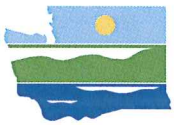
Sediment Characterization Study in Port Gardner and Lower Snohomish Estuary Port Gardner, WA

FINAL DATA REPORT

Prepared for



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Executive Summary

Puget Sound is a unique ecosystem and an economically important natural resource for the state of Washington. Unfortunately, Puget Sound's ecosystem is in trouble. While its symptoms are not easily visible, the science is undeniable and impacts from pollution are getting worse. The state has recognized the need to protect and restore this national treasure. In 2006, legislation was approved that provides substantial funding for the Puget Sound Initiative for restoration and recovery by the year 2020. In response to this initiative, the Department of Ecology's Toxics Cleanup Program is focusing on in-water and upland sites within a half mile of Puget Sound for cleanup and restoration.

As part of the Puget Sound Initiative, Ecology identified Port Gardner Bay and the Lower Snohomish River Estuary as a high priority area for cleanup and restoration because of its important habitat and valuable natural resources. It is one of seven priority bays Ecology is working on throughout Puget Sound, which also includes conducting bay wide sediment characterizations to inform cleanup and restoration decisions. The Port Gardner/Snohomish River Estuary Sediment Study was done to identify potential areas of sediment contamination and confirm the priority areas for cleanup in the Bay and surrounding area. Ecology designed this study to provide information on the overall quality of sediments, determine the general nature and extent of sediment contamination, and help develop protective cleanup levels.

The study area included Port Gardner, the Lower Snohomish River and the Estuary area. We divided the Bay into four areas: East Waterway including the southern shore of Port Gardner; the main stem of the Lower Snohomish River including the estuary and Maulsby mud flats; Steamboat Slough; and the Northern Snohomish Delta including Ebey Slough.

Sediment evaluation occurred at 82 locations of which 53 have been analyzed for chemistry and 17 for biological toxicity. Subsurface sediment samples were taken up to a depth of 11 feet from 16 locations and analyzed for chemistry. Sediment samples were analyzed for the full suite of 47 Sediment Management Standards chemicals, plus tributyl tin, dioxin/furans and biological toxicity. Sediment Profile Imagery was used to understand the general biological condition of the sediments by viewing the benthic community and vegetation. A video probe was used to observe layering of the sediments to a depth of 6 feet.

Fish, shellfish, crab and plant samples were taken for tissue chemistry analysis. The Department of Health will use these results to conduct a separate Health Consultation which will provide insight regarding human health issues. Ecology will work with local and state health agencies to evaluate these results and communicate potential health risks to Port Gardner communities.

Based on the results of the initial sediment chemistry and biological toxicity data, the East Waterway sediments have the highest degree of impact from biological toxicity and chemicals in general. The Maulsby mud flats had high biological toxicity. Ebey Slough and Steamboat Slough each had one location with biological toxicity. East Waterway is impacted by concentrations of mercury, zinc, and 4-methyl phenol above the Sediment Management Standards. Biological toxicity also exists in specific areas potentially due to organic enrichment from the accumulation

of wood waste. Dioxin was detected in all four areas of the Bay with the highest concentration in the East Waterway area.

Results from this study complement and support Ecology's decision to focus cleanup and restoration efforts in the Port Gardner; specifically, the East Waterway as well as the industrial area near Maulsby mud flats. It is expected that Ecology's cleanup efforts in this area will greatly contribute to an overall reduction in risk these contaminants and impacts may pose. The results from this study also will help Ecology make decisions about further evaluation of the Estuary and sloughs for cleanup and restoration.

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List of Acronyms

AET	apparent effects threshold
BSAF	biota sediment accumulation factor
CSL	cleanup screening level
cy	cubic yards
DGPS	differential global positioning system
DMMP	Dredged Material Management Program
DO	dissolved oxygen
dw	dry weight
Ecology	Washington State Department of Ecology
HPAH	high molecular polycyclic aromatic hydrocarbon
MDL	method detection limits
MLLW	mean lower low water
MRL	method reporting limits
MTCA	Model Toxics Control Act
OSI	organism-sediment index
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PCDD	polychlorinated dibenzodioxin
PCDF	polychlorinated dibenzofuran
PCP	pentachlorophenol
pg	picogram
PSAMP	Puget Sound Ambient Monitoring Program
PSEP	Puget Sound Estuary Program
PSI	Puget Sound Initiative
QA/QC	quality assurance/quality control
QAPP	Quality Assurance Project Plan
R/V	research vessel
RI/FS	remedial investigation/feasibility study
RPD	redox potential discontinuity
SAIC	Science Applications International Corporation

SAP	Sampling and Analysis Plan
SMARM	Sediment Management Annual Review Meetings
SMS	Sediment Management Standards
SPI	sediment profile imaging
SQS	Sediment Quality Standard
SVOC	semi-volatile organic compound
TEF	toxic equivalent factor
TEQ	toxic equivalent quotient
TOC	total organic carbon
TVS	total volatile solids
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
WAC	Washington Administrative Code
WHO	World Health Organization
ww	wet weight

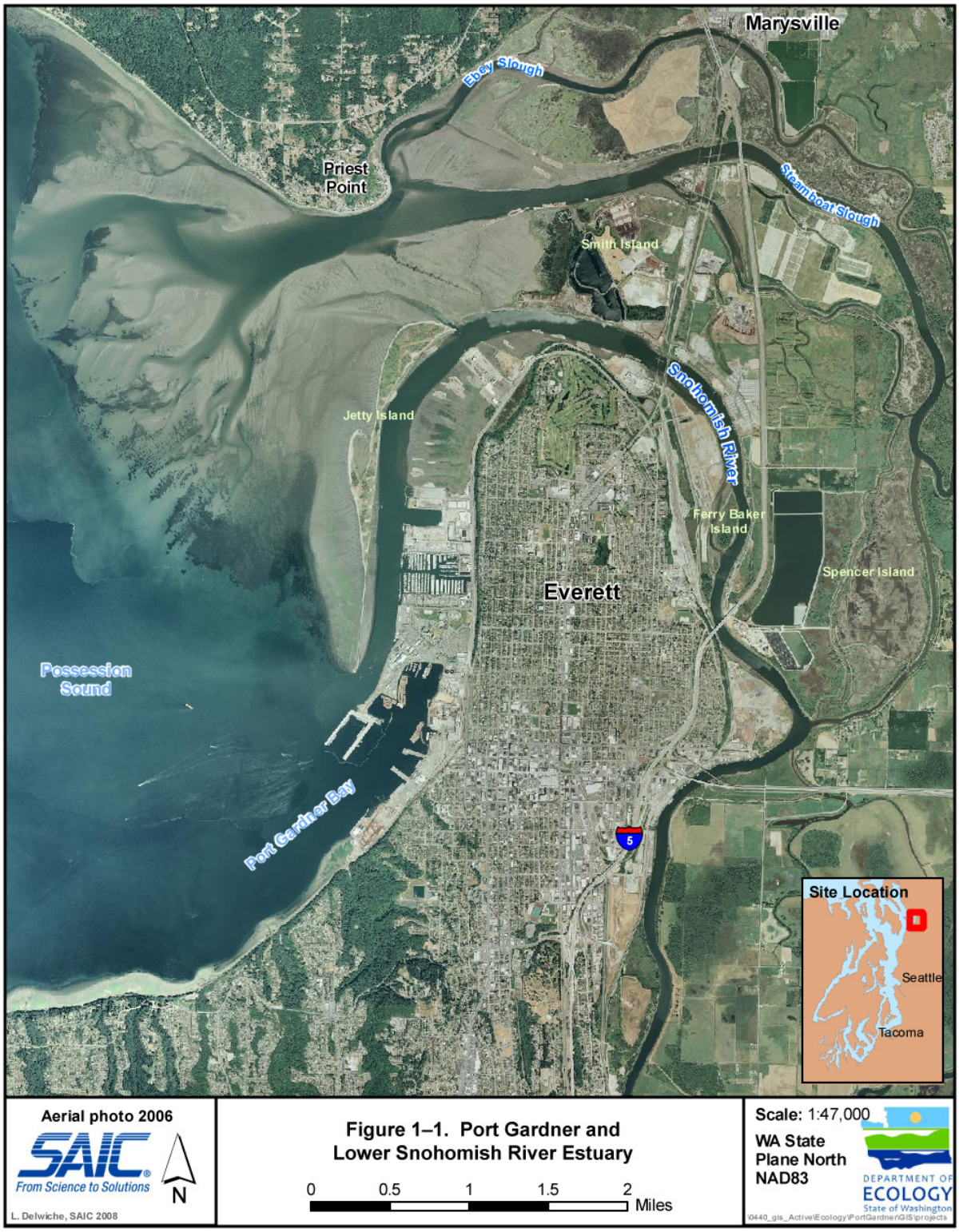
1.0 Introduction

Port Gardner and the lower Snohomish River Estuary (referred to as Port Gardner) are identified under the Toxics Cleanup Program's Puget Sound Initiative (PSI) for focused sediment cleanup and source control (Figure 1–1). Previous environmental investigations in the area have measured sediment chemical concentrations that have exceeded Sediment Management Standards (SMS), according to Chapter 173-204 Washington Administrative Code (WAC). However, much of the data are outdated and many areas of suspected contamination are not well characterized (Science Applications International Corporation [SAIC] 2008a). This report includes the results of sediment profile imaging (SPI), plan view photography, surface and subsurface sediment chemistry, sediment toxicity testing, and tissue analysis conducted following the study design and methods described in the *Sediment Characterization Study in Port Gardner and Lower Snohomish Estuary, Port Gardner, WA, Sediment Sampling and Analysis Plan (SAP) and Quality Assurance Project Plan (QAPP)* dated September 15, 2008 (SAIC 2008b).

1.1 Site Description

Port Gardner is an embayment of Puget Sound's Whidbey Basin, bounded to the east by the City of Everett (Figure 1–1). The Snohomish River system, the second largest river discharge into Puget Sound, empties into Port Gardner Bay at the City of Everett waterfront and provides approximately 30 percent of the freshwater discharge to the Whidbey Basin. Originating in the Cascade Mountains, tributaries of the Snohomish River drain a variety of forested, agricultural, and industrial properties. The mouth of the Snohomish River's main channel is bounded to the west by Jetty Island, a manmade island composed of sediment from continual maintenance dredging of the river channel. The Snohomish River estuary additionally consists of a series of interconnected sloughs that flow through the lowlands east and north of the river's main channel. These waterways can experience tidal influence as far as 20 miles upstream.

The fluvial sediment load of the Snohomish River maintains mud flats and tidal marshlands in the estuarine delta and is deposited throughout the deeper portions of Port Gardner Bay. The extensive tide flats and sloughs provide important habitat for the spawning and rearing of forage fish (e.g., Pacific herring, surf smelt, and sand lance) and the migration of juvenile salmonids. However, dikes and other forms of tidally-restrictive structures emplaced for agricultural development caused the loss of considerable wetland habitat throughout the estuary. The waterfront of the City of Everett is heavily industrialized, and tideland filling, shoreline armoring, and over-water structures are present throughout the region.


Marysville
Ebey Slough
Priest Point
Steamboat Slough
Smith Island
Snohomish River
Jetty Island
Ferry Baker Island
Spencer Island
Everett
Possession Sound
Port Gardner Bay
5
Site Location
Seattle
Tacoma
Aerial photo 2006
SAIC
From Science to Solutions
N
L. Delwiche, SAIC 2008
Figure 1–1. Port Gardner and Lower Snohomish River Estuary
0 0.5 1 1.5 2 Miles
Scale: 1:47,000
WA State Plane North NAD83
DEPARTMENT OF ECOLOGY
State of Washington

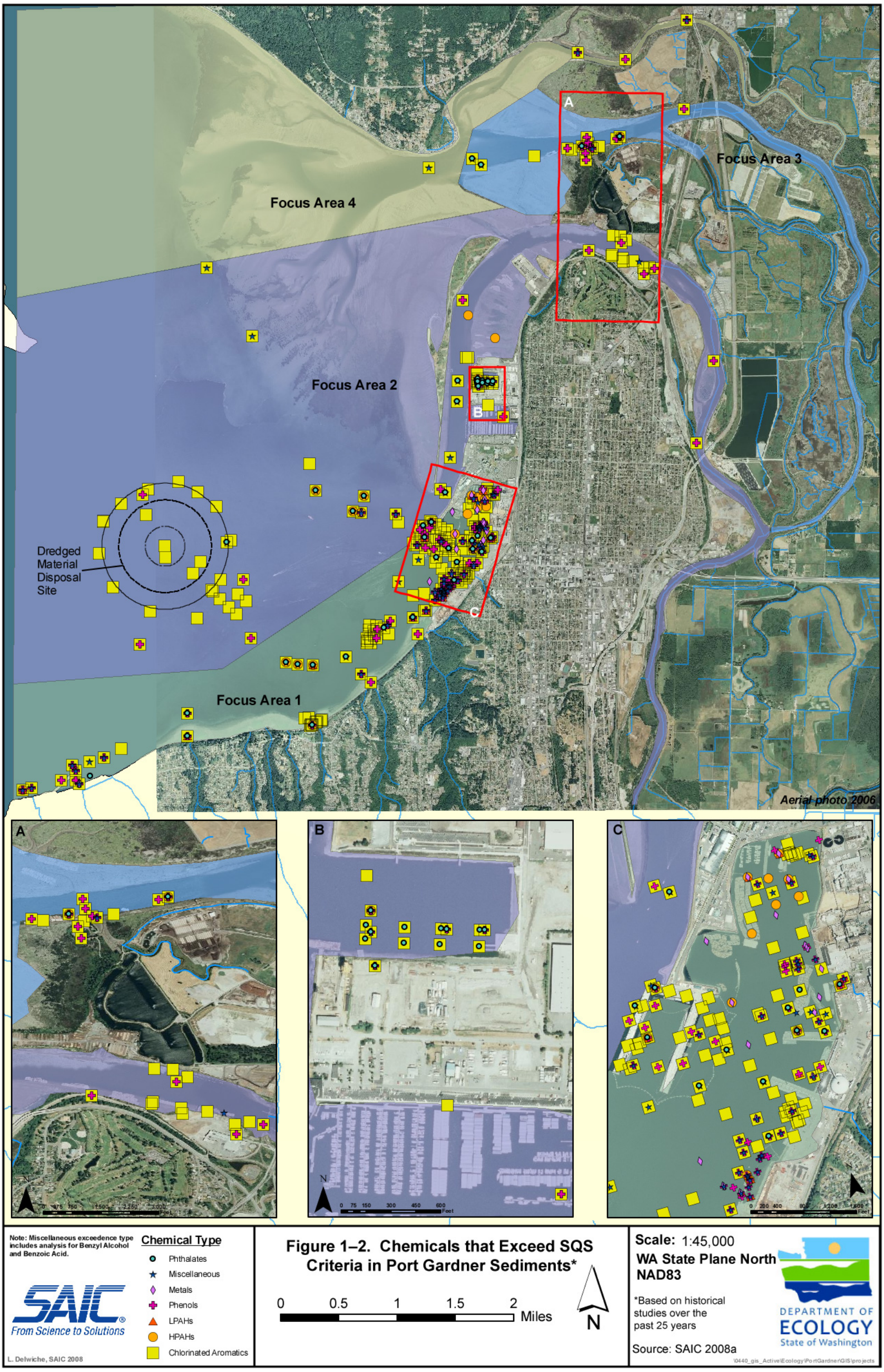
1.2 Site History

The Port Gardner Data Gaps Report provides a detailed description of the site, operational history, and summary of previous investigations (SAIC 2008a). Port Gardner has a wide variety of commercial and industrial activities, multiple potential point sources of contamination, and an overall history of contamination. Since the early 1900s, the lower Snohomish River has been used for commercial and industrial purposes, often related to timber and maritime industries (saw mills, paper production, boat building, and waste disposal). In the last 25 years, several sediment investigations have detected chlorinated aromatics, polycyclic aromatic hydrocarbons (PAHs), metals, miscellaneous extractables, pesticides, phenols, and phthalates at levels exceeding current SMS criteria at numerous locations throughout Port Gardner. The most extensive contamination has been identified within the East Waterway (Figure 1–2), which has historically been dredged with subsequent sediment disposal at the Dredged Material Management Program (DMMP) open-water dredged material disposal site in Port Gardner Bay. Only sediments that are determined suitable for open-water disposal (i.e., pass DMMP screening level criteria; U.S. Army Corps of Engineers [USACE] 2003) are allowed for disposal at the DMMP site.

Ten sites within the region have recently been identified as PSI sites for focused sediment cleanup and source control (Figure 1–3). Currently the lower Snohomish River Estuary is home to numerous sites of environmental remediation projects focused on tideland recovery and habitat restoration (Figure 1–3).

1.3 Project Scope and Objectives

The scope of this Sediment Investigation was limited geographically to the aquatic areas of Port Gardner Bay, the lower Snohomish River, Steamboat Slough, and Ebey Slough.


Focus Area 4
Focus Area 3
Focus Area 2
Focus Area 1
A
B
C
Dredged Material Disposal Site
Aerial photo 2006
Note: Miscellaneous exceedence type includes analysis for Benzyl Alcohol and Benzoic Acid.
Chemical Type
Phthalates
Miscellaneous
Metals
Phenols
LPAHs
HPAHs
Chlorinated Aromatics
SAIC
From Science to Solutions
L. Delwiche, SAIC 2008
Figure 1–2. Chemicals that Exceed SQS Criteria in Port Gardner Sediments*
0 0.5 1 1.5 2 Miles
N
Scale: 1:45,000
WA State Plane North NAD83
*Based on historical studies over the past 25 years
Source: SAIC 2008a
DEPARTMENT OF ECOLOGY
State of Washington


Ebey Slough
Tulalip Landfill
Hansen Boat Company Outfall
Priest Point Project Site
Marysville Ebey Slought Project Site (Completed)
Qwuloolt Project Site
City of Marysville Outfall
Hansen Boat Company
Weyerhaeuser Solid Waste Landfill
Biringer Project Site
Steamboat Slough
North Ebey Project Site
Smith Island Delta Front Project Site
Former Weyerhaeuser Mills C and D
Bay Wood Property
Jetty Island Project Site
Jeld-Wen
Snohomish River
Former Weyerhaeuser Mills B and E
5
Smith Island Project Site
Former Everett Smelter
Everett STP
North Marina West End Site
North Marina Ameron/Hulbert Site
Riverside Business Park
Union Slough Project Site
North Tip Ebey Project Site
PS01
PS02
PS03
Everett Shipyard
Lake Stevens Sewer District
City of Everett Sewage Lagoon
SR01
SR02
SR03
North Spencer Island Project Site
Former Riverside Chip Mill/Storage Areas City of Everett/Kimberly-Clark
Kimberly Clark Pulp and Paper Mill
PS04
PS05
PS06
PS07
East Waterway Sediment
Exxon/Mobile Bulk Plant
South Spencer Island Project Site (Completed)
SR04
SR07
36th Street Port of Everett
Everett STP
Former Weyerhaeuser Mill A Sediment Site
SR08
Everett Landfill
South Ebey WDFW Project Site
Simpson Site
Riverfront Enhancement Project Site
DD6 Project Site
Aerial Photo 2006
Key
PSI Sites
Main Outfall
CSO or Emergency Outfall
Restoration Sites
SAIC
From Science to Solutions
L. Delwiche, SAIC 2008
Figure 1–3. Puget Sound Initiative Cleanup and Habitat Restoration Sites in Port Gardner
0 0.5 1 1.5 2 Miles
0 0.25 0.5 1 1.5 2 Kilometers
Scale: 1:32,000
WA State Plane North
NAD83
N
DEPARTMENT OF ECOLOGY
State of Washington
\0440_gis_Active\Ecology\PortGardner\GIS\projects


Focus Area 3
Focus Area 4
Focus Area 2
Focus Area 1
Aerial photo 2006
SAIC
From Science to Solutions
N
L. Delwiche, SAIC 2008
Figure 1–4. Port Gardner Sediment Characterization Study Focus Areas
0 0.5 1 1.5 2 Miles
Scale: 1:47,000
WA State Plane North NAD83
DEPARTMENT OF ECOLOGY
State of Washington

The objectives of the 2008 Sediment Investigation were to conduct a multi-faceted, tiered sediment characterization in order to define the nature and extent of sediment contamination in Port Gardner. The specific objectives of the sediment investigation included the following:

- Conduct an intensive sampling and analysis effort to characterize the overall nature and extent of sediment contamination in Port Gardner, evaluate potential sources of contaminants, and provide a scale of priority for areas providing the greatest return in restored ecological values and function upon cleanup.
- Collect, process, and analyze representative sediment data to characterize the site in accordance with protocols, timing, and quality assurance/quality control (QA/QC) requirements outlined by Washington State Sediment Management Standards (SMS) protocols, Sampling and Analysis Plan Appendix (SAPA), Puget Sound Estuary Program (PSEP) protocols, and subsequent Sediment Management Annual Review Meetings (SMARM) updates.
- Compare the sediment chemistry results to Washington State SMS, Sediment Quality Standards (SQS), and Cleanup Screening Levels (CSL).
- Analyze for dioxin/furan congeners in sediments so the Washington State Department of Ecology (Ecology) can evaluate the dioxin/furan concentrations relative to human health and ecological health concerns.
- Conduct a suite of sediment toxicity tests on synoptic surface sediment samples that exceed the SQS chemical criteria. The suite of toxicity tests will include a larval development bioassay, an amphipod mortality bioassay, and a juvenile polychaete growth bioassay.
- Collect subsurface sediment cores to determine the vertical extent of woody debris and potential contamination through chemical analysis.
- Perform a subsurface video probe survey to determine the vertical variation in sediment physical characteristics and the extent of sedimentary woody debris accumulation.
- Conduct a SPI and plan view photography survey to determine the physical conditions of the bottom substrate and benthic habitat types.
- Collect fish, shellfish, and plant tissue for archival and residue analysis for bioaccumulative compounds measured in sediments.

1.4 Document Organization

This Data Report summarizes and evaluates the results of the Port Gardner Sediment Investigation within the context of the project scope and study objectives as outlined in Section 1.0. Section 2.0 of this document describes the study design and the methods for sample collection, SPI and plan view image evaluation, subsurface sediment probe video evaluation, chemical analysis, biological testing, and tissue collection, as well as any deviations from the SAP (SAIC 2008b). The data results, including the SPI survey, plan view photograph survey, subsurface video probe survey, surface and subsurface sediment chemistry (SMS analytes and dioxin/furan concentrations), biological testing, and tissue collection are presented in Section 3.0. A summary of the data validation reports for the chemical analysis is provided in Section 4.0. Section 5.0 presents the summary of results and identification of data gaps. References are provided in Section 6.0. The appendices include:

2.0 Data Collection and Analytical Methods

2.1 Study Design

The study area was limited geographically to the aquatic areas of Port Gardner Bay, the lower Snohomish River, Steamboat Slough, and Ebey Slough. The study area was divided into four Focus Areas as shown in Figure 1–4. Focus Area 1 consists of East Waterway and the southern portion of Port Gardner Bay within approximately 0.7 mile of the southern shoreline. Focus Area 2 consists of the central Port Gardner Bay and the lower Snohomish River's main channel, extending approximately 9 miles upstream from the river mouth. Focus Area 3 consists of approximately 6 miles of Steamboat Slough, from its divergence from the Snohomish River at the southern tip of Spencer Island to its mouth in northern Port Gardner Bay. Focus Area 4 consists of the lower 5 miles of Ebey Slough and northern Port Gardner Bay.

A tiered field sampling approach was used to conduct the Port Gardner Sediment Investigation. The first phase of sampling (Phase I) included SPI and plan view photography, subsurface video probing, surface sediment grab sampling, subsurface sediment coring, and fish and shellfish tissue sampling in the Port Gardner study area (Figures 2–1 through 2–3). The Phase II sampling event occurred approximately 2 months following the Phase I event. During Phase II, a second set of surface sediment samples was collected at selected locations for bioassay testing. The locations of these samples were determined based on the chemical results from Phase I (e.g., elevated conventional parameters or chemical concentrations exceeding SMS standards). The Phase II sampling also included the collection of plant tissues at two locations in the Snohomish River Estuary, in coordination with the Tulalip Tribe.

2.2 Sampling Platforms

Several sampling vessels were used to meet the multiple data collection objectives. The R/V *Kittiwake*, owned and operated by Mr. Charles Eaton of Bio-Marine Enterprises, was used for the SPI and plan view photography surveys, sediment grab sampling, and bottom trawling. The R/V *Growler*, owned and operated by SAIC, was used to collect sediment grab samples at locations inaccessible by the R/V *Kittiwake*. The R/V *Nancy Anne*, owned and operated by Mr. Bill Jaworski of Marine Sampling Systems, was used for the subsurface sediment collection and subsurface video probe survey. Geographic coordinates for all sampling locations are provided in Appendix A.

Figure 2-1. SPI and Plan View Photography and Subsurface Video Probe Locations

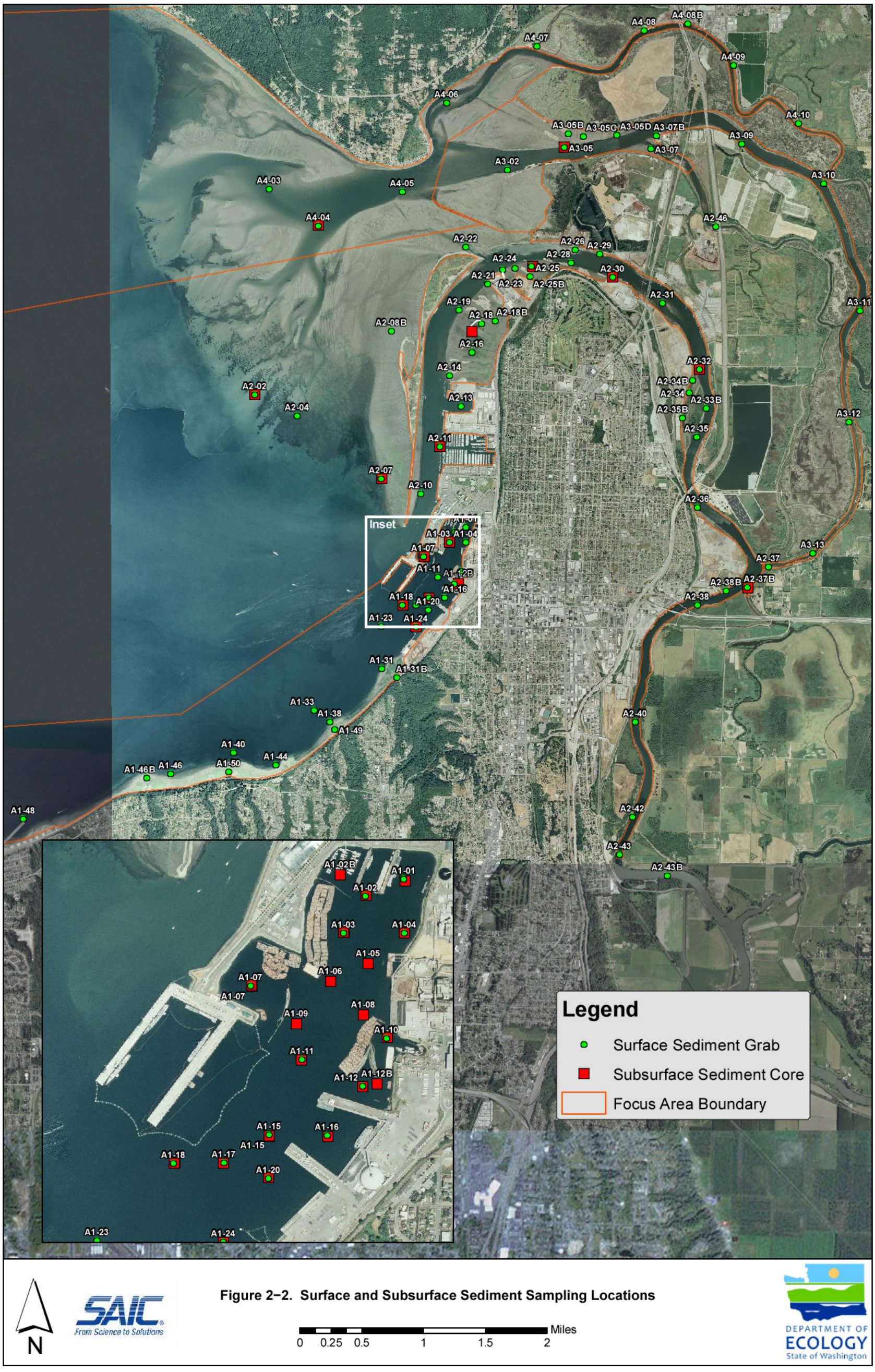


Figure 2−2. Surface and Subsurface Sediment Sampling Locations

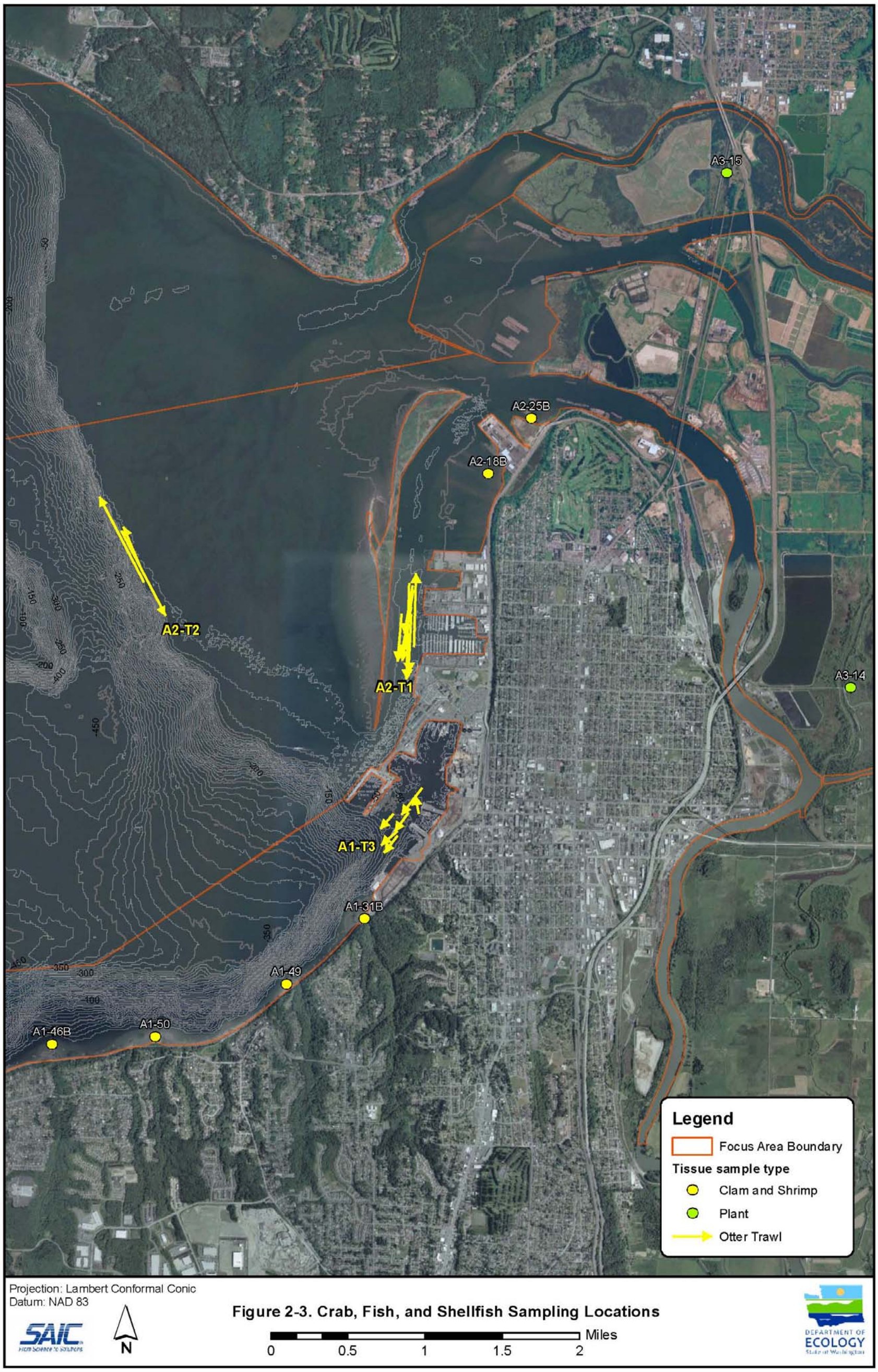


Figure 2-3. Crab, Fish, and Shellfish Sampling Locations

2.3 Sediment Profile Imaging and Plan View Photography

The initial component of the investigation was to conduct an area-wide survey using SPI and plan view camera systems to assess the condition of the benthic habitat and physical characteristics of the surface sediment. SPI provides a cross-sectional photograph of the sediment/water interface (in profile) and near-surface sediment (15 by 20 cm area). Images were collected using a Benthos model 3731 SPI camera equipped with an Ocean Imaging System digital system. The SPI camera consists of a wedge-shaped prism with a Plexiglas faceplate and a back mirror mounted at a 45-degree angle. Light is provided by an internal strobe. The mirror reflected the image of the profile of the sediment/water interface to a digital camera mounted horizontally on top of the prism (Figure 2–4). Three replicate images were collected from each SPI sampling location and parameters measured or determined using the images included:

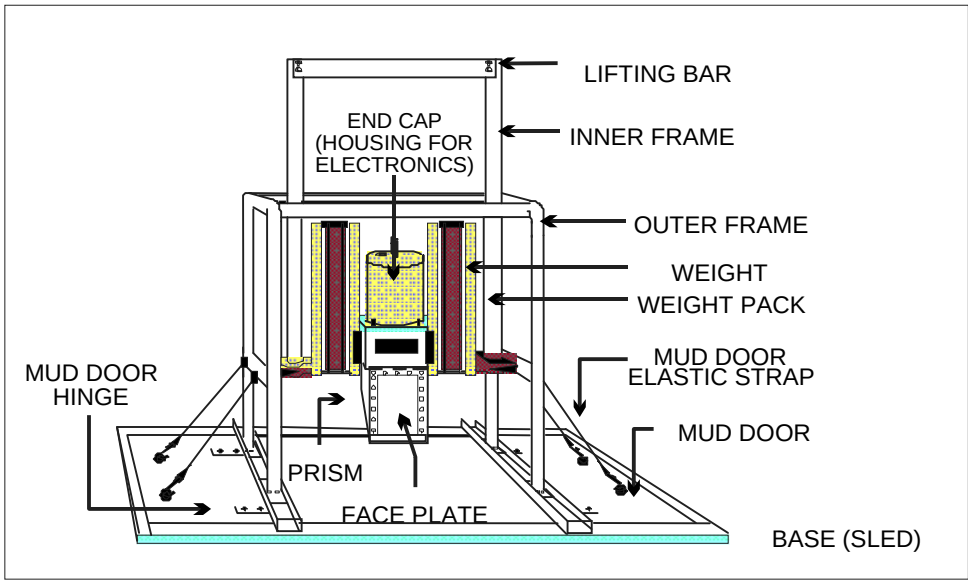
- Presence and estimate of wood debris,
- Grain size mode and range,
- Depth of apparent redox potential discontinuity (RPD),
- Sedimentary methane,
- Infaunal successional stage,
- Calculation of the organism-sediment index (OSI), and
- Benthic habitat classification type.

