Dioxin/Furan Concentrations at The Non-Dispersive Open-Water Dredged Material Disposal Sites in Puget Sound

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WASHINGTON STATE DEPARTMENT OF
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LIST OF ACRONYMS AND ABBREVIATIONS

°C	degrees Celsius
Axys	Axys Analytical Services Ltd.
BSAF	biota sediment accumulation factors
CAS	Columbia Analytical Services
DMMP	Dredged Material Management Program
DNR	Department of Natural Resources
dw	dry weight
Ecology	Washington State Department of Ecology
MDL	method detection limits
pg/g	picograms per gram
PSDDA	Puget Sound Dredged Disposal Analysis
PSEP	Puget Sound Estuary Program
QASAP	Quality Assurance Sampling and Analysis Plan
R/V	research vessel
SAIC	Science Applications International Corporation
TEF	toxic equivalent factor
TEQ	toxic equivalent quotient
TOC	total organic carbon
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
ww	wet weight

1.0 INTRODUCTION

This document provides a summary of dioxin/furan concentrations in sediments and tissues measured at the Dredged Material Management Program (DMMP) non-dispersive, open-water dredged material disposal sites in Puget Sound. The five disposal sites were established in 1988 by the Puget Sound Dredged Disposal Analysis (PSDDA) program (PSDDA 1988a-d) and are located in Bellingham Bay, Port Gardner, Elliott Bay, Commencement Bay, and the Anderson/Ketron Islands (Figure 1–1).

The DMMP is currently engaged in a broad, stakeholder, interagency deliberative process to develop a dioxin regulatory framework for evaluating the open-water suitability of dioxin/furan concentrations in dredged material sediments. As part of this process, current levels of dioxin/furan congeners in sediments and in tissue of selected species were measured at the disposal sites in conjunction with the environmental site monitoring efforts conducted in 2005 (Anderson/Ketron Islands), 2006 (Port Gardner), and 2007 (Bellingham Bay, Elliott Bay, and Commencement Bay) (Science Applications International Corporation [SAIC] 2005, 2006, 2007, 2008). The disposal site monitoring program ensures compliance with federal Clean Water Act Section 404(b)(1) guidelines, verifies that unacceptable adverse effects have not occurred within or beyond the disposal site, and assures that dredged material disposed of at the sites remains within the disposal site boundary (PSDDA 1988a-d, 1989a,b).

The DMMP is responsible for the environmental management of dredged material in western Washington and is an interagency partnership consisting of the Department of Natural Resources (DNR), the U.S. Army Corps of Engineers, Seattle District (USACE), the Washington State Department of Ecology (Ecology), and the U.S. Environmental Protection Agency, Region 10 (USEPA). The DMMP provides guidance for evaluating proposed dredged material to determine its suitability for unconfined, open-water disposal, obtaining disposal site use permits, and monitoring disposal sites following dredged material disposal.

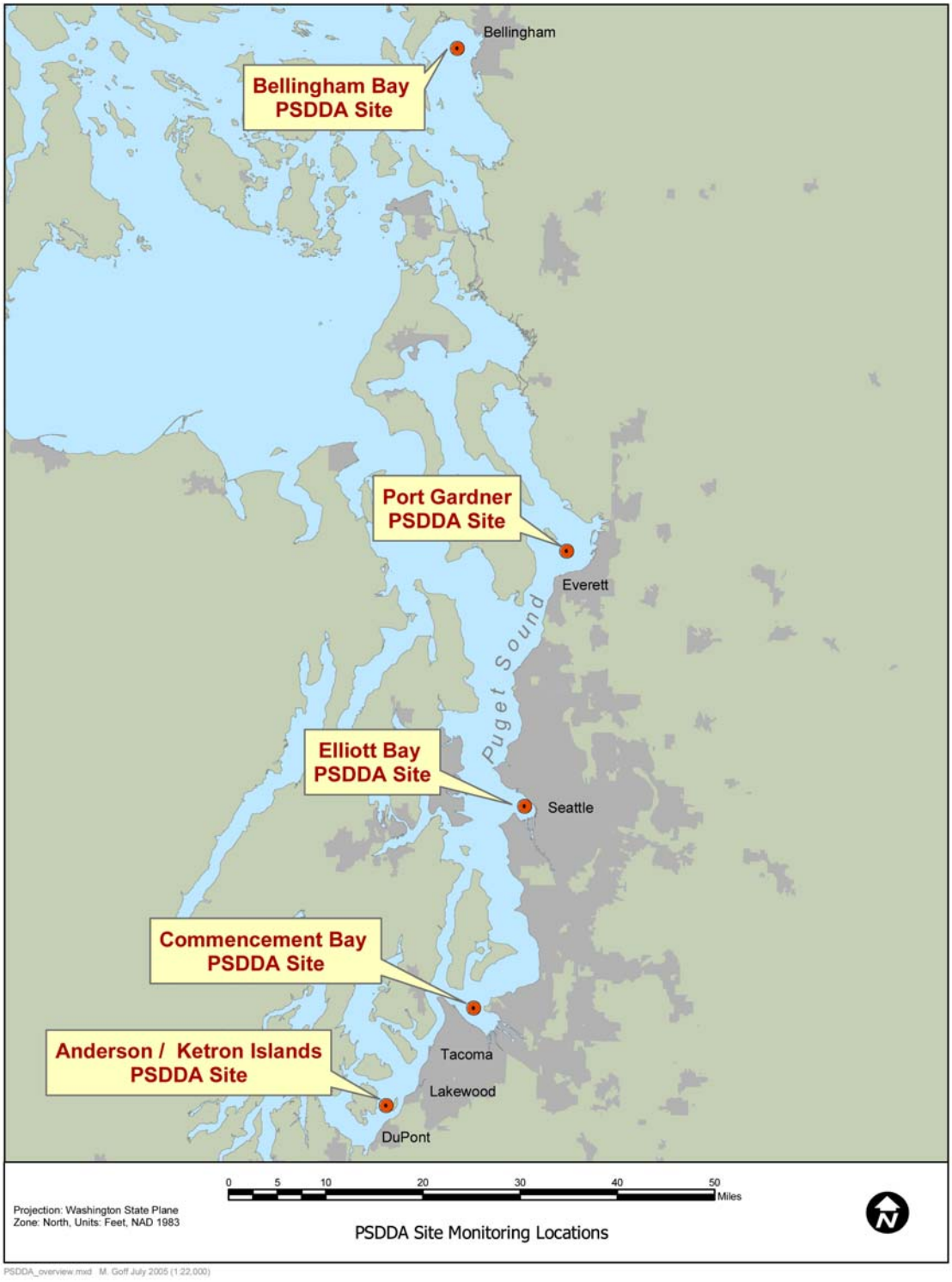


Figure 1-1. Non-dispersive Dredged Material Disposal Sites in Puget Sound

2.0 SUMMARY OF FIELD SURVEYS AND METHODS

This section includes a summary of the field surveys conducted at the five Puget Sound dredged material disposal sites, plus a brief discussion of the field sampling and analytical methods. All dioxin/furan congener results are reported in Appendix A. When measured, sediment conventional parameters are also reported.

2.1 Anderson/Ketron Islands

Samples collected and archived during the July 2005 full environmental monitoring survey at the Anderson/Ketron Islands DMMP disposal site (SAIC 2005) were analyzed for dioxin/furan congeners in April 2006. All sampling activities were conducted aboard the research vessel (R/V*) Kittiwake*. Dioxins/furans analyses were conducted on a total of eight sediment and 14 tissue samples collected at the Anderson/Ketron site. Stations sampled included one onsite (AKZ01), four perimeter (AKP01, AKP02, AKP03, and AKP04), two benchmark (AKB02 and AKB03), and one transect (AKT01) stations (Figure 2–1). Two reference sediments were also collected from Carr Inlet, Washington (CR-23W and CR-24) (see Section 2.6). Dioxin/furan congeners were analyzed using USEPA Method 1613B.

2.1.1 Grab Samples

Frozen (-18 degrees Celsius [°C]) archived sediment samples for the onsite, perimeter, and benchmark stations, and one refrigerated sample from a transect station (AKT01), were analyzed by Alta Analytical Laboratory, Inc., of El Dorado Hills, California, using USEPA Method 1613B for dioxin/furan congeners (Figure 2–1). All sediment samples were collected using the 0.2 m^2 stainless steel double van Veen grab sampler. Sediment from triplicate grabs was collected and composited for dioxin/furan analysis. Sediments from the onsite (AKZ01) and transect (AKT01) stations consisted of the top 10 cm. Sediments from the four perimeter (AKP01, AKP02, AKP03, and AKP04) and two benchmark (AKB02 and AKB03) stations consisted of the top 2 cm. The DMMP agencies targeted co-located sediment and tissue data for this study. DMMP sample storage protocols recommend archiving dioxin/furan samples at -18 °C with a holding time of one year.[1] However, since dioxin/furan congeners are thought to be highly resistant to degradation and the analytical method allows a holding time of one year at 4°C, the DMMP decided to analyze the one refrigerated transect sediment sample. Total organic carbon (TOC) and other conventional parameters were analyzed by Columbia Analytical Services (CAS) of Kelso, Washington.

