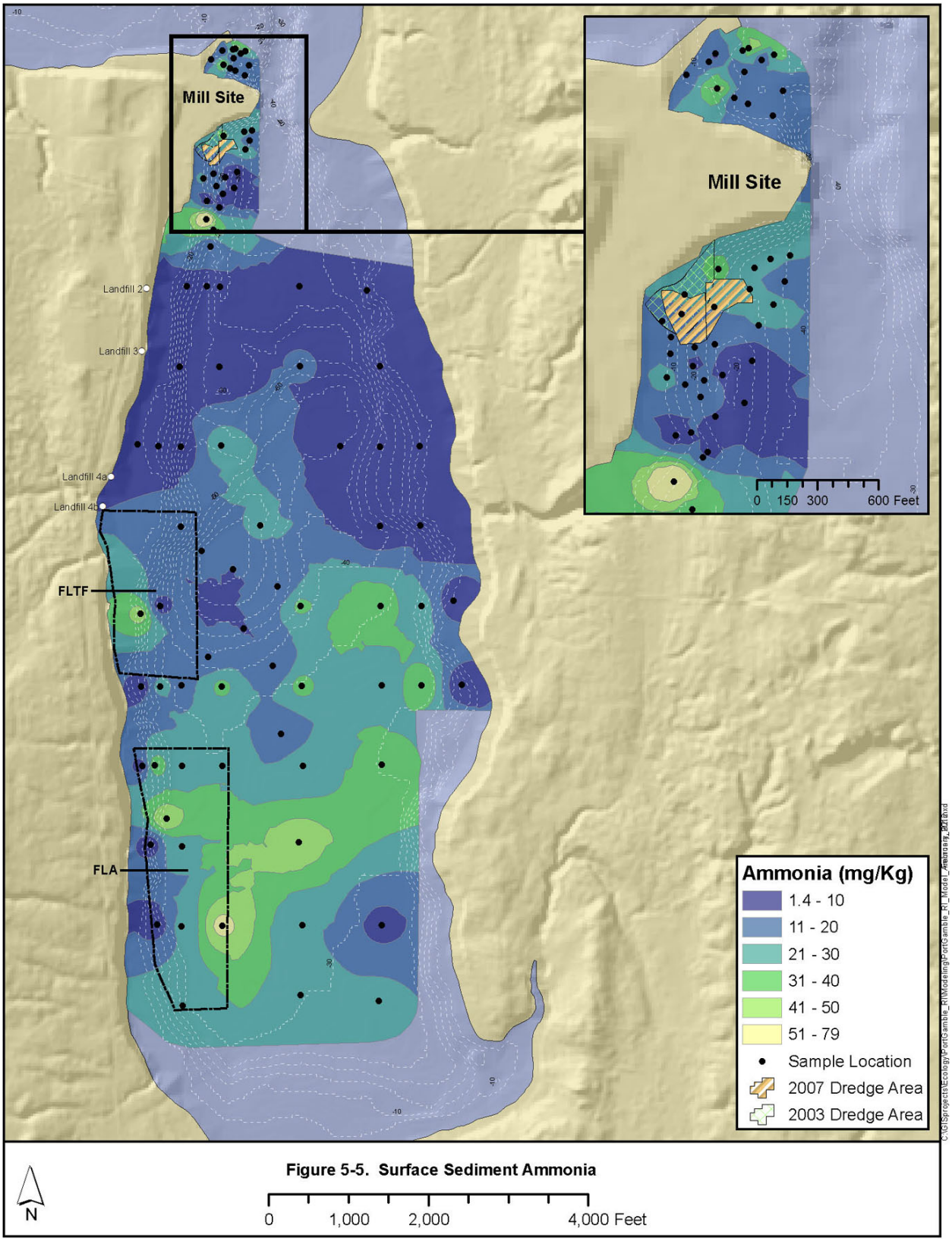


Figure 5-5. Surface Sediment Ammonia

Table 5-2. Summary of Sediment Fatty and Resin Acid Results

	Port Gamble Bay Samples						Mill Area Samples					
	Samples	Detects	Minimum	Maximum	Mean	90th %ile	Samples	Detects	Minimum	Maximum	Mean	90th %ile
Subtidal Samples												
Resin Acids in µg/kg												
9,10-Dichlorostearic Acid	49	0	95	100	97.8	99	2	0	97	99	98	98.8
Abietic Acid	56	14	95	4400	280	530	8	3	84	320	146	306
Dehydroabietic Acid	56	18	86	950	152	275	8	2	62	210	98.3	179
Isopimaric Acid	49	1	95	160	99.1	99	2	0	97	99	98	98.8
Linoleic Acid	49	28	96	830	200	442	2	2	110	170	140	164
Neoabietic Acid	29	0	96	100	98.2	99.2	2	0	97	99	98	98.8
Oleic Acid	49	49	370	8400	2150	5220	2	2	1600	4600	3100	4300
Palustric Acid	49	0	95	100	97.8	99	2	0	97	99	98	98.8
Pimaric Acid	56	0	95	100	98	99	8	0	47	99	60.3	97.6
Sandaracopimaric Acid	49	0	95	100	97.8	99	2	0	97	99	98	98.8

Non-detects included in descriptive statistics.

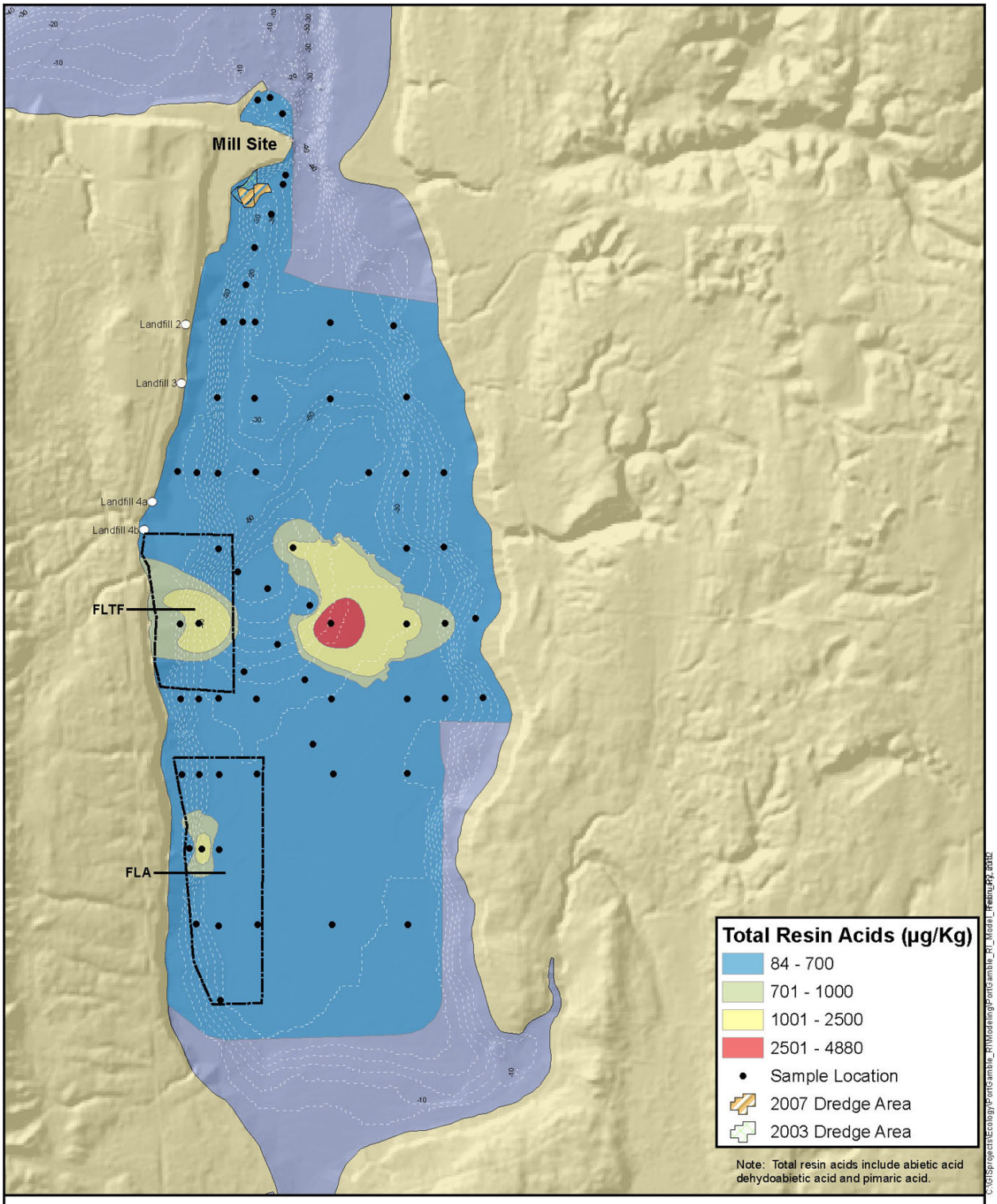


Figure 5-6. Surface Sediment Total Resin Acids

Resin acid concentrations in Douglas Fir are approximately 2,000–2,700 mg/kg based on analysis of the ether-extractable fraction of wood, with concentrations decreasing in the following order: isopimaric > palustric > abietic > neoabietic > dehydroabietic acids. Palustric acid and isopimaric acid each constitute about 20–30% of the total resin acids in Douglas Fir.

Based on the distribution of fatty and resin acids combined with SPI images and visual observations of sediment samples, resin acids appear to be a good indicator of wood waste. Fatty acids may reflect the presence of both wood waste and naturally occurring algae.

5.4 Total Metals

All metals concentrations were below applicable SQS screening criteria (Table 5-3). Therefore, the metals selected for discussion below were evaluated due to their potential human health effects (see Section 8). Concentrations on the figures are generally shown relative to natural background concentrations; in addition, undetected values are shown in blue with a "u" symbol. Samples with the highest metals concentrations were generally from the southern half of the bay; the higher metals concentrations may be associated with the fine-grained silt and clay or ephemeral stream inputs present in this area. For most metals, concentrations in intertidal samples were lower than in subtidal sediments, likely due to the more coarse-grained nature of the sediments.

Arsenic was detected in 6 of 44 subtidal samples in the bay, with detected concentrations in subtidal samples ranging from 2.25–20 mg/kg. Near the former mill, concentrations were similar, ranging from 2.6–25.4 mg/kg. In intertidal samples, arsenic was detected in all samples at lower levels of 0.92–6.1 mg/kg (Figure 5-7). The detection limits in the existing studies were above these concentrations, and thus lower detection limits were obtained during the 2011 NewFields RI to obtain a better sense of the actual concentrations for human health evaluations and natural background comparisons.

Cadmium was detected in 39 of 44 subtidal samples in the bay, with detected concentrations ranging from 0.33.1 mg/kg, with concentrations similar in the bay and near the former mill site. Cadmium was detected in 6 of 15 intertidal samples at concentrations of 0.1–1.1 mg/kg. Cadmium concentrations tend to be highest in the southern portion of the bay where sediments are very fine-grained (Figure 5-8).

Copper was detected in all samples, ranging from 3.4–40.2 mg/kg in the bay, 8.4–52.7 near the former mill, and 5.9–48.2 in intertidal sediments (Figure 5-9). Like cadmium, higher concentrations tend to be found in the southern half of the bay.

Mercury was detected in 25 of 44 subtidal samples, with detected concentrations ranging from 0.02–0.13 mg/kg in the bay and 0.014–0.07 near the former mill. Mercury was detected in 5 of 15 intertidal samples at concentrations of 0.03–0.08 mg/kg (Figure 5-10). Like the other metals, mercury tends to be slightly elevated in the fine-grained central portion of the bay.

Table 5-3. Summary of Sediment Metals Results

	Port Gamble Bay Samples						Mill Area Samples					
	Samples	**Detects**	**Minimum**	**Maximum**	**Mean**	**90th %ile**	**Samples**	**Detects**	**Minimum**	**Maximum**	**Mean**	**90th %ile**
Subtidal Samples												
Metals in mg/kg												
Arsenic	52	10	2.25	20	8.89	10	15	11	2.6	25.4	6.41	10.2
Cadmium	52	48	0.1	3.1	1.32	2.3	15	14	0.2	2.6	0.947	2.07
Chromium	52	52	7.3	53	34.6	49	12	12	15	88	27.6	29.7
Copper	52	52	3.4	40.2	24.8	38.2	15	15	8.4	52.7	22.3	38.2
Lead	52	45	2	15	8.49	13.9	15	15	3	37.4	11.1	28.1
Silver	52	0	0.1	1	0.612	0.9	12	0	0.1	0.6	0.35	0.5
Zinc	52	52	16	94	62.2	90	15	15	29	109.85	54.3	93.4
Mercury	52	32	0.02	0.13	0.0757	0.1	12	1	0.014	0.07	0.0338	0.059
Intertidal Samples												
Metals in mg/kg												
Arsenic	15	15	1.5	6.1	2.88	4.58	10	10	0.92	4.1	2.48	3.92
Cadmium	15	6	0.1	0.74	0.196	0.3	10	5	0.10	1.1	0.376	1.1
Chromium	15	15	15	40	26.2	36.3	10	10	9.00	31.4	20.7	25.9
Copper	15	15	5.9	48.2	13.6	20.2	10	10	15.00	41.6	26.1	36.6
Lead	15	9	2	31	6.63	13.5	10	10	3.70	24	10.8	19.5
Silver	15	0	0.072	0.9	0.445	0.72	10	0	0.06	0.9	0.337	0.9
Zinc	15	15	23	91.5	38.5	57.8	10	10	36.00	175	66.1	159
Mercury	15	5	0.014	0.08	0.0323	0.052	10	2	0.01	0.03	0.019	0.03

Non-detects included in descriptive statistics.

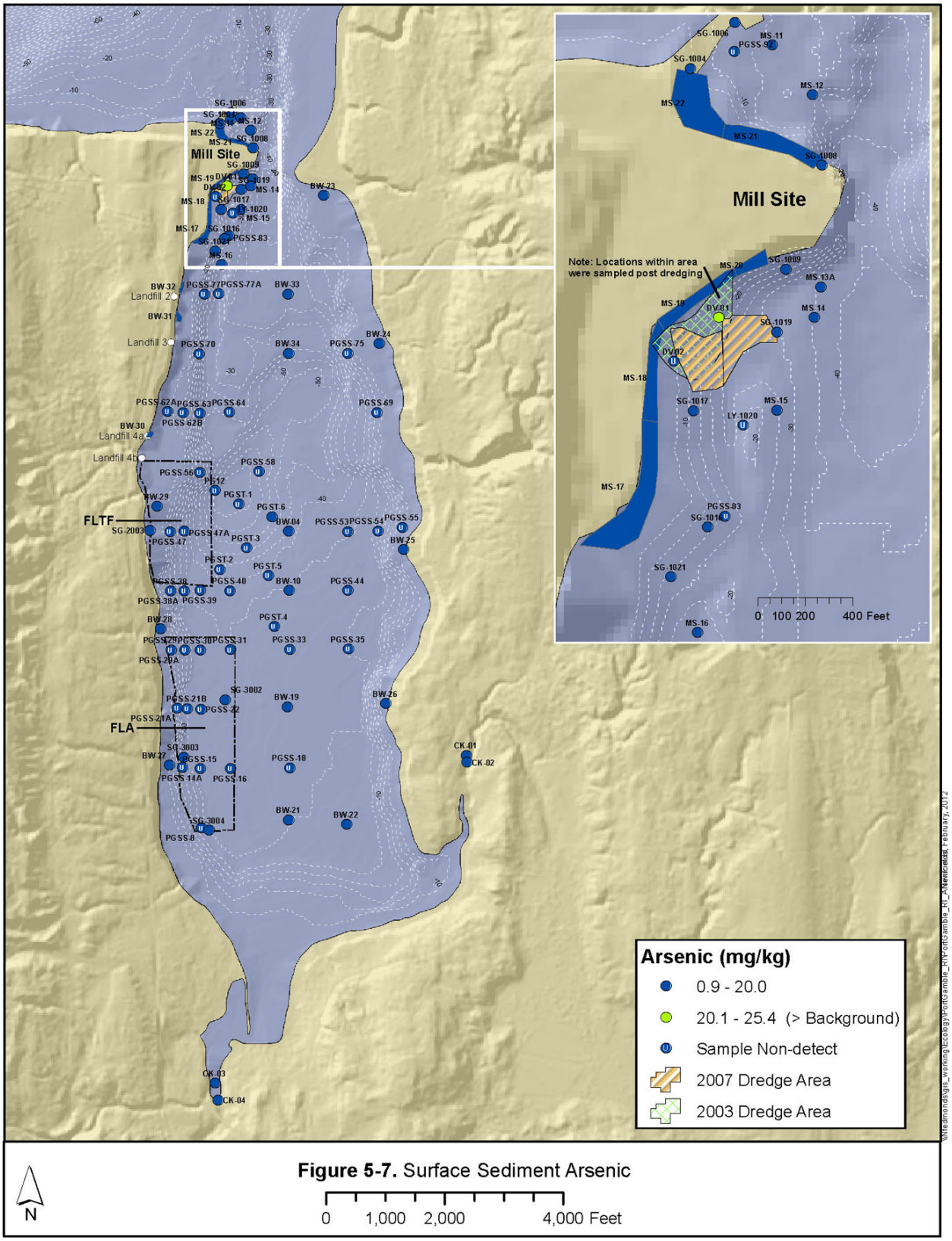


Figure 5-7. Surface Sediment Arsenic

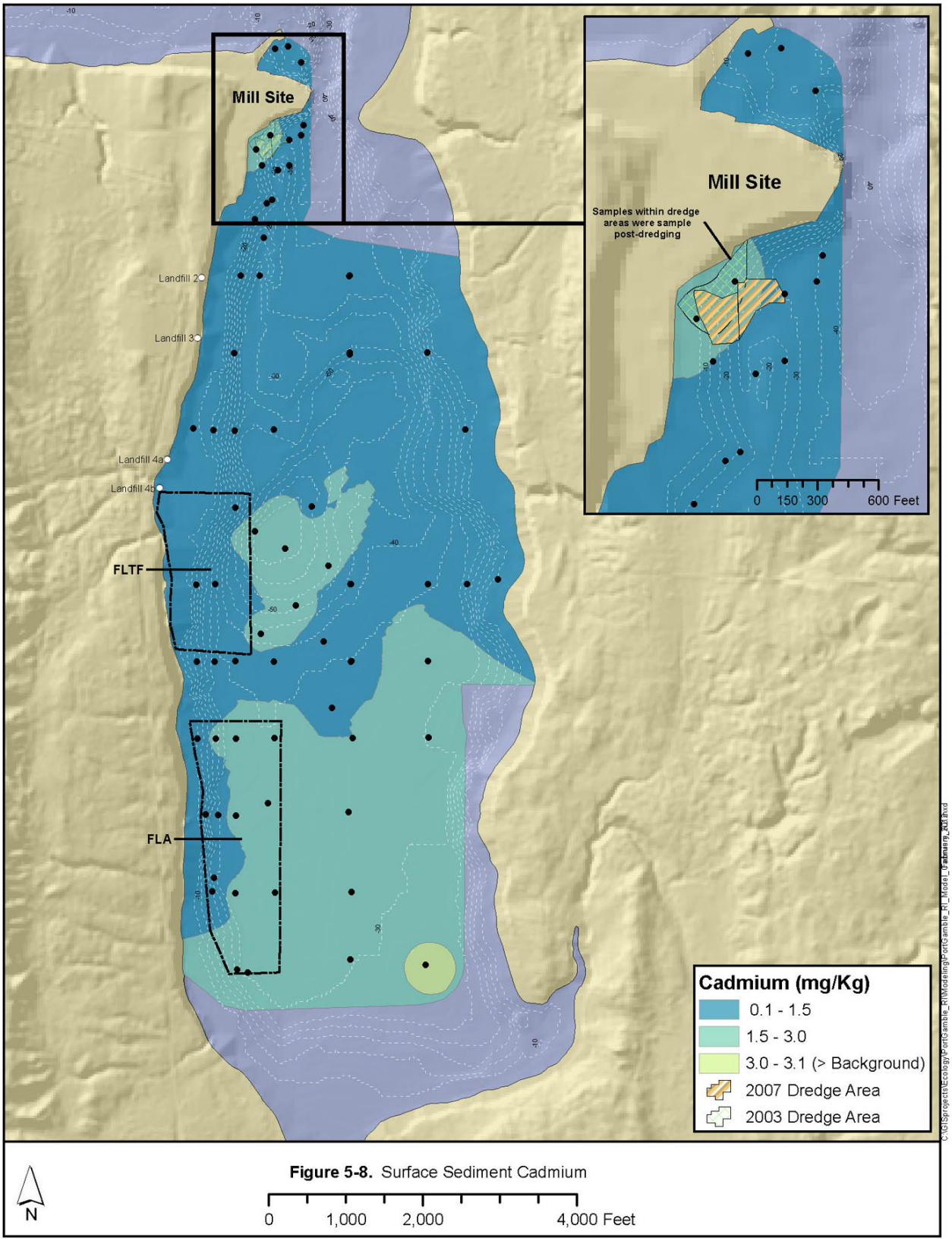


Figure 5-8. Surface Sediment Cadmium

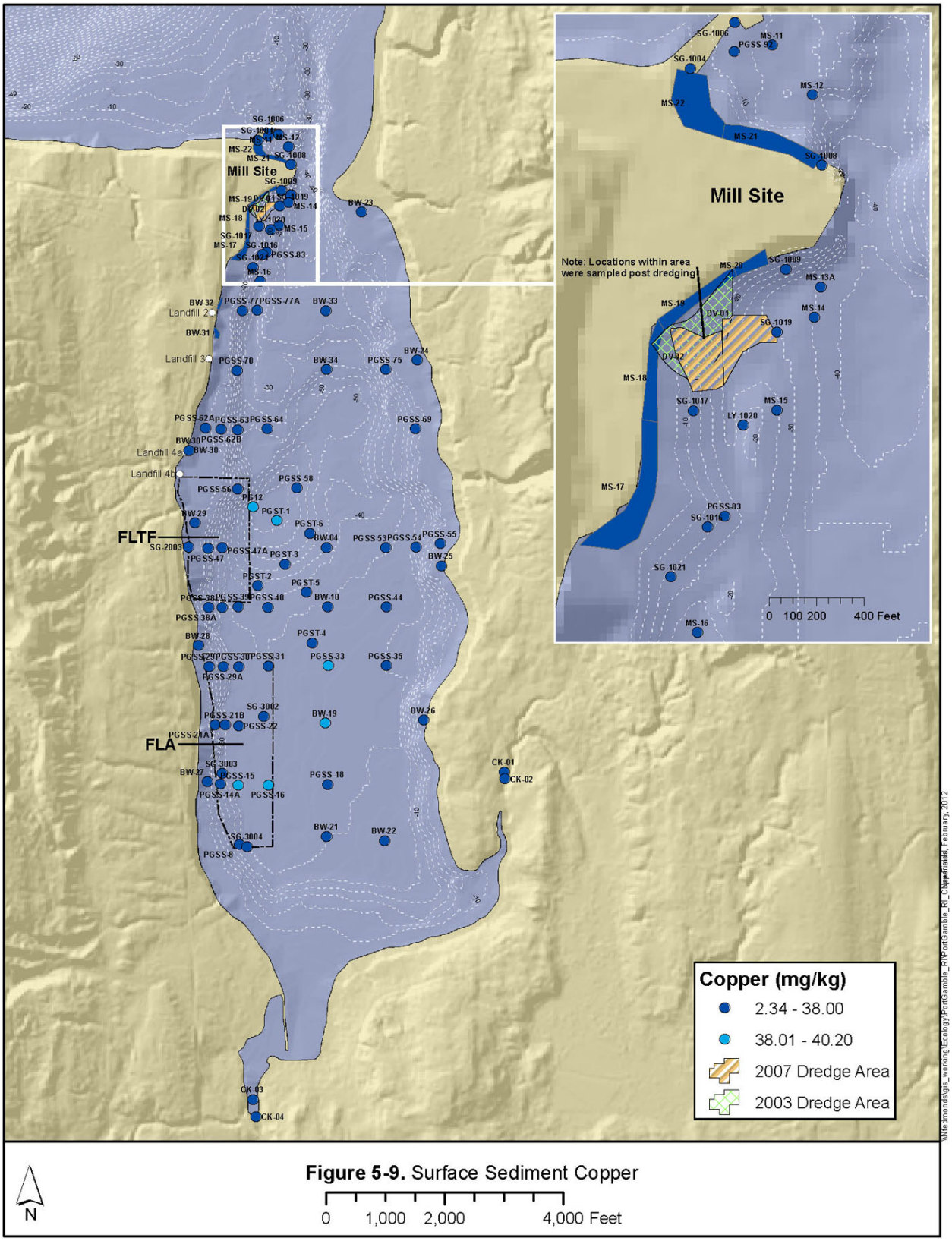


Figure 5-9. Surface Sediment Copper

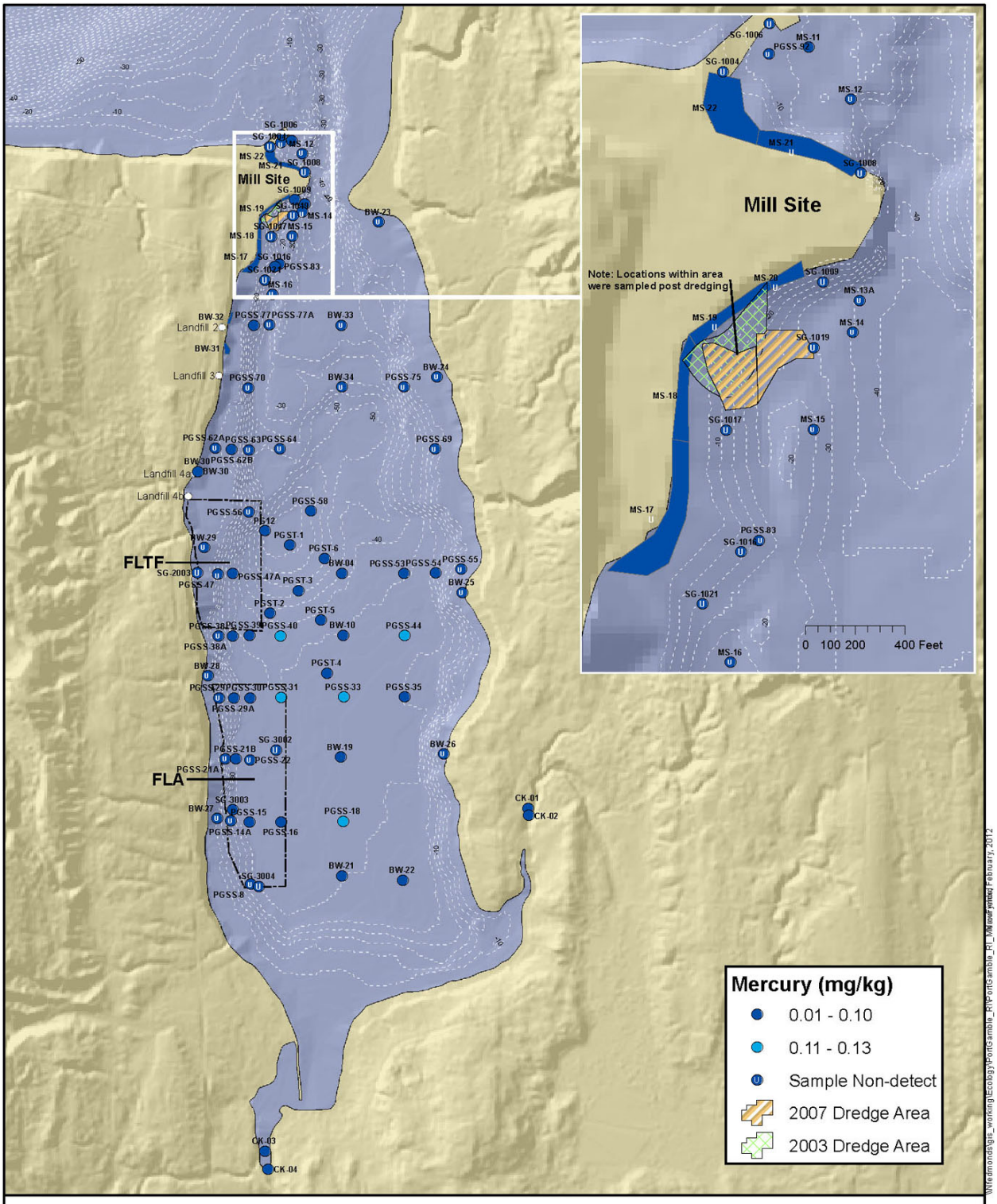


Figure 5-10. Surface Sediment Mercury

The relationship between metals concentrations and percent fines was further investigated to confirm the observed patterns, using the most recent data from both the subtidal and intertidal zones (n = 54; New Fields 2011 and Hart Crowser 2010). Scatterplots (Figures 5-11, 5-12) were used to visualize the data and assist in outlier identification. On these scatterplots, data values below detection are shown as dashed lines between 0 and the detection limit. The best fit regression lines are the ordinary least squares regression for endpoints with all data values above detection limits (i.e., chromium, copper, and zinc), or the Akritas-Theil-Sen nonparametric regression for endpoints with some values below detection (i.e., arsenic, cadmium, and mercury). Pearson's correlation coefficient was used to identify the strength and direction of the linear correlations for endpoints with all values above detection limits; otherwise Kendall's tau was used to describe the level of rank correlation.

The correlations (Table 5-4) were significant for all of the metals investigated (cadmium, chromium, copper, mercury, and zinc, $p < 0.05$) except for arsenic (p=0.11). Arsenic was detected in only half the observations and included some very high detection limits. Even with the uncertainty of the non-detects, the rank correlation was still very strong (p=0.11). The relationships between metals and fines appeared to be similar for mill area and bay samples for most of the metals investigated (Figure 5-11 A–D), with the exception of copper and zinc. The mill area stations had a small range of percent fines values (0–24%), which provided limited information for the correlation analysis. When the relationship appeared to be somewhat different for the mill area stations, correlations were conducted for two groups: all samples, and samples excluding stations in the mill area.

Table 5-4. Correlation Coefficients between Metals and Fines

Percent Fines vs.	Detection Frequency for the Metal	Correlation Test	Correlation Coefficient (p-value)	Outlier Samples
Arsenic	28/54	Kendall's tau	0.143 (p = 0.11)	None
Cadmium	41/54	Kendall's tau	0.776 (p = 0)	None
Chromium	54/54	Pearson's r	0.731 (p = 0)	Subtidal sample MS-12
Copper	54/54	Pearson's r	Bay: 0.846 (p = 0) Subtidal: 0.931 (p = 0) All samples: 0.502 (p = 0)	Intertidal samples MS-20, MS-21, MS-22, and BW-31
Mercury	25/54	Kendall's tau	0.521 (p = 0)	None
Zinc	54/54	Pearson's r	0.516 (p = 0)	Intertidal samples MS-19, MS-20

There were a number of samples with low fines and higher copper concentrations (Figure 5-12A). These were primarily mill area stations, but not exclusively. Many of the mill area stations did follow the general positive correlation pattern of increasing copper with increasing percent fines. A second plot of the copper data was prepared distinguishing between subtidal and intertidal stations (Figure 5-12B). The four unusual samples are all intertidal, but many more intertidal samples follow the general positive correlation pattern. The four intertidal stations with low fines (3% or less) and higher copper concentrations are MS-21 (34 mg/kg copper), MS-22 (34 mg/kg copper), MS-20 (42 mg/kg copper), and BW-31 (48 mg/kg copper). The best relationship appears to be among the subtidal samples, with the intertidal areas exhibiting substantial variability in copper concentrations within the low % fines range.

Chromium (Figure 5-11C) and zinc (Figure 5-12C) also had one or two stations that appeared to be outliers to the general patterns for these metals. These were samples with very low fines and very high

concentrations of these two metals. For chromium, the outlier was subtidal sample MS-12 from the mill area (6% fines and 88 mg/kg chromium). For zinc, the outliers were intertidal samples MS-19 and MS-20 from the mill area (3% fines and 175 and 157 mg/kg zinc, respectively). Debris was observed along the northwestern shoreline during field sampling, and these results suggest that this debris and related sources (e.g., landfills) may be contributing to concentrations observed in intertidal samples from this area.

Overall, the patterns and correlations observed suggest that metals concentrations in the bay are heavily influenced by fine-grained sediments, binding to clay and being transported to the very high fines (>80%) areas of the bay to the south. Several individual samples appear to be exceptions to this rule, generally in intertidal areas near the former mill.

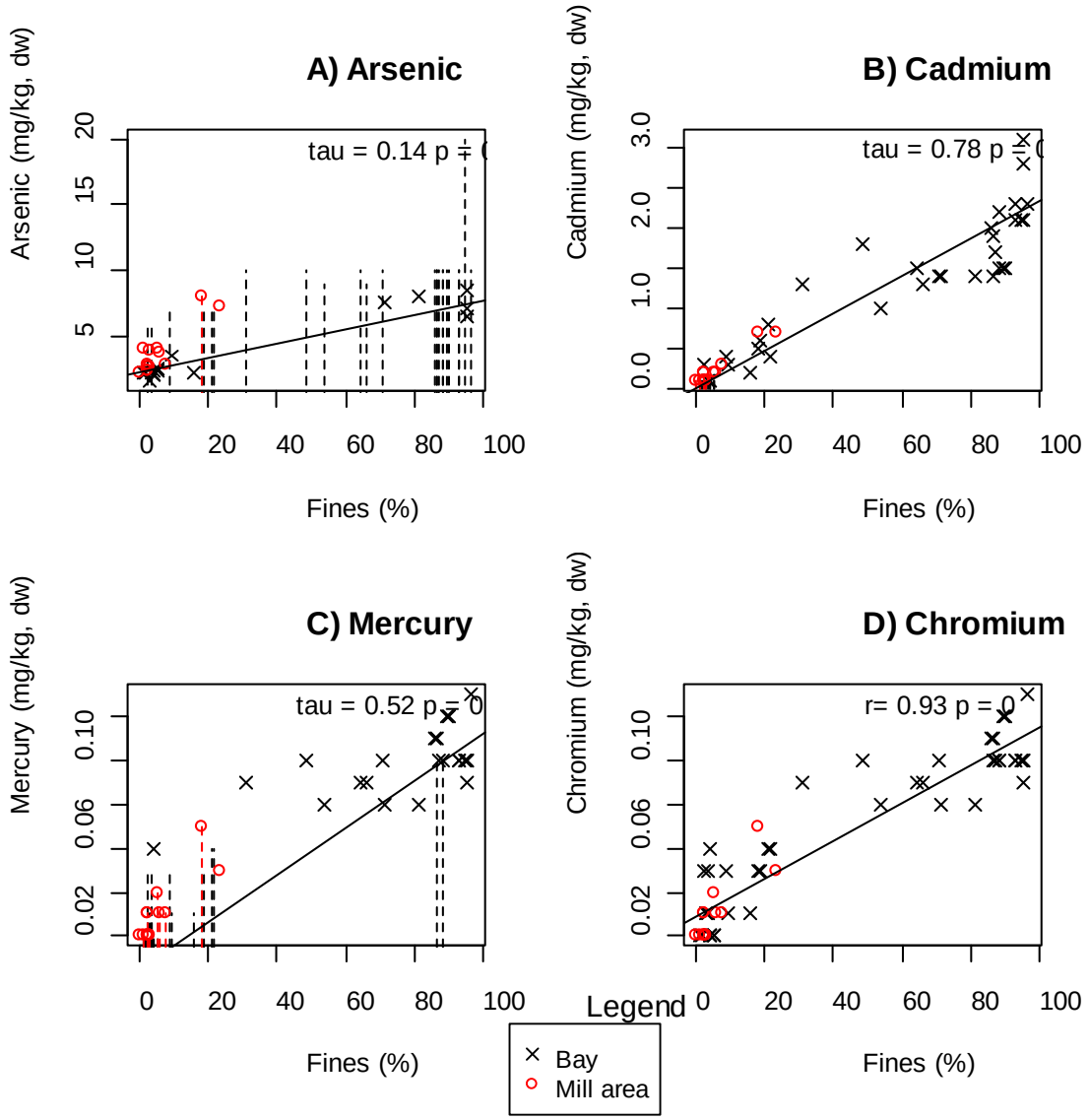


Figure 5-11. Correlations between Arsenic, Cadmium, Chromium, and Mercury and the Fine-Grained Sediment Fraction.

The best-fit regression line, the correlation coefficient (Kendall's tau or Pearson's r), and its significance level (p) are shown on each plot. Values below detection are shown as dashed lines between 0 and the detection limit.

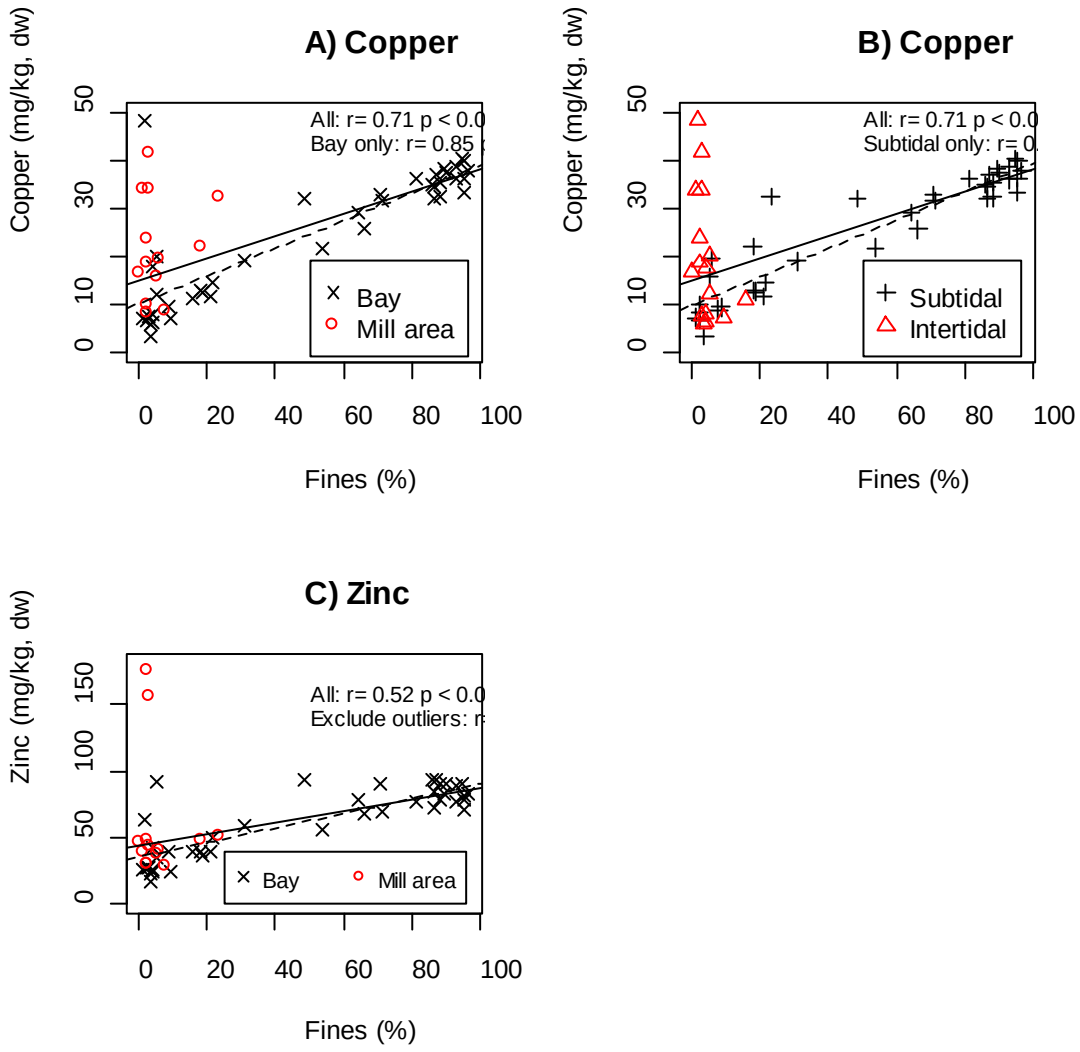


Figure 5-12. Correlations between Copper and Zinc Concentrations and the Fine-Grained Sediment Fraction.

The best-fit regression line, the Pearson correlation coefficient (r), and its significance level (p) are shown on each plot. The solid line shows the best-fit regression line for all of the data; the dashed line shows the best-fit regression line for the bay-only samples or the subtidal-only samples.

5.5 Semivolatile Organic Compounds

Except for locations PGSS-8, PGSS-20, PGSS-21B, PGSS-22, PGSS-30, PGSS-31, PGSS-44, PGSS-75, PGSS-80, and BW-22S, subtidal sediment TOC concentrations were within the 0.5–3.5% range for organic carbon (OC) normalization of nonpolar organics. However, most of the intertidal samples were well outside this range (TOC too low around the bay and too high in creek samples), and should not be OC normalized. Thus, both dry weight and OC-normalized values are presented for SMS chemicals with OC-normalized criteria.

Other than phenol, none of these analytes exceeded SMS OC normalized criteria or apparent effects threshold dry-weight screening values for nonpolar organic compounds. No phthalates or chlorinated benzenes were detected in any of the samples. Of the detected SVOCs, carcinogenic PAHs (cPAHs) are considered contaminants of concern for human health (see Section 8) and are discussed in greater detail below.

5.5.1 Polynuclear Aromatic Hydrocarbons

PAHs were detected in all but six subtidal samples analyzed, with cPAH toxic equivalency quotient (TEQs) ranging from 5.2–94.8 (µg/kg) in the bay and up to 280 µg/kg near the mill (Tables 5-5 and 5-6). Lower levels were found in intertidal samples, ranging from 1.51–47.9 µg/kg in the bay and up to 340 µg/kg near the mill. In general, samples with the highest concentrations of cPAHs above natural background were near the mill (both north and south) and in the central and southern bay (Figure 5-13).

While cPAH concentrations were often above natural background, the range of concentrations measured at Port Gamble were comparable to or lower than data from other bay-wide studies within Puget Sound. In addition to Port Gamble, sediment investigations have been conducted at Fidalgo Bay, Budd Inlet, Port Angeles, and Port Gardner as part of the Puget Sound Initiative. These bays represent varying degrees of urban density and proportion of historic versus current industrial activity. The range of subtidal surface sediment cPAH concentrations from these investigations is presented in Figure 5-14. For reference, data from the highly urban/industrial Lower Duwamish Waterway (LDW) and the Port Gamble natural background data set were also included. All data were available in Ecology's Environmental Information Management (EIM).

All of the data presented in Figure 5-14 were normalized to OC content to minimize the differences in physical characteristics between the investigations. The OC-normalization also allows a more meaningful comparison with respect to availability of the cPAHs, since uptake from sediments is mediated by the organic fraction. The upper and lower bars represent the 90^{th} and 10^{th} percentiles, while the upper and lower bounds of the box represent the 75^{th} and 25^{th} percentiles, respectively. As discussed in Section 9.1, Port Gamble Bay sediments were above the natural background for cPAHs. The 90^{th} percentile at Port Gamble Bay was the lowest of all of the investigations, indicating that Port Gamble Bay does not have sediments in the higher concentration ranges measured elsewhere in Puget Sound. The majority of the sediment samples from Port Gamble Bay, those under the 75^{th} percentile, were similar to Fidalgo Bay, but lower than the more urban Port Gardner, Port Angeles, and Budd Inlet.