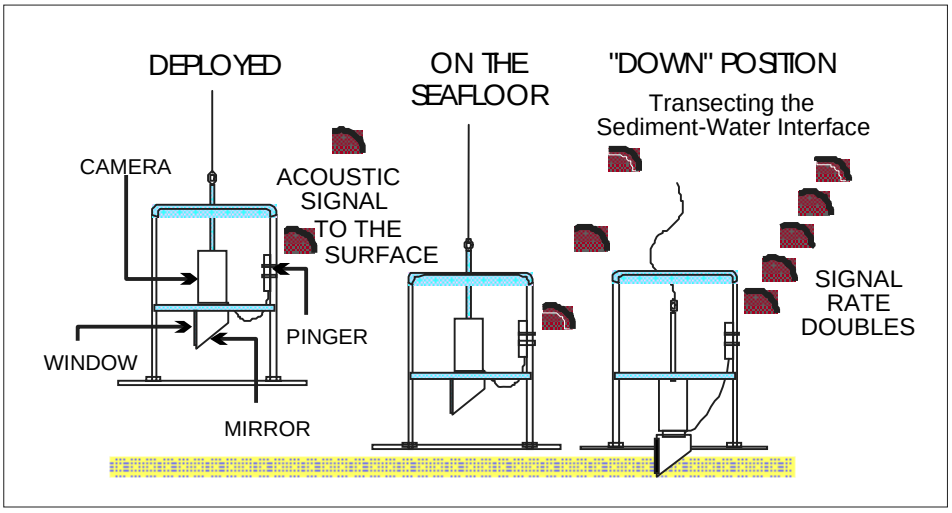
Plan view underwater still photography was conducted simultaneously with the SPI photography. Plan view images were taken using a downward-looking PhotoSea underwater 35 millimeter camera and strobe that were mounted on the SPI camera frame. The plan view camera provided a photograph of the sediment surface (20 by 30 cm area) near the front of the SPI camera faceplate. The 35 millimeter slide film was digitized following completion of the survey and one representative image from each location was evaluated for the presence of wood debris and macrofauna, and surface sediment characteristics.

A total of 101 locations were surveyed using the SPI and plan view cameras: 47 locations in Focus Area 1, 38 locations in Focus Area 2, eight locations in Focus Area 3, and eight locations in Focus Area 4 (Figure 2–1).

2.4 Subsurface Sediment Video Probe

Subsurface sediment video probing was used to determine the vertical variation in sediment characteristics and the extent of sedimentary woody debris accumulation. This device allowed for real-time observations of the sediment as the video probe was advanced into the sediment column. The physical characteristics of the sediment were determined with depth, up to a maximum depth of 6.5 feet. Co-located with SPI sampling locations, the video probing efforts were focused in areas where woody debris accumulation was likely to be present (Figure 2–1).





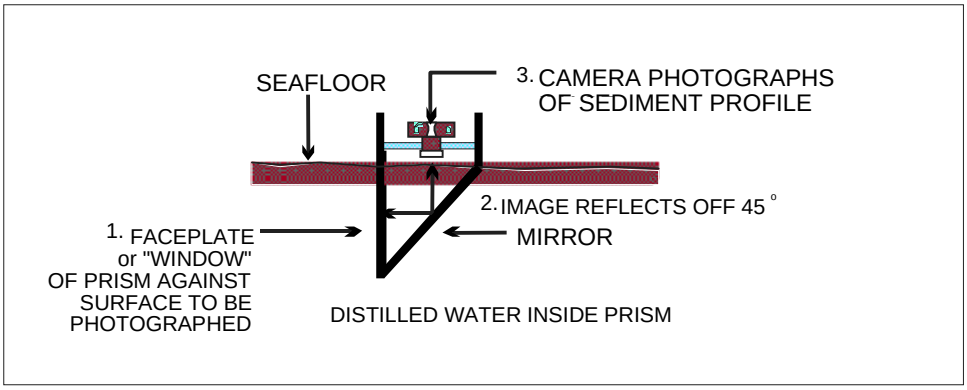


Figure 2-4. Schematic Diagram of Sediment-Profile Camera and Sequence of Operation on Deployment

2.5 Surface Sediment Samples

Collection of surface sediment (0 to 10 cm) samples was conducted using a 0.1 m^2 modified Young van Veen grab sampler. Sampling procedures followed Puget Sound Estuary Program (PSEP) protocols. If accessible during low tide events, surface sediment samples from intertidal areas (i.e., clam sampling locations) were collected by hand with stainless steel spoons. Sampling locations were selected based on the results of previous investigations, and to provide broad spatial coverage to define the overall extent of sediment contamination in Port Gardner. A total of 82 locations were sampled: 25 in Focus Area 1, 37 locations in Focus Area 2, 11 locations in Focus Area 3, and 9 locations in Focus Area 4. A total of 38 samples were initially analyzed with the remaining samples archived for potential future analysis (Figure 2–2).

2.5.1 Chemical Analysis

Table 2–1 lists the surface sediment samples selected for analysis. These samples were analyzed for conventional parameters (ammonia, total sulfides, total organic carbon [TOC], total volatile solids [TVS], total solids, and grain size) and the Washington State SMS chemicals of concern. A total of 15 of the samples were analyzed for dioxin/furan congeners. An additional subset of seven samples was analyzed for pesticide compounds, eight samples for tributyltin, and nine samples for guaiacols/resin acids. Selection of these samples was based on presence of possible sources as identified by SAIC (2008a) (see Table 2–1).

Table 2-1. Chemical and Biological Analysis of Port Gardner Surface Sediment Samples

Station	Conventionals	SMS Chemicals[1]	Pesticides	Tributyltin	Guaiacols/ Resin Acids	Dioxin/ Furan Congeners	Bioassays	Archive
A1-01	X	X					X	
A1-02	X	X			X			
A1-03	X	X		X		X	X	
A1-04								X
A1-07	X	X					X	
A1-10	X	X				X	X	
A1-11								X
A1-12								X
A1-15	X	X						
A1-16	X	X					X	
A1-17								X
A1-18	X	X				X		
A1-20								X
A1-23	X	X						
A1-24	X	X			X	X	X	
A1-31								X
A1-31B	X	X				X		
A1-33								X
A1-38	X	X						
A1-40								X
A1-44	X	X						
A1-46								X
A1-46B	X	X				X		
A1-48								X
A1-49								X
A1-50								X
A2-02	X	X				X		
A2-04								X
A2-07	X	X						
A2-08	X	X				X		
A2-10	X	X					X	
A2-11	X	X		X			X	
A2-13	X	X		X			X	
A2-14	X	X					X	
A2-16	X							X
A2-18	X	X	X		X	X	X	
A2-18B	X	X				X		
A2-19								X
A2-21	X						X	
A2-22	X	X						
A2-23	X	X						
A2-24								X
A2-25	X	X			X	X	X	
A2-25B	X	X				X		
A2-26	X	X						

Station	Conventionals	SMS Chemicals[1]	Pesticides	Tributyltin	Guaiacols/ Resin Acids	Dioxin/ Furan Congeners	Bioassays	Archive
A2-28	X	X						
A2-29	X	X						
A2-30	X	X			X	X		
A2-31								X
A2-32	X	X	X	X	X	X		
A2-33B	X	X						
A2-34	X	X						
A2-34B	X	X						
A2-35								X
A2-35B								X
A2-36	X	X			X		X	
A2-37	X	X	X			X		X
A2-37B	X	X	X			X		
A2-38	X	X						
A2-38B	X	X						
A2-40								X
A2-42	X	X	X					
A2-43								X
A2-43B	X	X						
A2-46	X	X						
A3-02								X
A3-05	X	X		X	X	X		
A3-05B	X							
A3-05C								X
A3-05D	X							
A3-05E	X						X	
A3-07								X
A3-07B	X	X		X			X	
A3-09	X	X	X					
A3-10								X
A3-11	X	X	X					
A3-12								X
A3-13	X	X		X				
A4-03								X
A4-04	X	X						
A4-05	X	X						
A4-06								X
A4-07	X	X	X	X	X	X		
A4-08								X
A4-08B	X	X					X	
A4-09	X	X						
A4-10								X

Notes

1. SMS chemicals include semi-volatile organics, metals, and PCB Aroclors.

2.5.2 Toxicity Testing

Surface sediment was collected from 17 locations and 3 reference locations for confirmatory biological testing. In order to meet the 56-day holding time, sediment collected for toxicity testing was not collected at the same time as for the chemical analysis. The decision to collect additional sediment at a given location and conduct confirmatory biological testing was contingent on the chemistry results for the surface chemistry samples. Locations that exceeded the SMS chemical SQS standards or had elevated concentrations of conventional parameters (sulfides, ammonia, TOC, or TVS) were re-sampled and submitted for biological testing with the exception of one location (Table 2–2). Station A3-05E was selected in Focus Area 3 based on expected wood debris in this location. However, conventional parameters were not elevated at station A3-05E.

Four bioassays were conducted on each sample, including: amphipod mortality (*Eohaustorius estuarius*), larval development (*Mytilus* sp.), juvenile polychaete growth (*Neanthes arenaceodentata*), and microtox bioluminescence (*Vibrio fischeri)*. All biological testing was in strict compliance with Recommended Guidelines for Conducting Laboratory Bioassays on Puget Sound Sediments (PSEP 1995). Further details on the toxicity testing methodology are provided in the SAP (SAIC 2008b). The results of the toxicity testing are provided in Section 3.3.

2.6 Subsurface Sediment Cores

Subsurface sediment cores were collected at 16 locations to determine the vertical extent of chemical contamination and woody debris accumulation (Figure 2–2). The cores were advanced to 11 feet below the sediment surface or refusal using a vibracore sampler. Sediment core processing include a physical description of the stratigraphy (Appendix B), including presence or absence of wood debris, and the collection of core sediment composites by depth interval (0 to 1, 1 to 3, 3 to 5, 5 to 7, 7 to 9, 9 to 11 feet) for the analysis of conventionals and SMS parameters. Two subsurface intervals were analyzed at 10 of the core locations, and one subsurface interval was analyzed at five of the core locations (Table 2–3). Five subsurface intervals were analyzed for dioxin/furan congeners. All sample intervals were archived at one location (A1-12B). All remaining core sample intervals were archived for potential future analysis.

Table 2-2. Conventional Parameters and SMS Chemistry for Bioassay Stations

Station ID	TOC[1]	TVS[1]	Ammonia[1]	Sulfides[1]	SMS Analyte	Concentration
A1-01	4.41	16.45	11.6	3780		
A1-03	7.06	24.53	23.9	2540		
A1-07	3.55	21.85	26.3	3030	Mercury	0.7 mg/kg dw
A1-10	5.23	14.17	9.03	1560	4-Methylphenol	1200 µg/kg dw
A1-16		5.9	3.94	169		
A1-24		13.09	5.37	377	Zinc	415 mg/kg dw
A2-10			4.58	126		
A2-11			4.13	109		
A2-13		6.82	8.79	137		
A2-14		9.99	12.7	105		
A2-18			4.67	74.6		
A2-21		7.48	13.9	805		
A2-25		5.13	6.28			
A2-36		5.56		615		
A3-05E						
A3-07B			9.44	46.7		
A4-08B		5.37	10.0	61.6		

Notes:

1. Relative Concentrations of Conventional Parameters:

Conventionals	Low	Medium	High
TOC (% dry weight [dw])	3.5 – 5.0	5.0 – 7.0	> 7.0
TVS (% dw)	5.0 – 10.0	10.0 – 15.0	>15.0
Ammonia (mg-N/kg dw)	3.0 – 5.0	5.0 – 8.0	>8.0
Total Sulfides (mg/kg dw)	20 – 50	50 – 100	>100

Dark gray shading indicates chemical concentration exceeds CSL criteria
Light gray shading indicates chemical concentration exceeds SQS criteria

Table 2-3. Chemical Analysis of Port Gardner Subsurface Sediment Samples

	Subsurface Depth Interval					
Station	**0–1 feet**	**1–3 feet**	**3–5 feet**	**5–7 feet**	**7–9 feet**	**9–11 feet**
A1-03	A	C,S	C,S	A	A	A
A1-07	A	C,S	C,S	A	A	A
A1-12B	A	A	A	A	A	A
A1-15	A	C,S	C,S	A	A	A
A1-18	A	C,S	C,S	A	A	A
A1-24	A	C,S,D	C,S	A	A	A
A2-02	A	C,S	A	A	A	A
A2-07	A	C,S	A	A	A	A
A2-11	A	C,S	A	A	A	A
A2-18	A	C,S,D	C,S	A	A	A
A2-25	A	C,S	C,S	A	A	A
A2-30	A	C,S,D	C,S	A	A	A
A2-32	A	C,S,D	C,S	A	A	A
A2-37	A	C,S	A	A	A	A
A3-05	A	C,S,D	C,S	A	A	A
A4-04	A	C,S	A	A	A	A

A Archived
C Conventional Parameters
S SMS Parameters
D Dioxin/Furan Congeners

2.7 Tissue Sampling

Fish, crab, clam, and plant specimens in Port Gardner were collected for tissue residue analysis of bioaccumulative chemicals of concern. Bottom trawling and intertidal hand sampling were used to collect these specimens (Figure 2–3). The specimens collected included English sole (*Parophrys vetulus*), Dungeness crab (*Cancer magister*), Eastern softshell clams (*Mya arenaria*) purple varnish clams (*Nuttallia obscurata*), stems of the tule plant (Hard Stemmed Bullrush) (*Scirpus lacustris*), and the lower stems/roots of the cattail (*Typha latifolia*). Target plant specimens were identified in coordination with the Tulalip Tribe and collected at two locations in the Snohomish River estuary. In addition, ghost shrimp (*Neotrypaea californiensis*) were collected and archived at four locations.

2.7.1 Bottom Trawl Sampling

A 7.6-meter otter trawl was used to target the collection of Dungeness crab and English sole. Trawl sampling was conducted in three target areas in Port Gardner, but with no particular attention to hitting specific stations. Triplicate English sole and Dungeness crab samples were collected in each area. English sole with a minimum length of 20 cm were targeted for collection. Each English sole sample consisted of five fish. The whole bodies of each fish were homogenized separately. Equal volumes from each fish homogenate were combined to make a final composite sample for analysis. Dungeness crabs with a minimum length of 9 cm were targeted for collection. Each Dungeness crab sample consisted of five crabs. The crabs in each sample were dissected for crab meat and hepatopancreas tissue samples.

A total of three English sole, three Dungeness crab meat, and three hepatopancreas (one replicate sample from each area) were initially analyzed (Table 2–4). The remaining samples were archived for potential future analysis.

2.7.2 Intertidal Tissue Samples

Small shovels were used to collect Eastern softshell and purple varnish clams at low tide from designated locations in Focus Areas 1 and 2 (Figure 2–3). Triplicate clam samples were collected in six areas. Four clam samples (one replicate sample each from locations A1-31B, A1-46B, A2-18B, and A2-25B) were analyzed for metals, Aroclor PCBs, and dioxin/furan congeners. The remaining tissue samples were archived (Table 2–4).

All clam tissues collected from two locations (A1-49 and A1-50) were archived. In addition, ghost shrimp samples were also collected at four of the locations (A1-31B, A1-49B, A1-49, and A1-50) and archived. At hand sampling locations, co-located sediment samples were collected and analyzed for the sediment conventionals, SMS parameters, and dioxin/furan congeners (see Table 2–1).

Plant tissues were collected by hand at two locations within the Snohomish River estuary. Stems of the tule plant and the lower stems/roots of the cattail were analyzed for metals, Aroclor PCBs, and pesticides. The roots of a third plant species (Silverweed; *Potentilla anserine*) were also targeted for collection, but were not present at the proposed sampling locations.

Table 2-4. Chemical Analysis of Port Gardner Tissue Samples

Station	Tissue Type	Replicate	SMS Metals	PCBs (Aroclors)	Dioxin/Furan Congeners
TRAWL A2-T1	English Sole	1	X	X	X
	English Sole	2	A	A	A
	English Sole	3	A	A	A
	Dungeness Crab Meat	1	X	X	X
	Dungeness Crab Meat	2	A	A	A
	Dungeness Crab Meat	3	A	A	A
	Dungeness Hepatopancreas	1	X	X	X
	Dungeness Hepatopancreas	2	A	A	A
	Dungeness Hepatopancreas	3	A	A	A
TRAWL A2-T2	English Sole	1	X	X	X
	English Sole	2	A	A	A
	English Sole	3	A	A	A
	Dungeness Crab Meat	1	X	X	X
	Dungeness Crab Meat	2	A	A	A
	Dungeness Crab Meat	3	A	A	A
	Dungeness Hepatopancreas	1	X	X	X
	Dungeness Hepatopancreas	2	A	A	A
	Dungeness Hepatopancreas	3	A	A	A
TRAWL A1-T3	English Sole	1	X	X	X
	English Sole	2	A	A	A
	English Sole	3	A	A	A
	Dungeness Crab Meat	1	X	X	X
	Dungeness Crab Meat	2	A	A	A
	Dungeness Crab Meat	3	A	A	A
	Dungeness Hepatopancreas	1	X	X	X
	Dungeness Hepatopancreas	2	A	A	A
	Dungeness Hepatopancreas	3	A	A	A
A1-31B	Varnish Clams	1	X	X	X
	Varnish Clams	2	A	A	A
	Varnish Clams	3	A	A	A
	Ghost Shrimp	1	A	A	A
	Ghost Shrimp	2	A	A	A
	Ghost Shrimp	3	A	A	A
A1-46B	Varnish Clams	1	X	X	X
	Varnish Clams	2	A	A	A
	Varnish Clams	3	A	A	A
	Ghost Shrimp	1	A	A	A
	Ghost Shrimp	2	A	A	A
	Ghost Shrimp	3	A	A	A
A1-49	Varnish Clams	1	A	A	A
	Varnish Clams	2	A	A	A
	Varnish Clams	3	A	A	A
	Ghost Shrimp	1	A	A	A
	Ghost Shrimp	2	A	A	A
	Ghost Shrimp	3	A	A	A

Station	Tissue Type	Replicate	SMS Metals	PCBs (Aroclors)	Dioxin/Furan Congeners
A1-50	Varnish Clams	1	A	A	A
	Varnish Clams	2	A	A	A
	Varnish Clams	3	A	A	A
	Ghost Shrimp	1	A	A	A
	Ghost Shrimp	2	A	A	A
	Ghost Shrimp	3	A	A	A
A2-18B	Eastern Softshell Clams	1	X	X	X
	Eastern Softshell Clams	2	A	A	A
	Eastern Softshell Clams	3	A	A	A
A2-25B	Eastern Softshell Clams	1	X	X	X
	Eastern Softshell Clams	2	A	A	A
	Eastern Softshell Clams	3	A	A	A

Notes:
X Sample Analyzed
A Archived

3.0 Results

This section presents the results of the SPI and plan view photography survey, subsurface video probe survey, surface and subsurface sediment chemistry results, surface sediment toxicity testing, tissue chemistry results, and dioxin/furan congener profiling. Chemistry data validation results are summarized in Section 4.0, and a summary of results and identification of data gaps is provided in Section 5.0.

3.1 SPI and Plan View Survey Results

SPI photography was used to determine the horizontal extent of woody debris in surface sediments and assess the relative health of the benthic habitat in Port Gardner. Plan view images were used to supplement the SPI data to help determine the presence or absence of wood debris, and to identify physical and biological surface sediment features. A total of 101 locations were surveyed in Port Gardner. Triplicate images were analyzed using a computer-based image analysis system to determine several physical and biological parameters (see Section 2.3). The image analysis results for the SPI and plan view images are provided in Appendix C. The SPI and plan view images are also provided electronically on a DVD as part of Appendix C.

3.1.1 Surface Wood Debris Distribution

A proportional estimate of wood debris (percent by area) was visually determined from the SPI (vertical profile to a maximum depth of 20 cm) and plan view images (20 by 30 cm surface area) at each location (Munsell 2000). Wood debris identified in surface sediments generally consisted of wood chips/fragments, bark pieces, and other small woody material.

The greatest accumulation of wood debris was observed in the East Waterway (Focus Area 1), an area of current and historical log storage, wood, pulp, and paper industries. The SPI images showed the presence of wood debris at 16 of 22 locations (73 percent) in the East Waterway, with accumulation as high as 30 percent by vertical area at station A1-14 (Figure 3–1). The plan view images showed the presence of wood debris at 14 of 22 locations (64 percent), with accumulation as high as 75 percent by surface area at station A1-14 (Figure 3–2). In the northern portion of the East Waterway, wood debris included decaying bark and log pieces on the sediment surface (Figure 3–3). Wood debris in the central portion of the East Waterway consisted of abundant wood and bark pieces on the sediment surface (Figures 3–4 and 3–5). Wood debris was generally absent in the southern portions of Focus Area 1 (southern Port Gardner).

Wood debris accumulation in surface sediments was much lower or absent in the Snohomish River and delta, Steamboat slough, and Ebey slough (Focus Areas 2, 3, and 4, respectively). The SPI survey identified wood debris at 20 of 56 locations (36 percent) in these areas. Plan view images showed the presence of wood debris at 13 of 50 locations sampled (26 percent). In Focus Area 2, the greatest accumulation of wood debris (15 percent by area) was observed in the SPI images from station A2-30, near the former Weyerhaeuser Mills C and D site (Figure 3–6). At station A2-11, located at the entrance to the Port of Everett Marina, small accumulations of

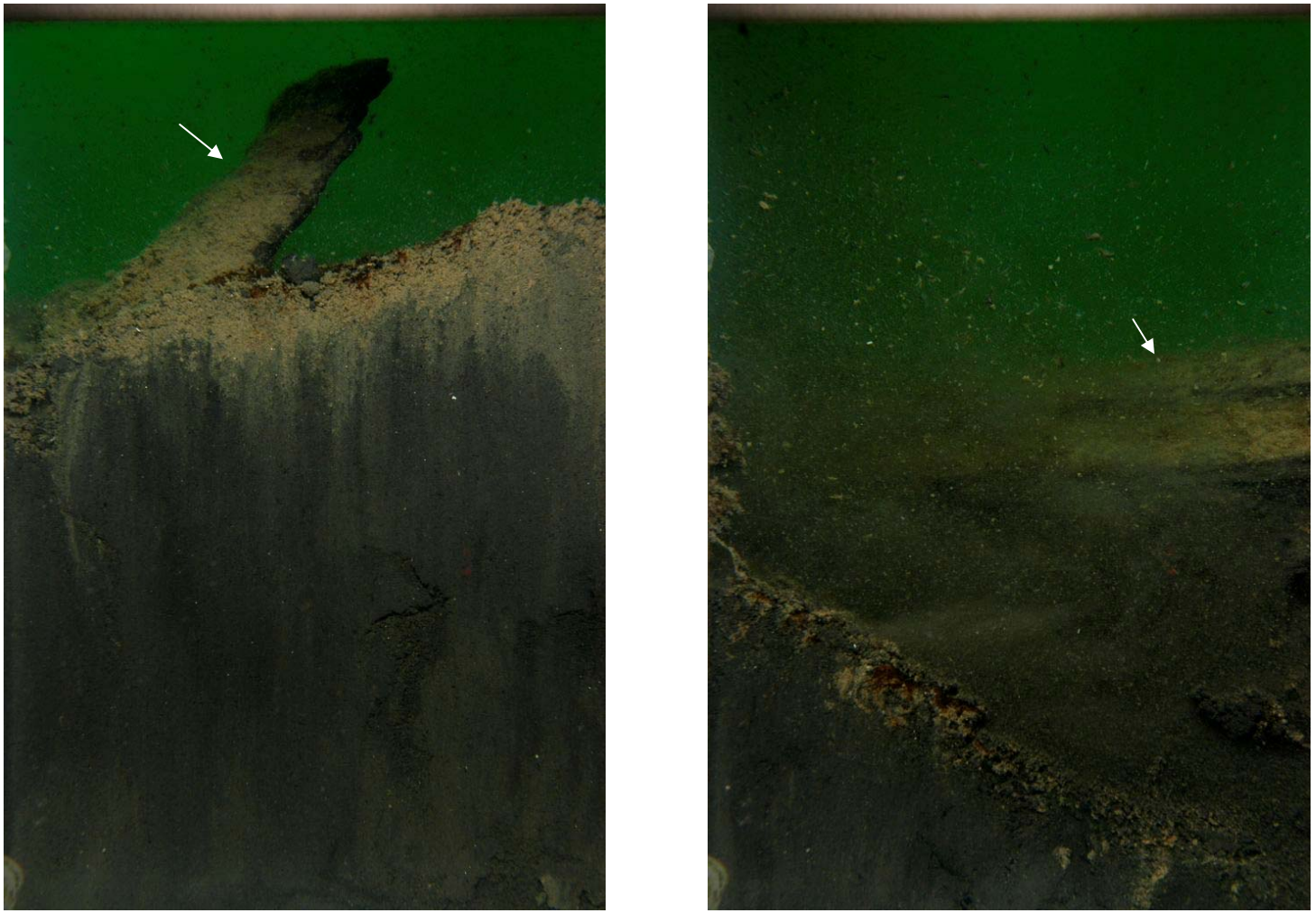
woody debris (five to 10 percent by area) consisted of small weathered wood pieces and fragments (Figure 3–7). Although SPI and plan view photography showed minimal wood debris in the mud flats just north of the Port of Everett Marina (Maulsby mud flats), wood debris was observed in scattered low lying areas during sediment collection activities (Figures 3–7 and 3–8). Wood debris was generally absent in surface sediments on the Snohomish River delta.

In Focus Area 3, wood debris accumulation consisted of minor amounts of weathered wood and bark pieces along the entrance channel to Steamboat slough near historical log rafting areas. At station A3-03, SPI and plan view images show weathered wood pieces on the sediment surface and a possible buried log (Figure 3–9). At station A3-05, weathered wood and bark pieces are observed on sandy surface sediments (Figure 3–10). Wood debris accumulation was absent in Focus Area 4, with the exception of very fine wood particles observed in SPI images at stations A4-02 and A4-07 (one to two percent by area).

Figure 3−1. Percent Wood Debris in Port Gardner SPI Images

Figure 3−2. Percent Wood Debris in Port Gardner Plan View Images

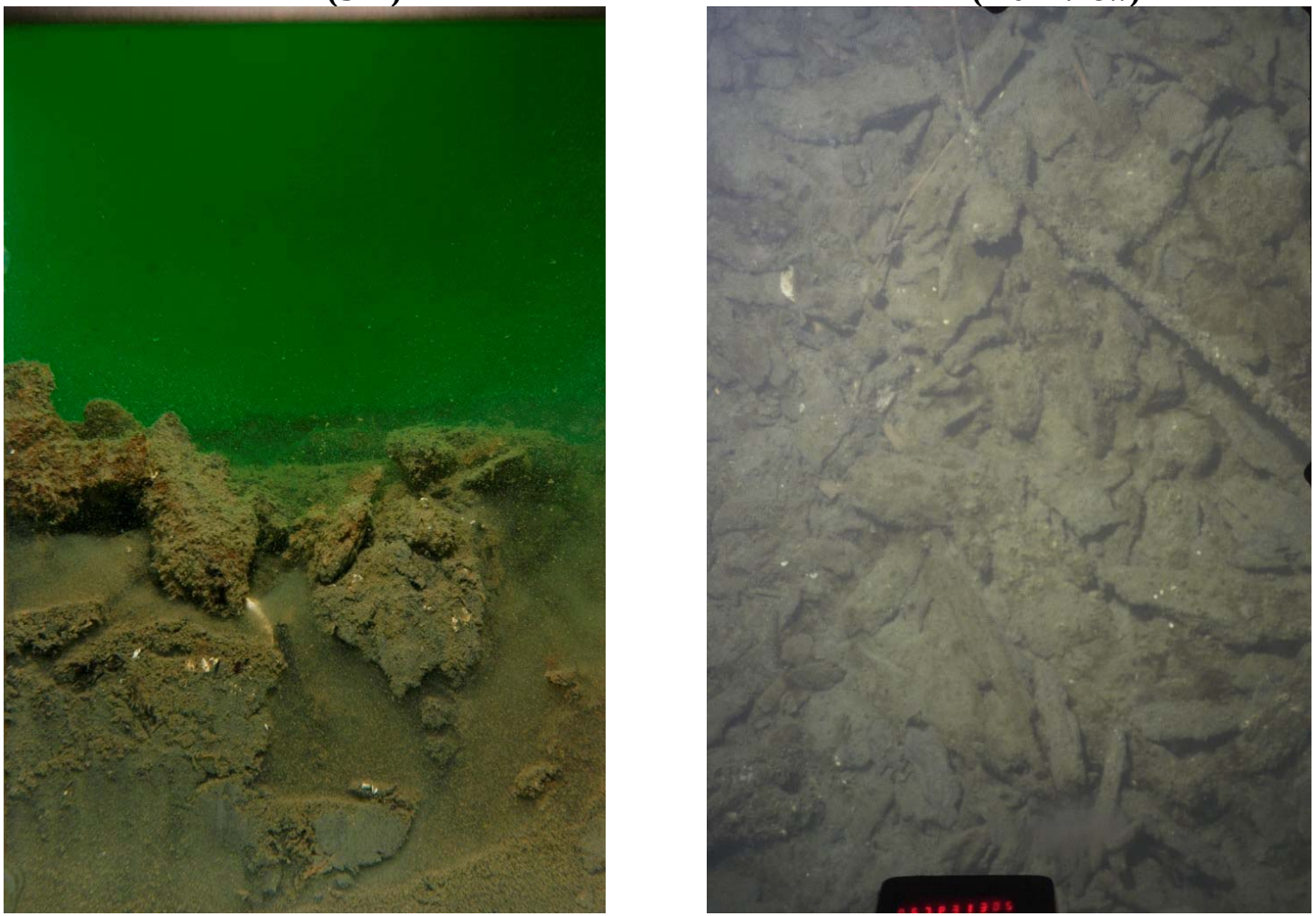
A1-01A **A1-03A**



SPI images showing the presence of large wood debris on the sediment surface in the inner East Waterway. Station A1-01A shows a silt draped wood/bark piece (arrow) over dark, reduced, silt/clay surface sediments. Wood debris at this location represents approximately 10 percent by area. The SPI image at station A1-03A shows a large decaying log piece in the far field of the image (arrow). The near field of the image shows a sloping surface with patches of brown cyanobacteria or diatom cover over reduced sediments.

Figure 3-3. SPI Images from Stations A1-01 (Replicate A) and A1-03 (Replicate A)

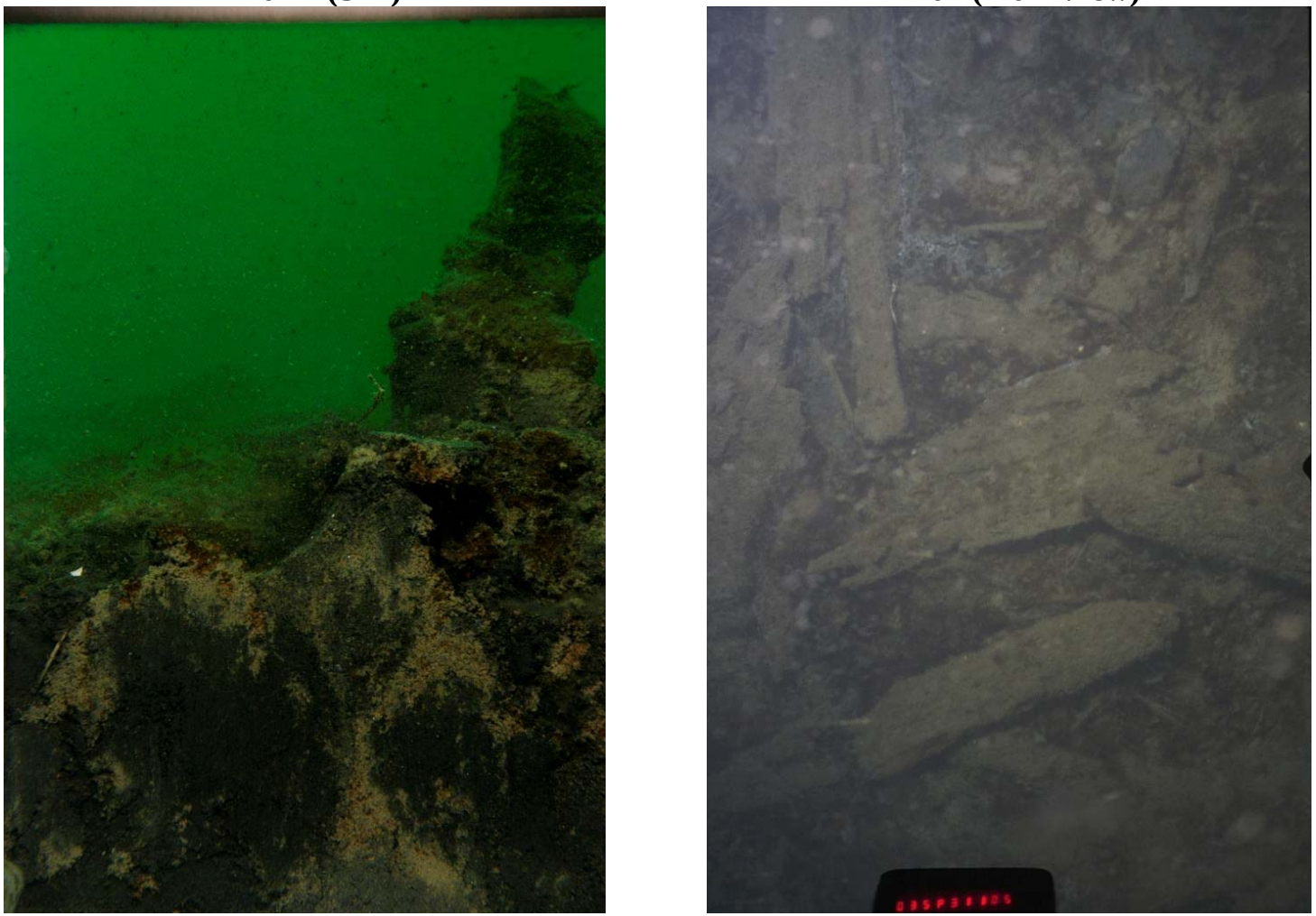
A1-14A (SPI) **A1-14 (Plan View)**



SPI and plan view images showing the presence of wood debris within surface sediments in the central East Waterway. The SPI image shows abundant wood chip and bark pieces on the sediment surface, representing approximately 30 percent by area. The plan view image shows the accumulation of abundant wood debris across the sediment surface. The surface coverage is approximately 75 percent by area.