Compsomyax subdiaphana clams, the target tissue species for chemical analysis, were generally low in abundance at the transect and benchmark stations, and only three stations showed sufficient clam densities for replicate tissue samples. During the survey, all clams collected at the transect and benchmark stations were retained and archived at -18°C. In addition to *Compsomyax subdiaphana*, *Yoldia* sp., and *Macoma nasuta* bivalves were found at high abundances at some stations and were retained and archived. A total of three *Compsomyax* (AKT01, AKB02, and AKB03), one *Yoldia* (AKT01), and one *Macoma* (AKB03) samples were collected at the co-located sediment locations and submitted to Alta in April 2006 for analysis of dioxin/furan congeners, percent lipids, and percent moisture.

[1] USEPA Method 1613B specified a one-year holding time at 4°C in the dark.

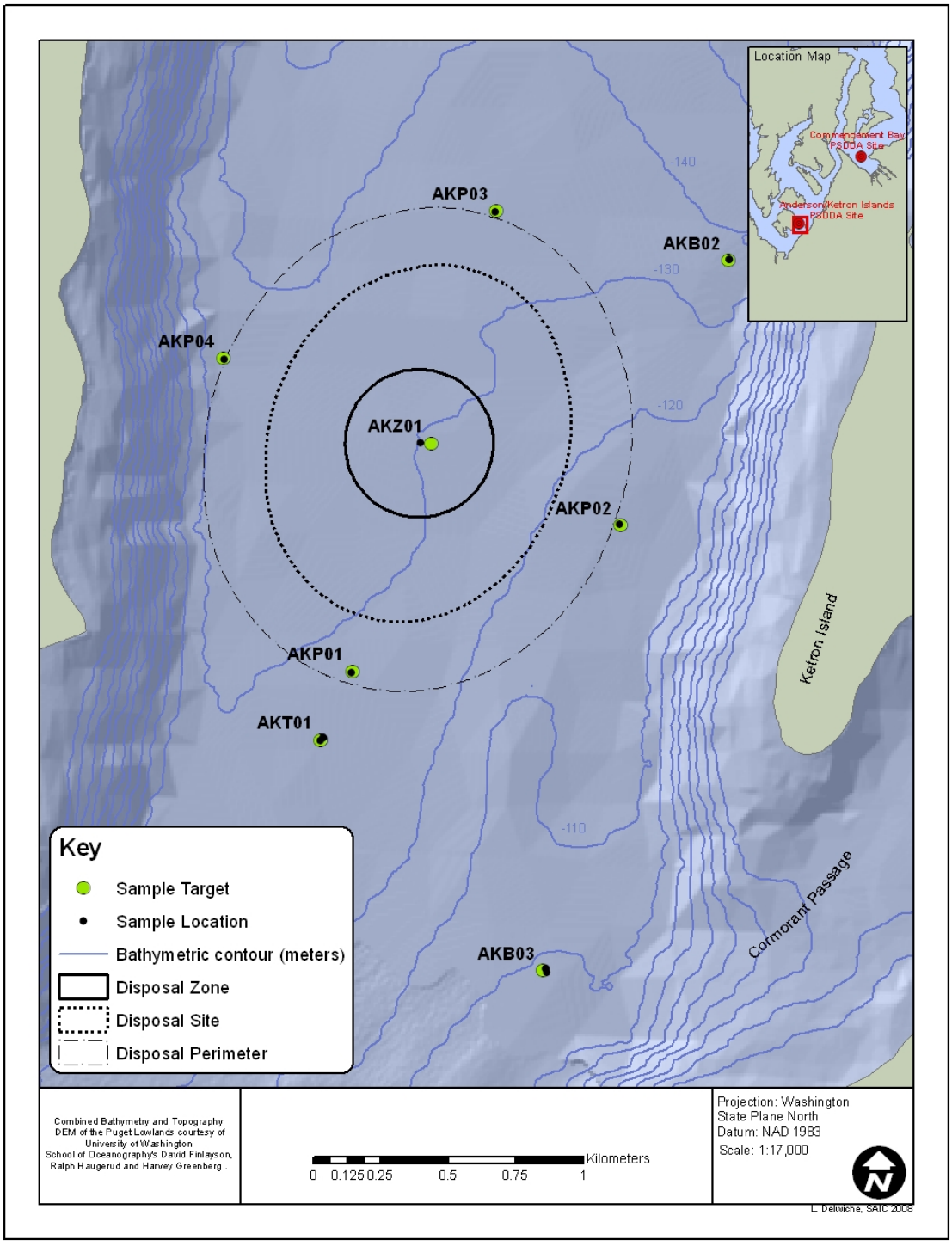


Figure 2-1. Anderson/Ketron Sediment and Tissue Sampling Locations

2.1.2 Trawl Samples

Dungeness crab and English sole were collected by trawl at the Anderson/Ketron Islands DMMP disposal site on May 30, 2007. All tissue samples were collected in two trawls (Figure 2–2). The first trawl was conducted north and east of Anderson Island, and the second trawl was between Anderson and Ketron Islands, just west of the disposal site. Triplicate samples were archived at -18°C at the SAIC warehouse and submitted to Axys Analytical Services Ltd. (Axys), of Sidney, B.C., for dioxin/furan analysis using USEPA method 1613B. Each English sole sample consisted of five fish. The whole bodies of each fish were homogenized and equal tissue volumes were taken from each fish and composited for analysis. The Dungeness crab samples consisted of five crabs each and dioxin/furan analysis was conducted on both the edible meat and hepatopancreas tissues.

2.2 Bellingham Bay

Sediment and tissue collection for the Bellingham Bay dioxin/furan investigation was conducted from July 19 through July 24, 2007. All sampling activities were conducted aboard the R/V *Kittiwake*. A total of 11 stations (Figure 2–3) were sampled at Bellingham Bay to acquire sediments and tissues for analysis of dioxin/furan congeners. Sediments were also analyzed for TOC. Stations sampled included one onsite (BBZ01), four perimeter (BBP01, BBP02, BBP03, and BBP04), three benchmark (BBB01, BBB02, and BBB04), and three transect (BBT04, BBT05, and BBT06) stations. Field sampling procedures were outlined in the Quality Assurance Sampling and Analysis Plan (QASAP) (SAIC 2007). Dioxin/furan congeners were analyzed by Axys, using USEPA Method 1613B.

2.2.1 Grab Samples

All sediment samples were collected using the 0.2 m^2 stainless steel double van Veen grab sampler. Sample handling, compositing, storage, equipment decontamination, and chain-of-custody procedures were conducted in accordance with the Puget Sound Estuary Program (PSEP) (1986, 1987, 1997a,b,c) and PSDDA (1989) protocols.[2]

The 0.2 m^2 stainless steel double van Veen grab was used as the primary sampler for all stations. At stations where both sediment and tissues were collected (perimeter, transect, and benchmark stations), the top 10 cm of sediment was removed for chemistry, and the remaining sediment was inspected for biological specimens by rinsing through a 2.0 mm sieve. At each station, surface sediment (0–10 cm) from triplicate grabs was collected and composited for dioxin/furan analysis.

Tissue samples consisting of one replicate each of a bivalve and polychaete species were initially targeted for collection at each of the Bellingham Bay stations. The sampling approach was to collect the species with high enough abundance for chemical analysis (a minimum of 10 grams of tissue per sample). A total of eight bivalve samples (five *Compsomyax* and 3 *Macoma* clam samples) and 13 polychaete samples (Capitellidae, Glyceridae, and Spionidae polychaetes) were analyzed for dioxin/furan congeners, percent lipids, and percent moisture (Table 3–2).

Dioxin/furan analysis of sediments and tissues were conducted by Axys. Analysis of sediment TOC was conducted by CAS. Analysis of sediments was conducted immediately following collection in August 2007. Tissues were initially archived at -18°C and submitted for dioxin/furan analysis in October 2007.

[2] PSEP (1986, 1987, 1997a,b,c) and PSDDA (1989) protocols were followed for sampling at all of the DMMP sites in support of these dioxin/furan investigations.