Table 5-5. Summary of Sediment Polycyclic Aromatic Hydrocarbon (PAH) Results – Dry Weight

	Port Gamble Bay Samples						Mill Area Samples					
	Samples	Detects	Minimum	Maximum	Mean	90th %ile	Samples	Detects	Minimum	Maximum	Mean	90th %ile
Subtidal Samples												
PAHs in µg/kg												
Naphthalene	51	31	11	1600	196	390	15	8	3.8	585	132	396
Acenaphthylene	51	28	6	450	61.4	100	15	7	1.4	47	25.5	40.5
Acenaphthene	51	28	3.1	120	26.8	45	15	8	6.9	151.5	36.6	58
Fluorene	51	28	2.2	81	24.6	40	15	8	6.2	161	36.9	59.8
Phenanthrene	51	36	11	630	98.5	210	15	15	19	410	156	316
Anthracene	51	31	3.3	130	31.3	48	15	12	8.5	120	51.5	103
2-Methylnaphthalene	51	28	2.7	92	23.9	40	15	7	2	112	28.4	49.8
1-Methylnaphthalene	48	28	2.6	78	20.8	33.4	8	6	3.1	30	16.8	27.6
Total LPAHs	51	37	11	3171	398	765	15	15	19	1617	392	872
Fluoranthene	51	42	9.7	560	110	250	15	15	30	590	280	546
Pyrene	51	40	12	550	111	250	15	15	32	430	205	392
Benzo(a)anthracene	51	35	4	71	28.3	47	15	15	12	200	91.3	189
Chrysene	51	39	5.2	91	36.3	62	15	15	12	570	181	368
Benzo(b)fluoranthene	41	29	4.4	58	29	48	10	9	11	255	93.9	251
Benzo(k)fluoranthene	41	29	2.4	57	19.2	26	10	9	6	140	53.6	136
Total Benzofluoranthenes	48	37	6.8	130	47.2	77.2	10	9	17	390	146	378
Benzo(a)pyrene	51	35	4	69	30.6	56	15	15	9.5	210	80.5	184
Indeno(1,2,3-cd)pyrene	51	32	2.5	47	19.7	39	15	12	3.6	92	40.3	83.2
Dibenz(a,h)anthracene	51	20	2.4	47	13.3	20	15	5	2.5	39	18.8	32.8
Benzo(g,h,i)perylene	51	33	2.9	70	27	47	15	11	5.4	95.5	38.2	83.4
Total HPAHs	51	42	9.7	1588.7	359	830	15	15	100	2268	1000	1940
cPAH TEQ	51	*	5.2	94.8	35.8	71.9	15	*	13.4	279	106	254
Intertidal Samples												
PAHs in µg/kg												
Naphthalene	15	12	3.3	300	46.1	119	10	2	3.9	63	19.6	22.5
Acenaphthylene	15	6	1.3	54	9.86	28.8	10	3	1.3	18	10	18
Acenaphthene	15	5	1.2	21	4.93	14	10	5	1.2	18	11.4	18
Fluorene	15	6	1.3	21	5.26	13.8	10	6	1.3	54	15.5	21.6
Phenanthrene	15	14	1.9	160	32.7	84.4	10	8	12.0	200	71.3	164
Anthracene	15	7	2.1	26	7.63	20.2	10	7	4.3	250	40.1	70
2-Methylnaphthalene	15	6	1.9	21	5.15	11.5	10	4	1.9	18	9.21	18
1-Methylnaphthalene	14	5	1.5	18	4	10.2	6	4	1.5	8.8	5.33	8
Total LPAHs	15	15	6.1	571	92.7	265	10	8	16.0	504	131	275
Fluoranthene	15	14	3	150	44.9	128	10	9	16.0	760	171	391
Pyrene	15	14	2.6	160	42.5	112	10	9	16.0	430	106	205
Benzo(a)anthracene	15	10	1.8	56	10.4	18.8	10	9	16.0	200	56.1	155

Table 5-5. Summary of Sediment Polycyclic Aromatic Hydrocarbon (PAH) Results – Dry Weight

	Port Gamble Bay Samples						Mill Area Samples					
	Samples	Detects	Minimum	Maximum	Mean	90th %ile	Samples	Detects	Minimum	Maximum	Mean	90th %ile
Chrysene	15	10	2.2	110	15.9	21.4	10	9	16.0	590	135	419
Benzo(b)fluoranthene	14	9	1.9	17	7.58	16.7	6	6	18.0	420	101	240
Benzo(k)fluoranthene	14	8	2.1	8.4	4.24	7.82	6	6	8.5	200	47.3	115
Total Benzofluoranthenes	14	9	2.1	24.4	10.8	24.1	6	6	26.5	620	148	355
Benzo(a)pyrene	15	9	2.1	39	9.86	19.8	10	9	14.0	240	56.7	132
Indeno(1,2,3-cd)pyrene	15	7	2.6	21	5.43	10.6	10	7	4.6	91	26	64.9
Dibenz(a,h)anthracene	15	0	2.5	21	3.79	2.66	10	4	2.5	33	12.1	19.5
Benzo(g,h,i)perylene	15	9	2.4	22	7.68	21	10	7	5.0	92	24.4	55.1
Total HPAHs	15	14	3	455	139	380	10	9	16.0	3056	653	1490
cPAH TEQ	15	*	1.51	47.9	12.2	25.0	10	*	10.5	340	74.8	166

Non-detects included in descriptive statistics.

* TEQs shown in this table used the method described in Section 8.2.4. Using this method, all final estimated TEQ values are treated as detected; therefore, summary statistics can be calculated on the estimated TEQs even if most or all of the component congeners were undetected.

Table 5-6. Summary of Sediment Polycyclic Aromatic Hydrocarbon (PAH) Results – Organic Carbon Normalized

	Port Gamble Bay Samples						Mill Area Samples					
	Samples	Detects	Minimum	Maximum	Mean	90th %ile	Samples	Detects	Minimum	Maximum	Mean	90th %ile
Subtidal Samples												
PAHs in mg/kg OC												
Naphthalene	51	31	0.38	42	6.62	15	15	8	0.4	8.9	3.14	7.32
Acenaphthylene	51	28	0.18	12	2.38	4.2	15	7	0.16	2	0.796	1.62
Acenaphthene	51	28	0.091	7	1.31	2.2	15	8	0.2	3.5	1.08	1.78
Fluorene	51	28	0.1	7	1.24	2.1	15	8	0.23	3	1.03	1.82
Phenanthrene	51	36	0.32	16	3.71	7.1	15	15	0.84	16	4.99	12.3
Anthracene	51	31	0.16	7	1.47	2.6	15	12	0.31	11	1.87	2.94
2-Methylnaphthalene	51	28	0.094	7	1.21	2.2	15	7	0.19	1.9	0.701	1.12
1-Methylnaphthalene	48	28	0.088	7	1.14	2	8	6	0.49	1.8	0.918	1.26
Total LPAHs	51	37	0.32	82	13.2	33	15	15	1	33	11.1	22
Fluoranthene	51	42	0.71	14	4.21	9.4	15	15	0.94	42	10.3	26.2
Pyrene	51	40	0.71	14	4.23	9.8	15	15	0.74	35	7.85	19.4
Benzo(a)anthracene	51	35	0.24	7	1.4	2	15	15	0.4	7.05	2.53	5.46
Chrysene	51	39	0.32	7	1.7	2.6	15	15	0.4	14.95	5.16	11.5
Benzo(b)fluoranthene	41	29	0.27	7	1.6	2.2	10	9	0.64	10.15	3.18	7.5
Benzo(k)fluoranthene	41	29	0.15	7	1.23	2.2	10	9	0.36	5.25	1.67	3.5
Total Benzofluoranthenes	48	37	0.41	7	2.13	3.33	10	9	0.66	15.65	4.71	10.6
Benzo(a)pyrene	51	35	0.24	7	1.49	2.2	15	15	0.37	8.65	2.32	4.7

Table 5-6. Summary of Sediment Polycyclic Aromatic Hydrocarbon (PAH) Results – Organic Carbon Normalized

	Port Gamble Bay Samples						Mill Area Samples					
	Samples	**Detects**	**Minimum**	**Maximum**	**Mean**	**90th %ile**	**Samples**	**Detects**	**Minimum**	**Maximum**	**Mean**	**90th %ile**
Indeno(1,2,3-cd)pyrene	51	32	0.14	7	1.09	2	15	12	0.22	3.25	1.06	1.82
Dibenz(a,h)anthracene	51	20	0.057	7	0.871	2	15	5	0.071	1.9	0.569	1.07
Benzo(g,h,i)perylene	51	33	0.18	7	1.35	2.2	15	11	0.31	3.95	1.1	1.96
Total HPAHs	51	42	1.1	43	13.2	32	15	15	3.3	120	33.6	89.4
cPAH TEQ	51	*	0.323	4.86	1.58	2.80	15	*	0.472	7.89	2.84	6.79
Intertidal Samples												
PAHs in mg/kg OC												
Naphthalene	15	12	0.24	6.6	2.94	6.32	10	2	0.29	20	4.74	9.74
Acenaphthylene	15	6	0.026	1.8	0.7	1.4	10	3	0.15	20	3.18	7.4
Acenaphthene	15	5	0.016	1.8	0.46	1.01	10	5	0.19	20	3.52	7.4
Fluorene	15	6	0.016	1.8	0.54	1.22	10	6	0.33	20	3.71	7.4
Phenanthrene	15	14	0.12	4.9	2.61	4.36	10	8	1.5	31	10.1	21.1
Anthracene	15	7	0.028	1.8	0.74	1.36	10	7	0.76	20	5.51	17.3
2-Methylnaphthalene	15	6	0.037	1.8	0.54	1.1	10	4	0.079	20	3.24	7.4
1-Methylnaphthalene	14	5	0.02	0.64	0.38	0.627	6	4	0.12	1.5	0.78	1.35
Total LPAHs	15	15	0.12	16	6.6	13.2	10	8	1.5	41	15.8	34.7
Fluoranthene	15	14	0.11	13	4.27	8.44	10	9	5.7	33	17.2	25.8
Pyrene	15	14	0.09	8.3	3.88	7.76	10	9	4.3	22	12.7	20.2
Benzo(a)anthracene	15	10	0.023	4.7	1.2	3.34	10	9	2.2	20	7.33	11
Chrysene	15	10	0.028	9.2	1.75	3.7	10	9	5	27	12.1	20.7
Benzo(b)fluoranthene	14	9	0.039	2.7	0.95	2.15	6	6	4	9.3	7.33	9.1
Benzo(k)fluoranthene	14	8	0.027	1.5	0.59	1.24	6	6	1.9	4.2	3.37	4.2
Total Benzofluoranthenes	14	9	0.042	4.1	1.36	3.44	6	6	5.8	13	10.6	13
Benzo(a)pyrene	15	9	0.027	3.3	1.14	2.82	10	9	2.2	20	7.07	11
Indeno(1,2,3-cd)pyrene	15	7	0.034	1.8	0.65	1.16	10	7	1	20	4.47	7.4
Dibenz(a,h)anthracene	15	0	0.032	1.8	0.5	0.872	10	4	0.43	20	3.32	7.4
Benzo(g,h,i)perylene	15	9	0.029	1.8	0.82	1.44	10	7	0.42	20	4.46	7.4
Total HPAHs	15	14	0.35	38	13.6	31	10	9	20	100	58.8	99.1
cPAH TEQ	14	*	0.00587	0.197	0.0548	0.116	6	*	0.0143	0.0572	0.0408	0.0569

Non-detects included in descriptive statistics.

* TEQs shown in this table used the method described in Section 8.2.4. Using this method, all final estimated TEQ values are treated as detected; therefore, summary statistics can be calculated on the estimated TEQs even if most or all of the component congeners were undetected.

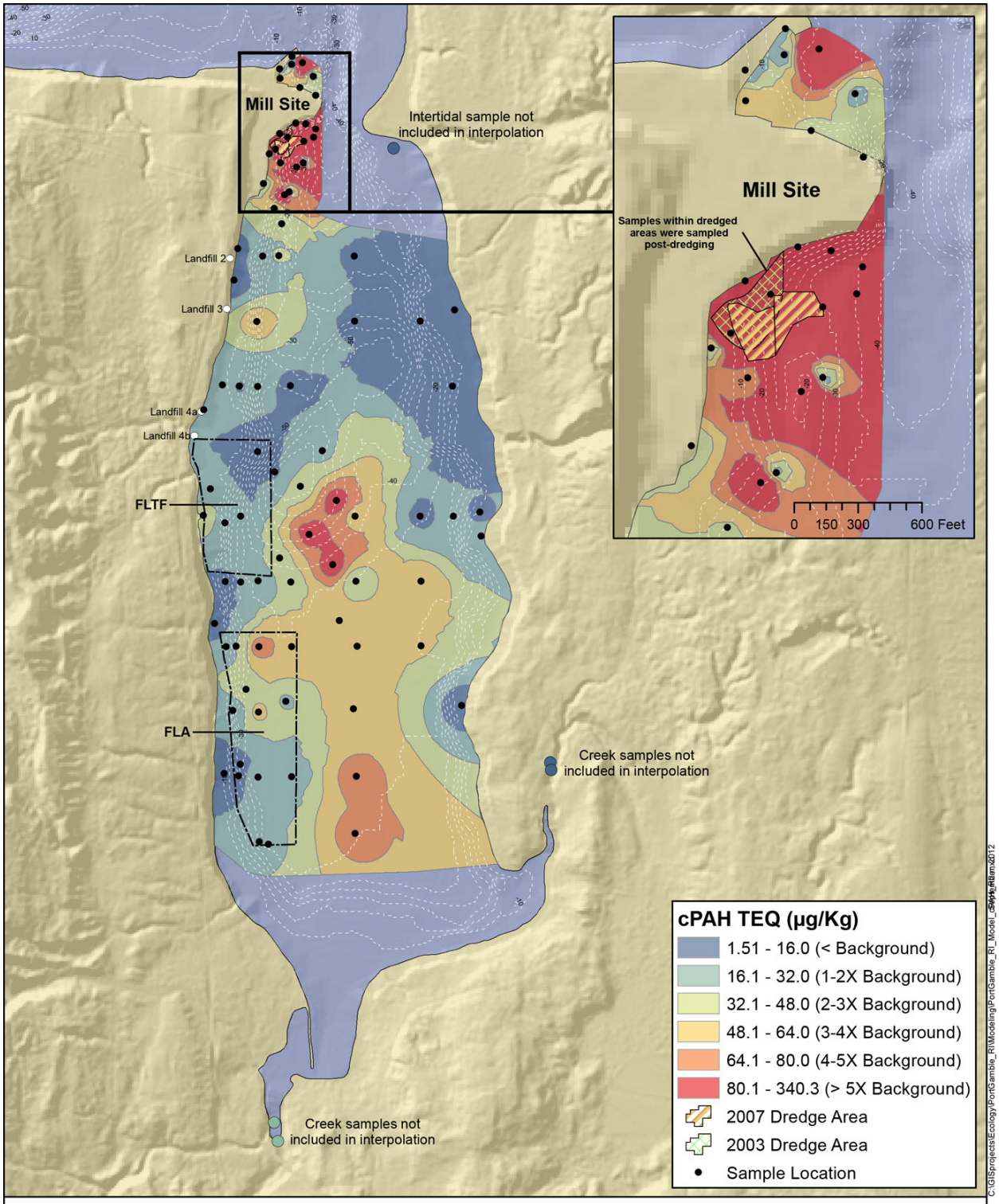


Figure 5-13. Surface Sediment Carcinogenic PAHs (cPAHs)

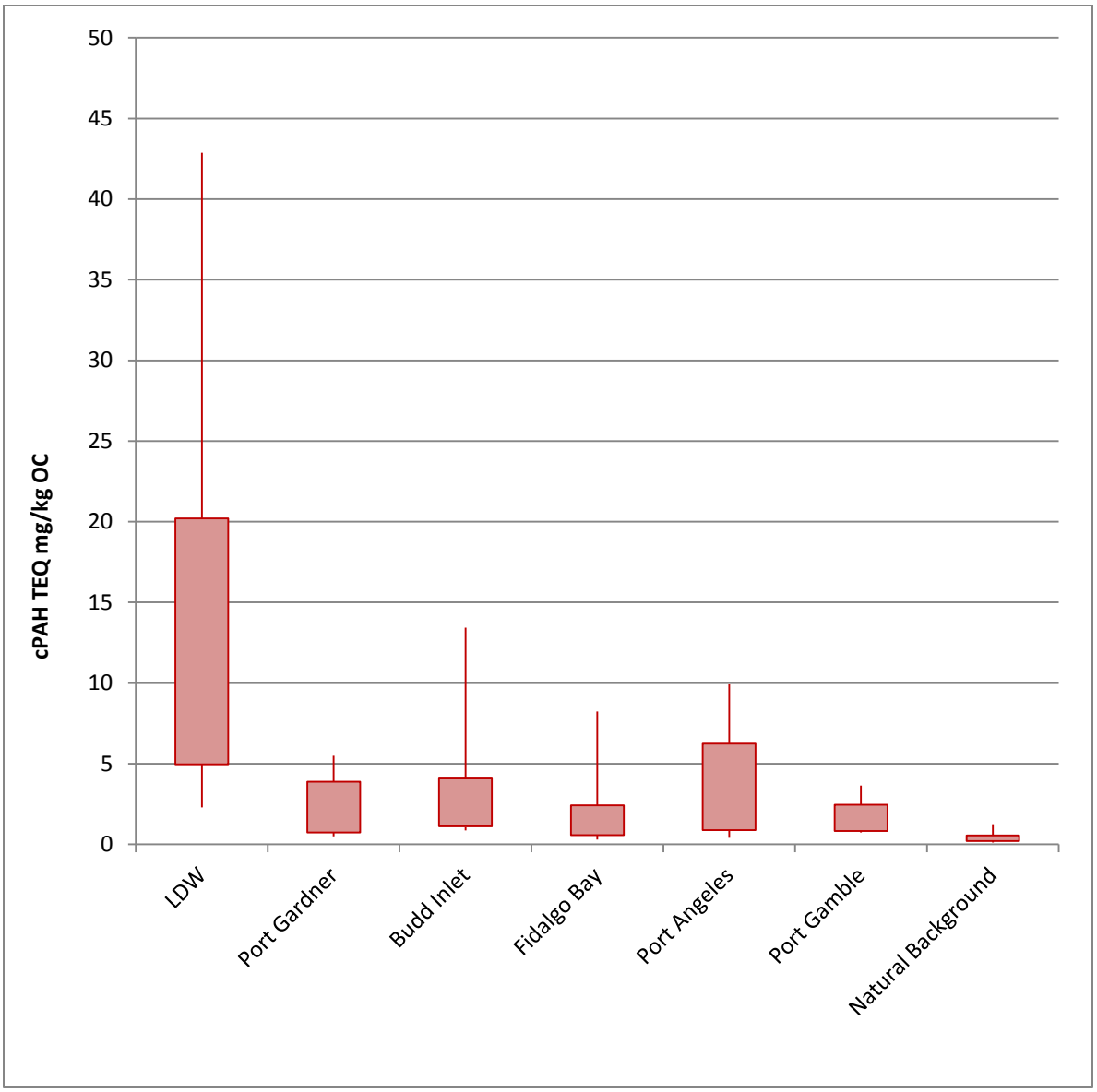


Figure 5-14. Surface Sediment cPAH Concentrations from Investigations Conducted in Puget Sound

Correlations between percent fines and the cPAH TEQ were investigated in the same manner as for metals. There were two unusually high TEQs, found at intertidal station MS-20 and subtidal station MS-11. A scatterplot excluding these outliers (Figure 5-15) indicates a fairly strong correlation for the stations in the bay, less so when stations near the mill are included.

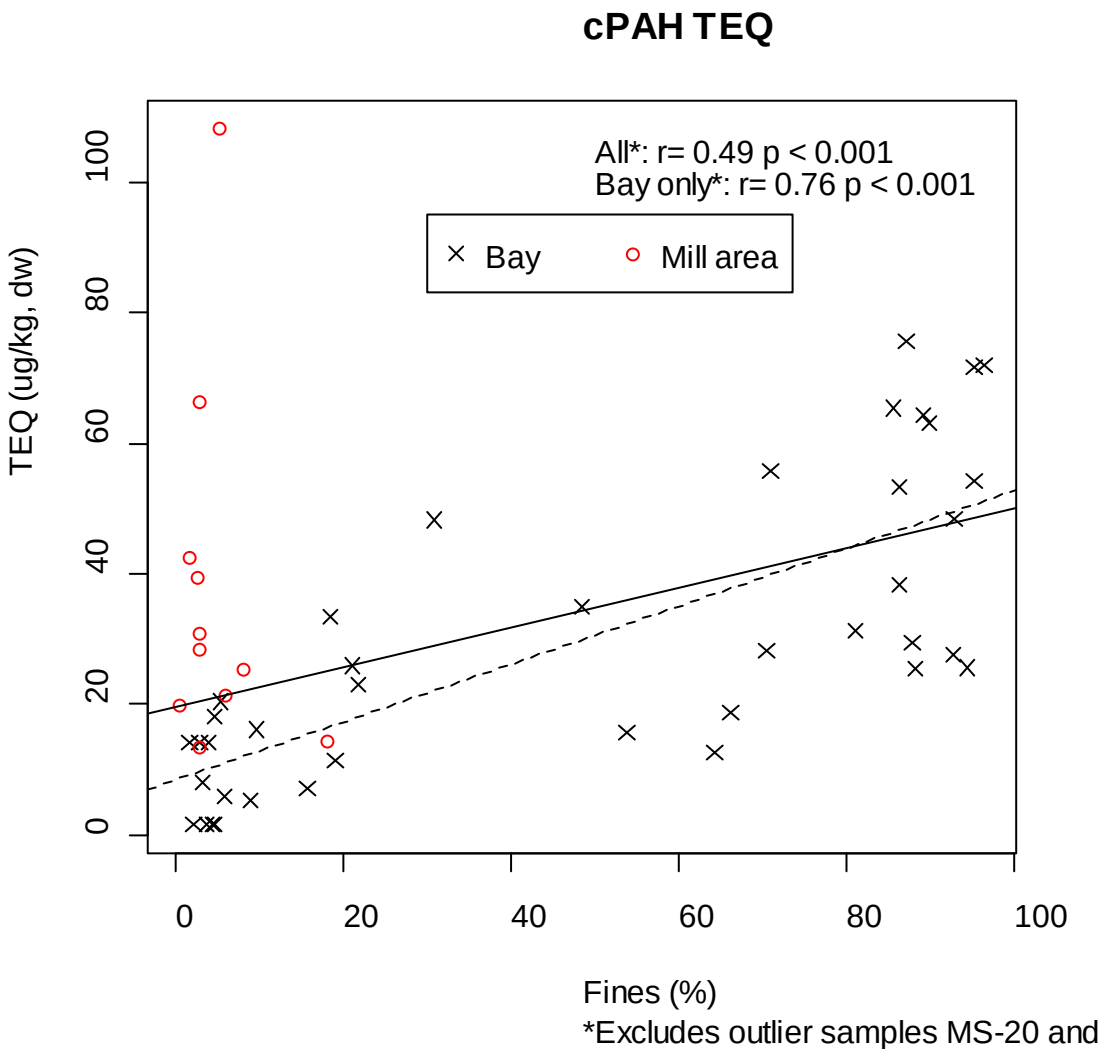


Figure 5-15. Correlations between Carcinogenic PAH TEQ Values and the Fine-Grained Sediment Fraction.

The best-fit regression line, the Pearson correlation coefficient (r), and its significance level (p) are shown. The solid line shows the best-fit regression line for all the data; the dashed line shows the best-fit regression line for the bay-only samples.

The ratios of different PAH compounds can sometimes be used to help identify potential sources. PAHs in sediments can be separated into two primary categories, petrogenic and pyrogenic. Petrogenic PAHs are directly derived from fossil fuels, particularly petroleum and its distillates. Sources of petrogenic PAHs include crude oil, fuel oils, lubricating oils, refined fuels such as diesel, and coal. Pyrogenic PAHs are formed during incomplete or inefficient combustion of fossil fuels and other organic matter at high temperatures. Sources of pyrogenic PAHs include wood burning emissions, automobile exhaust, and highway dust. Creosote and coal tar are also considered pyrogenic PAHs since they are created using controlled pyrolytic processes (Zemo 2009). There are also natural sources of petrogenic and pyrogenic PAHs.

PAHs are composed of multiple aromatic rings. In general, increasing the number of rings on a PAH compound increases the environmental stability of that compound. PAHs may also contain carbon side chains referred to as alkyl groups. PAHs that do not contain alkyl groups are referred to as nonalkylated, or parent PAHs (Stout 2003). Several statistical methods have been used to differentiate petrogenic and pyrogenic PAHs and to further identify individual sources. Most of these methods rely on a detailed evaluation of a suite of 40 or more PAHs, many of which are alkylated (Stout et al. 2002). However, the PAHs analyzed in Port Gamble sediments comprise the 16 "priority pollutant" parent PAH compounds. Statistical methods and their ability to distinguish between sources are more limited with this subset of data, particularly when there are multiple sources of PAHs and the overall concentrations of PAHs are relatively low. However, Zemo (2009), Stout (2003), and Stout and Graan (2010) have developed several tools that can be used to provide an indication of PAH sources using the 16 priority pollutant PAHs. These approaches were used in combination to evaluate the potential sources of PAHs in Port Gamble Bay.

Zemo (2009) developed a combination of ratios (double-ratio cross plots) to evaluate PAH sources in Puget Sound, particularly in the Duwamish Waterway and Elliott Bay. Isometric ratios are calculated between PAHs with the same molecular weight and number of rings to minimize the effects of environmental weathering on dissimilar structures (i.e., anthracene and phenanthrene degrade at similar rates by similar processes). To evaluate whether PAHs in Port Gamble Bay were more petrogenic or pyrogenic in nature, two ratio pairings were evaluated (Figure 5-16):

- Anthracene/(anthracene + phenanthrene) vs. fluoranthene/(fluoranthene + pyrene)
- Benzo(a)anthracene/ (benzo(a)anthracene + chrysene) vs. fluoranthene/(fluoranthene + pyrene)

Based on these pairings, the sediments in Port Gamble Bay appear to be pyrogenic in nature (derived from combustion) and do not appear to include more petrogenic sources (derived from petroleum).

Zemo (2009) also established a second set of cross plots with isometric relationships to better distinguish between PAHs associated with "urban background" sources and creosote-related PAHs. Urban background includes a variety of sources that may be present in the Port Gamble Bay area, including wood burning emissions, automobile exhaust, and highway dust. For this site, the term "urban background" may be misleading, since the large volumes of wood waste burned over 150 years at the mill contribute to this signature and the surrounding area is not urban. Thus, this category of sources will be referred to as "airborne emissions" to distinguish it from creosote-related sources.

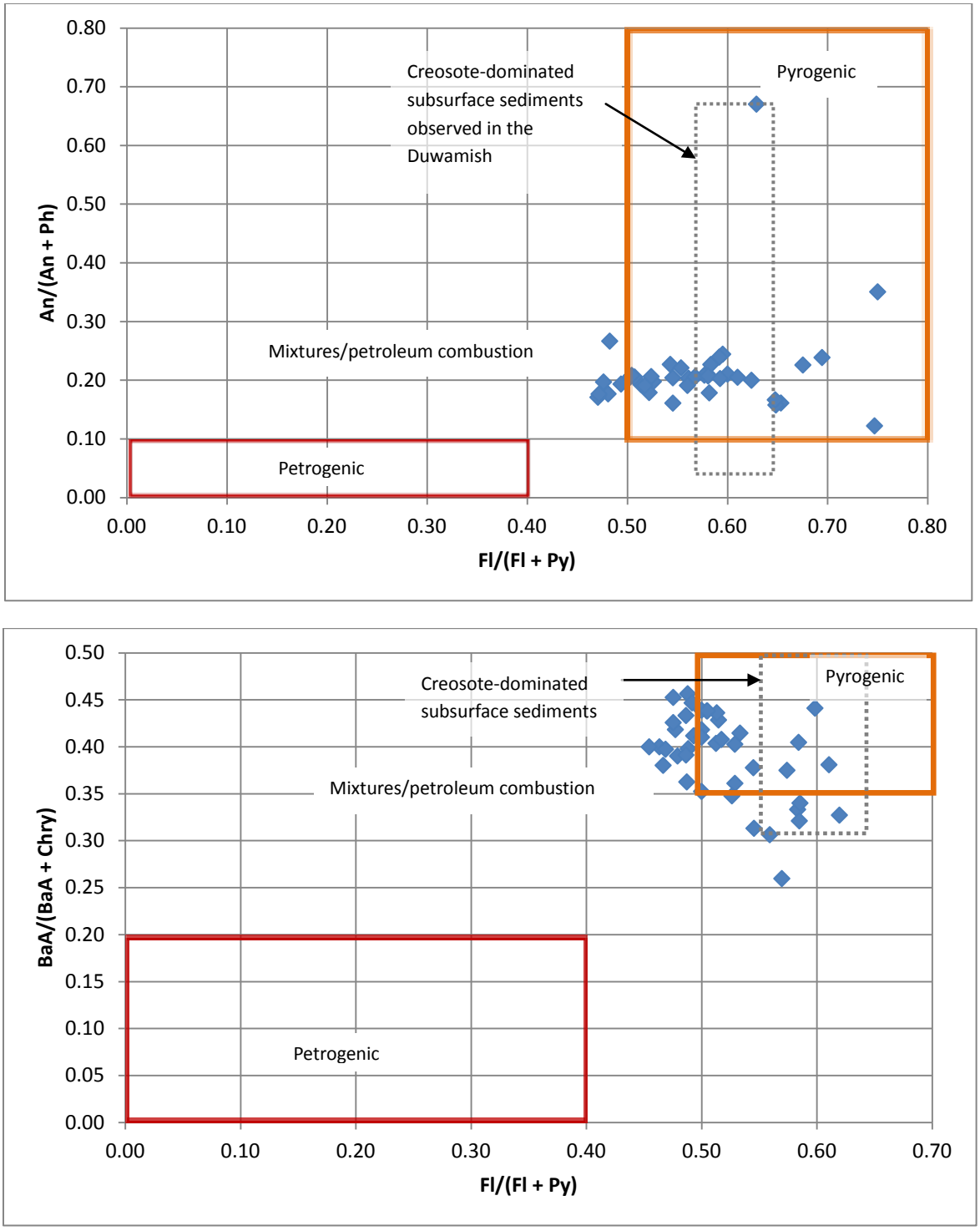


Figure 5-16. Cross-Plots of Selected PAHs Observed in Port Gamble Bay.
Values compared to ranges for petrogenic and pyrogenic PAHs established for Puget Sound (Zemo 2009).

The ratios used in this analysis were as follows:

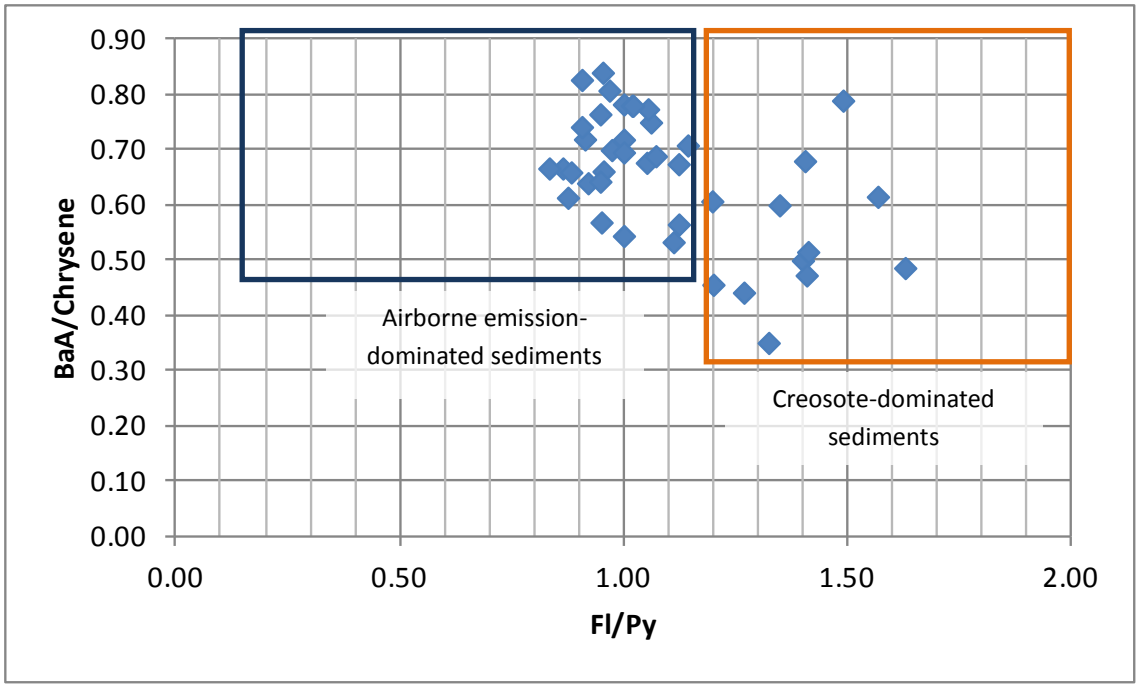
- Benzo(a)anthracene/chrysene vs. fluoranthene/pyrene
- Benzo(a)anthracene/ benzo(a)pyrene vs. fluoranthene/pyrene

Based on this analysis, the majority of samples collected in Port Gamble Bay fall into the ranges observed for airborne emissions (Figure 5-17). However, a subgroup of stations north and south of the former mill site had ratios similar to those of creosote-dominated sediments: Stations MS-11, 13, 14, 15, DV-02/03, and SG-1016, 1017, 1019, 1020, and 1021.

To further evaluate the sources of PAHs, a principal components analysis (PCA) was used to better understand the distribution of PAHs throughout the bay. The PCA helps determine which PAHs or groups of PAHs are most important in explaining the overall distribution of PAHs in the bay and provides a basis for grouping stations with similar distributions of PAHs. PCA is a statistical procedure that serves to reduce the number of variables that explain the variance in the PAH data set by creating new variables that are linear combinations of the original list of PAHs that show similar patterns among the samples. Components with eigenvalues greater than one were retained in the analysis and an orthogonal rotation was applied. The orthogonal rotation results in uncorrelated components. Two PCA analyses were run using normalized values for each PAH, with one-half the detection limit used for analytes with "U" values. Samples with a high number of non-detects were not included in the analysis. The first (Run A) included total benzofluoranthenes but excluded five samples for which no data were available for these analytes. The second (Run B) included the five samples but excluded benzofluoranthenes.

While the primary factors in the two runs differed slightly, the station groupings were very similar. For the purposes of this discussion, the second run with all stations not including total benzofluoranthenes will be used. Run B produced three factors with eigenvalues greater than one, which accounted for a cumulative 94% of the variance (69%, 17%, and 8%, respectively). Factor 1 was driven primarily by the HPAHs chrysene, benzo(a)pyrene, benzo(a)anthracene, and indeno(1,2,3-cd)pyrene. Factor 2 included the LPAHs naphthalene, anthracene, and phenanthrene. A third factor (fluorene, 2-methylnaphthalene, and acenaphthene) distinguished only one sample (DV-02) from the rest and was not plotted.

The majority of samples (Group A) in Port Gamble Bay were characterized by nearly equal distributions of Factors 1 and 2 (Figure 5-18). This is reflected in the relative proportions of LPAH and HPAH in the majority of the Port Gamble Bay sediments, which generally range from 40–50% for LPAHs and 50–60% for HPAHs. The relative proportions of PAHs for stations representative of this group (Station BW-11 and BW-19) are shown in Figure 5-19A.



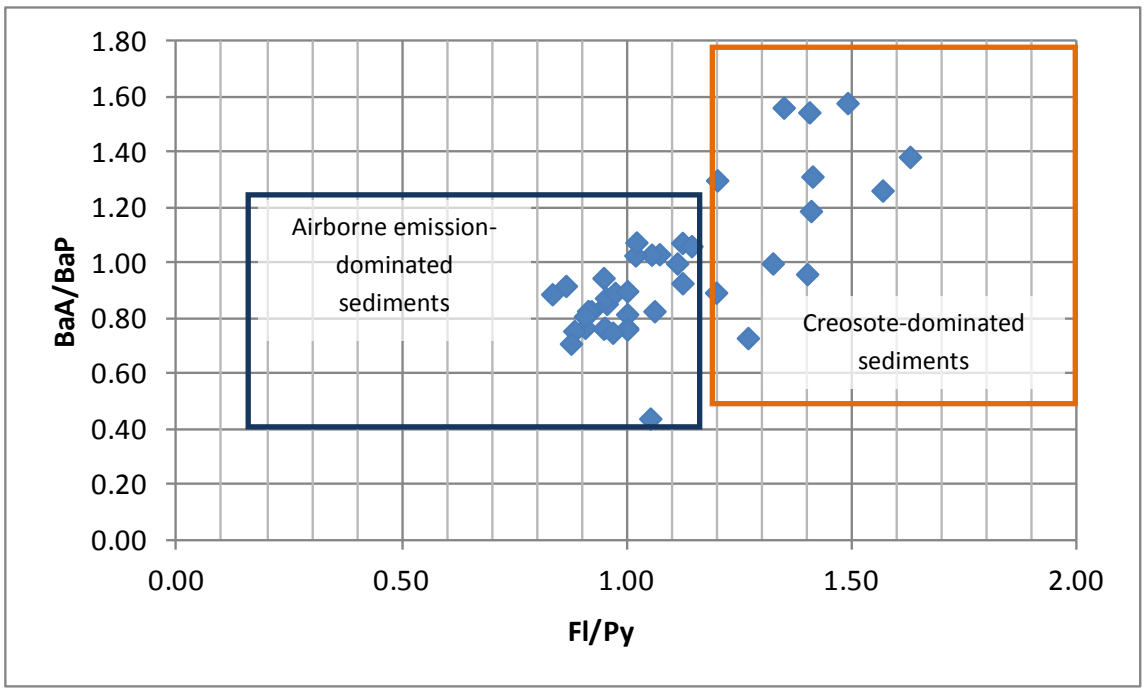


Figure 5-17. Cross-Plots of Selected PAHs Observed in Port Gamble Bay.
Values compared to ranges for urban sources (airborne emissions) and creosote-dominated sediments established for Puget Sound (Zemo 2009).

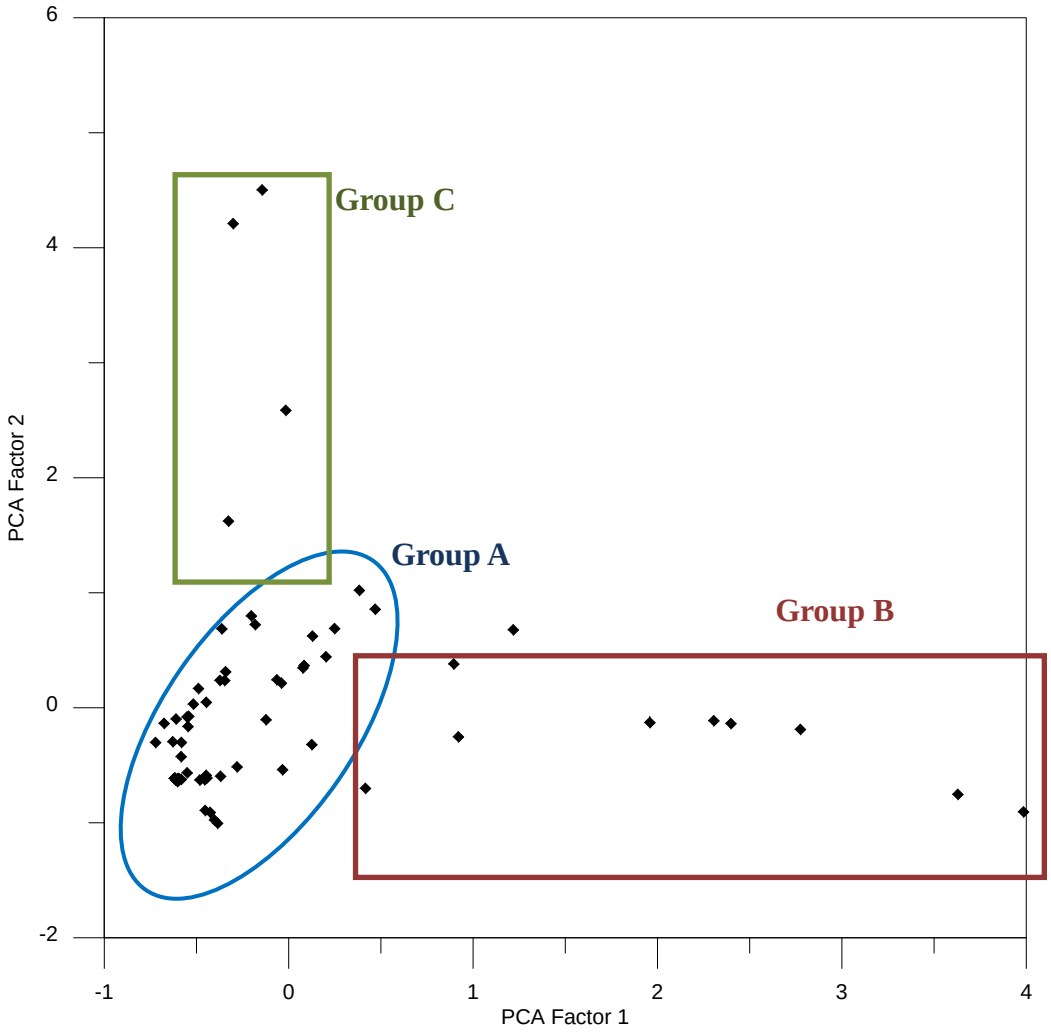
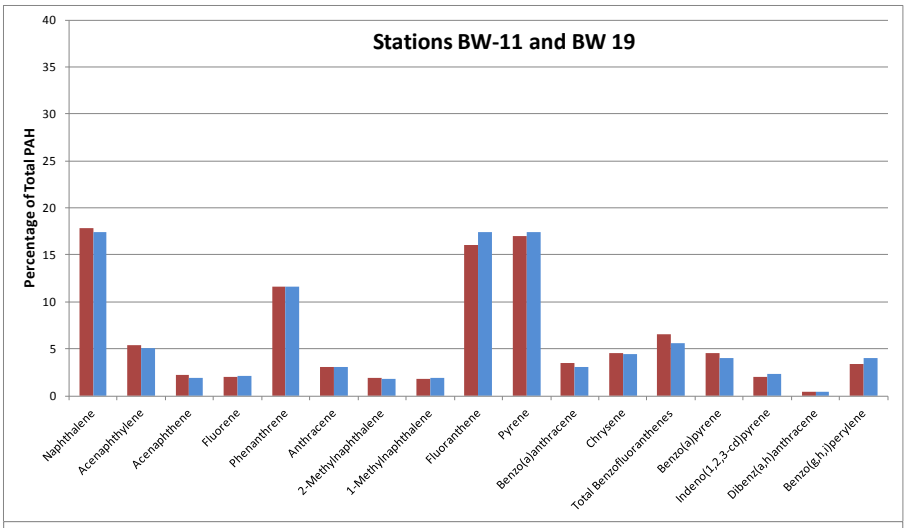
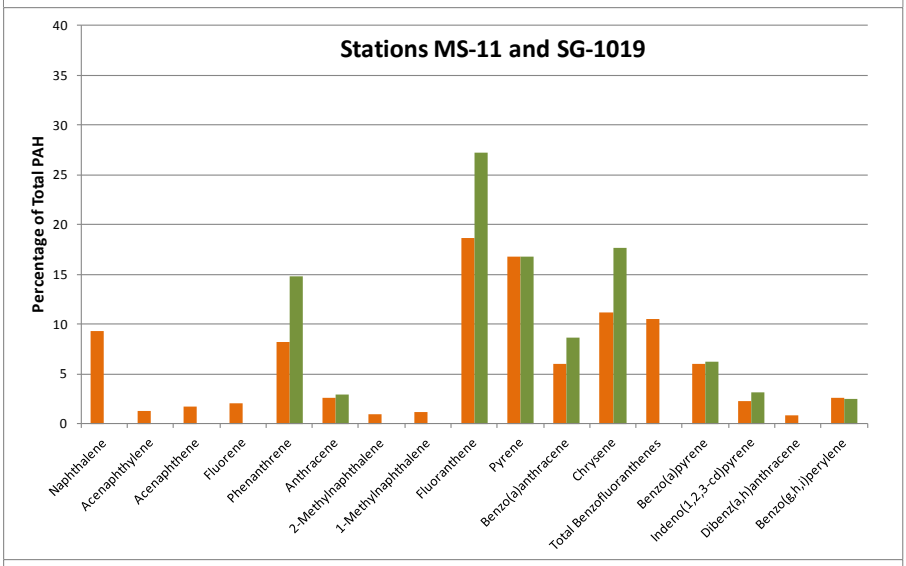


Figure 5-18. Principal Component Analysis for PAHs in Port Gamble

Group A



Group B



Group C

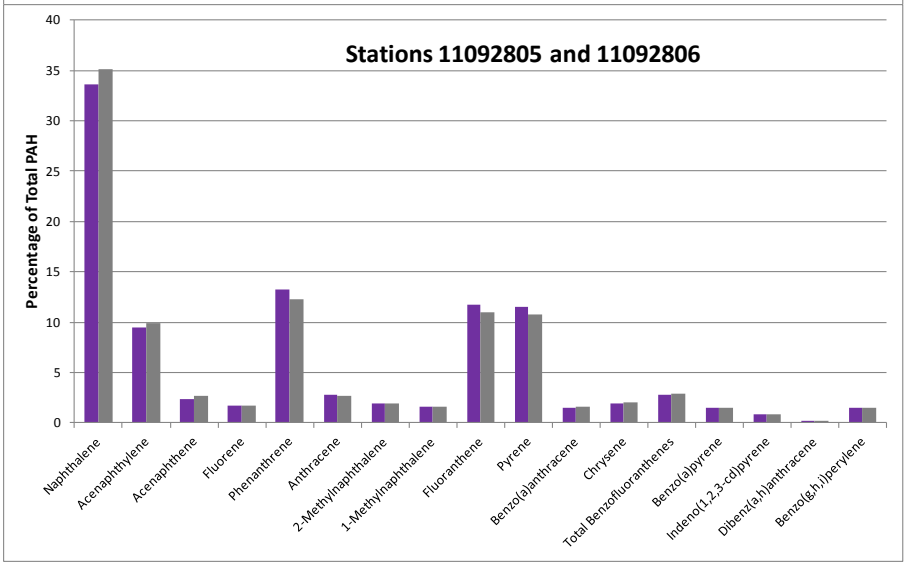


Figure 5-19. Distributions of PAHs in Samples Representative of Groups A, B, and C

A second group of samples (Group B) were characterized by a higher proportion of HPAHs. This group included one station in the northern embayment (Stations MS-11), one station immediately south of the point (Station MS-13) and a group of stations along the boundary of the 2007 dredge area (Stations DV-01, 02/03, SG-1017, 1019, and 1020). As predicted by the PCA, these sediments have higher concentrations of HPAHs and the LPAHs comprise a small fraction of the total PAH (Figure 5-19B). These samples are suggestive of creosote-dominated sources.