Figure 3-4. SPI and plan view images from station A1-14

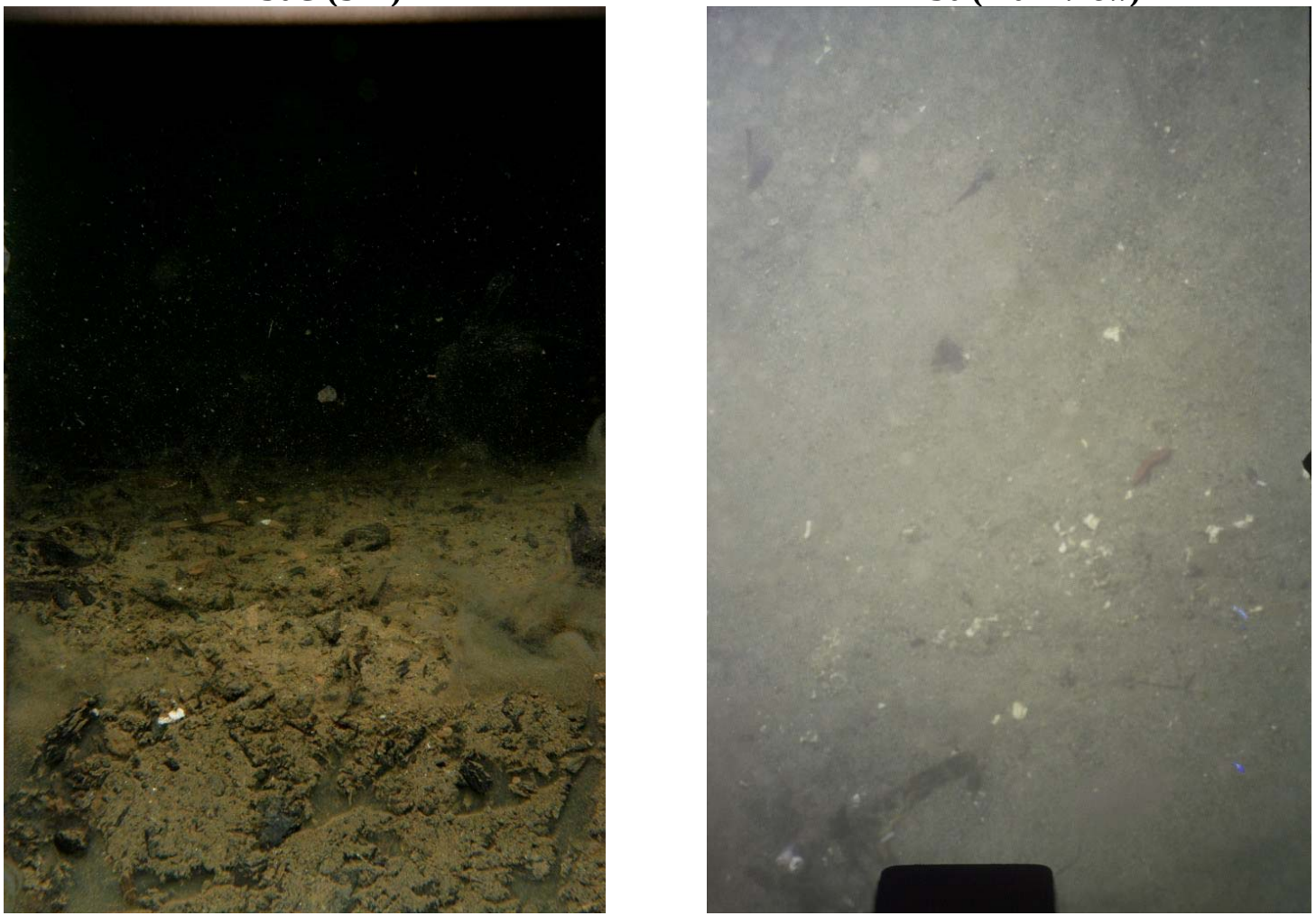
A1-07A (SPI) **A1-07 (Plan View)**



SPI and plan view images from Station A1-07, an active log storage area along the western shoreline of the East Waterway. The SPI image shows the presence of large wood pieces on reduced surface sediments. The wood debris represents approximately 25 percent by area.
The plan view image shows the accumulation of abundant wood debris across the sediment surface. The surface coverage estimate is 45 percent by area.

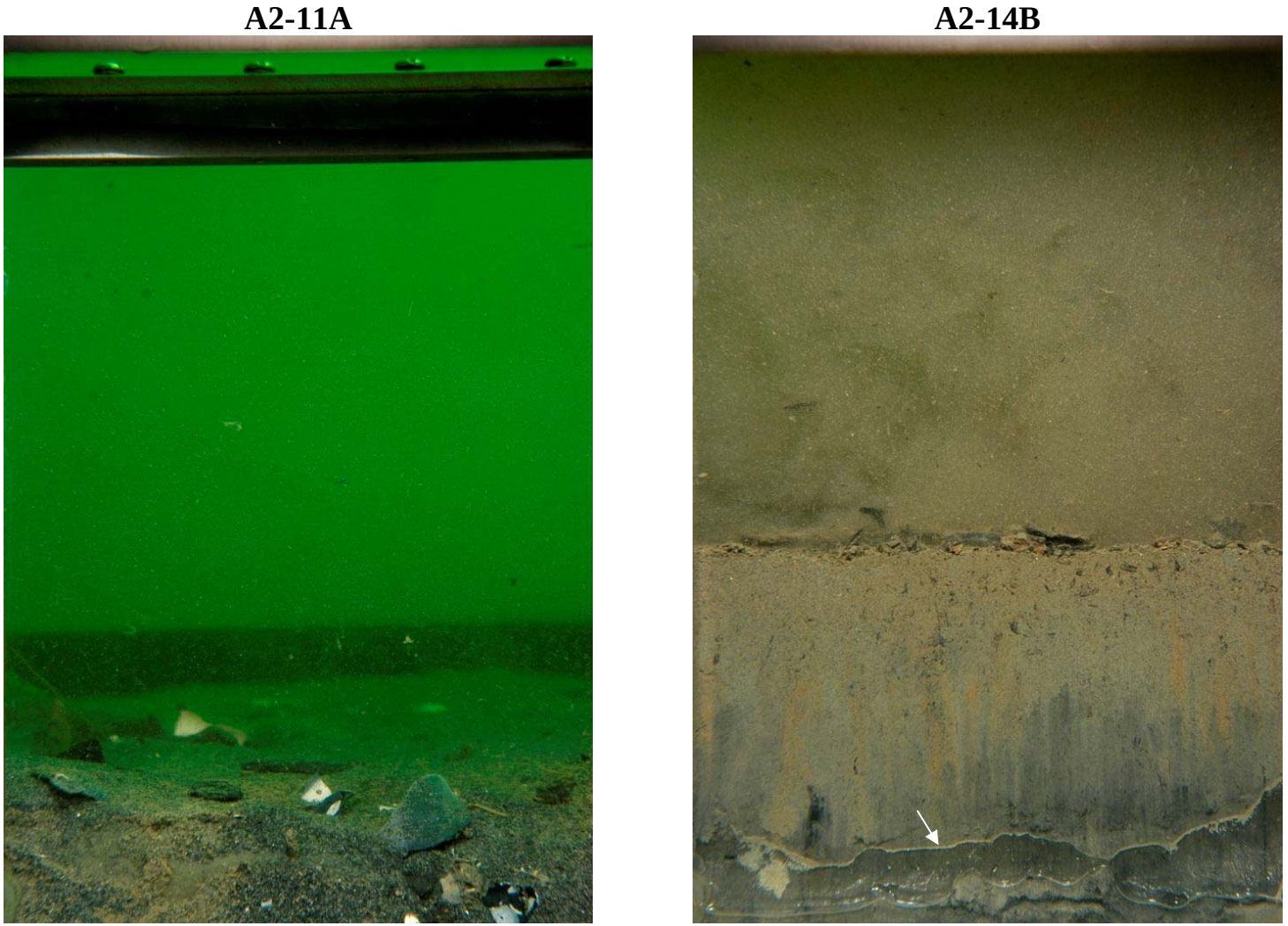
Figure 3-5. SPI and plan view images from station A1-07

A2-30C (SPI) **A2-30 (Plan View)**



SPI and plan view images from surface sediments near the former Weyerhaeuser Mills C and D site in the Snohomish River. The SPI image shows small weathered wood and bark chips mixed within the surface sediments. The wood debris represents approximately 15 percent by area. The plan view image shows less accumulation of wood debris on the sediment surface. Scattered wood particles (approximately three percent by area) and shell particles are present on sandy surface sediments.

Figure 3-6. SPI and plan view images from station A2-30



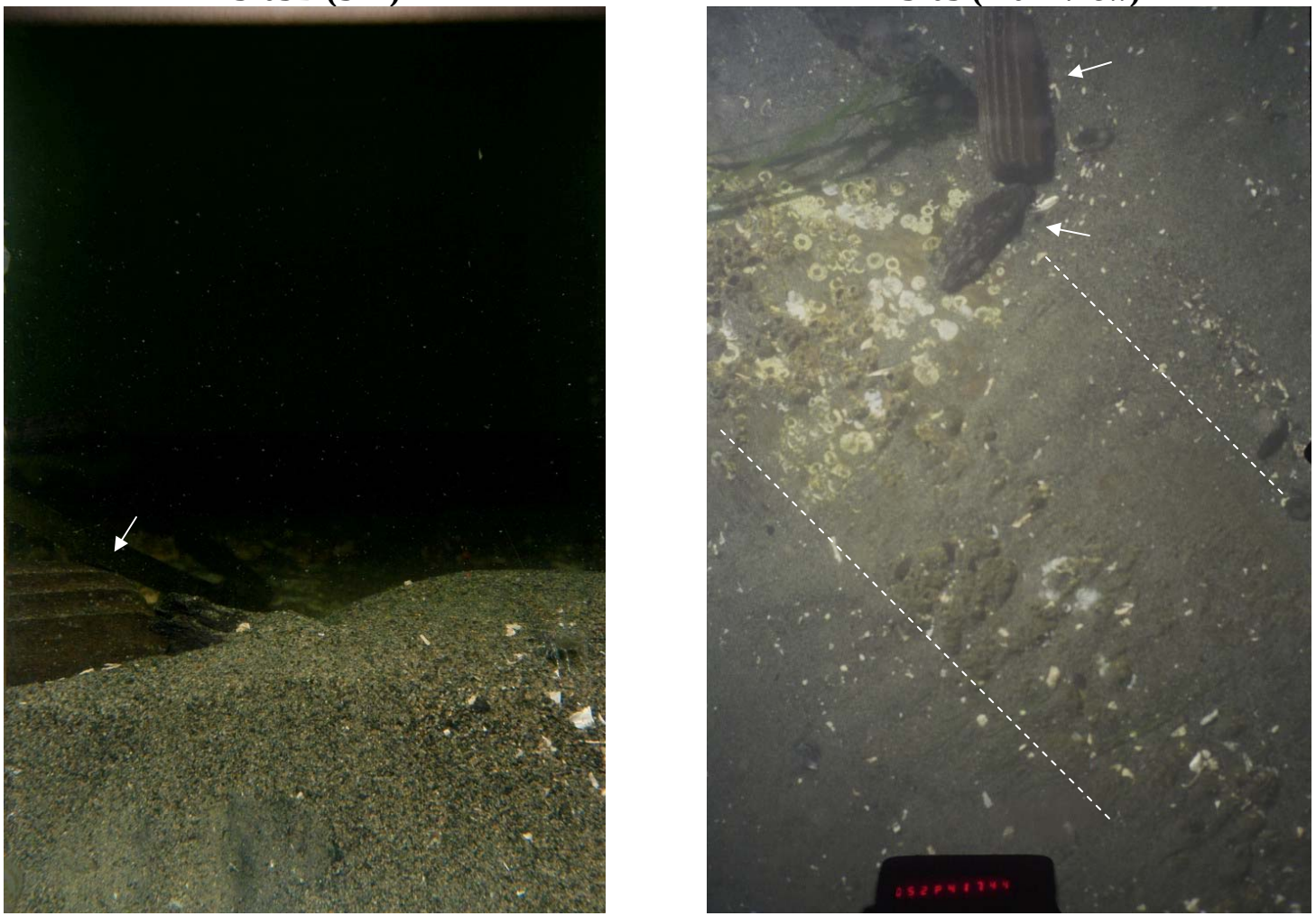
SPI images showing small accumulations of wood debris along the lower Snohomish River. Station A2-11A, located at the entrance to the Port of Everett Marina, shows small weathered wood pieces (approximately seven percent by area) on sandy surface sediments. At station A2-14B, just to the north of the Port of Everett public boat launch, fine wood particles (approximately five percent by area) are visible in the upper three centimeters of the sediment column. A large methane gas bubble (arrow) is present across the bottom of the image.

Figure 3-7. SPI images from stations A2-11A and A2-14B

Wood debris was visible in scattered low lying areas of the Maulsby mud flats, east of Jetty Island. This photograph was taken near station A2-18B, where clam tissues were collected for chemical analysis. During tissue collection, abundant wood debris was encountered in underlying sediments.

Figure 3-8. Photograph of Maulsby Mud Flats East of Jetty Island, Snohomish River

A3-03B (SPI) **A3-03 (Plan View)**



SPI and plan view images from station A3-03 in Steamboat slough. The SPI image shows a piece of weathered wood debris (approximately 10 percent by area) on the sediment surface (arrow). Surface sediments consist of medium sand with scattered shell particles. The plan view image shows two pieces of weathered wood near the top of the image (arrows). A large log previously encrusted with barnacles (between dashed lines) may be buried within the center of the plan view image. Wood debris is estimated at 25 percent by area in the plan view image.

Figure 3-9. SPI and plan view images from station A3-03

A3-05B (SPI) **A3-05 (Plan View)**

SPI and plan view images from station A3-05 in Steamboat slough. The SPI image shows wood fragments and weathered particles (approximately 5 percent by area) on the sediment surface (arrows). Surface sediments consist of medium to coarse sand with scattered shell particles. The plan view image shows a large wood piece and accumulation of smaller wood particles on the sediment surface. Wood debris is estimated at 20 percent by area in the plan view image.

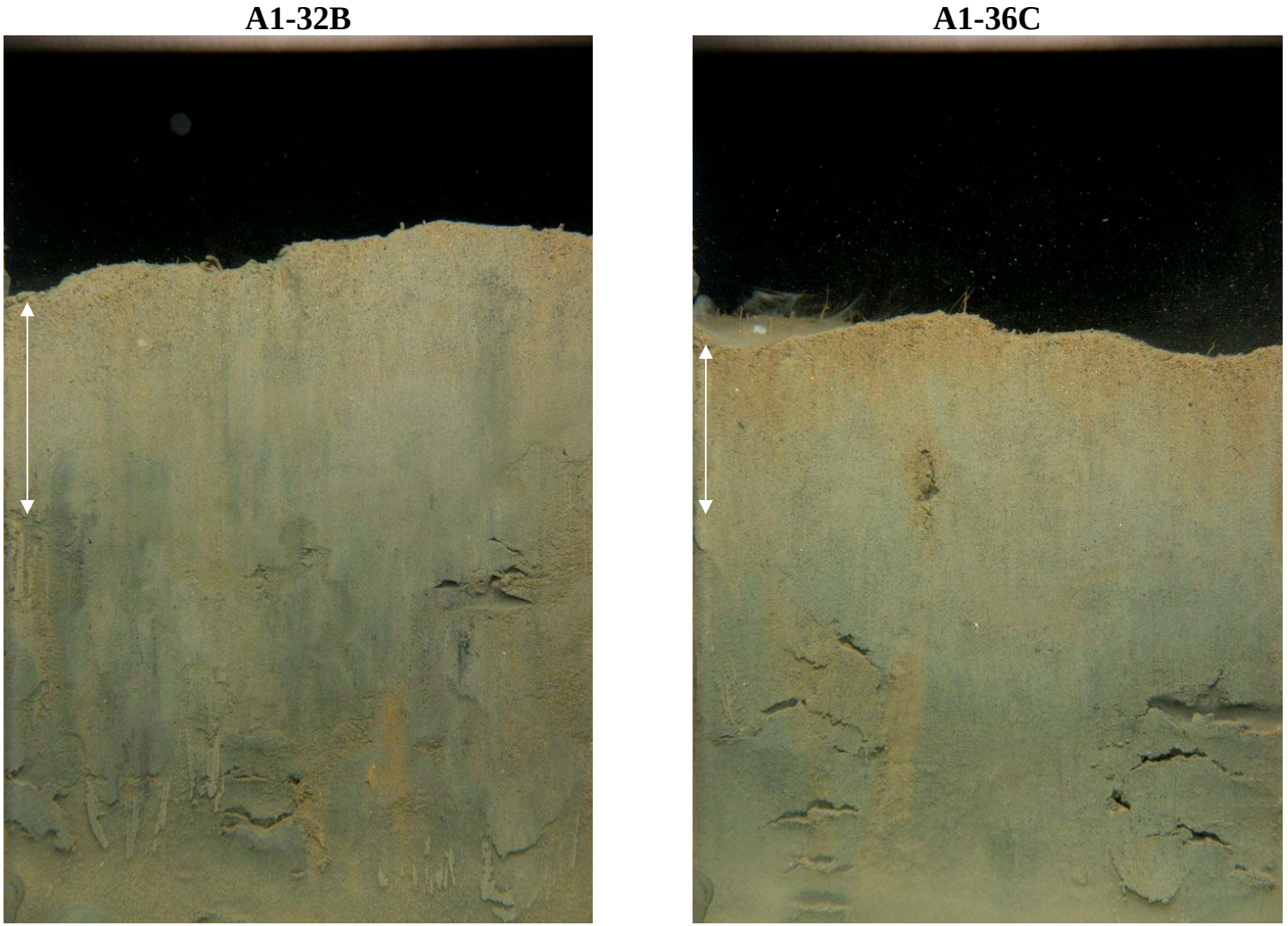
Figure 3-10. SPI and plan view images from station A3-05

3.1.2 Grain Size Major Mode

The sediment grain size major mode, in phi units, was visually determined from the SPI images by comparison with grain size scales included in the image analysis software interface. The grain size comparator is a series of seven Udden-Wentworth size classes (equal to or less than coarse silt up to granule and larger sizes): ≥ 4 phi (silt/clay), 4 to 3 phi (very fine sand), 3 to 2 phi (fine sand), 2 to 1 phi (medium sand), 1 to 0 phi (coarse sand), 0 to -1 phi (very coarse sand), and <-1 phi (gravels). The sediment grain size major mode in Port Gardner varied by location (Figure 3–11). In Focus Area 1, sediments within the East Waterway consisted primarily of dark to dark gray silts and clays (> 4 phi) (see Figures 3–3 through 3–5). In southern Port Gardner, sediment grain size major mode varied by water depth. Near shore areas consisted primarily of fine to medium sands (3 to 2 phi and 2 to 1 phi, respectively), with some areas of coarse sand (1 to 0 phi). Deeper offshore areas had higher concentrations of silts and clays (Figure 3–12).

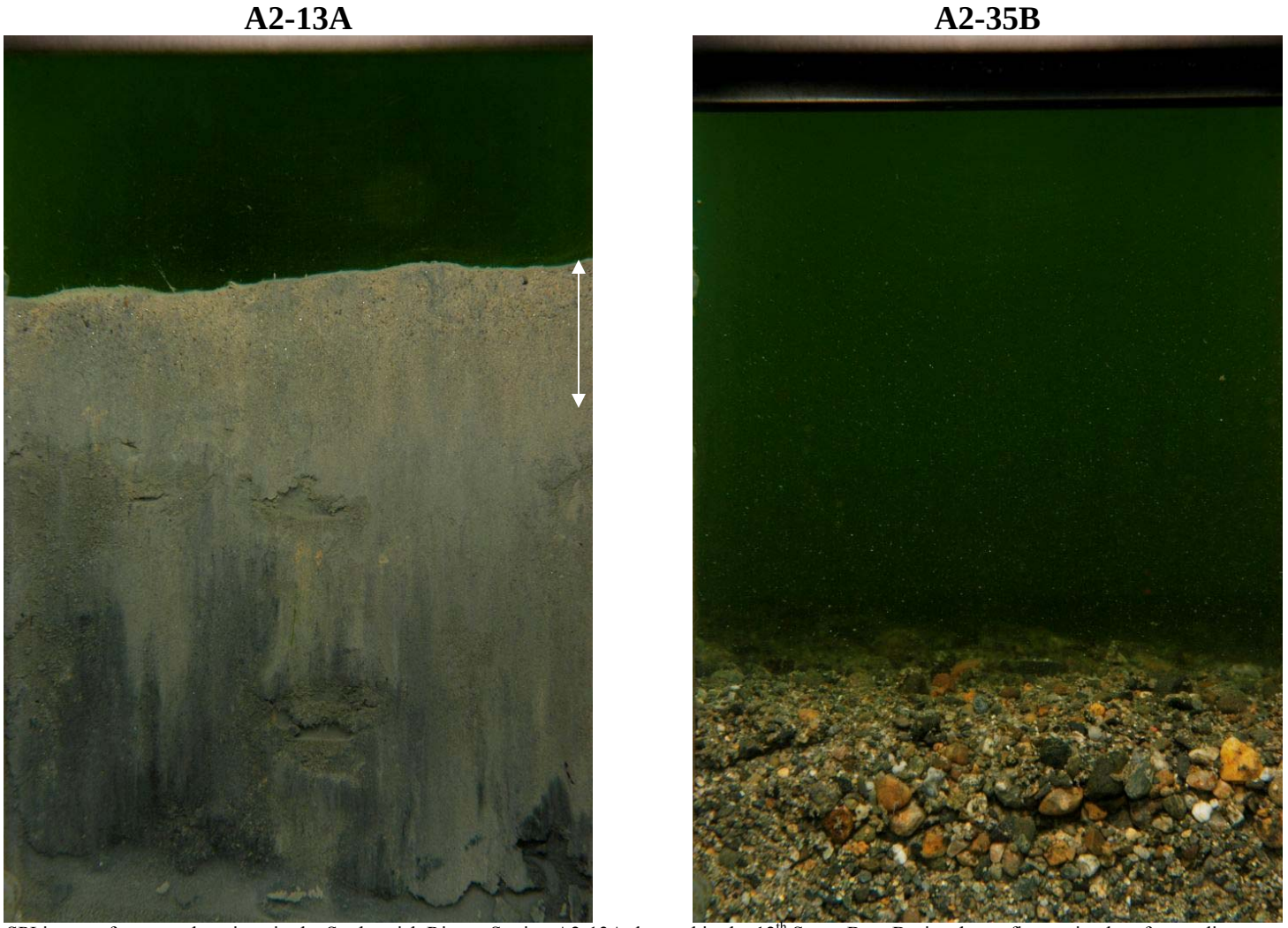
In Focus Areas 2, 3, and 4 (Snohomish River and delta, Steamboat slough, and Ebey slough, respectively), fine and medium sands dominate the surface sediments. Three locations in the Snohomish River (A2-13 in the 12th Street Boat Basin; A2-15 and A2-16 in the mud flats north of the Port of Everett Marina) were in depositional areas and had surface sediments consisting of silts and clays (> 4 phi). In addition, three locations in the Snohomish River (A2-09, A2-35B, and A2-37), sediments were classified as < -1 phi (gravels or larger) due to the presence of strong bottom currents in these areas (Figure 3–13).

Figure 3−11. Grain Size Major Mode Distribution in Port Gardner



SPI images showing tan to gray, fine-grained surface sediments in deeper offshore areas in southern Port Gardner. Both stations show relatively deep camera prism penetration, deep apparent RPD depths (arrows), evidence of Stage I tubes on the sediment surface, and Stage III infauna evidenced by subsurface feeding voids.

Figure 3-12. SPI images from stations A1-32B and A1-36C



SPI images from two locations in the Snohomish River. Station A2-13A, located in the 12th Street Boat Basin, shows fine grained surface sediments. The mean apparent RPD depth is 2.92 cm (arrow) and Stage I surface tubes and Stage III feeding voids are present, indicating a Stage I on III infaunal successional stage. Station A2-35B is located south of Ferry Baker Island and shows the presence of gravels and coarse sands, suggesting the presence of strong bottom currents.

Figure 3-13. SPI images from stations A2-13A and A2-35B

3.1.3 Apparent RPD Depth

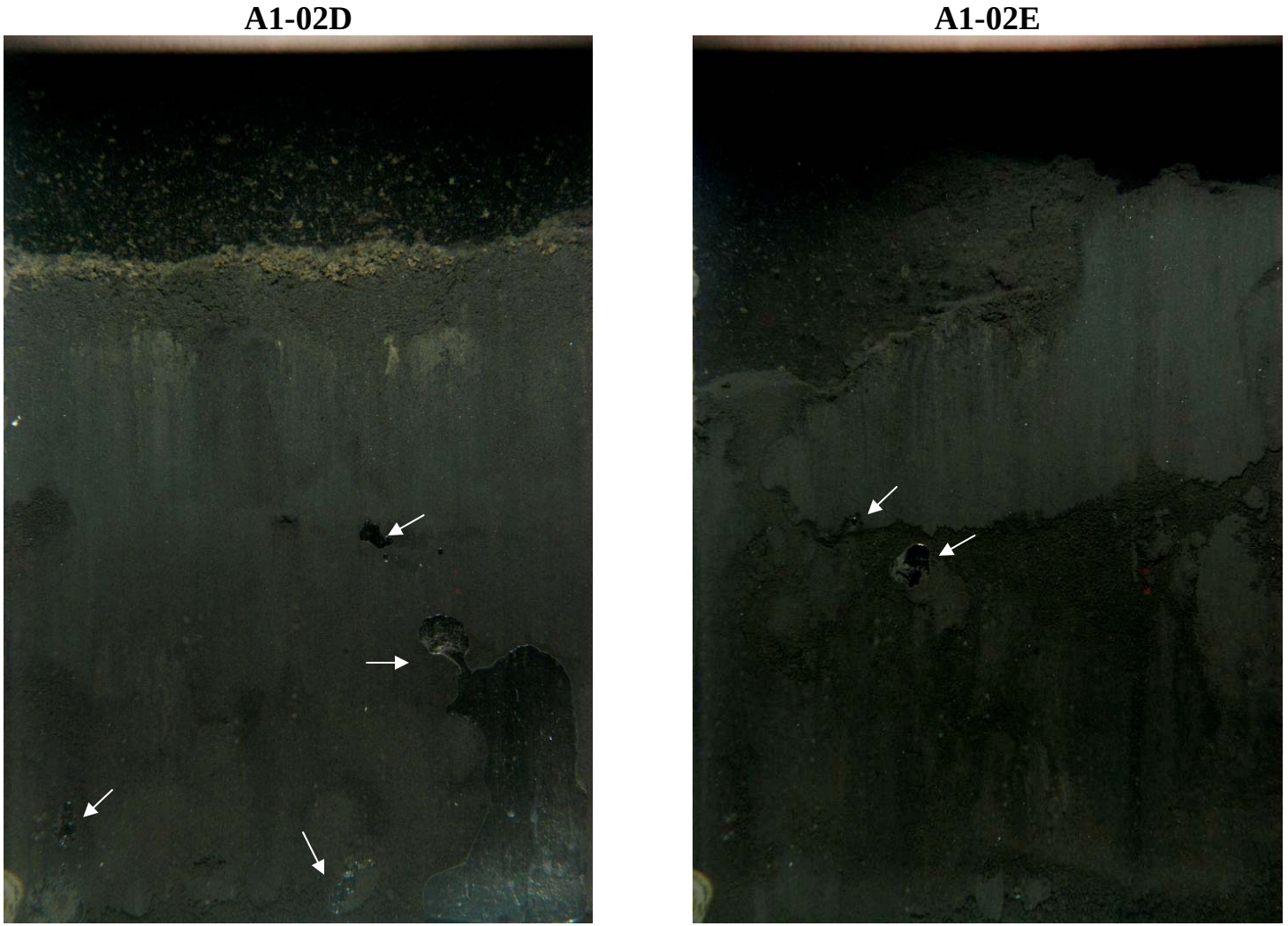
Apparent RPD depth estimates the depth of oxygenation in the upper sediment column and generally reflects the degree of biogenic sediment mixing. The upper surface of aerobic fine-grained sediments has a higher light reflectance value than underlying hypoxic or anoxic sediments. This is apparent in SPI images and is due to oxidized surface sediment that contains minerals in an oxidized state (typically an olive or tan color), while the reduced sediments below this oxygenated layer are generally gray or black. The apparent RPD depth provides an estimate of the biogenic sediment mixing depth because bioturbating organisms mix the oxidized sediment particles downward into the sediment column.

The distribution of mean apparent RPD depths in Port Gardner ranged from 0.3 cm at station A1-02 in the East Waterway, to a high of 9.8 cm at station A3-01 near the confluence of the Steamboat and Ebey sloughs (Figure 3–14). The mean apparent RPD depth for Port Gardner was 2.96 cm.

The shallowest apparent RPD depths (less than 2.0 cm) were measured in the East Waterway, the area of greatest wood debris accumulation (Focus Area 1). Several locations show high apparent RPD contrast relative to the underlying anoxic sediments (see Figures 3–3 through 3–5). High RPD contrast is often related to high inputs of organic-rich material (e.g., wood debris, dredged material, phytoplankton detritus), which increases sediment oxygen demand and results in more highly reduced sediments at depth. Station A1-02 was classified as azoic, with almost no discernable apparent RPD depth (Figure 3–15). The mean apparent RPD depth in the East Waterway was 1.63 cm.

Relatively deep apparent RPD depths were measured in Steamboat and Ebey sloughs, parts of the Snohomish River, and the northern portion of the delta (Figure 3–14). The mean apparent RPD depths in Steamboat slough (Focus Area 3) and Ebey slough (Focus Area 4) were 4.30 cm and 4.11 cm, respectively. Unconsolidated coarse grained sediments and active sediment transport are present in these areas, and can result in deeper apparent RPDs. In this environment, hydrodynamic processes increase the depth of oxygenation in the sediment column, rather than biogenic sediment mixing. This is the case at several locations (Figure 3–16).

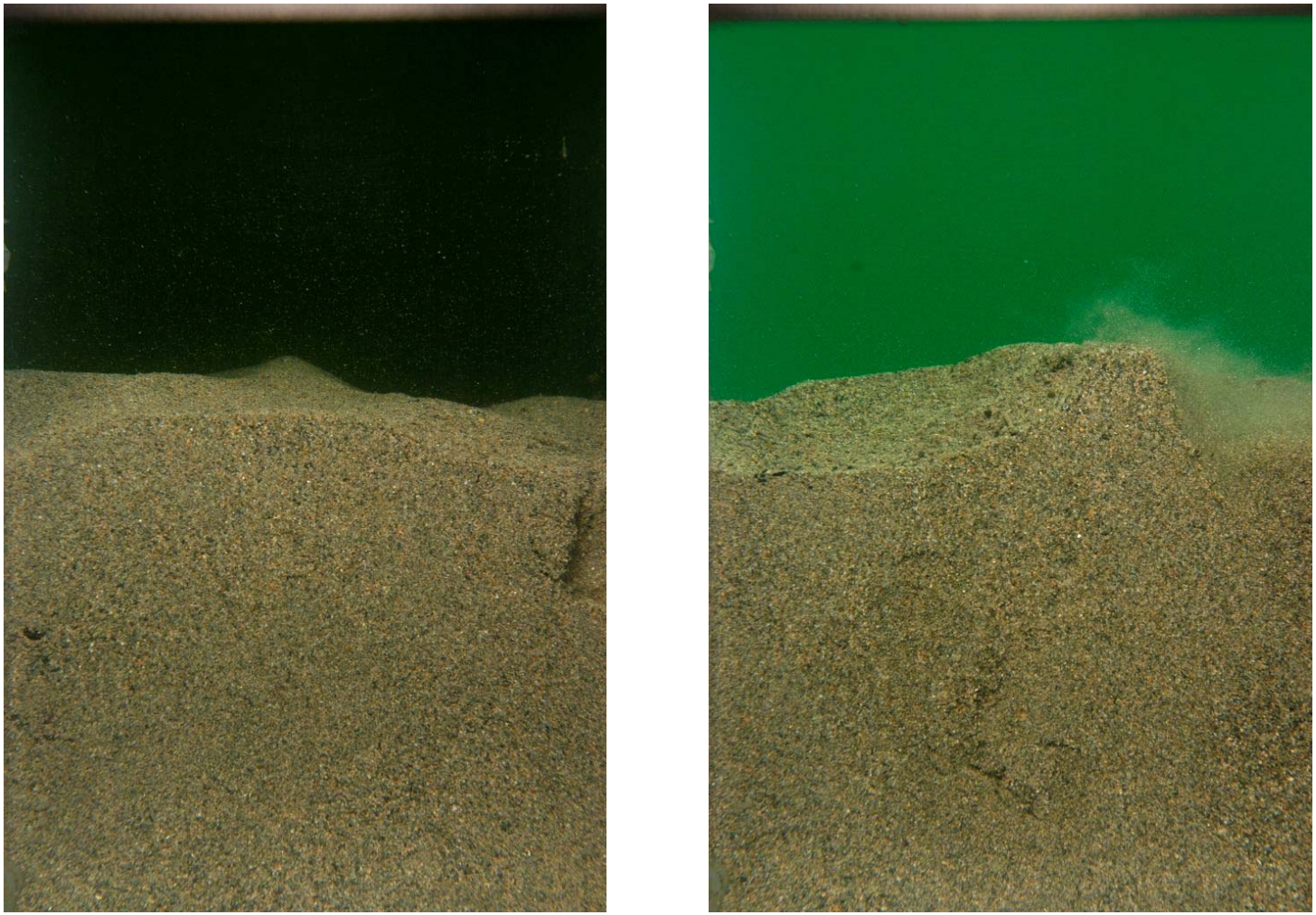
Figure 3−14. Apparent RPD Depths in Port Gardner



SPI images from station A1-02 (Replicates D and E) located in the upper East Waterway. Both images show black, highly reduced, fine grained sediments devoid of infaunal organisms (azoic classification). Replicate D shows a very thin RPD (0.16 cm) and several methane gas bubbles at depth (arrows). Replicate E shows no apparent RPD depth and methane bubbles are also present depth (arrows).