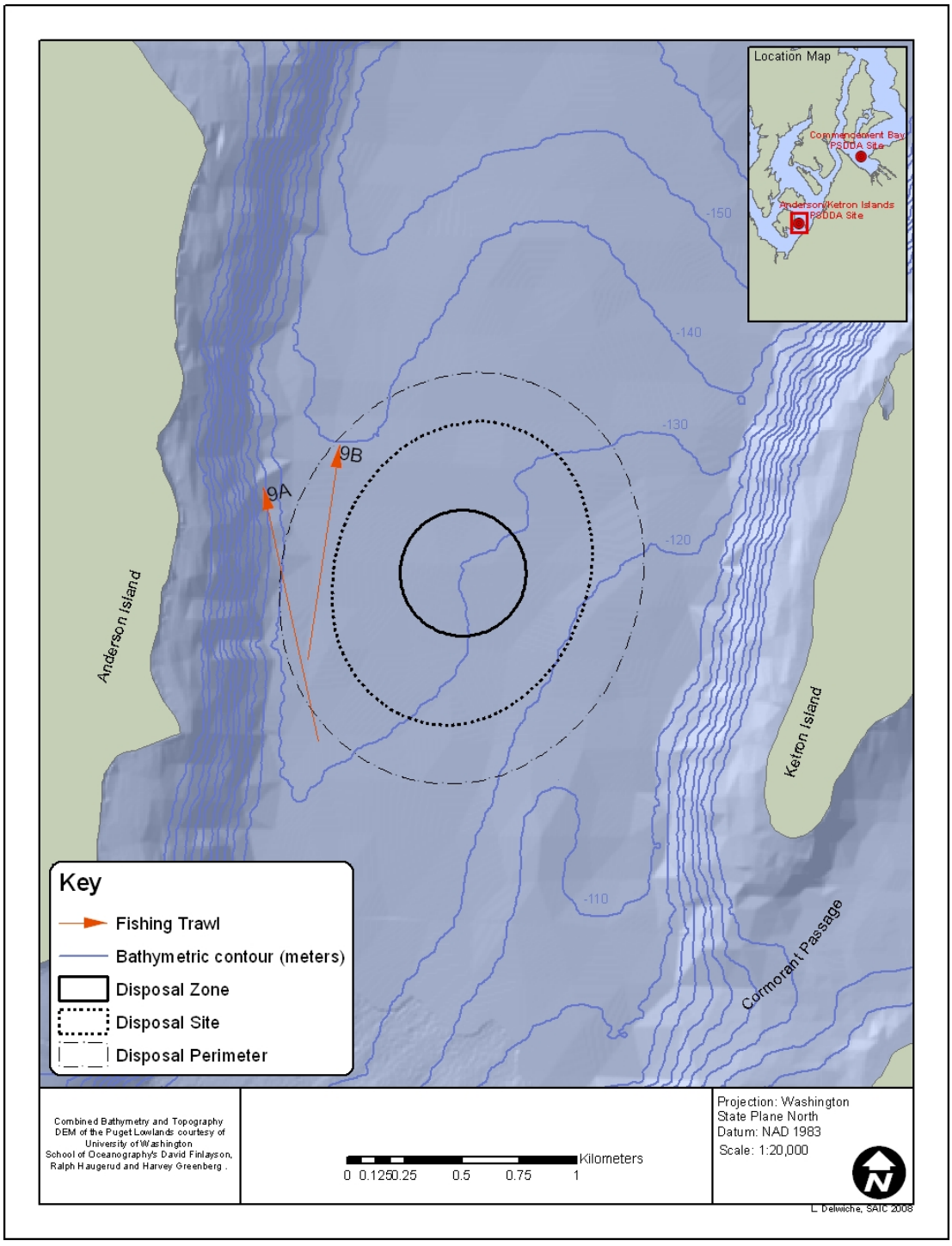


Figure 2-2. Anderson/Ketron Bottom Trawl Locations

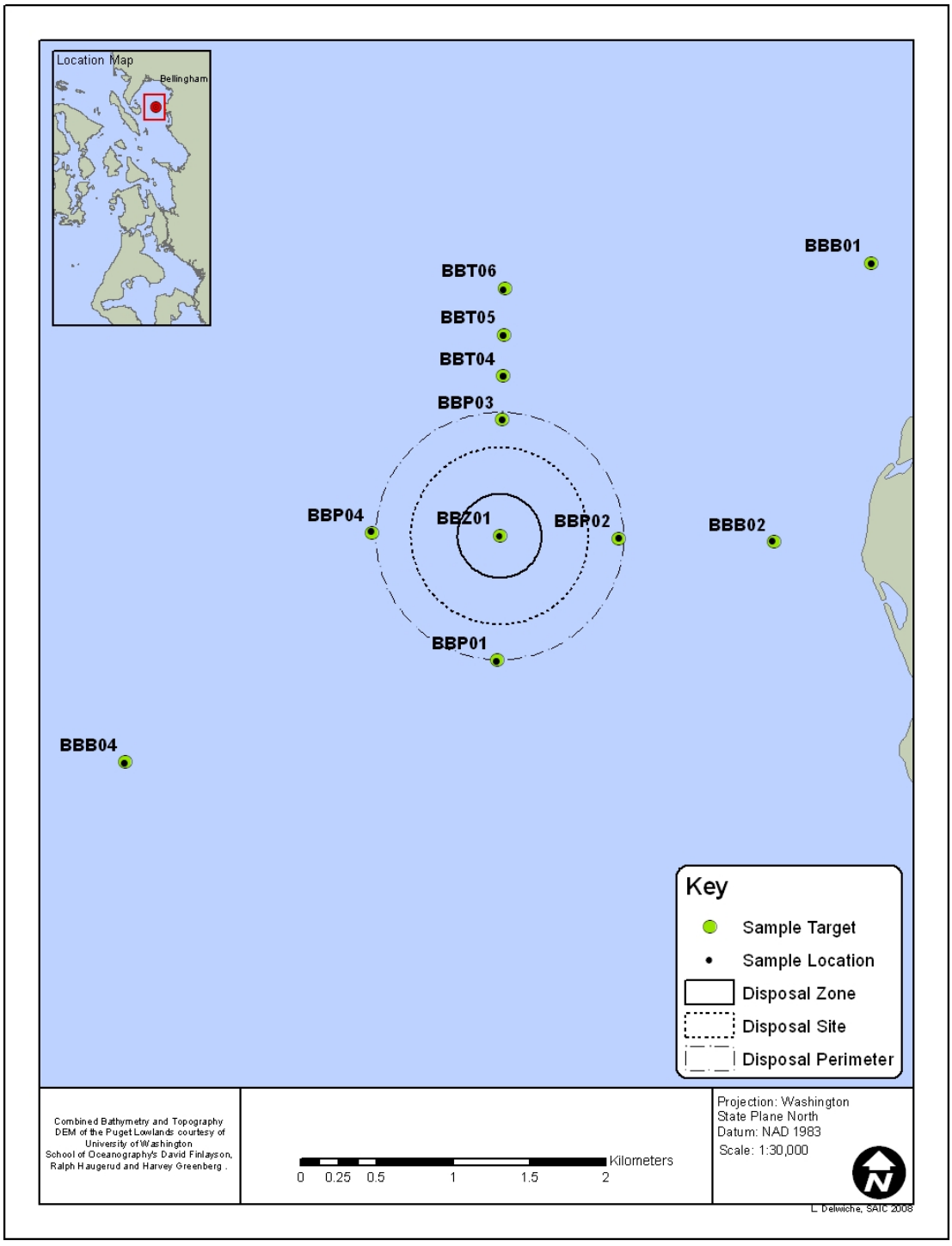


Figure 2-3. Bellingham Bay Sediment and Tissue Sampling Locations

2.2.2 Trawl Samples

A 7.6-meter high Otter trawl was used to collect Dungeness crab and English sole in Bellingham Bay. Five trawl transects were conducted in the vicinity of the Bellingham Bay disposal site (Figure 2–4), but with no particular attention to hitting specific stations (e.g., onsite, transect, perimeter). The most abundant species collected in the trawls included longfin smelt, blackbelly eelpout, starry flounder, and snake prickleback. English sole and starry flounder with a minimum length of 20 cm were retained for analysis. Male Dungeness crabs with a minimum carapice length of 9 cm were collected. Triplicate Dungeness crab, English sole, and starry flounder tissue samples, consisting of five individuals each, were initially archived at -18°C at the SAIC warehouse and submitted to Axys for dioxin/furan analysis in October 2007.

Each English sole or starry flounder sample consisted of five fish. The whole bodies of each fish were homogenized and equal tissue volumes were taken from each fish and composited for analysis. Each Dungeness crab sample consisted of five crabs and dioxin/furan analysis was conducted on both the edible meat and hepatopancreas tissues. Three replicates were analyzed for starry flounder, one for English sole, and three for Dungeness crab (both meat and hepatopancreas) (Table 3–3).

2.3 Commencement Bay

Commencement Bay sediment and tissue collections for analysis of dioxin/furan congeners and TOC were conducted between June 27 through July 11, 2007. This activity was conducted as part of the 2007 DMMP full monitoring of the Commencement Bay DMMP site (SAIC 2008). All sampling activities were conducted aboard the R/V *Kittiwake*. Thirteen Commencement Bay stations were sampled to acquire sediments for dioxin/furan analysis (Figure 2–5). Collection methods were consistent with the QASAP (SAIC 2007). Stations sampled included three onsite (CBZ01, CBS01, and CBS08), four perimeter (CBP01, CBP03, CBP07, and CBP11), three benchmark (CBB01, CBB02, and CBB03), and three transect (CBT13, CBT14, and CBT16) stations. Three reference sediments were also collected from Carr Inlet (CR-02, CR-23, MSMP-43) and analyzed for dioxin/furan congeners (see Section 2.6). Dioxin/furan congeners were analyzed by Axys, using USEPA Method 1613B.

2.3.1 Grab Samples

All sediment samples were collected using the 0.2 m^2 stainless steel double van Veen grab sampler. At stations where both sediment and tissues were collected (perimeter, transect, and benchmark stations), the top 10 cm of sediment was removed for chemistry, and the remaining sediment was inspected for biological specimens by rinsing through a 2.0 mm sieve. Surface sediment (0–10 cm) from triplicate grabs was collected and composited for dioxin/furan analysis. Tissue samples consisting of one replicate each of a bivalve and polychaete species were initially targeted for collection at each of the Bellingham Bay stations. The sampling approach was to collect the species with high enough abundance for chemical analysis (a minimum of 10 grams of tissue per sample). In general, bivalve populations were low at Commencement Bay. *Compsomyax* sp. bivalves were only collected at two stations (CBT13 and CBT14). Multiple species of polychaetes were collected where found in abundance (Glyceridae, Maldanidae, *Travisia*, and *Nephtys* polychaetes). In total, 17 tissue samples (2 bivalve and 15 polychaete samples) were collected for the analysis of dioxin/furan congeners, percent lipids, and percent moisture (Table 3–3).

Dioxin/furan analysis of sediments and tissues were conducted by Axys. Analysis of sediment TOC was conducted by CAS. Analysis of sediments and tissues was conducted immediately following collection in August 2007.