The third group (Group C) is characterized by high proportions of LPAHs, in particular naphthalene, anthracene, and phenanthrene (Figure 5-19C). Group C included four stations located offshore of the log-transfer facility (PGST-03, 04, 05, and 06). It is unusual to see high concentrations of these easily weathered, short-chain PAHs in subtidal sediments. It is unclear why these stations are different; all four samples were collected during the same survey (PGST 2011), suggesting the potential for field contamination. It is interesting to note that two other stations collected during the same survey (PGST-01 and -02), as well as stations collected during the NewFields 2011 survey (Stations BW-04, BW-10, and BW-15), fell into Group A.

It is important to note that it is difficult to "fingerprint" the nature and sources of PAHs using the 16 priority pollutant PAHs alone. This is particularly true when there are low concentrations and a mixture of sources, as occurs in Port Gamble Bay. However, Zemo (2009), Stout (2003), and Stout and Graan (2010) provide some basis for comparison using priority PAHs, particularly in Puget Sound, since some of the defined relationships were developed in Puget Sound. Furthermore, the PAHs used in these relationships were detected in a majority of samples.

While there are limitations in this data set, it does appear that the PAHs detected in Port Gamble Bay are generally similar with several exceptions. The detected PAHs for most samples indicate a mixture of pyrogenic sources including both airborne emissions and creosote. A more detailed chemical analysis with alkylated PAHs and higher concentrations would be required to further distinguish among sources. For a subset of samples in the vicinity of the former mill, there does appear to be a group of samples of creosote origin. An additional group of stations were dominated by three LPAHs. It is unclear what the source is for these samples; however, these are easily degraded PAHs that are not typically found in subtidal sediments.

5.5.2 Phenols

Phenol was the most commonly detected ionizable SVOC, found in 25 of 51 subtidal samples in the bay, 12 of 15 samples near the mill, and 10 of 14 intertidal samples (Figure 5-20, Tables 5-7, 5-8). Two samples within the FLA, PGSS-8 AND PGSS-22, exceeded the SQS screening level of 420 mg/kg and one sample collected just east of the FLTF, PGSS-58, also exceeded the SQS criterion. One sample in the north embayment near the mill had the highest concentration of 3900 mg/kg. Most other phenol detections were in samples collected from the western edge of the bay between the FLTF and the former mill. Levels in intertidal sediments were lower, ranging up to 92 µg/kg, below the SQS. Phenol is generally correlated with the presence of wood, high TVS/TOC ratio, sulfide, and ammonia. Phenol is a product of wood degradation and is also a component of creosote.

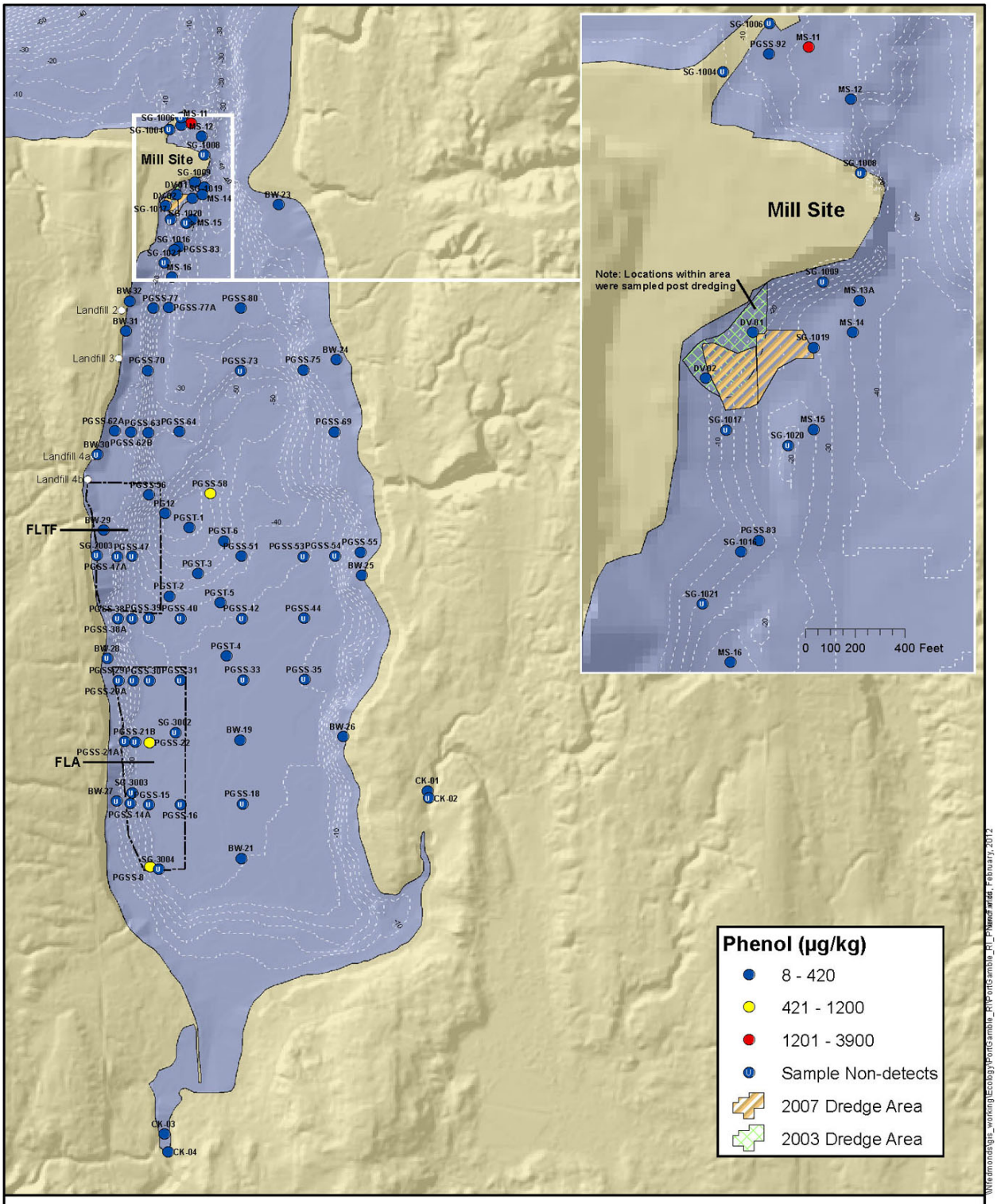


Figure 5-20. Surface Sediment Phenol

Table 5-7. Summary of Sediment Semivolatile Organic Compound (SVOC) Results – Dry Weight

	Port Gamble Bay Samples						Mill Area Samples					
	Samples	Detects	Minimum	Maximum	Mean	90th %ile	Samples	Detects	Minimum	Maximum	Mean	90th %ile
Subtidal Samples												
Chlorinated Benzenes in µg/kg												
1,2-Dichlorobenzene	51	0	2.4	40	19.1	20	15	0	2.3	20	5.71	14.1
1,3-Dichlorobenzene	51	0	2.5	40	19.1	20	13	0	2.4	20	5.99	16.6
1,4-Dichlorobenzene	51	0	2.8	40	19.1	20	15	1	2.6	20	6.11	14.1
1,2,4-Trichlorobenzene	51	0	2.1	40	19	20	15	1	2.1	20	7.31	16.2
Hexachlorobenzene	51	0	2.1	40	19	20	15	1	2.1	20	9.61	19.6
Phthalate Esters in µg/kg												
Dimethylphthalate	51	0	2.8	47	21	20	15	1	2.7	39	14.4	32.8
Diethylphthalate	51	1	19	50	26.3	48	15	1	11	39	28.5	35.6
Di-n-Butylphthalate	51	0	7.9	47	21.2	20	15	2	7.5	39	17	32.8
Butylbenzylphthalate	51	0	5.9	47	21.1	20	15	1	4.6	39	15.5	32.8
bis(2-Ethylhexyl)phthalate	51	5	11	50	23.4	39	15	7	9.8	92	28.8	57.4
Di-n-Octyl phthalate	51	0	5.6	47	21.1	20	15	2	3.7	54	17.2	37.8
Miscellaneous Compounds in µg/kg												
Dibenzofuran	51	9	5.2	110	26.7	45	15	8	6.6	118.5	32.8	50.4
Hexachlorobutadiene	51	0	2.1	99	19.5	20	15	1	2.1	23	10.2	21.2
N-Nitrosodiphenylamine	51	0	5.2	40	20	20	15	1	4.9	20	10.6	19.6
Guaiacol	39	0	19	40	20.9	20	2	0	19	20	19.5	19.9
Retene	39	4	10	110	23.2	20	2	0	19	20	19.5	19.9
Ionizable Organic Compounds in µg/kg												
Phenol	51	25	19	720	90.5	220	15	12	12	3900	333	230
2-Methylphenol	51	0	5.1	40	20	20	15	2	4.8	20	11.5	19.6
4-Methylphenol	51	13	18	240	47.7	120	15	9	15	1850	165	112
2,4-Dimethylphenol	51	0	3.3	40	20.3	20	15	2	3.2	86	16.9	20
Pentachlorophenol	51	0	47	200	117	190	15	1	27	160	75.3	134
Benzyl Alcohol	51	0	5.9	47	21.1	20	15	2	5.6	39	17.2	32.8
Benzoic Acid	51	8	97	600	205	230	15	2	93	785	203	322
Intertidal Samples												
Chlorinated Benzenes in µg/kg												
1,2-Dichlorobenzene	15	0	2.2	2.7	2.38	2.4	4	0	2.1	3	2.67	2.94
1,3-Dichlorobenzene	15	0	2.3	2.7	2.49	2.6	4	0	2.1	3	2.67	2.94
1,4-Dichlorobenzene	15	0	2.5	2.8	2.7	2.8	4	0	2.1	3	2.67	2.94
1,2,4-Trichlorobenzene	15	0	2.1	3.4	3.22	3.4	4	0	1.7	1.8	1.75	1.8
Hexachlorobenzene	15	0	2.1	4.2	3.91	4.2	4	0	1.7	1.8	1.75	1.8
Phthalate Esters in µg/kg												
Dimethylphthalate	15	0	2.6	21	3.95	2.8	4	0	16.0	18	17.5	18
Diethylphthalate	15	1	13	36	32.2	35.6	4	0	16.0	18	17.5	18

Table 5-7. Summary of Sediment Semivolatile Organic Compound (SVOC) Results – Dry Weight

	Port Gamble Bay Samples						Mill Area Samples					
	Samples	**Detects**	**Minimum**	**Maximum**	**Mean**	**90th %ile**	**Samples**	**Detects**	**Minimum**	**Maximum**	**Mean**	**90th %ile**
Di-n-Butylphthalate	15	0	7.3	21	8.59	7.96	4	0	16.0	18	17.5	18
Butylbenzylphthalate	15	1	5.5	29	7.35	6	4	0	16.0	18	17.5	18
bis(2-Ethylhexyl)phthalate	15	1	13	21	14.2	14	4	1	16.0	22	18.5	20.8
Di-n-Octyl phthalate	15	0	5.2	21	6.55	5.7	4	0	16.0	18	17.5	18
Miscellaneous Compounds in µg/kg												
Dibenzofuran	15	6	1.7	26	6.94	19.8	10	5	1.8	18	12.9	18
Hexachlorobutadiene	15	0	2.1	4.5	4.17	4.4	4	0	1.7	1.8	1.75	1.8
N-Nitrosodiphenylamine	15	0	4.8	10	5.41	5.26	4	0	8.0	9	8.75	9
Ionizable Organic Compounds in µg/kg												
Phenol	15	10	7.7	92	26.3	43.2	4	0	16.0	18	17.5	18
2-Methylphenol	15	1	4.7	11	5.69	8.04	4	0	8.0	9	8.75	9
4-Methylphenol	15	0	5.9	21	7.23	6.46	4	0	16.0	18	17.5	18
2,4-Dimethylphenol	15	0	3.1	10	3.72	3.4	4	0	8.0	9	8.75	9
Pentachlorophenol	15	0	43	82	48.2	47.6	4	0	66.0	74	70.3	73.1
Benzyl Alcohol	15	0	5.4	3300	226	15	4	0	16.0	18	17.5	18
Benzoic Acid	15	2	90	750	165	328	4	0	82.0	92	87.8	91.1

Non-detects included in descriptive statistics.

Table 5-8. Summary of Sediment Semivolatile Organic Compound (SVOC) Results – Organic Carbon Normalized

	Port Gamble Bay Samples						Mill Area Samples					
	Samples	Detects	Minimum	Maximum	Mean	90th %ile	Samples	Detects	Minimum	Maximum	Mean	90th %ile
Subtidal Samples												
Chlorinated Benzenes in mg/kg OC												
1,2-Dichlorobenzene	51	0	0.11	6.1	1	1.5	15	0	0.015	1	0.234	0.624
1,3-Dichlorobenzene	51	0	0.12	6.1	1	1.5	13	0	0.062	1	0.27	0.646
1,4-Dichlorobenzene	51	0	0.13	6.1	1	1.5	15	1	0.022	1	0.246	0.652
1,2,4-Trichlorobenzene	51	0	0.12	6.1	1	1.5	15	1	0.017	1	0.277	0.732
Hexachlorobenzene	51	0	0.12	6.1	1	1.5	15	1	0.024	1	0.333	0.846
Phthalate Esters in mg/kg OC												
Dimethylphthalate	51	0	0.13	6.1	1.07	1.6	15	1	0.021	1.9	0.465	0.864
Diethylphthalate	51	1	0.4	6.1	1.24	1.9	15	1	0.067	8.3	1.56	2.1
Di-n-Butylphthalate	51	0	0.37	6.1	1.08	1.6	15	2	0.034	1.9	0.633	1.48
Butylbenzylphthalate	51	0	0.27	6.1	1.08	1.6	15	1	0.017	1.9	0.567	1.24
bis(2-Ethylhexyl)phthalate	51	5	0.36	6.1	1.14	1.6	15	7	0.12	3.3	0.974	2.14
Di-n-Octyl phthalate	51	0	0.26	6.1	1.08	1.6	15	2	0.014	1.9	0.607	1.36
Miscellaneous Compounds in mg/kg OC												
Dibenzofuran	51	9	0.16	610	14.6	2.7	15	8	0.15	3.3	1.03	1.78
Hexachlorobutadiene	51	6	0.12	6.1	1.02	2	15	1	0.016	1	0.349	0.864
N-Nitrosodiphenylamine	51	0	0.24	6.1	1.04	1.5	15	1	0.025	1.2	0.414	0.964
Intertidal Samples												
Chlorinated Benzenes in mg/kg OC												
1,2-Dichlorobenzene	15	0	0.029	0.94	0.37	0.618	4	0	0.18	3.5	1.22	2.75
1,3-Dichlorobenzene	15	0	0.031	0.98	0.38	0.644	4	0	0.18	3.5	1.22	2.75
1,4-Dichlorobenzene	15	0	0.034	1.1	0.42	0.694	4	0	0.18	3.5	1.22	2.75
1,2,4-Trichlorobenzene	15	0	0.042	1.3	0.5	0.856	4	0	0.12	2.1	0.74	1.64
Hexachlorobenzene	15	0	0.05	1.6	0.62	1.06	4	0	0.12	2.1	0.74	1.64
Phthalate Esters in mg/kg OC												
Dimethylphthalate	15	0	0.034	1.8	0.53	0.952	4	0	1.2	20	7.18	15.8
Diethylphthalate	15	1	0.24	14	5.25	8.88	4	0	1.2	20	7.18	15.8
Di-n-Butylphthalate	15	0	0.096	3.1	1.28	2.02	4	0	1.2	20	7.18	15.8
Butylbenzylphthalate	15	1	0.072	2.4	1.03	2.02	4	0	1.2	20	7.18	15.8
bis(2-Ethylhexyl)phthalate	15	1	0.17	5.5	2.17	3.56	4	1	1.5	20	7.25	15.8
Di-n-Octyl phthalate	15	0	0.068	2.2	0.94	1.68	4	0	1.2	20	7.18	15.8
Miscellaneous Compounds in mg/kg OC												
Dibenzofuran	15	6	0.033	1.8	0.61	1.2	10	5	0.19	20	3.75	7.4
Hexachlorobutadiene	15	0	0.054	1.7	0.66	1.12	4	0	0.12	2.1	0.74	1.64
N-Nitrosodiphenylamine	15	0	0.063	2	0.81	1.32	4	0	0.6	10	3.59	7.9

Non-detects included in descriptive statistics.

In addition to phenol, 4-methylphenol was detected in 22 of 66 subtidal samples and 2-methylphenol was detected in 2 of 66 subtidal and 1 of 14 intertidal samples. Two of these samples near the mill site exceeded the CSL for 4-methylphenol. These compounds are also often associated with wood waste as well as creosote. None of the phenols or other ionizable organic compounds detected are considered contaminants of concern for human health (see Section 8).

5.5.3 Other Semivolatile Analytes

Diethylphthalate, bis(2-ethylhexyl)phthalate, dibenzofuran, retene, and benzoic acid were detected at 1–5 subtidal stations each at levels below the SQS. Diethylphthalate, dibenzofuran, and benzoic acid were also detected at 1-6 intertidal stations each, at levels below the SQS. Phthalates are often associated with stormwater outfalls. Dibenzofuran is a constituent of creosote, while retene and benzoic acid are degradation products of wood waste. None of these compounds is considered a contaminant of concern for human health (see Section 8).

5.6 Polychlorinated Biphenyls

Aroclor 1254 was detected in two samples in the bay at concentrations below the SQS screening criterion (Tables 5-9, 5-10). Aroclors 1242 and 1260 were detected in two samples near the former mill, and one of these samples exceeded the SQS criterion.

To evaluate human health risks from recreational and tribal use of beach areas, including general beach use and shellfish collection activities, PCB congeners were analyzed at all 14 intertidal sediments (Table 5-11, Figure 5-21). At least some PCB congeners were detected at all stations, and dioxin-like PCB congener TEQs (corresponding to 2,3,7,8- tetrachlorodibenzo-p-dioxin (TCDD) equivalents) ranged from 0.0059–0.197 ng/kg in the bay and 0.014–0.0572 near the former mill. The highest concentration was located at station BW-27 near the FLA.

5.7 Dioxins/Furans

Analytical results for dioxins/furans expressed as 2,3,7,8-TCDD toxic equivalents (TEQs) are presented in Table 5-12 and Figure 5-22. TEQs were calculated using the World Health Organization (WHO) 2005 toxic equivalency factors (TEF) for mammals, because dioxins/furans are considered contaminants of concern for human health and are not of concern to benthic organisms. Values were calculated using the KM approach with 1/2 the detection limit for non-detected results (see Section 8).

Dioxin/furan congeners were detected in all samples. Total TEQ concentrations ranged from 0.34–6.5 ng/kg in the bay, with the highest concentrations located in the central fine-grained portion of the bay. Dioxin/furan congeners were also measured in all 14 intertidal samples around the bay, and TEQs ranged from 0.162–2.04 ng/kg, somewhat lower than in subtidal sediments. At intertidal stations near the mill, dioxin/furan TEQs ranged from 1.23–16 ng/kg, with the highest concentrations along the southern shoreline of the former mill.

Table 5-9. Summary of Sediment Polychlorinated Biphenyl (PCB) Aroclor Results – Dry Weight

	Bay-wide Samples						Mill Area Samples					
	Samples	**Detects**	**Minimum**	**Maximum**	**Mean**	**90th %ile**	**Samples**	**Detects**	**Minimum**	**Maximum**	**Mean**	**90th %ile**
Subtidal Samples												
PCBs in µg/kg												
Aroclor 1016	48	0	3.8	20	6.34	19	11	0	3.7	21	6.93	19
Aroclor 1221	48	0	3.8	20	6.5	19	11	0	3.7	19	5.57	6.1
Aroclor 1232	48	0	3.8	20	6.5	19	11	0	3.7	21	6.93	19
Aroclor 1242	48	0	3.8	20	6.34	19	11	1	3.7	115	16.9	21
Aroclor 1248	48	0	3.8	20	6.34	19	11	0	3.7	19	6.75	19
Aroclor 1254	48	2	3.8	20	6.55	19	11	0	3.7	19	6.02	11
Aroclor 1260	48	0	3.8	20	6.34	19	11	1	3.7	42.5	9.22	19
Aroclor 1262	41	0	3.8	6.1	4.08	4	8	0	3.7	3.9	3.84	3.9
Aroclor 1268	41	0	3.8	6.1	4.08	4	8	0	3.7	3.9	3.84	3.9
Total PCBs	48	2	3.8	20	6.8	19	11	1	3.7	157.5	20.7	21

Non-detects included in descriptive statistics.

Table 5-10. Summary of Sediment Polychlorinated Biphenyl (PCB) Aroclor Results – Organic Carbon Normalized

	Bay-wide Samples						Mill Area Samples					
	Samples	**Detects**	**Minimum**	**Maximum**	**Mean**	**90th %ile**	**Samples**	**Detects**	**Minimum**	**Maximum**	**Mean**	**90th %ile**
Subtidal Samples												
PCBs in mg/kg OC												
Aroclor 1016	48	0	0.077	1.2	0.273	0.509	11	0	0.041	0.92	0.238	0.23
Aroclor 1221	48	0	0.077	1.2	0.278	0.509	11	0	0.021	0.92	0.234	0.23
Aroclor 1232	48	0	0.077	1.2	0.277	0.509	11	0	0.041	0.92	0.238	0.23
Aroclor 1242	48	0	0.077	1.2	0.273	0.509	11	1	0.071	0.92	0.311	0.84
Aroclor 1248	48	0	0.077	1.2	0.273	0.509	11	0	0.041	0.92	0.238	0.23
Aroclor 1254	48	2	0.077	1.2	0.281	0.554	11	0	0.037	0.92	0.235	0.23
Aroclor 1260	48	0	0.077	1.2	0.273	0.509	11	1	0.031	0.92	0.259	0.31
Aroclor 1262	41	0	0.077	1.2	0.227	0.36	8	0	0.13	0.92	0.285	0.437
Aroclor 1268	41	0	0.077	1.2	0.227	0.36	8	0	0.13	0.92	0.285	0.437
Total PCBs	48	2	0.077	1.2	0.289	0.554	11	1	0.071	1.13	0.337	0.92

Non-detects included in descriptive statistics.

Table 5-11. Summary of Polychlorinated Biphenyl (PCB) Congener Results – Dry Weight

	Bay-wide Samples						Mill Area Samples					
	Samples	**Detects**	**Minimum**	**Maximum**	**Mean**	**90th %ile**	**Samples**	**Detects**	**Minimum**	**Maximum**	**Mean**	**90th %ile**
Intertidal Samples												
PCB Congeners in pg/g												
PCB-077	14	14	0.423	5.26	2.18	4.58	6	6	1.14	13.3	6.99	11.3
PCB-081	14	1	0.0627	0.316	0.152	0.217	6	1	0.09	0.566	0.323	0.497
PCB-105	14	14	1.88	547.5	53.4	54.5	6	5	13.90	69.4	45.9	65.3
PCB-114	14	11	0.09	27.4	2.59	2.59	6	6	0.48	3.34	2.06	3.1
PCB-118	14	14	4.15	1267	122	120	6	6	28.70	148	97.5	141
PCB-123	14	10	0.1	19.735	2.07	2.11	6	5	0.57	3.31	2.16	3.12
PCB-126	14	3	0.0559	1.95	0.491	1.03	6	0	0.13	0.484	0.343	0.469
PCB-156/157	14	13	0.452	157.7	17.5	20.9	6	6	6.15	37.2	16.6	30.1
PCB-167	14	12	0.183	47.75	6.33	10.6	6	6	2.35	15.5	6.14	11.8
PCB-169	14	0	0.0704	1.13	0.242	0.329	6	0	0.09	0.612	0.218	0.401
PCB-170	14	13	1.04	259	35.4	72.2	6	6	10.90	234	57.4	135
PCB-180/193	14	14	2.25	1010	110	142	6	6	22.10	574	144	330
PCB-189	14	10	0.0555	8.37	1.34	2.68	6	5	0.38	8.79	2.19	5.1
PCB TEQ	14	14	0.00587	0.197	0.0547	0.116	6	6	0.014	0.0572	0.0408	0.0568

Non-detects included in descriptive statistics.

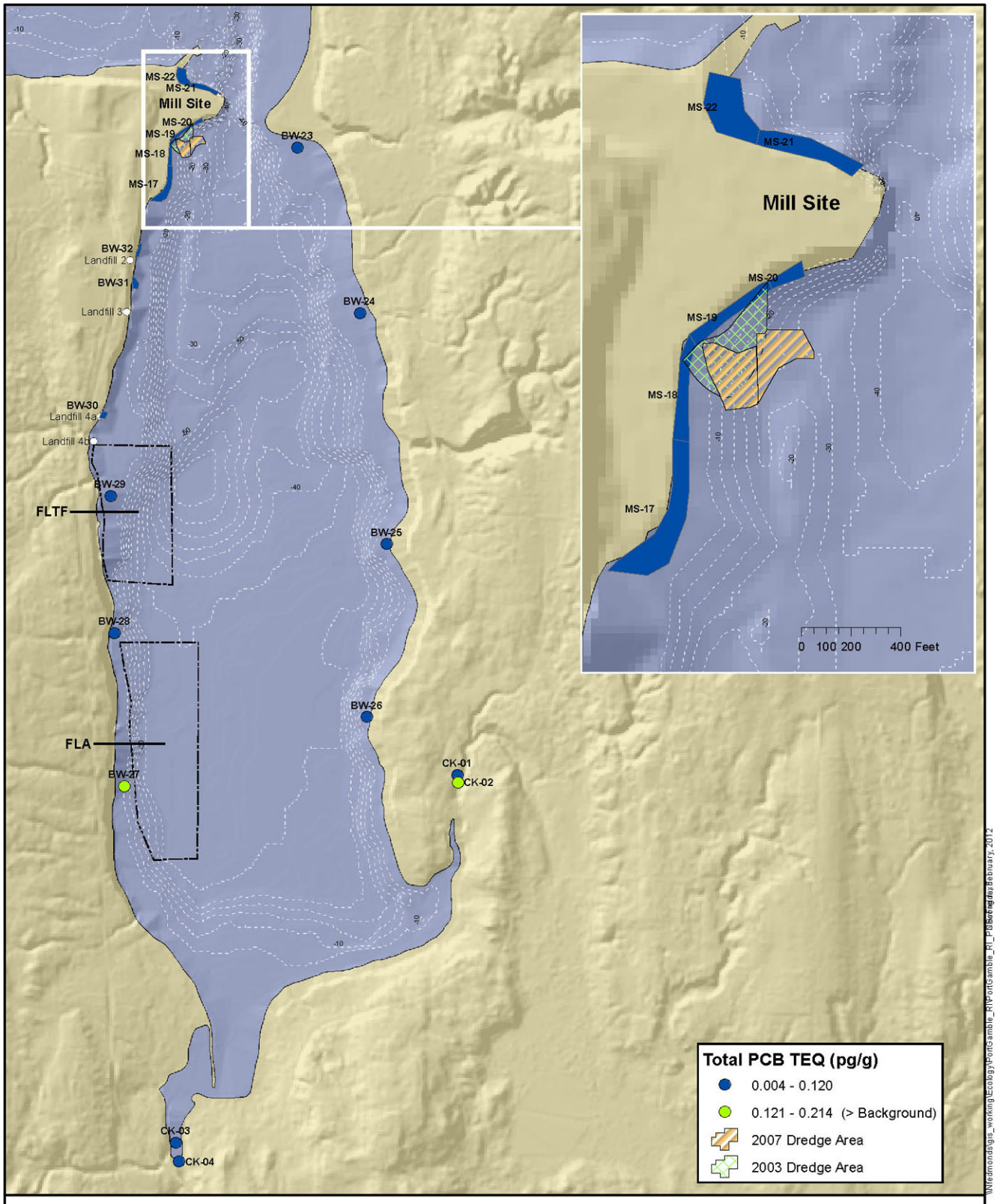


Figure 5-21. Surface Sediment PCB TEQ

Table 5-12. Summary of Sediment Dioxin/Furan Congener Results

	Bay-wide Samples						Mill Area Samples					
	Samples	Detects	Minimum	Maximum	Mean	90th %ile	Samples	Detects	Minimum	Maximum	Mean	90th %ile
Subtidal Results												
Dioxins/furans in ng/kg												
2,3,7,8-TCDD	18	5	0.0877	1.02	0.395	0.729	1	0	0.11	0.11	0.11	0.11
1,2,3,7,8-PeCDD	18	9	0.242	2.25	0.991	1.78	1	1	0.555	0.555	0.555	0.555
1,2,3,4,7,8-HxCDD	18	7	0.356	2.44	0.982	1.68	1	0	0.375	0.375	0.375	0.375
1,2,3,6,7,8-HxCDD	18	13	0.376	6.05	2.87	5.77	1	1	2.38	2.38	2.38	2.38
1,2,3,7,8,9-HxCDD	18	12	0.206	6.11	2.76	5.33	1	1	1.17	1.17	1.17	1.17
1,2,3,4,6,7,8-HpCDD	18	18	1.42	105	45.2	86.4	1	1	89.8	89.8	89.8	89.8
OCDD	18	18	10.5	1000	403	798	1	1	922	922	922	922
2,3,7,8-TCDF	18	15	0.099	4	2	3.63	1	1	0.832	0.832	0.832	0.832
1,2,3,7,8-PeCDF	18	12	0.279	1.69	0.851	1.53	1	1	0.413	0.413	0.413	0.413
2,3,4,7,8-PeCDF	18	12	0.228	2.27	1.01	1.8	1	0	0.241	0.241	0.241	0.241
1,2,3,4,7,8-HxCDF	18	9	0.502	1.84	0.994	1.64	1	0	0.529	0.529	0.529	0.529
1,2,3,6,7,8-HxCDF	18	7	0.12	1.17	0.537	1.06	1	0	0.127	0.127	0.127	0.127
1,2,3,7,8,9-HxCDF	18	2	0.0508	0.344	0.18	0.275	1	0	0.244	0.244	0.244	0.244
2,3,4,6,7,8-HxCDF	18	10	0.274	1.36	0.684	1.21	1	1	0.537	0.537	0.537	0.537
1,2,3,4,6,7,8-HpCDF	18	17	0.504	15.7	7.3	14	1	1	8.08	8.08	8.08	8.08
1,2,3,4,7,8,9-HpCDF	18	7	0.295	0.804	0.596	0.773	1	0	0.547	0.547	0.547	0.547
OCDF	18	17	0.649	36.9	15.6	31.5	1	1	26	26	26	26
Dioxin/furan TEQ	18	*	0.344	6.50	3.13	6.01	1	*	2.40	2.40	2.40	2.40
Intertidal Results												
Dioxins/furans in ng/kg												
2,3,7,8-TCDD	14	1	0.073	0.3	0.136	0.251	6	4	0.10	0.272	0.182	0.253
1,2,3,7,8-PeCDD	14	11	0.055	0.638	0.226	0.507	6	5	0.34	0.821	0.582	0.778
1,2,3,4,7,8-HxCDD	14	12	0.052	0.656	0.243	0.599	6	6	0.42	4.1	1.48	2.69
1,2,3,6,7,8-HxCDD	14	13	0.151	1.72	0.647	1.38	6	6	1.90	12.5	5.06	8.65
1,2,3,7,8,9-HxCDD	14	8	0.147	1.88	0.687	1.44	6	4	1.13	24.1	6.37	14.8
1,2,3,4,6,7,8-HpCDD	14	14	1.36	45.9	9.29	17.6	6	6	9.18	956	206	576
OCDD	14	14	10.8	356	66.2	106	6	6	40.00	9290	2050	5870
2,3,7,8-TCDF	14	13	0.207	1.3	0.459	0.824	6	4	0.25	0.592	0.369	0.509
1,2,3,7,8-PeCDF	14	9	0.0474	0.772	0.203	0.373	6	5	0.10	0.577	0.344	0.522
2,3,4,7,8-PeCDF	14	8	0.057	0.93	0.25	0.483	6	6	0.15	0.376	0.297	0.368
1,2,3,4,7,8-HxCDF	14	9	0.054	0.802	0.244	0.442	6	6	0.24	6.19	1.73	3.91
1,2,3,6,7,8-HxCDF	14	11	0.0474	0.617	0.174	0.356	6	6	0.23	1.48	0.573	1.01
1,2,3,7,8,9-HxCDF	14	2	0.0468	0.076	0.0569	0.0728	6	1	0.05	0.076	0.0565	0.0705
2,3,4,6,7,8-HxCDF	14	4	0.0474	0.59	0.166	0.333	6	5	0.20	0.754	0.434	0.657
1,2,3,4,6,7,8-HpCDF	14	13	0.298	4.45	1.39	2.67	6	6	2.93	41.3	18.6	41
1,2,3,4,7,8,9-HpCDF	14	7	0.0474	0.336	0.118	0.168	6	4	0.12	3.24	0.97	2.15

Table 5-12. Summary of Sediment Dioxin/Furan Congener Results

	Bay-wide Samples						Mill Area Samples					
	Samples	**Detects**	**Minimum**	**Maximum**	**Mean**	**90th %ile**	**Samples**	**Detects**	**Minimum**	**Maximum**	**Mean**	**90th %ile**
OCDF	14	8	0.44	5.27	2.14	4.51	6	6	2.52	214	51.1	133
Dioxin/furan TEQ	14	*	0.162	2.04	0.697	1.37	6	*	1.23	16.0	4.87	10.5

Non-detects included in descriptive statistics.

* TEQs shown in this table used the method described in Section 8.2.4. Using this method, all final estimated TEQ values are treated as detected; therefore, summary statistics can be calculated on the estimated TEQs even if most or all of the component congeners were undetected.

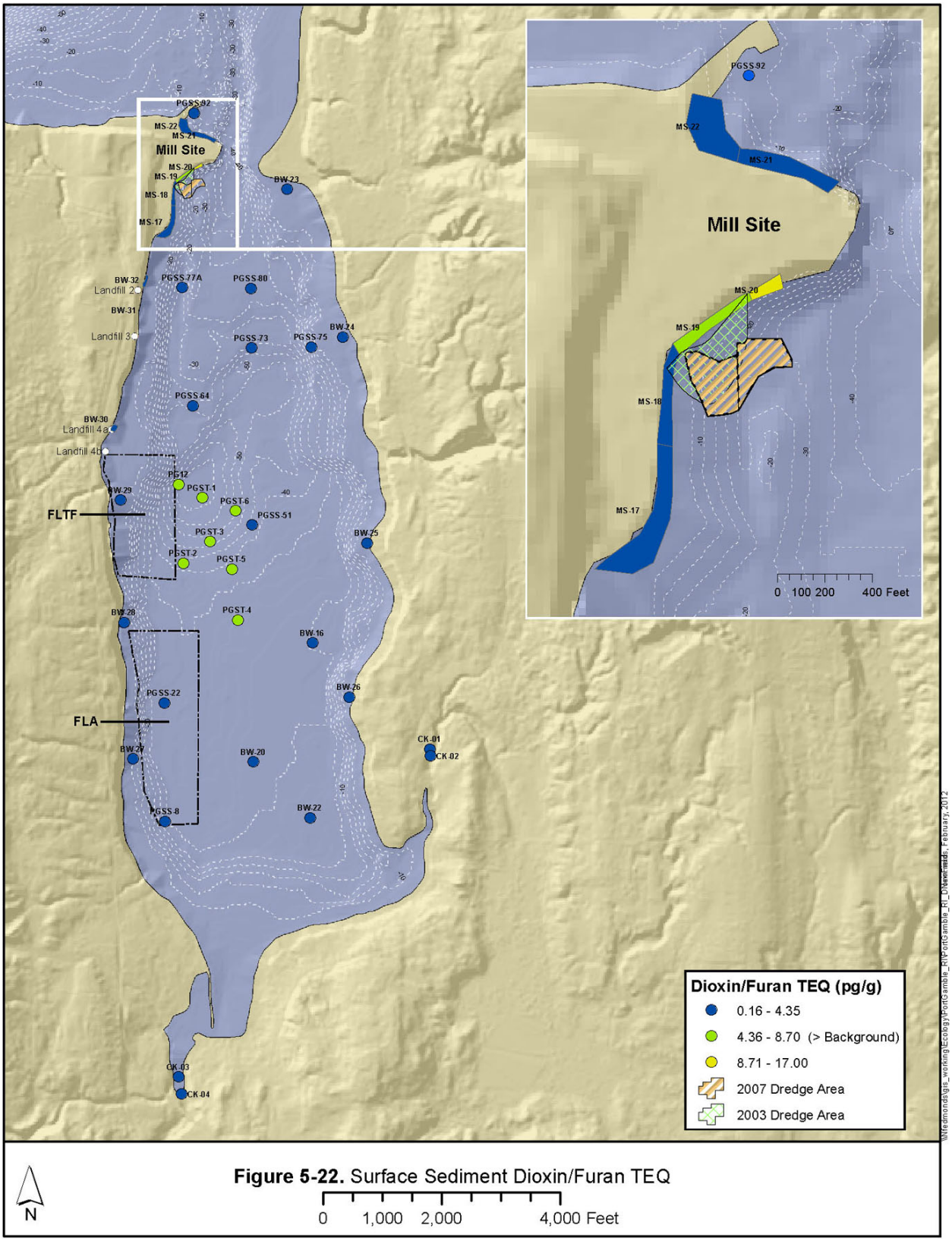


Figure 5-22. Surface Sediment Dioxin/Furan TEQ

Correlations between percent fines and the dioxin/furan TEQs were investigated in the same manner as for metals and PAHs. There were two extreme valued TEQs, found at intertidal station MS-20 and subtidal station MS-11. These stations had TEQ values nearly three times the next highest value. A scatterplot excluding these outliers (Figure 5-23) indicates that there is a fairly strong correlation among stations in the bay, and less so for stations near the mill.

Fingerprint analysis for dioxin/furan congeners involves determining the congener profile, which is the relative amount of each congener to the total dioxin/furan concentration for each sample. Congener profiles from a given site or study area are compared against each other to determine whether differences may exist as a result of unique sources. Individual congener profiles can also be compared to known source profiles as a means of determining the potential source of dioxin for a given area (Cleverly 1997). Table 5-13 shows the number of non-detected and estimated (J-qualified) congener concentrations present in the subtidal, intertidal, and reference data from Port Gamble.

Some of the congeners were rarely detected, including 2,3,7,8-TCDD and 1,2,3,7,8,9-HxCDF. Several other congeners were detected in about half of the samples, but estimated in the many of the remaining samples. From this table, only four congeners were detected in the majority of samples: 1,2,3,4,6,7,8-HpCDD, octachlorodibenzo-p-dioxin (OCDD), 1,2,3,4,6,7,8-HpCDF and octachlorodibenzofuran (OCDF). Unfortunately, this small number of detected congeners precluded the use of PCA as a statistical tool for this data set.

One option for the analysis of the Port Gamble data set was to create ratio cross plots similar to those used for the PAH source identification. Although such cross-plots have little precedent for use with dioxin/furan congeners, they offer two advantages with this data set: they allow all four of the selected congeners to be displayed in two dimensions, and they provide a quick visual screening for outliers or differences between the Port Gamble and reference data sets. Ratios were calculated as the concentrations of furans divided by dioxins for the hepta and octa congeners. As for the PAHs, these ratios were selected to minimize the impacts of weathering. OCDD and OCDF are both fully chlorinated, with 1,2,3,4,6,7,8-HpCDD and 1,2,3,4,6,7,8-HpCDF chlorinated in the same molecular positions. It was assumed that the congeners in each pair would weather at the same rates due to the similar positioning of the chlorine atoms, and thus any ratio differences would be due to differing sources. Ratios were calculated only when all four congeners were detected. As a result, seven samples were excluded, six intertidal and one subtidal (Table 5-13).

The top panel of Figure 5-24 shows the cross-plot ratios for all samples. Three samples are outliers: R_CAR_5 from the reference samples, PG11-MS-22-S from the intertidal samples, and PG-75 from the subtidal samples. There is no spatial or concentration pattern among these samples, so it is not clear why they were outliers.

The bottom panel of Figure 5-24 shows the cross plot ratios without the outliers. There was a high degree of overlap between the intertidal and subtidal samples from Port Gamble and moderate overlap between the reference sediment and that from Port Gamble. While the reference sediment may be slightly enriched in furans relative to dioxin, there is not a large enough distinction between the data

sets to identify a significant difference in the dioxin/furan congener distributions between the Port Gamble and the reference data sets.

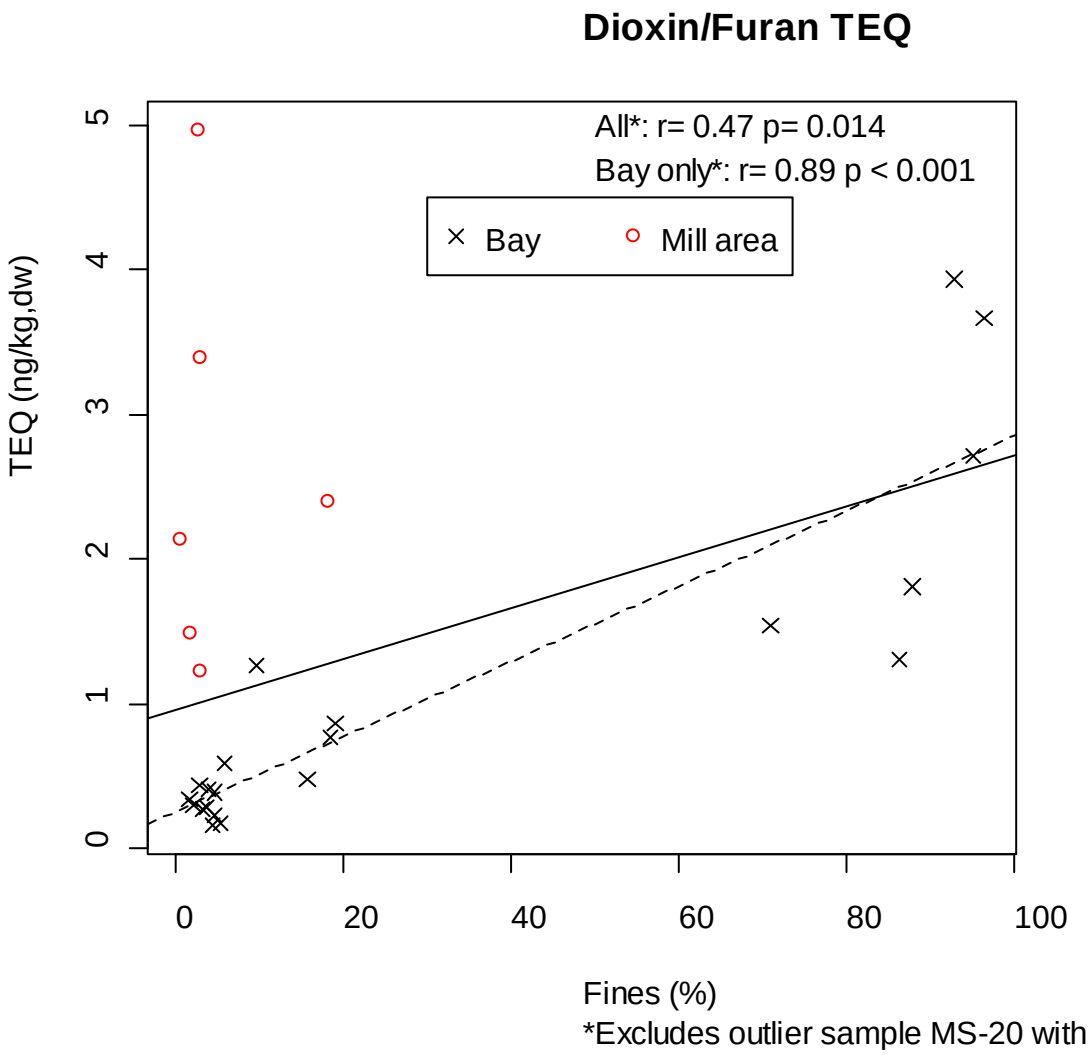


Figure 5-23. Correlations between Dioxin/Furan TEQ Values and the Fine-Grained Sediment Fraction. The best-fit regression line, the Pearson correlation coefficient (r), and its significance level (p) are shown. The solid line shows the best-fit regression line for all the data; the dashed line shows the best-fit regression line for the bay-only samples.