Figure 3-15. SPI images from station A1-02

A3-01A **A4-02A**



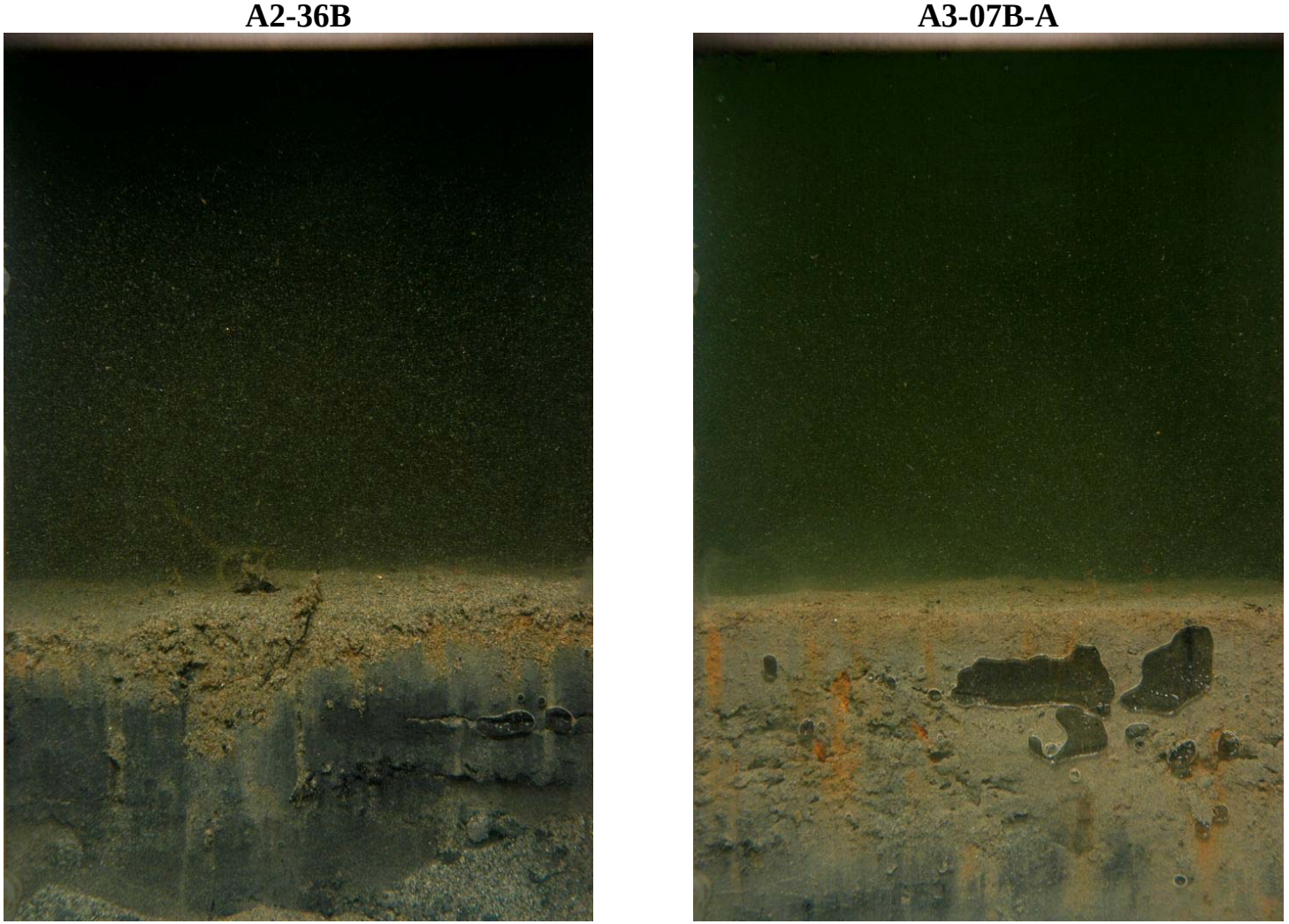
SPI images from the Steamboat slough (A3-01A) and the Snohomish River delta (A4-02A) showing light tan to gray, clean, medium sands in the Snohomish River. Camera prism penetration is relatively deep at both locations, suggesting relatively unconsolidated sandy sediments. Ripples/bedforms are visible on the sediment surface suggesting active sediment transport. The mean apparent RPD depths at these locations were classified as deeper than prism penetration due to hydrodynamic processes.

Figure 3-16. SPI images from stations A3-01A and A4-02A

3.1.4 Sedimentary Methane

Sedimentary methane bubbles were observed at six locations during the SPI survey in Port Gardner (A1-02, A1-06, A1-21, A2-14, A2-36, A3-07B, and A4-07) (Figure 3–17). At these locations, organic enrichment has resulted in oxygen depletion in sediment pore waters and anaerobic reactions have taken over. The result is the release of hydrogen sulfide and methane gas. In the East Waterway (A1-02, A1-06, A1-21), the organic enrichment is likely related to wood debris from current and historical log storage, pulp, and paper industries. In the Snohomish River and Steamboat and Ebey sloughs, the organic enrichment appears related to natural inputs from the river systems (e.g., leaf litter, plant and wood debris), although wood debris from anthropogenic sources may also contribute to the organic enrichment (Figure 3–18).

Figure 3–17. Methane Gas Observed in Port Gardner SPI Images



SPI images from the Snohomish River (A2-36B) and Steamboat slough (A3-07B-A) showing methane gas bubbles in surface sediments. Station A2-36B, located in the Snohomish River in the vicinity of the former Riverside Chip/Mill storage area, shows a layer of reduced silt/clay between tan to gray sand. Station A3-07B-A, located near the Hanson Boat Company on Steamboat slough, shows tan to gray sandy silt with areas of orange/brown sediment staining.

Figure 3-18. SPI images from stations A2-36B and A3-07B-A

3.1.5 Infaunal Successional Stage

Benthic infaunal communities generally follow a three-stage succession following a disturbance of the seafloor (Figure 3–19) (Pearson and Rosenberg 1978; Rhoads and Germano 1986). Stage I infauna are typically the first organisms to colonize the sediment surface. These opportunistic organisms may consist of small, tubicolous, surface-dwelling polychaetes. Stage II organisms are typically shallow-dwelling bivalves or tube-dwelling amphipods. Stage II communities are considered a transitional community before reaching Stage III, the high-order successional stage consisting of long-lived, infaunal deposit-feeding organisms. Stage III infauna consist of large, deep-burrowing infauna (e.g., maldanid and pectinid polychaetes, *Molpadia intermedia* sea cucumbers) that feed in a head-down orientation. This localized feeding activity results in distinctive excavations called "feeding voids." Diagnostic features of these feeding structures include a generally semicircular shape with a flat bottom and arched roof, and contain coarse sediment that are rejected by the infauna during the feeding process.

The majority of infaunal successional stages observed in SPI images collected in Port Gardner were Stage I (65 percent), followed by Stage I on III (31 percent), and azoic (one percent) (Figure 3–20). Stage I taxa can persist, as they are opportunistic feeders, and are commonly associated with a Stage III community (Rhoads and Germano 1986). Infaunal successional stage was indeterminate at two locations (2 percent) due to the presence of a hard or rocky substrate (A2-09 and A2-37).

A gradient of successional stage was observed in the East Waterway, likely due to impacts from wood debris accumulation (Figure 3–20). Station A1-02, in the northern end of the East Waterway was classified as azoic, with infaunal organisms absent in surface sediments (see Figure 3–15). Stage I communities were observed in the central and inner portions of the East Waterway. Stage III communities, evidenced by feeding voids, were observed at the entrance to the East Waterway, and in the deeper regions to the south in Port Gardner Bay (see Figure 3–12).

In sandy substrates, such as the majority of locations in Port Gardner (southern Port Gardner Bay, Snohomish River and delta, Steamboat and Ebey sloughs), the climax communities may consist primarily of surface dwellers (e.g., amphipods) that reside in the upper 1 cm of the sediment surface and have few, if any, naturally burrowing community members. 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 deeper areas in southern Port Gardner.

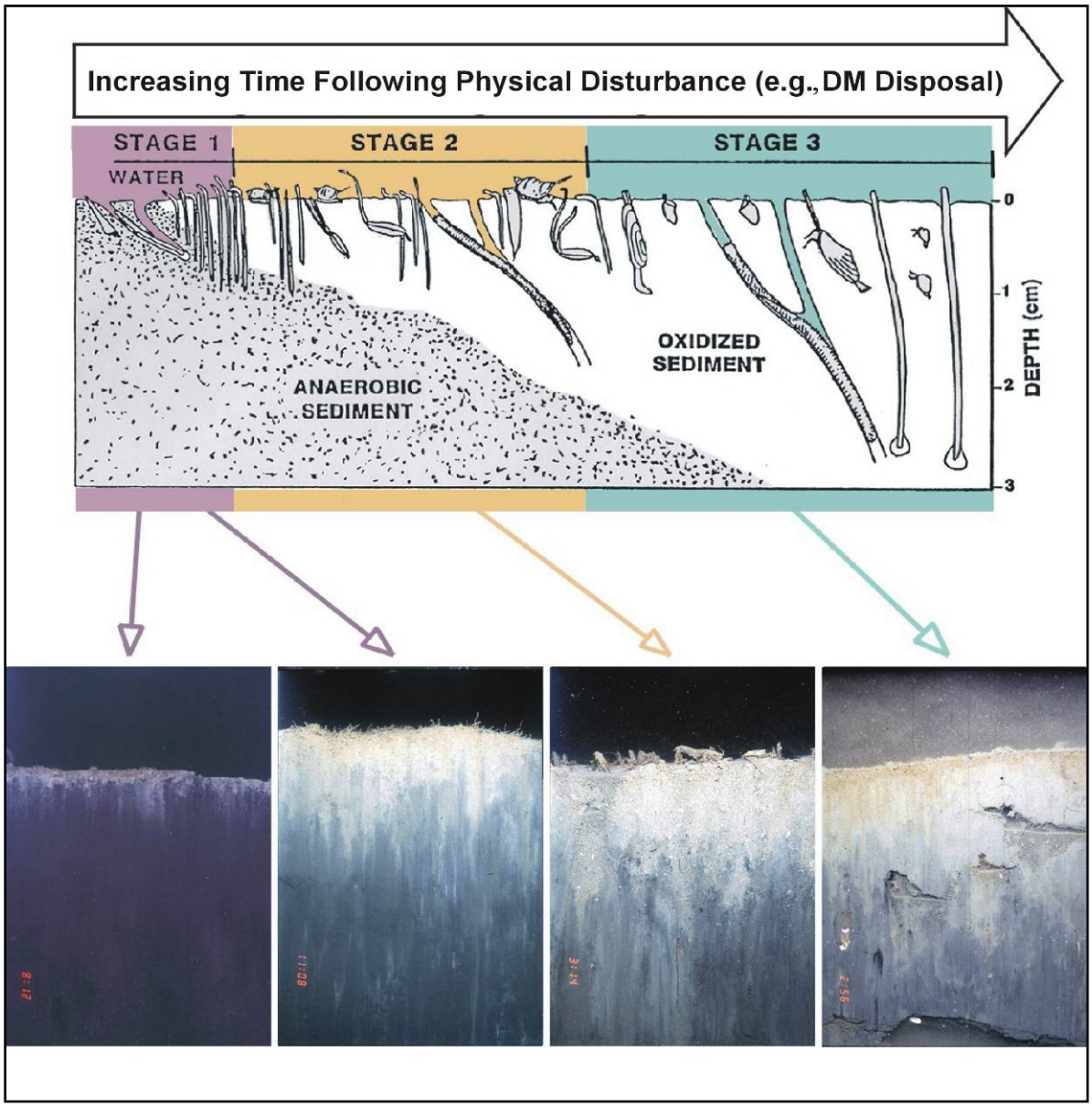


Figure 3-19. Idealized Development of Infaunal Succession Stages Over Time Following a Physical Disturbance with Example SPI Images

Figure 3−20. Infaunal Successional Stage in Port Gardner

3.1.6 Organism-Sediment Index

The OSI provides a measure of general benthic habitat quality based on dissolved oxygen (DO) conditions, depth of the apparent RPD, infaunal successional stage, and presence or absence of sedimentary methane (Rhoads and Germano 1986). The OSI is a numerical index ranging from -10 to +11 (Table 3–1). The lowest OSI value is given to bottom sediments with low or no DO in the overlying bottom water, no apparent macrofaunal life, and methane gas present in the sediment. High OSI values are given to aerobic bottom sediments with a deep apparent RPD, mature macrofaunal community, and no methane gas. An OSI value of +6 or higher is generally considered indicative of undisturbed, healthy benthic habitat conditions.

The distribution of OSI values is presented in Figure 3–21. Mean OSI values ranged from -7 to +11 in Port Gardner and an OSI value of +6 or greater was observed at 50 percent of the locations. East Waterway had the highest proportion of OSI values less than +6 (18 of 22 locations; 82 percent). The lowest OSI value (-7) was recorded at station A1-02, due to the low DO conditions, little to no RPD depth, no apparent macrofaunal life, and presence of methane (see Figure 3–15). Shallow RPD depths were the main contributor to low OSI values in the East Waterway.

OSI values less than +6 were also observed in near shore areas along southern Port Gardner, and in various locations within the Snohomish River and delta, Steamboat, and Ebey sloughs. The presence of methane at four locations (A2-14, A2-36, A3-07B, and A4-07) contributed to low OSI values. However, these areas also have higher concentrations of sand in surface sediments. The OSI was developed for assessing general benthic habitat quality in soft-bottom subtidal sediments (Rhoads and Germano 1986) and may not accurately characterize habitat quality for sandy sediments in shallow or intertidal areas, or areas heavily influenced by river systems.

Table 3-1. Calculation of the Organism- Sediment Index

Choose One Value:	
Mean RPD Depth Classes	**Index Value**
0.00 cm	0
>0 – 0.75 cm	1
0.76 – 1.50 cm	2
1.51 – 2.25 cm	3
2.26 – 3.00 cm	4
3.01 – 3.75 cm	5
>3.75 cm	6
Choose One Value:	
Successional Stage	**Index Value**
Azoic	- 4
Stage I	1
Stage I - II	2
Stage II	3
Stage II – III	4
Stage III	5
Stage I on III[1]	5
Stage II on III[1]	5
Choose One or Both if Appropriate:	
Chemical Parameters	**Index Value**
Methane Present	- 2
No/Low Dissolved Oxygen[2]	- 4
Organism – Sediment Index =	**Total of Above Subset Indices (Range: - 10 + 11)**

Notes:

1. Stage I taxa can persist, as they are opportunistic feeders and are commonly associated with Stage III community (Rhoads and Germano 1986). Similarly, in the transition from Stage II to Stage III both taxa can be present resulting in a Stage II or III classification.
2. No/low dissolved oxygen is based on the imaged evidence of reduced, low reflectance (i.e., high oxygen demand) sediment at the sediment-water interface. It is not a chemical measurement using Winkler titration or polargraphic electrode.

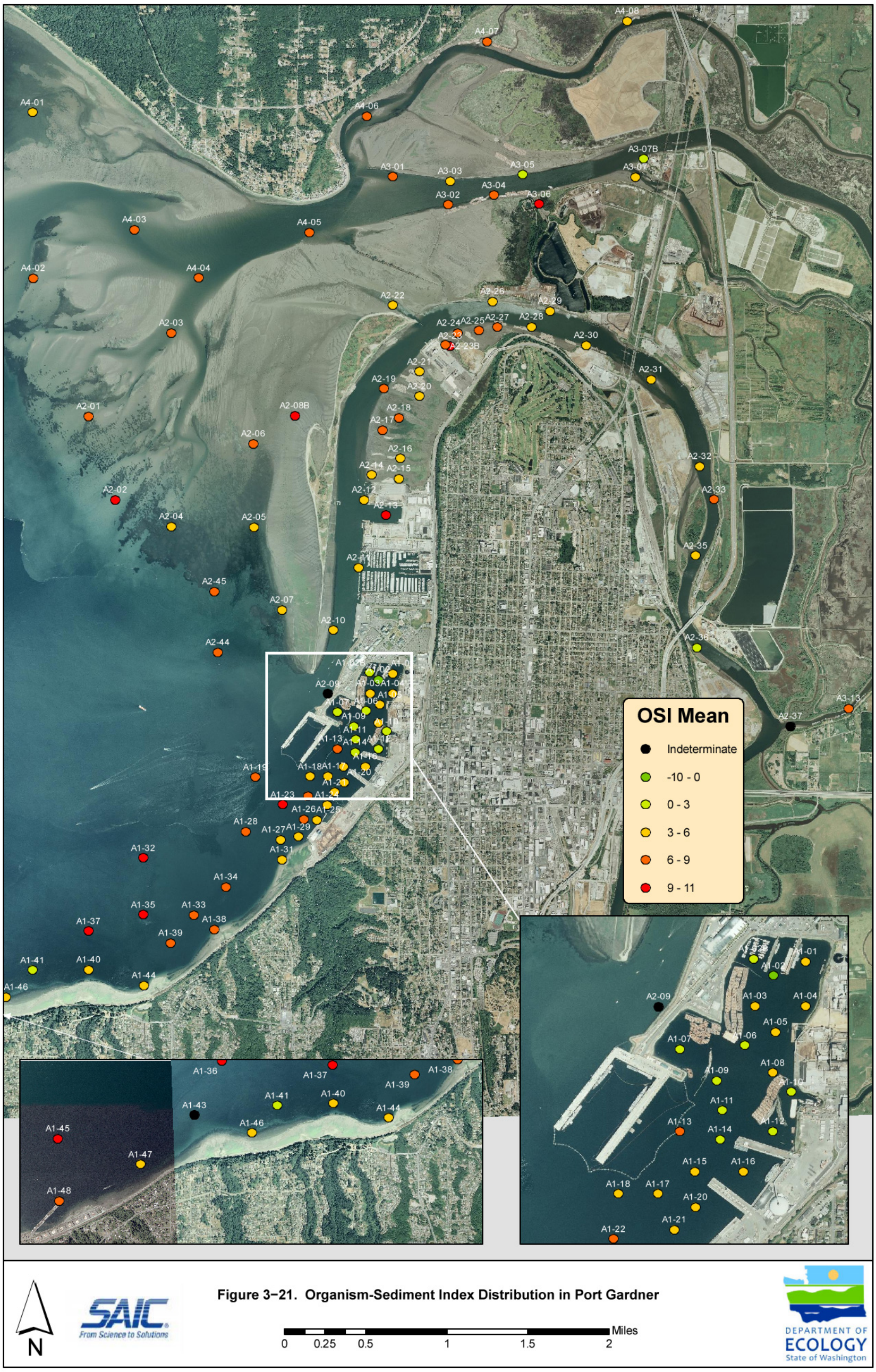


Figure 3−21. Organism-Sediment Index Distribution in Port Gardner

3.1.7 Benthic Habitat Type

The benthic habitat categories determined from SPI images are based on the physical substrate type, the infaunal successional stage present, and the presence or absence of epifauna (Diaz 1995). The categories are organized by sediment type and include hard sand bottom, hard rock or gravel bottom (HR), and unconsolidated soft bottom. In addition, a separate category is provided for the presence of amphipod tube mats (*Ampelisca* spp.) at the sediment-water interface. The full list of categories and descriptions is provided in Table 3–2. Example SPI images showing benthic habitat categories observed in Port Gardner are provided in Figure 4.

The benthic habitat classifications generally followed the grain size major mode distribution measured from SPI images (Figure 3–22). The highest number of locations were classified as UN.SF (50 percent), consisting of unconsolidated silt and clay sediments (> 4 phi) and was the dominant classification in Focus Area 1 and in depositional areas in the Snohomish River and Steamboat slough. Silty unconsolidated soft bottom (UN.SI) and sandy/silty unconsolidated soft bottom (UN.SS) were also observed at one percent and three percent of the locations, respectively.

Hard sandy bottom consisting of fine sand (SA.F), medium sand (SA.M) and medium sandy with gravel (SA.G) were observed at 42 percent of the locations. Hard sandy bottom classifications were found in near shore areas in southern Port Gardner, and in the Snohomish River, Steamboat, and Ebey sloughs. Four locations (A1-05, A2-09, A2-37, A3-05) were classified with a hard rock or gravel bottom (HR). One location near the former fuel depot pier in Mukilteo (A1-48) was classified as a shell bed over silty sediment (SH.SI). In addition, six locations exhibited the presence of eelgrass (*Zostera* sp.). Intact eelgrass beds were observed at one location in southern Port Gardner Bay (A1-46), in the southern (A2-04, A2-05, and A2-07) and northern (A4-01) portions of the Snohomish River delta, and at one location in Steamboat slough (A3-02).

Table 3-2. Benthic Habitat Categories Assigned to Sediment Profile Images

Habitat AM: *Ampelisca* Mat Uniformly fine-grained (i.e., silty) sediments having well-formed amphipod (*Ampelisca* spp.) tube mats at the sediment-water interface.
Habitat SH: Shell Bed A layer of dead shells and shell fragments at the sediment surface overlying sediment ranging from hard sand to silts. Epifauna (e.g., bryozoans, tube-building polychaetes) commonly found attached to or living among the shells. Two distinct shell bed habitats: **SH.SI: Shell Bed over silty sediment—**shell layer overlying sediments ranging from fine sands to silts to silt-clay. **SH.SA: Shell Bed over sandy sediment**—shell layer overlying sediments ranging from fine to coarse sand.
Habitat SA: Hard Sand Bottom Homogeneous hard sandy sediment, does not appear to be bioturbated, bedforms common, successional stage mostly indeterminate because of low prism penetration. **SA.F: Fine sand**—uniform very fine sand (4 to 3 phi) or fine sand sediments (3 to 2 phi). **SA.M: Medium sand**—uniform medium sand sediments (grain size: 2 to 1 phi). **SA.G: Medium sand with gravel**—predominately medium to coarse sand with a minor gravel fraction.
Habitat HR: Hard Rock/Gravel Bottom Hard bottom consisting of pebbles, cobbles, and/or boulders, resulting in no or minimal penetration of the SPI camera prism. Some images show pebbles overlying silty sediments. The HR surfaces are typically covered with epifauna (e.g., bryozoans, sponges, tunicates).
Habitat UN: Unconsolidated Soft Bottom Fine-grained sediments ranging from very fine sand to silt-clay, with a complete range of successional stages (I, II, and III). Biogenic features may be common (e.g., amphipod and polychaete tubes at the sediment surface, small surface pits and mounds, large burrow openings, and feeding voids at depth). Several sub-categories: **UN.SS: Fine Sand/Silty**—very fine sand mixed with silt (grain size range from 4 to 2 phi), with little or no shell hash. **UN.SI: Silty**—homogeneous soft, silty sediments (grain size range from >4 to 3 phi), with little or no shell hash. Generally deep prism penetration. **UN.SF: Very Soft Mud**—very soft muddy sediments (>4 phi) of high apparent water content and deep prism penetration.

Source: Diaz 1995

Figure 3−22. Benthic Habitat Classifications in Port Gardner

3.2 Subsurface Video Probe Results

Video probe data were used to determine the vertical extent of woody debris in the upper 6 feet of the sediment column. Video probes were conducted at 44 different locations throughout the four focus areas (Figure 3–23). Percent wood debris (proportional estimate) was determined for each 0.5 foot interval and data plots are provided in Figure 3–24. Focus Area 2 had the greatest average amount of woody debris (average of 14 percent), followed by Focus Area 3 (6.9 percent), Focus Area 1 (4.2 percent), and Focus Area 4 (2.1 percent) for all depth intervals sampled in each area. Average percent woody debris was determined for the entire video probe (0 to 6 feet), unless specified otherwise below. Within Focus Areas 1 and 2, woody debris was dominantly found in the upper 3 feet of the sediment column. However woody debris was generally absent or sparse in the upper 3 feet of the sediment column within Focus Areas 3 and 4.

3.2.1 Focus Area 1

Sediment video probes were conducted at 18 locations within Focus Area 1. Woody debris found in the upper 6 feet of the sediment column (0.5 foot intervals) ranged from 0 to 50 percent, with an average of 4.2 percent. Overall, Focus Area 1 has a heterogeneous dispersal of sedimentary woody debris both spatially and with depth. Woody debris was often concentrated in "mats" greater than one foot thick, however some sediment intervals were found to be wood free. In the East Waterway, the majority of woody debris was observed at locations farthest from the entrance and closest to the shoreline. In contrast, the central channel of the East Waterway contained little woody debris. Sampling location A1-16 had the greatest average percentage of woody debris (13.7 percent), with large wood fragments (>3 cm) encountered at the surface and 3.0 feet below mudline. The lowest amount of woody debris (<1 percent) were observed at A1-02B and A1-17, where small wood fragments (<0.5 cm) were present. At 13 of the 18 locations within Focus Area 1, the upper 3 feet of sediment contained a greater amount of woody debris than the 3 to 6 foot interval. Four of the five locations with a greater amount of woody debris in the 3 to 6 foot interval are located at the head of the East Waterway.

3.2.2 Focus Area 2

Sediment video probes were conducted at 18 locations within Focus Area 2. Woody debris found in the upper 6 feet of the sediment column ranged from 0 to 95 percent, with an average of 14 percent. At all five stations located in the Maulsby mud flat region north of the Port of Everett Marina (A2-14, -16, -18, -20, and -21), full penetration of the video probe was impeded by large fragments of woody debris. These locations and station A2-11 had the greatest average percentage of woody debris (25 to 39 percent). Virtually no woody debris was found at sampling locations within the Snohomish River upstream of station A2-30, with the exception of station A2-37 at the junction of Steamboat Slough.

Figure 3-23. Percent Wood Debris with Depth Measured Using Video Probing

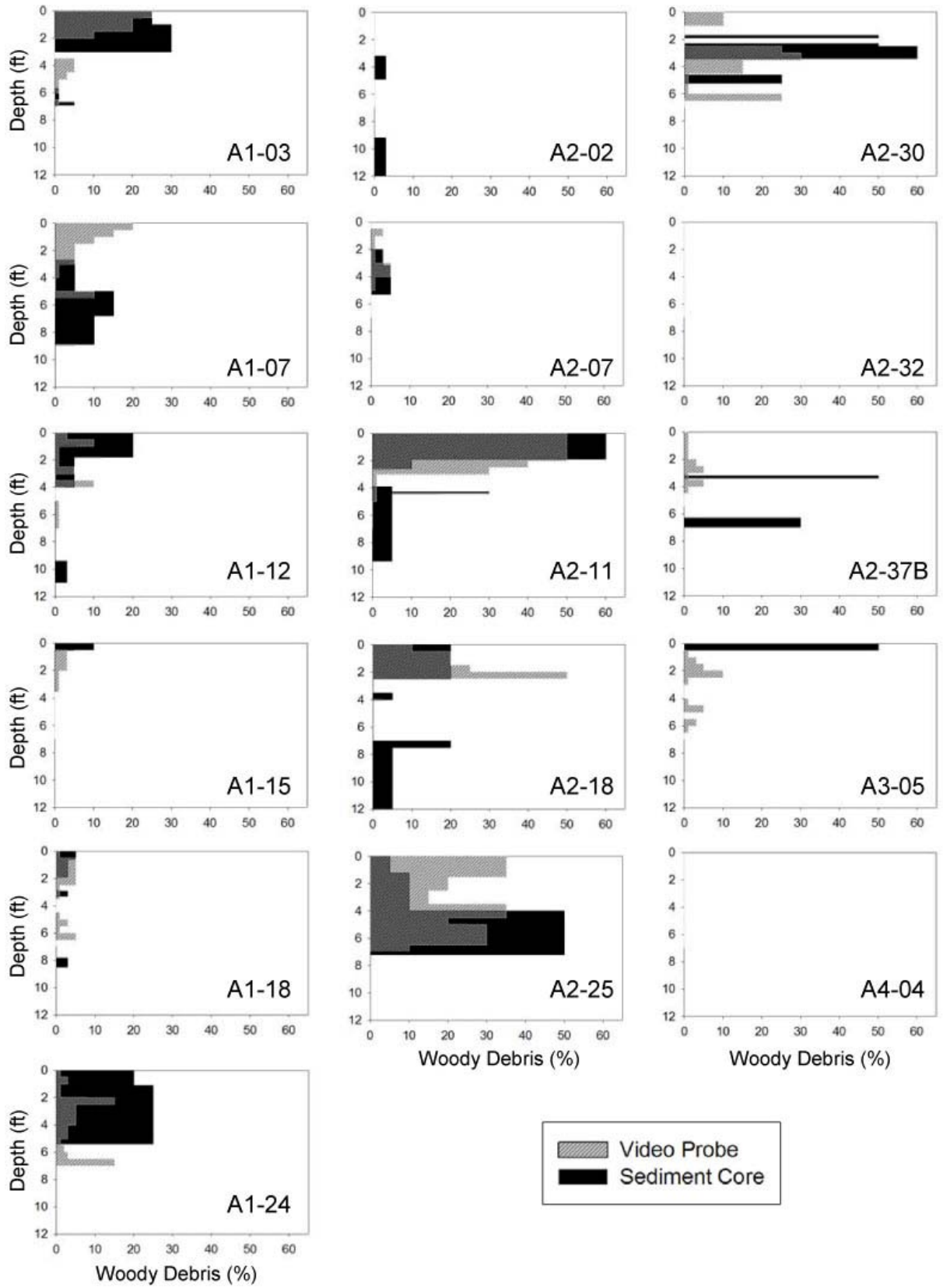


Figure 3-24. Comparison of Wood Debris between Video Probes and Core Samples

3.2.3 Focus Area 3

Sediment video probes were conducted at five locations within Focus Area 3. Woody debris found in the upper 6 feet of the sediment column ranged from 0 to 75 percent, with an average of 6.9 percent. The sampling location A3-07, located at the confluence of Steamboat and Union Sloughs, had the greatest average percentage of woody debris (15 percent), with large wood fragments encountered at 1.0 and 4.0 feet below mudline. The least average woody debris was observed at A3-05 (2.1 percent) consisting of small, loose wood fragments intermixed with shell hash from the surface to 6.0 feet below mudline. In general, the 3 to 6 foot interval of sediment in Focus Area 3 contained a greater amount of woody debris (8.6 percent) than the upper 3 feet (5.4 percent).

3.2.4 Focus Area 4

Sediment video probes were conducted at three locations within Focus Area 4. Woody debris found in the upper 6 feet of the sediment column ranged from 0 to 25 percent, with an average of 2.1 percent. No wood debris was found in the surface sediments within Focus Area 4. Location A4-05 had the greatest average percentage of woody debris (4.3 percent), consisting of scattered wood fragments found 3.0 to 6.0 feet below mudline. No woody debris was observed at location A4-04.

3.2.5 Evaluation of Woody Debris in Sediment Cores

Sixteen subsurface sediment cores were collected to visually confirm estimates of subsurface wood debris accumulation made with the video probe, as well as for chemical testing to determine whether chemical contaminants exceed SMS criteria (Sections 3.3 and 3.4).

Wood debris measured by the video probe was generally confirmed by the sediment cores (Figure 3–24). In general, the distribution of woody debris matched between the two methods with the exception of two scenarios: (1) when wood was present at the mudline during one sampling but not the other (e.g. A2-30, A3-05), and (2) when the deeper penetration of the sediment core revealed a more extensive wood layer than observed by the video probe (e.g. A1-07, A2-11). Sources of variability such as spatial heterogeneity, differences in visual identification, and differences in the observed diameter of area (1.5 inch diameter video probe versus 3.5 inch core barrel), may account for discrepancies between the two methods of estimating woody debris in nearby locations. Woody debris in the upper 6 feet of the sediment cores ranged from 0 to 60 percent. Wood debris consisted primarily of fibers and small pieces of wood or bark. As observed with the video probe, cores A2-11 and A2-25 had the greatest total amount of woody debris, while no woody debris was observed at locations A2-32 and A4-04.

3.3 Surface Sediment Chemistry

Fifty-two surface sediment samples were submitted for SMS chemistry analysis. Further analysis of dioxin/furan congeners was carried out on 15 of the samples. This section describes the sediment conventional parameters, SMS chemistry, and dioxin/furan concentrations. The SMS

chemical results are discussed in terms of the concentrations relative to the SMS SQS and the cleanup screening levels and the relative spatial distribution of these contaminants. Data completeness and validation results are discussed in Section 4.0.

3.3.1 Conventional Parameters

Conventional parameters are summarized in Table 3–3. The vast majority of sampling locations were dominated by sands, averaging 70 percent of all surface samples. These sandy locations include a variety of high energy environments such as riverbeds, beaches, and shallow offshore sites. Within Focus Areas 1, 2, and 3, limited depositional areas exist where sediments contain greater than 45 percent fines (silt + clay) (Figure 3–25). The fines content of Focus Area 1 sediments was highest at the five stations closest to the head of the East Waterway. At these locations, fines were 53 to 89 percent of total grain size distribution, followed in abundance by sand ranging from 7 to 41 percent. The locations closer to the mouth of the East Waterway contained more sand, with fractions ranging from 46 to 64 percent. Sediments of the East Waterway contained significant gravel, averaging 6.0 percent as opposed to 1.3 percent at other stations, despite their high fine-grained content. Within Focus Area 2, 46 to 83 percent fines were observed in the vicinity of the Everett Marina (A2-13), on the mud flat region north of the marina (A2-14, -25, and 25B), and along the bank of the Snohomish River (A2-36 and A2-38B). The only location in Focus Area 3 with considerable fines content is located near the confluence of Steamboat and Union Sloughs, in the vicinity of the Hansen Boat Company outfall.

Percent TOC, total volatile solids (TVS), ammonia, and sulfides varied greatly through the region with ranges of 0.11 to 7.1 percent, 0.92 to 25 percent, 0.11 to 84 mg/kg, and 1.2 to 3800 mg/kg, respectively. In general, the higher values of these conventional parameters occurred at locations with the greatest fine-grained sediment content. Locations within the East Waterway consistently had greater concentrations of TOC (>2.6 percent), TVS (>11 percent), ammonia (>15 mg/kg), and sulfides (>800 mg/kg) than observed elsewhere. The distribution of TOC and TVS are presented in Figures 3-26 and 3–27, respectively. The only other locations where the presence of sulfides indicates moderately-reduced sediment conditions (>150 mg/kg) are a shallow site along the southern shore of Port Gardner Bay (A1-46B), the mud flats in the vicinity of Jeld-Wen (A2-21), and the riverbed in the vicinity of the former Riverside Chip/Mill storage area (A2-36) (Figure 3–28).