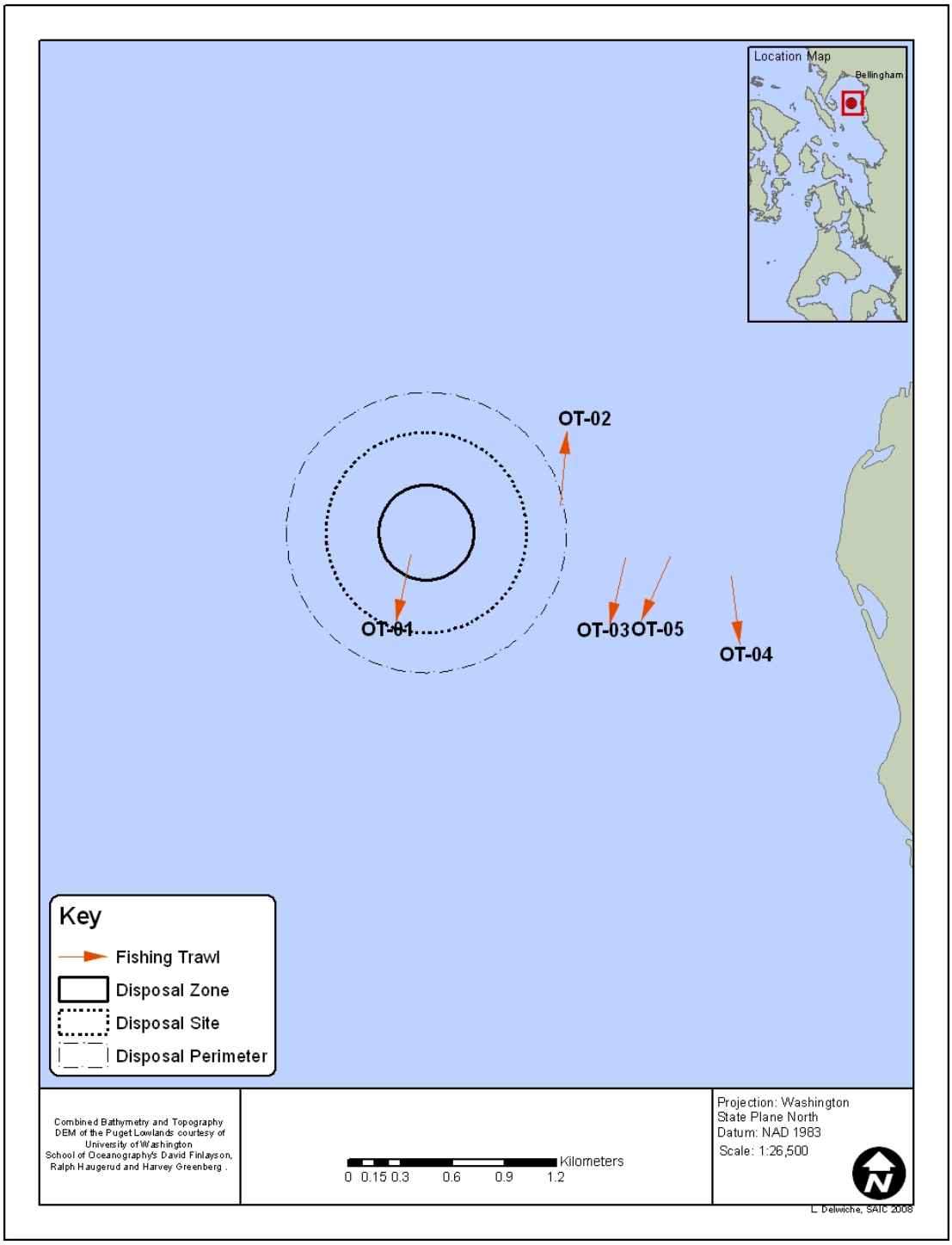


Figure 2-4. Bellingham Bay Bottom Trawl Locations

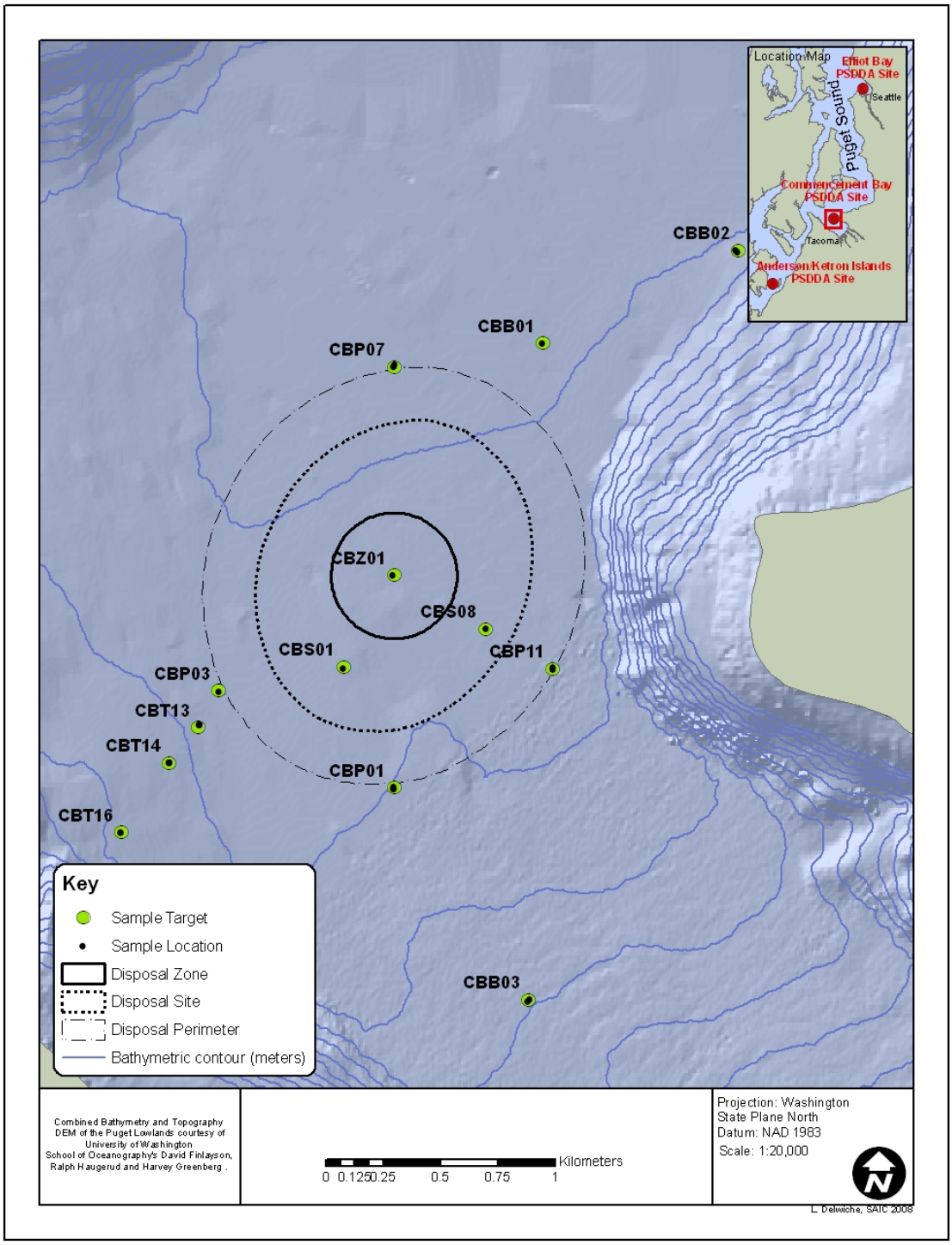


Figure 2-5. Commencement Bay Sediment and Tissue Sampling Locations

2.3.2 Trawl Samples

A 7.6-meter otter trawl was used to collect English sole in Commencement Bay on July 10 and 11, 2007. Trawl sampling was conducted at three stations along a transect through the existing Commencement Bay DMMP disposal site and at three stations along a transect through the former Alternative site (evaluated in the 1988 final environmental impact statement), covering a total of 1.4 hectare of area (Figure 2–6). The most abundant species collected in the trawls included spotted ratfish, Pacific hake, and English sole. Bottom fish were identified, enumerated, and released with the exception of English sole with a minimum length of 20 cm, which were retained for dioxin/furan analysis. The whole bodies of each fish were homogenized separately. Equal volumes from each fish homogenate were combined to make a final composite sample for dioxin/furan analysis. The three English sole samples collected were submitted to Axys on July 17, 2007. No Dungeness crabs were encountered during the survey (Table 3–3).

2.4 Elliott Bay

Two surveys have been conducted at the Elliott Bay DMMP disposal site to evaluate dioxin/furan contamination. In 2007, the dioxin/furan investigation for the Elliott Bay site was conducted from July 12 through July 17. A total of 14 Elliott Bay stations (Figure 2–7) were sampled to acquire sediments and tissues for analysis of dioxin/furan congeners. Field collection methods are documented in the QASAP (SAIC 2007). Stations sampled included three onsite (EBZ01, EBS02, EBS04), four perimeter (EBP01, EBP03, EBP07, EBP11), four benchmark (EBB01, EBB02, EBB03, EBB04), and three transect (EBT01, EBT03, EBT05) stations. Eleven of those stations were targeted for tissue collection (Figure 2–7). Dioxin/furan analysis was conducted using USEPA Method 1613B.