Table 5-13. Nondetected and Estimated Dioxin/Furan Congeners for Port Gamble Bay

	Intertidal		Subtidal		Reference		Total	
	N = 20		N = 19		N = 14		N = 47	
	ND	Estimates	ND	Estimates	ND	Estimates	ND	Estimates
2,3,7,8-TCDD	15	3	14	0	14	0	43	3
1,2,3,7,8-PeCDD	4	8	9	4	10	4	23	16
1,2,3,4,7,8-HxCDD	2	5	12	4	10	4	24	13
1,2,3,6,7,8-HxCDD	1	1	5	5	3	11	9	17
1,2,3,7,8,9-HxCDD	8	6	6	3	6	8	20	17
1,2,3,4,6,7,8-HpCDD	0	0	0	2	0	2	0	4
OCDD	0	0	0	0	0	1	0	1
2,3,7,8-TCDF	3	0	3	4	2	8	8	12
1,2,3,7,8-PeCDF	6	14	6	7	6	7	18	28
2,3,4,7,8-PeCDF	6	7	7	4	3	10	16	21
1,2,3,4,7,8-HxCDF	5	12	10	4	7	7	22	23
1,2,3,6,7,8-HxCDF	3	7	12	4	7	7	22	18
1,2,3,7,8,9-HxCDF	17	3	17	1	12	2	46	6
2,3,4,6,7,8-HxCDF	11	9	8	9	5	9	24	27
1,2,3,4,6,7,8-HpCDF	1	0	1	6	0	11	2	17
1,2,3,4,7,8,9-HpCDF	9	3	12	7	10	4	31	14
OCDF	6	2	1	5	0	11	7	18

ND: Non-detected concentration (U qualified)

Estimates: Detected below reporting limits (T or J qualified)

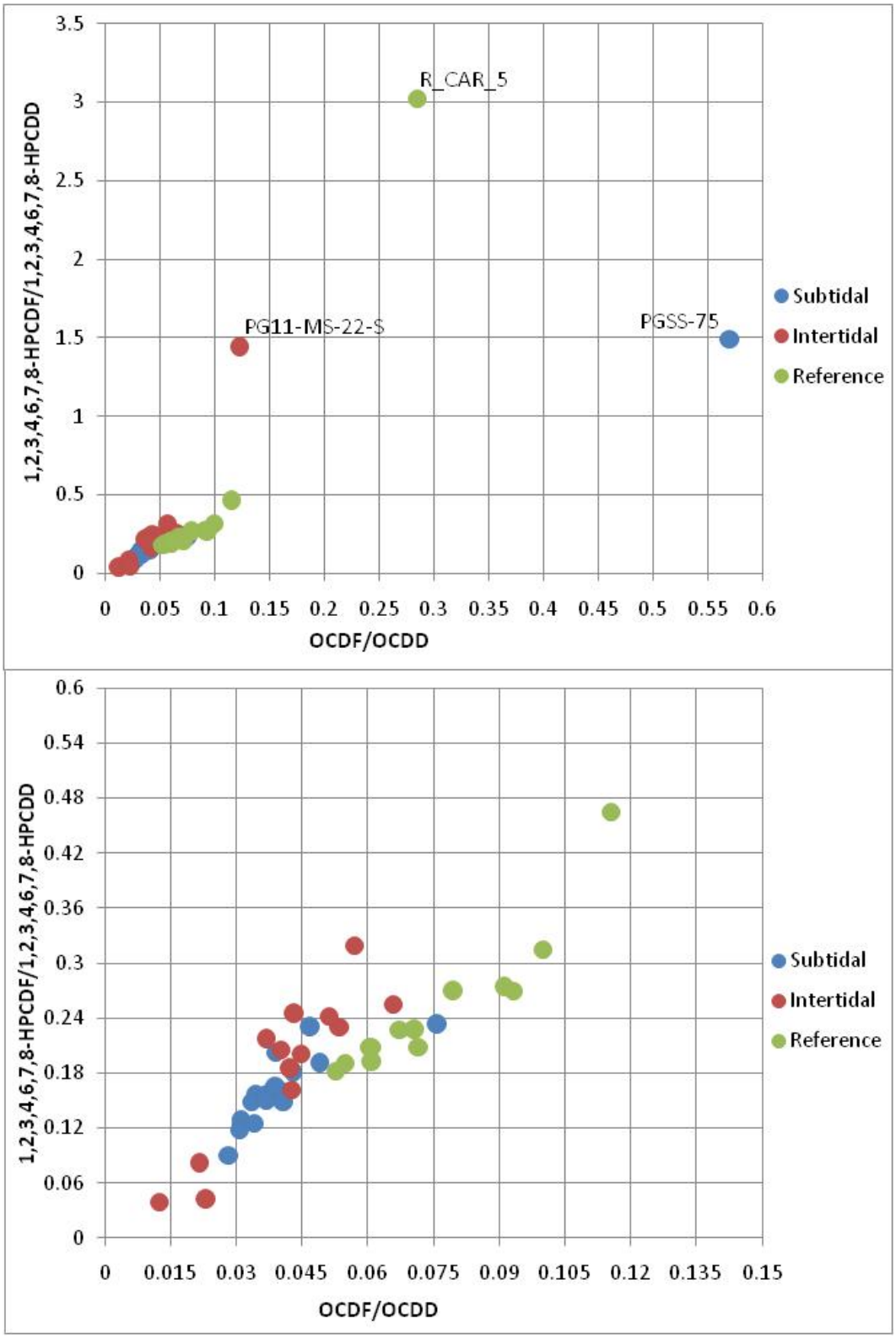


Figure 5-24. Cross-plot Ratios of Hepta Furan/Dioxin Ratio to Octa Furan/Dioxin Ratio

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6.0 TISSUE CHEMISTRY RESULTS

Sample locations for tissue testing results are shown in Figure 3-1. Numeric SMS standards are not available for protection of human health; instead, human health-based cleanup standards are calculated in Section 10 using these data and natural background concentrations. Contaminants in tissues exceeding natural background concentrations are shown in Figure 6-1 and Table 6-1.

6.1 Lipids

Percent lipids ranged widely in tissues from 0.208–6.9% wet weight (ww) (Table 6-2). The lowest lipids were typically found in Dungeness crab meat, as well as cockles, manila clams, and some littleneck clams. The highest lipids were found in Dungeness crab hepatopancreas, followed by oysters.

6.2 Metals

The metals discussed below are those that were considered potential contaminants of concern for human health (see Section 8). Summary concentrations for other metals can be found in Table 6-2 and for individual samples in Appendix A. In general, metals concentrations tended to vary with the percent lipids, with higher metals concentrations corresponding to higher lipid concentrations. In most cases, geographic differences were not as apparent as species differences. Unless otherwise noted, samples near the mill were similar to samples around other areas of the bay.

Arsenic was detected in most samples, except one oyster sample and all cockle samples, ranging from 1–8 mg/kg. The lowest concentrations were found in geoduck, oysters, manila clams, and cockles, and the highest concentrations were found in crab hepatopancreas.

Cadmium was detected in most samples, except two crab meat samples and several cockle samples, ranging from 0.04–1.49 mg/kg. The lowest concentrations were found in crab meat and cockles, while the highest concentrations were found in crab hepatopancreas and oysters.

Copper was detected in all tissue samples ranging from 0.91–19.2 mg/kg around the bay, and 1.86–33.5 near the former mill. The lowest concentrations were found in cockles, followed by littleneck and manila clams, and the highest concentrations were found in crab hepatopancreas and oysters.

Mercury was detected in most samples, except two littleneck clam and two cockle samples, ranging from 0.005–0.047 mg/kg. Lower concentrations were found in geoducks, oysters, and clams, while higher concentrations were found in crab meat and hepatopancreas.

6.3 Polynuclear Aromatic Hydrocarbons

At least one PAH was detected in most oysters and littleneck, manila, and cockle clam samples. PAHs were not detected in geoduck, crab meat, or hepatopancreas samples. In samples where PAHs were detected, cPAH TEQs ranged from 0.35–4.36 µg/kg around the bay, and 0.46–19.0 near the former mill (Table 6-2). The highest concentrations were found in littleneck clam samples near the former mill. Elevated concentrations of cPAH in tissue are generally colocated with areas of creosoted pilings.

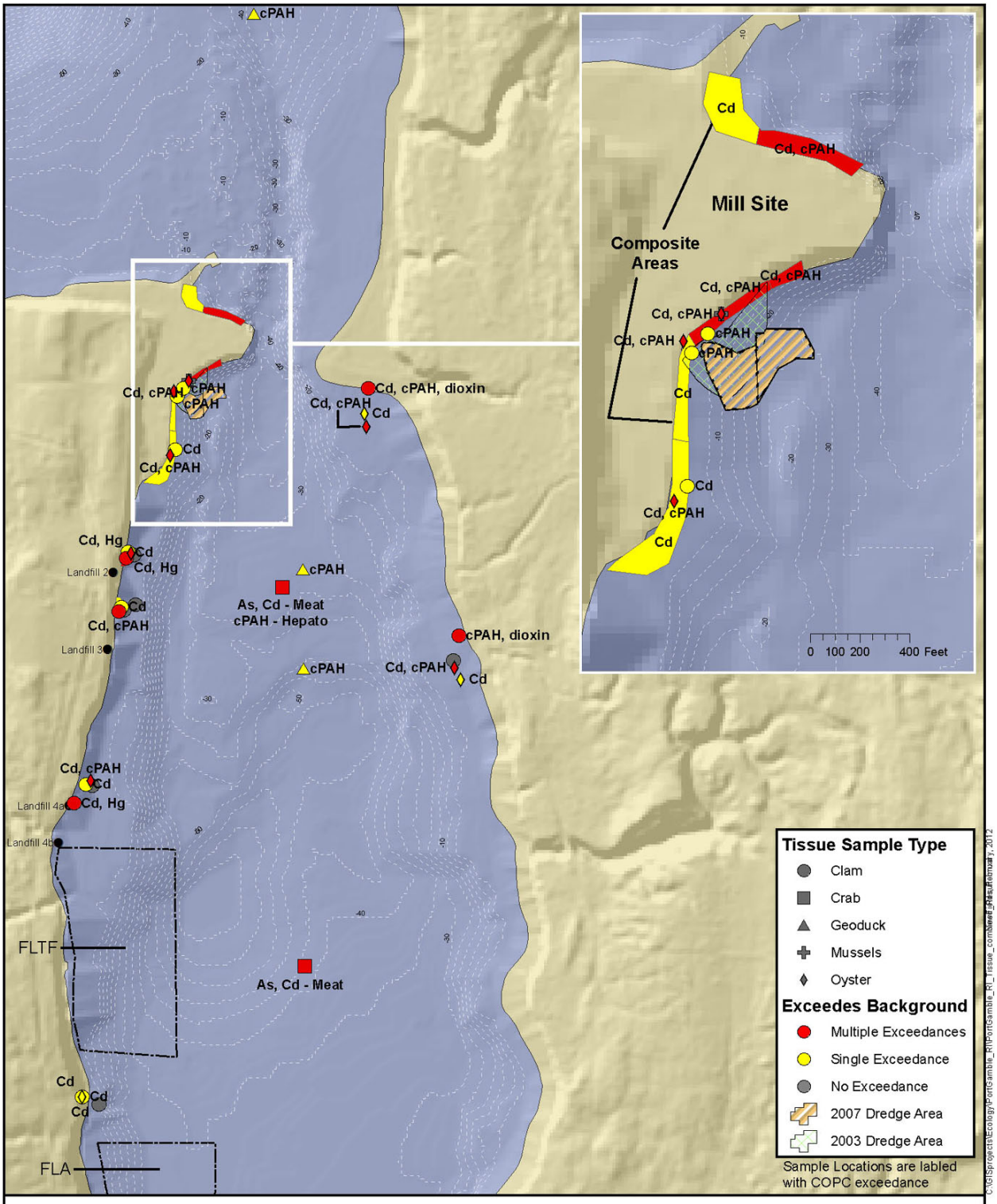

Figure 6-1. Tissue Chemistry Exceedances above Background

Table 6-1. Tissue Concentrations Exceeding Natural Background Concentrations

Sample ID	Organism	Tissue Type	Cadmium	Arsenic (Inorganic)	Mercury	cPAH TEQ	Dioxin/Furan
Maximum Natural Background			**0.26 µg/kg**	**0.62 µg/kg**	**0.014 µg/kg**	**1.3 µg/kg**	**0.27 ng/kg**
CLAM1A	Littleneck Clams	Whole	0.36	--	--	3.5	0.35
MS-17	Littleneck Clams	Whole	0.71	--	--	--	--
MS-18	Littleneck Clams	Whole	0.47	--	--	--	--
MS-19	Littleneck Clams	Whole	0.4	--	--	4.6	--
MS-20	Littleneck Clams	Whole	0.43	--	--	8.2	--
MS-21	Littleneck Clams	Whole	0.4	--	--	7.5	--
MS-22	Littleneck Clams	Whole	0.63	--	--	--	--
BW-30	Littleneck Clams	Whole	0.66	--	0.014	--	--
BW-31	Littleneck Clams	Whole	0.6	--	--	--	--
BW-32	Littleneck Clams	Whole	0.64	--	0.016	--	--
B1_L	Littleneck Clams	Whole	0.29	--	--	--	--
LF3_LN	Littleneck Clams	Whole	--	--	--	4.4	--
LF4_L	Littleneck Clams	Whole	0.37	--	--	--	--
LS_L	Littleneck Clams	Whole	0.45	--	--	--	--
CLAM2A	Littleneck Clams	Whole	--	--	--	3.5	0.37
LF2_M	Manila Clams	Whole	0.29	--	--	--	--
LF3_M	Manila Clams	Whole	0.27	--	--	2.7	--
LS_M	Manila Clams	Whole	0.35	--	--	--	--
B2_C	Cockles	Whole	--	--	--	1.9	--
B3_C	Cockles	Whole	--	--	--	1.7	--
OYSTER1A	Oyster†	Whole	0.99	--	--	3.5	0.37
OYSTER2A	Oyster†	Whole	0.96	--	--	3.5	0.37
B1_O	Oyster†	Whole	1.00	--	--	2.1	--
B2_O	Oyster†	Whole	1.27	--	--	9.5	--
B3_O	Oyster†	Whole	1.35	--	--	19.0	--
LF2_O	Oyster†	Whole	1.18	--	--	1.5	--
LF4_O	Oyster†	Whole	1.20	--	0.014	--	--
LS_O	Oyster†	Whole	1.28	--	--	--	--
PJ_O	Oyster†	Whole	1.13	--	--	--	--
RS1_O	Oyster†	Whole	1.23	--	--	--	--
SRS_O	Oyster†	Whole	1.49	--	--	--	--
Maximum Background			**0.34 µg/kg**	**0.62 µg/kg**	**0.042 µg/kg**	**0.17 µg/kg**	**1.4 ng/kg**
GD1A	Geoduck	Whole	--	--	--	3.4	--
GD2A	Geoduck	Whole	--	--	--	3.5	--
Maximum Background			**0.013 µg/kg**	**0.04 µg/kg**	**0.086 µg/kg**	**1.6 µg/kg**	**1.4 ng/kg**
CRAB1A	Dungeness	Edible Meat	0.04	0.14	--	3.5	--
BW-04*	Dungeness	Edible Meat	0.04	0.1	--	--	--
Maximum Background			**2.4 µg/kg**	**0.34 µg/kg**	**0.095 µg/kg**	**0.89 µg/kg**	**2.6 ng/kg**
CRAB1A	Dungeness	Hepato-pancreas	--	--	--	3.4	--

Maximum background = maximum concentration in natural background tissue data set (see Section 9).

*Average of 2 individuals. -- Did not exceed maximum background concentration.

†Oyster background data not available. Comparison made to clam values.

Non-detect with detection limit above maximum background concentration.

Table 6-2. Summary of Tissue Metals, PAHs, and PCB Results – Wet Weight

	Bay-wide Samples						Mill Area Samples					
	Samples	**Detects**	**Minimum**	**Maximum**	**Mean**	**90th %ile**	**Samples**	**Detects**	**Minimum**	**Maximum**	**Mean**	**90th %ile**
Percent Lipids[a]												
Lipids	33	33	0.208	6.9	1.23	2.59	13	13	0.33	2.28	0.99	2.05
Metals in mg/kg ww												
Arsenic	33	27	1	8	2.55	5	13	9	1	5	2.08	3
Cadmium	33	28	0.04	1.49	0.496	1.2	13	13	0.04	1.35	0.545	1.22
Chromium	33	32	0.1	0.7	0.206	0.3	13	13	0.1	1.9	0.4	0.48
Copper	33	33	0.91	19.2	4.62	8.6	13	13	1.86	33.5	8.55	23
Lead	33	1	0.4	0.4	0.4	0.4	13	3	0.4	2	0.654	1.7
Silver	32	20	0.06	1.15	0.165	0.187	9	-1	0.06	0.3	0.107	0.18
Zinc	33	33	8.6	174	41.5	134	13	13	12.6	263	58.8	180
Mercury	33	29	0.005	0.047	0.0133	0.0278	13	10	0.005	0.012	0.00708	0.01
PCBs in µg/kg ww												
Aroclor 1016	26	0	3.9	8	4.89	8	7	0	3.9	4	3.96	4
Aroclor 1221	26	0	3.9	8	4.89	8	7	0	3.9	4	3.96	4
Aroclor 1232	26	0	3.9	8	4.97	8	7	0	3.9	6	4.53	5.94
Aroclor 1242	26	0	3.9	8	4.89	8	7	2	3.9	21	6.44	10.9
Aroclor 1248	26	0	3.9	12	5.12	8	7	1	3.9	7.2	4.41	5.28
Aroclor 1254	26	0	3.9	20	5.81	8.9	7	0	3.9	16	6.83	11.2
Aroclor 1260	26	1	3.9	15	5.16	8	7	0	3.9	4	3.96	4
Total PCBs	26	1	3.9	15	5.62	8.95	7	3	4	21	7.76	12.7
PAHs in µg/kg ww												
Benzo(a)anthracene	33	15	0.5	4.2	1.05	1.86	13	13	1	48	10.9	23.4
Benzo(a)pyrene	33	5	0.5	3.3	0.994	2	13	7	0.5	7.7	2.26	5
Benzo(b)fluoranthene	26	8	0.5	2.3	1.3	2.1	7	6	0.5	28	6.86	19
Benzo(k)fluoranthene	26	8	0.5	2.3	1.05	1.95	7	6	0.5	28	6.86	19
Benzofluoranthenes	33	8	0.14	4.6	1.46	3.52	13	12	0.5	56	9.72	23.2
Chrysene	33	15	0.5	4.5	1.43	3.68	13	12	0.5	62	11.8	34.8
Dibenz(a,h)anthracene	33	1	0.5	1.3	0.694	1.3	13	2	0.5	5	1.24	4.22
Indeno(1,2,3-cd)pyrene	33	2	0.5	1.3	0.614	0.83	13	2	0.5	5	1.26	4.26
c PAH TEQ	33	*	0.35	4.36	1.44	3.45	13	*	0.463	19.0	4.50	9.26

Non-detects included in descriptive statistics.

[a] Lipids were analyzed separately for both ARI samples (metals, PAH, PCB) and Axys samples (dioxin/furan and PCB congeners).

* TEQs shown in this table were calculated using the methods described in Section 8.2.4. Using this method, all TEQ values are treated as detected; therefore, summary statistics can be calculated for the TEQs even if most or all of the congeners were undetected.

6.4 Polychlorinated Biphenyls

PCB Aroclors were not detected in tissue samples, with the exception of Aroclor 1260 in one crab hepatopancreas sample from the bay at 15 µg/kg and Aroclor 1242 and 1248 from three samples near the mill ranging up to 21 µg/kg (Table 6-2). At least some PCB congeners were detected in all tissue samples in which they were analyzed, at TEQ concentrations ranging from 0.0215–1.65 ng/kg (Table 6-3). Geoduck, clam, oyster, and crab meat concentrations were relatively low, while crab hepatopancreas concentrations were highest.

6.5 Dioxins/Furans

At least one dioxin/furan congener was detected in most samples in which they were analyzed, with the exception of two littleneck clam samples, one crab meat sample, and both oyster samples (Table 6-3). Dioxin/furan TEQs in samples in which they were detected ranged from 0.077–2.22 (Figure 26). Concentrations were lowest in crab meat and some littleneck clam samples, and highest in crab hepatopancreas.

Table 6-3. Summary of Tissue Dioxin/Furan and PCB Congeners

	Bay-wide Samples						Mill Area Samples					
	Samples	**Detects**	**Minimum**	**Maximum**	**Mean**	**90th %ile**	**Samples**	**Detects**	**Minimum**	**Maximum**	**Mean**	**90th %ile**
Percent Lipids[a]												
Lipids	15	15	0.208	7.79	1.88	5.36	6	6	1.18	1.6	1.41	1.53
Dioxin/Furan Congeners in ng/kg ww												
2,3,7,8-TCDD	15	1	0.0475	0.275	0.109	0.174	6	0	0.0475	0.055	0.0494	0.0525
1,2,3,7,8-PeCDD	15	3	0.0475	0.96	0.28	0.613	6	1	0.0475	0.05	0.0484	0.0493
1,2,3,4,7,8-HxCDD	15	2	0.0475	0.573	0.281	0.4	6	0	0.0475	0.056	0.0498	0.053
1,2,3,6,7,8-HxCDD	15	3	0.0475	2.45	0.568	1.54	6	3	0.0486	0.131	0.0879	0.123
1,2,3,7,8,9-HxCDD	15	2	0.0475	0.954	0.242	0.492	6	2	0.0478	0.207	0.0854	0.149
1,2,3,4,6,7,8-HpCDD	15	3	0.119	3.88	0.815	2.3	6	3	0.41	3.32	1.08	2.16
OCDD	15	9	0.224	4.13	1.57	3.02	6	6	2.23	26.3	8.81	19.3
2,3,7,8-TCDF	15	6	0.0475	1.85	0.392	1.36	6	0	0.0475	0.0506	0.0488	0.0503
1,2,3,7,8-PeCDF	15	2	0.0475	0.494	0.225	0.314	6	0	0.0475	0.05	0.0483	0.0493
2,3,4,7,8-PeCDF	15	4	0.0475	0.874	0.257	0.517	6	1	0.0475	0.059	0.0519	0.0585
1,2,3,4,7,8-HxCDF	15	1	0.0475	0.564	0.352	0.555	6	0	0.0475	0.05	0.0483	0.0493
1,2,3,6,7,8-HxCDF	15	2	0.0475	0.213	0.111	0.163	6	0	0.0475	0.05	0.0483	0.0493
1,2,3,7,8,9-HxCDF	15	0	0.047	0.261	0.155	0.256	6	0	0.0475	0.05	0.0483	0.0493
2,3,4,6,7,8-HxCDF	15	1	0.0475	0.308	0.199	0.303	6	0	0.0475	0.05	0.0483	0.0493
1,2,3,4,6,7,8-HpCDF	15	2	0.0484	0.935	0.417	0.685	6	0	0.056	0.205	0.117	0.188
1,2,3,4,7,8,9-HpCDF	15	0	0.047	0.584	0.319	0.574	6	0	0.0475	0.05	0.0483	0.0493
OCDF	15	0	0.0484	0.727	0.421	0.714	6	1	0.109	0.755	0.264	0.515
Dioxin TEQ	15	*	0.077	2.22	0.505	1.26	6	6	0.0804	0.140	0.103	0.136
PCBs Congeners in ng/kg ww												
PCB-077	15	9	0.523	37.1	7.82	29.6	6	6	0.405	3	1.71	2.72
PCB-081	15	0	0.145	1.69	0.762	1.24	6	0	0.186	0.32	0.238	0.308
PCB-105	15	15	3.09	802	167	598	6	6	4.87	43.4	28.5	43.2
PCB-114	15	7	0.35	44.2	8.94	33.5	6	4	0.253	2.68	1.56	2.56
PCB-118	15	15	8.05	2120	461	1680	6	6	13.2	109	70.6	109
PCB-123	15	8	0.324	40.2	7.86	29.6	6	4	0.278	2.1	1.34	2.02
PCB-126	15	2	0.203	15.8	2.52	6.95	6	0	0.245	0.392	0.293	0.348
PCB-156/157	15	13	1.76	429	74.7	266	6	6	3.19	19.9	13.5	19.5
PCB-167	15	13	0.879	188	36	133	6	6	1.53	8.08	5.54	8
PCB-169	15	0	0.163	3.33	0.974	2.2	6	0	0.151	0.245	0.204	0.236
PCB-189	15	7	0.612	46.9	7.18	25.4	6	5	0.358	2.3	1.4	2.09
PCB TEQ	15	*	0.0215	1.65	0.263	0.814	6	*	0.0255	0.0442	0.0336	0.0392

Table 6-3. Summary of Tissue Dioxin/Furan and PCB Congeners

Bay-wide Samples						Mill Area Samples					
Samples	**Detects**	**Minimum**	**Maximum**	**Mean**	**90th %ile**	**Samples**	**Detects**	**Minimum**	**Maximum**	**Mean**	**90th %ile**

Non-detects included in descriptive statistics.

[a] Lipids were analyzed separately for both ARI samples (metals, PAH, PCB) and Axys samples (dioxin/furan and PCB congeners).

* TEQs shown in this table were calculated using the methods described in Section 8.2.4. Using this method, all TEQ values are treated as detected; therefore, summary statistics can be calculated for the TEQs even if most or all of the congeners were undetected.

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7.0 SEDIMENT BIOASSAY TESTING RESULTS

Sediment quality was evaluated based on biological criteria established in the SMS, which are used to identify areas with adverse biological effects. These criteria are based on both statistical significance (a statistical comparison to a reference station) and the degree of biological response (a numerical comparison to reference). Similar to the chemical criteria, the SMS establishes the SQS (a level at or below which no adverse effects are expected) and the CSL (a level at or below which only minor adverse effects are expected) criteria for evaluating sediment quality. The SQS is more stringent than the CSL and allows for less biological response in the test treatments.

Bioassay pass/fail test results relative to SQS and CSL criteria are based on a comparison of responses observed in the test sediment compared to those in the reference sediment. Reference and test sediments are matched based on sediment grain size with the recommended difference in percent fines between reference and test sediment being ≤20%.

The Microtox bioassay was performed as an exploratory test to evaluate its suitability as a rapid screening test for effects associated with wood waste. For SMS decision-making purposes, the Mill area and Port Gamble Bay RIs included a full suite of PSEP toxicity tests, including the 10-day amphipod survival test using *Eohaustorius estuarius*, the larval development test using either *Dendraster excentricus* or *Mytilus galloprovincialis*, and the chronic 20-day polychaete survival and growth test using *Neanthes arenaceodentata*. Laboratory results and sediment bioassay summaries from four sediment bioassay testing events are included in this RI (Anchor 2006a, 2009; Hart Crowser 2010; and NewFields 2011b). While there have been some bioassays conducted prior to these studies, they have been superseded by more recent data or the areas sampled have since been dredged.

The Mill Area RI in 2006 (Anchor 2006a) included a full suite of toxicity tests with sediment collected from 11 stations. Based on grain size, the following reference and test comparisons were made during the 2006 Mill Area RI:

- Reference sediment R1 (79.7% fines): Stations AS-01, 02, 03, 05, 07, 09, 13, 14, 3001, 3002, and 3004.

A supplemental remedial investigation (SRI) of the mill area was conducted in 2008 (Anchor 2009) using the amphipod test, the larval echinoderm test, and the Microtox test. None of the stations sampled were the same as the 2006 field investigation (Figure 3-1). Based on grain size, the following reference and test comparisons were made during the 2008 Mill Area SRI:

- Carr Inlet reference sediment CR-1 (55% fines): Stations AS-108, 113, and B14
- Carr Inlet reference sediment CR-22 (15% fines): AS-101, 102, 106, 112, B09, and B15
- Sequim Bay reference sediment SBREF35 (35% fines): AS-B11, B16, and B18

In 2009, Hart Crowser conducted an RI of Port Gamble Bay that included a full suite of toxicity tests conducted with sediment from 32 stations (Hart Crowser 2009). Based on similarity in grain size, the following reference and test sediment comparisons were performed during the 2009 Port Gamble Bay RI:

- Carr Inlet reference sediment CR20W (79.7% fines): Stations PGSS-8, 15, 16, 18, 20, 22, 30, 31, 33, 35, 39, 40, 42, 44, 45, 51, 53, 54, and 58.
- Carr Inlet reference sediment MSMP43 (6.4% fines): Stations PGSS-47, 56, 62, 67, 73, 75, 77A, and 92.
- Carr Inlet reference sediment CR23Mod (51.6% fines): Stations PGSS-21B, 29A, 38A, 63, and 64.

A supplementary investigation of Port Gamble Bay was conducted by NewFields in 2011 and included the juvenile polychaete test and the bivalve larval test. The following reference and test sediment comparisons were performed during the 2011 Port Gamble Bay Supplemental RI:

- Carr Inlet reference sediment CI-01 (6.1% fines): Stations BW-01, 02, 03, MS-02, 06, and 09.
- Carr Inlet reference sediment CI-02 (42.7% fines): Stations BW-07, 12, 17, MS-01, 03, 04, 05, 07, 08, and 10.
- Carr Inlet reference sediment CI-03 (77.7% fines): Stations BW-04, 05, 06, 08, 09, 10, 11, 13, 14, 15, 18, 19, 20, and 21.

7.1 Microtox Bioassay Results

7.1.1 Anchor Mill Area 2008 Supplemental RI

Microtox testing was included as a chronic test endpoint for the 2008 SRI of the mill area. A total of 13 stations were submitted for Microtox analysis. All treatments were between 97% and 121% of their respective reference, meeting both the SQS and CSL criteria (Table 7-1).

7.1.2 Hart Crowser 2008 RI

Fifty-two surface sediment samples and three reference samples were submitted to Nautilus Environmental for Microtox analyses. Six samples (PGSS-16, 62B, 51, 58, 63, and 69) exceeded the SQS criteria of mean test sediment light output <80% of reference and were statistically different from the reference (Table 7-2).

The laboratory noted that sample PGSS-16 had low salinity (9 ppt) and turbidity greater than 100 NTU. Due to the high turbidity, the transmission of light from the bacteria may have been inhibited and the result may be an artifact of the testing, not an indication of toxicity. This interpretation is supported by the observation that sample PGSS-16 passed the other bioassay tests.

Reference sample CR23MOD did not meet the acceptability criteria relative to the control sample in Test Batches 10 and 11, and the associated samples were subsequently compared to the control. Only one of

these samples, PGSS-63, failed the comparison to the control, so it was designated an SQS level hit. However, sample PGSS-63 passed the other bioassay tests.

The Microtox bioassay was not found to be well correlated with indicators of the presence or toxicity of wood waste, unlike several of the other bioassays (Hart Crowser 2010). Therefore, it was not used in subsequent rounds of testing or for SMS decision making.

Table 7-1. Microtox Bioassay Results, Anchor 2008 Mill Area SRI

Station	Percent Fines	Reference	Change in Output at 5 min. (%)		Change in Output at 15 min. (%)		Sig. Diff.	SMS Interpretation LO_{Test} / LO_{Ref}	
			Mean	SD	Mean	SD		Value	SQS > 80%
Control			96	1	88	2	--	Pass QA (LO_f/LO_i > 80%)	
SBREF-35	35	Control[a]	99	4	95	5	No	108	Pass QA
AS-106	8.4	SBREF35[b]	98	1	93	5	No	97	Pass
AS-101	23.9	SBREF35	97	1	94	1	No	98	Pass
AS-112	12.8	SBREF35[b]	99	4	94	2	No	99	Pass
AS-B18	31.9	SBREF35	100	1	97	1	No	102	Pass
Control	--		92	2	83	2	--	Pass QA (LO_f/LO_i > 80%)	
SBREF-35	35	Control[a]	102	3	100	2	No	121	Pass QA
AS-B15	39.5	SBREF35	100	1	94	2	Yes	94	Pass
AS-B09	4.9	SBREF35[b]	101	1	98	3	No	98	Pass
AS-102	20.7	SBREF35	97	1	92	4	No	92	Pass
Control	--		96	4	88	7	--	Pass QA (LO_f/LO_i > 80%)	
CR-1	55	Control[a]	102	3	101	7	No	115	Pass QA
AS-108	23.9	CR-1	103	2	98	1	No	97	Pass
AS-113	44.0	CR-1	101	2	98	1	No	97	Pass
AS-B11	33.8	CR-1	102	4	100	5	No	99	Pass

[a] Reference treatments are compared to the control; performance standard is $LO_{F(Ref)}$ / $LO_{F(Control)}$ >80%.

[b] Alternative reference; no data for CR-22 – coarse grained sand, no porewater available for analysis.

Table 7-2. Microtox Bioassay Results, Hart Crowser 2008 RI

Station	Percent Fines	Reference	Change in Output at 5 min. (%)		Change in Output at 15 min. (%)		Sig. Diff	SMS Interpretation LO_{Test} / LO_{Ref}	
			Mean	SD	Mean	SD		Value	SQS > 80%
Control	--		96	4	91	4		Pass QA (LO_f/LO_i > 80%)	
CR20W	79.7	Control[a]	101	1	99	3		99	Pass QA
PGSS-08	87.9	CR20W	102	5	98	6		99	Pass
PGSS-30	87.6	CR20W	99	1	92	2		93	Pass
PGSS-39	88.7	CR20W	100	1	93	2		94	Pass
PGSS-35	91.0	CR20W	103	2	98	3		99	Pass
Control	--		102	2	98	2		Pass QA (LO_f/LO_i > 80%)	
CR20W	79.7	Control[a]	108	2	106	2		108	Pass QA
PGSS-20	93.6	CR20W	105	2	102	2		96	Pass
PGSS-15	92.7	CR20W	106	2	105	4		99	Pass
PGSS-40	84.1	CR20W	106	2	105	1		99	Pass
PGSS-22	92.2	CR20W	109	3	110	1		104	Pass
Control	--		97	1	91	2		Pass QA (LO_f/LO_i > 80%)	
CR20W	79.7	Control[a]	104	2	102	3		112	Pass QA
PGSS-33	87.0	CR20W	100	2	96	4		94	Pass
PGSS-31	88.6	CR20W	102	2	98	4		96	Pass
PGSS-18	94.8	CR20W	101	1	95	2		93	Pass
PGSS-16	94.4	CR20W	76	3	74	4	Yes	73	Fail
Control	--		99	2	91	3		Pass QA (LO_f/LO_i > 80%)	
MSMP43	6.4	Control[a]	99	2	93	2		102	Pass QA
PGSS-14A	NA	MSMP43	99	1	93	2		100	Pass
PGSS-21A	NA	MSMP43	101	2	95	2		102	Pass
PGSS-29	NA	MSMP43	99	1	92	2		99	Pass
PGSS-46	NA	MSMP43	101	1	94	3		101	Pass
Control	--		96	1	83	1		Pass QA (LO_f/LO_i > 80%)	
MSMP43	6.4	Control[a]	97	1	88	1		106	Pass QA
PGSS-38	NA	MSMP43	99	2	89	4		101	Pass
PGSS-47	22.0	MSMP43	97	1	87	2		99	Pass
PGSS-56	12.6	MSMP43	98	2	85	3		97	Pass
PGSS-61	NA	MSMP43	98	2	88	2		100	Pass
Control	--		94	2	86	3		Pass QA (LO_f/LO_i > 80%)	
MSMP43	6.4	Control[a]	98	3	92	3		107	Pass QA
PGSS-62	6.7	MSMP43	96	4	88	5		96	Pass
PGSS-62A	NA	MSMP43	99	3	91	3		99	Pass
PGSS-62B	NA	MSMP43	55	5	49	4	Yes	53	Fail
PGSS-67	15.3	MSMP43	98	2	90	2		98	Pass
Control	--		100	5	98	4		Pass QA (LO_f/LO_i > 80%)	
MSMP43	6.4	Control[a]	106	7	106	11	No	91	Pass QA
PGSS-68	NA	CR20W	104	3	101	9	No	95	Pass
Control	--		96	4	89	3		Pass QA (LO_f/LO_i > 80%)	
CR20W	79.7	Control[a]	96	5	92	4	No	103	Pass QA
PGSS-42	77.4	CR23MOD	100	2	93	3	No	101	Pass
PGSS-44	85.4	CR23MOD	102	2	96	4	No	104	Pass
PGSS-51	65.3	CR23MOD	56	3	47	2	Yes	51	Fail

Table 7-2. Microtox Bioassay Results, Hart Crowser 2008 RI

Station	Percent Fines	Reference	Change in Output at 5 min. (%)		Change in Output at 15 min. (%)		Sig. Diff	SMS Interpretation LO_{Test} / LO_{Ref}	
			Mean	SD	Mean	SD		Value	SQS > 80%
Control	--		96	1	86	1		Pass QA (LO_f/LO_i > 80%)	
CR20W	79.7	Control[a]	95	5	91	3	No	106	Pass QA
PGSS-54	60.8	CR20W	103	1	95	3	No	104	Pass
PGSS-45	85.8	CR20W	80	3	73	3	No	80	Pass
PGSS-58	70.5	CR20W	67	2	61	2	Yes	67	Fail
PGSS-53	58.9	CR20W	103	3	93	2	No	102	Pass
Control	--		96	2	92	5		Pass QA (LO_f/LO_i > 80%)	
CR23MOD	51.6	Control[a]	48	1	43	2	Yes	47	Fail QA[b]
PGSS-55	NA	CR23MOD	102	1	100	1	No	109	Pass
PGSS-38A	52.4	CR23MOD	103	5	101	6	No	110	Pass
PGSS-77	NA	CR23MOD	104	1	102	2	No	111	Pass
PGSS-47A	NA	CR23MOD	102	5	99	6	No	108	Pass
Control	--		96	3	89	2		Pass QA (LO_f/LO_i > 80%)	
CR23MOD	51.6	Control[a]	55	3	49	3	Yes	55	Fail QA[b]
PGSS-64	23.2	CR23MOD	99	2	94	2	No	106	Pass
PGSS-63	21.8	CR23MOD	69	4	66	3	Yes	74	Fail
PGSS-21B	50.2	CR23MOD	102	1	96	2	No	108	Pass
PGSS-29A	69.9	CR23MOD	104	2	99	4	No	111	Pass
Control	--		95	2	91	1		Pass QA (LO_f/LO_i > 80%)	
MSMP43	6.4	Control[a]	97	3	95	4	No	104	Pass QA
PGSS-GEO3	NA	MSMP43	99	2	97	5	No	100	Pass
PGSS-82	NA	MSMP43	99	1	94	2	No	102	Pass
PGSS-69	NA	MSMP43	59	2	54	2	Yes	99	Fail
PGSS-71	NA	MSMP43	101	6	98	6	No	57	Pass
Control	--		95	2	88	3		Pass QA (LO_f/LO_i > 80%)	
MSMP43	6.4	Control[a]	100	7	97	9	No	110	Pass QA
PGSS-70	NA	MSMP43	97	1	90	1	No	93	Pass
PGSS-92	18.0	MSMP43	97	4	92	3	No	95	Pass
PGSS-80	NA	MSMP43	97	1	92	2	No	95	Pass
PGSS-77A	18.5	MSMP43	97	2	93	4	No	96	Pass
Control	--		94	4	87	5		Pass QA (LO_f/LO_i > 80%)	
MSMP43	6.4	Control[a]	97	4	93	4	No	107	Pass QA
PGSS-73	6.1	MSMP43	95	5	95	8	No	102	Pass
PGSS-78	NA	MSMP43	95	2	92	4	No	99	Pass
PGSS-83	NA	MSMP43	97	4	90	5	No	97	Pass
PGSS-75	3.9	MSMP43	95	3	87	2	No	94	Pass

[a] Reference treatments are compared to the control; performance standard is $LO_{F(Ref)} \div LO_{F(Control)}$ >80%.

[b] Test treatments compared to the control.

7.2 Amphipod Bioassay Results

The amphipod test provides an estimate of acute sediment toxicity and is based on the survival of burrowing amphipods exposed to test sediments relative to survival in the appropriate reference sediment. Under the SMS program, an amphipod bioassay test sample fails the SQS if the mean mortality is >25% higher than that of the reference sediment and the difference is statistically significant. Samples fail the CSL if the test sample mortality is >30% higher than that of the reference sediment and the difference is statistically significant.

Amphipod tests with *Eohaustorius estuarius* were conducted as part of three sediment investigations: the Mill Area RI (Anchor 2006a), the Mill Area SRI (Anchor 2009), and the Port Gamble Bay RI (Hart Crowser 2009).

7.2.1 Anchor 2006 Mill Area RI

A total of 11 sediment samples were evaluated for toxicity; eight samples were collected from the vicinity of the former mill and three samples were from the greater Port Gamble Bay. Mortality in the control and reference treatments was within acceptable limits (Table 7-3). With the exception of two samples in the embayment north of the former mill, all treatments pass both SQS and CSL criteria. Stations AS-01 and AS-03 failed the CSL criteria.

7.2.2 Anchor 2008 Mill Area Supplemental RI

The Mill Area SRI conducted in 2008 (Anchor 2009) collected sediment from 14 additional stations in the northern embayment and the area immediately south of the former mill. Mortality in the control and reference treatments met the quality control limits for the amphipod test (Table 7-3). All 14 treatments passed both the SQS and CSL criteria, with mortality ranging from 3 to 11%.

7.2.3 Hart Crowser 2008 RI

All 32 amphipod test results passed the SQS criteria (Table 7-4). While 17 of the test samples had mortality significantly higher than the associated reference sediment samples, the percent difference between the test and reference survival was less than the 25% threshold.

Table 7-3. Amphipod Bioassay Results for *Eohaustorius estuarius*, Anchor 2006/2008 Mill Area RI/SRI

Station	Percent Fines	Reference	Percent Mortality		Sig. Diff.	SMS Interpretation M_{Test} - M_{Ref}		
			Mean	SD		Value	SQS >25%	CSL >30%
Control	--		7.0	4.5			Pass QA (M < 10%)	
AS-R1	15.3	Control[a]	13.0	4.5	--	--	Pass QA[a]	
AS-R3	39.7	Control[a]	6.0	8.9	--	--	Pass QA[a]	
AS-01	23.9	R1	47.0	39.1	Yes	34	Fail	Fail
AS-02	20.7	R1	31.0	22.5	Yes	18	Pass	Pass
AS-03	14.7	R1	72.0	39.5	Yes	59	Fail	Fail
AS-05	50.1	R3	12.0	12.5	No	6	Pass	Pass
AS-07	42.6	R3	10.0	5.0	No	4	Pass	Pass
AS-09	26.1	R1	12.0	4.5	No	-1	Pass	Pass
AS-13	17.6	R1	5.0	5.0	No	-6	Pass	Pass
AS-14	6.7	R1	11.0	5.5	No	-2	Pass	Pass
AS-3001	54.7	R3	10.0	5.0	No	4	Pass	Pass
AS-3002	83.5	R3	15.0	9.4	Yes	9	Pass	Pass
AS-3004	83.8	R3	22.0	43.7	No	16	Pass	Pass
Control	--		10.0	6.1			Pass QA (M < 10%)	
CR-1	55	Control[a]	16.0	6.5	--	--	Pass QA[a]	
CR-22	15	Control[a]	7.0	4.5	--	--	Pass QA[a]	
SBR-35	35	Control[a]	10.0	10.6	--	--	Pass QA[a]	
AS-101	7.7	CR-22	11.0	8.9	No	4	Pass	Pass
AS-102	6.2	CR-22	11.0	4.2	No	4	Pass	Pass
AS-106	8.4	CR-22	4.0	4.2	No	-3	Pass	Pass
AS-108	46.2	CR-1	5.0	5.0	No	-2	Pass	Pass
AS-112	12.8	CR-22	3.0	2.7	No	-4	Pass	Pass
AS-113	44.0	CR-1	10.0	5.0	No	-5	Pass	Pass
AS-B09	4.9	CR-22	7.0	5.7	No	0	Pass	Pass
AS-B11	33.7	SBR-35	10.0	5.0	No	0	Pass	Pass
AS-B14	57.8	CR-1	6.0	8.2	No	-10	Pass	Pass
AS-B15	ND	CR-22	6.0	4.2	No	-1	Pass	Pass
AS-B16	26.7	SBR-35	7.5	6.1	No	-2.5	Pass	Pass
AS-B18	32.0	SBR-35	6.0	6.5	No	-4	Pass	Pass

[a] Reference treatments are compared to the control; Performance standard is $M_{Ref} - M_{Control} \leq 20\%$.

[b] No available data; comparison made based on RI/FS (Anchor 2009).