Table 3-3. Summary of Surface Sediment Conventional Parameters

Focus Area	Summary Statistic	# of Samples	TOC (%)	Station ID[1]	TVS (%)	Station ID[1]	Total Solids (%)	Station ID[1]	Ammonia (mg-N/kg)	Station ID[1]	Sulfides (mg/kg)	Station ID[1]
1	Min	16	0.3	A1-46B	1.0	A1-31	28.5	A1-07	0.9	A1-46B	0.0	A1-31B
	Max		7.1	A1-03	24.5	A1-03	78.9	A1-31	83.5	A1-02	3780.0	A1-01
	Average		2.1		8.3		57.5		11.7		917.0	
2	Min	30	0.1	A2-42	0.9	A2-34	48.1	A2-14	0.0	A2-22	0.0	Many
	Max		2.5	A2-18B	10.0	A2-14	93.5	A2-42	13.9	A2-21	805.0	A2-21
	Average		0.9		3.4		68.6		3.9		72.8	
3	Min	8	0.1	A3-11	1.1	A3-13	56.1	A3-05B	0.0	Many	0.0	Many
	Max		1.8	A3-05B	5.0	A3-05B	77.0	A3-13	9.4	A3-07B	46.7	A3-07B
	Average		0.7		2.8		66.6		3.6		11.7	
4	Min	5	0.2	A4-05	1.2	A4-05	51.0	A4-08B	0.4	A4-05	0.0	Many
	Max		1.1	A4-09	5.4	A4-08B	76.3	A4-05	10.0	A4-08B	61.6	A4-08B
	Average		0.6		3.1		64.8		4.2		21.9	

Notes:

1. Station location with the minimum or maximum within each focus area

Figure 3-25. Surface Sediment Grain Size (Percent Gravel, Sand, Silt, and Clay)

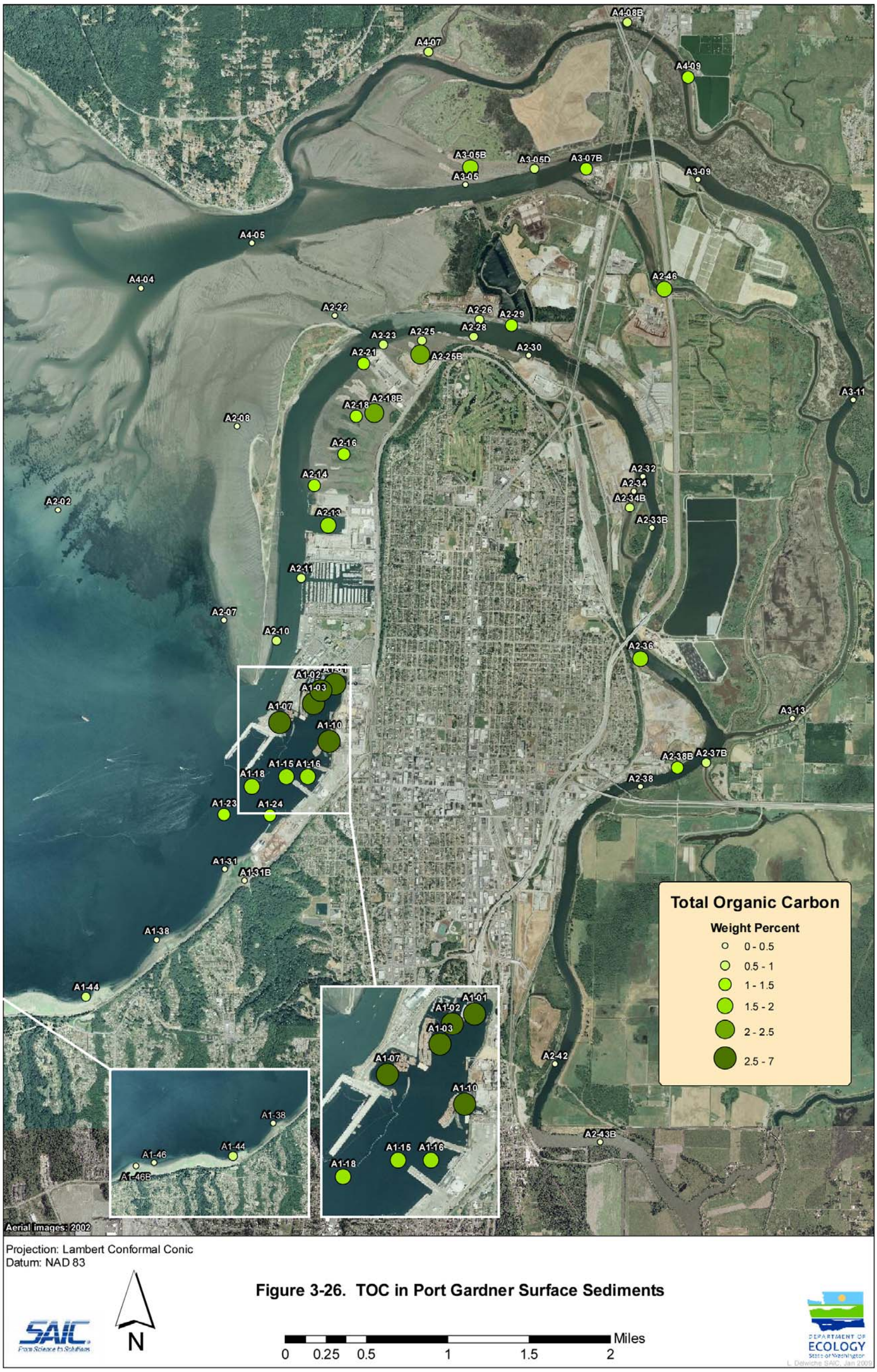


Figure 3-26. TOC in Port Gardner Surface Sediments

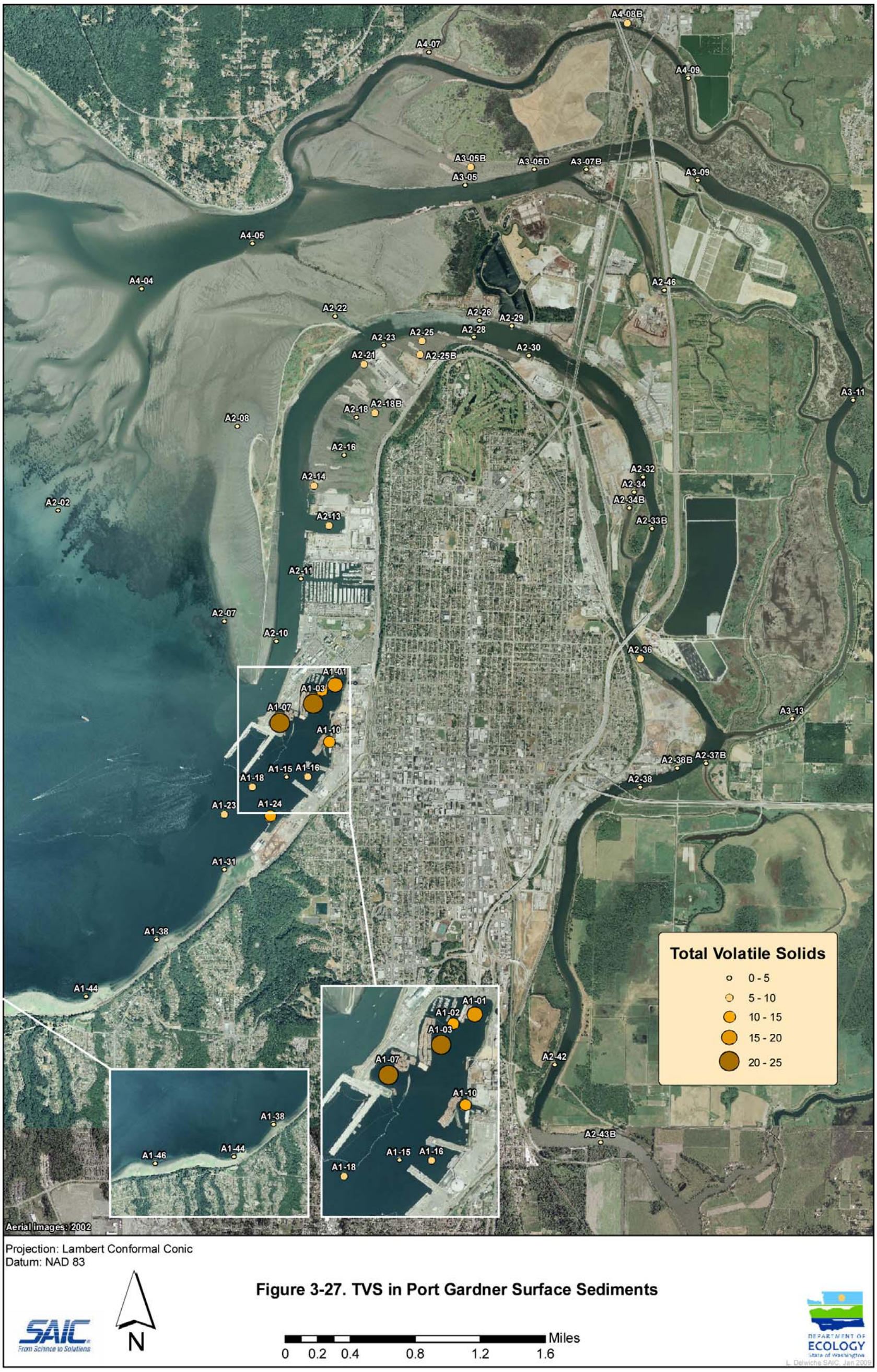


Figure 3-27. TVS in Port Gardner Surface Sediments

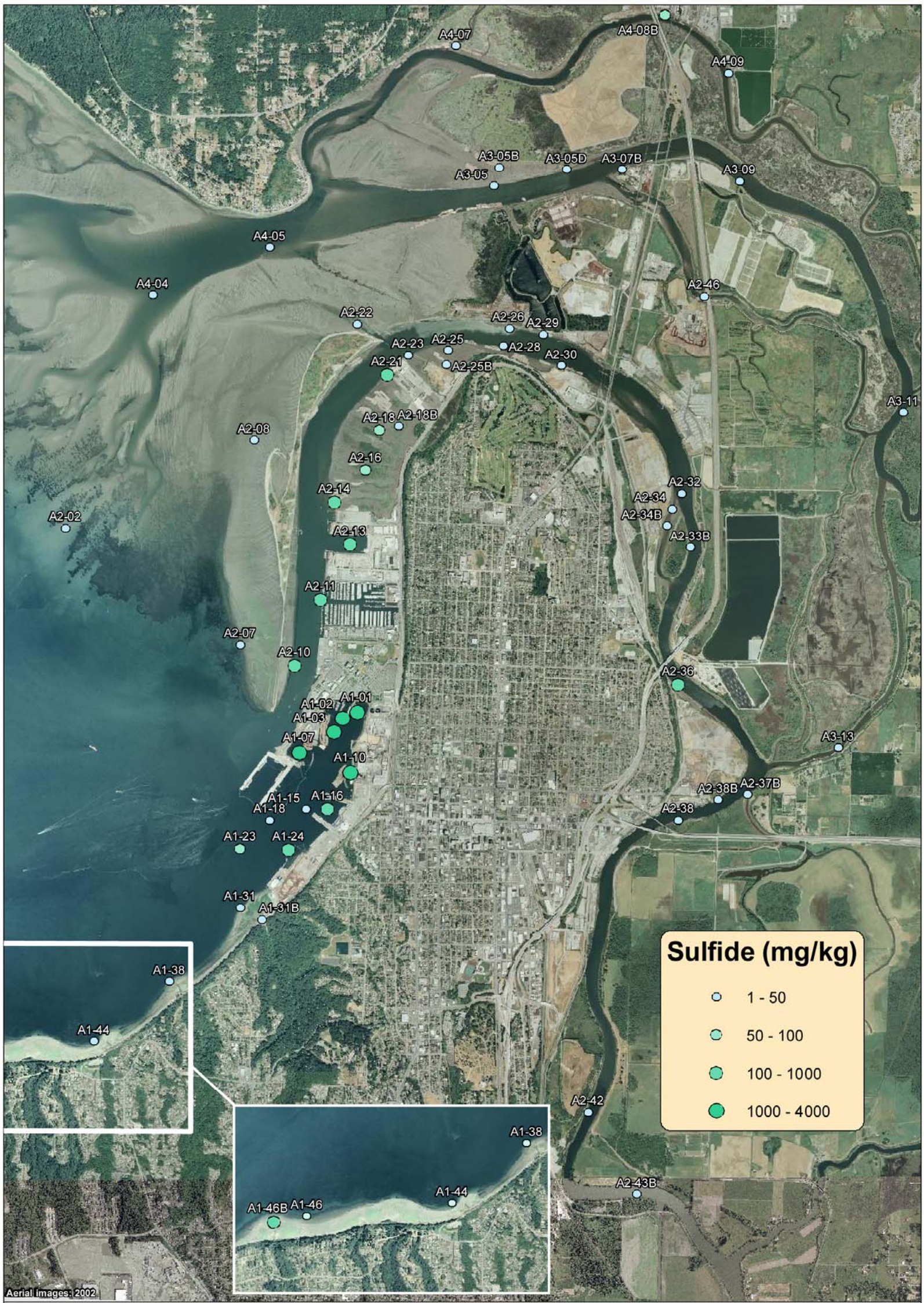


Figure 3-28. Total Sulfides in Port Gardner Surface Sediments

3.3.2 SMS Chemistry

Three of the 52 samples analyzed for SMS chemistry exceeded either the SQS or CSL criteria (Table 3–4). All other analyzed samples contained concentrations of SMS analytes either lower than SMS criteria or below detection limits.

Sediment samples exceeding SMS criteria were all located in the East Waterway region of Focus Area 1 (Figure 3–29). At station A1-07, mercury was the only detected compound to exceed the SMS criteria with a concentration of 0.7 mg/kg (CSL = 0.59 mg/kg). Mercury was detected at all other locations in the East Waterway at concentrations below SQS criteria. At station A1-10, 4-methylphenol (CSL = 670 µg/kg) was detected at levels exceeding SMS criteria with a concentration of 1200 µg/kg. 4-Methylphenol was also detected at all other locations within the East Waterway. Zinc was detected at a level that exceeded SMS criteria (SQS = 410 mg/kg) at station A1-24 with a concentration 415 mg/kg. Although zinc was detected in every other sample in this study, all concentrations were nearly an order of magnitude lower than those measured within samples of the East Waterway.

Elevated Reporting Limits

The reported values for several undetected analytes exceeded SMS criteria (Appendix D). It is important to note that the values associated with these undetected analytes are the method reporting limits (MRL), which are typically a factor of 2-5 times higher than the method detection limits (MDL) for most SVOCs. Both MRL and MDL values for each analyte are presented in Appendix E Analytical Laboratory Reports. Analytes whose MRLs frequently exceeded the SMS numeric criteria included: 1,4-dichlorobenzene in 5 of 52 (9.6 percent); 1,2-dichlorobenzene in 18 of 52 (34.6 percent); 1,2,4-trichlorobenzene in 34 of 52 (65.4 percent); and hexachlorobenzene in 46 of 52 samples (88.5 percent).

It should be noted that the SMS numerical criteria were exceeded primarily due to low levels of TOC, particularly in samples collected with high sand content in the Snohomish River, Steamboat, and Ebey sloughs. A comparison of dry weight concentrations shows that undetected values for 1,4-dichlorobenzene, 1,2-dichlorobenzne, 1,2,4-trichlorobenzene, and hexachlorobenzene all fall below the 1988 dry weight equivalents to SMS criteria (see Appendix D).

Table 3-4. Surface Sediment Exceedances of Washington State SMS Criteria

Station Number	SQS	CSL	A1-07	A1-10	A1-24
Metals in mg/kg					
Mercury	0.41	0.59	**0.7**		
Zinc	410	960			415
Phenols in µg/kg					
4-Methylphenol	670	670		**1200**	

Notes:
Bold font indicates exceedance of CSL, while normal font indicates exceedance of SQS.

Figure 3–29. Chemicals that Exceed SMS Criteria in Surface and Subsurface Sediments

3.3.3 Dioxin/Furan Congeners

Dioxin/furan congeners were measured in 15 surface samples. For each sample, a toxic equivalent quotient (TEQ) was calculated using the most recent mammalian TEF values from the WHO (Van den Berg et al. 2006). The TEQ was calculated using one-half the detection limit for undetected congeners. Surface sediment TEQs in this study ranged from 0.16 to 47 pg/g, with an average concentration of 7.8 pg/g. Dioxin/furan concentrations do not have numeric criteria for comparison under SMS. However, a comparison to the Method B soil criterion for protection of human health (14 pg/g TEQ at most soil sites for unrestricted land use) shows that three samples collected within the East Waterway had dioxin/furan concentrations measured above this criterion (Figure 3–30). These same three samples (20 percent) are also above the proposed freshwater sediment apparent effects threshold for benthic infauna (8.8 pg/g TEQ). Just as wood debris may have contributed to reduced sediment conditions within the East Waterway, debris from paper mills is frequently a source for dioxin/furan contamination. However, high TEQ concentrations are not persistent throughout Focus Area 1, as the two samples collected outside of the East Waterway have some of the lowest TEQ values (Figure 3–29). Overall the lowest TEQ concentrations occurred in Focus Area 2, in both the upper Snohomish River estuary and outside the river mouth (Figure 3–30). Of the seven samples in Focus Area 2, the maximum concentration occurred on the mud flat region with a value of 3.4 pg/g TEQ. Only single surface samples within Focus Areas 3 and 4 were analyzed for dioxin/furan congeners. Of these two samples, site A4-07 had a greater concentration of 0.85 pg/g TEQ compared to 0.17 pg/g TEQ at site A3-05.

3.3.4 Guaiacols and Resin Acids

Guaiacols and resin acids are byproducts of wood decomposition. Although these compounds occur as a result of natural processes, concentrated wood waste from log rafting, chip loading, and processes related to pulp and paper mills can result in concentrations of guaiacols and resins that would not normally accumulate. In addition, guaiacols may become chlorinated as a result of the bleaching of paper products. Ten samples from Port Gardner were analyzed for guaiacols and resins. One of these samples, A2-21, was also analyzed for the PAH retene, a degradation product of abietic acid. There are no SQS criteria for guaiacols, resin acids, or retene.

None of the guaiacols were detected. Resin acids were detected in eight of the ten samples. Isopimaric acid was only detected in one sample (A4-07) at 120 µg/kg. Dehydroabietic acid was detected in eight samples ranging from 120 to 2600 µg/kg. Abietic acid was detected in four samples with concentrations ranging from 170 to 1600 µg/kg. Retene was detected in A2-21 at a concentration of 110 µg/kg. Abietic acid was detected, though qualified "J," in the same sample.

Location A1-24 had the highest concentrations of dehydroabietic and abietic acid. Of the ten samples analyzed, A1-24 also had the highest percent wood debris at 15 percent (Figure 3-1; Table D-1). There was no correlation between concentration and percent wood debris for the other samples. Location A2-30 had 10 percent wood debris and no detected guiacols or resin acids, while locations A1-02 and A4-07 had no visible wood debris and detected concentrations of two or more resin acids each.

Figure 3-30. Dioxin/Furan Congener TEQs for Port Gardner Surface Sediments

3.4 Subsurface Sediment Chemistry

This section provides a summary of the physical characteristics of sediment cores collected in support of the Port Gardner and Lower Snohomish Estuary Sediment Characterization. A total of 16 cores were collected to evaluate the vertical extent of potential sediment contamination within the region. Physical descriptions of the core stratigraphy were documented on core logs (Appendix B) and sediment composites were collected from the cores for potential chemical analysis.

Six sediment cores were collected at locations in Focus Area 1, all within the East Waterway (Figure 2–2). The sediment stratigraphy was generally similar at all six locations. Surface sediments consisted of dark gray to black, organic-rich silt, with varying amounts of scattered wood debris. An overwhelming strong sulfide smell was noted in surface sediment at sites A1-03 and A1-07. A petroleum odor and oily sheen was also observed at station A1-07 at 5 to 7 feet below the surface. All cores contained some wood debris scattered throughout, with the exception of station A1-15 which only had wood debris in the surface layer. Scattered shell pieces were generally found below a depth of 7 feet.

A total of eight sediment cores were collected in Focus Area 2 (Figure 2–2). These cores are representative of a variety of depositional environments in both Port Gardner Bay and the Lower Snohomish River estuary. Sediment cores at stations A2-02 and A2-07 located outside the mouth of the Snohomish River in Port Gardner Bay consisted dominantly of homogenous sands mottled with gray silt. Small amounts of wood debris (<5 percent) were scattered throughout, with shell debris increasing in abundance with depth. Sediment cores collected at stations A2-11, A2-18, A2-25, A2-30, A2-32, and A2-37B are all within the Snohomish River channel. All but station A2-32 were dominantly composed of dark greenish gray sandy silt with woody debris found both as discrete layers at various depths (A2-11, A2-25, and A2-30) and scattered throughout (Figure 3–24). The sediment core at station A2-32 was much sandier, consisting of dark gray, medium to fine sands, with virtually no wood debris.

Sediment cores collected at stations A3-05 and A4-04 were composed of dark gray sands becoming coarser with depth. Unlike the sandy stations A2-02 and A2-07, no shell debris was observed in Focus Areas 3 and 4. The only wood debris observed in these cores was a distinct 0.5-foot-thick, surface wood layer at station A3-05.

3.4.1 Conventional Parameters

Of the 16 sediment cores collected, 15 cores had their 1 to 3 foot depth interval and 10 cores had their 3 to 5 foot interval analyzed for sediment conventionals and SMS chemistry.

Five sediment cores were analyzed for locations in Focus Area 1, all within the East Waterway (Figure 2–2). Surface sediments at all East Waterway stations contained a smaller proportion of fine-grained material than deeper intervals. Within Focus Area 2, four of the eight sediment cores displayed a substantial down-core change in grain size. While sites A2-11, A2-30, and A2-37B all have coarser-grained sediments in their surface interval, only site A2-25 displays the opposite trend. The cores collected in Focus Areas 3 and 4 overwhelmingly consist of sands throughout.

Percent TOC generally varied directly with percent fines for each station, with the exception of the 3 to 5 foot intervals of A1-03 and A1-15 that have uncharacteristically low TOC for their high fine-grained sediment content. Ammonia concentrations generally increased by an order of magnitude between surface and deep intervals. When sulfides were measured at a concentration of >1000 mg/kg in surface sediments (A1-03 and A1-07), subsurface layers were also found to be above this level. At stations A2-30 and A2-37B, sulfides were undetected in surface sediments but found in concentrations >1000 mg/kg in subsurface samples.

3.4.2 SMS Chemistry

Three of the 25 subsurface samples analyzed for SMS chemistry exceeded either the SQS or CSL criteria (Table 3–5). All other analyzed subsurface samples contained concentrations of SMS analytes either lower than SMS criteria or below detection limits.

The only detected chemical compound that exceeded SMS criteria in subsurface sediments was 4-methylphenol. These exceedances occurred at two locations within the East Waterway (Figure 3–29). At station A1-03, 4-methylphenol was measured at a concentration of 2300 µg/kg (SQS and CSL = 670 µg/kg) in the 1 to 3 foot depth interval. Although 4-methylphenol was detected in both the surface grab (0 to 10 cm) and the 3 to 5 foot depth core interval at station A1-03, its concentration did not exceed SMS criteria. At station A1-24, 4-methylphenol exceeded SMS criteria in both the 1 to 3 and 3 to 5 foot intervals with concentrations of 870 and 890 µg/kg, respectively. The surface sediment concentration of 4-methyl phenol at this location did not exceed SMS criteria (200 µg/kg).

Table 3-5. Subsurface Sediment Exceedances of Washington State SMS Criteria

Station Number	SQS	CSL	A1-03-C1-3	A1-24-C1-3	A1-24-C3-5
Phenols in µg/kg					
4-Methylphenol	670	670	**2300**	**870**	**890**

Notes:
Bold font indicates exceedance of CSL, while normal font indicates exceedance of SQS.

Elevated Reporting Limits

As in surface sediments, the reported values for several undetected analytes exceeded SMS criteria for subsurface sediments (Appendix D). Analytes whose MRLs frequently exceeded the SMS numeric criteria included in subsurface sediments: 1,4-dichlorobenzene in three of 25 (12 percent); 1,2-dichlorobenzene in seven of 25 (28 percent); 1,2,4-trichlorobenzene in 12 of 25 (48 percent); hexachlorobenzene in 21 of 25 samples (84 percent); butylbenzylphthalate in four of 25 samples (16 percent); 2,4 dimethylphenol in one of 25 samples (4.0 percent); and hexachlorobutadiene in three of 25 samples (12 percent).

Similar to the surface sediment chemistry, the SMS numerical criteria were exceeded primarily due to low levels of TOC, particularly in samples collected with high sand content in the Snohomish River, Steamboat, and Ebey sloughs. A comparison of dry weight concentrations shows that undetected values for the above compounds all fall below the 1988 dry weight equivalents to SMS criteria (see Appendix D).

3.4.3 Dioxin/Furan Congeners

Dioxin/furan congeners were measured in five subsurface samples collected from the 1 to 3 foot depth interval. TEQ values calculated using one-half the detection limit for undetected congeners ranged from 0.13 to 50.5 pg/g, with an average concentration of 12.0 pg/g. Only the subsurface sample collected at station A1-24 (50.5 pg/g TEQ) exceeds both the Method B soil criterion for protection of human health (14 pg/g TEQ at most soil sites for unrestricted land use) and the proposed freshwater sediment apparent effects threshold for benthic infauna (8.8 pg/g TEQ).

3.5 Biological Toxicity Testing Results

The confirmatory biological testing was performed on a total of 17 sediment samples from Port Gardner and the Lower Snohomish estuary (Figure 3–31) and three reference sediments (Carr Inlet). Four additional reference sediments were collected for a larval re-test (2 from Carr Inlet, 2 from Sequim Bay). The bioassays were conducted in two batches (Batch 1: 17 test sediments; Batch 2: nine test sediments—larval re-test only) and included the following:

- 10-day amphipod mortality (*Eohaustorius estuarius*),
- 48-hour larval development (*Mytilus* sp.),
- 20-day juvenile polychaete growth (*Neanthes arenaceodentata*), and
- 15-minute Microtox bioluminescence (*Vibrio fischeri*).

Newfields (Port Gamble, Washington) conducted the amphipod mortality, larval development, and juvenile polychaete growth bioassays. Nautilus Environmental (Fife, Washington) conducted the Microtox bioluminescence bioassay. The following sections summarize the results of the confirmatory biological testing. The bioassay laboratory report is provided in Appendix F.

3.5.1 Bioassay Water Quality Results

The water quality test condition protocols and summary of daily measurements are presented in Table 3–6. The temperature, salinity, DO, and pH were all within control limits and acceptable ranges throughout the tests, with one minor exception. The temperature dropped below the control limits for the juvenile polychaete growth bioassays. However, this water quality deviation was not believed to have had a significant effect on the test results. Water quality is not monitored as part of the Microtox bioluminescence bioassay as the 100 percent porewater extract of the sediment sample is pH, DO, and salinity-adjusted prior to testing.

The water quality measurements for ammonia (interstitial and overlying) and sulfides (interstitial) are presented in Table 3–7. The total ammonia and sulfide concentrations were all below levels of potential concern in bioassay test results (DMMP 2002; DMMP 2004). Based on the water quality measurements, there is no reason to believe there were any adverse effects on test organisms due to laboratory test conditions.

Figure 3-31. Port Gardner Bioassay Sampling Locations

Table 3-6. Water Quality Test Results Compared to Test Control Limits

Test (Test Species)	Control Limits/Test Results	Temperature	Salinity	DO	pH[1]
Amphipod Mortality (*E. estuarius*)	Control Limits	15 ± 1°C	Ambient[3]	n/a[4]	---
	Test Results[2]	14.8 to 16.2 °C	26 – 29 ppt	6.4-8.3 mg/L	7.4 – 8.1
Larval Development (*Mytilus* sp.)	Control Limits	16 ± 1°C	28 ± 1 ppt	>60% saturation	---
	Batch 1 Test Results[2,5]	15.5 to 16.9 °C	27 – 28 ppt	4.3 – 7.6 mg/L	7.1 – 7.9
	Batch 2 Test Results[2,5]	16.0 to 16.8 °C	27 ppt	5.1 – 7.8 mg/L	7.5 – 7.9
Juvenile Polychaete Growth (*N. arenaceodentata*)	Control Limits	20 ± 1°C	28 ± 2 ppt	n/a[4]	---
	Test Results[2]	16.8 to 20.5 °C	26 – 29 ppt	7.0 – 8.3 mg/L	7.0 – 8.3
Microtox Bioluminescence (*V. fischeri)*	n/a[6]	15 °C[6,7]	20 ± 2 ppt[6]	50 – 100% saturation[6]	7.9 – 8.2[6]

Notes:
ppt = parts per thousand; n/a = not applicable
1. pH is required for water quality monitoring but does not have explicit control limits.
2. Water quality test results are for reference and test sediment parameters only; does not include negative control results.
3. Same as interstitial.
4. Continuous aeration is required by the protocol, so the DO should not be a cause of concern.
5. Batch 1 is the original larval test, Batch 2 is the larval re-test.
6. The 100 percent porewater extract of the sediment sample is adjusted for temperature, pH, dissolved oxygen, and salinity.
7. Temperature is maintained at 15°C in an incubator during testing.

Source: Ecology 2003

Table 3-7. Water Quality Measurements of Total Ammonia and Sulfides

Test (Test Species)	Batch	Interstitial Ammonia Total NH3 (mg/L)	Overlying Ammonia Total NH3 (mg/L)	Sulfides (mg/L)
Amphipod Mortality (*E. estuarius*)	1	<0.5– 5.04	<0.5 – 3.60	0.02 – 0.798[1]
Larval Development (*Mytilus* sp.)	1	n/a	<1.0 - 0.140	<0.01 – 0.165[2]
	2	n/a	<0.5	<0.01 – 0.135[2]
Juvenile Polychaete Growth (*N. arenaceodentata*)	1	<0.5 – 7.08	<0.5 – 5.96	0.016 – 0.627[1]
Microtox Bioluminescence (*V. fischeri*)	1	n/a	n/a	n/a

Notes:
n/a = not applicable
1. Sulfides measurement is interstitial water.
2. Sulfides measurement is overlying water.

3.5.2 Negative Control and Reference Sediment Performance Results

The reference sediments are used in comparison with test sediments for interpreting the results of the bioassays. Three locations from Carr Inlet were sampled for comparison to the test sediments collected for the Port Gardner Bay Sediment Characterization. Carr Inlet is recognized as a suitable reference area for the collection of sediments for interpreting bioassay results. For the larval re-test, additional reference sediment was collected from Sequim Bay, a designated reference location.

The percent fines, the total of the silt and clay grain size fractions, are used for pairing the appropriate reference sediment with a given test sediment (Table 3–8). Test sediments with less than 30.8 percent fines were compared to reference sediment CR-22-S and those with percent fines between 30.8 and 61.8 percent were compared to reference sediment CR-23-S. Test sediments with greater than 61.8 percent fines were compared to the reference sediment CR-20/24-S. The TOC results for reference and test sediments are included in Table 3–8 for comparison.

The reference sediment comparisons for the larval re-test included the addition of two Sequim Bay reference sediments (SB-REF-48 and SB-REF-76), as well as two Carr Inlet reference sediments (CR-20/24-S and CR-23-49-S). Larval re-test sediments with fines less than 57 percent were compared to SB-REF-48, and re-test sediments with fines greater than 57 percent were compared to SB-REF-76. In addition, the test sediments with fines less than 62.3 percent were compared to CR-23-49-S, and sediments with fines greater than 62.3 percent were compared to CR-20/24-S.

The performance results of the negative control and reference sediments for each bioassay are presented in Table 3–9. The negative control performance standards were met for all four bioassays. Therefore, the test results for the amphipod mortality, larval development, and juvenile polychaete bioassays should be considered valid for the purposes of the SMS confirmatory biological tests. Several of the sediments collected for reference sediments did not meet the performance criteria. For the Batch 1 larval development bioassays, CR-23-S and CR-20/24-S did not meet the performance criteria prompting a re-test using both Carr Inlet and Sequim Bay reference sediments. For the Batch 2 larval development bioassays, none of the four reference sediments met the performance criteria. Therefore the interpretation of the larval development test requires an alternate evaluation of results using comparisons to negative controls and additional lines of evidence. The interpretation of the larval development bioassay results are presented in Section 3.5.5. The reference sediment CR-20/24-S did not meet the performance criteria for the Microtox bioluminescence bioassay. The interpretation of the Microtox bioluminescence bioassay results are presented in Section 3.5.7.

Table 3-8. Grain Size and TOC Results for Determining Reference Sediments Comparisons

Sample ID	Percent Fines (silt + clay)	TOC (%)	Reference Sediment for Comparison[1,2]
Reference CR-22-S	**11.1**	**0.31**	**n/a**
Reference CR-23-S	**50.4**	**0.573**	**n/a**
Reference CR-20/24-S	**73.2**	**0.596**	**n/a**
BATCH 1			
A1-01	48.1	5.71	CR-23
A1-03	52.9	7.03	CR-23
A1-07	65.2	5.02	CR-20/24-S
A1-10	44.4	3.18	CR-23
A1-16	21.9	2.55	CR-22-S
A1-24	51.1	2.42	CR-23
A2-10	33.5	0.881	CR-23
A2-11	8.7	1.27	CR-22-S
A2-13	78.9	1.82	CR-20/24-S
A2-14	55.2	0.802	CR-23
A2-18	58.7	1.2	CR-23
A2-21	61.4	1.65	CR-23
A2-25	57.7	0.867	CR-23
A2-36	33.5	1.33	CR-23
A3-05E	26.8	0.617	CR-22-S
A3-07B	54.8	1.37	CR-23
A4-08B	56.9	1.22	CR-23
BATCH 2 (Larval Re-Test Only)			
Reference SB-REF-48	**25.2**	**1.45**	**n/a**
Reference CR-23-49-S	**52.6**	**0.535**	**n/a**
Reference CR-20-24-S	**71.9**	**0.635**	**n/a**
Reference SB-REF-76	**88.8**	**3.25**	**n/a**
A1-01	48.1	5.71	SB-REF-48 / CR-23-49-S
A1-03	52.9	7.03	SB-REF-48 / CR-23-49-S
A1-07	65.2	5.02	SB-REF-76/ CR-20-24-S
A2-13	78.9	1.82	SB-REF-76/ CR-20-24-S
A2-18	58.7	1.2	SB-REF-76/ CR-23-49-S
A2-21	61.4	1.65	SB-REF-76/ CR-23-49-S
A2-25	57.7	0.867	SB-REF-76/ CR-23-49-S
A3-07B-S	54.8	1.37	SB-REF-48 / CR-23-49-S
A4-08B-S	56.9	1.22	SB-REF-48 / CR-23-49-S

Notes:

1. Batch 1: Test sediments with fines < 30.8 percent are paired with CR-22-S, between 30.8 and 61.8 percent are paired with CR-23-S, and > 61.8 percent are paired with CR-20/24-S.
2. Batch 2: Larval re-test sediments were compared to reference sediments from both Carr Inlet and Sequim Bay. Sediments with fines < 57 percent were compared to SB-REF-48 and with fines > 57 were compared to SB-REF-76; sediments with fines < 62.3 percent were compared to CR-23-49-S and with fines > 62.3 percent were compared to CR-20-24-S.

Table 3-9. Performance Standards and Results for Negative Controls and Reference Sediments

Test (Test Species)	Negative Control Performance Standard	Negative Control Results		Reference Sediment Performance Standard	Reference Sediment Results	
		Batch 1	Batch 2		Batch 1	Batch 2
Amphipod Mortality (*E. estuarius)*	$M_C \leq 10\%$	7%	n/a	$M_R \leq 25\%$	CR-22-S: 1%; CR-23-S: 2%; CR-20/24-S: 3%	n/a
Larval Development (*Mytilus* sp.)	$N_C \div I \geq 0.70$	0.947	0.957	$N_R \div N_C \geq 65\%$	CR-22-S: 75.0%; CR-23-S: 56.9%; CR-20/24-S: 63.5%	CR-20/24-65S: 59.5%; CR-23-49-S: 31.7%; SB-REF-76: 59.0%; SB-REF-48: 45.0%
Juvenile Polychaete Growth (*N. arenaceodentata*)	$M_C \leq 10\%$ and $MIG_C \geq 0.38$[1]	0.0%; 0.634	n/a	$MIG_R \div MIG_C \geq 0.80$	CR-22-S: 0.979; CR-23-S: 0.912; CR-20/24-S: 1.07	n/a
Microtox Bioluminescence (*V. fischeri*)	$M_C > 80\%$[2]	82-85%[3]	n/a	$M_R > 80\%$[2]	CR-22-S: 90-97%;[3] CR-23-S: 86-95%;[3] CR-20/24-S: 73%	n/a

Notes:
Bold Font: Performance criteria not met
M mean mortality.
N mean normal development survival in seawater control.
I initial count; Batch 1 = 369.8; Batch 2 = 201.4.
MIG mean individual growth rate (mg/individual/day)
Subscripts: R = reference; C = negative control
1. Target MIGc is 0.72 mg/individual/day; the test is considered to be failed if the Control MIG is less than 0.38 mg/individual/day.
2. Percent mean light output of final control or reference relative to initial control or reference.
3. The bioassays were performed in several batches. Therefore, the reference sediment results are provided as a range.

3.5.3 Positive Control Results

The results of the reference toxicant tests for the bioassays are provided in Table 3–10. The LC50 values for all the bioassays fell within the acceptable range of mean ± two standard deviations for historical reference toxicant data generated by the NewFields Northwest biological laboratory. The reference toxicant results indicate the test organisms appeared to be sufficiently sensitive for demonstrating a toxic response and sufficiently robust for laboratory testing. The reference control charts with both the current and running means and standard deviations are provided in Appendix F.