On June 20, 2005, a one-day field survey aboard the R/V *Kittiwake* was conducted to sample sediment at the three onsite stations (EBZ01, EBS02, EBS04) (Figure 2–7). The analyses were conducted as part of a contaminant investigation at the Elliott Bay site to evaluate the possible impacts from the unauthorized disposal of unsuitable material (SAIC 2005). For the 2005 study, dioxin/furan congener analysis was conducted using USEPA Method 8290.

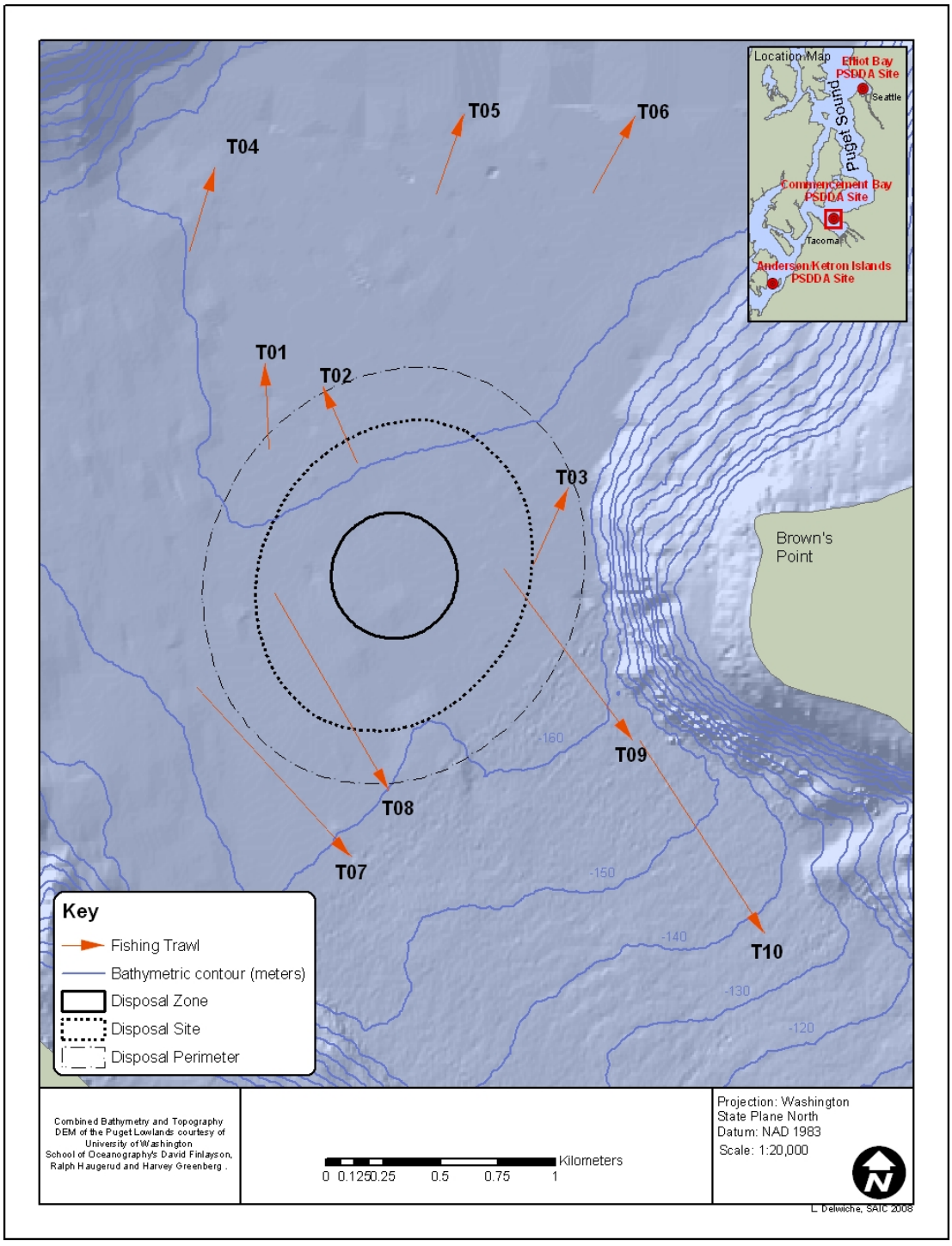


Figure 2-6. Commencement Bay Bottom Trawl Locations

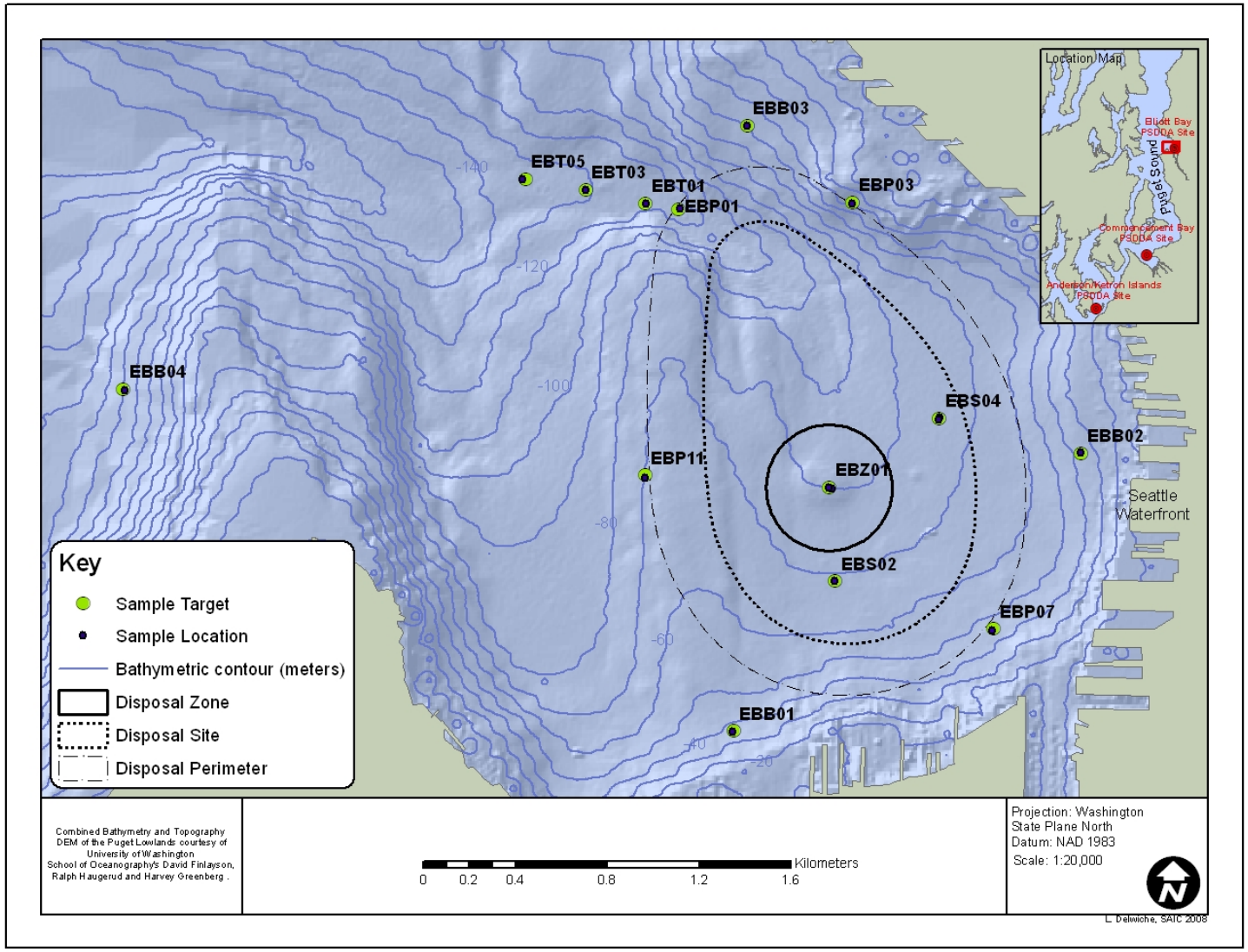


Figure 2-7. Elliott Bay Sediment and Tissue Sampling Locations

2.4.1 Grab Samples

In 2007, the 0.2 m^2 stainless double van Veen grab was used as the primary sampler for all stations. At stations where both sediment and tissue species were collected (benchmark, perimeter, and transect stations), the top 10 cm of sediment were removed for chemistry, and the remaining sediment was inspected for biological specimens by rinsing through a 2.0 mm sieve. Sediment from triplicate grabs was collected and composited for dioxin/furan analysis. Dioxin/furan congener samples were shipped to Axys, on July 17, 2007. Sediment samples for TOC analysis were shipped to CAS, on July 18, 2007.

In 2005, a 0.06 m^2 modified Young van Veen grab or a 0.2 m^2 stainless double van Veen grab was used to collect surface sediments (top 10 cm). Sediment from triplicate grabs was collected and composited for dioxin/furan and DMMP conventional parameters analysis. Samples were submitted to CAS, on June 21, 2005.

No tissues were collected in the 2005 survey. In 2007, tissue samples consisting of one replicate each of a bivalve and polychaete species were initially targeted for collection from 11 Elliott Bay stations (Figure 2–7). The sampling approach was to collect the species with high enough abundance for chemical analysis (a minimum of 10 grams of tissue per sample). Bivalve populations were low at Elliott Bay. *Yoldia* and *Compsomyax* clams were present, but not in abundance for chemical analysis. A total of 12 polychaete samples (Glyceridae, Maldanidae, and *Travisia* polychaetes) were collected in Elliott Bay (Table 3–2). These tissue samples were initially archived at -18°C and submitted to Axys for dioxin/furan, percent lipids, and percent moisture analysis in October 2007.