Table 7-4. Amphipod Bioassay Results for *Eohaustorius estuarius*, Hart Crowser 2008 RI

Station	Percent Fines	Reference	Percent Mortality		Sig. Diff.	SMS Interpretation M_{Test} - M_{Ref}		
			Mean	SD		Value	SQS >25%	CSL >30%
Batch 1								
Control	--		0.0	0.0			Pass QA (M < 10%)	
MSMP43	6.4	Control[a]	1.0	2.2	--	--	Pass QA[a]	
CR20W	79.7	Control[a]	1.0	2.2	--	--	Pass QA[a]	
CR23 MOD	51.6	Control[a]	1.0	2.2	--	--	Pass QA[a]	
PGSS-08	87.9	CR20W	4.0	2.2	Yes	3	Pass	Pass
PGSS-15	92.7	CR20W	13.0	11.0	Yes	12	Pass	Pass
PGSS-16	94.4	CR20W	3.0	6.7	No	2	Pass	Pass
PGSS-18	94.8	CR20W	18.0	24.1	Yes	17	Pass	Pass
PGSS-20	93.6	CR20W	11.0	5.5	Yes	10	Pass	Pass
PGSS-21B	50.2	CR23MOD	2.0	2.7	No	1	Pass	Pass
PGSS-22	92.2	CR20W	3.0	6.7	No	2	Pass	Pass
PGSS-29A	69.9	CR20W	8.0	6.7	Yes	7	Pass	Pass
PGSS-30	87.6	CR20W	12.0	7.6	Yes	11	Pass	Pass
PGSS-31	88.6	CR20W	10.0	9.4	Yes	9	Pass	Pass
PGSS-33	87.0	CR20W	4.0	4.2	No	3	Pass	Pass
PGSS-35	91.0	CR20W	8.0	5.7	Yes	7	Pass	Pass
PGSS-38A	52.4	CR23MOD	10.0	3.5	Yes	9	Pass	Pass
PGSS-39	88.7	CR20W	11.0	6.5	Yes	10	Pass	Pass
PGSS-40	84.1	CR20W	5.0	5.0	No	4	Pass	Pass
PGSS-42	77.4	CR20W	16.0	12.9	Yes	15	Pass	Pass
Batch 2								
Control			3.0	4.5			Pass QA (M < 10%)	
MSMP43	6.4	Control[a]	2.0	2.7	--	--	Pass QA[a]	
CR20W	79.7	Control[a]	2.0	2.7	--	--	Pass QA[a]	
CR23 MOD	51.6	Control[a]	2.0	2.7	--	--	Pass QA[a]	
PGSS-44	85.4	CR20W	12.0	7.6	Yes	10	Pass	Pass
PGSS-45	85.8	CR20W	18.0	18.9	Yes	16	Pass	Pass
PGSS-47	22	MSMP43	4.0	4.2	No	2	Pass	Pass
PGSS-51	65.3	CR23MOD	9.0	10.8	No	7	Pass	Pass
PGSS-53	58.9	CR23MOD	10.0	7.9	Yes	8	Pass	Pass
PGSS-54	60.8	CR23MOD	19.0	6.5	Yes	17	Pass	Pass
PGSS-56	12.6	MSMP43	4.0	4.2	No	2	Pass	Pass
PGSS-58	70.5	CR20W	3.0	4.5	No	1	Pass	Pass
PGSS-62	6.7	MSMP43	2.0	4.5	No	0	Pass	Pass
PGSS-63	21.8	MSMP43	10.0	7.9	Yes	8	Pass	Pass
PGSS-64	23.2	MSMP43	6.0	6.5	No	4	Pass	Pass
PGSS-67	15.3	MSMP43	8.0	6.7	No	6	Pass	Pass
PGSS-73	6.1	MSMP43	2.0	2.7	No	0	Pass	Pass
PGSS-75	3.9	MSMP43	1.0	2.2	No	-1	Pass	Pass
PGSS-77A	18.5	MSMP43	13.0	10.4	Yes	11	Pass	Pass
PGSS-92	18	MSMP43	5.0	5.0	No	3	Pass	Pass

[a] Reference treatments are compared to the control; performance standard is $M_{Ref} - M_{Control} \leq 20\%$.

7.3 Juvenile Polychaete Bioassay Results

The juvenile polychaete test provides an estimate of chronic toxicity and is based on mean individual growth (MIG) in the test treatments relative to the MIG in the appropriate reference over a period of 20 days. MIG is expressed as mg biomass per individual per day. A bioassay sample fails the SQS if the MIG in the test sediment is <70% of that in the reference and the difference is statistically significant. A sample fails the CSL if the MIG is <50% of the reference and is statistically different. The juvenile polychaete test was included in three sediment investigations, the Mill Area RI (Anchor 2006a) and the Port Gamble Bay RI (Hart Crowser 2009) and SRI (NewFields 2011b).

7.3.1 Anchor 2006 Mill Area RI

Control and reference survival and growth met quality criteria for test samples evaluated in the 2006 Mill Area RI (Table 7-5). Mean individual growth for all samples passed the CSL criterion; however, MIG in four samples (AS-02, 05, AS-3001, and AS-3004) was below the SQS criterion when compared to the appropriate reference.

Table 7-5. Polychaete Bioassay Results for *Neanthes arenaceodentata*, Anchor 2006 Mill Area RI

Station	Percent Fines	Reference	Mean Individual Growth		Sig. Diff.	SMS Interpretation MIG_{Test} / MIG_{Ref}			Sample Retested
			Mean	SD		Value	SQS <70%	CSL <50%	
Control	--		0.70	0.13			Pass QA (MIG > 0.38)		
R1	15.3	Control[a]	0.66	0.11	--	0.94	Pass QA[a]		
R3	39.7	Control[a]	0.56	0.09	--	0.80	Pass QA[a]		
AS-01	23.9	R1	0.50	0.10	Yes	76	Pass	Pass	MS-01
AS-02	20.7	R1	0.45	0.11	Yes	68	Fail	Pass	
AS-03	14.7	R1	0.47	0.15	Yes	71	Pass	Pass	MS-03
AS-05	50.1	R3	0.35	0.15	Yes	62	Fail	Pass	MS-04
AS-07	42.6	R3	0.50	0.08	No	89	Pass	Pass	
AS-09	26.1	R1	0.53	0.07	Yes	80	Pass	Pass	
AS-13	17.6	R1	0.55	0.15	No	83	Pass	Pass	
AS-14	6.7	R1	0.55	0.10	No	83	Pass	Pass	
AS-3001	54.7	R3	0.45	0.10	No	80	Pass	Pass	
AS-3002	83.5	R3	0.52	0.10	No	93	Pass	Pass	
AS-3004	83.8	R3	0.34	0.08	Yes	61	Fail	Pass	PGSS-08

[a] Reference treatments are compared to the control; performance standard is MIG_{Ref} / $MIG_{Control}$ ≥ 0.80.

[b] Test treatments were compared to both an alternative reference and the control; results are presented for both comparisons.

7.3.2 Hart Crowser 2008 RI

Control survival and growth met quality criteria for both batches of test samples evaluated in the 2009 Port Gamble Bay RI (Table 7-6). With the exception of the fine-grained reference (CR-20W) in the first test batch, all references met the reference sediment performance standards. The growth rate for reference CR-20W in Batch 1 was 71.2% of the control, below the 80% performance criterion. While SMS does not provide explicit guidance when reference samples fail performance criteria, for the purposes of the 2009 RI, fine grain-sized sediments were compared to both the control and the medium grain-size reference (CR-23 MOD). The control represented the most conservative point of reference. Reference CR-23 MOD represented the next most similar grain size reference with acceptable growth.

Growth rates were statistically lower than the corresponding references or controls for nine of the 32 test sediments (Table 7-6). All test samples passed the CSL criterion with growth that was greater than 50% of the references or control. With the exception of five samples, all stations met the SQS criterion with growth greater than 70% of the reference or control. Samples PGSS-18, 30, 33, 39, and 40 failed the SQS performance standard for growth when compared to the control. However, when compared to the alternate medium grain-size reference (CR-23 MOD), only sample PGSS-30 failed the SQS criterion.

The cause of the SQS failures at these stations was further investigated as part of the Port Gamble Bay SRI. Because juvenile worm biomass is very small and the mass of ingested sediment can be relatively high, the ingested sediment can affect the outcome of sediment comparisons. This is particularly true when comparing fine-grained sediments to coarse sands. Recent studies have indicated that as much as 50% of the biomass in worms exposed to a sand control can be due to the sediment in the gut, whereas for fine-grained references, the range is 19–34% (NewFields 2010c, 2011c). Sibley et al. (1997) found similar sources of variation associated with different types of sediment retained in the guts of *Chironomus* sp. larvae. To correctly compare between dissimilar sediments, AFDW is used as a biomass endpoint. AFDW subtracts out the sediment weight and is purely a comparison of tissue biomass. AFDW is the standard measure for biomass for other nationally recognized test protocols for organisms that ingest sediment, such as *Chironomus* sp. (Sibley et al. 1997; EPA 2000). Those stations that were associated with the reference failure during the 2009 RI were therefore rerun with AFDW used to calculate MIG (Table 7-7).

Table 7-6. Polychaete Bioassay Results for *Neanthes arenaceodentata*, Hart Crowser 2008 RI

Station	Percent Fines	Reference	Mean Individual Growth		Sig. Diff.	SMS Interpretation MIG_{Test} / MIG_{Ref}			Sample Tested in SRI
			Mean	SD		Value	SQS <70%	CSL <50%	
Batch 1									
Control	--		1.04	0.0			Pass QA (MIG > 0.38)		
MSMP43	6.4	Control[a]	0.92	0.21	--	0.88	Pass QA[a]		•
CR20W	79.7	Control[a]	0.74	0.26	--	0.71	Fails QA[a]		•
CR23 MOD	51.6	Control[a]	0.91	0.21	--	0.84	Pass QA[a]		•
PGSS-08	87.9	CR23/Control[b]	1.00	0.09	No	1.10/0.96	Pass	Pass	
PGSS-15	92.7	CR23/Control[b]	0.78	0.21	No	0.86/0.75	Pass	Pass	
PGSS-16	94.4	CR23/Control[b]	0.84	0.10	No	0.92/0.81	Pass	Pass	
PGSS-18	94.8	CR23/Control[b]	0.70	0.12	No/Yes	0.77/0.67	Pass/Fail	Pass	BW-20
PGSS-20	93.6	CR23/Control[b]	0.82	0.18	No	0.90/0.79	Pass	Pass	
PGSS-21B	50.2	CR23	0.73	0.12	No	0.80	Pass	Pass	
PGSS-22	92.2	CR23/Control[b]	0.89	0.17	No	0.98/0.86	Pass	Pass	
PGSS-29A	69.9	CR23	0.77	0.15	No	0.85	Pass	Pass	
PGSS-30	87.6	CR23/Control[b]	0.62	0.18	Yes/Yes	0.68/0.60	Fail/Fail	Pass	BW-13
PGSS-31	88.6	CR23/Control[b]	0.79	0.07	No	0.87/0.76	Pass	Pass	
PGSS-33	87.0	CR23/Control[b]	0.68	0.20	No/Yes	0.75/0.65	Pass/Fail	Pass	BW-15
PGSS-35	91.0	CR23/Control[b]	0.85	0.06	No	0.93/0.82	Pass	Pass	
PGSS-38A	52.4	CR23	0.75	0.24	No	0.82	Pass	Pass	
PGSS-39	88.7	CR23/Control[b]	0.71	0.16	No/Yes	0.78/0.68	Pass/Fail	Pass	BW-08
PGSS-40	84.1	CR23/Control[b]	0.65	0.10	No/Yes	0.71/0.63	Pass/Fail	Pass	BW-09
PGSS-42	77.4	CR23/Control[b]	0.77	0.15	No	0.85/0.74	Pass	Pass	
Batch 2									
Control	--		1.04	4.5			Pass QA (MIG > 0.38)		
MSMP43	6.4	Control[a]	0.86	0.16	--	0.82	Pass QA[a]		
CR20W	79.7	Control[a]	1.06	0.18	--	1.02	Pass QA[a]		
CR23 MOD	51.6	Control[a]	0.99	0.12	--	0.95	Pass QA[a]		
PGSS-44	85.4	CR20W	0.77	0.14	Yes	0.73	Pass	Pass	
PGSS-45	85.8	CR20W	0.89	0.09	Yes	0.84	Pass	Pass	
PGSS-47	22.0	MSMP43	0.93	0.21	No	1.08	Pass	Pass	
PGSS-51	65.3	CR23MOD	0.88	0.11	No	0.89	Pass	Pass	
PGSS-53	58.9	CR23MOD	0.84	0.13	No	0.85	Pass	Pass	
PGSS-54	60.8	CR23MOD	0.81	0.12	Yes	0.82	Pass	Pass	
PGSS-56	12.6	MSMP43	1.01	0.26	No	1.17	Pass	Pass	
PGSS-58	70.5	CR20W	0.83	0.20	Yes	0.84	Pass	Pass	
PGSS-62	6.7	MSMP43	1.03	0.13	No	1.20	Pass	Pass	
PGSS-63	21.8	MSMP43	0.84	0.12	No	0.98	Pass	Pass	
PGSS-64	23.2	MSMP43	0.83	0.22	No	0.97	Pass	Pass	
PGSS-67	15.3	MSMP43	0.94	0.19	No	1.09	Pass	Pass	
PGSS-73	6.1	MSMP43	1.01	0.21	No	1.17	Pass	Pass	
PGSS-75	3.9	MSMP43	0.91	0.12	No	1.06	Pass	Pass	
PGSS-77A	18.5	MSMP43	0.78	0.06	No	0.91	Pass	Pass	
PGSS-92	18.0	MSMP43	0.89	0.07	No	1.03	Pass	Pass	

[a] Reference treatments are compared to the control; performance standard is MIG_{Ref} / $MIG_{Control} \geq 0.80$.

[b] Test treatments were compared to both an alternative reference and the control; results are presented for both comparisons.

Table 7-7. Polychaete Bioassay Results for *Neanthes arenaceodentata*, NewFields 2011 RI

2011 SRI Station	2009 RI Station	Percent Fines	Reference	Mean Individual Growth mg/ind/day Dry Weight						Mean Individual Growth mg/ind/day Ash-Free Dry Weight					
				Mean	SD	Sig. Diff.	SMS Interpretation MIG_{Test} / MIG_{Ref}			Mean	SD	Sig. Diff.	SMS Interpretation MIG_{Test} / MIG_{Ref}		
							Value	SQS <0.70	CSL <0.50				Value	SQS <0.70	CSL <0.50
Control				0.61	0.04		Pass QA (MIG > 0.38)			0.48	0.06		Pass QA (MIG > 0.38)		
CI-01	--	6.1	Control[a]	0.57	0.08	--	0.93	Pass QA[a]		0.45	0.04	--	0.93	Pass QA[a]	
CI-02	--	42.7	Control[a]	0.66	0.17	--	1.08	Pass QA[a]		0.52	0.15	--	1.08	Pass QA[a]	
CI-03	--	77.7	Control[a]	0.66	0.05	--	1.08	Pass QA[a]		0.53	0.05	--	1.08	Pass QA[a]	
MS-02	AS-104	18.0	CI-01	0.50	0.20	No	0.88	Pass	Pass	0.42	0.17	No	0.92	Pass	Pass
MS-04	AS-05	55.8	CI-02	0.55	0.06	No	0.84	Pass	Pass	0.47	0.05	No	0.91	Pass	Pass
MS-05	NA	17.1	CI-01	0.59	0.13	No	1.04	Pass	Pass	0.55	0.18	No	1.22	Pass	Pass
MS-09	NA	16.3	CI-01	0.41	0.09	Yes	0.72	Pass	Pass	0.36	0.09	Yes	0.79	Pass	Pass
MS-10	AS-B16	38.5	CI-02	0.52	0.14	No	0.79	Pass	Pass	0.46	0.12	No	0.89	Pass	Pass
BW-08	PGSS-39	88.2	CI-03	0.60	0.10	No	0.90	Pass	Pass	0.49	0.09	No	0.92	Pass	Pass
BW-09	PGSS-40	86.4	CI-03	0.61	0.03	Yes	0.92	Pass	Pass	0.50	0.03	No	0.95	Pass	Pass
BW-13	PGSS-30	87.2	CI-03	0.65	0.06	No	0.98	Pass	Pass	0.53	0.05	No	0.99	Pass	Pass
BW-15	PGSS-33	90	CI-03	0.64	0.03	No	0.96	Pass	Pass	0.52	0.03	No	0.99	Pass	Pass
BW-19	NA	95.3	CI-03	0.62	0.05	No	0.94	Pass	Pass	0.51	0.05	No	0.96	Pass	Pass
BW-20	PGSS-18	96.5	CI-03	0.61	0.07	No	0.92	Pass	Pass	0.51	0.06	No	0.96	Pass	Pass
BW-21	NA	95.3	CI-03	0.60	0.04	Yes	0.90	Pass	Pass	0.51	0.03	No	0.96	Pass	Pass

[a] Reference treatments are compared to the control; performance standard is MIG_{Ref} / $MIG_{Control} \geq 0.80$.

7.3.3 NewFields 2011 RI

To refine the estimates of toxicity at those stations with reference failures, the juvenile polychaete growth test was retested for Stations PGSS-18, 30, 33, 39, and 40 in the bay, as well as Stations AS-05, 104, and B16 from the vicinity of the former mill. In addition, two new stations in the vicinity of Station PGSS-18 were tested to better characterize this portion of the lower bay. Two new stations in the mill area (MS-05 and 08) were included to better characterize the area near the former log yard.

Control survival and growth met quality criteria for the juvenile polychaete test (Table 7-7). Survival and growth in each of the references met the survival and growth criteria, with growth that was 93–108% of the control. Growth rates were statistically lower than the corresponding references or controls for 3 of the 12 test sediments. All test samples passed the both the SQS and CSL criteria, with growth that was greater than 72% of the corresponding references for both dry weight and AFDW.

7.4 Larval Bioassay Results

For the larval test, benthic toxicity is evaluated based on the average number of normal larvae that are recovered in the test treatments relative to the number of normal larvae that are recovered from the appropriate reference sediment. A bioassay sample fails the SQS if mean normal survivorship is <85% of the reference sediment and the difference is statistically significant. A bioassay sample fails the CSL if normal survivorship is <70% of the reference sediment and the difference is statistically significant. Larval toxicity tests were included in the Mill Area RI (Anchor 2006a) and SRI (Anchor 2009) and the Port Gamble Bay RI (Hart Crowser 2009) and SRI (NewFields 2011b).

7.4.1 Anchor 2006 Mill Area RI

In 2006, 11 sediment samples were tested for acute toxicity using the larval echinoderm, *Dendraster excentricus*. Normal development in both the control and the R1 reference sample met the SMS acceptability criterion (65% of control; Table 7-8). The reference, AS-R3, had 50% normal survival relative to the control and was not considered acceptable for interpretation of test sediments. The reference AS-R1 was therefore used to evaluate all test sediments.

With the exception of Station AS-3002, all stations failed the SQS criterion for the larval test with less than 85% normal survival relative to the reference. Sediment from Stations AS-03, 14, 3001, and 3004 also failed the CSL criterion with less than 70% normal survival relative to the reference.

7.4.2 Anchor 2008 Mill Area Supplemental RI

The Mill Area SRI included 14 additional stations in the vicinity of the former Pope and Talbot Mill. None of the stations directly replaced stations collected during the 2006 RI. Normal survivorship in the control and reference treatments met the SMS acceptability criteria (Table 7-8). A total of 10 stations failed the SQS criterion with less than 85% normal survivorship relative to the reference. Two stations in the embayment immediately south of the mill (AS-B11 and B14) had normal survivorship below the CSL criterion of 70% relative to the reference.

Table 7-8. Larval Bioassay Results for *Dendraster excentricus*, Anchor 2006/2008 Mill Area RI/SRI

Station	Percent Fines	Reference	Number Normal		Sig. Diff.	SMS Interpretation N_{Test} / N_{Ref}			Sample Tested in SRI
			Mean	SD		Value	SQS <0.85	CSL <0.70	
2006 Mill Area Remedial Investigation									
Control	--		354	19			Pass QA (N > 70%)		
AS-R1	15.3	Control[a]	298	53	--	0.84	Pass QA[a]		
AS-R3	39.7	Control[a]	178	35	--	0.50	Fails QA[a]		
AS-01	23.9	AS-R1	216	22	Yes	0.72	Fail	Pass	MS-01
AS-02	20.7	AS-R1	235	57	Yes	0.79	Fail	Pass	
AS-03	14.7	AS-R1	183	57	Yes	0.61	Fail	Fail	MS-03
AS-05	50.1	AS-R1[b]	224	37	Yes	0.75	Fail	Pass	MS-04
AS-07	42.6	AS-R1[b]	214	72	Yes	0.72	Fail	Pass	
AS-09	26.1	AS-R1	215	41	Yes	0.72	Fail	Pass	
AS-13	17.6	AS-R1	237	60	Yes	0.80	Fail	Pass	
AS-14	6.7	AS-R1	205	55	Yes	0.69	Fail	Fail	MS-08
AS-3001	54.7	AS-R1[b]	143	37	Yes	0.48	Fail	Fail	BW-12
AS-3002	83.5	AS-R1[b]	254	16	No	0.85	Pass	Pass	
AS-3004	83.9	AS-R1[b]	172	51	Yes	0.58	Fail	Fail	PGSS-8
2008 Mill Area Supplemental Remedial Investigation									
Control	--		231	14			Pass QA (N > 70%)		
CR-1	55	Control[a]	214	15	--	0.93	Pass QA[a]		
CR-22	15	Control[a]	221	7	--	0.96	Pass QA[a]		
SBR-35	35	Control[a]	210	8	--	0.91	Pass QA[a]		
AS-101	7.7	CR-22	190	21	Yes	0.86	Pass	Pass	
AS-102	6.2	CR-22	189	17	Yes	0.86	Pass	Pass	
AS-106	8.4	CR-22	162	11	Yes	0.73	Fail	Pass	
AS-108	46.2	CR-1	227	6	No	1.06	Pass	Pass	
AS-112	12.8	CR-22	169	11	Yes	0.76	Fail	Pass	
AS-113	44.0	CR-1	170	20	Yes	0.79	Fail	Pass	
AS-B09	4.9	CR-22	166	18	Yes	0.75	Fail	Pass	
AS-B11	33.7	SBR-35	124	21	Yes	0.59	Fail	Fail	MS-07
AS-B14	57.8	CR-1	127	23	Yes	0.59	Pass	Fail	MS-06
AS-B15	ND[c]	CR-22	171	10	Yes	0.77	Fail	Pass	
AS-B16	26.7	SBR-35	160	29	Yes	0.76	Fail	Pass	MS-10
AS-B18	32.0	SBR-35	160	15	Yes	0.76	Fail	Pass	

[a] Reference treatments are compared to the control; performance standard is N_{Ref} / $N_{Control}$ ≥ 0.65.

[b] The appropriate reference failed QA; treatment compared to AS-R1;

[c] No available data; comparison made based on RI/FS (Anchor 2009).

7.4.3 Hart Crowser 2008 RI

Larval tests were conducted on 32 sediments throughout Port Gamble Bay with the mussel, *Mytilus* sp. The controls for both test batches met the SMS acceptability requirement, with 100% and 97% mean normal survivorship (Table 7-9). With the exception of CR-23 MOD in Batch 1, each of the references met the reference sediment performance standard, with >65% mean normal survivorship relative to the control. The medium-grained size reference, CR-23 MOD, failed to meet the reference performance standard with 52.2% normal survivorship relative to the control. For the purposes of the RI, the fine-grained reference CR-20W was used for SMS comparisons.

Table 7-9. Larval Bioassay Results for *Mytilus* sp., Hart Crowser 2008 RI

Station	Percent Fines	Reference	Number Normal		Sig. Diff.	SMS Interpretation N_{Test} / N_{Ref}			Sample Tested in SRI
			Mean	SD		Value	SQS <0.85	CSL <0.70	
Batch 1									
Control	--		304	28			Pass QA (N > 70%)		
MSMP43	6.4	Control[a]	226	32	--	0.74	Pass QA[a]		•
CR20W	79.7	Control[a]	229	19	--	0.75	Pass QA[a]		•
CR23 MOD	51.6	Control[a]	159*	42	--	0.52	Fails QA[a]		•
PGSS-08	87.9	CR20W	205	27	Yes	0.90	Pass	Pass	
PGSS-15	92.7	CR20W	200	29	Yes	0.87	Pass	Pass	
PGSS-16	94.4	CR20W	196	32	Yes	0.86	Pass	Pass	
PGSS-18	94.8	CR20W	177	36	Yes	0.77	Fail	Pass	BW-20
PGSS-20	93.6	CR20W	203	28	Yes	0.89	Pass	Pass	
PGSS-21B	50.2	CR20W	154	32	Yes	0.67	Fail	Fail	BW-17
PGSS-22	92.2	CR20W	140	9	Yes	0.61	Fail	Fail	BW-18
PGSS-29A	69.9	CR20W	177	13	Yes	0.77	Fail	Pass	BW-12
PGSS-30	87.6	CR20W	174	32	Yes	0.76	Fail	Pass	BW-13
PGSS-31	88.6	CR20W	172	40	Yes	0.75	Fail	Pass	BW-14
PGSS-33	87.0	CR20W	185	38	Yes	0.81	Fail	Pass	BW-15
PGSS-35	91.0	CR20W	192	13	Yes	0.84	Fail	Pass	BW-16
PGSS-38A	52.4	CR20W	151	65	Yes	0.66	Fail	Fail	BW-07
PGSS-39	88.7	CR20W	159	46	Yes	0.69	Fail	Fail	BW-08
PGSS-40	84.1	CR20W	157	35	Yes	0.69	Fail	Fail	BW-09
PGSS-42	77.4	CR20W	128	20	Yes	0.56	Fail	Fail	BW-10
Batch 2									
Control	--		277	17					
MSMP43	6.4	Control[a]	203	8	--	0.73		Pass QA[a]	
CR20W	79.7	Control[a]	248	29	--	0.90		Pass QA[a]	
CR23 MOD	51.6	Control[a]	216	30	--	0.78		Pass QA[a]	
PGSS-44	85.4	CR20W	200	28	Yes	0.81	Fail	Pass	BW-11
PGSS-45	85.8	CR20W	215	17	Yes	0.87	Pass	Pass	
PGSS-47	22.0	MSMP43	163	31	Yes	0.80	Fail	Pass	BW-03
PGSS-51	65.3	CR23MOD	209	41	No	0.97	Pass	Pass	BW-04
PGSS-53	58.9	CR23MOD	199	26	No	0.92	Pass	Pass	BW-05
PGSS-54	60.8	CR23MOD	142	30	Yes	0.66	Fail	Fail	BW-06
PGSS-56	12.6	MSMP43	128	23	Yes	0.63	Fail	Fail	BW-02
PGSS-58	70.5	CR20W	216	30	Yes	0.87	Pass	Pass	
PGSS-62	6.7	MSMP43	244	21	No	1.20	Pass	Pass	
PGSS-63	21.8	MSMP43	196	14	No	0.97	Pass	Pass	
PGSS-64	23.2	MSMP43	150	36	Yes	0.74	Fail	Pass	BW-01
PGSS-67	15.3	MSMP43	188	50	No	0.93	Pass	Pass	
PGSS-73	6.1	MSMP43	219	26	No	1.08	Pass	Pass	
PGSS-75	3.9	MSMP43	217	19	No	1.07	Pass	Pass	
PGSS-77A	18.5	MSMP43	214	33	No	1.05	Pass	Pass	
PGSS-92	18.0	MSMP43	198	41	No	0.98	Pass	Pass	

[a] Reference treatments are compared to the control; performance standard is N_{Ref} / $N_{Control}$ ≥ 0.65.

When compared to the appropriate grain-size reference, 22 of the test treatments had normal survivorship that was significantly different than their associated reference samples (Table 7-9). Sediment from 16 of those stations failed the SQS criterion. Sediment from Stations PGSS-21B, 38A, 39, 40, 42, 54, and 56 also failed the CSL criterion.

Based on a review of the larval toxicity test results, stations with larval test failures were generally associated with fine-grained sediments typical of Port Gamble Bay. The PSEP larval test is susceptible to interference issues in sediments with a high percentage of fine-grained silts and clays (EPA 1993; Ecology 1999; NewFields 2010a,b,c, 2011c; MEC 2004). The PSEP larval test method involves shaking the test sediments in seawater prior to starting the test, with less dense or finer material such as silts, clays, and organic matter separating out and forming a blanket of fine sediment or flocculent material over the sediment surface (Figure 7-1). This stratification is an artifact of the test method and does not represent the sediment as it occurs in nature. In such sediments, the non-swimming, early-stage larvae can become buried or entrained in the finer material that settles after test initiation. When large amounts of fine material are present, larvae can become sufficiently buried that they cannot swim up into the water column once they develop into the motile blastula and gastrula stages. In such cases, the number of larvae recovered is low, but the larvae that are recovered develop normally.

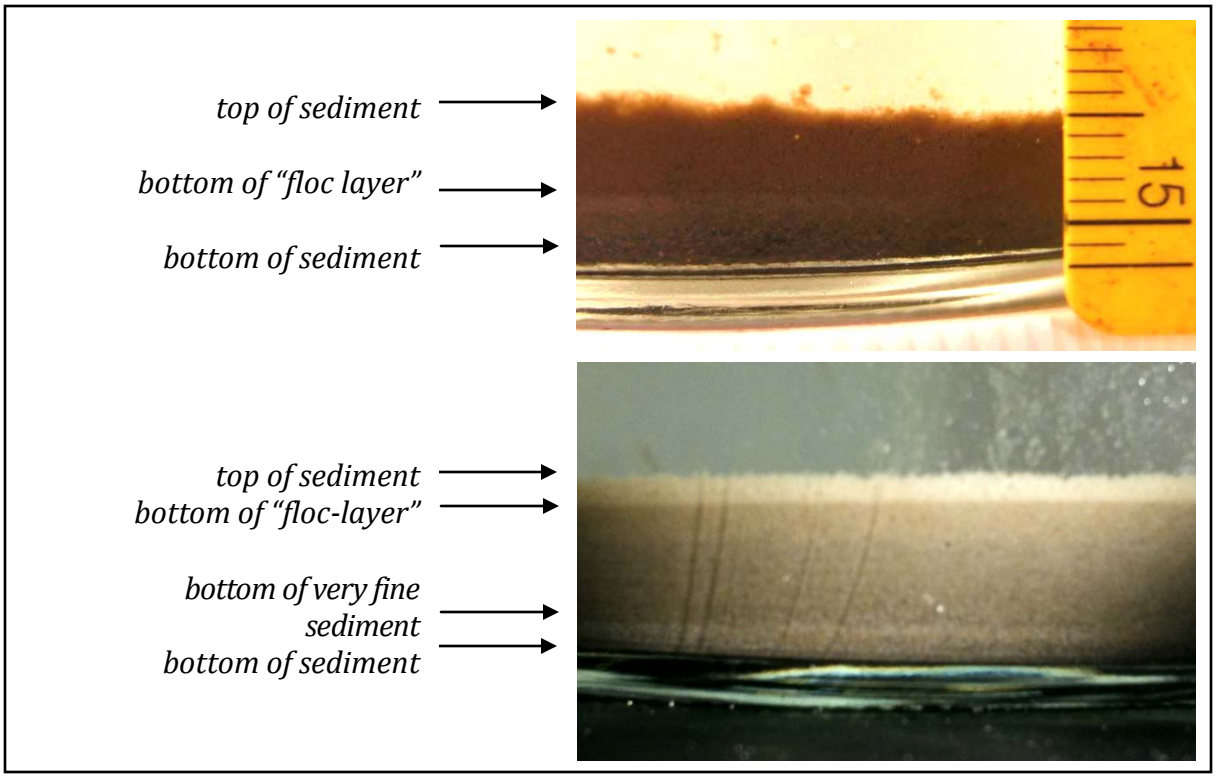

Figure 7-1. Examples of Fine-Grained Sediment and Flocculent Layers Forming in Larval Test Chambers

Recent studies have indicated that buried larvae can still develop normally if sediments are not toxic; however, they are not recovered at the end of the test because they are entrained in the bedded sediment (MEC 2004; NewFields 2010a,b,c). An alternative method for test termination was developed

to help understand the potential interference of fine-grained sediment and fine organic matter. In this method, the PSEP test is conducted and terminated following the standard protocol (water overlying the bedded sediment is decanted and then subsampled for larval counts). However, once the subsample is collected, the seawater that has been decanted is poured back into the test chamber with the original sediment and the mixture is homogenized with a perforated plunger. Following a settling period (generally overnight) the test is "re-terminated" following the standard protocol (decanting the overlying water and subsampling for enumeration). Any larvae (normal or abnormal) that were buried, as well as those in the water column, are then recovered and enumerated.

This "resuspension" method has been included in several recent test efforts in Ostrich Bay, Grays Harbor, and the Lower Duwamish River (NewFields 2010a,b; SAIC 2010a,b; SAIC and NewFields 2011). In cases where burial was not an issue, there was little change in the test results. However, for both reference and test sediments in which substantial fine-grained sediments and organic material were present, the number of normal larvae recovered increased, capturing those larvae that were developing within the sediment.

Data from the central and southern portion of Port Gamble Bay indicate that nearly 30% of the sediment is clay, and the formation of a fine-grained layer was observed in the test chambers. The mean number of normal larvae recovered in many of the test treatments in Port Gamble Bay was reduced in the RI; however, a high proportion of the larvae recovered were normally developed. This provided an indication that burial of larval may have affected larval recovery for the fine-grained reference and some of the test treatments evaluated.

7.4.4 NewFields 2011 RI

To better understand the results of the 2009 RI larval tests, a subset of stations were selected for reevaluation using the resuspension method for termination, alongside the standard PSEP method. Selected stations included those that did not pass the SQS or CSL standards, as well as nearby stations that did pass the SMS standards (Table 7-10). The seawater controls met the SMS performance standard, with >90% normal survivorship for test batches 1 and 2 terminated with both the PSEP and resuspension methods. Each of the reference sediments passed the reference performance standard of >65% normal survivorship relative to the control for both test batches. Similar larval recoveries were observed in the reference sediments for both the PSEP and resuspension termination method.

In general, larval recoveries with the PSEP method were similar to those of the previous investigations, with reduced numbers of larvae recovered and >95% normal development (>95% of the larvae recovered developed to normal D-shaped larvae). Using the resuspension method, larval recovery increased for a number of test treatments (BW-04, 05, 05, 07, 08, 09, 10, 11, 13, 14, 15, 20, 21, MS-01, 02, 03, and 04). For these samples, the mean number of normal larvae recovered ranged from 164 to 234 using the PSEP method and from 216 to 301 using the resuspension method. In some cases there was little change in the number of larvae recovered, particularly in the coarser sediment samples (BW-01, 02, 03, 12, 17, MS-5, 08, and 09), as well as some samples with finer-grained sediment (BW-16, 18, 19, MS-06, 07, and 10).

Table 7-10. Larval Bioassay Results for *Mytilus* sp., NewFields 2011 RI

2011 SRI Station	2009 RI Station	Percent Fines	Reference	PSEP Method		Resuspension Method					
				Number Normal		Number Normal		Significant Difference	SMS Interpretation N_{Test} / N_{Ref}		
				Mean	SD	Mean	SD		Value	SQS <0.85	CSL <0.70
Batch 1											
Control	--	--	--	318	15	319	10			Pass QA (N > 70%)	
CI-01	--	6.1	Control[a]	279	45	277	21	--	0.87	Pass QA[a]	
CI-02	--	42.7	Control[a]	273	33	274	35	--	0.86	Pass QA[a]	
CI-03	--	77.7	Control[a]	279	15	262	13	--	0.82	Pass QA[a]	
BW-01	PGSS-64	18.1	CI-01	259	17	269	19	No	0.97	Pass	Pass
BW-02	PGSS-56	8.8	CI-01	291	26	260	14	Yes	0.94	Pass	Pass
BW-03	NA	21.1	CI-01	285	27	250	20	Yes	0.90	Pass	Pass
BW-04	PGSS-51	71.0	CI-03	193	69	270	35	No	1.03	Pass	Pass
BW-05	PGSS-53	64.3	CI-03	199	14	283	11	No	1.08	Pass	Pass
BW-06	PGSS-54	66.2	CI-03	168	24	291	31	No	1.10	Pass	Pass
BW-07	PGSS-38A	53.8	CI-02	217	13	279	12	No	1.03	Pass	Pass
BW-08	PGSS-39	88.2	CI-03	224	28	270	16	No	1.03	Pass	Pass
BW-09	PGSS-40	86.4	CI-03	202	12	265	28	No	1.01	Pass	Pass
BW-10	PGSS-42	81.2	CI-03	175	32	277	24	No	1.06	Pass	Pass
BW-11	PGSS-44	85.7	CI-03	196	42	220	13	Yes	0.84	Fail	Pass
BW-12	NA	48.4	CI-02	207	27	208	20	Yes	0.77	Fail	Pass
BW-13	PGSS-30	87.2	CI-03	179	28	231	17	Yes	0.88	Pass	Pass
BW-14	PGSS-31	90	CI-03	223	17	254	17	No	0.97	Pass	Pass
BW-15	PGSS-33	90.1	CI-03	201	7	222	17	Yes	0.85	Fail	Pass
BW-16	PGSS-35	92.9	CI-03	212	24	202	18	Yes	0.77	Fail	Pass
BW-17	NA	30.8	CI-02	226	26	235	12	Yes	0.87	Pass	Pass

Table 7-10. Larval Bioassay Results for *Mytilus* sp., NewFields 2011 RI

2011 SRI Station	2009 RI Station	Percent Fines	Reference	PSEP Method		Resuspension Method					
				Number Normal		Number Normal		Significant Difference	SMS Interpretation N_{Test} / N_{Ref}		
				Mean	SD	Mean	SD		Value	SQS <0.85	CSL <0.70
Batch 2											
Control	--	--		321	18	297	22			Pass QA (N > 70%)	
CI-01	--	6.1	Control[a]	249	41	295	30	--	0.99	Pass QA[a]	
CI-02	--	42.7	Control[a]	254	23	292	26	--	0.98	Pass QA[a]	
CI-03	--	77.7	Control[a]	279	15	249	22	--	0.79	Pass QA[a]	
BW-18	PGSS-22	86.4	CI-03	168	22	195	7	Yes	0.78	Fail	Pass
BW-19	NA	95.3	CI-03	180	33	210	9	Yes	0.84	Fail	Pass
BW-20	PGSS-18	96.5	CI-03	189	19	224	16	Yes	0.90	Pass	Pass
BW-21	NA	95.3	CI-03	164	15	216	26	Yes	0.87	Pass	Pass
MS-01	AS-01	27.4	CI-02	234	22	299	32	No	1.01	Pass	Pass
MS-02	AS-104	18.0	CI-01	235	26	301	21	No	1.02	Pass	Pass
MS-03	AS-03	25.5	CI-02	228	33	264	16	Yes	0.93	Pass	Pass
MS-04	AS-05	55.8	CI-02	214	17	280	25	Yes	0.97	Pass	Pass
MS-05	NA	17.1	CI-02	242	17	249	20	No	0.87	Pass	Pass
MS-06	AS-B14	50.8	CI-01	209	15	230	13	Yes	0.81	Fail	Pass
MS-07	AS-B11	32.7	CI-02	200	52	224	68	Yes	0.79	Fail	Pass
MS-08	AS-14	7.1	CI-02	245	11	238	14	No	0.83	Fail	Pass
MS-09	NA	16.3	CI-01	205	27	213	34	Yes	0.74	Fail	Pass
MS-10	AS-B16	38..5	CI-02	217	19	240	16	Yes	0.84	Fail	Pass

[a] Reference treatments are compared to the control; performance standard is N_{Ref} / $N_{Control}$ ≥ 0.65.

For the purposes of evaluating sediment quality under SMS, the results of the resuspension method were used. When compared to the appropriate grain-size reference, 12 of the test treatments had normal survivorship that was significantly different than their associated reference samples (Table 7-10). Sediment from 12 stations (BW-11, 12, 15, 16, 18, 19, MS-06, 07, 08, 09, and 10) failed the SQS criterion, with <85% normal survivorship relative to reference. All of the test sediments passed the CSL criterion for the larval test.

7.5 SMS Interpretation

SMS determinations of toxicity were based on data collected in the Mill Area and Port Gamble Bay RI and SRI investigations, with test results from the 2011 Supplemental RI superseding those of the previous studies in cases where stations were retested. The SQS for toxicity is exceeded if one of the sediment biological tests failed the specified SQS criterion. The CSL is exceeded if one test failed its CSL criterion or if two tests failed their SQS criteria. A total of 21 locations in Port Gamble Bay exceeded the SQS, based on the larval test (Table 7-11 and Figure 7-2). None of these stations exceeded the CSL for the larval test. Two of the 61 locations evaluated in Port Gamble Bay (Stations MS-01 and MS-03) exceeded the CSL due to a CSL exceedance for the amphipod test.

Table 7-11. SMS Interpretation of Toxicity Test Results

Station	Amphipod Mortality	Juvenile Polychaete Growth	Larval Development	SMS Interpretation
AS-02	Pass	Pass	Fails SQS	Fails SQS
AS-07	Pass	Pass	Fails SQS	Fails SQS
AS-09	Pass	Pass	Fails SQS	Fails SQS
AS-101	Pass	--	Pass	Pass
AS-102	Pass	--	Pass	Pass
AS-106	Pass	--	Fails SQS	Fails SQS
AS-108	Pass	--	Pass	Pass
AS-112	Pass	--	Fails SQS	Fails SQS
AS-113	Pass	--	Fails SQS	Fails SQS
AS-13	Pass	Pass	Fails SQS	Fails SQS
AS-3002	Pass	Pass	Pass	Pass
AS-B09	Pass	--	Fails SQS	Fails SQS
AS-B15	Pass	--	Fails SQS	Fails SQS
AS-B18	Pass	Pass	Fails SQS	Fails SQS
BW-01	Pass[a]	Pass[a]	Pass	Pass
BW-02	Pass[a]	Pass[a]	Pass	Pass
BW-03	Pass[a]	Pass[a]	Pass	Pass
BW-04	Pass[a]	Pass[a]	Pass	Pass
BW-05	Pass[a]	Pass[a]	Pass	Pass
BW-06	Pass[a]	Pass[a]	Pass	Pass
BW-07	Pass[a]	Pass[a]	Pass	Pass
BW-08	Pass[a]	Pass	Pass	Pass
BW-09	Pass[a]	Pass	Pass	Pass
BW-10	Pass[a]	Pass[a]	Pass	Pass
BW-11	Pass[a]	Pass[a]	Fails SQS	Fails SQS
BW-12	Pass[b]	Pass	Fails SQS	Fails SQS
BW-13	Pass[a]	Pass	Pass	Pass

Table 7-11. SMS Interpretation of Toxicity Test Results

Station	Amphipod Mortality	Juvenile Polychaete Growth	Larval Development	SMS Interpretation
BW-14	Pass[a]	Pass	Pass	Pass
BW-15	Pass[a]	Pass	Fails SQS	Fails SQS
BW-16	Pass[a]	Pass[a]	Fails SQS	Fails SQS
BW-17	Pass[a]	Pass	Pass	Pass
BW-18	Pass[a]	Pass[a]	Fails SQS	Fails SQS
BW-19	--	Pass	Fails SQS	Fails SQS
BW-20	Pass[a]	Pass	Pass	Pass
BW-21	--	Pass	Pass	Pass
MS-01	Fails CSL[b]	Pass	Pass	Fails CSL
MS-02	Pass[c]	Pass	Pass	Pass
MS-03	Fails CSL[b]	Pass	Pass	Fails CSL
MS-04	Pass[b]	Pass	Pass	Pass
MS-05	--	Pass	Pass	Pass
MS-06	Pass[c]	--	Fails SQS	Fails SQS
MS-07	Pass[c]	--	Fails SQS	Fails SQS
MS-08	Pass[b]	Pass	Fails SQS	Fails SQS
MS-09	--	Pass	Fails SQS	Fails SQS
MS-10	Pass[c]	Pass	Fails SQS	Fails SQS
PGSS-8	Pass	Pass	Pass	Pass
PGSS-15	Pass	Pass	Pass	Pass
PGSS-16	Pass	Pass	Pass	Pass
PGSS-20	Pass	Pass	Pass	Pass
PGSS-45	Pass	Pass	Pass	Pass
PGSS-46	Pass	Pass	Pass	Pass
PGSS-58	Pass	Pass	Pass	Pass
PGSS-62	Pass	Pass	Pass	Pass
PGSS-62B	Pass	Pass	Pass	Pass
PGSS-63	Pass	Pass	Pass	Pass
PGSS-67	Pass	Pass	Pass	Pass
PGSS-69	Pass	Pass	Pass	Pass
PGSS-73	Pass	Pass	Pass	Pass
PGSS-75	Pass	Pass	Pass	Pass
PGSS-77A	Pass	Pass	Pass	Pass
PGSS-92	Pass	Pass	Pass	Pass

[a]Determination based on data collected during the Hart Crowser 2008 RI (Hart Crowser 2010).

[b]Determination based on data collected during the Anchor 2006 Mill Area RI (Anchor 2006a).

[c]Determination based on data collected during the Anchor 2008 Mill Area SRI (Anchor 2009).

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8.0 HUMAN HEALTH RISK

Human health risk is one important component of developing cleanup standards for the site and identifying site boundaries and SMAs. The cleanup standard is defined as the highest of 1) risk-based concentrations, 2) natural background concentrations, and 3) practical quantitation limits (PQLs). This section addresses human health risk, Section 9 addresses natural background comparisons, and Section 11 describes how these are combined with PQLs to identify contaminants of concern and select site-specific cleanup levels.

This assessment focuses on risks associated with tribal collection and ingestion of shellfish from Port Gamble Bay. Risks are presented for concentrations found in shellfish and intertidal sediments Port Gamble Bay, as well as natural background concentrations for Puget Sound.

8.1 Exposure Pathways and Reasonable Maximum Exposure Scenarios

Two exposure pathways were identified for Port Gamble Bay:

- Ingestion of shellfish, using tribal consumption rates that are considered protective of other subsistence and recreational consumers.
- Direct sediment contact (incidental sediment ingestion and dermal contact) during shellfish gathering.