Table 3-10. Reference Toxicant Results

Test (Test Species)	Reference Toxicant	Endpoint	Test Batch	LC50	Laboratory Historical Range (mean ± 2SD)
Amphipod Mortality (*E. estuarius*)	Cadmium chloride	96-hour survival	1	6.85 mg/L Cd	3.95 – 12.2 mg/L Cd
Larval Development (*Mytilus* sp.)	Copper chloride	normality	1	10.3 µg/L Cu	3.42 – 18.7 µg/L Cu
			2	10.6 µg/L Cu	3.57 – 18.7 µg/L Cu
Juvenile Polychaete Growth (*N. arenaceodentata*)	Cadmium chloride	96-hour survival	1	6.84 mg/L Cd	2.41 – 16.9 mg/L Cd
Microtox Bioluminescence (*V. fischeri*)	Phenol	luminescence	1	53.9 – 54.1 mg/L phenol	25.0 – 65.6

3.5.4 Amphipod Mortality Bioassay

The amphipod mortality tests were initiated on October 28, 2008, using test organisms (*E. estuarius*) obtained from Northwest Aquatic Sciences, Newport, Oregon. The results of the amphipod mortality bioassay are presented in Table 3–11. The amphipod mean mortality ranged from 0 to 10 percent in the test sediments. All test sediments passed both the SMS SQS and CSL biological effects interpretive criteria for the amphipod mortality bioassay. The bioassay results are displayed in Figure 3–32.

Figure 3-32. Port Gardner Bioassay Results

Table 3-11. Amphipod Mortality Bioassay (*E. estuarius*) Results and Evaluation Guidelines

Sample ID	Percent Mortality[1]	Mean Mortality[2]	Reference Sediment[3]	Comparison to Reference[4]		SQS	CSL
				MT – MR;	MT vs MR SD;p = 0.05:significant?(test)	MT – MR >25% and MT vs MR SD (p = 0.05)	MT – MR >30% and MT vs MR SD (p = 0.05)
						Pass/Fail	Pass/Fail
Control	5 5 5 15 5	7 ± 4.5	n/a	n/a	n/a	n/a	n/a
Reference CR-22-S	0 5 0 0 0	1 ± 2.2	n/a	n/a	n/a	n/a	n/a
Reference CR-23-S	0 5 0 5 0	2 ± 2.7	n/a	n/a	n/a	n/a	n/a
Reference CR-20/24-S	0 5 5 0 5	3 ± 2.7	n/a	n/a	n/a	n/a	n/a
A1-01	15 10 5 0 15	9 ± 6.5	CR-23	7.0%	Yes; (Students t-Test)	Pass	Pass
A1-03	0 5 0 5 0	2 ± 2.7	CR-23	0.0%	No; (Mann-Whitney)	Pass	Pass

Table 3-11. Amphipod Mortality Bioassay (*E. estuarius*) Results and Evaluation Guidelines (continued).

Sample ID	Percent Mortality[1]	Mean Mortality[2]	Reference Sediment[3]	Comparison to Reference[4]		SQS	CSL
				MT – MR;	MT vs MR SD;p = 0.05:significant?(test)	MT – MR >25% and MT vs MR SD (p = 0.05)	MT – MR >30% and MT vs MR SD (p = 0.05)
						Pass/Fail	Pass/Fail
A1-07	5 0 0 5 5	3 ± 2.7	CR-20/24-S	0.0%	No; (Mann-Whitney)	Pass	Pass
A1-10	5 10 5 0 5	5 ± 3.5	CR-23	3.0%	No; (Student's t-Test)	Pass	Pass
A1-16	0 5 0 20 0	5 ± 8.7	CR-22-S	4.0%	No; (Student's t-Test)[5]	Pass	Pass
A1-24	0 0 0 10 0	2 ± 4.5	CR-23	0.0%	No; (Mann-Whitney)	Pass	Pass
A2-10	0 5 0 5 5	2 ± 4.5	CR-23	0.0%	No; (Mann-Whitney)	Pass	Pass
A2-11	0 0 15 0 0	3 ± 6.7	CR-22-S	2.0%	No; (Mann-Whitney)	Pass	Pass

Table 3-11. Amphipod Mortality Bioassay (*E. estuarius*) Results and Evaluation Guidelines (continued).

Sample ID	Percent Mortality[1]	Mean Mortality[2]	Reference Sediment[3]	Comparison to Reference[4]		SQS	CSL
				MT – MR;	MT vs MR SD;p = 0.05:significant?(test)	MT – MR >25% and MT vs MR SD (p = 0.05)	MT – MR >30% and MT vs MR SD (p = 0.05)
						Pass/Fail	Pass/Fail
A2-13	5 10 10 10 15	10 ± 3.5	CR-20/24-S	7.0%	Yes; (Student's t-Test)[5]	Pass	Pass
A2-14	0 0 0 0 5	1 ± 2.2	CR-23	-1.0%	No; (Mann-Whitney)	Pass	Pass
A2-18	0 5 0 0 0	1 ± 2.2	CR-23	-1.0%	No; (Mann-Whitney)	Pass	Pass
A2-21	10 5 10 0 0	5 ± 5.0	CR-23	3.0%	No; (Mann-Whitney)	Pass	Pass
A2-25	5 0 5 5 5	4 ± 2.2	CR-23	2.0%	No; (Student's t-Test)	Pass	Pass
A2-36	0 0 0 0 5	1 ± 2.2	CR-23	-1.0%	No; (Mann-Whitney)	Pass	Pass

Table 3-11. Amphipod Mortality Bioassay (*E. estuarius*) Results and Evaluation Guidelines (continued).

Sample ID	Percent Mortality[1]	Mean Mortality[2]	Reference Sediment[3]	Comparison to Reference[4]		SQS	CSL
				MT – MR;	MT vs MR SD;p = 0.05:significant?(test)	MT – MR >25% and MT vs MR SD (p = 0.05)	MT – MR >30% and MT vs MR SD (p = 0.05)
						Pass/Fail	Pass/Fail
A3-05E	0 0 0 0 0	0 ± 0.0	CR-22-S	-1.0%	No; (approximate t-Test)[5]	Pass	Pass
A3-07B	5 0 5 0 5	3 ± 2.7	CR-23	1.0%	No; (Mann-Whitney)	Pass	Pass
A4-08B	0 5 0 0 0	1 ± 2.2	CR-23	-1.0%	No; (Mann-Whitney)	Pass	Pass

Notes:

SQS sediment quality standard
CSL cleanup screening level
M mortality
SD statistically different
Pass meet SMS interpretive criteria
Fail exceed SMS interpretive criteria
n/a not applicable

Subscripts: R = reference; C = negative control; T = test sediment

1. Percent mortality observed in individual replicates.
2. Mean percent mortality ± standard deviation observed in test sample.
3. Reference, background, or control sediment used for comparison.
4. Comparison to reference includes the numeric result for the comparative criteria, the result of the statistical test, and the statistical test used. All statistics were conducted using BioStat (DMMP/SMS Bioassay Statistics Program; Beta v4.1). All amphipod mortality data were arcsine transformed for statistical analysis, unless noted otherwise.
5. Rankit transformation used due to non-normality and non-homoscedasticity.

3.5.5 Larval Development Bioassay

The larval development tests were initiated on November 7 (Batch 1) and 26, 2008 (Batch 2), using test organisms (*Mytilus* sp.) provided by Carlsbad Aquafarms, Carlsbad, California. The results of the larval development bioassay are presented in Tables 3–12 and 3–13. Due to the failure for two of the three reference sediments to meet the performance criteria in the intial test (Batch 1), nine test sediments were submitted for a larval bioassay re-test (Batch 2). Unfortunately, all four reference sediments failed to meet the performance criteria for the larval re-test. Therefore, it was necessary to use negative control results for comparative purposes to interpret the results of the two larval tests. The negative control for larval tests consists of seawater only (for performance criteria and normalization of test results), however NewFields biological laboratories also runs a sediment control with the larval tests. The sediment control consists of 18 grams of clean sand added to the seawater. The SMS data interpretation in Tables 3–12 and 3–13, uses both the seawater and sediment controls for comparative purposes. The sediment control provides a more similar comparison to test results due to the presence of sand, which may obscure the ability to count all the larvae present at test completion; whereas the seawater control provides a more conservative comparison since the larvae are easier to identify and count in solution.

The results for the larval development bioassay ranged from 14.2 to 91.9 mean percent normal survival in Batch 1, and 20.1 to 63.3 mean percent normal survival for the Batch 2 test sediments. Ten of the 17 test sediments in Batch 1 failed the CSL criteria when compared to the seawater control, whereas only eight fail the CSL when compared to the sediment control. A total of 13 test sediments in Batch 1 fail the SQS when compared to the seawater control, whereas only 11 fail the SQS when compared to the sediment control. All nine test sediments in Batch 2 fail the CSL when compared to the seawater control, whereas only eight fail the CSL when compared to the sediment control. Based on the different results between batches and within batches relative to comparison to controls, multiple line of evidence (i.e. other test results) should be taken into consideration to determine the extent of the observed toxicity at a given location. The most conservative interpretation of the bioassay results are displayed in Figure 3–32.

Table 3-12. Batch 1: Larval Development Bioassay (*Mytilus* sp.) Results and Evaluation Guidelines

Sample ID	Percent Normal Survival[1]	Mean Normal Survival[2]	Reference Sediment[3,4]	Comparison to Reference[5,6]		SQS	CSL
				$N_T \div N_R$	N_T vs N_R SD; p = 0.10: significant? (test)	N_T vs N_R SD (p = 0.10); $N_T \div N_R$ <0.85; Pass/ Fail	N_T vs N_R SD (p = 0.10); $N_T \div N_R$ <0.70; Pass/ Fail
Sea Water Control[4,5]	90.4 99.0 94.1 96.8 93.4	94.7 ± 3.3	n/a	n/a	n/a	n/a	n/a
Sediment Control	95.8 100.0 72.3 83.9 89.0	88.2 ± 10.8	n/a	n/a	n/a	n/a	n/a
Reference CR-22-S	75.9 70.7 75.1 73.1 79.9	75.0 ± 3.4	n/a	n/a	n/a	n/a	n/a
Reference CR-23-S	53.7 55.6 60.4 56.4 58.4	56.9 ± 2.6	n/a	n/a	n/a	n/a	n/a
Reference CR-20/24-S	56.8 64.8 69.2 48.5 78.3	63.5 ± 11.4	n/a	n/a	n/a	n/a	n/a
A1-01[7]	68.8 76.3 81.9 76.3 75.9	75.8 ± 4.7	Sea Water; Sediment Control[4]	0.800; 0.859	Yes; (Students t-Test); Yes; (Students t-Test)[8]	Fail;[6] Pass	Pass

Table 3-12. Batch 1: Larval Development Bioassay (*Mytilus* sp.) Results and Evaluation Guidelines (continued).

Sample ID	Percent Normal Survival[1]	Mean Normal Survival[2]	Reference Sediment[3,4]	Comparison to Reference[5,6]		SQS	CSL
				$N_T \div N_R$	N_T vs N_R SD; p = 0.10: significant? (test)	N_T vs N_R SD (p = 0.10); $N_T \div N_R$ <0.85; Pass/ Fail	N_T vs N_R SD (p = 0.10); $N_T \div N_R$ <0.70; Pass/ Fail
A1-03[7]	57.2 17.9 58.4 17.5 36.2	37.4 ± 20.1	Sea Water; Sediment Control[4]	0.395; 0.424	Yes; (Approximate t-Test); Yes; (Students t-Test);	Fail	Fail
A1-07[7]	53.3 66.4 66.0 56.8 66.0	61.7 ± 6.2	Sea Water; Sediment Control[4]	0.652; 0.700	Yes; (Students t-Test); Yes; (Students t-Test);	Fail	Fail;[6] Pass
A1-10	26.6 41.7 9.5 11.5 50.1	27.9 ± 18.0	Sea Water; Sediment Control[4]	0.295; 0.316	Yes; (Approximate t-Test); Yes; (Students t-Test);	Fail	Fail
A1-16	76.3 72.3 72.7 70.3 73.9	73.1 ± 2.2	CR-22-S	0.975	No; (Students t-Test)	Pass	Pass
A1-24	66.8 34.6 50.1 41.7 37.4	46.1 ± 13.0	Sea Water; Sediment Control[4]	0.487; 0.523	Yes; (Students t-Test); Yes; (Students t-Test);	Fail	Fail
A2-10	81.5 90.2 89.0 83.5 89.8	86.8 ± 4.0	Sea Water; Sediment Control[4]	0.917; 0.984	Yes; (Students t-Test); No; (Students t-Test);	Pass	Pass

Table 3-12. Batch 1: Larval Development Bioassay (*Mytilus* sp.) Results and Evaluation Guidelines (continued).

Sample ID	Percent Normal Survival[1]	Mean Normal Survival[2]	Reference Sediment[3,4]	Comparison to Reference[5,6]		SQS	CSL
				$N_T \div N_R$	N_T vs N_R SD; p = 0.10: significant? (test)	N_T vs N_R SD (p = 0.10); $N_T \div N_R$ <0.85; Pass/ Fail	N_T vs N_R SD (p = 0.10); $N_T \div N_R$ <0.70; Pass/ Fail
A2-11	82.7 93.4 95.8 86.6 97.0	91.1 ± 6.2	CR-22-S	1.215	No; (Approximate t-Test)	Pass	Pass
A2-13[7]	13.9 72.7 73.5 78.7 75.5	62.9 ± 27.5	Sea Water; Sediment Control[4]	0.664; 0.713	Yes; (Mann-Whitney); Yes; (Mann-Whitney);	Fail	Fail;[6] Pass
A2-14	46.1 70.3 51.3 54.8 53.7	55.2 ± 9.1	Sea Water; Sediment Control[4]	0.583; 0.625	Yes; (Students t-Test); Yes; (Students t-Test)	Fail	Fail
A2-18[7]	77.1 76.7 73.5 85.9 82.7	79.2 ± 5.0	Sea Water; Sediment Control[4]	0.836; 0.898	Yes; (Students t-Test); Yes; (Students t-Test)	Fail;[6] Pass	Pass
A2-21[7]	25.8 34.6 24.2 32.6 32.6	30.0 ± 4.6	Sea Water; Sediment Control[4]	0.317; 0.340	Yes; (Students t-Test); Yes; (Students t-Test)	Fail	Fail
A2-25[7]	65.2 80.7 66.8 67.2 65.6	69.1 ± 6.5	Sea Water; Sediment Control[4]	0.730; 0.783	Yes; (Mann-Whitney); Yes; (Students t-Test)	Fail	Pass

Table 3-12. Batch 1: Larval Development Bioassay (*Mytilus* sp.) Results and Evaluation Guidelines (continued).

Sample ID	Percent Normal Survival[1]	Mean Normal Survival[2]	Reference Sediment[3,4]	Comparison to Reference[5,6]		SQS	CSL
				$N_T \div N_R$	N_T vs N_R SD; p = 0.10: significant? (test)	N_T vs N_R SD (p = 0.10); $N_T \div N_R$ <0.85; Pass/ Fail	N_T vs N_R SD (p = 0.10); $N_T \div N_R$ <0.70; Pass/ Fail
A2-36	9.1 18.7 21.9 16.7 24.6	18.2 ± 5.9	Sea Water; Sediment Control[4]	0.192; 0.206	Yes; (Students t-Test); Yes; (Students t-Test)	Fail	Fail
A3-05E	71.5 64.0 88.2 91.8 83.1	79.7 ± 11.7	CR-22-S	1.063	No; (Approximate t-Test)	Pass	Pass
A3-07B[7]	11.5 13.1 11.9 7.9 26.6	14.2 ± 7.2	Sea Water; Sediment Control[4]	0.150; 0.161	Yes; (Students t-Test); Yes; (Students t-Test)	Fail	Fail
A4-08B[7]	15.5 25.0 15.1 21.1 12.7	17.9 ± 5.0	Sea Water; Sediment Control[4]	0.189; 0.203	Yes; (Students t-Test); Yes; (Students t-Test);	Fail	Fail

Notes:

N normal development; SD = statistically different

SQS sediment quality standards; CSL = cleanup screening level; n/a = not applicable

Subscripts: R = reference; T = test sediment

Pale yellow shading indicates a SQS failure

Rose shading indicated a CSL failure

Light blue shading indicates a discrepancy between the interpretive comparisons

1. Percent normal survivors observed in individual replicates.
2. Mean percent normal survivors ± standard deviation observed in test sample. All reference and test sediment results are normalized to seawater control.
3. Reference, background, or control sediment used for comparison.
4. The sea water and sediment controls were both used for interpretation since the grain-size appropriate reference sediment did not meet the performance criteria.

5. Comparison to reference includes the numeric result for the comparative criteria, the result of the statistical test, and the statistical test used. All statistics were conducted using BioStat (DMMP/SMS Bioassay Statistics Program; Beta v4.1). All larval development data were arcsine transformed for statistical analysis, unless indicated otherwise.
6. Comparison to seawater control listed first; comparison to sediment control listed second.
7. Sample included in larval re-test.
8. Rankit transformation used due to non-normality and non-homoscedasticity.

Table 3-13. Batch 2: Larval Development Bioassay (*Mytilus sp.*) Results and Evaluation Guidelines

Sample ID	Percent Normal Survival[1]	Mean Normal Survival[2]	Reference Sediment[3,4]	Comparison to Reference[5,6]		SQS	CSL
				$N_T \div N_R$	N_T vs N_R SD; p = 0.10: significant? (test)	N_T vs N_R SD (p = 0.10); $N_T \div N_R$ <0.85; Pass/ Fail	N_T vs N_R SD (p = 0.10); $N_T \div N_R$ <0.70; Pass/ Fail
Sea Water Control[2,4]	90.6 93.3 100.0 100.0 94.4	95.7 ± 4.2	n/a	n/a	n/a	n/a	n/a
Sediment Control	85.1 88.3 92.2 85.1 85.8	87.3 ± 3.1	n/a	n/a	n/a	n/a	n/a
Reference SB-REF-48	44.3 49.7 47.2 42.9 40.7	45.0 ± 3.5	Failed	n/a	n/a	n/a	n/a
Reference CR-23-49-S	36.5 29.7 35.0 31.8 25.7	31.7 ± 4.3	Failed	n/a	n/a	n/a	n/a
Reference CR-20-24-S	51.5 47.2 62.5 57.5 78.6	59.5 ± 12.2	Failed	n/a	n/a	n/a	n/a
Reference SB-REF-76	59.0 52.2 62.9 62.5 58.6	59.0 ± 4.3	Failed	n/a	n/a	n/a	n/a

Table 3-13. Batch 2: Larval Development Bioassay (Mytilus sp.) Results and Evaluation Guidelines (continued).

Sample ID	Percent Normal Survival[1]	Mean Normal Survival[2]	Reference Sediment[3,4]	Comparison to Reference[5,6]		SQS	CSL
				$N_T \div N_R$	N_T vs N_R SD; p = 0.10: significant? (test)	N_T vs N_R SD (p = 0.10); $N_T \div N_R$ <0.85; Pass/ Fail	N_T vs N_R SD (p = 0.10); $N_T \div N_R$ <0.70; Pass/ Fail
A1-01	13.9 25.0 16.1 31.1 14.3	20.1 ± 7.6	Sea Water; Sediment Control[4]	0.210; 0.230	Yes; (Approximate t-Test); Yes; (Approximate t-Test)	Fail	Fail
A1-03	26.1 34.0 24.3 23.6 21.4	25.9 ± 4.8	Sea Water; Sediment Control[4]	0.271; 0.297	Yes; (Approximate t-Test); Yes; (Students t-Test)	Fail	Fail
A1-07	39.7 65.4 39.3 58.6 39.7	48.5 ± 12.5	Sea Water; Sediment Control[4]	0.507; 0.556	Yes; (Approximate t-Test); Yes; (Approximate t-Test)	Fail	Fail
A2-13	52.9 52.5 76.1 56.8 77.9	63.3 ± 12.7	Sea Water; Sediment Control[4]	0.661; 0.725	Yes; (Approximate t-Test); Yes; (Approximate t-Test)	Fail	Fail;[6] Pass
A2-18	66.5 48.2 34.7 62.2 66.8	55.7 ± 14.0	Sea Water; Sediment Control[4]	0.582; 0.638	Yes; (Approximate t-Test); Yes; (Approximate t-Test)	Fail	Fail
A2-21	51.8 43.2 44.3 49.0 42.5	46.2 ± 4.0	Sea Water; Sediment Control[4]	0.483; 0.529	Yes; (Approximate t-Test); Yes; (Approximate t-Test)	Fail	Fail

Table 3-13. Batch 2: Larval Development Bioassay (Mytilus sp.) Results and Evaluation Guidelines (continued).

Sample ID	Percent Normal Survival[1]	Mean Normal Survival[2]	Reference Sediment[3,4]	Comparison to Reference[5,6]		SQS	CSL
				$N_T \div N_R$	N_T vs N_R SD; p = 0.10: significant? (test)	N_T vs N_R SD (p = 0.10); $N_T \div N_R$ <0.85; Pass/ Fail	N_T vs N_R SD (p = 0.10); $N_T \div N_R$ <0.70; Pass/ Fail
A2-25	63.3 68.3 60.4 60.0 45.7	59.5 ± 8.4	Sea Water; Sediment Control[4]	0.622; 0.681	Yes; (Approximate t-Test); Yes; (Students t-Test)	Fail	Fail
A3-07B-S	33.6 47.2 39.7 36.1 49.7	41.2 ± 7.0	Sea Water; Sediment Control[4]	0.431; 0.472	Yes; (Approximate t-Test); Yes; (Approximate t-Test)	Fail	Fail
A4-08B-S	30.0 26.4 25.0 20.7 28.9	26.2 ± 3.7	Sea Water; Sediment Control[4]	0.274; 0.300	Yes; (Approximate t-Test); Yes; (Students t-Test)	Fail	Fail

Notes:

N normal development; SD = statistically different

SQS sediment quality standards; CSL = cleanup screening level; n/a = not applicable

Subscripts: R = reference; T = test sediment

Pale yellow shading indicates a SQS failure

Rose shading indicated a CSL failure

Light blue shading indicates a discrepancy between the interpretive comparisons

1. Percent normal survivors observed in individual replicates.
2. Mean percent normal survivors ± standard deviation observed in test sample. All reference and test sediment results are normalized to seawater control.
3. Reference, background, or control sediment used for comparison.
4. The sea water and sediment controls were both used for interpretation since the grain-size appropriate reference sediment did not meet the performance criteria.
5. Comparison to reference includes the numeric result for the comparative criteria, the result of the statistical test, and the statistical test used. All statistics were conducted using BioStat (DMMP/SMS Bioassay Statistics Program; Beta v4.1). All larval development data were arcsine transformed for statistical analysis, unless indicated otherwise.
6. Comparison to seawater control listed first; comparison to sediment control listed second.

3.5.6 Juvenile Polychaete Growth Bioassay

The juvenile polychaete growth tests were initiated on October 23, 2008, using the test organism (*N. arenaceodentata*) obtained from Dr. Donald Reish, California State University, Long Beach, California. The results of the juvenile polychaete growth bioassay are presented in Table 3–14. The results of the juvenile polychaete growth bioassay ranged from 0.356 to 0.705 mean individual growth (mg/individual/day) for the test sediments. Two of the 17 test sediments (A2-14 and A2-21) failed the SQS biological interpretive criteria for the juvenile polychaete growth test. All of the test sediments met the CSL biological interpretive criteria for the juvenile polychaete growth test. The bioassay results are displayed in Figures 3–31 and 3–32).

Table 3-14. Juvenile Polychaete Growth Bioassay (*N. arenaceodentata*) Results and Evaluation Guidelines

Sample ID	MIG [1]	Mean MIG[2]	Reference Sediment[3]	Comparison to Reference[4]		SQS	CSL
				MIG_T/MIG_R	MIG_T vs MIG_R SD; p = 0.05: significant?; (test)	MIG_T vs MIG_R SD (p = 0.05); MIG_T/MIG_R <0.70	MIG_T vs MIG_R SD (p = 0.05); MIG_T/MIG_R <0.50
						Pass/ Fail	Pass/ Fail
Negative Control	0.502 0.653 0.574 0.688 0.753	0.634 ± 0.1	n/a	n/a	n/a	n/a	n/a
Reference CR-22-S	0.454 0.330 0.765 0.696 0.861	0.621 ± 0.2	n/a	n/a	n/a	n/a	n/a
Reference CR-23-S	0.413 0.698 0.631 0.598 0.550	0.578 ± 0.1	n/a	n/a	n/a	n/a	n/a
Reference CR-20/24-S	0.696 0.568 0.787 0.554 0.778	0.677 ± 0.1	n/a	n/a	n/a	n/a	n/a
A1-01	0.553 0.456 0.341 0.543 0.573	0.493 ± 0.1	CR-23-S	0.853	No (Students t-Test)	Pass	Pass
A1-03	0.730 0.413 0.500 0.556 0.532	0.546 ± 0.1	CR-23-S	0.945	No (Students t-Test)	Pass	Pass

Table 3-14. Juvenile Polychaete Growth Bioassay (*N. arenaceodentata*) Results and Evaluation Guidelines (continued).

Sample ID	MIG [1]	Mean MIG[2]	Reference Sediment[3]	Comparison to Reference[4]		SQS	CSL
				MIG_T/MIG_R	MIG_T vs MIG_R SD; p = 0.05: significant?; (test)	MIG_T vs MIG_R SD (p = 0.05); MIG_T/MIG_R <0.70	MIG_T vs MIG_R SD (p = 0.05); MIG_T/MIG_R <0.50
						Pass/ Fail	Pass/ Fail
A1-07	0.480 0.706 0.679 0.716 0.945	0.705 ± 0.2	CR-20/24-S	1.041	No (Students t-Test)	Pass	Pass
A1-10	0.724 0.561 0.467 0.688 0.524	0.593 ± 0.1	CR-23-S	1.026	No (Students t-Test)	Pass	Pass
A1-16	0.623 0.675 0.642 0.364 0.428	0.546 ± 0.1	CR-22-S	0.879	No (Students t-Test)	Pass	Pass
A1-24	0.742 0.585 0.905 0.498 0.572	0.660 ± 0.2	CR-23-S	1.142	No (Students t-Test)	Pass	Pass
A2-10	0.721 0.832 0.678 0.424 0.556	0.642 ± 0.2	CR-23-S	1.111	No (Students t-Test)	Pass	Pass
A2-11	0.443 0.333 0.609 0.451 0.275	0.422 ± 0.1	CR-22-S	0.680	No (Students t-Test)	Pass	Pass

Table 3-14. Juvenile Polychaete Growth Bioassay (*N. arenaceodentata*) Results and Evaluation Guidelines (continued).

Sample ID	MIG [1]	Mean MIG[2]	Reference Sediment[3]	Comparison to Reference[4]		SQS	CSL
				MIG_T/MIG_R	MIG_T vs MIG_R SD; p = 0.05: significant?; (test)	MIG_T vs MIG_R SD (p = 0.05); MIG_T/MIG_R <0.70	MIG_T vs MIG_R SD (p = 0.05); MIG_T/MIG_R <0.50
						Pass/ Fail	Pass/ Fail
A2-13	0.575 0.373 0.631 0.469 0.354	0.480 ± 0.1	CR-20/24-S	0.709	Yes (Students t-Test)	Pass	Pass
A2-14	0.372 0.344 0.523 0.263 0.281	0.356 ± 0.1	CR-23-S	0.616	Yes (Students t-Test)	Fail	Pass
A2-18	0.636 0.565 0.529 0.406 0.694	0.566 ± 0.1	CR-23-S	0.979	No (Students t-Test)	Pass	Pass
A2-21	0.429 0.385 0.252 0.481 0.348	0.379 ± 0.1	CR-23-S	0.656	Yes (Students t-Test)	Fail	Pass
A2-25	0.508 0.500 0.553 0.585 0.540	0.537 ± 0.0	CR-23-S	0.929	No (Students t-Test)	Pass	Pass
A2-36	0.753 0.197 0.349 0.567 0.505	0.474 ± 0.2	CR-23-S	0.820	No (Students t-Test)	Pass	Pass

Table 3-14. Juvenile Polychaete Growth Bioassay (*N. arenaceodentata*) Results and Evaluation Guidelines (continued).

Sample ID	MIG [1]	Mean MIG[2]	Reference Sediment[3]	Comparison to Reference[4]		SQS	CSL
				MIG_T/MIG_R	MIG_T vs MIG_R SD; p = 0.05: significant?; (test)	MIG_T vs MIG_R SD (p = 0.05); MIG_T/MIG_R <0.70	MIG_T vs MIG_R SD (p = 0.05); MIG_T/MIG_R <0.50
						Pass/ Fail	Pass/ Fail
A3-05E	0.366 0.805 0.261 0.479 0.354	0.453 ± 0.2	CR-22-S	0.729	No (Students t-Test)	Pass	Pass
A3-07B	0.496 0.666 0.624 0.615 0.223	0.525 ± 0.2	CR-23-S	0.908	No (Students t-Test)	Pass	Pass
A4-08B	0.513 0.557 0.380 0.367 0.241	0.412 ± 0.1	CR-23-S	0.713	Yes (Students t-Test)	Pass	Pass

Notes:
MIG mean individual growth rate (mg/individual/day)
SD statistically different
SQS sediment quality standards
CSL cleanup screening level
n/a not applicable
Subscripts: R = reference; T = test sediment
Pale yellow shading indicates a SQS failure

1. Mean individual growth per replicate (mg/individual/day).
2. Mean individual growth ± standard deviation for sample (mg/individual/day).
3. Reference sediment used for comparison.
4. Comparison to reference includes the numeric result for the comparative criteria, the result of the statistical test, and the statistical test used. All statistics were conducted using BioStat (DMMP/SMS Bioassay Statistics Program; Beta v4.1). All juvenile polychaete growth data were log10 transformed for statistical analysis unless otherwise noted.
5. Rankit transformation used due to non-normality and non-homoscedasticity.

3.5.7 Microtox Bioluminescence Bioassay

The Microtox bioluminescence bioassays were run in six different batches on November 3 through 4, 2008, at the Nautilus Environmental biological laboratory, in Fife, Washington using the test organism (*V. fischeri*) obtained from Strategic Diagnosis, Inc. The results of the Microtox bioassay are presented in Table 3–15. Reference samples tested in each batch were selected by the biological laboratory and were not based on grain size comparisons. The results of the Microtox bioluminescence bioassay ranged from 0.544 to 1.411 mean change in light output after 15 minutes for the test sediments. Three of the 17 test sediments (A1-10, A2-14, and A2-36) failed the SQS biological interpretive criteria for Microtox bioluminescence test. No SMS criteria exist for CSL comparison using Microtox data. The bioassay results are displayed in Figures 3–31 and 3–32).

Table 3-15. Microtox Bioluminescence Bioassay (*V. fisheri*) Results and Evaluation Guidelines

Sample ID	I_{15}[1]	Mean I_{15}[2]	Reference Sediment[3]	Comparison to Reference[4]		SQS[5]
				TI_{15}/RI_{15}	TI_{15} vs RI_{15} SD; p = 0.05: significant?; (test)	TI_{15} vs RI_{15} SD (p = 0.05); TI_{15}/RI_{15} <0.80
						Pass/ Fail
Batch 1						
Negative Control	0.87 0.80 0.85 0.91 0.83	0.85 ± 0.04	n/a	n/a	n/a	n/a
Reference CR-22-S	0.92 0.89 0.90 0.89 0.91	0.90 ± 0.01	n/a	n/a	n/a	n/a
A3-05E	0.83 0.79 0.78 0.87 0.83	0.82 ± 0.03	CR-22-S	0.911	Yes; (Approximate t-Test)	Pass
A2-14	0.63 0.61 0.64 0.63 0.64	0.63 ± 0.01	CR-22-S	0.700	Yes; (Students t-Test)	Fail[6]
A2-36	0.52 0.46 0.43 0.53 0.53	0.49 ± 0.05	CR-22-S	0.544	Yes; (Approximate t-Test)	Fail[6]

Table 3-15. Microtox Bioluminescence Bioassay (*V. fisheri*) Results and Evaluation Guidelines (continued)

Sample ID	I_{15}[1]	Mean I_{15}[2]	Reference Sediment[3]	Comparison to Reference[4]		SQS[5]
				TI_{15}/RI_{15}	TI_{15} vs RI_{15} SD; p = 0.05: significant?; (test)	TI_{15} vs RI_{15} SD (p = 0.05); TI_{15}/RI_{15} <0.80
						Pass/ Fail
Batch 2						
Control	0.86 0.88 0.81 0.86 0.83	0.85 ± 0.03	n/a	n/a	n/a	n/a
CR-22-S	0.96 0.96 0.99 0.96 0.97	0.97 ± 0.01	n/a	n/a	n/a	n/a
A1-24	0.93 0.94 0.93 0.94 0.92	0.93 ± 0.01	CR-22-S	1.094	Yes; (Students t-Test)	Pass
A1-16	0.94 0.94 0.98 0.95 0.95	0.95 ± 0.02	CR-22-S	1.118	Yes; (Mann-Whitney)	Pass
A2-10	0.92 0.95 0.94 0.93 0.93	0.93 ± 0.01	CR-22-S	1.094	Yes; (Students t-Test)	Pass
A2-11	0.94 0.91 0.90 0.89 0.92	0.91 ± 0.02	CR-22-S	1.071	Yes; (Students t-Test)	Pass
Batch 3						
Control	0.77 0.80 0.84 0.87 0.87	0.83 ± 0.04	n/a	n/a	n/a	n/a
CR-20/24-S	0.72 0.74 0.74 0.73 0.71	0.73 ± 0.01	n/a	n/a	n/a	n/a

Table 3-15. Microtox Bioluminescence Bioassay (*V. fisheri*) Results and Evaluation Guidelines (continued)

Sample ID	I_{15}[1]	Mean I_{15}[2]	Reference Sediment[3]	Comparison to Reference[4]		SQS[5]
				TI_{15}/RI_{15}	TI_{15} vs RI_{15} SD; p = 0.05: significant?; (test)	TI_{15} vs RI_{15} SD (p = 0.05); TI_{15}/RI_{15} <0.80 Pass/ Fail
A2-13	1.02 1.00 1.08 1.04 1.01	1.03 ± 0.03	CR-20/24-S	1.411	No; (Students t-Test)	Pass
Batch 4						
Control	0.81 0.81 0.88 0.83 0.82	0.83 ± 0.03	n/a	n/a	n/a	n/a
CR-23-S	0.87 0.92 0.91 0.93 0.91	0.91 ± 0.02	n/a	n/a	n/a	n/a
A2-18	0.88 0.85 0.86 0.86 0.91	0.87 ± 0.03	CR-23-S	0.956	Yes; (Students t-Test)	Pass
Batch 5						
Control	0.86 0.78 0.80 0.81 0.84	0.82 ± 0.03	n/a	n/a	n/a	n/a
CR-23-S	0.85 0.85 0.85 0.86 0.89	0.86 ± 0.02	n/a	n/a	n/a	n/a
A2-25	0.79 0.83 0.81 0.82 0.85	0.82 ± 0.02	CR-23-S	0.953	Yes; (Students t-Test)	Pass
A2-21	0.85 0.86 0.86 0.83 0.90	0.86 ± 0.03	CR-23-S	1.000	No; (Students t-Test)	Pass

Table 3-15. Microtox Bioluminescence Bioassay (*V. fisheri*) Results and Evaluation Guidelines (continued)

Sample ID	I_{15}[1]	Mean I_{15}[2]	Reference Sediment[3]	Comparison to Reference[4]		SQS[5]
				TI_{15}/RI_{15}	TI_{15} vs RI_{15} SD; p = 0.05: significant?; (test)	TI_{15} vs RI_{15} SD (p = 0.05); TI_{15}/RI_{15} <0.80
						Pass/ Fail
A1-10	0.60 0.55 0.51 0.59 0.57	0.57 ± 0.04	CR-23-S	0.663	Yes; (Approximate t-Test)	Fail
A1-07	0.83 0.73 0.77 0.78 0.82	0.79 ± 0.04	CR-23-S	0.919	Yes; (Approximate t-Test)	Pass
Batch 6						
Control	0.86 0.81 0.85 0.85 0.85	0.85 ± 0.02	n/a	n/a	n/a	n/a
CR-23-S	0.96 0.95 0.95 0.95 0.94	0.95 ± 0.01	n/a	n/a	n/a	n/a
A3-07B	0.90 0.85 0.82 0.90 0.84	0.86 ± 0.04	CR-23-S	0.905	Yes; (Approximate t-Test)	Pass
A4-08B	0.86 0.89 0.91 0.87 0.89	0.88 ± 0.02	CR-23-S	0.926	Yes; (Approximate t-Test)	Pass
A1-01	0.91 0.99 0.94 0.97 0.97	0.96 ± 0.03	CR-23-S	1.011	No; (Approximate t-Test)	Pass
A1-03	1.00 0.96 0.96 0.93 0.95	0.96 ± 0.03	CR-23-S	1.011	No; (Students t-Test)	Pass

Notes:

I change in light output; I_{15}= change in light output after 15 minutes; T =Test sediment; R = Reference sediment

SD statistically different

SQS sediment quality standards

n/a not applicable

Pale yellow shading indicates a SQS failure

1. Replicate change in light output after 15 minutes.
2. Mean change in light output after 15 minutes ± standard deviation for sample.
3. Reference sediment used for comparison as selected by laboratory.
4. Comparison to reference includes the numeric result for the comparative criteria, the result of the statistical test, and the statistical test used. All statistics were conducted using BioStat (DMMP/SMS Bioassay Statistics Program; Beta v4.1). All Microtox data were arcsine transformed for statistical analysis, unless indicated otherwise.
5. No SMS criteria exist for CSL comparison using Microtox data.
6. Data may be skewed due to excessive turbidity in the sample.