2.4.2 Trawl Samples

A 7.6-meter high rise otter trawl was used to collect Dungeness crab and English sole in Elliott Bay in the 2007 investigation (Figure 2–8). Trawl sampling was conducted in the vicinity of the Elliott Bay disposal site, but with no particular attention to hitting specific stations (e.g., onsite, transect, perimeter). Species collected in the trawls in order of abundance included slender sole, blackbelly eelpout, spotted ratfish, and English sole. The abundance of Dungeness crab was relatively low in the vicinity of the Elliott Bay disposal site. Only one Dungeness crab sample (consisting of five crabs) could be collected in a total of eight trawls. The one Dungeness crab and three English sole tissue samples were collected and initially archived at -18°C at the SAIC warehouse and submitted to Axys for dioxin/furan analysis in October 2007 (Table 3–3). Each English sole sample consisted of five fish. The whole bodies of each fish were homogenized and equal tissue volumes were taken from each fish and composited for analysis. The Dungeness crab sample consisted of five crabs and dioxin/furan analysis was conducted on both the edible meat and hepatopancreas tissues.

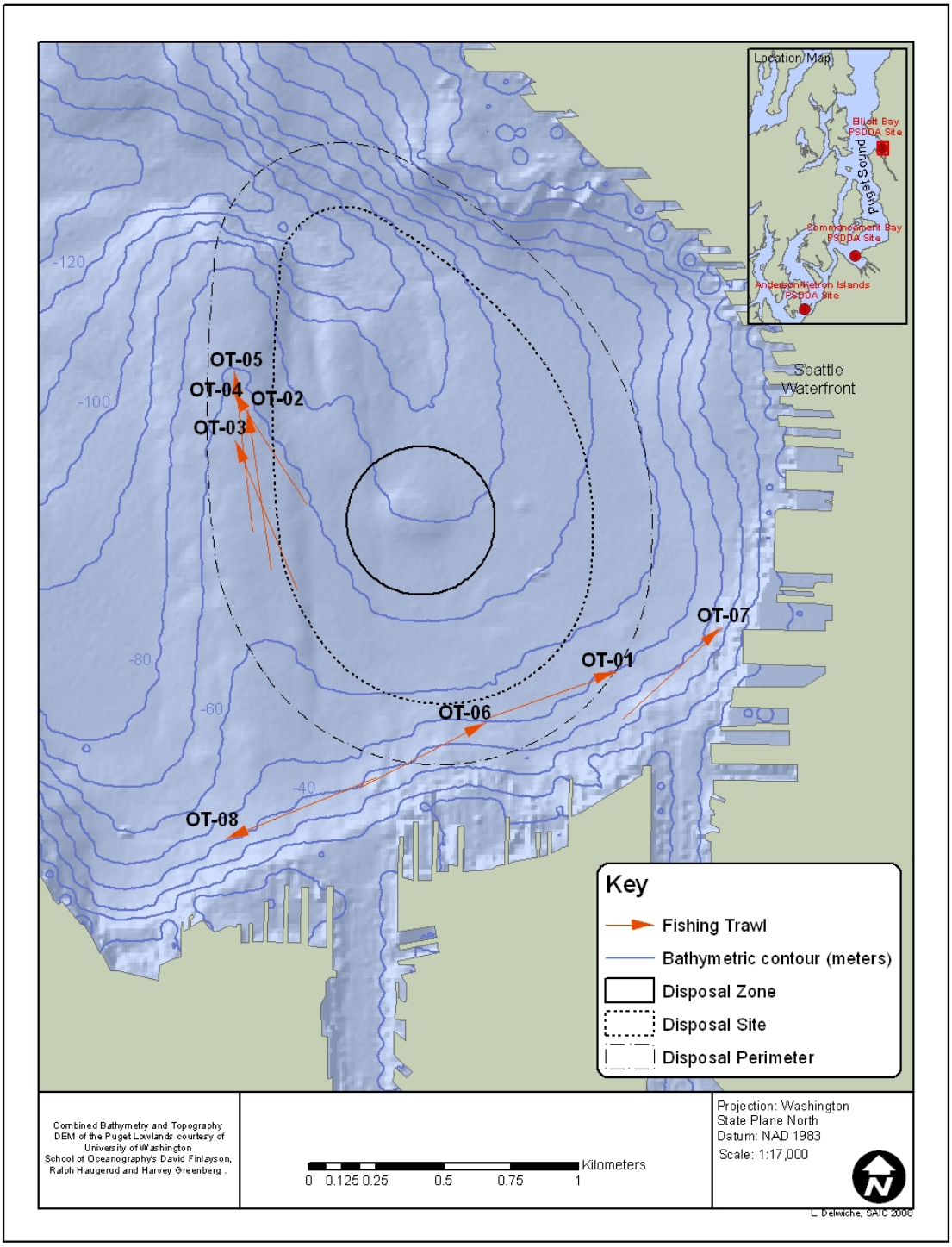


Figure 2-8. Elliott Bay Bottom Trawl Locations

2.4.3 Port Gardner

Sampling operations for dioxin/furan analysis at the Port Gardner DMMP disposal site were conducted from June 20 through July 6, 2006. This activity was conducted as part of the 2006 DMMP full monitoring of the Port Gardner DMMP site (SAIC 2006). All sampling activities were conducted aboard the R/V *Kittiwake*, and consisted of sediment and tissue collections. Positioning and field sampling efforts followed procedures outlined in the 2006 Full Monitoring at Port Gardner QASAP (SAIC 2006). Dioxins/furans were analyzed using USEPA Method 1613B. Sediment and tissue samples from 12 stations in Port Gardner were collected for dioxin/furan analysis (Figure 2–9). The stations included three onsite (PGZ06, PGS04, PGS08), four perimeter (PGP01, PGP07, PGP08, PGP09), three transect (PGT11, PGT13, PGT15), and two benchmark (PGB01, PGB09) stations. Two reference stations (CR-23W, CR-24) were also sampled in Carr Inlet for dioxin/furan testing (Section 3.6).

2.4.4 Grab Samples

Surface sediments (top 10 cm) were collected at each onsite, perimeter, transect, and benchmark station, and analyzed for dioxin/furan congeners (Table 3–1). A 0.2 m^2 double van Veen grab sampler was used and sediment from triplicate grabs was collected and composited for analysis. For the collection of tissue samples, surface sediments collected with the van Veen sampler were rinsed through a 2.0 mm sieve and inspected for bivalves, polychaetes, or other organisms present in high numbers. In consultation with the DMMP agencies, the *Nephtys* and *Travisia* polychaetes were targeted for collection. One replicate sample each of the *Nephtys* and *Travisia* polychaetes was collected at each perimeter, transect, and benchmark station and analyzed for dioxin/furan congeners, percent moisture, and percent lipids (Table 3–2). Dioxin/furan analysis of sediments and tissues were conducted by Axys. Analysis of sediment TOC was conducted by CAS.

2.4.5 Trawl Samples

Six trawls were conducted at the Port Gardner site to collect English sole and Dungeness crab for dioxin/furan analysis (Figure 2–10). The 3-meter Gunderson beam trawl was used to target the collection of Dungeness crab and the 7.6-meter Otter trawl was used target the collection of English sole. Species collected in the trawls in order of abundance included slender sole, spotted ratfish, midshipman, Dungeness crab (female), English sole, blackbelly eelpout, and Pacific hake. Triplicate English sole and Dungeness crab samples were submitted to Axys and analyzed for dioxin/furan congeners, percent moisture, and percent lipids (Table 3–3). Each English sole sample consisted of five fish. The whole bodies of each fish were homogenized and equal tissue volumes were taken from each fish and composited for analysis. Each Dungeness crab sample consisted of five crabs and dioxin/furan analysis was conducted on both the edible meat and hepatopancreas tissues.