Four reasonable maximum exposure (RME) scenarios were developed to address these exposure pathways: (1) adult and child tribal seafood ingestion scenarios, with a focus on shellfish ingestion, and (2) adult and child tribal clamming scenario. The RME scenarios were developed for Port Gamble Bay based on the EPA tribal framework document (EPA 2007). As described below, procedures and relevant exposure parameter values were taken from the recent EPA and Ecology-approved human health risk assessment for the LDW site, including direction from EPA regarding exposure parameters for shellfish ingestion and the clamming RME scenarios (Windward 2007).

In addition to shellfish collection and ingestion, risk from incidental contact with potentially contaminated sediment could occur from activities such as recreational use of the intertidal areas of the bay or use of fishing nets. However, these risks are expected to be significantly lower than the exposure pathways evaluated below.

8.2 Ingestion of Shellfish

For tribal ingestion of shellfish, CoPCs, exposure data for shellfish, and calculation of exposures as chronic daily intake (CDI) are presented below.

8.2.1 Chemicals of Potential Concern

CoPCs were identified in the screening level risk assessment (Hart Crowser 2009). In addition, mercury was added due to its potential to accumulate in seafood. The following CoPCs were evaluated:

- Metals, including arsenic, cadmium, copper, and mercury
- cPAHs
- PCBs, both as Aroclors and selected PCB congeners with dioxin-like activity
- PCDD/PCDFs, congeners, and homolog groups

8.2.2 Target Species

Shellfish species evaluated included Dungeness crab, geoduck, oysters, littleneck clams, manila clams, and cockles. Numbers and locations of tissue samples as well as tissue concentrations of the above CoPCs are presented in Sections 3.3 and 6.0 and in Appendix A.

8.2.3 Site-Specific Consumption Rates

Consumption rates for each of these seafood categories were developed following the EPA Tribal Fish and Shellfish Consumption Framework (EPA 2007) and consultation with the Port Gamble S'Klallam Tribe. In addition, although salmon are a highly preferred and consumed fish from Port Gamble Bay, human health risks were not calculated for salmon consumption. Port Gamble Bay sediment contaminants are not expected to significantly contribute to salmon tissue concentrations because of the relatively small portion of their lifetime spent in the bay, consistent with the EPA Framework document (EPA 2007).

A daily tribal shellfish consumption rate of 499 g/day was used, with the following breakdown for the species collected from the bay:

- Geoduck – 96.8 g/day. Samples submitted for analysis included the gutball; the skin was removed from the siphon prior to analysis.
- Clams – 255.9 g/day, whole organism without shell. Littleneck clams, manila clams, and cockles were pooled together under the clam category.
- Oysters – 62.4 g/day, whole organism without shell.
- Dungeness crab – 83.9 g/day, assuming 25% hepatopancreas (20.975 g/day) and 75% meat (62.925 g/day), which were analyzed separately.

The total ingestion rate for shellfish was consistent with the Tribal Framework Document (EPA 2007) using the Suquamish survey data, as agreed between Ecology and the Port Gamble S'Klallam Tribe. The total shellfish ingestion rate was allocated among the shellfish categories of clams, geoducks, oysters, and crabs following the rates identified by EPA in the risk assessment for the LDW site (Windward 2007).

8.2.4 Chemical-Specific Summation Methods

Dioxins/furans, PCBs, and PAHs were evaluated as chemical groups. The PCB, dioxin/furan, and cPAH TEQs were calculated by applying the TEF to each congener or chemical and then summing multiple chemical values using KM summation methods where appropriate (Helsel 2010) or substitution at one-half the detection limit. The KM sum was only calculated when the frequency of detection was 50% or

greater across all congeners or individual chemicals within a sample, otherwise simple substitution at one-half the detection limit was used for all congeners. When TEQs were calculated using the KM method, if the highest or lowest toxic equivalency concentrations (TECs) were non-detects these were treated as detected as reported to avoid a low bias in the KM estimation method.

The following chemical-specific methods were used:

- Dioxins/furans were represented as total TCDD toxic equivalents (TEQs). WHO 2005 dioxin TEFs from MTCA Table 708-1 were used to calculate total TEQs.
- PCBs were represented both as the sum of Aroclors and TCDD TEQs for PCB congeners with dioxin-like activity. Aroclors were summed following the procedure described in the SMS. WHO 2005 PCB congener TEFs listed in MTCA Table 708-4 were used to calculate PCB TEQs.
- cPAHs were represented as benzo(a)pyrene TEQs. The California-EPA 2005 cPAH TEFs listed in MTCA Table 708-2 were used to calculate benzo(a)pyrene equivalents.
- The toxic and carcinogenic form of arsenic is inorganic arsenic. The amount of inorganic arsenic in the shellfish categories was estimated from the measured total arsenic by assuming 1.2% inorganic arsenic in clams, and 0.2% inorganic arsenic in crabs, as documented for Puget Sound organisms (Ecology 2002).

8.2.5 Exposure Point Concentrations

The exposure point concentration (EPC) was calculated as:

- The smaller of the maximum detected concentration or the 95th upper confidence limit (UCL) on the mean for CoPCs with at least one detected concentration.
- The maximum non-detect value was used as a proxy for the EPC for the CoPCs with no detected concentrations.

All EPC calculations and distributional evaluations were performed in ProUCL version 4.1.

The distribution for each CoPC data set was evaluated to determine if it followed a normal, lognormal, or gamma distribution at the 0.05 significance level, using appropriate methods for censored data when non-detected values were present. If a parametric distribution was found to be suitable by the goodness of fit tests used by ProUCL 4.1, then suitable parametric estimates of the 95th UCL on the mean were calculated. Otherwise, non-parametric estimates of the 95th UCL on the mean were calculated using the method most suited to the data, per ProUCL recommendations. A minimum of five samples was necessary to determine the distribution and calculate a UCL.

The specific methods used for each CoPC are identified in the EPC tables in Appendix B.

8.2.6 Risk Calculations

Carcinogenic risks and noncarcinogenic health effects were evaluated separately because of differences in assumptions about the mechanism of these toxic effects. The toxicity values used to evaluate exposure to chemicals with noncarcinogenic and carcinogenic effects are the reference dose (RfD) and cancer slope factor (CSF), respectively.

Carcinogenic chemicals are assumed to have no threshold for carcinogenicity. Carcinogenic risks are presented as the chance of contracting cancer over a 70-year lifetime due to site-related exposure. These risks are considered excess cancer risks that are in addition to the national rates of cancer for the general population (approximately a 1 in 3 chance, according to the American Cancer Society). For example, a $1x10^{-6}$ risk predicts that one person in a population of one million will develop cancer due to site-related exposures.

Noncarcinogenic risks are considered to have a threshold concentration (reference dose or RfD) above which some form of toxic response may be experienced. These types of risk are evaluated using a hazard quotient (HQ), which is the ratio of the exposure concentration to the lowest concentration that has toxic effects. For example, a hazard quotient of 2 indicates that a person has been exposed to twice the lowest concentration thought to have adverse effects. This concentration may or may not result in the more toxic effects possible for that chemical; higher hazard quotients indicate greater risks and a greater possibility of more severe effects.

Contaminant data for evaluating exposures from shellfish consumption were available for crabs, clams, oysters, and geoducks collected from Port Gamble Bay and for natural background areas in Puget Sound. CDIs were calculated for the CoPCs identified above. The CDI for the adult tribal ingestion scenario for each tissue was calculated as follows:

$$CDI_a = \frac{EPC \cdot IR \cdot FI \cdot EF \cdot ED}{BW \cdot AT}$$

where

CDI_a = Chronic daily intake for adult ingestion (mg/kg-day)
EPC = Exposure point concentration (mg/kg)
IR = Ingestion rate (kg/day)
FI = Fractional exposure (unitless)
EF = Exposure frequency (days/year)
ED = Exposure duration (years)
BW = Body weight (kg)
AT = Averaging time (days)

The CDI for the child tribal ingestion scenario for each tissue was calculated as follows:

$$CDI_c = \sum_{i=1}^{6} \frac{EPC \cdot IR \cdot FI \cdot EF \cdot ED_i}{BW_i \cdot AT}$$

where

CDI_c = Chronic daily intake for child ingestion (mg/kg-day)
EPC = Exposure point concentration (mg/kg)
IR = Ingestion rate (kg/day)
FI = Fractional exposure (unitless)
EF = Exposure frequency (days/year)
ED_i = Exposure duration (years) for years *i* = 1, 2, 3, 4, 5, 6
BW_i = Body weight (kg) for years *i* = 1, 2, 3, 4, 5, 6
AT = Averaging time (days)

Table 8-1 shows the exposure parameters that were assumed for these calculations for ingestion of crabs, clams, whole body geoduck, and oysters.

After the CDI was calculated for ingestion for each carcinogenic CoPC and tissue, ingestion risks for adult and child were calculated as follows:

$$risk_a = CDI_a \cdot SFo$$

$$risk_c = CDI_c \cdot SFo$$

where

CDI_c = Chronic daily intake for child ingestion (mg/kg-day)
CDI_a = Chronic daily intake for adult ingestion (mg/kg-day)
$risk_a$ = Ingestion risk for adult (unitless)
$risk_c$ = Ingestion risk for child (unitless)
SFo = Carcinogenic slope factor for oral ingestion (kg-day/mg)

Ingestion HQs for adult and child were calculated as follows:

$$HQ_a = \frac{CDI_a}{RfDo}$$

$$HQ_c = \frac{CDI_c}{RfDo}$$

where

CDI_a = Chronic daily intake for adult ingestion (mg/kg-day)
CDI_c = Chronic daily intake for child ingestion (mg/kg-day)
HQ_a = Non-carcinogenic hazard adult quotient (unitless)
HQ_c = Non-carcinogenic hazard child quotient (unitless)
RfDo = Non-carcinogenic reference dose for oral ingestion (mg/kg-day)

The carcinogenic SFo and non-carcinogenic RfD toxicity values were obtained from the June 2011 EPA Regional Screening Levels (RSLs) at http://www.epa.gov/region9/superfund/prg/, except that in accordance with MTCA, a CPF of $1.5x10^5$ was used for dioxins/furans and dioxin-like PCBs. Table 8-2 shows the carcinogenic toxicity values used in the human health risk assessment calculations for all CoPCs for both sediment and tissue. Table 8-3 shows the non-carcinogenic toxicity values used in the human health risk assessment calculations for all CoPCs for both sediment and tissue.

Table 8-1. Exposure Parameters for Tissue Ingestion

Parameter	Units	Clams		Crab - hepatopancreas		Crabs - muscle		Geoduck		Oysters	
		Adult	Child	Adult	Child	Adult	Child	Adult	Child	Adult	Child
Ingestion											
Tissue ingestion rate	kg/day	0.2559[a]	0.0151[b]	0.020975[a]	0.0042[b]	0.062925[a]	0.0132[b]	0.062925[a]	0.0151[b]	0.062925[a]	0.0151[b]
Fraction of exposure[a]	unitless	1	1	1	1	1	1	1	1	1	1
Exposure frequency[a]	days/year	365	365	365	365	365	365	365	365	365	365
Exposure duration[a]	years	70	(<1 yr) 1 (1–2) 1 (2–3) 1 (3–4) 1 (4–5) 1 (5–6) 1	70	(<1 yr) 1 (1–2) 1 (2–3) 1 (3–4) 1 (4–5) 1 (5–6) 1	70	(<1 yr) 1 (1–2) 1 (2–3) 1 (3–4) 1 (4–5) 1 (5–6) 1	70	(<1 yr) 1 (1–2) 1 (2–3) 1 (3–4) 1 (4–5) 1 (5–6) 1	70	(<1 yr) 1 (1–2) 1 (2–3) 1 (3–4) 1 (4–5) 1 (5–6) 1
Body weight[a]	kg	79	(<1 yr) 9.1 (1–2) 11.3 (2–3) 13.3 (3–4) 15.3 (4–5) 17.4 (5–6) 19.7	79	(<1 yr) 9.1 (1–2) 11.3 (2–3) 13.3 (3–4) 15.3 (4–5) 17.4 (5–6) 19.7	79	(<1 yr) 9.1 (1–2) 11.3 (2–3) 13.3 (3–4) 15.3 (4–5) 17.4 (5–6) 19.7	79	(<1 yr) 9.1 (1–2) 11.3 (2–3) 13.3 (3–4) 15.3 (4–5) 17.4 (5–6) 19.7	79	(<1 yr) 9.1 (1–2) 11.3 (2–3) 13.3 (3–4) 15.3 (4–5) 17.4 (5–6) 19.7
Carcinogen averaging time	days	25,550	25,550	25,550	25,550	25,550	25,550	25,550	25,550	25,550	25,550
Noncarcinogen averaging time	days	25,550	2190	25,550	2190	25,550	2190	25,550	2190	25,550	2190

[a] Hart Crowser (2009)

[b] Windward (2007)

Table 8-2. Carcinogenic Toxicity Values for Ingestion and Dermal Pathways

Analysis Type	CoPC	CAS Number	Oral SF (kg-day/mg)	GAF (unitless)	AF (mg/cm^2-day)	ABS (unitless)	Dermal SF (kg-day/mg)
Inorganics	Arsenic (inorganic)	7440-38-2	1.5	1	0.2	0.03	1.5
Inorganics	Cadmium (diet)	7440-43-9	--	0.025	0.2	0.001	--
Inorganics	Copper	7440-50-8	--	1	0.2	--	--
Inorganics	Mercury (as mercuric chloride)	7439-97-6	--	0.07	0.2	--	--
PAH	cPAH TEQ (BaP)	50-32-8	7.3	1	0.2	0.13	7.3
PCB	PCB TEQ (2,3,7,8-TCDD)	1746-01-6	1.5E+05	1	0.2	0.03	1.5E+05
Dioxin/Furan	Dioxin/Furan TEQ (2,3,7,8-TCDD)	1746-01-6	1.5E+05	1	0.2	0.03	1.5E+05

SF = slope factor

GAF = gastrointestinal absorption factor

AF = adherence factor

ABS = dermal absorption fraction

Table 8-3. Non-carcinogenic Toxicity Values for Ingestion and Dermal Pathways

Analysis Type	CoPC	CAS Number	Oral RfD (mg/kg-day)	GAF (unitless)	AF (mg/cm^2-day)	ABS (unitless)	Dermal RfD (mg/kg-day)
Inorganics	Arsenic (inorganic)	7440-38-2	3.0E-04	1	0.2	0.03	3.0E-04
Inorganics	Cadmium (diet)	7440-43-9	0.001	0.025	0.2	0.001	2.5E-05
Inorganics	Copper	7440-50-8	0.04	1	0.2	--	0.04
Inorganics	Mercury (as mercuric chloride)	7439-97-6	0.0003	0.07	0.2	--	2.1E-05
PAH	cPAH TEQ (BaP)	50-32-8	--	1	0.2	0.13	--
PCB	PCB TEQ (2,3,7,8-TCDD)	1746-01-6	1.0E-09	1	0.2	0.03	1.0E-09
Dioxin/Furan	Dioxin/Furan TEQ (2,3,7,8-TCDD)	1746-01-6	1.0E-09	1	0.2	0.03	1.0E-09

RfD = reference dose

GAF = gastrointestinal absorption factor

AF = adherence factor

ABS = dermal absorption fraction

8.3 Dermal and Ingestion Exposure to Beach Sediments

EPCs for dermal exposure and incidental ingestion of intertidal sediments during clam-digging or other beach use were calculated as described for the ingestion pathway using intertidal sediment data for Port Gamble Bay, and are shown in tables in Appendix B.

8.3.1 Ingestion of Intertidal Sediments

The CDI for the adult tribal ingestion scenario for sediment was calculated as follows:

$$CDI_{ing,a} = \frac{EPC \cdot IR \cdot FI \cdot EF \cdot ED}{BW \cdot AT}$$

where

$CDI_{ing,a}$ = Chronic daily intake for ingestion for adult (mg/kg-day)
EPC = Exposure point concentration (mg/kg)
IR = Ingestion rate (kg/day)
FI = Fractional exposure (unitless)
EF = Exposure frequency (days/year)
ED = Exposure duration (years)
BW = Body weight (kg)
AT = Averaging time (days)

The CDI for the child tribal ingestion scenario for sediment was calculated as follows:

$$CDI_{ing,c} = \sum_{i=1}^{6} \frac{EPC \cdot IR \cdot FI \cdot EF \cdot ED_i}{BW_i \cdot AT}$$

where

$CDI_{ing,c}$ = Chronic daily intake for ingestion for child (mg/kg-day)
EPC = Exposure point concentration (mg/kg)
IR = Ingestion rate (kg/day)
FI = Fractional exposure (unitless)
EF = Exposure frequency (days/year)
ED_i = Exposure duration (years) for years *i* = 1, 2, 3, 4, 5, 6
BW_i = Body weight (kg) for years *i* = 1, 2, 3, 4, 5, 6
AT = Averaging time (days)

Table 8-4 shows the exposure parameters that were assumed for the ingestion calculations.

After the CDI was calculated for ingestion for each CoPC, ingestion risks for adult and child were calculated as follows:

$$risk_{ing,a} = CDI_{ing,a} \cdot SFo$$

$$risk_{ing,c} = CDI_{ing,c} \cdot SFo$$

where

$CDI_{ing,c}$ = Chronic daily intake for ingestion for child (mg/kg-day)
$CDI_{ing,a}$ = Chronic daily intake for ingestion for adult (mg/kg-day)
$risk_{ing,a}$ = Ingestion risk for adult (unitless)
$risk_{ing,c}$ = Ingestion risk for child (unitless)
SFo = Carcinogenic slope factor for oral ingestion (kg-day/mg)

Ingestion HQs for adult and child were calculated as follows:

$$HQ_{ing,a} = \frac{CDI_{ing,a}}{RfDo}$$

$$HQ_{ing,c} = \frac{CDI_{ing,c}}{RfDo}$$

where

$CDI_{ing,c}$	=	Chronic daily intake for ingestion for child (mg/kg-day)
$CDI_{ing,a}$	=	Chronic daily intake for ingestion for adult (mg/kg-day)
$HQ_{ing,a}$	=	Non-carcinogenic hazard quotient for adult (unitless)
$HQ_{ing,c}$	=	Non-carcinogenic hazard quotient for child (unitless)
RfDo	=	Non-carcinogenic reference dose for oral ingestion (mg/kg-day)

The carcinogenic SFo and non-carcinogenic RfDo toxicity values are listed in Tables 8-2 and 8-3.

Table 8-4. Exposure Parameters for Intertidal Sediment Ingestion

Parameter	Units	Adult Tribal	Child Tribal
Sediment ingestion rate	kg/day	0.0001[a]	0.0002[b]
Fraction of exposure[b]	unitless	1	1
Exposure frequency[b]	days/year	365	365
Exposure duration	years	70[b]	(<1 yr) 1[c] (1–2) 1[c] (2–3) 1[c] (3–4) 1[c] (4–5) 1[c] (5–6) 1[c]
Body weight	kg	79[b]	(<1 yr) 9.1[c] (1–2) 11.3[c] (2–3) 13.3[c] (3–4) 15.3[c] (4–5) 17.4[c] (5–6) 19.7[c]
Carcinogen averaging time	days	25,550	25,550
Noncarcinogen averaging time	days	25,550	2190

[a] U.S. EPA default

[b] Hart Crowser (2009)

[c] Windward (2007)

8.3.2 Dermal Exposure to Intertidal Sediments

The CDI for the adult tribal dermal scenario for sediment was calculated as follows:

$$CDI_{der,a} = \frac{EPC \cdot CF \cdot SA \cdot AF \cdot ABS \cdot EF \cdot ED}{BW \cdot AT}$$

where

$CDI_{der,a}$ = Chronic daily intake for dermal for adult (mg/kg-day)
EPC = Exposure point concentration (mg/kg)
CF = Conversion factor (kg/mg)
SA = Skin area (cm^2)
AF = Adherence factor (mg/cm^2-day)
ABS = Absorption fraction (unitless)
EF = Exposure frequency (days/year)
ED = Exposure duration (years)
BW = Body weight (kg)
AT = Averaging time (days)

The CDI for the child tribal dermal scenario for sediment was calculated as follows:

$$CDI_{der,c} = \sum_{i=1}^{6} \frac{EPC \cdot CF \cdot SA_i \cdot AF \cdot ABS \cdot EF \cdot ED_i}{BW_i \cdot AT}$$

where

$CDI_{der,c}$ = Chronic daily intake for dermal for child (mg/kg-day)
EPC = Exposure point concentration (mg/kg)
CF = Conversion factor (kg/mg)
SA_i = Skin area (cm^2) for years *i* = 1, 2, 3, 4, 5, 6
AF = Adherence factor (mg/cm^2-day)
ABS = Absorption fraction (unitless)
EF = Exposure frequency (days/year)
ED_i = Exposure duration (years) for years *i* = 1, 2, 3, 4, 5, 6
BW_i = Body weight (kg) for years *i* = 1, 2, 3, 4, 5, 6
AT = Averaging time (days)

Table 8-5 shows the exposure parameters that were assumed for sediment calculations for dermal exposure.

After the CDI was calculated for dermal exposure for each CoPC, adult and child dermal risks were calculated as follows:

$$risk_{der,a} = CDI_{der,a} \cdot SFd$$

$$risk_{der,c} = CDI_{der,c} \cdot SFd$$

where

$CDI_{der,c}$ = Chronic daily intake for dermal for child (mg/kg-day)
$CDI_{der,a}$ = Chronic daily intake for dermal for adult (mg/kg-day)
$risk_{der,a}$ = Carcinogenic dermal risk for adult (unitless)
$risk_{der,c}$ = Carcinogenic dermal risk for child (unitless)
SFd = Carcinogenic slope factor for dermal (kg-day/mg)

Dermal HQs for adult and child were calculated as follows:

$$HQ_{der,a} = \frac{CDI_{der,a}}{RfDd}$$

$$HQ_{der,c} = \frac{CDI_{der,c}}{RfDd}$$

where

$CDI_{der,c}$ = Chronic daily intake for dermal for child (mg/kg-day)
$CDI_{der,a}$ = Chronic daily intake for dermal for adult (mg/kg-day)
$HQ_{der,a}$ = Non-carcinogenic dermal hazard quotient for adult (unitless)
$HQ_{der,c}$ = Non-carcinogenic dermal hazard quotient for child (unitless)
RfDd = Non-carcinogenic reference dose for dermal (mg/kg-day)

The carcinogenic SFd dermal toxicity values were derived from the oral slope factors using the gastrointestinal absorption factors listed in Table 8-2. Similarly, the non-carcinogenic RfDd dermal toxicity values were derived from the oral reference doses listed in Table 8-3.

Table 8-5. Exposure Parameters for Sediment Dermal Exposure

Parameter	Units	Adult Tribal	Child Tribal
Skin area	cm^2	5700[a]	(<1 yr) 1330[b] (1–2) 1750[b] (2–3) 2069[b] (3–4) 2298[b] (4–5) 2515[b] (5–6) 2751[b]
Adherence factor	mg/cm^2-day	0.07[a]	0.2
Absorption fraction	unitless	CS	CS
Exposure frequency	days/year	365	365
Exposure duration	years	70[c]	(<1 yr) 1[b] (1–2) 1[b] (2–3) 1[b] (3–4) 1[b] (4–5) 1[b] (5–6) 1[b]
Body weight	kg	79[c]	(<1 yr) 9.1[b] (1–2) 11.3[b] (2–3) 13.3[b] (3–4) 15.3[b] (4–5) 17.4[b] (5–6) 19.7[b]
Carcinogen averaging time	days	25,550	25,550
Noncarcinogen averaging time	days	25,550	2190
Conversion factor	kg/mg	1E-6	1E-6

CS = contaminant-specific value
[a] U.S. EPA default
[b] Windward (2007)
[c] Hart Crowser (2009)

8.4 Risk Characterization

8.4.1 Port Gamble Bay

Table 8-6 and Figure 8-1 summarize the risks for all exposure pathways and tissue types for Port Gamble Bay, for the tribal shellfish consumption and beach exposure scenarios described above. Detailed calculations for the risk assessment are presented in Appendix B.

Total carcinogenic risks to adults are 9.0×10^{-4} for the seafood ingestion pathway, exceeding the MTCA/SMS risk threshold of 1×10^{-5}. Carcinogenic risks to children are 6.7×10^{-5}. The total hazard index for noncarcinogenic chemicals is 7.9 for adults and 7.4 for children, both greater than the 1.0 MTCA/SMS risk threshold. In general, risks to children are lower than those to adults.

Dermal and ingestion exposures to intertidal sediments are in the $7–8 \times 10^{-6}$ range for adults and children, below the cumulative MTCA/SMS threshold. Arsenic contributes the majority of this risk. The hazard index is ≤0.23, below the MTCA/SMS threshold.

Inorganic arsenic, dioxin/furans, PCB dioxin-like congeners, and cPAHs for all tissues and pathways combined have cancer risks above the 1×10^{-6} threshold for individual chemicals, for both the adult and child scenarios:

- Inorganic arsenic, adult cancer risk = 2.5×10^{-4}, child cancer risk = 1.9×10^{-5}
- cPAH TEQ, adult cancer risk = 1.9×10^{-4}, child cancer risk = 1.6×10^{-5}
- PCB congener TEQ, adult cancer risk = 1.2×10^{-4}, child cancer risk = 1.0×10^{-5}
- Dioxin/furan TEQ, adult cancer risk = 3.6×10^{-4}, child cancer risk = 2.9×10^{-5}

From the above, it can be seen that each of these chemicals or chemical classes contributes roughly equally to the overall risk from ingestion of shellfish. The risk from exposure to intertidal sediments is significantly lower, and is primarily associated with inorganic arsenic.

Among the individual chemicals and groups, cadmium, copper, and the dioxin/furan TEQ had hazard quotients >1.0:

- Cadmium, adult HQ = 2.8, child HQ = 2.6
- Copper, adult HQ = 1.2, child HQ = 1.1
- Dioxins/furans, adult HQ = 2.4, child HQ = 2.3

HQs for arsenic, mercury, and PCBs were <1.0.

8.4.2 Natural Background

Table 8-7 and Figure 8-2 summarize the risks for natural background concentrations of the human health CoPCs in tissues in Puget Sound (see Section 9.2 for a description of the natural background data

set). Natural background risks could not be calculated for oysters or for intertidal sediment exposures due to lack of data. Detailed calculations for the risk assessment are presented in Appendix B.

Total carcinogenic risks to adults associated with natural background concentrations in Puget Sound are $2.5x10^{-3}$ for the tribal seafood ingestion exposure scenario, also above the cumulative MTCA/SMS risk threshold of $1x10^{-5}$. Carcinogenic risks to children are $1.1x10^{-4}$. The total hazard index for noncarcinogenic chemicals is 9.1 for adults and 6.5 for children, both greater than the 1.0 MTCA/SMS risk threshold. In general, risks to children are lower than those to adults.

Inorganic arsenic, dioxin/furans, and cPAHs have cancer risks above the $1x10^{-6}$ threshold for individual chemicals, for both the adult and child scenarios:

- Inorganic arsenic, adult cancer risk = $2.1x10^{-3}$, child cancer risk = $7.3x10^{-5}$
- cPAH TEQ, adult cancer risk = $4.1x10^{-5}$, child cancer risk = $2.0x10^{-6}$
- Dioxin/furan TEQ, adult cancer risk = $3.7x10^{-4}$, child cancer risk = $3.1x10^{-5}$

Among the individual chemicals and groups, arsenic, cadmium and the dioxin/furan TEQ have hazard quotients >1.0:

- Arsenic, adult HQ = 4.6, child HQ = 1.9
- Cadmium, adult HQ = 1.2, child HQ = 1.1
- Dioxins/furans, adult HQ = 2.4, child HQ = 2.4

Hazard quotients for copper and mercury were <1.0.

Table 8-8 and Figures 8-3 and 8-4 provide a summary comparison of risks associated with shellfish ingestion from Port Gamble Bay vs. natural background concentrations in Puget Sound. Based on Table 8-8 and the above comparisons, some general conclusions can be drawn:

- Overall risks from consumption of Port Gamble Bay shellfish are similar to or slightly lower than risks associated with shellfish from natural background areas in Puget Sound. This is true even though PCBs are included in the Port Gamble data, but there were no PCB congener data available for natural background areas. These differences are relatively small and likely within the error of the calculations.
- Risks for clams contribute most to the total risk in both areas, but particularly in natural background areas of Puget Sound.
- Detailed comparison of Tables 8-6 and 8-7 reveals some chemical-specific differences in risk between natural background areas and Port Gamble Bay. In general, risks associated with arsenic in the greater Puget Sound region are higher than in Port Gamble Bay, while risks associated with cadmium, copper, and cPAHs are higher in Port Gamble Bay than in Puget Sound. Risks associated with dioxins/furans are very similar between the two areas.

Table 8-6. Human Health Risks from Exposure to Tissues and Sediments of Port Gamble Bay

		All Chemicals		Arsenic*		Cadmium	Copper	Mercury	cPAH TEQ	PCB TEQ		Dioxin/Furan TEQ	
Medium	**Receptor**	**Risk**	**HI**	**Risk**	**HQ**	**HQ**	**HQ**	**HQ**	**Risk**	**Risk**	**HQ**	**Risk**	**HQ**
Clams	Adult	**4.1E-04**	**3.12**	1.6E-04	0.32	1.2	0.4	0.09	8.3E-05	2.7E-05	0.18	1.4E-04	0.93
Clams	Child	**1.2E-05**	**1.09**	4.3E-06	0.11	0.42	0.14	0.031	2.5E-06	8.1E-07	0.063	4.2E-06	0.33
Crab hepatopancreas	Adult	**1.7E-04**	**1.57**	6.4E-06	0.014	0.37	0.13	0.027	6.6E-06	6.6E-05	0.44	8.8E-05	0.59
Crab hepatopancreas	Child	**1.7E-05**	**1.86**	6.4E-07	0.017	0.44	0.15	0.031	6.6E-07	6.6E-06	0.52	8.9E-06	0.7
Crab muscle	Adult	**9.0E-05**	**0.72**	1.7E-05	0.037	0.032	0.17	0.13	2.1E-05	7.5E-06	0.05	4.4E-05	0.3
Crab muscle	Child	**9.5E-06**	**0.87**	1.8E-06	0.05	0.04	0.21	0.15	2.2E-06	8.0E-07	0.062	4.7E-06	0.36
Geoduck whole body	Adult	**1.0E-04**	**0.64**	2.9E-05	0.064	0.15	0.065	0.027	2.1E-05	8.0E-06	0.053	4.2E-05	0.28
Geoduck whole body	Child	**1.2E-05**	**0.89**	3.5E-06	0.09	0.21	0.091	0.038	2.5E-06	9.7E-07	0.075	5.0E-06	0.39
Oyster	Adult	**1.4E-04**	**1.84**	2.9E-05	0.064	1	0.38	0.034	5.8E-05	8.5E-06	0.057	4.5E-05	0.3
Oyster	Child	**1.7E-05**	**2.68**	3.5E-06	0.09	1.5	0.54	0.048	7.0E-06	1.0E-06	0.08	5.4E-06	0.42
Intertidal sediment	Adult	**7.7E-06**	**0.02**	5.7E-06	0.013	5.9E-04	8.2E-04	2.5E-04	1.1E-06	1.5E-08	9.9E-05	9.1E-07	6.1E-03
Intertidal sediment	Child	**7.3E-06**	**0.23**	5.5E-06	0.14	6.4E-03	9.7E-03	2.9E-03	8.9E-07	1.4E-08	1.1E-03	8.7E-07	0.068
Total	**Adult**	**9.1E-04**	**7.90**	**2.5E-04**	**0.51**	**2.75**	**1.15**	**0.31**	**1.9E-04**	**1.2E-04**	**0.78**	**3.6E-04**	**2.41**
Total	**Child**	**7.4E-05**	**7.62**	**1.9E-05**	**0.50**	**2.62**	**1.14**	**0.30**	**1.6E-05**	**1.0E-05**	**0.80**	**2.9E-05**	**2.27**

Risk = cancer risk over a lifetime, HI = hazard index, HQ = hazard quotient, TEQ = toxic equivalence quotient.

* Inorganic arsenic.

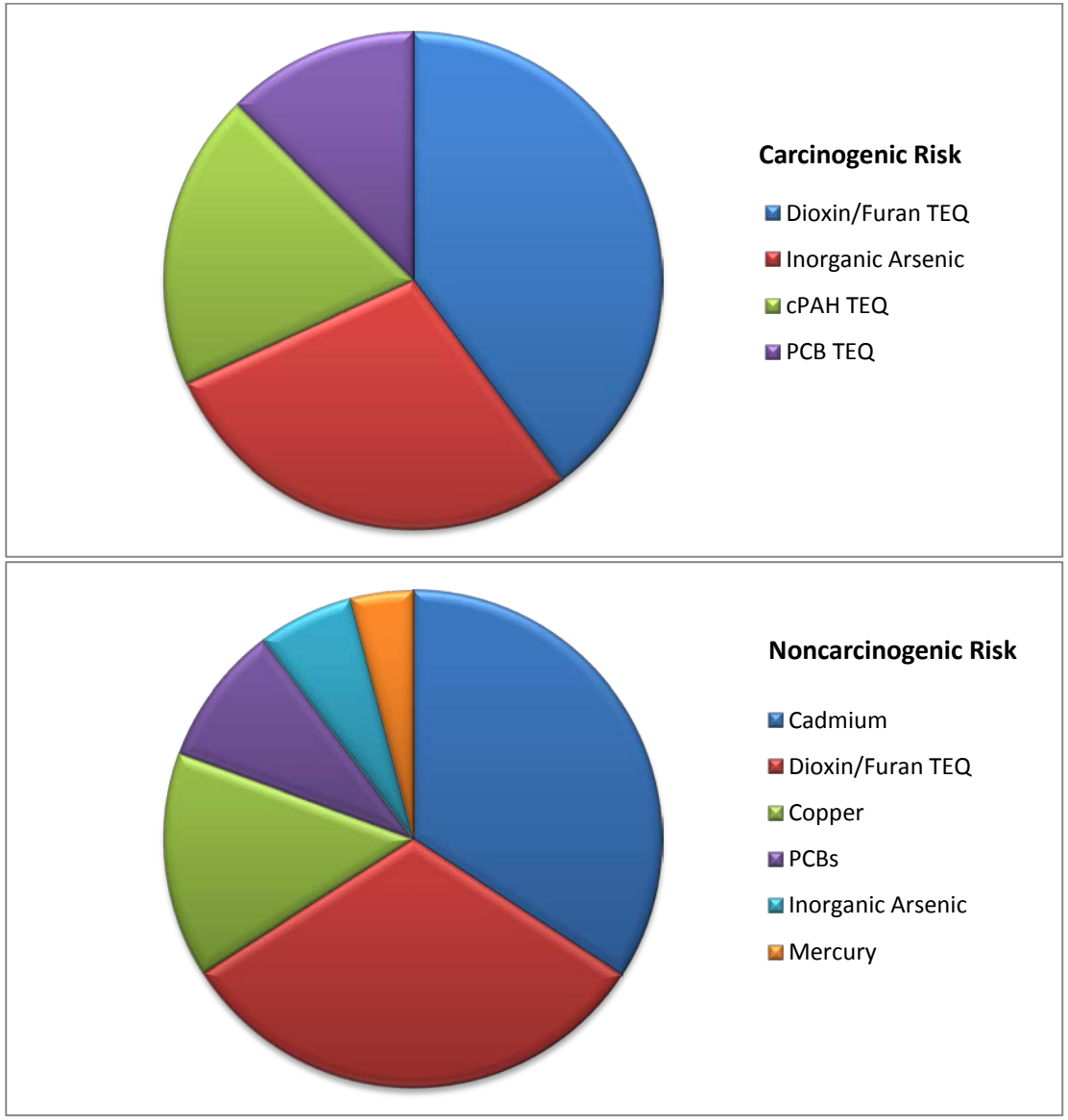


Figure 8-1. Relative Contributions to Human Health Risks in Port Gamble Bay

Table 8-7. Human Health Risks from Exposure to Natural Background Concentrations in Tissues

		All Chemicals		Arsenic*		Cadmium	Copper	Mercury	cPAH TEQ	Dioxin/Furan TEQ	
Medium	**Receptor**	**Risk**	**HI**	**Risk**	**HQ**	**HQ**	**HQ**	**HQ**	**Risk**	**Risk**	**HQ**
Clams	Adult	**2.1E-03**	**5.4**	1.9E-03	4.2	0.24	--	0.085	3.1E-05	1.3E-04	0.86
Clams	Child	**6.1E-05**	**2.0**	5.6E-05	1.5	0.084	--	0.085	9.2E-07	3.9E-06	0.30
Crab hepatopancreas	Adult	**1.7E-04**	**1.5**	1.4E-04	0.30	0.58	0.31	0.074	1.4E-06	3.6E-05	0.24
Crab hepatopancreas	Child	**1.7E-05**	**1.8**	1.4E-05	0.36	0.69	0.36	0.088	1.4E-07	3.6E-06	0.28
Crab muscle	Adult	**9.7E-05**	**0.84**	3.1E-05	0.067	0.092	0.094	0.19	7.6E-06	5.9E-05	0.40
Crab muscle	Child	**1.0E-05**	**0.94**	3.2E-06	0.084	0.011	0.12	0.23	8.0E-07	6.3E-06	0.49
Geoduck whole body	Adult	**1.4E-04**	**1.3**	--	--	0.26	0.054	0.080	8.1E-07	1.4E-04	0.91
Geoduck whole body	Child	**1.7E-05**	**1.8**	--	--	0.36	0.076	0.11	9.9E-08	1.7E-05	1.3
Total	**Adult**	**2.5E-03**	**9.1**	**2.1E-03**	**4.6**	**1.2**	**0.46**	**0.43**	**4.1E-05**	**3.7E-04**	**2.4**
Total	**Child**	**1.1E-04**	**6.5**	**7.3E-05**	**1.9**	**1.1**	**0.56**	**0.51**	**2.0E-06**	**3.1 E-05**	**2.4**

Risk = cancer risk over a lifetime, HI = hazard index, HQ = hazard quotient, TEQ = toxic equivalence quotient.

* Inorganic arsenic

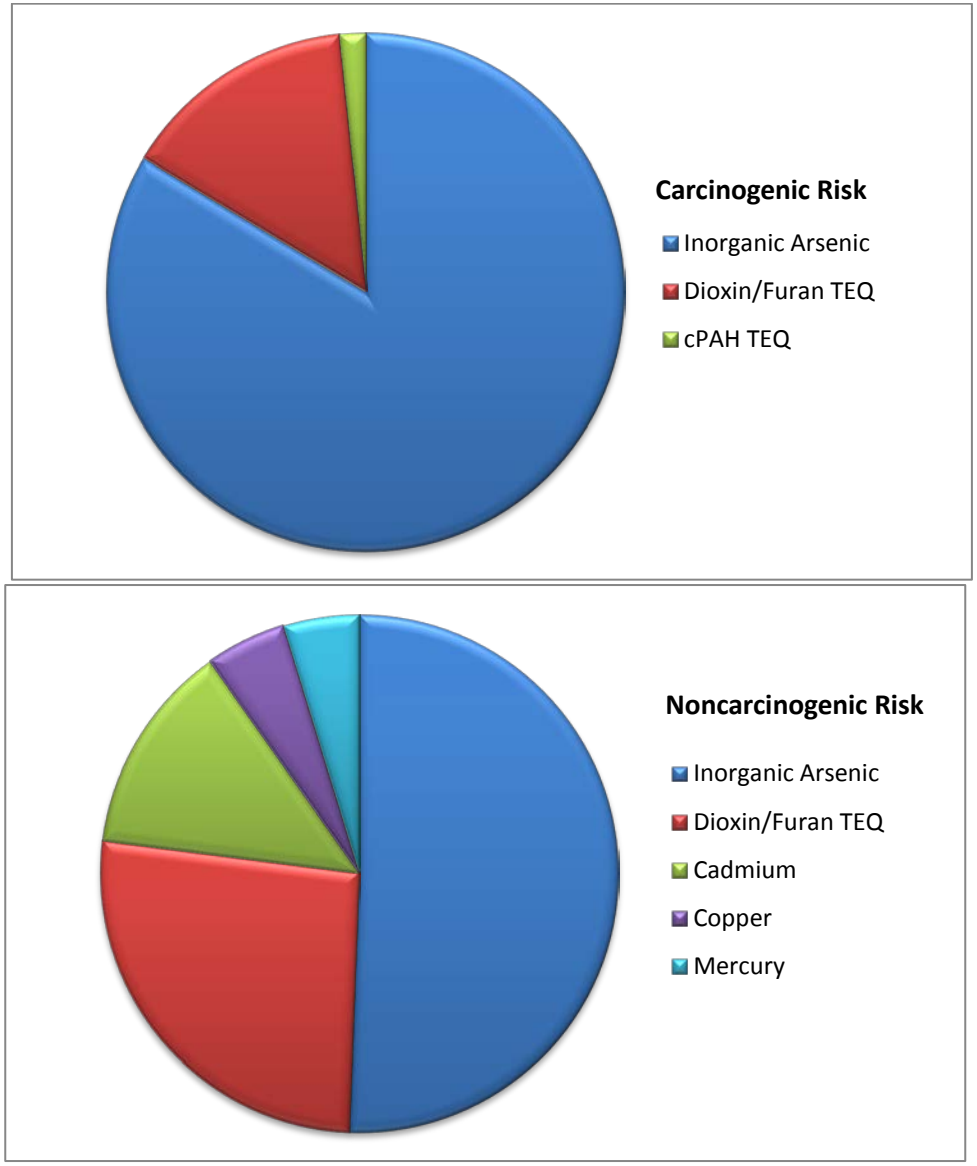


Figure 8-2. Relative Contributions to Human Health Risks in Natural Background Areas of Puget Sound

Table 8-8. Comparison of Human Health Risks between Natural Background Areas in Puget Sound and Port Gamble Bay Shellfish

Media	Receptor	Port Gamble with PCBs		Background without PCBs*	
		Risk	HI	Risk	HI
Clams	Adult	4.1E-04	3.1	2.1E-03	5.4
Clams	Child	1.2E-05	1.1	6.1E-05	2.0
Crab hepatopancreas	Adult	1.7E-04	1.6	1.7E-04	1.5
Crab hepatopancreas	Child	1.7E-05	1.9	1.7E-05	1.8
Crab muscle	Adult	9.0E-05	0.72	9.7E-05	0.84
Crab muscle	Child	9.5E-06	0.87	1.0E-05	0.94
Geoduck whole body	Adult	1.0E-04	0.64	1.4E-04	1.3
Geoduck whole body	Child	1.2E-05	0.89	1.7E-05	1.8
Oyster	Adult	1.4E-04	1.8	NA	NA
Oyster	Child	1.7E-05	2.7	NA	NA

NA – not available

Risk = cancer risk over a lifetime, HI = hazard index for noncarcinogenic chemicals.

* PCB congener data are not available for natural background tissues.