3.5.8 Summary of Bioassay Results

A summary of the results for the suite of four bioassays is presented in Table 3–16 and Figure 3-32. If all four bioassays pass the SMS biological interpretive criteria (SQS and CSL), the location is considered to have passed the SMS standards. If one of four bioassays fails the SQS biological interpretive criteria, the location is considered to have failed SMS SQS criteria. If two or more bioassays fail the SQS biological interpretive criteria or one or more bioassays fail the CSL biological interpretive criteria, the location is considered to have failed the SMS CSL criteria. As a result of the biological testing, four of the 17 locations passed the SMS criteria, and 13 locations failed the SMS CSL criteria. Of the 13 locations that failed the CSL, four locations demonstrated adverse toxic effects in multiple bioassays, whereas nine locations that failed were due to CSL failures for the larval development bioassay. Four locations that failed the larval development CSL interpretive criteria included a discrepancy in interpretation between the two batches tested and/or control (seawater or sediment) used for comparative purposes. The summary table and figure defaults to the more conservative interpretation for the final SMS determination.

Table 3-16. Summary of Bioassay Results

Station ID	Amphipod Mortality	Larval Development	Juvenile Polychaete Growth	Microtox Bioluminescence	SMS Results[1]
A1-01	**Pass**	**Fails SQS/Pass; Fails CSL**	**Pass**	**Pass**	Fails CSL
A1-03	**Pass**	**Fails CSL; Fails CSL**	**Pass**	**Pass**	Fails CSL
A1-07	**Pass**	**Fails SQS/CSL; Fails CSL**	**Pass**	**Pass**	Fails CSL
A1-10	**Pass**	**Fails CSL**	**Pass**	**Fail SQS**	Fails CSL
A1-16	**Pass**	**Pass**	**Pass**	**Pass**	**Pass**
A1-24	**Pass**	**Fails CSL**	**Pass**	**Pass**	Fails CSL
A2-10	**Pass**	**Pass**	**Pass**	**Pass**	**Pass**
A2-11	**Pass**	**Pass**	**Pass**	**Pass**	**Pass**
A2-13	**Pass**	**Fails SQS/CSL; Fails CSL**	**Pass**	**Pass**	Fails CSL
A2-14	**Pass**	**Fails CSL**	**Fails SQS**	**Fails SQS**	Fails CSL
A2-18	**Pass**	**Fails SQS/Pass; Fails CSL**	**Pass**	**Pass**	Fails CSL
A2-21	**Pass**	**Fails CSL; Fails CSL**	**Fails SQS**	**Pass**	Fails CSL
A2-25	**Pass**	**Fails SQS; Fails CSL**	**Pass**	**Pass**	Fails CSL
A2-36	**Pass**	**Fails CSL**	**Pass**	**Fails SQS**	Fails CSL
A3-05E	**Pass**	**Pass**	**Pass**	**Pass**	**Pass**
A3-07B	**Pass**	**Fails CSL; Fails CSL**	**Pass**	**Pass**	Fails CSL
A4-08B	**Pass**	**Fails CSL; Fails CSL**	**Pass**	**Pass**	Fails CSL

	Pale yellow shading indicates a SQS failure
	Rose shading indicated a CSL failure
	Light blue shading indicates a discrepancy between the interpretive comparisons

Notes:

1. The SMS results column provides a summary of the results for the suite of three bioassays. 'Pass' indicates all four bioassays pass the SMS biological interpretive criteria. If one of four bioassays fails the SQS biological interpretive criteria, the location fails SQS. If two or more bioassays fail the SQS biological interpretive criteria or one or more bioassays fail the CSL biological interpretive criteria, the location fails the CSL.

3.6 Tissue Collection and Chemistry

A total of 13 tissue samples were chemically analyzed for metals, Aroclor PCBs, dioxin/furan congeners, and lipids. The samples included three Dungeness crab meat, three Dungeness crab hepatopancreas, three English sole, two Eastern softshell clam, and two purple varnish clam samples (one replicate sample from each area) (see Table 2–3). The remaining samples were archived for potential future analysis. The Dungeness crab and English sole samples were collected by trawls at three locations in Port Gardner, the Eastern softshell clams were collected by hand in two areas with mud flats in the Snohomish River, and the purple varnish clams were collected by hand in two areas in southern Port Gardner (Figure 2–3). This section describes the analytical results for the tissue samples and any relationship present between species or location. Summary tables for the tissue results can be found in Appendix D.

3.6.1 Metals

The concentration of metals in tissues was generally low for all samples and varied mainly by species. Lead was undetected in all samples. Mercury was detected at low concentrations in 12 of 13 samples (mean of 0.02 mg/kg) and did not vary greatly by species. The Dungeness crab samples generally had higher concentrations of some metals in comparison to the English sole and clam tissue samples (Table 3–17). The crab hepatopancreas samples contained the highest concentrations of cadmium (mean of 1.03 mg/kg wet weight [ww]), copper (mean of 55.6 mg/kg ww), and silver (mean of 0.49 mg/kg ww). The crab meat samples contained the highest concentrations of zinc (mean of 38.4 mg/kg ww). In all cases, the hepatopancreas samples had the highest percentage of lipids. Given that metals are not lipophilic, the lipid content had little effect on concentrations.

Metals concentrations in the English sole and clam tissues were generally lower than the crab tissues, with the exception of chromium (Table 3–18). Chromium concentrations in the English sole and clam tissues (mean of 0.67 mg/kg ww) were approximately four times as high as the crab tissues (mean of 0.16 mg/kg ww). The Eastern softshell clam had the highest chromium concentration (mean of 0.8 mg/kg ww) of all species. Metals in the clam tissues did not vary greatly between species with the exception of cadmium and zinc. Cadmium was undetected in the purple varnish clams but detected in the Eastern softshell clams (mean of 0.08 mg/kg ww). Zinc concentrations were twice as high in the purple varnish clams (mean of 29.0 mg/kg ww) compared to the Eastern softshell clams (13.7 mg/kg ww).

Table 3-17. Port Gardner Dungeness Crab Tissue Chemistry

	A1-T3			A1-T3			A2-T1			A2-T1			A2-T2			A2-T2		
	Hepato	**LQ**	**VQ**	**Meat**	**LQ**	**VQ**	**Hepato**	**LQ**	**VQ**	**Meat**	**LQ**	**VQ**	**Hepato**	**LQ**	**VQ**	**Meat**	**LQ**	**VQ**
Lipid	7.39			0.24			13.8			0.238			4.77			0.198		
Metals in mg/kg ww																		
Arsenic	5			5			3			3			3			3		
Cadmium	1.18			0.08			1.39			0.11			0.52			0.04		
Chromium	0.2		J	0.05	U	UJ	0.4		J	0.1		J	0.1		J	0.1		J
Copper	54.8			12.4			50.3			16.2			61.8			11.9		
Lead	0.04	U	U	0.04	U	U	0.08	U	U	0.04	U	U	0.04	U	U	0.04	U	U
Mercury	0.044			0.044			0.04			0.07			0.02			0.03		
Selenium																		
Silver	0.74		J	0.11		J	0.3		J	0.11		J	0.43		J	0.09		J
Zinc	36.4			45.3			35.7			38.3			17.8			31.5		
PCBs in µg/kg ww																		
Aroclor-1221	6.6	U	U	6.6	U	U	6.6	U	U	6.6	U	U	6.5	U	U	6.6	U	U
Aroclor-1232	6.6	U	U	6.6	U	U	6.6	U	U	6.6	U	U	6.5	U	U	6.6	U	U
Aroclor-1242	6.6	U	U	6.6	U	U	6.6	U	U	6.6	U	U	6.5	U	U	6.6	U	U
Aroclor-1016	6.6	U	U	6.6	U	U	6.6	U	U	6.6	U	U	6.5	U	U	6.6	U	U
Aroclor-1248	6.6	Y	U	6.6	U	U	6.6	Y	U	6.6	U	U	6.5	Y	U	6.6	U	U
Aroclor-1254	85		J	6.6	U	U	130		NJ	6.6	U	U	52		NJ	6.6	U	U
Aroclor-1260	74			6.6	U	U	130			6.6	U	U	41			6.6	U	U
Aroclor-1262	6.6	U	U	6.6	U	U	6.6	U	U	6.6	U	U	6.5	U	U	6.6	U	U
Aroclor-1268	6.6	U	U	6.6	U	U	6.6	U	U	6.6	U	U	6.5	U	U	6.6	U	U
Total PCBs	159		J	6.6	U	U	260		NJ	6.6	U	U	93		NJ	6.6	U	U
Dioxin/Furan pg TEQ/g ww																		
TEQ 1/2 DL	3.48			0.155			4.38			0.0886			3.6			0.136		
Axys Lipids	9.97			0.28			13.1			0.23			11.5			0.26		

Hepato Hepatopancreas
ww wet weight
DL detection limit
LQ laboratory qualifier – data qualifier applied by the laboratory based on the analytical method
VQ validation qualifier – data qualifier applied by independent validation of laboratory results
U The compound was analyzed for, but was not detected ("non-detect") at or above the MDL.

J	The analyte was positively identified; the associated value is the approximate concentration.
Y	The analyte is not detected, but the reporting limit has been raised due to chromatographic interference.
NJ	The analysis indicates the presence of a "tentatively identified" analyte. Reported value is approximate.
A1-T3	East Waterway Trawl Location
A2-T1	Mouth of the Snohomish River Trawl Location
A2-T2	Snohomish River Delta Trawl Location

Table 3-18. English Sole and Clam Tissue Chemistry

	A1-T3			A2-T1*			A2-T2			A1-31B			A1-46B			A2-18B			A2-25B		
	English Sole	LQ	VQ	English Sole	LQ	VQ	English Sole	LQ	VQ	Varnish Clam	LQ	VQ	Varnish Clam	LQ	VQ	Eastern Softshell	LQ	VQ	Eastern Softshell	LQ	VQ
Lipid	0.158			3.27			1.63			0.534			0.497			1.8			0.0593		
Metals in mg/kg ww																					
Arsenic	2			1			3			1			0.1	U	U	2			2		
Cadmium	0.004	U	U	0.004	U	U	0.004	U	U	0.004	U	U	0.004	U	U	0.07			0.08		
Chromium	0.3		J	0.6		J	0.5		J	0.8			0.5			0.7			0.8		
Copper	1.02			2.04			1.31			2.9			2.21			2.23			2.69		
Lead	0.04	U	U	0.04	U	U	0.04	U	U	0.04	U	U	0.04	U	U	0.04	U	U	0.04	U	U
Mercury	0.01			0.02			0.04			0.01			0.0009	U	U	0.01			0.01		
Silver	0.022	U	UJ	0.022	U	UJ	0.022	U	UJ	0.022	U	UJ	0.022	U	UJ	0.021	U	UJ	0.021	U	UJ
Zinc	14.9			13.7			15.3			35.2			22.7			14.2			13.1		
PCBs in µg/kg ww																					
Aroclor-1221	6.6	U	U	20	U	U	6.6	U	U	6.6	U	U	6.6	U	U	6.6	U	U	6.6	U	U
Aroclor-1232	6.6	U	U	20	U	U	6.6	U	U	6.6	U	U	6.6	U	U	6.6	U	U	6.6	U	U
Aroclor-1242	6.6	U	U	20	U	U	6.6	U	U	6.6	U	U	6.6	U	U	6.6	U	U	6.6	U	U
Aroclor-1016	6.6	U	U	20	U	U	6.6	U	U	6.6	U	U	6.6	U	U	6.6	U	U	6.6	U	UJ
Aroclor-1248	6.6	U	U	20	U	U	6.6	U	U	6.6	U	U	6.6	U	U	6.6	U	U	6.6	U	U
Aroclor-1254	6.6	U	U	20	U	U	6.6	U	U	6.6	U	U	6.6	U	U	6.6	U	U	6.6	U	U
Aroclor-1260	6.6	U	U	20	U	U	6.6	U	U	6.6	U	U	6.6	U	U	6.6	U	U	6.6	U	U
Aroclor-1262	6.6	U	U	20	U	U	6.6	U	U	6.6	U	U	6.6	U	U	6.6	U	U	6.6	U	U
Aroclor-1268	6.6	U	U	20	U	U	6.6	U	U	6.6	U	U	6.6	U	U	6.6	U	U	6.6	U	U
Total PCBs	6.6	U	U	20	U	U	6.6	U	U	6.6	U	U	6.6	U	U	6.6	U	U	6.6	U	U
Dioxin/Furan pg TEQ/g ww																					
TEQ 1/2 DL	0.306			0.128			0.214			0.104			0.0258			0.034			0.0156		
Axys Lipids	2.21			3.65			2.37			0.98			1.14			0.68			0.33		

* Aroclor PCBs were reanalyzed because Aroclor 1221 was tentatively identified in the sample with qualifications. All Aroclors were undetected and the reanalysis results are report (see Appendix G).
ww wet weight
DL detection limit
LQ laboratory qualifier
VQ validation qualifier
U The compound was analyzed for, but was not detected ("non-detect") at or above the MDL.
J The analyte was positively identified; the associated value is the approximate concentration.
P The analyte was detected on both columns, but values differ by >40% with no chromatographic interference.
NJ The analysis indicates the presence of a "tentatively identified" analyte. Reported value is approximate.
A1-T3 East Waterway Trawl Location
A2-T1 Mouth of the Snohomish River Trawl Location
A2-T2 Snohomish River Delta Trawl Location

3.6.2 Aroclor PCBs

Aroclor PCBs were undetected in all tissue samples with the exception of the Dungeness crab hepatopancreas samples and initially in one English sole sample (Tables 3–17 and 3–18). Aroclors 1254 and 1260 were detected in all three hepatopancreas samples. Aroclor 1221 was initially detected in the English sole sample from trawl location A2-T1. Though Aroclor 1221 was reported at 330 µg/kg ww, it was qualified "P" by the analytical laboratory, and "NJ" during validation. These qualifiers indicate that the results from the two columns used in the analysis differed by more than 60 percent, and that the reported concentration for Aroclor 1221 was tentatively identified at an approximate concentration. Subsequently, the sample was reanalyzed in duplicate and Aroclor 1221 was not detected in the reanalysis (Appendix G). Total PCBs in the hepatopancreas samples ranged from a low of 93 µg/kg ww at trawl location A2-T2 (Snohomish Delta) to a high of 260 µg/kg ww at A2-T1 (mouth of the Snohomish River).

3.6.3 Dioxin/Furan Congeners

Dioxin/furan congeners were analyzed in all tissue samples and concentrations were largely dependent upon lipid content for the different species. TEQ values calculated using one-half the detection limit for undetected congeners were highest in the Dungeness crab hepatopancreas samples and lowest in the clam tissue samples (Tables 3–17 and 3–18). Hepatopancreas tissue had the highest concentrations, reaching 4.38 pg TEQ/g and 13.1 percent lipid at A2-T1 (mouth of the Snohomish River). Dioxin/furan concentrations in crab meat samples ranged from 0.155 pg TEQ/g at A1-T3 (East Waterway) to 0.089 pg TEQ/g at A2-T1 (mouth of the Snohomish River). Dioxin/furan concentrations in whole body English sole tissues were slightly higher, with an average of 0.22 pg TEQ/g. The lowest concentrations were found in clam tissues, with an average of 0.045 pg TEQ/g for the Eastern softshell and varnish clams.

3.6.4 Plant Tissues

Stems of the tule plant and the lower stems/roots of the cattail were analyzed for metals, Aroclor PCBs, and pesticides. These two plants are culturally important estuarine plant species identified by the Tulalip Tribe. Plant tissues were collected and analyzed from two locations (A3-14 and A3-15) within the Snohomish River estuary (Figure 2–3). Silverweed was also identified as a culturally important species, but not present at the two sampling locations.

All metals were undetected in the plant tissues with the exception of low concentrations of chromium, copper, and zinc (Table 3–19). The cattail sample collected at station A3-15 contained the highest concentrations of copper and zinc at 6.3 mg/kg and 9.6 mg/kg ww, respectively. The highest concentration of chromium (2.2 mg/kg ww) was measured in the cattail sample collected at station A3-14. Aroclor PCBs and pesticides were undetected in all samples.

Table 3-19. Port Gardner Plant Tissue Chemistry

	PG-A3-14			PG-A3-14			PG-A3-15			PG-A3-15		
	Cattail	**LQ**	**VQ**	**Tule**	**LQ**	**VQ**	**Cattail**	**LQ**	**VQ**	**Tule**	**LQ**	**VQ**
Metals in mg/kg ww												
Arsenic	0.5	U	UJ	0.51	U	UJ	0.48	U	UJ	0.51	U	UJ
Cadmium	0.019	U	UJ	0.02	U	UJ	0.018	U	UJ	0.02	U	UJ
Chromium	2.2			0.274	U	U	1.9			0.7		
Copper	2.5		J	0.8		J	6.3		J	0.9		J
Lead	0.19	U	U	0.2	U	U	0.18	U	U	0.2	U	U
Mercury	0.0036	U	U	0.004	U	U	0.0042	U	U	0.004	U	U
Selenium	0.97	U	U	0.99	U	U	0.93	U	U	0.99	U	U
Silver	0.105	U	U	0.108	U	U	0.101	U	U	0.108	U	U
Zinc	7		J	4		J	9.6		J	3		J

ww wet weight
DL detection limit
LQ laboratory qualifier
VQ validation qualifier
U The compound was analyzed for, but was not detected ("non-detect") at or above the MDL.
J The analyte was positively identified; the associated value is the approximate concentration.
UJ The analyte was not detected above the quantitation limit. However, the quantitation limit is considered approximate.

3.7 Dioxin/Furan Congener Profiling

This section describes the dioxin/furan congener profiles and biota sediment accumulation factors (BSAF) as calculated for the sediment and tissue samples. Congener profiles can help determine the potential sources of the dioxin/furan contamination to the sediment, while BSAF values are a measure of the uptake of dioxin/furan contamination by species.

3.7.1 Congener Profiles

Dioxin/furan congeners are unintentionally produced by both natural and anthropogenic activities. Natural sources are more limited and include forest fires and volcanoes. Anthropogenic sources include incomplete combustion of materials in the presence of chloride, chlorine bleaching of pulp and paper, and chlorinated pesticide manufacturing. Dioxin/furan production from each of these sources favors some congener over others, resulting in a unique congener profile, or fingerprint, from each source. The USEPA has created congener profiles for 18 well known sources (Cleverly et al. 1997). In most cases, dioxin/furan contamination at a give location is a result of multiple sources, and statistical un-mixing models are needed to parse out individual source signatures.

For this report, congener profiles of individual samples are presented, and average profiles are compared against those from previous investigations. Congener profiles for individual surface and subsurface samples are plotted in Figure 3-33. Samples where seven or more of the 17 congeners were non-detects were excluded from the figure. Eight of the 15 surface samples were excluded, while two of the five subsurface samples were excluded.

Congener profiles for the seven surface samples were comparable (Figure 3-33-A). In each sample, OCDD made up the bulk of the congener distribution, ranging from 76.6 to 83 percent of the total concentration. 1,2,3,4,6,7,8-HPCDD was the next most prominent congener, with a relative abundance ranging from 9.3 to 11.5 percent. OCDF and 1,2,3,4,6,7,8-HPCDF make up 1.1 to 6.3 percent of the total. No other congener made up more than 2 percent of the total distribution.

The three subsurface samples have congener profiles similar to those of the surface samples, but contain more variability (Figure 3-33-B). OCDD ranges from 69 to 86.6 percent of the congener distribution. OCDF is present in relatively larger amounts, ranging from 3.1 to 9.3 percent. The most notable conger profile is for A1-24-C1-3. This sample is composed of 69 percent OCDD, and 10.6 percent 1,2,3,4-TCDF. This corresponds to a TCDF concentration of 332 pg/g. The next highest concentration was 36 pg/g.

Figure 3-34 shows the average congener profiles of the surface and subsurface sediment from the Port Gardner Sediment investigation compared to the Budd Inlet Sediment Investigation conducted by Ecology in 2007 (SAIC 2008c) and the DMMP Port Gardner dredged material disposal site characterization (SAIC 2008d). Each study shows a consistent profile made up mainly of OCDD and 1,2,3,4,6,7,8-HPCDD. However, there are small deviations from this pattern. For both the Port Gardner and Budd Inlet Sediment Investigations, the congener profiles for the subsurface sediment are more variable. Dechlorination of dioxin/furan congeners in the older, deeper, subsurface sediment may be responsible for the differences in congener profiles.

In the final report for the Budd Inlet sediment investigation, this congener profile was attributed to the pentachlorophenol (PCP) signature (SAIC 2008c; Cleverly et al. 1997). While Port Gardner does not have the same detailed history of PCP usage as Budd Inlet, it is likely the chemical was used in some of the saw mills and wood treatment plants. However, given the greater number of potential dioxin/furan sources at Port Gardner, congener profile analysis using a statistical model may help differentiate sources.

The same criteria used for sediment was used for the tissue samples; congener profiles were not calculated for samples where seven or more of the congeners were non-detects. As a result, congener profiles were only calculated for the three Dungeness crab hepatopancreas samples. The congener profiles for these three samples are shown in Figure 3-35. For comparison, Dungeness hepatopancreas profiles from three samples collected at the Port Gardner disposal site in July 2006 are also included (SAIC 2008b).

The OCDD signature isn't as dominant in hepatopancreas tissue as in sediment. OCDD makes up 11.4, 35, and 33.4 percent of samples A2-T2, A2-T1, and A1-T3, respectively. In the disposal site tissue, OCDD reaches 46.1 percent of the total profile in sample RepC. OCDF is less abundant in tissue as well. In the sediment samples (Figure 3-33), OCDF is present at twice the abundance of 1,2,3,4,6,7,8-HPCDF. In the tissue, this pattern is reversed.

Overall, the congener profile of the tissue indicates greater amounts of lesser chlorinated congeners relative to the sediment. 1,2,3,4,6,7,8-HPCDD ranges from 19.4 to 25.3 percent of the total, and both 1,2,3,6,7,8-HXCDD and 2,3,7,8-TCDF are near or above 10 percent in five of the six samples shown in Figure 3-35. The congener profiles for tissue also show a greater degree of

variability between samples. The standard deviation of OCDD in the surface sediment samples was 2.4 percent. The standard deviation of OCDD for the three samples collected in this investigation is 11.1 percent.

3.7.2 Biota Sediment Accumulation Factors

The differences between the tissue and sediment profiles suggest that dioxin/furan congeners undergo preferential in the crab hepatopancreas. To better understand this uptake, biota sediment accumulation factors (BSAF) were calculated for all tissue samples. BSAF is the ratio of the lipid normalized concentration of each dioxin/furan congener divided by the TOC normalized concentration of that congener in the sediment (Equation 1).

$$BSAF = \frac{C_t / f_l}{C_s / f_{oc}} \qquad \text{(Equation 1)}$$

C_t is the tissue concentration (pg/g ww), f_l is the fraction by weight lipid concentration, C_s is the sediment concentration (pg/g dw), and f_{oc} is the fraction of TOC in the sediment (USEPA 2000).

The BSAF is based on the assumption of equilibrium partitioning between the organic carbon in the tissue and sediment. However, deviations from equilibrium may be caused by metabolism or dechlorination of dioxin/furan congeners by the organism, mass transfer resistance from the sediment, differential biotic uptake, or uptake from an unquantified source (Wong 2000).

Site specific BSAF values were calculated for paired sediment/tissue sample at A1-31B, A1-46B, A2-18B, and A2-25B. For the trawl data, BSAF values were determined by using averaged congener and TOC concentrations for each area (all samples from Focus Area 1 were averaged for use with Focus Area 1 trawls). If a congener was undetected in either the tissue or sediment sample, a BSAF value was not calculated.

BSAF values for crab hepatopancreas are presented in Table 3-20. Congeners with low abundance in the sediment (Figure 3-33) and high abundance in the tissue (Figure 3-35) have the largest BSAF values, indicating greater uptake of dioxin/furan contamination. 2,3,7,8-TCDD, 2,3,7,8-TCDF, and 2,3,4,7,8-PECDF all have BSAF values greater than 0.5 for A2-T1 and A2-T2. In contrast, OCDD and OCDF have BSAF values near zero, indicating a reduced presence of the higher chlorinated dioxin/furan congeners in hepatopancreas relative to sediment. BSAF values in hepatopancreas collected from the Port Gardner disposal site have show similar patterns (SAIC 2008d). BSAF values in A1-T3 are much lower than those from Focus Area 2 trawl samples. This is largely due to the higher dioxin/furan concentrations in Focus Area 1.

Frequent non-detects in the crab muscle and English sole tissue samples make BSAF comparisons between samples and congeners more difficult. From the available data, the same pattern of BSAF values matches the hepatopancreas: The tetra- and penta- congeners in Focus Area 2 have the highest values, and Focus Area 1 has lower BSAF.

BSAF values in bivalve samples are also limited due to non-detects (Table 3-21). Only the penta- and octa -congeners consistently had a BSAF value in each sample. Unlike the crab and English sole, BSAF values are similar for each sample. 1,2,3,4,6,7,8-HPCDF has a BSAF of

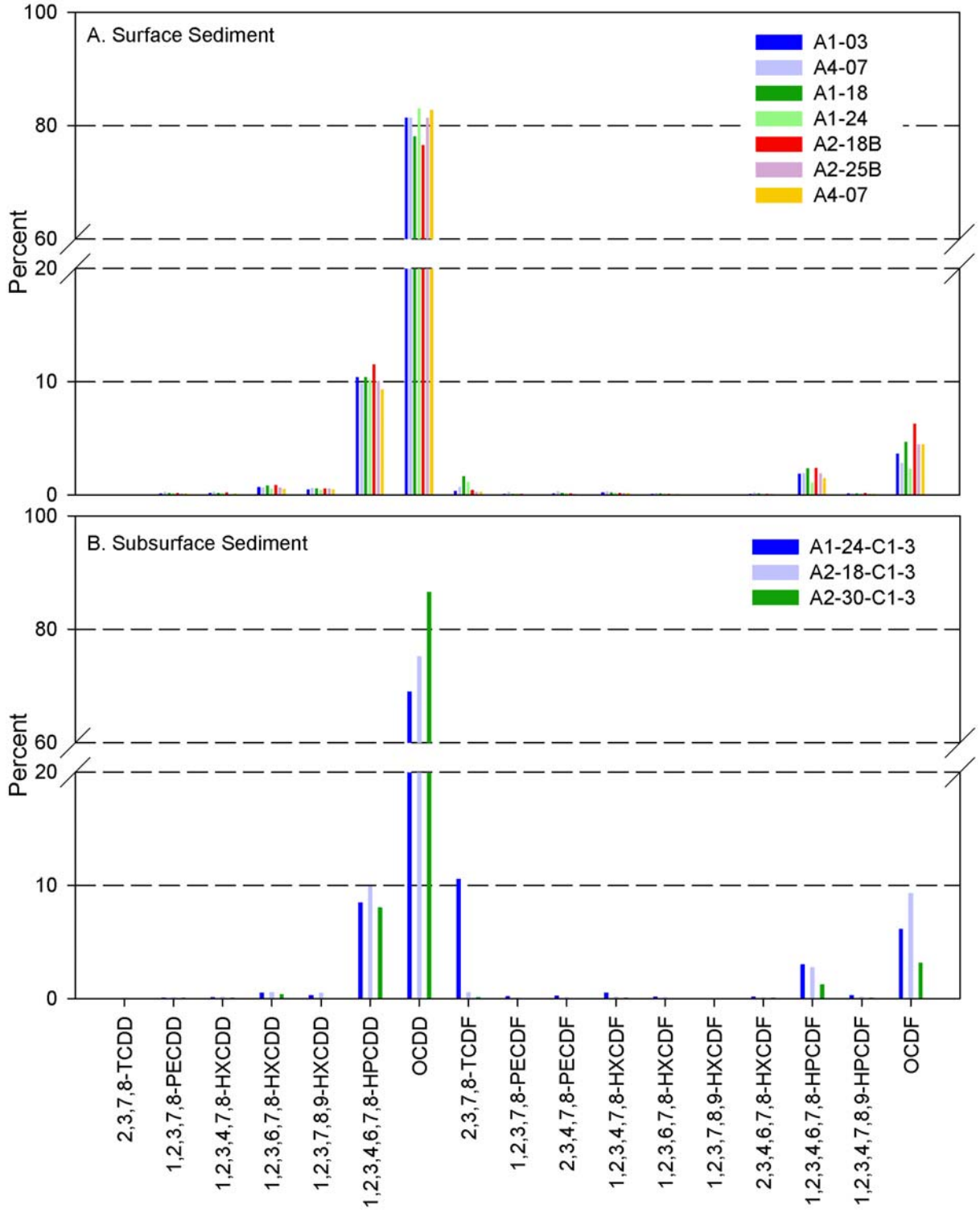
0.39 in A1-31, and a BSAF of 0.27 for OCDF. Data from previous studies indicates that bivalve congener profiles tend to match the sediment profile better than flat fish or crabs, therefore BSAF values are more similar between congeners (SAIC 2008b).

Table 3-20. BSAF Values for Dungeness Crab Hepatopancreas

Congener	A1-T3	A2-T1	A2-T2
Kg TOC per kg lipid	Hepato	Hepato	Hepato
2,3,7,8-TCDD	0.09	0.73	0.68
1,2,3,7,8-PECDD	0.08	0.49	0.41
1,2,3,4,7,8-HXCDD	0.04	0.29	0.36
1,2,3,6,7,8-HXCDD	0.06	0.30	0.27
1,2,3,7,8,9-HXCDD	0.03	0.13	0.17
1,2,3,4,6,7,8-HPCDD	0.01	0.04	0.03
OCDD	0.00	0.01	0.00
2,3,7,8-TCDF	0.08	0.72	0.71
1,2,3,7,8-PECDF	0.03	0.30	0.28
2,3,4,7,8-PECDF	0.05	0.51	0.53
1,2,3,4,7,8-HXCDF	0.02	0.14	0.15
1,2,3,6,7,8-HXCDF	0.02	0.21	0.20
1,2,3,7,8,9-HXCDF	-	-	-
2,3,4,6,7,8-HXCDF	0.02	0.14	0.18
1,2,3,4,6,7,8-HPCDF	0.01	0.03	0.03
1,2,3,4,7,8,9-HPCDF	-	-	-
OCDF	0.00	0.00	0.00

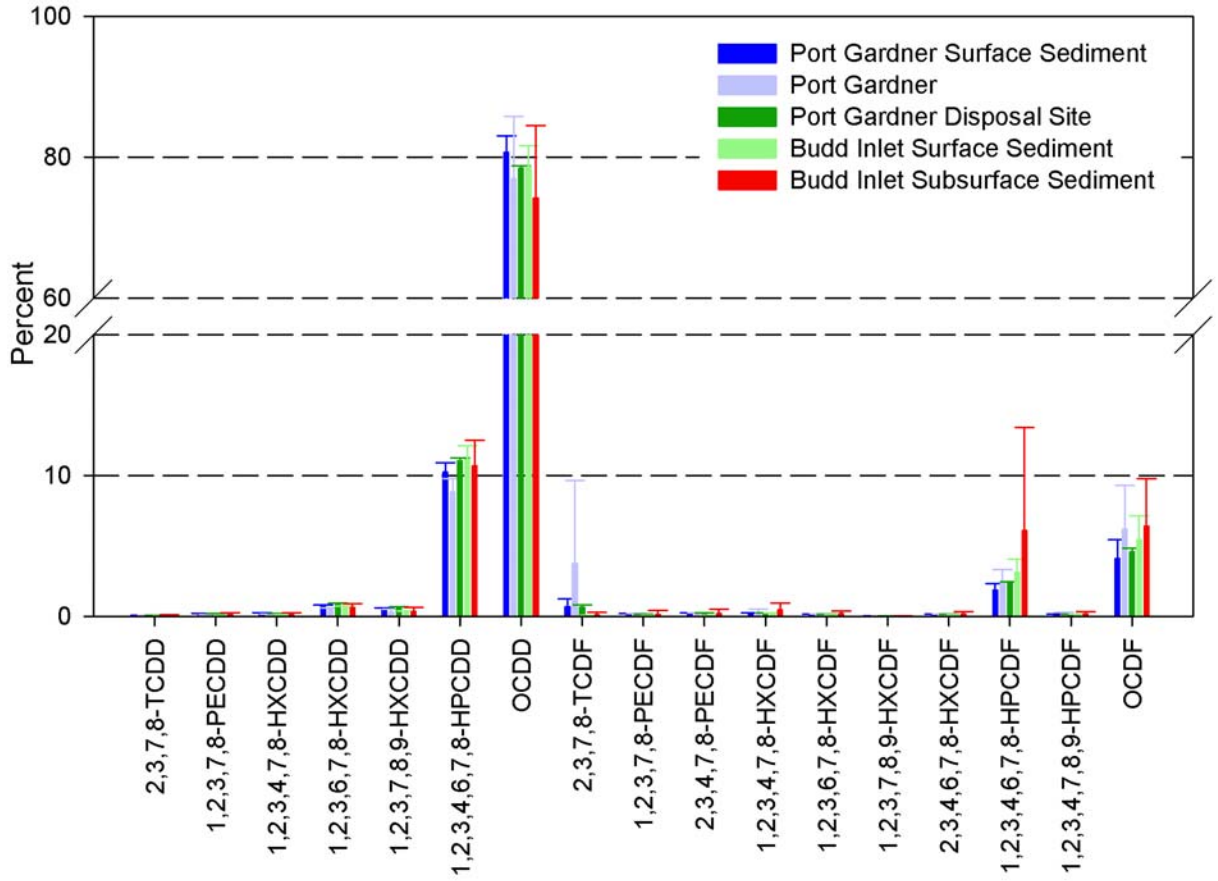
Table 3-21. BSAF Values for Bivalve Samples

Congener	A1-31B	A1-46B	A2-18B	A2-25B
Kg TOC per kg lipid	Varnish Clam	Varnish Clam	Eastern Softshell	Eastern Softshell
1,2,3,6,7,8-HXCDD	-	-	0.08	-
1,2,3,7,8,9-HXCDD	-	-	0.09	-
1,2,3,4,6,7,8-HPCDD	0.27	0.09	0.08	0.16
OCDD	0.22	0.05	0.07	0.15
1,2,3,4,6,7,8-HPCDF	0.39	0.11	0.07	0.16
OCDF	0.37	0.10	0.04	0.15



Note: Samples with seven or more undetected congeners were excluded

Figure 3-33. Congener Profiles for Dioxin/Furan Samples Analyzed at Port Gardner



Note: Error bars represent the standard deviation.