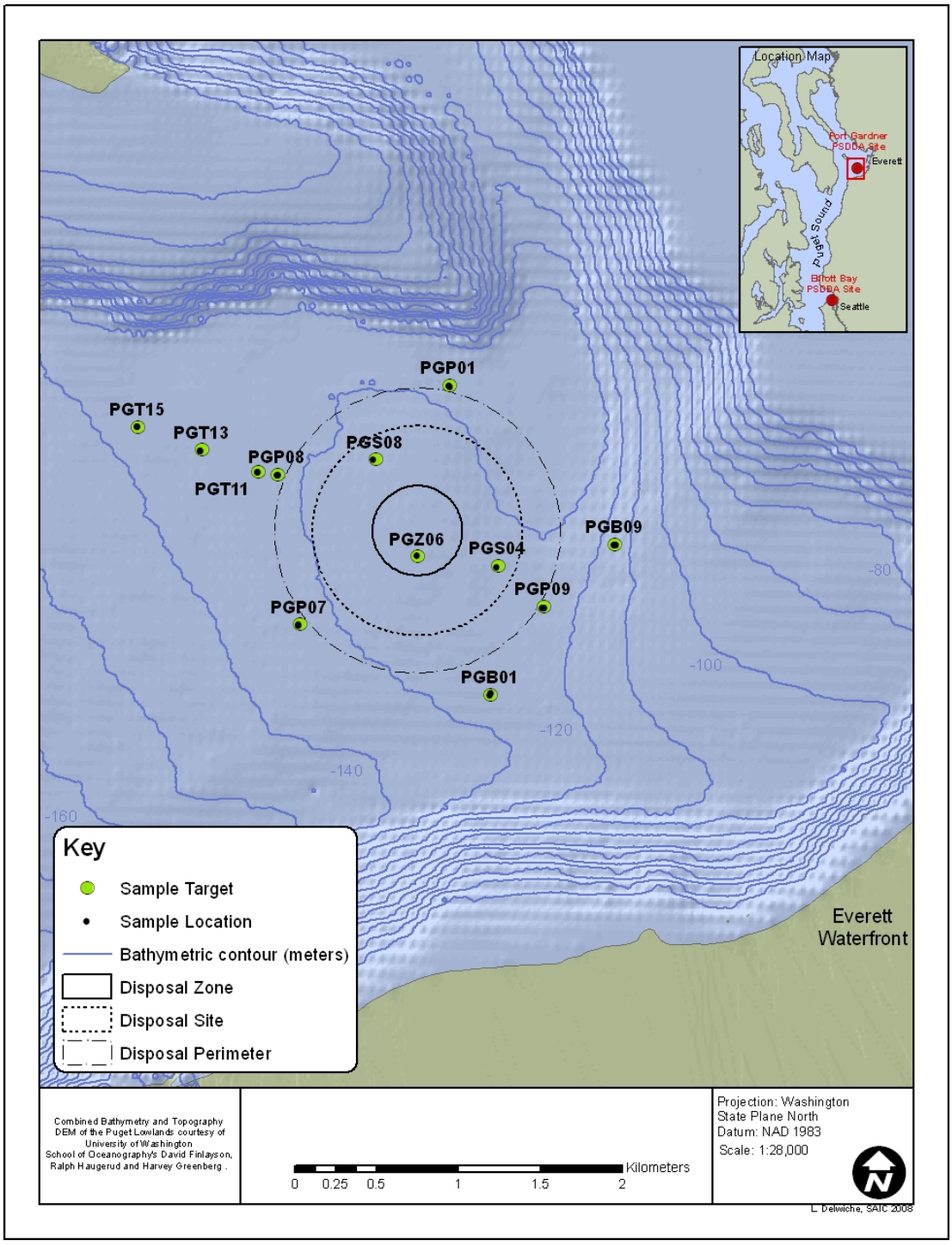


Figure 2-9. Port Gardner Sediment and Tissue Sampling Locations

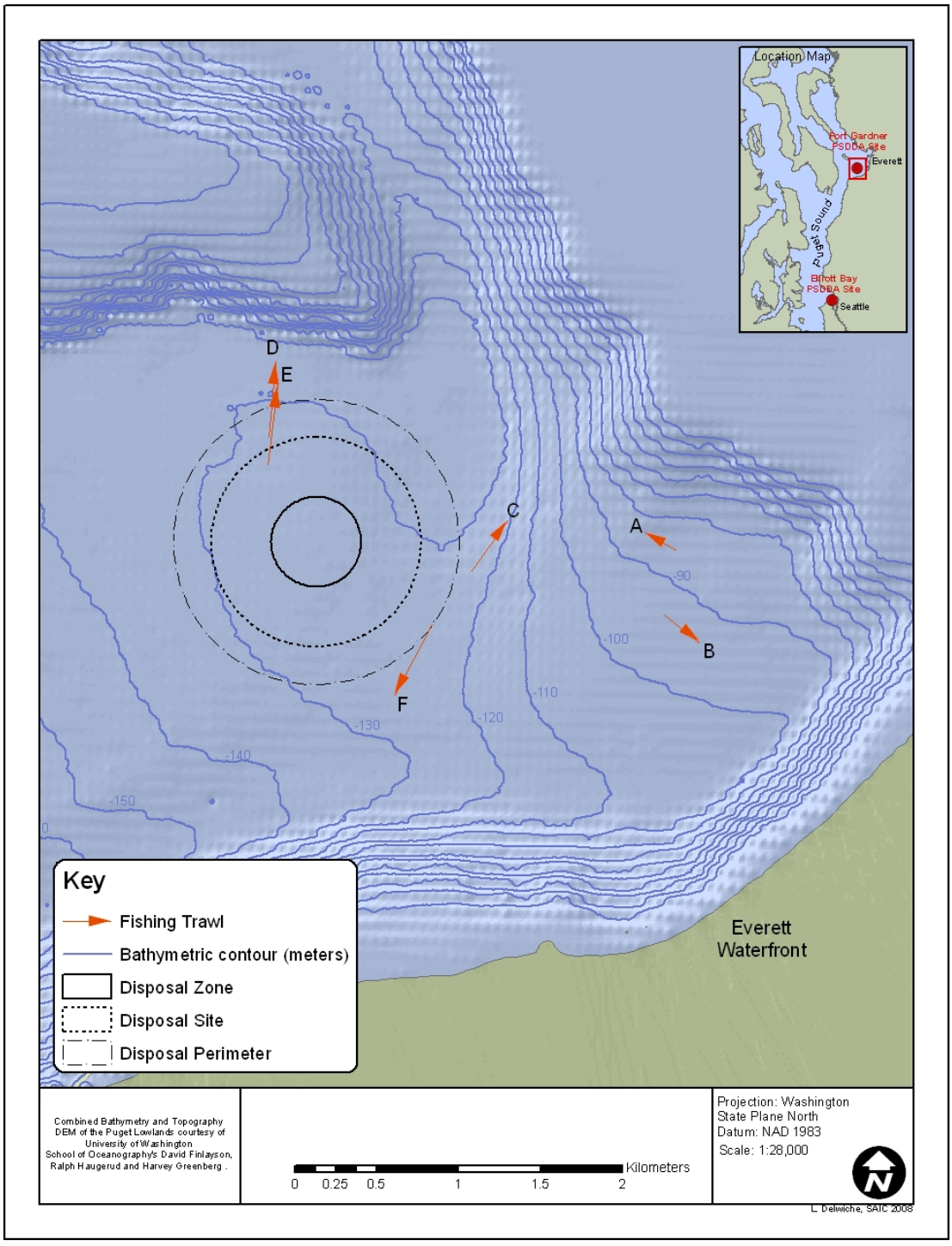


Figure 2-10. Port Gardner Bottom Trawl Locations

2.4.6 Carr Inlet Reference Sediment

Carr Inlet was sampled for sediment as a reference site for both the 2006 DMMP full monitoring of the Port Gardner DMMP site (SAIC 2006) and the 2007 DMMP dioxin/furan characterization projects (Figure 2–11). In 2006, two reference stations (CR-23W and CR-24) were sampled in Carr Inlet for dioxin/furan congener analysis. In 2007**,** three reference sediments were collected from Carr Inlet (CR-02, CR-23, MSMP-43) and analyzed for dioxin/furan congeners. The 0.2 m^2 stainless double van Veen grab was used for all stations. The top 10 cm of sediment were removed for analysis. Sediment from triplicate grabs was collected and composited for dioxin/furan analysis. Dioxin/furan congener samples were analyzed by Axys.