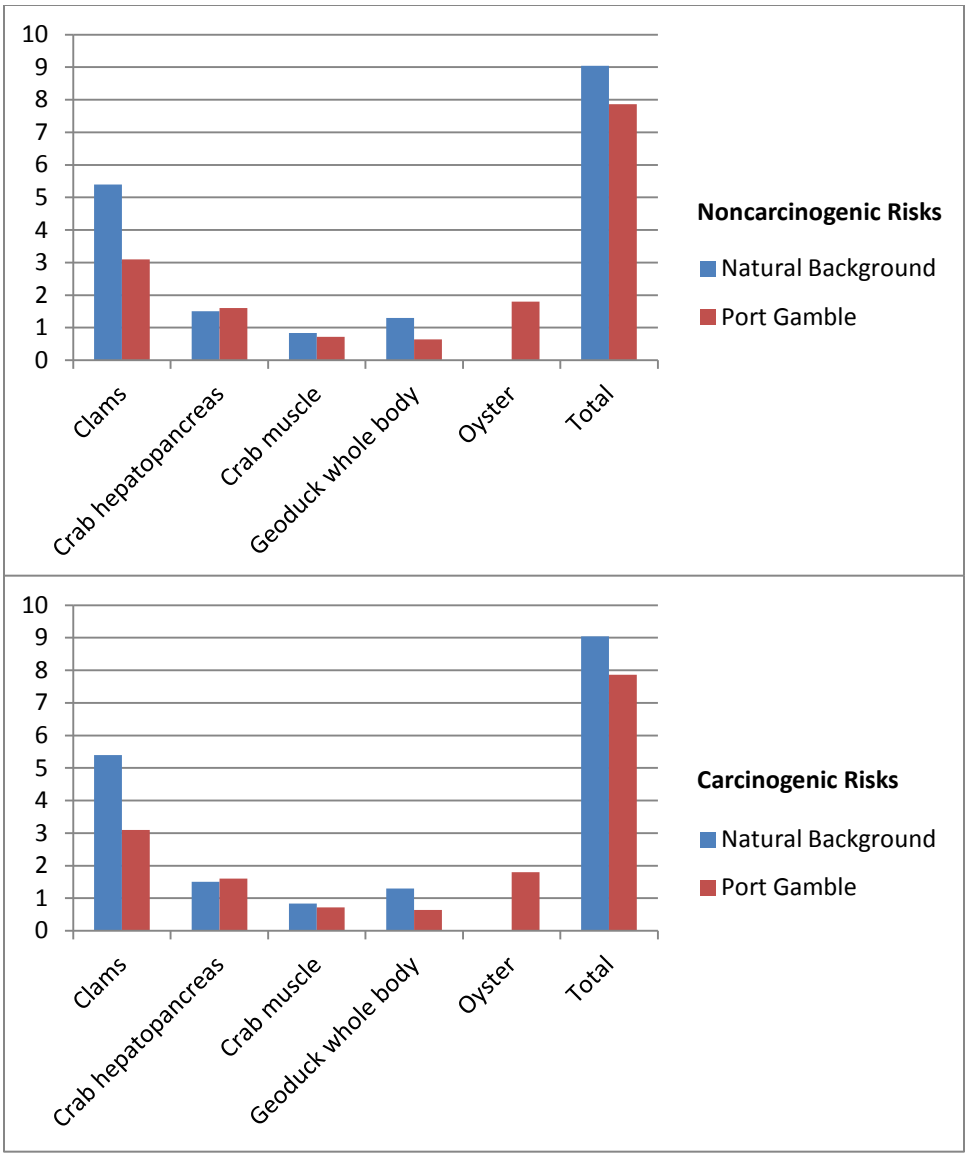
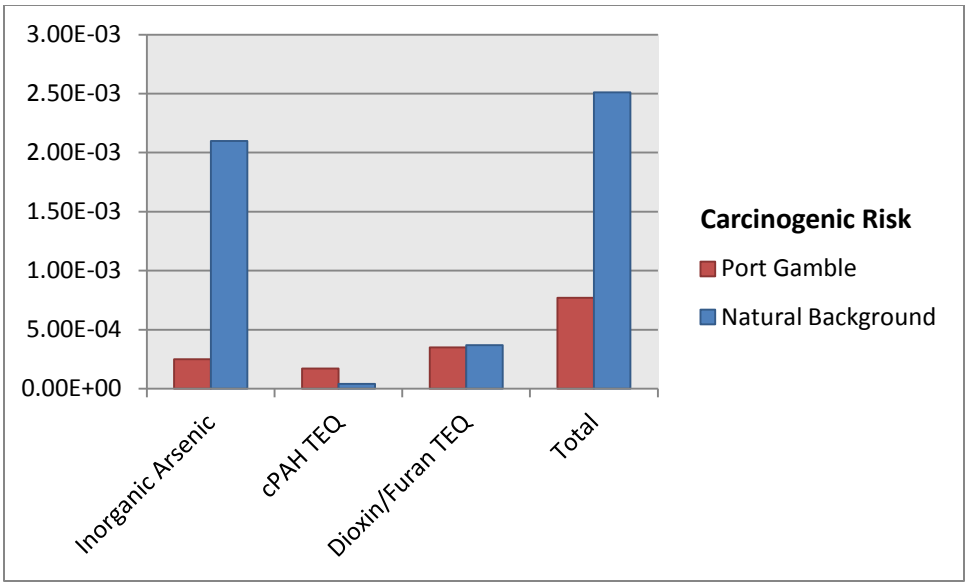


Figure 8-3. Comparison of Port Gamble Bay and Natural Background Risks in Shellfish Species



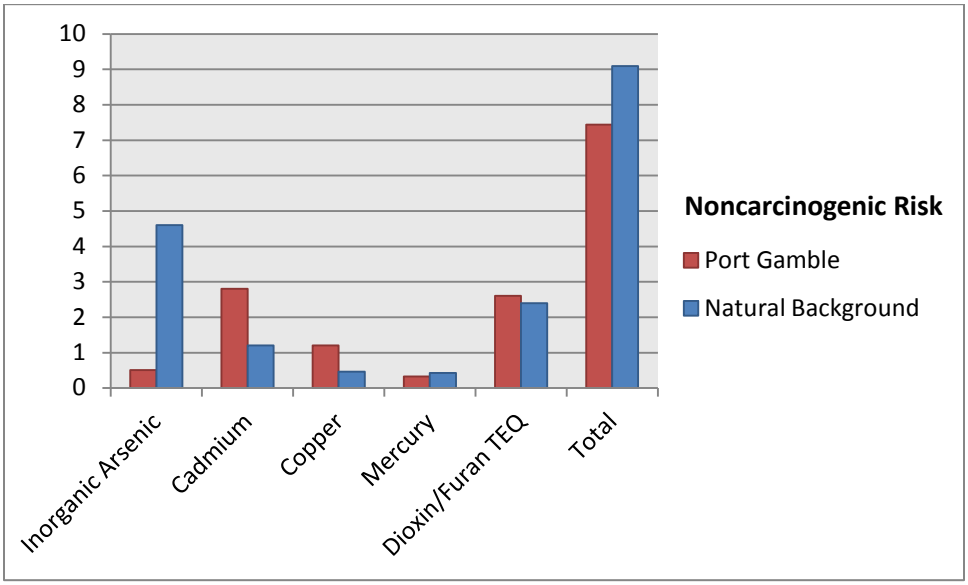


Figure 8-4. Comparison of Port Gamble Bay and Natural Background Risks among Chemicals

Natural geological concentrations of arsenic in the Cascade and Pacific Coast mountain ranges are quite high, leading to concentrations in soils, groundwater, surface water, and sediments in the Puget Sound area that frequently exceed MTCA or other risk-based levels for protection of human health (Huntting 1956; Johnson 2002; Ferguson and Johnson 2005; Thomas et al. 1997). Mining and smelting activities that tend to concentrate the arsenic and make it more bioavailable have exacerbated this problem in many areas around the Cascades; however, these activities do not appear to have impacted Port Gamble Bay.

In addition to natural sources, natural background as defined in MTCA includes globally distributed concentrations of chemicals such as dioxins/furans, PCBs, and PAHs. These chemicals are or have been in widespread use throughout the world and are distributed through regional atmospheric deposition, global weather patterns, and other large-scale transport pathways (e.g., bioconcentration in oceanic food resources in polar areas). Because MTCA is designed to deal with releases from individual facilities, these global concentrations are considered part of the background that cannot be addressed through cleanup of a single site. Instead, source control and use reduction programs as well as international treaties are tools that are used to eventually reduce this background to safe levels.

Finally, the majority of these calculated risks are associated with chemicals that were not detected in sediments or tissues at the site, even using very sensitive analytical methods. In these cases, a concentration was assumed for these chemicals based on their detection limits. However, these chemicals may or may not be present at the concentrations assumed, and if present, are at very low levels. As discussed in the uncertainty section below, this practice, along with the many other conservative approaches and assumptions used in the risk assessment, results in an upper bound estimate of risk. Risks at the site as well as in natural background areas of Puget Sound may be significantly lower than estimated here.

Because natural geologic and globally distributed concentrations of chemicals are likely to be similar in Port Gamble Bay and in other areas of Puget Sound, and because detection limits were used to estimate concentrations for so many of the chemicals of potential concern for both Port Gamble and Puget Sound sediments and tissues, the calculated risks for the two areas are quite similar. This indicates that for most CoCs for human health, local sources associated with individual facilities have not substantially increased concentrations in sediments or tissues over natural background. Carcinogenic PAHs and cadmium are exceptions, with risks that are significantly higher in Port Gamble Bay than in Puget Sound natural background areas.

8.5 Uncertainties

The following uncertainties in the human health risk evaluation are noted:

8.5.1 Data collection and analysis

- The majority of the calculated risks for dioxins/furans, PCB congeners, and cPAHs are associated with undetected values. Therefore, there is greater uncertainty regarding the actual concentrations and risks associated with these chemicals.

- Inorganic arsenic concentrations in Port Gamble Bay tissues were estimated based on percentages of total arsenic obtained from Ecology (2002). Actual percentages may vary; therefore, this approximation contributes to uncertainty in these results.
- There were only three composited crab samples and two composited geoduck samples from the bay. Because of these limited numbers of samples, the exposure estimates for crab and geoduck are relatively uncertain and may be biased high due to the statistical methods that are applied when there are fewer samples.

8.5.2 Exposure scenarios

- Survey data on the ingestion of shellfish by the Port Gamble S'Klallam Tribe are unavailable; shellfish ingestion rates were based on the Suquamish Tribe survey and were selected in consultation with the Port Gamble S'Klallam Tribe. The exposure assumptions for tribal fishermen may be low because finfish were not included in the exposure scenario, and because estimates of seafood consumption developed in recent years may have been suppressed due to concerns about contamination and reductions in fish and shellfish resources available for harvest. On the other hand, shellfish ingestion rates based on data collected for a short period of time (less than a week) may overestimate the amount of shellfish people eat on a regular basis for the longer time periods (years) considered in this risk assessment.
- Shellfish consumption rates based on the Suquamish Tribal survey likely represent overestimates for the general population. Information compiled by the EPA (EPA 2011) indicates that recreational fishermen using Port Gamble Bay are likely to be exposed to lower amounts of these chemicals in shellfish due to much lower consumption rates.

8.5.3 Toxicity Values

- The models used by EPA to develop cancer potency factors rely on information from population groups with high exposures (such as industrial workers) and/or from laboratory studies with animals. This information is used to estimate risks for the general human population. There are many uncertainties associated with extrapolating from high to low exposures and from animals to humans. The CSFs used in this assessment were developed by EPA using methods that are designed to provide an upper bound estimate of cancer risks.
- In 2010, EPA completed draft CSFs for arsenic and dioxins/furans and distributed these evaluations for scientific peer review. In both cases, the draft CSFs are somewhat more stringent than the values used to prepare this risk assessment. However, the differences between the current and draft values are not large enough to alter the overall risk assessment conclusions.
- The non-cancer risk models used by EPA to develop reference doses also rely on information from population groups with high exposures and/or from laboratory studies with animals. As with cancer models, there are many uncertainties associated with extrapolating from high to low exposures and from animals to humans. EPA uses methods that are designed to provide a conservative estimate of a "no effects" or "safe" level. EPA is currently evaluating non-cancer studies for dioxins, arsenic, and PCBs. With respect to dioxins, EPA has announced that it plans to adopt a new oral reference dose that is slightly lower (slightly more stringent) than the value

used for this risk assessment. However, the difference between the current and draft value is not large enough to alter the overall risk assessment conclusions.

8.5.4 Overall Risk Estimates

- Ecology has used a wide range of information and assumptions to prepare the human health risk assessment. Taking into account all of the uncertainties described above, Ecology believes that the risk estimates presented in this section are upper-bound estimates.

8.6 Summary

The following conclusions can be drawn from the human health risk assessment:

- Risks associated with arsenic, cPAHs, PCBs, and dioxins/furans in Port Gamble Bay shellfish exceed MTCA/SMS threshold risk levels. The risk associated with cadmium slightly exceeds the MTCA/SMS risk threshold, copper was approximately equal to the threshold, and mercury was below the threshold.
- Most of the risks associated with these chemicals are associated with natural background concentrations or undetected chemicals. Overall health risks in Port Gamble Bay are similar to those in natural background areas in Puget Sound.
- cPAHs and cadmium in shellfish have higher risks in Port Gamble Bay than in natural background areas of Puget Sound, while risks associated with arsenic are lower in Port Gamble Bay. Risks associated with dioxins/furans are approximately similar to natural background areas of Puget Sound.
- Arsenic is also associated with low-level risks due to exposure to intertidal sediment during clam-digging or other beach activities. These risks are believed to be due to natural concentrations of arsenic in the sediments.

Section 9 provides a statistical comparison of sediment and tissue data to more definitively determine which of these chemicals are elevated in Port Gamble Bay compared to Puget Sound natural background concentrations.

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9.0 NATURAL BACKGROUND COMPARISONS

Natural background comparisons are an important component of developing cleanup standards for the site and identifying site boundaries and SMAs. The cleanup standard is defined as the highest of 1) risk-based concentrations, 2) natural background concentrations, and 3) practical quantitation limits (PQLs). Section 8 addresses human health risk, this section addresses natural background comparisons, and Section 11 describes how these are combined with PQLs to identify contaminants of concern and select site-specific cleanup levels.

Human health and/or environmental risks may exist at natural background concentrations. However, if site concentrations are statistically similar to natural background concentrations, it can be inferred that concentrations are not elevated at the site due to site-related sources, and that risks at the site due to these chemicals are similar to risks throughout Puget Sound due to natural sources as well as regional and global sources of anthropogenic compounds.

Statistical comparisons between Port Gamble Bay and Puget Sound natural background concentrations in sediments and tissues were conducted only for the CoPCs identified for human health, because levels of concern to benthic organisms are generally higher than background and environmental adverse effects can be evaluated using existing chemical and biological standards.

Natural background comparisons can be done in a variety of ways. Comparison of the central tendencies (means or medians) of the distributions is useful for evaluating whether the distributions as a whole are different from one another. Comparing the highest concentrations in the distributions (upper tails) is also useful because even if most of the distribution is the same, it may identify individual stations that are higher than normal. The following discussion uses both types of evaluations to compare the distributions of concentrations in Port Gamble Bay to natural background areas.

Following the most recent statistical guidance for natural background comparisons (RSET 2008), non-parametric analyses were conducted in ProUCL for distributional comparisons between site data and natural background data, using comparison of medians tests (i.e., either the Mann-Whitney rank or Gehan score test, depending on whether non-detects were present in the data set). Graphical comparisons in the form of overlaid empirical cumulative distribution function plots (ECDF plots) were also generated to facilitate comparison of site and natural background distributions for each chemical and sample type. The Quantile test was used to compare the upper tails of the two distributions, and was performed only when the cumulative distribution plots indicated that any Port Gamble concentrations above the median exceeded natural background.

Statistical analyses were performed using EPA's ProUCL (EPA 2010) software, or following ProUCL methods in R (R Development Core Team 2011). The PCB, dioxin/furan, and cPAH TEQs were calculated by summing multiple chemical values using KM summation methods where appropriate (Helsel 2010) or substitution at one-half the detection limit. The KM sum was only calculated when the frequency of detection was 50% or greater across all congeners or individual chemicals within a sample. TEQs calculated by KM were flagged if the highest or lowest TECs were non-detects and were treated as

detected to avoid being biased low by the KM estimation method. When the frequency of detection was less than 50%, substitution at one-half the detection limit was used for all non-detects.

9.1 Sediments

Natural background sediment data were obtained from the Puget Sound sediment database developed from the EPA Bold survey (DMMP 2009). Fifteen stations were selected from the Bold survey data set from the three established reference areas closest and most geohydrologically similar to Port Gamble Bay. The following set of stations was selected as representative of natural background (as defined in MTCA):

- Holmes Harbor: R_HOL_0, R_HOL_1, R_HOL_3, R_HOL_4, R_HOL_7
- Dabob Bay: R_DAB_0, R_DAB_1, R_DAB_2, R_DAB_5, and R_DAB_7_C
- Carr Inlet: R_CAR_0, R_CAR_1, R_CAR_4, R_CAR_5, R_CAR_6_C

One station, R_CAR_5, had a dioxin/furan TEQ that was relatively high (5.1 ng/kg TEC). This station was not a statistical outlier for dioxin/furan TEQ relative to the other 14 stations in this natural background data set using a skewed distribution such as gamma or lognormal, typical of environmental data sets. However, evaluations involving dioxin/furan TEQs in natural background sediments were done both with and without this sample to assess its influence on the overall conclusions. This station was not a statistical outlier for any other chemical being evaluated.

Summary statistics for site and natural background sediment data for metals, total PCBs, and the cPAH, dioxin/furan, and PCB TEQs are presented in Table 9-1. Results of the statistical comparisons between site and natural background subtidal sediments are presented in Table 9-2. All sediment data are expressed in units of dry weight. Conclusions are summarized below:

- Arsenic was not widely detected in Port Gamble Bay subtidal sediment samples with only 31% (21/67) of the subtidal sediments having detected concentrations. The median concentration in Port Gamble Bay was 3.9 mg/kg compared to 6.3 mg/kg in natural background sediments. Statistical tests indicate that the Port Gamble Bay subtidal sediments were not significantly different from natural background for (p = 1.0, Table 9-2). The cumulative distribution plots (Figure 9-1) illustrate that the arsenic concentrations in both the subtidal and intertidal sediments of Port Gamble Bay are below natural background, with the exception of one historical sample (DV-01 sampled 9/18/2003 by Parametrix) with a detected concentration of 25.4 mg/kg, and four more recent samples (PGSS-16 from 2008, and 110928-01, -02, and -04 from 2011) all reported as undetected at 20 mg/kg.
- Cadmium was frequently detected in Port Gamble Bay with 93% (62/67) of the subtidal sediments and 48% (10/21) of the intertidal sediments having detected concentrations. The median cadmium concentration in Port Gamble Bay was statistically higher than the median in natural background sediment samples (p = 0.001, Table 9-2). The Port Gamble median concentration was 1.3 mg/kg, while the natural background median concentration was 0.39 mg/kg. The Quantile test could not be completed because of non-detected values in the upper

tail of the site distribution. However, the concentration for Port Gamble sample BW-22 (3.1 mg/kg) exceeded all background concentrations. The distribution of cadmium concentrations in subtidal sediments exceeded natural background, while intertidal concentrations were all below natural background (Figure 9-1).

- Copper was detected in every Port Gamble Bay sediment sample. Copper in Port Gamble Bay sediments appears to be within natural background concentrations, with a Port Gamble Bay median concentration of 27 mg/kg and a natural background median concentration of 25 mg/kg. The median copper concentration from Port Gamble was not significantly different from natural background (p = 0.45, Table 9-2) and the cumulative distribution plots are nearly identical (Figure 9-1). The distribution of intertidal concentrations of copper was also similar to that of natural background (Table 9-1 and Figure 9-1).
- Mercury was detected in 52% (33/64) of the Port Gamble Bay subtidal sediments and only 14% (3/21) of the intertidal sediments. The mercury concentrations found in Port Gamble Bay sediments were well below natural background concentrations (Figure 9-1). The Port Gamble Bay median concentration was 0.05 mg/kg, while the natural background median concentration was 0.10 mg/kg. The site distribution was not significantly different from natural background (p = 0.99, Table 9-2).
- Carcinogenic PAH TEQs in Port Gamble Bay sediments were clearly elevated above Puget Sound natural background (Figure 9-1) with significant differences for both the median and the upper tail of the distribution (p < 0.001, Table 9-2). The median cPAH TEQ value for subtidal sediments from Port Gamble Bay was 30 µg/kg, while the median for the intertidal sediments was 20 µg/kg. The Puget Sound natural background median cPAH TEQ value was 3.6 µg/kg. The highest concentration was found at intertidal station PG11-MS-20 (340 µg/kg TEQ). However on average, the concentrations in Port Gamble intertidal sediments were lower than those in the subtidal areas.
- For PCB Aroclors, both Port Gamble Bay and natural background sediments had very few detections. Port Gamble Bay had a 5% (3/59) detection frequency in subtidal sediments, with a KM mean of 7.1 µg/kg. Puget Sound natural background sediments had a 33% (5/15) detection frequency and a KM mean of 6.0 µg/kg (Table 9-1). The median of the Port Gamble subtidal sediments was not significantly different from natural background (p = 0.98, Table 9-2) and the distribution of total PCBs in Port Gamble sediments was also within natural background (Figure 9-1), except for one extreme concentration (158 µg/kg) at Station DV-02 (Parametrix 2003).
- PCB congeners were analyzed only in intertidal samples from Port Gamble, collected both near the former mill site and from intertidal areas throughout the Bay. Both the median and the upper tail of the PCB congener TEQs in Port Gamble Bay intertidal sediments were within natural background (p > 0.05, Table 9-2 and Figure 9-1). The Puget Sound natural background median PCB TEQ value was 0.047 ng/kg, greater than the median PCB TEQ values for Port Gamble Bay intertidal sediments (0.028 ng/kg). There were two intertidal stations with elevated PCB TEQs (BW-27 at 0.20 ng/kg, and BW-32 at 0.11 ng/kg), but the remaining 14 intertidal stations were below the natural background median value.

- The median dioxin/furan TEQ in Port Gamble subtidal sediments was significantly higher than Puget Sound natural background values (p = 0.011, Table 9-2). The median dioxin/furan TEQ value for subtidal sediments from Port Gamble Bay was 2.7 ng/kg, while the median for the intertidal sediments was 0.53 ng/kg. The Puget Sound natural background median dioxin/furan TEQ value was 1.1 or 1.0 ng/kg, with and without CAR-5, respectively. The Quantile test comparing the upper tails of the Port Gamble distribution with the natural background distribution (excluding CAR-5) was significant ($p < 0.05$, Table 9-2), indicating that the upper tail of the Port Gamble distribution is significantly greater than natural background. The cumulative distribution plots (Figure 9-1) illustrate that the distribution of dioxin/furan TEQs in Port Gamble subtidal sediments is consistently elevated above natural background, while the intertidal TEQs only exceed natural background in the upper ends of the distribution. There were 15 Port Gamble stations with TEQs that exceeded the maximum background TEQ (2.1 pg/g, excluding CAR-5): 11 subtidal stations plus four intertidal stations from the former mill area. The most extreme dioxin/furan TEQ value was reported for intertidal station MS-20 with a value of 16 pg/g, approximately 2.5 times the next highest TEQ value.

Table 9-1. Comparison of Concentrations in Port Gamble Bay Subtidal Sediments to Puget Sound Natural Background Sediments

Endpoint	Location	Valid Data Pts	No. of NDs	No. of Detects	% Detected	Min Detected	Mean Detected	Max Detected	Max Non-Detect	Overall Median (KM)[2]	Overall Mean (KM)[2]
Arsenic	Background	15	0	15	100%	1.6	6.9	18	NA	6.3	6.9
	Intertidal	21	0	21	100%	0.92	2.3	4.1	NA	2.3	2.3
	Subtidal	67	46	21	31%	2.3	6.3	25	20	3.9	4.7
Cadmium	Background	15	0	15	100%	0.032	0.56	2.8	NA	0.39	0.56
	Intertidal	21	11	10	48%	0.10	0.47	1.1	0.10	NA	0.28
	Subtidal	67	5	62	93%	0.20	1.3	3.1	2.6	1.3	1.2
Copper	Background	15	0	15	100%	3.3	26	57	NA	25	26
	Intertidal	21	0	21	100%	5.9	20	48	NA	17	20
	Subtidal	67	0	67	100%	3.4	24	53	NA	27	24
Mercury	Background	15	5	10	67%	0.072	0.16	0.26	0.062	0.10	0.13
	Intertidal	21	18	3	14%	0.020	0.033	0.060	0.030	NA	0.022
	Subtidal	64	31	33	52%	0.030	0.088	0.13	0.10	0.050	0.061
Dioxin TEQ KM+HalfDL pg/g, dw	Background	15	NA	NA	--	0.24	1.3	5.1	NA	1.1	1.3
	Background-Ex[1]	14	NA	NA	--	0.24	1.0	2.1	NA	1.0	1.0
	Intertidal	16	NA	NA	--	0.16	2.1	16	NA	0.53	2.1
	Subtidal	19	NA	NA	--	0.34	3.1	6.5	NA	2.7	3.1
cPAH TEQ µg/kg, dw	Background	15	NA	NA	--	1.4	4.9	13	NA	3.6	4.9
	Intertidal	21	NA	NA	--	1.5	42	340	NA	20	42
	Subtidal	66	NA	NA	--	5.2	52	280	NA	30	52
PCB Aroclors	Background	15	10	5	33%	2.1	12	31	17	2.9	6.0
	Intertidal	0	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Subtidal	59	56	3	5%	4.3	59	160	21	NA	7.1
PCB TEQ pg/g, dw	Background	15	NA	NA	--	0.018	0.047	0.093	NA	0.047	0.047
	Intertidal	16	NA	NA	--	0.0059	0.043	0.20	NA	0.028	0.043
	Subtidal	0	NA	NA	NA	NA	NA	NA	NA	NA	NA

[1]The "Background-Ex" group excludes station CAR-5.

[2] The median cannot be estimated when the detection frequency is too low; estimates of the mean become more uncertain as the percentage of non-detects increases above 50%.

Table 9-2. Distributional Comparisons between Subtidal Sediments in Port Gamble Bay and Puget Sound Natural Background

Endpoint	Test	*p*	Conclusion
Arsenic	Gehan Test	0.997	Site ≤ background
Cadmium	Gehan Test Quantile	0.001	Site > background Nondetect values in the upper tail; cannot complete test
Copper	Mann-Whitney	0.45	Site ≤ background
Mercury	Gehan Test	0.99	Site ≤ background
Dioxin TEQ **Excluding CAR-5**[1]	Mann-Whitney Quantile Test	0.011	Site > background Site > background excluding CAR-5
cPAH TEQ	Mann-Whitney Quantile	2E-09	Site > background Site > background
Total PCBs **(sum of Aroclors)**	Gehan Test[2] Quantile	0.977	Site ≤ background Nondetect values in the upper tail; cannot complete test
PCB TEQ (intertidal sediments)	Mann-Whitney Quantile	0.931	Site ≤ background Site ≤ background

Mann-Whitney and Gehan Test null hypothesis: site ≤ background.

[1]CAR-5 was a high value in the background data set for dioxins. Comparisons were done with and without this sample for dioxin only.

[2] Score tests are not greatly affected by single high values.

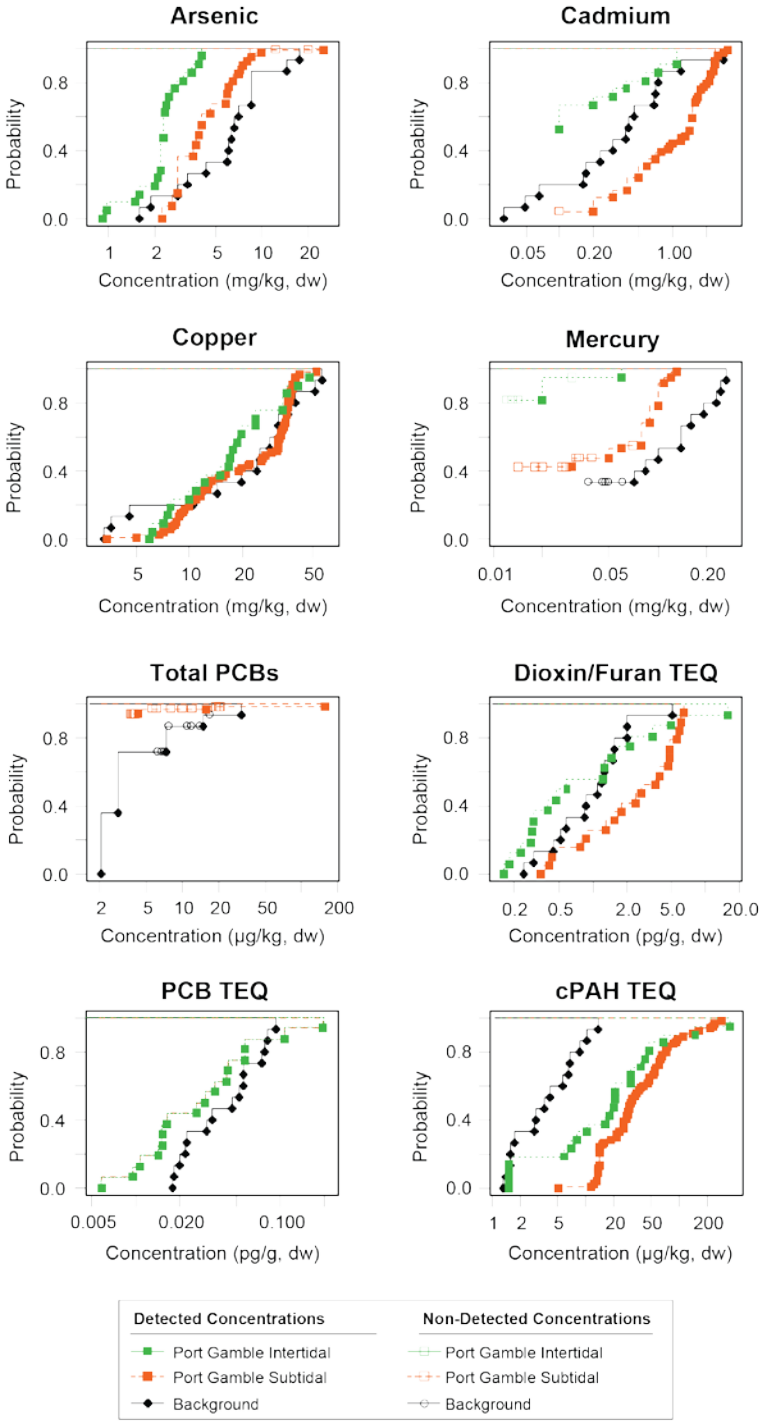

Figure 9-1. Empirical cumulative distribution plots for sediments

9.2 Tissue Samples

Concentrations in shellfish tissue collected from EPA or Ecology-recognized natural background locations were assembled for the selected CoCs. Natural background data were identified for:

- Dioxins/furans in crabs (muscle tissue and hepatopancreas), clams, geoducks (whole body), and oysters
- Arsenic in crabs (muscle tissue and hepatopancreas) and clams
- Cadmium in crabs (muscle tissue and hepatopancreas), clams, and geoducks
- Copper in crabs (muscle tissue and hepatopancreas) and geoducks
- Mercury in crabs (muscle tissue and hepatopancreas), clams, and geoducks
- PAH TEQs in crabs (muscle tissue and hepatopancreas), clams, and geoducks
- Total PCBs in crabs (muscle tissue and hepatopancreas) and clams

Natural background tissue data are summarized and compared to Port Gamble Bay tissue concentrations in Tables 9-3 and 9-4. Complete data tables for natural background tissue concentrations are provided in Appendix C (all tissue data are reported in wet weight). The following data sets were compiled to determine natural background tissue concentrations:

- Data on dioxin TEQs in crabs were available from Ecology's EIM database for natural background locations from Dungeness Bay, Freshwater Bay, Skagit Bay, and Padilla/Fidalgo Bay (PSEP 1991a, Malcolm Pirnie 2007, Ecology 2000). Three samples from Pedder Bay that were used in the previous Port Gamble RI were also included. Each tissue sample was made up of 1–5 individual crabs per sample. The TEQs included non-detected values at one-half the RL. In total, there were data for 26 hepatopancreas and 27 muscle tissue samples. Because not all of these TEQs were calculated in the same manner and some had elevated detection limits, comparisons using these data are of limited value for decision making. Additional background data are anticipated to be collected in the near future and will be substituted once available.
- Data on dioxin TEQs in clams and geoducks from natural background locations were also available from Ecology's EIM database. Two littleneck clam composite samples (10–20 individuals per sample) were collected from Salsbury Point in 2003 (Parametrix 2003b). Seven geoduck samples (whole body, one individual per sample) were collected from Dungeness Bay and Freshwater Bay (Malcolm Pirnie 2007), and at a natural background site for the 2008 Port Angeles Harbor Sediment Investigation (Ecology 2009).
- Data on inorganic arsenic in clams collected from natural background locations were taken from EPA and Ecology-approved data reports for the RI for the LDW site (Windward 2005a, Windward 2006). Clams were collected from bays on Bainbridge Island, Vashon Island, Dungeness National Wildlife Refuge, and Seahurst Park. A total of 24 composite samples were available, each composite consisting of 10–28 individual clams with either exclusively eastern softshell clams (*Mya arenaria*) or mixed species.

- Data on inorganic arsenic in crabs collected from natural background locations were taken from an EPA and Ecology-approved data report for the RI for the LDW site (Windward 2005b). Crabs were collected from Blake Island and East Passage; data from a total of 12 composite muscle tissue samples were available, six of Dungeness crab and six of slender crab. Data were also available from a total of four composite hepatopancreas samples, two of Dungeness crab and two of slender crab.
- Data on cadmium in clams and geoducks from natural background locations were available from Ecology's EIM database. Two littleneck clam composite samples and 128 butter clam composites were collected from natural background locations between 1998 and 2010 (King County 2000–2010). Specifics on the number of individual clams per composite were not available. Six geoduck samples (whole body, one individual per sample) were collected from Dungeness Bay and Freshwater Bay for the 2002 Former Rayonier Mill Site RI (Malcolm Pirnie 2007).
- Data on cadmium in crabs collected from natural background locations were taken from the 2002 Rayonier Mill Site RI (Malcolm Pirnie 2007). Six Dungeness crabs were collected from Dungeness Bay and Freshwater Bay; data were available for muscle and hepatopancreas tissues from the six individual crabs.
- Data on copper in geoducks from natural background locations were available from Ecology's EIM database. Six geoduck samples (whole body, one individual per sample) were collected from Dungeness Bay and Freshwater Bay (Malcolm Pirnie 2007) and one was collected near Port Angeles for the Port Angeles Harbor Sediment Investigation Study (Ecology 2009).
- Data on copper in crabs collected from natural background locations were taken from the 2002 Rayonier Mill Site RI (Malcolm Pirnie 2007). Six Dungeness crabs were collected from Dungeness Bay and Freshwater Bay; data were available for muscle and hepatopancreas tissues from the six individual crabs.
- Data on mercury in clams and geoducks from natural background locations were available from Ecology's EIM database. A total of 128 butter clam composites were collected from natural background locations between 1998 and 2010 (King County 2000–2010). Specifics on the number of individuals per composite were not available. Six geoduck samples (whole body, one individual per sample) were collected from Dungeness Bay and Freshwater Bay (Malcolm Pirnie 2007) and one was collected near Port Angeles for the Port Angeles Harbor Sediment Investigation Study (Ecology 2009).
- Data on mercury in crabs collected from natural background locations were taken from the 2002 Rayonier Mill Site RI (Malcolm Pirnie 2007) and the 1999 Padilla Bay Shellfish Screening for Metals and Organics (Ecology 2000). Dungeness crabs were collected from Dungeness Bay, Freshwater Bay, off Samish Island and near Hat Island; data were available for a total of eight muscle tissues (six samples of individual crabs and two composites with five crabs per sample) and six hepatopancreas tissues from individual crabs.
- Data on carcinogenic PAH TEQs in clams and geoducks from natural background locations were taken from Ecology's EIM database for samples from EPA-approved background locations for the LDW RI. A total of 14 littleneck clam composites were available from locations at Salsbury

Point, Port Washington Narrows, and Keyport (Ecology 2002, Parametrix 2003b, and URS 2009). Composite samples were comprised of 10–20 or an unspecified number of individuals per sample. Seven geoduck samples (whole body, one individual per sample) were collected from Dungeness Bay and Freshwater Bay (Malcolm Pirnie 2007) and a reference site near Port Angeles (Ecology 2009). Carcinogenic PAH TEQs were used as reported.

- Data on carcinogenic PAH TEQs in crabs from natural background locations were taken from the 2002 Rayonier Mill Site RI (Malcolm Pirnie 2007) and the 1999 Padilla Bay Shellfish Screening for Metals and Organics (Ecology 2000). Dungeness crabs were collected from Dungeness Bay, Freshwater Bay, off Samish Island and near Hat Island; data were available for a total of eight muscle and seven hepatopancreas tissue samples with 1–5 individual crabs per sample. Carcinogenic PAH TEQs were used as reported.
- PCB data for natural background tissue samples were only available as total PCBs, calculated as the sum of Aroclors using methods described in the SMS. Clams were collected from natural background locations near Gorsuch Creek on Vashon Island (King County 2005) and Salsbury Point (Parametrix 2003). A total of four butter clam and two littleneck clam composite samples were available, each sample comprised of 8–20 individuals, or an unspecified number of individuals per composite. All samples had non-detected concentrations of total PCBs.
- Total PCBs in crabs from natural background locations were taken from the 2006 Rayonier Mill Site Phase 2 Addendum RI (Malcolm Pirnie 2007) and the 1999 Padilla Bay Shellfish Screening for Metals and Organics (Ecology 2000). Dungeness crabs were collected from Dungeness Bay, Freshwater Bay, off Samish Island and near Hat Island; data were available for a total of 17 muscle and 15 hepatopancreas tissue samples with 1–5 individual crabs per sample.

Table 9-3. Summary of Port Gamble Bay and Puget Sound Natural Background Tissue Concentrations – Metals and PCB Aroclors

Endpoint	Tissue	Location	Valid Data Pts	Number of NDs	Number of Detects	% Detected	Min Detected	Mean Detected	Max Detected	Max Non-Detect	Overall Median (KM)[a]	Overall Mean (KM)[a]
Arsenic, Inorganic mg/kg, ww	Clam	Background	24	0	24	100%	0.044	0.21	0.62	--	0.11	0.21
		Port Gamble	28	8	20	71%	0.012	0.030	0.060	0.012	0.024	0.025
	Crab – muscle	Background	12	0	12	100%	0.010	0.021	0.040	--	0.020	0.021
		Port Gamble	3	0	3	100%	0.010	0.011	0.014	--	0.010	0.011
	Crab – hepato	Background	4	0	4	100%	0.080	0.19	0.34	--	0.080	0.19
		Port Gamble	3	0	3	100%	0.0080	0.013	0.016	--	0.016	0.013
	Geoduck	Background	0	0	0	--	--	--	--	--	--	--
		Port Gamble	2	0	2	100%	0.012	0.018	0.024	--	0.024	0.018
	Oyster	Background	0	0	0	--	--	--	--	--	--	--
		Port Gamble	10	1	9	90%	0.012	0.016	0.024	0.012	0.012	0.016
Cadmium mg/kg, ww	Clam	Background	130	0	130	100%	0.041	0.065	0.255	--	0.061	0.065
		Port Gamble	28	3	25	89%	0.040	0.33	0.71	0.040	0.29	0.30
	Crab – muscle	Background	6	1	5	83%	0.006	0.009	0.013	0.007	0.007	0.0087
		Port Gamble	3	2	1	33%	0.040	0.040	0.04	0.04	--	0.04
	Crab - hepato	Background	6	0	6	100%	1.3	1.8	2.4	--	1.5	1.8
		Port Gamble	3	0	3	100%	0.34	0.87	1.44	--	0.83	0.87
	Geoduck	Background	6	0	6	100%	0.16	0.26	0.34	--	0.30	0.26
		Port Gamble	2	0	2	100%	0.19	0.19	0.19	--	0.19	0.19
	Oyster	Background	0	0	0	--	--	--	--	--	--	--
		Port Gamble	10	0	10	100%	0.96	1.2	1.5	--	1.2	1.2
Copper	Clam	Background	0	0	0	--	--	--	--	--	--	--
		Port Gamble	28	0	28	100%	0.91	3.8	26	--	2.6	3.8
	Crab - muscle	Background	6	0	6	100%	3.6	4.2	5.1	--	4.0	4.2
		Port Gamble	3	0	3	100%	3.8	6.0	8.7	--	5.7	6.0
	Crab - hepato	Background	6	0	6	100%	5.8	29	55	--	16	29
		Port Gamble	3	0	3	100%	4.0	9.1	19	--	4.1	9.1
	Geoduck	Background	7	0	7	100%	1.6	2.2	3.3	--	2.1	2.2
		Port Gamble	2	0	2	100%	2.9	3.1	3.3	--	3.3	3.1
	Oyster	Background	0	0	0	--	--	--	--	--	--	--
		Port Gamble	10	0	10	100%	4.0	11	34	--	8.4	11

Table 9-3. Summary of Port Gamble Bay and Puget Sound Natural Background Tissue Concentrations – Metals and PCB Aroclors

Endpoint	Tissue	Location	Valid Data Pts	Number of NDs	Number of Detects	% Detected	Min Detected	Mean Detected	Max Detected	Max Non-Detect	Overall Median (KM)[a]	Overall Mean (KM)[a]
Mercury mg/kg, ww	Clam	Background	128	2	126	98%	0.0032	0.0070	0.014	0.0041	0.0063	0.0070
		Port Gamble	28	7	21	75%	0.0050	0.0080	0.016	0.010	0.0060	0.0073
	Crab - muscle	Background	8	0	8	100%	0.031	0.056	0.086	--	0.051	0.056
		Port Gamble	3	0	3	100%	0.027	0.037	0.047	--	0.036	0.037
	Crab - hepato	Background	6	0	6	100%	0.048	0.061	0.095	--	0.054	0.061
		Port Gamble	3	0	3	100%	0.02	0.026	0.03	--	0.028	0.026
	Geoduck	Background	7	1	6	86%	0.013	0.024	0.042	0.0086	0.019	0.022
		Port Gamble	2	0	2	100%	0.01	0.01	0.01	--	0.01	0.01
	Oyster	Background	0	0	0	--	--	--	--	--	--	--
		Port Gamble	10	0	10	100%	0.010	0.011	0.014	--	0.010	0.011
Total PCBS Aroclor Sum (U = 0) µg/kg, ww	Clam	Background	6	6	0	0%	--	--	--	5.0	--	--
		Port Gamble	19	18	1	5%	4.2	4.2	4.2	12	--	4.2
	Crab - muscle	Background	17	0	17	100%	0.44	0.87	1.92	--	0.80	0.87
		Port Gamble	1	1	0	0%	--	--	--	8	--	--
	Crab - hepato	Background	15	0	15	100%	8.8	21	50	--	15	21
		Port Gamble	1	1	0	0%	--	--	--	20	--	--
	Geoduck	Background	0	--	--	--	--	--	--	--	--	--
		Port Gamble	2	2	0	0%	--	--	--	4	--	--
	Oyster	Background	0	--	--	--	--	--	--	--	--	--
		Port Gamble	10	8	2	20%	7.2	14.1	21	9.9	--	8.58

-- Insufficient data to calculate this statistic.

[a] Overall mean and median calculated based on all detected and non-detected data using Kaplan-Meier (KM) methods for censored data sets.

Table 9-4. Summary of Port Gamble Bay and Puget Sound Natural Background Tissue Concentrations – PAH, PCB, and Dioxin/Furan TEQs[a]

Endpoint	Tissue	Location	Valid Data Pts	Minimum	Median	Mean	Maximum
PAH TEQ µg/kg, ww	Clam	Background	14	0.11	1.0	0.85	1.3
		Port Gamble	28	0.35	0.51	1.7	8.2
	Crab - muscle	Background	8	0.11	0.11	0.41	1.6
		Port Gamble	3	0.35	0.35	1.4	3.5
	Crab - hepato	Background	7	0.11	0.11	0.23	0.90
		Port Gamble	3	0.35	0.35	1.4	3.4
	Geoduck	Background	7	0.069	0.11	0.12	0.17
		Port Gamble	2	3.4	3.5	3.5	3.5
	Oyster	Background	0	--	--	--	--
		Port Gamble	10	0.82	1.8	4.3	19
PCB TEQ pg/g, ww	Clam	Background	0	--	--	--	--
		Port Gamble	11	0.022	0.034	0.043	0.080
	Crab - muscle	Background	0	--	--	--	--
		Port Gamble	3	0.033	0.044	0.046	0.063
	Crab - hepato	Background	0	--	--	--	--
		Port Gamble	3	0.81	0.82	1.1	1.7
	Geoduck	Background	0	--	--	--	--
		Port Gamble	2	0.057	0.062	0.062	0.067
	Oyster	Background	0	--	--	--	--
		Port Gamble	2	0.070	0.071	0.071	0.071
Dioxin/furan TEQ, pg/g, ww	Clam	Background	2	0.23	0.25	0.25	0.27
		Port Gamble	11	0.077	0.083	0.14	0.37
	Crab - muscle	Background	27	0.027	0.067	0.22	1.4
		Port Gamble	3	0.083	0.095	0.18	0.37
	Crab - hepato	Background	26	0.18	0.52	0.69	2.6
		Port Gamble	3	0.94	1.5	1.5	2.2
	Geoduck	Background	7	0.21	0.24	0.41	1.4
		Port Gamble	2	0.34	0.34	0.34	0.35
	Oyster	Background	0	--	--	--	--
		Port Gamble	2	0.37	0.37	0.37	0.37

-- Insufficient data to calculate this statistic.

[a] TEQs shown in this table were calculated using the method described in Section 8.2.4. Using this method, all final estimated TEQ values are treated as detected; therefore, summary statistics can be calculated on the estimated TEQs even if most or all of the component congeners were undetected.

Results of the statistical comparisons are presented in Table 9-5 and are graphically shown in Figures 9-2 through 9-5. A summary of the natural background comparisons for tissues is presented below.