Figure 3-34. Comparison of Average Congener Profiles at Port Gardner to Those at the Port Gardner Disposal Site and the Budd Inlet Sediment Investigation

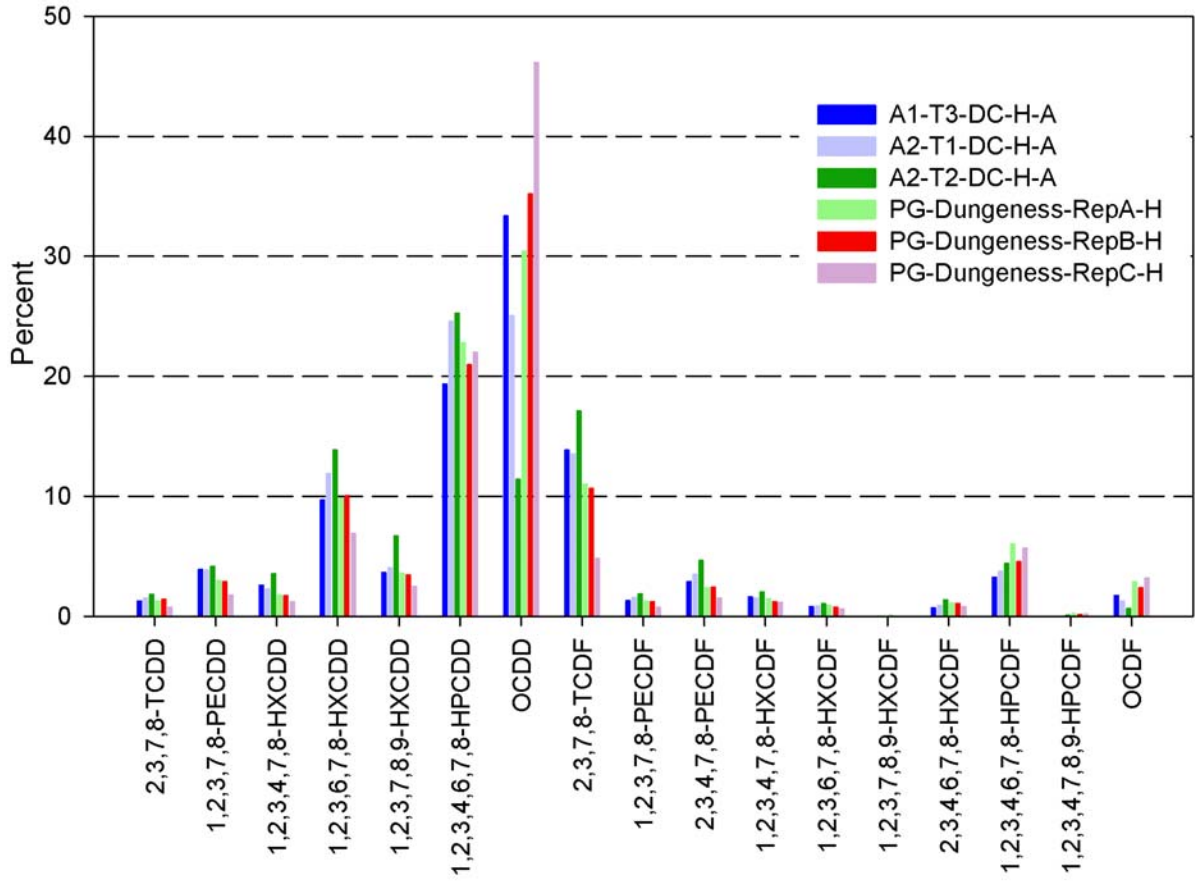


Figure 3-35. Congener Profiles in Dungeness Crab Hepatopancreas Analyzed as Part of the Port Gardner Sediment Investigation and the Port Gardner Disposal Site Monitoring

4.0 Data Validation

All chemistry data generated for this report underwent an independent quality assurance review and data validation. A QA2 data review was conducted to examine the complete analytical process, and a QA1 data review was conducted to evaluate the acceptability of test results. Both data reviews were carried out by EcoChem, Inc. of Seattle, Washington. Data validation results and the completeness of the dataset are summarized here. The full data validation reports are provided in Appendix E.

Completeness refers to the amount of data collected relative to that needed to assess the project's objectives. The completeness of data for the 2008 Port Gardner and Lower Snohomish Estuary Sediment Characterization has been summarized three ways: field sampling, analytical, and technical (Table 4–1).

Field sampling completeness is the number of samples collected divided by the amount of results reported. For this study, 100 percent of all samples sent to the analytical laboratories for analysis were reported. The number of samples that have not been qualified by either the analytical laboratory or EcoChem divided by the number of results reported is the analytical completeness. Of the COCs, analytical completeness was highest for the metals (12 to 100 percent) and lowest (0 to 33 percent) for butyltins, pesticides, chlorinated aromatics, phthalates, phenols, miscellaneous extractables, and PCBs (Table 4–1).

The most important measure of completeness is the number of valid results divided by the total number of results reported. Though referred to as technical completeness, this is a direct measure of the percent usable results. No analytes were flagged as either rejected or do not report and are therefore considered to be valid and usable as qualified for the purposes of this investigation.

Table 4-1. Port Gardner Chemistry Data Validation Summary

Analyte	Samples Collected and Analyzed	Qualified Samples			Completeness		
		Total	Rejected	Do Not Report	Field Sampling	Analytical	Technical
Conventionals							
Total Organic Carbon	88	0	0	0	100%	100%	100%
TVS	88	0	0	0	100%	100%	100%
Total Solids	88	0	0	0	100%	100%	100%
Preserved Total Solids	88	0	0	0	100%	100%	100%
Ammonia	88	50	0	0	100%	100%	100%
Total Sulfides	88	64	0	0	100%	100%	100%
Grain Size	88	25	0	0	100%	100%	100%
Metals							
Arsenic	82	23	0	0	100%	72%	100%
Cadmium	82	54	0	0	100%	37%	100%
Chromium	82	12	0	0	100%	85%	100%
Copper	82	0	0	0	100%	100%	100%
Lead	82	3	0	0	100%	96%	100%
Mercury	82	56	0	0	100%	34%	100%
Silver	82	81	0	0	100%	12%	100%
Zinc	82	10	0	0	100%	88%	100%
Butyltins µg/kg DW							
Dibutyl Tin Ion	9	9	0	0	100%	0%	100%
Tributyl Tin Ion	9	9	0	0	100%	0%	100%
Butyl Tin Ion	9	9	0	0	100%	0%	100%
LPAH							
Naphthalene	80	53	0	0	100%	34%	100%
Acenaphthylene	80	66	0	0	100%	18%	100%
Acenaphthene	80	68	0	0	100%	15%	100%
Fluorene	80	62	0	0	100%	23%	100%
Phenanthrene	80	47	0	0	100%	41%	100%
Anthracene	80	60	0	0	100%	25%	100%
1-Methylnaphthalene	80	72	0	0	100%	10%	100%
2-Methylnaphthalene	80	70	0	0	100%	13%	100%
HPAH							
Fluoranthene	80	37	0	0	100%	54%	100%
Pyrene	80	38	0	0	100%	53%	100%
Benzo(a)anthracene	80	54	0	0	100%	33%	100%
Chrysene	80	42	0	0	100%	48%	100%
Benzo(b)fluoranthene	80	51	0	0	100%	36%	100%
Benzo(k)fluoranthene	80	54	0	0	100%	33%	100%
Benzofluoranthenes*	80	50	0	0	100%	38%	100%
Benzo(a)pyrene	80	55	0	0	100%	31%	100%
Indeno(1,2,3-cd)pyrene	80	60	0	0	100%	25%	100%
Dibenz(a,h)anthracene	80	72	0	0	100%	10%	100%
Benzo(g,h,i)perylene	80	66	0	0	100%	18%	100%

Analyte	Samples Collected and Analyzed	Qualified Samples			Completeness		
		Total	Rejected	Do Not Report	Field Sampling	Analytical	Technical
Chlorinated Aromatics							
1,3-Dichlorobenzene	80	79	0	0	100%	1%	100%
1,4-Dichlorobenzene	80	79	0	0	100%	1%	100%
1,2-Dichlorobenzene	80	79	0	0	100%	1%	100%
1,2,4-Trichlorobenzene	80	79	0	0	100%	1%	100%
Hexachlorobenzene	80	79	0	0	100%	1%	100%
Phthalate Esters							
Dimethylphthalate	80	79	0	0	100%	1%	100%
Diethylphthalate	80	78	0	0	100%	3%	100%
Di-n-Butylphthalate	80	77	0	0	100%	4%	100%
Butylbenzylphthalate	80	79	0	0	100%	1%	100%
bis(2-Ethylhexyl)phthalate	80	55	0	0	100%	31%	100%
Di-n-Octylphthalate	80	79	0	0	100%	1%	100%
Phenols							
Phenol	80	70	0	0	100%	13%	100%
2-Methylphenol	80	77	0	0	100%	4%	100%
4-Methylphenol	80	54	0	0	100%	33%	100%
2,4-Dimethylphenol	80	77	0	0	100%	4%	100%
Pentachlorophenol	80	79	0	0	100%	1%	100%
Guaiacols and Resins							
Guaiacol	9	9	0	0	100%	0%	100%
4,5-Dichloroguaiacol	9	9	0	0	100%	0%	100%
4,5,6-Trichloroguaiacol	9	9	0	0	100%	0%	100%
3,4,5-Trichloroguaiacol	9	9	0	0	100%	0%	100%
Tetrachloroguaiacol	9	9	0	0	100%	0%	100%
Pimaric Acid	9	9	0	0	100%	0%	100%
Isopimaric Acid	9	8	0	0	100%	11%	100%
Dehydroabietic Acid	9	3	0	0	100%	67%	100%
Abietic Acid	9	9	0	0	100%	0%	100%
Miscellaneous Extractables							
Benzyl Alcohol	80	79	0	0	100%	1%	100%
Benzoic Acid	80	79	0	0	100%	1%	100%
Dibenzofuran	80	68	0	0	100%	15%	100%
Hexachlorobutadiene	80	79	0	0	100%	1%	100%
N-Nitrosodiphenylamine	80	65	0	0	100%	19%	100%
PCBs							
Aroclor-1221	80	79	0	0	100%	1%	100%
Aroclor-1232	80	79	0	0	100%	1%	100%
Aroclor-1242	80	79	0	0	100%	1%	100%
Aroclor-1016	80	79	0	0	100%	1%	100%
Aroclor-1248	80	77	0	0	100%	4%	100%
Aroclor-1254	80	68	0	0	100%	15%	100%
Aroclor-1260	80	77	0	0	100%	4%	100%

Analyte	Samples Collected and Analyzed	Qualified Samples			Completeness		
		Total	Rejected	Do Not Report	Field Sampling	Analytical	Technical
Aroclor-1262	80	79	0	0	100%	1%	100%
Aroclor-1268	80	79	0	0	100%	1%	100%
Pesticides							
4,4'-DDT	7	7	0	0	100%	0%	100%
4,4'-DDE	7	7	0	0	100%	0%	100%
4,4'-DDD	7	7	0	0	100%	0%	100%
gamma-BHC (Lindane)	7	7	0	0	100%	0%	100%
Heptachlor	7	7	0	0	100%	0%	100%
Aldrin	7	7	0	0	100%	0%	100%
Dieldrin	7	7	0	0	100%	0%	100%
gamma Chlordane	7	7	0	0	100%	0%	100%
alpha Chlordane	7	7	0	0	100%	0%	100%
oxy Chlordane	7	7	0	0	100%	0%	100%
cis-Nonachlor	7	7	0	0	100%	0%	100%
trans-Nonachlor	7	7	0	0	100%	0%	100%
Dioxin/Furan							
2,3,7,8-TCDD	20	15	0	0	100%	25%	100%
1,2,3,7,8-PECDD	20	18	0	0	100%	10%	100%
1,2,3,4,7,8-HXCDD	20	18	0	0	100%	10%	100%
1,2,3,6,7,8-HXCDD	20	14	0	0	100%	30%	100%
1,2,3,7,8,9-HXCDD	20	15	0	0	100%	25%	100%
1,2,3,4,6,7,8-HPCDD	20	9	0	0	100%	55%	100%
OCDD	20	2	0	0	100%	90%	100%
2,3,7,8-TCDF	20	12	0	0	100%	40%	100%
1,2,3,7,8-PECDF	20	17	0	0	100%	15%	100%
2,3,4,7,8-PECDF	20	16	0	0	100%	20%	100%
1,2,3,4,7,8-HXCDF	20	16	0	0	100%	20%	100%
1,2,3,6,7,8-HXCDF	20	17	0	0	100%	15%	100%
1,2,3,7,8,9-HXCDF	20	20	0	0	100%	0%	100%
2,3,4,6,7,8-HXCDF	20	17	0	0	100%	15%	100%
1,2,3,4,6,7,8-HPCDF	20	11	0	0	100%	45%	100%
1,2,3,4,7,8,9-HPCDF	20	17	0	0	100%	15%	100%
OCDF	20	10	0	0	100%	50%	100%

5.0 Summary and Identification of Data Gaps

5.1 Summary

5.1.1 Wood Debris Distribution in Port Gardner

The distribution of wood debris in Port Gardner was evaluated using SPI, plan view photography, and subsurface video probing. Based on SPI and plan view photography, the greatest accumulation of wood debris in surface sediments was measured in the East Waterway (Focus Area 1). The SPI images showed the presence of wood debris at 16 of 22 locations (73 percent) in the East Waterway, with the highest surface accumulation at station A1-14 (30 percent wood debris by vertical area). The plan view images showed the presence of wood debris at 14 of 22 locations (64 percent) with the highest accumulation also observed at station A1-14 (75 percent wood debris by surface area).

Wood debris accumulation in surface sediments was much lower or absent in Focus Areas 2, 3, and 4 (Snohomish River and delta, Steamboat slough, and Ebey slough, respectively), based on SPI and plan view photography. The SPI and plan view surveys identified wood debris at 20 of 56 locations (36 percent) and 13 of 50 locations (26 percent), respectively. In Area 2, the greatest accumulation of wood debris was measured in SPI images at station A2-30 (15 percent by area), near the former Weyerhaeuser Mills C and D site. In Area 3, stations A3-03 and A3-05 in Steamboat slough showed wood debris in plan view images at 25 and 20 percent by area, respectively. Only two stations in Area 4 (A4-02 and A4-07) showed minor amounts of wood debris (one to two percent by area).

Subsurface video probing in Port Gardner allowed the identification of wood debris to a depth of 6 feet below the surface. In the East Waterway (Focus Area 1), wood debris in the upper 6 feet ranged from 0 to 50 percent, with an average of 4.2 percent. Wood debris was often concentrated in "mats" greater than one foot thick. However, some sediment intervals were found to be wood free. In the lower Snohomish River (Focus Area 2), wood debris accumulation in subsurface sediments appeared to be greater than that measured in surface sediments using SPI and plan view photography. Wood debris in the upper 6 feet ranged from 0 to 95 percent, with an average of 14 percent. In the mud flat region north of the Port of Everett Marina, large wood debris impeded full penetration of the video probe. Subsurface wood debris accumulation in Focus Areas 3 and 4 were much lower (average of 6.9 and 2.1 percent, respectively), similar to observations made during the SPI and plan view photography surveys.

5.1.2 Summary of SPI Parameters

In additional to wood debris accumulation, SPI parameters measured during the Port Gardner survey included grain size major mode, benthic habitat type, apparent RPD depth, sedimentary methane, infaunal successional stage, and OSI. The distributions of grain size major mode and benthic habitat type were similar in Port Gardner. The highest number of locations (50 percent) was characterized by unconsolidated silt and clay sediments and was found in Focus Area 1 and in depositional areas in the Snohomish River and Steamboat slough. A hard sandy bottom with

fine and medium sands was observed in the nearshore areas of Focus Area 1, and in the Snohomish River, Steamboat, and Ebey sloughs (42 percent of the locations).

The shallowest apparent RPD depths were measured in the East Waterway (less than 2.0 cm), in areas with wood debris accumulation in surface sediments. Station A1-02 showed almost no discernable apparent RPD depth. Apparent RPD depths were deeper in other areas of Port Gardner. Focus Areas 2, 3, and 4, had mean apparent RPD depths of 3.21 cm, 4.30 cm, and 4.11 cm, respectively.

Sedimentary methane bubbles were observed at six locations during the SPI survey. Anaerobic reactions in surface sediments are likely occurring due to organic enrichment. In the East Waterway (A1-02, A1-06, A1-21), the organic enrichment is likely related to wood debris from current and historical log, pulp, and paper industries. In Focus Areas 2, 3, and 4, natural input from the river systems may also provide organic enrichment.

The majority of infaunal successional stages observed in SPI images were Stage I (65 percent), followed by Stage I on III (31 percent) and azoic (1 percent). A gradient of successional stage was observed in the East Waterway, likely due to impacts from wood debris accumulation. Station A1-02, in the northern end of the East Waterway, was classified as azoic. The majority of locations in Port Gardner have sandy substrates, and Stage I communities may be the highest successional stage obtained.

The distribution of OSI values ranged from -7 to +11, with OSI values greater than +6 at 50 percent of the locations. The lowest OSI values (-7) was measured at station A1-02, in the East Waterway. Shallow RPD depths were the main contributor to low OSI values in the East Waterway.

5.1.3 Surface Sediment Chemistry

The vast majority of locations in Port Gardner were dominated by sands, averaging 70 percent for all surface sediment samples. Fine grained sediments (silts and clays) were measured in the East Waterway, near the Port of Everett Marina, the mud flat region north of the marina, and some locations along the Snohomish River. Areas with high conventional parameters (TOC, TVS, ammonia, total sulfides) were generally associated with fine grained sediments. Locations within the East Waterway consistently had higher concentrations of TOC (>2.6 percent), TVS (>11 percent), ammonia (>15 mg/kg) and sulfides (>800 mg/kg) than other areas of Port Gardner.

Three of the 52 samples analyzed for SMS chemistry exceeded either the SQS or CSL criteria and were located in the East Waterway. Station A1-07 exceeded the CSL criteria for mercury. Station A1-10 exceeded the CSL for 4-methylphenol, and station A1-24 exceeded the SQS for zinc.

Resin acids, a byproduct of wood decomposition, were measured in eight of 10 samples analyzed. Location A1-24, with 15 percent wood debris measured during the SPI survey, had the highest concentration of dehydroabietic and abietic acid (2600 and 1600 µg/kg dw, respectively).

A clear correlation between resin acid concentrations in surface sediments and visible wood debris was not observed. It is likely that wood debris decomposition rates differ by location.

Dioxin/furan congeners were measured in 15 surface samples and ranged from 0.16 to 47 pg TEQ/g, with an average of 7.8 pg TEQ/g. Four samples in the East Waterway ranged from 4.45 pg TEQ/g at station A1-18 to 47 pg TEQ/g at station A1-10. Of the seven samples in Focus Area 2, the maximum concentration occurred on the mud flat region (3.4 pg TEQ/g). One sample each was analyzed in Focus Areas 3 and 4, and dioxin/furan congeners were measured at 0.85 and 0.17 pg TEQ/g, respectively.

5.1.4 Subsurface Sediment Chemistry

A total of 25 subsurface sediment samples were analyzed for conventionals and SMS chemistry. The 1 to 3 foot depth interval was analyzed for 15 cores, and the 3-5 foot interval was analyzed for 10 cores. Ammonia concentrations generally increased by an order of magnitude between surface and deep intervals. Subsurface intervals with elevated total sulfides (>1000 mg/kg) included stations A1-03, A1-07, A2-30, and A2-37B.

Three of the 25 subsurface samples analyzed for SMS chemistry exceeded the SQS and CSL criteria for 4-methylpheonol. All three samples were located in the East Waterway. Station A1-03, 4-methylphenol was measured in the 1 to 3 foot interval at 2300 µg/kg (SQS and CSL = 670 µg/kg). At station A1-24, 4-methylphenol was measured in the 1 to 3 foot and 3 to 5 foot intervals at 870 and 890 µg/kg, respectively.

Dioxin/furan congeners were measured in five subsurface samples (1 to 3 foot depth intervals) and ranged from 0.13 to 50.5 pg TEQ/g, with an average of 12 pg TEQ/g. The highest concentration in the 1 to 3 foot depth interval (50.5 pg TEQ/g) was measured at station A1-24.

5.1.5 Biological Toxicity Testing

Surface sediment samples from 17 locations in Port Gardner were tested for confirmatory biological testing. Locations that exceeded the SMS chemical standards or had elevated concentrations of conventional parameters (sulfides, ammonia, TOC, or TVS) were re-sampled and submitted for biological testing.

The biological testing resulted in four of the 17 locations passing the SMS bioassay criteria, and 13 locations failing the SMS CSL criteria (Table 5–1). Of the four locations passing SMS criteria, one location did not have elevated conventional parameters (A3-05E), and three locations had elevated total sulfides. Of the 13 locations that failed the CSL, four locations demonstrated adverse toxic effects in multiple bioassays (A1-10, A1-24, A2-14, and A2-21). These locations also exhibited elevated sulfides and ammonia, and chemicals that exceeded the SQS or CSL (see Table 5-1). The remaining nine locations that failed were due to CSL failures for the larval development bioassay. Five of the locations (A1-03, A2-13, A2-36, A3-07B, and A4-08B) had one or more conventional parameter considered elevated. Four locations that failed the larval development CSL interpretive criteria (A1-01, A1-07, A2-18, and A2-25) included a discrepancy in interpretation between the two batches tested and/or control (seawater or sediment) used for comparative purposes.

Table 5-1. Conventional Parameters, SMS Chemistry, and Bioassay Results

Station ID	TOC[1]	TVS[1]	Ammonia[1]	Sulfides[1]	SMS Analyte	Concentration	Bioassay Results
A1-01	4.41	16.45	11.6	3780			Fails CSL
A1-03	7.06	24.53	23.9	2540			Fails CSL
A1-07	3.55	21.85	26.3	3030	Mercury	0.7 mg/kg dw	Fails CSL
A1-10	5.23	14.17	9.03	1560	4-Methylphenol	1200 µg/kg dw	Fails CSL[2]
A1-16		5.9	3.94	169			Pass
A1-24		13.09	5.37	377	Zinc	415 mg/kg dw	Fails CSL[2]
A2-10			4.58	126			Pass
A2-11			4.13	109			Pass
A2-13		6.82	8.79	137			Fails CSL
A2-14		9.99	12.7	105			Fails CSL[2]
A2-18			4.67	74.6			Fails CSL
A2-21		7.48	13.9	805			Fails CSL[2]
A2-25		5.13	6.28				Fails CSL
A2-36		5.56		615			Fails CSL
A3-05E							Pass
A3-07B			9.44	46.7			Fails CSL
A4-08B		5.37	10.0	61.6			Fails CSL

Notes:

1. Relative Concentrations of Conventional Parameters:

Conventionals	Low	Medium	High
TOC (% dw)	3.5 – 5.0	5.0 – 7.0	> 7.0
TVS (% dw)	5.0 – 10.0	10.0 – 15.0	>15.0
Ammonia (mg-N/kg dw)	3.0 – 5.0	5.0 – 8.0	>8.0
Total Sulfides (mg/kg dw)	20 – 50	50 – 100	>100

2. CSL failure due to two more bioassays failing the SQS biological interpretive criteria

Dark gray shading indicates chemical concentration exceeds CSL criteria
Light gray shading indicates chemical concentration exceeds SQS criteria
Light blue shading indicates a discrepancy between the interpretive comparisons for the larval test
Rose shading indicates a CSL failure

5.1.6 Crab, Fish, and Clam Tissue Chemistry

Dungeness crab (hepatopancreas and meat), English sole, Eastern softshell clams, and purple varnish clams were analyzed for metals, Aroclor PCBs, and dioxin/furan congeners. Single replicate samples were analyzed at each trawl or clam sampling location. Metals concentrations were generally low for all tissues and varied mainly by species. Aroclor PCBs were undetected with the exception of the three Dungeness crab hepatopancreas tissues (mean of 171 µg/kg ww). A relationship between PCB concentrations and potential source areas could not be determined.

Dioxin/furan congener concentrations in Port Gardner tissues were relatively low compared to other areas of Puget Sound. Concentrations were largely dependent upon lipid content for the different species. TEQ values calculated using one-half the detection limit for undetected congeners were highest in the Dungeness crab hepatopancreas (mean of 3.83 pg TEQ/g) and lowest in the clam tissue samples (mean of 0.045 pg TEQ/g).

5.1.7 Plant Tissue Chemistry

Two plant species of cultural importance to the Tulalip Tribe (tule and cattail) were chemically analyzed for metals, Aroclor PCBs, and pesticides. Three metals (chromium, copper, and zinc) were detected at low concentrations and Aroclor PCBs and pesticides were undetected. The lower stems/roots of the cattail contained slightly higher concentrations of the three metals compared to the stems of the tule plant.

5.1.8 Dioxin/Furan Congener Profiling

Congener profiles for the sediment samples were dominated by OCDD and 1,2,3,4,6,7,8-HPCDD. Profiles from Port Gardner matched those from the Budd Inlet Sediment Investigation and those from the Port Gardner disposal site. Within the tissue data, congener profiles were only calculated for the Dungeness crab hepatopancreas due to frequent non-detects in other tissue types. Hepatopancreas congener profiles differed from the sediment in that they had lower relative amounts of OCDD, and greater abundances of the lesser chlorinated congeners. BSAF values were calculated for detected congeners for the tissue data. In crab hepatopancreas, uptake of lower chlorinated congeners was preferred over OCDD and OCDF. For the bivalve samples, BSAF values were similar for detected congeners.

5.2 Scale of Priority for Cleanup Areas

One of the objectives of the Port Gardner Sediment Characterization was to provide a scale of priority for areas providing the greatest return in restored ecological values and function upon cleanup. Sediments in Focus Areas 3 and 4 appear to be the least impacted based on low levels of sediment chemistry, and absence of significant wood debris. Cleanup activities in these areas would likely provide the greatest return. Two locations failed CSL criteria for bioassay results (A3-07B and A4-08B), and may warrant further investigation. Station A3-07B, near the Hanson Boat Company, and Station A4-08B, in Ebey slough near the Interstate 5 overpass, had elevated levels of conventional parameters, particularly ammonia. Methane gas bubbles were also present in surface sediments at A3-07B (see Figure 3–18).

Focus Area 2 may provide the next greatest return in restored ecological function for potential cleanup opportunities. Elevated sediment chemistry and significant accumulation of wood debris were not observed in the upper reaches of the lower Snohomish River. Station A2-36B, near the former Riverside Chip/Mill storage area, failed the CSL bioassay criteria and may warrant further investigation. Methane gas bubbles were also observed in surface sediments at this location (Figure 3–18). The restoration of the mud flats north of the Port of Everett Marina and north of the Baywood property site would likely improve the ecological function of these areas. Significant amounts of wood debris appear to be present in subsurface sediments, and additional surveys would be necessary to determine the need and extent of wood debris removal for habitat enhancement. The bioassay testing of all samples collected in the mud flats (A2-14, A2-18, A2-21, and A2-25) failed CSL criteria.

The East Waterway in Focus Area 1 appears to be the most impacted area due to chemical contamination and impacts from wood debris accumulation. Significant organic enrichment and low water circulation in the inner East Waterway has degraded benthic habitat quality. Cleanup

activities in the East Waterway may require the most effort for the return on ecological function. However, some potential cleanup activities (e.g., removal of sediment with elevated dioxin/furan congeners at station A1-24) would likely reduce possible sediment sources of dioxin/furan congeners for uptake by ecological receptors.

5.3 Data Gaps

5.3.1 Dioxin/Furan Congeners in East Waterway Sediments

Elevated concentrations of dioxin/furan congeners were measured in surface and subsurface sediments in the East Waterway. Only a limited number of samples were originally analyzed. The analysis of surface samples in the vicinity of stations A1-03 (40.4 pg TEQ/g), A1-10 (46.9 pg TEQ/g, and A1-24 (16.6 pg TEQ/g) would help further delineate the dioxin/furan contamination in the East Waterway. Subsurface sample intervals that bound the 1 to 3 foot depth interval at station A1-24 (50.5 pg TEQ/g) should be analyzed. In addition, the analysis of subsurface intervals (1 to 3 foot depth interval) at stations A1-03 and A1-10 may be warranted.

5.3.2 Aroclor PCBs in Crab Hepatopancreas Tissues

Single replicate samples of Dungeness crab hepatopancreas tissues were analyzed in three areas of Port Gardner. Total Aroclor PCB concentrations ranged from 93 µg/kg ww at trawl location A2-T2 (Snohomish River delta) to a high of 260 µg/kg ww at A2-T1 (mouth of the Snohomish River). In contrast, a small survey (3 crabs) of Dungeness crab hepatopancreas tissues in the Lower Duwamish Waterway measured total Aroclor PCBs concentrations from 1,310 to 1,420 µg/kg ww (Windward 2006). Analysis of the remaining archived hepatopancreas tissues would reduce the variability of the measured concentrations of Aroclor PCBs and help determine whether concentrations are elevated near potential source areas (i.e., East Waterway).

6.0 References

Cleverly, D., J. Schaum, G. Schweer, J. Becker, and Winters. 1997. The congener profiles of anthropogenic sources of chlorinated dibenzo-p-dioxins and chlorinated dibenzofurans in the United States. *Ecoinforma Press.* Bayreuth, Germany,

Diaz, R.J. 1995. Benthic habitat classification of selected areas of Narragansett Bay, Rhode Island. Report to Normandeau Associates, Inc. Bedford, New Hampshire.

DMMP. 2002. Ammonia and Amphipod Testing. Prepared by Justine Barton (USEPA) for the DMMP agencies. June 15, 2002.

DMMP. 2004. Ammonia and Sulfide Guidance Relative to Neanthes Growth Bioassay. Prepared by David Kendall (USACE) and Justine Barton (USEPA) for the DMMP agencies. June 15, 2004.

Ecology. 2003. Sediment Sampling and Analysis Plan Appendix; Guidance on the Development of Sediment Sampling and Analysis Plans Meeting the Requirements of the Sediment Management Standards (Chapter 173-204 WAC). Prepared for the Washington State Department of Ecology, Sediment Management Unit, Lacey, WA. Prepared by PTI Environmental Service, Bellevue, WA. Ecology Publication No. 03-09-043. Revised April 2003.

Munsell. 2000. Charts for estimating proportions of mottles and coarse fragments. Munsell soil color charts. Year 2000. GretagMacBeth, New Windsor, NY.

Pearson, T.H. and R. Rosenberg. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanogr. Mar. Biol. Ann. Rev. 16: 229–311.

PSEP. 1995. Recommended Guidelines for Conducting Laboratory Bioassays on Puget Sound Sediments. Final Report. Prepared for U.S. Environmental Protection Agency, Region 10, Office of Puget Sound, Seattle, WA. Washington State Department of Ecology, Olympia, WA.

Rhoads, D.C. and J.D. Germano. 1986. Interpreting long-term changes in benthic community structure: a new protocol. Hydrobiology 142: 291–308.

SAIC. 2008a. Sediment characterization study in Port Gardner and lower Snohomish river estuary, Everett, WA. Data gaps report. Final. September 12, 2008. Prepared for the Washington State Dept of Ecology, Lacey, WA. Prepared by Science Applications International Corporation, Bothell, WA.

SAIC. 2008b. Sediment characterization study in Port Gardner and lower Snohomish river estuary, Everett, WA. Combined sampling and analysis plan (SAP) and quality assurance quality assurance project plan (QAPP). Final. September 15, 2008. Prepared

for the Washington State Dept of Ecology, Lacey, WA. Prepared by Science Applications International Corporation, Bothell, WA.

SAIC. 2008c. Sediment Characterization Study Budd Inlet, Olympia, WA, Final Data Report. March 12, 2008. Prepared for the Washington State Dept of Ecology, Lacey, WA. Prepared by Science Applications International Corporation, Bothell, WA.

SAIC. 2008d. Dioxin/Furan Concentrations at the Non-Dispersive Open-Water Dredged Material Disposal Sites in Puget Sound. July 10, 2008. Prepared for Washington State Department of Natural Resources, Olympia, WA. Prepared by Science Applications International Corporation, Bothell, WA.

USEPA. 2000. Bioaccumulation testing and interpretation for the purpose of sediment quality assessment: Status and needs. February 2000. USEPA Bioaccumulation Analysis Workgroup, Washington, D.C.

Van den Berg, M., L.S. Bimbaum, M. Denison, M. De Vito, W. Farland, M. Feeley, H. Fiedler, H. Hakansson, A. Hanberg, L. Haws, M. Rose, S. Safe, D. Schrenk, C. Tohyama, A. Tritscher, J. Tuomisto, M. Tysklind, N. Walker, and R. Peterson. The 2005 World Health Organization Re-Evaluation of Human and Mammalian Toxic Equivalency Factors for Dioxins and Dioxin-like Compounds. Prepared for the World Health Organization (WHO). ToxSci Advance Access published July 7, 2006. Published by Oxford University Press on behalf of the Society of Toxicology.

Windward. 2006. Data Report: Chemical Analyses of Fish and Crab Tissue, Samples Collected in 2005, Final. April 19, 2006. Lower Duwamish Waterway Remedial Investigation. Lower Duwamish Waterway Group. For submittal to the U.S. Environmental Protection Agency, Region 10, and the Washington State Dept of Ecology, Bellevue, WA. Prepared by Windward Environmental LLC, Seattle, WA.

Wong, C.S., Capel, P.D., Nowell, L.H. 2000. National scale, field-based evaluation of the biota-sediment accumulation factor model. *Environmental Science and Technology* 35(9): 1709-1715.