9.2.1 Clam Tissues

- Concentrations of inorganic arsenic from Port Gamble clam tissues did not exceed natural background concentrations.
- Cadmium concentrations in Port Gamble clam tissues were significantly elevated above natural background (both the median and upper percentile were significantly greater than natural background, $p < 0.05$). The median concentration for Port Gamble was 0.29 mg/kg, substantially higher than the natural background median concentration of 0.061 mg/kg.
- There were no copper concentrations for clam tissues from natural background locations to which the Port Gamble tissues could be compared.
- Concentrations of mercury in Port Gamble clam tissues were generally at or below natural background concentrations. One Port Gamble clam tissue had mercury at a concentration exceeding the maximum background concentration of 1.4 mg/kg: 1.6 mg/kg at station PG11-BW-32-LN.
- The median concentration of cPAH TEQs in Port Gamble clam tissues was 0.51 µg/kg, lower than the natural background median concentration of 1.0 µg/kg. The Port Gamble distribution of cPAH TEQs in clam tissues was fairly skewed, and the upper percentile of the distribution exceeded natural background ($p < 0.05$). There were nine stations with concentrations of cPAH TEQs in clam tissues exceeding the maximum background concentration of 1.3 µg/kg. These elevated Port Gamble concentrations ranged from 1.7 µg/kg (Mill area station B3_C_PGST_100429) to 8.2 µg/kg (Mill area station PG11-MS-20-LN).
- PCBs (sum of Aroclors) were detected in only one clam tissue sample (4.2 µg/kg at Station B-2 near the mill). Detection limits for the natural background clam samples ranged from 2.5–5 U µg/kg, while detection limits for the Port Gamble clam tissues ranged from 3.9–12 U µg/kg. The only detected Port Gamble concentration was below the maximum natural background non-detected value.
- Dioxin TEQs in Port Gamble clam tissues were generally at or below available natural background concentrations. Two Port Gamble clam tissues had dioxin/furan TEQ values exceeding the maximum background of 0.27 pg/g: CLAM 1A and 2A (Hart Crowser 2010) with values of 0.36 and 0.37 pg/g, respectively.

9.2.2 Geoduck Tissues

- Cadmium and mercury concentrations from Port Gamble geoduck tissues did not exceed natural background concentrations. The maximum concentrations for cadmium (0.19 mg/kg) and mercury (0.01 mg/kg) in Port Gamble geoduck tissues were at or below the median concentrations in natural background geoduck tissues.

- The median concentration of copper in Port Gamble geoduck tissues (3.1 mg/kg) was not significantly greater than natural background (2.1 mg/kg, $p \geq 0.05$), nor was the upper tail. The maximum copper concentration in Port Gamble was 3.3 mg/kg (GD Station 1A), identical to the maximum in natural background tissues.
- Carcinogenic PAH TEQs from all three of the Port Gamble geoduck tissues exceeded all of the natural background tissue TEQs (Mann-Whitney and Quantile test $p < 0.05$). The Port Gamble TEQs were 3.4 and 3.5 µg/kg, while the cPAH TEQs in natural background tissues ranged from 0.07 to 0.17 µg/kg.
- Dioxin/furan TEQs from the two Port Gamble geoduck tissues exceeded all of the TEQs in natural background tissues except one (TEQ = 1.4 ng/kg at RF06TG, a natural background station near Port Angeles). The medians and upper tails of the Port Gamble and natural background distributions were not statistically different ($p > 0.05$). The median and maximum dioxin/furan TEQs in Port Gamble geoduck tissues were 0.34 and 0.35 ng/kg, respectively, compared to 0.24 and 1.4 ng/kg in natural background tissues.
- There were no data available for arsenic or PCBs in geoduck tissues from natural background locations to which the Port Gamble tissues could be compared.

9.2.3 Crab Muscle Tissues

- Inorganic arsenic and mercury concentrations in Port Gamble crab muscle tissues did not exceed natural background. The maximum arsenic and mercury concentrations in Port Gamble tissues were 0.014 and 0.047 mg/kg, respectively, which were below the median natural background tissue concentrations of 0.020 and 0.051 mg/kg.
- Cadmium was detected in only one Port Gamble crab muscle tissue (0.04 mg/kg in CRAB1-A, Hart Crowser 2010). The detected concentration and the MRL for the non-detected Port Gamble tissues exceeded all the natural background concentrations (the maximum natural background concentration was 0.013 mg/kg). The Gehan test on medians was not statistically significant ($p > 0.05$); however, it was a low power test because of the small sample sizes and few detections.
- The median concentration of copper in Port Gamble crab muscle tissues (5.7 mg/kg) was not significantly greater than natural background (4.0 mg/kg, $p > 0.05$), but the upper tail of the distribution was significantly greater than natural background ($p < 0.05$). There were two crab muscle tissue samples with copper concentrations exceeding the maximum natural background concentration of 5.1 mg/kg: 5.7 and 8.7 mg/kg in PG11-BW-04-DCM-R1 (NewFields 2011) and CRAB1-A (Hart Crowser 2010), respectively.
- Carcinogenic PAH TEQs from the two Port Gamble composite crab muscle tissue samples collected in 2011 (0.35 and 0.35 µg/kg) were within the range of the natural background TEQs (0.11–1.6 µg/kg). The Port Gamble tissue sample collected in 2008 was higher, with a concentration of 3.5 µg/kg. The comparison of medians test indicated no difference (Mann-Whitney $p > 0.05$), but the Quantile test comparing the upper tails of the distributions indicated that the higher Port Gamble Bay sample was significantly elevated above natural background ($p < 0.05$).

- Data for total PCBs in crab muscle tissue were insufficient to make an adequate comparison to natural background. There were 17 natural background tissue samples with total PCBs ranging from 0.44 to 1.9 µg/kg, whereas the single Port Gamble crab muscle sample had a total PCB value reported as undetected at 8 U µg/kg.
- Dioxin/furan TEQs from Port Gamble crab muscle tissues were within the range of the natural background TEQs. Neither the median concentrations nor the upper tails of the distributions were statistically different ($p > 0.05$). The Port Gamble values ranged from 0.083 to 0.37 ng/kg, while the natural background values ranged from 0.027 to 0.38 ng/kg, in addition to two samples with elevated TEQs: 1.2 ng/kg in crabs collected near Hat Island and 1.4 ng/kg in crabs collected off Samish Island. Because not all of these TEQs were calculated in the same manner and detection limits varied significantly, these conclusions are not definitive and were not relied on for decision making.

9.2.4 Crab Hepatopancreas Tissues

- Inorganic arsenic, cadmium, copper, and mercury concentrations in Port Gamble crab hepatopancreas tissue samples were all well below natural background. The maximum concentrations among Port Gamble tissues were less than or comparable to the median concentrations in natural background crab hepatopancreas tissues.
- Carcinogenic PAH TEQs from the two Port Gamble composite crab hepatopancreas tissue samples collected in 2011 (0.35 and 0.35 µg/kg) were within the range of natural background TEQs (0.11–0.90 µg/kg). The Port Gamble tissue sample collected in 2008 was higher, with a concentration of 3.4 µg/kg. Both the median and upper tail of the Port Gamble distribution was significantly elevated relative to natural background ($p < 0.05$).
- Total PCBs in crab hepatopancreas tissue had insufficient data to adequately make a comparison to natural background. There were 15 natural background tissue samples with detected total PCB concentrations ranging from 8.8 to 50 µg/kg with a mean of 21 µg/kg. The single Port Gamble crab hepatopancreas sample had a total PCBs value reported as undetected at 20 U µg/kg. These data are limited, but they do not appear to indicate that total PCBs are elevated relative to natural background in crab hepatopancreas tissues.
- Dioxin/furan TEQs from Port Gamble crab hepatopancreas tissues had a median concentration (1.5 ng/kg) that was significantly elevated relative to natural background (0.52 ng/kg, $p < 0.05$). However, the upper tails of the two distributions overlapped and were not significantly different (Quantile test $p > 0.05$). The maximum TEQ for Port Gamble tissues was 2.2 ng/kg, less than the maximum of 2.6 ng/kg among natural background tissues (reported for sample 110111L from Skagit Bay), although detection limits were likely higher for the latter sample (PSEP 1991a).

Table 9-5. Comparison of Concentrations in Port Gamble Bay Tissues to Puget Sound Natural Background Tissues

Tissue Type	Endpoint	Test	p-value	Conclusion
Clams	**Arsenic**	Gehan	1.00	Site ≤ background
	Cadmium	Gehan	2E-04	Site > background
		Quantile		Site > background
	Copper	No background data		
	Mercury	Gehan	0.47	Site ≤ background
		Quantile		Site ≤ background
	Dioxin TEQ KM+Half	M-W	0.931	Site ≤ background
	PAH TEQ KM+Half	M-W	0.431	Site ≤ background
		Quantile		Site > background
	PCB TEQ KM+Half	No background data		
	Total PCBs (Sum of Aroclors; U = 0 or MaxDL)	Gehan	0.39	Site ≤ background
Geoduck	**Arsenic**	No background data		
	Cadmium	M-W	0.80	Site ≤ background
	Copper	M-W	0.072	Site ≤ background
		Quantile		Site ≤ background
	Mercury	Gehan	0.93	Site ≤ background
	Dioxin TEQ KM+Half	M-W	0.094	Site ≤ background
		Quantile		Site ≤ background
	PAH TEQ KM+Half	M-W	0.029	Site > background
		Quantile		Site > background
	PCB TEQ KM+Half	No background data		
	Total PCBs Sum of Aroclors (U=0 or Max DL)	No background data		
Oyster		No background data		

Table 9-5. Comparison of Concentrations in Port Gamble Bay Tissues to Puget Sound Natural Background Tissues

Tissue Type	Endpoint	Test	p-value	Conclusion
Crab - Muscle	**Arsenic**	M-W	0.964	Site ≤ background
	Cadmium	Gehan	0.155	Site ≤ background
	Copper	M-W Quantile	0.183	Site ≤ background Site > background
	Mercury	M-W	0.937	Site ≤ background
	Dioxin TEQ KM+Half	M-W Quantile	0.184	Site ≤ background Site ≤ background
	PAH TEQ KM+Half	M-W Quantile	0.0629	Site ≤ background Site > background
	PCB TEQ KM+Half	No background data		
	Total PCBs	Insufficient data for test (n = 1 in bay; 17 in background). The site value (8U) was greater than the maximum background value (1.9).		
Crab - Hepatopancreas	**Arsenic**	M-W	0.989	Site ≤ background
	Cadmium	M-W	0.974	Site ≤ background
	Copper	M-W	0.953	Site ≤ background
	Mercury	M-W	0.993	Site ≤ background
	Dioxin TEQ KM+Half	M-W Quantile	0.0173	Site > background Site ≤ background
	PAH TEQ KM+Half	M-W Quantile	0.0341	Site > background Site > background
	PCB TEQ KM+Half	No background data		
	Total PCBs	Insufficient data for test (n = 1 in bay; 15 in background). The site value (20U) was close to the mean of the background values (21).		

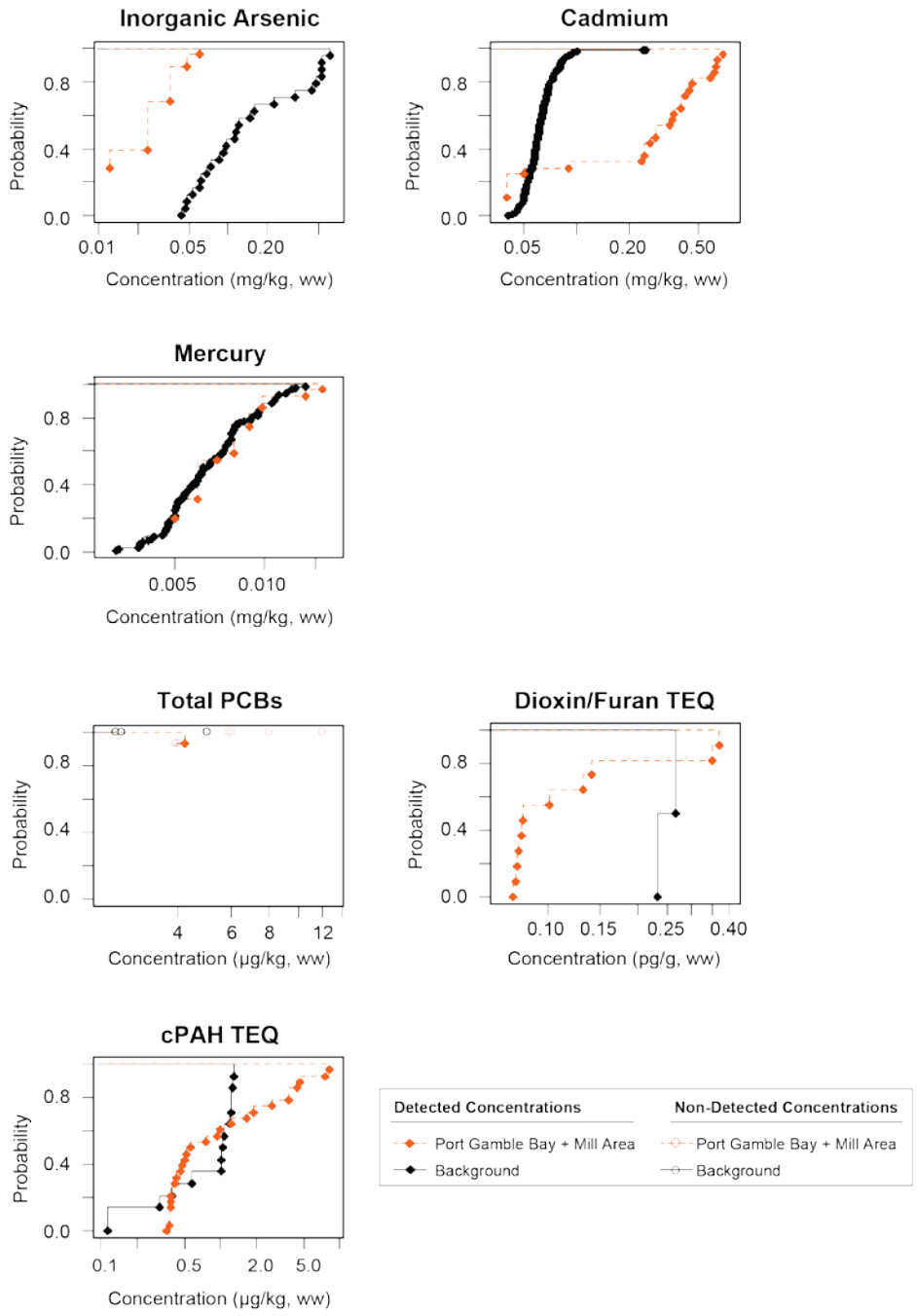

Figure 9-2. Empirical cumulative distribution plots for clam tissues

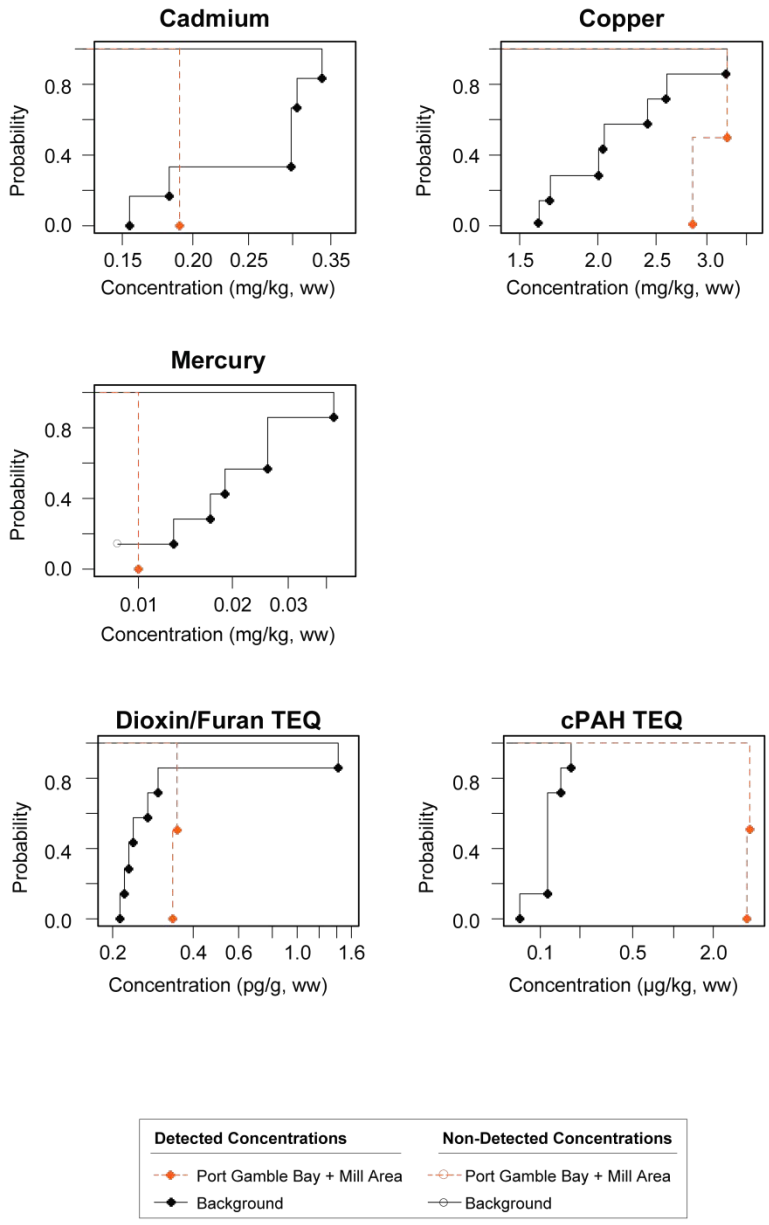

Figure 9-3. Empirical cumulative distribution plots for geoduck tissues

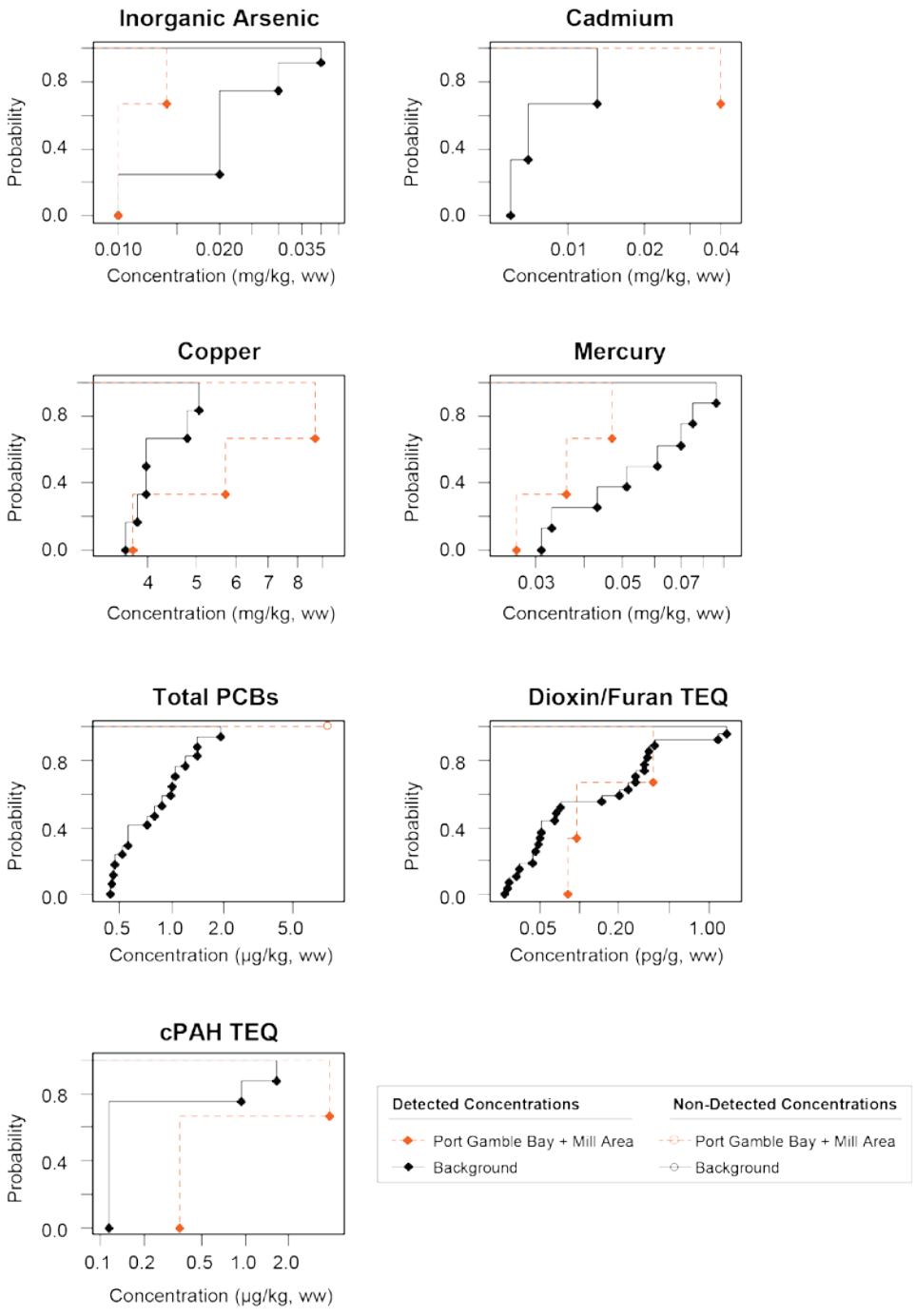

Figure 9-4. Empirical cumulative distribution plots for clam muscle tissues

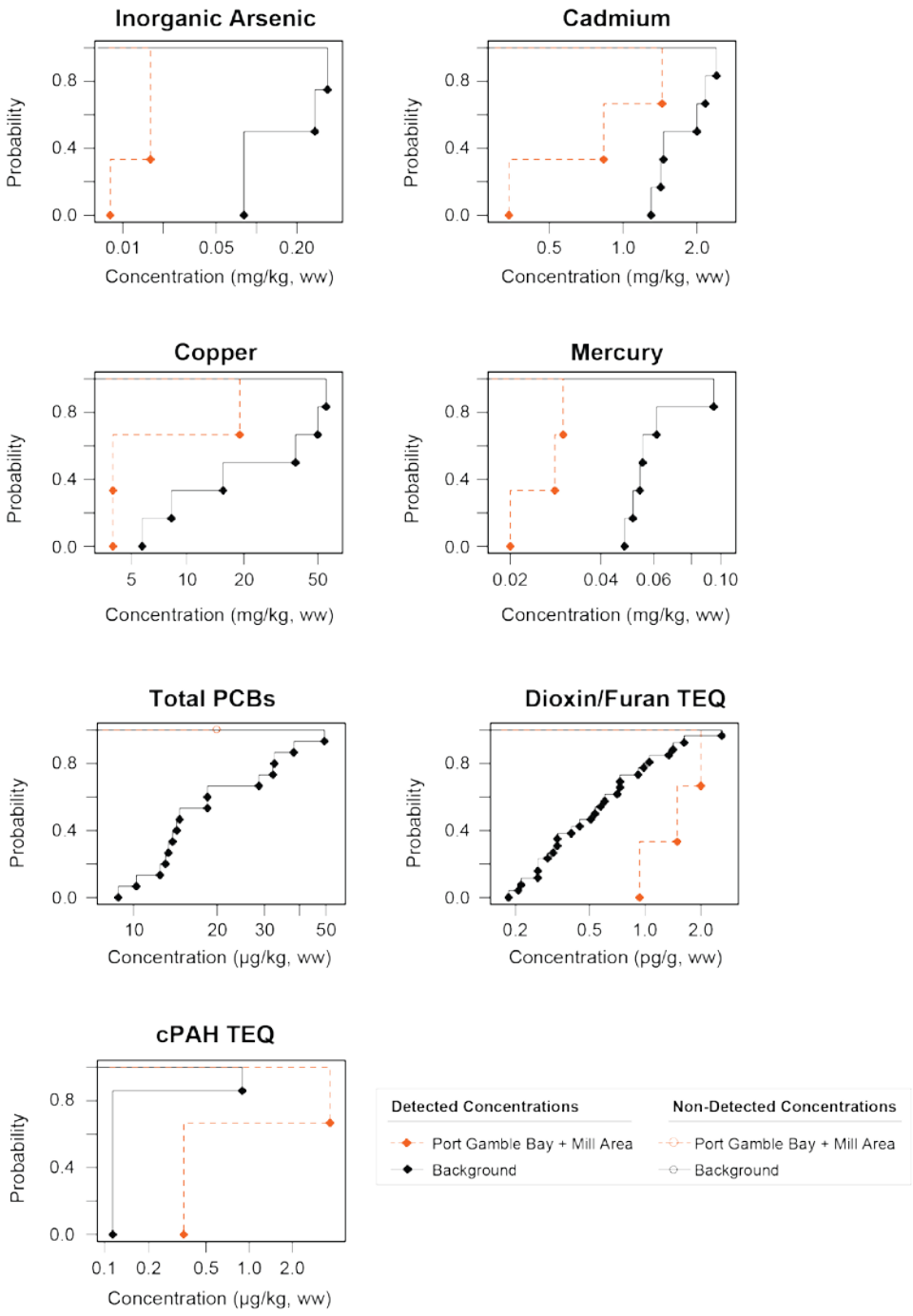

Figure 9-5. Empirical cumulative distribution plots for crab hepatopancreas tissues

9.3 Summary of Natural Background Comparisons for Sediments and Tissues

- **Arsenic.** The arsenic concentrations in the subtidal sediments of Port Gamble are comparable to natural background, and the intertidal sediment concentrations are well below natural background. Puget Sound natural background tissue data for arsenic were only available for clams and crabs; for these tissue types, Port Gamble inorganic arsenic concentrations were below Puget Sound natural background concentrations.
- **Cadmium.** The distribution of cadmium concentrations in Port Gamble Bay subtidal sediments was significantly elevated relative to Puget Sound natural background sediments. Cadmium in clam tissues was also significantly elevated relative to natural background concentrations. Only one of the three crab muscle tissue samples had a detected cadmium concentration, though this concentration exceeded all natural background values. Cadmium concentrations in crab hepatopancreas and geoduck tissues, as well as in intertidal sediments, were all below Puget Sound natural background concentrations.
- **Copper.** The distribution of copper in Port Gamble Bay subtidal sediments was comparable to natural background concentrations. The upper percentile of copper from Port Gamble crab muscle tissues exceeded natural background and both the upper percentile and the median Port Gamble concentration in geoduck exceeded natural background. Crab hepatopancreas tissue concentrations from Port Gamble were well below natural background.
- **Mercury.** The distributions of mercury in Port Gamble Bay subtidal sediments and tissues were comparable to Puget Sound natural background distributions.
- **cPAHs.** The median cPAH TEQ value found in Port Gamble Bay subtidal sediments was an order of magnitude above the natural background median sediment concentration. The upper percentile of cPAH TEQ values in Port Gamble tissues exceeded natural background for every tissue type, and median concentrations in Port Gamble Bay exceeded natural background for crab hepatopancreas and geoduck tissues. However, the upper percentile elevations calculated were based on non-detected concentrations in samples with elevated RLs.
- **Dioxins/Furans.** Concentrations of dioxin/furan TEQs in sediment of Port Gamble Bay were statistically elevated above natural background near the mill and in areas of the bay. Both the median and upper percentile sediment concentrations were significantly greater than natural background. The median dioxin/furan TEQ in crab hepatopancreas tissues from Port Gamble was significantly greater than in natural background tissues. Limited background data for other tissue types do not allow definitive conclusions at this time. Additional background data are expected to be gathered in upcoming sampling events that can be used for future monitoring events at Port Gamble.
- **PCBs.** Concentrations of PCBs in Port Gamble Bay sediments were generally within natural background ranges, with the exception of two intertidal sediment samples with elevated PCB TEQs (0.19 ng/kg and 0.24 ng/kg), which exceeded the maximum natural background TEQ by a factor of two. PCB Aroclors were largely undetected in Port Gamble sediments; site values are comparable to natural background ranges with the exception of one subtidal sample with elevated total PCBs (158 µg/kg). Total PCBs in tissues from Port Gamble were also largely undetected.

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10.0 CONCEPTUAL SITE MODEL

Based on all of the information presented above, the following conceptual site model has been developed for Port Gamble Bay:

10.1 Current and Former Sources

The following have been identified as likely contributors to contamination observed in Port Gamble Bay. While other potential sources exist (see Section 2), no other sources were identified despite additional sampling targeted at those potential areas.

- **Wood Waste.** Deposition of wood waste through log rafting, log transfer activities, chip loading, and other sources related to the former mill has resulted in thick deposits of wood chips, bark, and other debris both north and south of the mill site. Smaller amounts of wood debris can be seen at the FLA and at various locations along the shoreline. In turn, these wood waste deposits generate a variety of breakdown products, including toxic chemicals, resulting in elevated levels of TOC, TVS, sulfides, ammonia, resin acids, and phenols in sediments.
- **Creosoted Pilings.** Thousands of creosoted pilings and overwater structures are present near the former mill site and in areas to the south, with varying degrees of structural integrity. These pilings and structures continue to present an ongoing source of carcinogenic PAHs, other chemicals, and wood debris to the aquatic environment.
- **Wood Burning and Hog Fuel Boiler.** Historic burning of large quantities of wood debris at the mill, originally on an uncontained slab and later in a hog fuel boiler, released large but unknown amounts of particulate matter into the air. The prevailing winds indicate that much of this material would have settled out on the surrounding soils and in Port Gamble Bay, ultimately settling out into bottom sediments in the finer-grained areas of the bay. Ash was also generated by these wood-burning activities, which may have been deposited in the landfills or in other nearby upland areas. The particulates and ash would have contained PAHs, dioxins/furans, and potentially metals.
- **Upland Mill Activities.** Other historic industrial activities at the mill may have contributed to scattered exceedances of metals and PCB criteria along the southern and southwestern shoreline of the former mill.
- **Shoreline Debris.** Substantial shoreline debris is present at the former mill site and south along the shoreline in the landfill areas and continuing south to the FLTF and FLA areas. The debris varies from asphalted and creosoted materials to bricks, batteries, plastics, other landfill waste, and untreated wood. These materials may have contributed to some elevations observed (especially for metals) in coarser-grained areas where higher concentrations would not otherwise be expected.

10.2 Transport Pathways

The following contaminant transport pathways to human and ecological receptors formerly and/or currently exist at the site:

- **Currents and Tidal Fluctuations.** As wood deposits continue to break down near the mill through biological and chemical action, finer-grained organic matter is produced, which appears to be transported through currents and tidal action to the south-central areas of the bay and deposited there. All of the same wood waste breakdown products observed near the mill are found in this south-central portion of the bay, along with microscopic wood particles in the sediments.
- **Concentration of Clay Particles.** Similar processes concentrate very fine-grained natural sediments such as clays in the south end of the bay. Metals efficiently bind to clay particles and were found to be highly correlated with the percentage of clay in the sediments. Consistent with the patterns in metals concentrations observed, it appears that nearly all of the metals evaluated are naturally concentrated at the south end of the bay due to deposition of clay particles there. Cadmium levels in the very southeast corner of the bay exceed levels of concern through these natural processes.
- **Aerial Deposition.** Particulates from the wood burning activities at the former mill site would have been transported with the prevailing winds and deposited onto the surface of Port Gamble Bay, where currents and tidal fluctuations would have eventually deposited these particulates in the finer-grained south-central areas of the bay.
- **Stormwater Runoff.** Stormwater runoff of contaminants from the former mill site may have occurred during and after its operation. Based on the limited contamination observed of typical upland contaminants (e.g., metals, PCBs), this transport pathway likely affected mainly scattered intertidal sediments immediately adjacent to the site, primarily to the south and southwest of the former mill.

10.3 Ecological and Human Health Impacts

- **Benthic Effects.** Potential effects to benthic organisms have been evaluated through a variety of bioassay tests over 10 years of studies. Areas to the north and south of the former mill site consistently exceed larval bioassay biological criteria, and in some studies have exceeded amphipod and juvenile polychaete criteria as well. Smaller areas in the FLA and in the south-central portion of the bay also exceed larval bioassay biological criteria. The larval bioassay appears to be the test that is most sensitive to wood waste breakdown products and is of considerable concern due to the importance of shellfish reproduction in the bay.
- **Human Health Risks.** Several chemicals, including arsenic, cadmium, cPAHs, PCB congeners, and dioxin/furan congeners have predicted human health risks from seafood consumption that exceed MTCA/SMS risk levels, both in Port Gamble Bay and in natural background areas of Puget Sound. Of these, cadmium and cPAHs exceed Puget Sound natural background concentrations, and dioxin/furan concentrations exceed natural background concentrations over limited areas near the mill site and offshore of the FLTF.

11.0 CONTAMINANTS OF CONCERN AND CLEANUP STANDARDS

11.1 Contaminants of Concern

CoCs for ecological risk can generally be defined as wood waste breakdown products that are toxic to benthic organisms. Many of these chemicals do not have specific chemical criteria; however, they are composed of some combination of TOC, TVS, sulfides, ammonia, resin acids, and phenols, which were generally colocated with bioassay exceedances, as were areas of known wood waste deposits.

To be considered a site-related human health contaminant of concern, a chemical must meet several criteria:

- **Consistent with Conceptual Site Model.** The contaminant must be associated with known or suspected sources and pathways at the site. This first criterion is important to consider to avoid inclusion of contaminants that are present solely due to globally distributed transport pathways.
- **Human Health Risk.** The contaminant must be associated with a chemical-specific hazard index >1 or cancer risk $>10^{-6}$ for all exposure pathways combined.
- **Above Natural Background.** The contaminant must have elevated concentrations in site sediments above natural background concentrations in Puget Sound sediments. Comparison of site concentrations in tissue to natural background concentrations in tissue is an important secondary consideration; however, concentrations in tissues may have other sources and there are frequently fewer samples for comparison than in sediments.

Each chemical evaluated for human health risk is discussed according to these criteria below:

- **Arsenic.** There is no known pathway from the upland site despite intensive testing of soil and groundwater transport pathways and no other known sources around the bay. Arsenic appears to be present at the site due to naturally occurring geologic sources. Concentrations in sediments and tissues are lower than natural background concentrations. **Conclusion:** Arsenic is not a site-related CoC for human health.
- **Cadmium.** Cadmium may be associated with fly ash from wood-waste hog fuel burners, although there is no specific data indicating this. Cadmium is consistently but slightly elevated in sediments of the south-central part of the bay and is also elevated in some tissues (particularly clams) above natural background. It has a relatively low noncarcinogenic hazard quotient of approximately 3. **Conclusion:** Cadmium is a low-level CoC for human health.
- **Copper.** There are no known sources of copper at the site. The hazard quotient associated with copper is approximately 1. Copper is not elevated in sediments or tissues at the site compared to natural background except in geoducks. **Conclusion:** Copper is not a CoC for human health.
- **Mercury.** Mercury was removed from upland soils but was not observed at elevated levels in sediments adjacent to the mill or elsewhere in the bay. The hazard quotient associated with mercury is <1. Mercury is not elevated in sediments or tissues at the site compared to natural background. **Conclusion:** Mercury is not a CoC for human health.

- **Carcinogenic PAHs.** There are known sources of PAHs at the site, and carcinogenic risks are in the 10^{-4} range. Carcinogenic PAHs are elevated in both sediments and tissues compared to natural background. **Conclusion:** cPAHs are a primary site-related CoC for human health.
- **PCBs.** While there were isolated sources of PCBs on the upland mill site, there are no documented transport pathways to sediments and no other known sources of PCBs to the bay. PCBs are associated with risks of approximately $1x10^{-4}$; however, nearly all sediment and tissue samples are non-detects, so the calculated risks are based on detection limits. Two intertidal sediment concentrations exceeded natural background by a factor of 2 and will be included in active cleanup areas. No other tissues or sediments were above natural background concentrations/detection limits. **Conclusion:** PCBs are not a site-related CoC for human health.
- **Dioxins/Furans.** There was a known source of dioxins/furans at the former mill. Dioxins/furans at the site are associated with carcinogenic risks in the 10^{-4} range, and they are elevated in limited areas of sediments near the mill and offshore of the FLTF compared to natural background concentrations. Data for dioxins/furans in tissues in background areas are currently limited and largely undetected and, therefore, it is difficult to draw definitive conclusions with respect to background. **Conclusion:** Dioxins/furans are a site-related CoC for human health in specific areas of sediments. Future monitoring using a more robust and recent background tissue data set will allow clearer conclusions to be drawn regarding concentrations in tissues.

11.2 Ecological Risk-Based Cleanup Standards

As noted above, many of the wood waste breakdown products that are toxic to benthic organisms do not have numeric chemical criteria. In addition, a full suite of bioassay test results is available for nearly every station sampled near the mill and in Port Gamble Bay. Therefore, the SMS biological criteria will be used to delineate SMAs and as cleanup standards for ecological risk. Ecology has selected the SQS as the site-specific ecological cleanup standard for this site (see Section 7.5 and Figure 7-2 for stations that exceed the SQS).

11.3 Human Health Risk-Based Cleanup Standards

The cleanup standard for human health is defined as the highest of 1) risk-based concentrations, 2) natural background concentrations, and 3) practical quantitation limits (PQLs). Cleanup standards for cPAHs, cadmium, and dioxins/furans in sediment are based on the assumption that chemical concentrations in sediments are solely responsible for the chemical concentrations found in shellfish tissues in Port Gamble Bay.

Background threshold values (BTVs) were developed as one component of developing cleanup standards for human health and to identify individual site stations that are clearly different from background. BTVs were calculated as a 90/90 upper tolerance limit (UTL). A UTL is an upper confidence bound on a percentile, e.g., a 90/90 UTL is a 90% confidence bound on the 90^{th} percentile, indicating that 90% of the underlying background distribution is expected to be below this threshold with 90% confidence. This threshold was selected by Ecology to avoid including areas representative of natural

background as cleanup areas, and to be consistent with other sediment management programs in Puget Sound.

ProUCL was used to evaluate the characteristics of the background data distribution, and the best-fit distributions based on goodness of fit tests and probability plots were selected. Background summary statistics and the BTVs are presented in Table 11-1.

Table 11-1. Derivation of Background Threshold Values (BTVs)

CoPC	Distribution	Method[1]	Mean[2]	SD[2]	50th percentile	90th percentile	BTV (90/90 UTL)
cPAH TEQ (µg/kg)	Lognormal	MLE	1.3	0.77	3.6	9.6	16
Cadmium (mg/kg)	Lognormal	MLE	-1.2	1.2	0.39	0.99	3.0
Dioxin/furan TEQ (ng/kg)	Lognormal	MLE	1.31	1.19	0.97	2.71	4.35

[1]Method for estimating the population mean and standard deviation (SD): MLE = Maximum likelihood estimates.
[2]Mean and standard deviation (SD) are shown on log scale for lognormal distributions; on concentration scale for normal distributions.

The BTVs for cadmium and cPAH TEQs are above PQLs, and therefore, the BTVs are selected as the cleanup standards for these analytes. However, the BTV for dioxin/furan TEQs is below the PQL for most laboratories accredited to perform this analysis by Washington State. Two surveys of accredited laboratories in 2011 determined that the lowest PQL that could consistently be achieved by the majority of the laboratories without qualification for blank contamination was approximately 5 ng/kg (MFA 2011). The median PQL for all of the accredited laboratories was also approximately 5 ng/kg and the mean was 6 ng/kg (Hart Crowser 2011). Therefore, Ecology has selected 5 ng/kg as the cleanup standard for sediments at Port Gamble.

11.4 Summary of Cleanup Standards

In summary, the following cleanup standards will be applied:

- **Toxicity due to wood waste breakdown products:** SQS numeric biological standards described in WAC 173-204-320(3)
- **cPAH TEQ:** 16 µg/kg
- **Dioxin/furan TEQ:** 5 ng/kg
- **Cadmium:** 3.0 mg/kg

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12.0 SEDIMENT MANAGEMENT AREAS AND SITE BOUNDARIES

SMAs are defined below based on similar characteristics, such as contaminants present, biological toxicity, geographic contiguity, and hydrologic considerations.

The following SMAs have been defined for Port Gamble Bay (Figure 12-1):

- **Mill Site North.** This SMA encompasses the embayment to the northeast of the former mill, between the jetty and the point. Mill Site North is characterized by deep wood chip deposits, large numbers of creosoted pilings and structures, biological toxicity at SQS and CSL levels, and high concentrations of TOC, TVS, porewater sulfides, and carcinogenic PAHs.
- **Mill Site South.** This SMA extends south of the former mill to Station MS-10. This area is characterized by deep deposits of wood chips and bark and also contains significant numbers of pilings and overwater structures. Stations throughout this area consistently exceed SQS biological standards and also have high concentrations of TOC, TVS, porewater sulfides, and the highest levels of cPAHs in the bay. In addition, areas along the southern shoreline of the former mill have dioxin/furan levels exceeding the BTV.
- **Central Bay.** This SMA encompasses four stations with SQS biological exceedances in the south-central area of the bay that were colocated with elevated levels of TOC, TVS, sulfides, ammonia, and resin acids.
- **Former Lease Area.** This SMA includes a relatively small area in the FLA characterized by SQS bioassay failures and elevated TOC, ammonia, resin acids, and phenols.
- **Carcinogenic PAHs.** This large area encompasses all stations that exceed the BTV for cPAHs in the bay. It also includes a subtidal area offshore of the FLTF that slightly exceeds the BTV for dioxins/furans and one station to the southeast that exceeds the BTV for cadmium. This SMA surrounds and includes all the other SMAs, and thus also serves as the site boundary.

All areas that exceeded site-specific cleanup standards were included within an SMA. SMAs may be refined further in the FS, including subdividing and applying different cleanup alternatives to subareas of an SMA based on environmental benefit, technical feasibility, cost, integration with planned restoration alternatives, and other considerations.

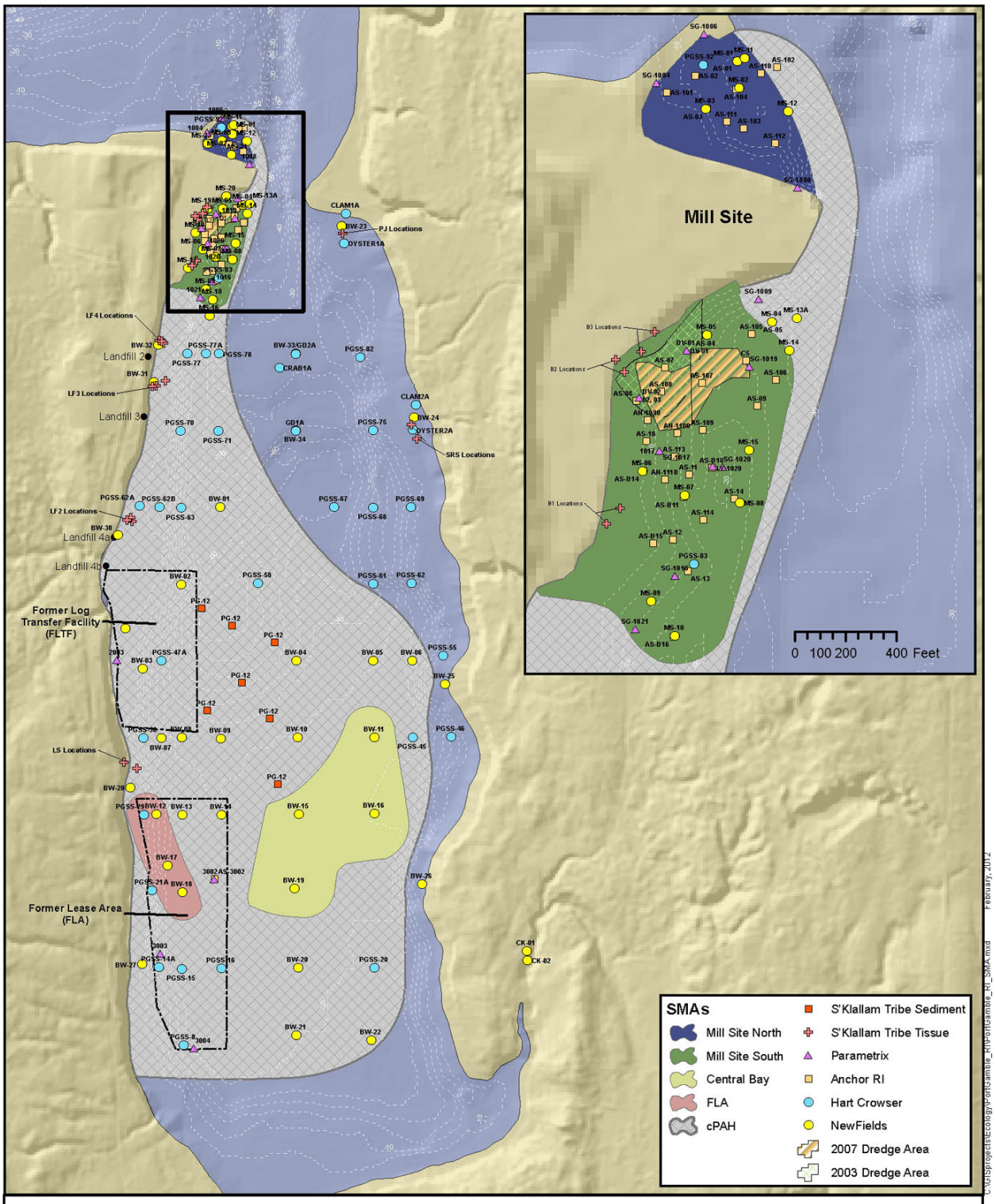

Figure 12-1. Sediment Management Area Boundaries

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APPENDIX A

SEDIMENT AND TISSUE DATA

APPENDIX B

HUMAN HEALTH EXPOSURE AND RISK CALCULATIONS

APPENDIX C

STATISTICAL EVALUATIONS AND NATURAL BACKGROUND COMPARISONS

APPENDIX D

REMEDIAL INVESTIGATION/FEASIBILITY STUDY
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