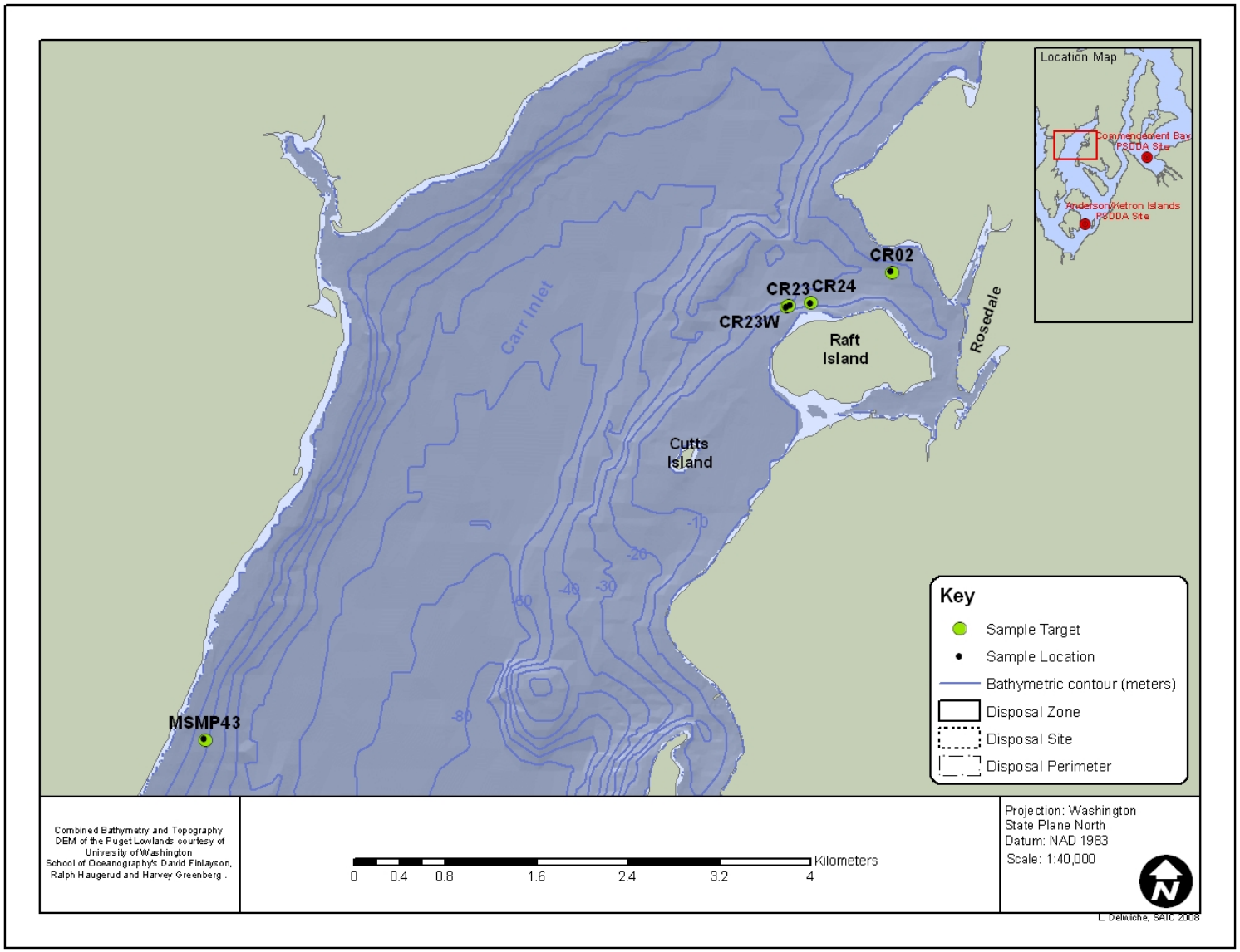


Figure 2-11. Reference Sediment Sampling Locations

3.0 RESULTS

The results of 175 dioxin/furan samples are reported in this section. For discussion purposes, all data presented has been converted to total toxic equivalent quotient (TEQs) based on the World Health Organization 2005 mammalian toxic equivalent factor (TEF) (Van den Berg et al. 2006). This includes the three 2005 samples from Elliott Bay that were originally calculated using the 1998 TEF (SAIC 2005). In addition, all TEQs were calculated substituting ½ the method detection limit for non-detected congeners. Sediment concentrations are reported as dry weight (dw), and tissue concentrations are reported as wet weight (ww).

3.1 Sediment

The number of collected sediment samples is summarized by disposal site and station type in Table 3–1. Sixty six sediment samples were collected, including five reference sediment samples. Concentrations are plotted by disposal site and station type in Figure 3–1.

Table 3-1. Sediment Samples Collected for Analysis of Dioxin/Furan Contamination at DMMP Dredged Material Disposal Sites

		Zone	Site	Perimeter	Transect	Benchmark	Reference
Sediment	**Anderson/Ketron**	1		4	1	2	
	Bellingham Bay	1		4	3	3	
	Commencement Bay	1	2	4	3	3	
	Elliott Bay	2	4	4	3	4	
	Port Gardner	1	2	4	3	2	
	Reference						**5**

3.1.1 Anderson/Ketron Islands

Dioxin/furan concentrations averaged 3.57 ± 1.61 picograms per gram (pg/g) TEQ at the Anderson/Ketron sampling sites. The highest concentration was 6.79 pg/g TEQ at AKP01, south of the disposal site, and the lowest was 1.70 pg/g TEQ at AKB02. There were no differences in contamination between the station types.

3.1.2 Bellingham Bay

Bellingham Bay had the highest average dioxin/furan concentration at 8.19 ± 4.86 pg/g TEQ. The highest and lowest concentrations measured in Bellingham Bay were benchmark locations. BBB01 is the innermost site in Bellingham Bay, with a concentration of 21.97 pg/g. BBB04, located farthest from the city of Bellingham and southwest of the disposal site (Figure 2–3), had the lowest concentration at 4.34 pg/g.

As evidenced by these two benchmark sites, dioxin/furan concentrations decrease with distance from shore. Sampling sites BBB02, BBP02, BBZ01, and BBP04 form a straight line moving east to west away from shore. Concentrations decrease from 10.49, 8.51, 6.10, to 5.20 pg/g TEQ, respectively.

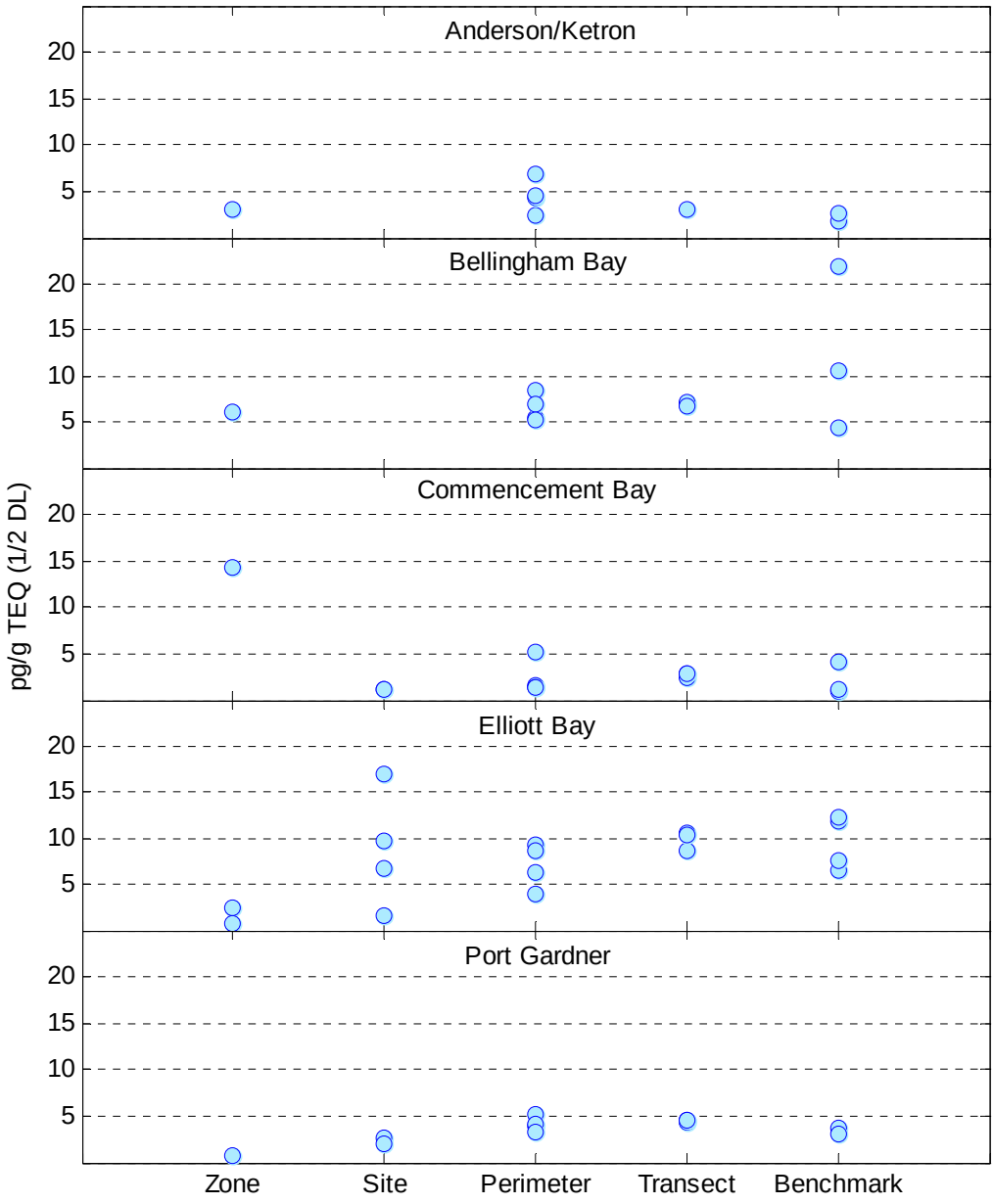


Figure 3-1. Sediment Dioxin/Furan Concentrations in pg/g dw TEQ at the five DMMP Dredged Material Disposal Sites

3.1.3 Commencement Bay

At 3.12 ± 3.61 pg/g TEQ, Commencement Bay had the lowest average dioxin/furan concentration of the five disposal sites. Of the 13 samples analyzed, seven were under 2.0 pg/g. Elevated concentrations were found at CBZ01. The dioxin/furan TEQ at CBZ01 was over 2.5 times higher than the next highest concentration at Commencement Bay (Figure 2–5).

3.1.4 Elliott Bay

Behind Bellingham Bay, Elliott Bay had the second highest dioxin/furan concentrations. The average TEQ for Elliott Bay was 7.91 ± 4.18 pg/g. Concentrations within the disposal zone were low. The site, perimeter, transect, and benchmark stations had higher concentrations with more variability.

Three sampling stations at Elliott Bay were sampled in both 2005 and 2007: EBZ01, EBS02, and EBS04. For all three stations, concentrations were higher in 2007. The increases in TEQ at EBZ01 and EBS02 were both under 3.0 pg/g, and may be due to the different analytical methods used (Section 2.3). At CBS04, concentrations were 1.55 pg/g in 2005, and 17.03 pg/g in 2007.

3.1.5 Port Gardner

Port Gardner had low concentrations (3.52 ± 1.25 pg/g TEQ) and a small amount of variability between samples. PGZ06 in the disposal zone had the lowest concentration, while perimeter station PGP01 had the highest (Figure 2–9).

3.1.6 Reference Sediment

Reference sediment concentrations from Carr Inlet were low, averaging 0.91 ± 0.80 pg/g TEQ.

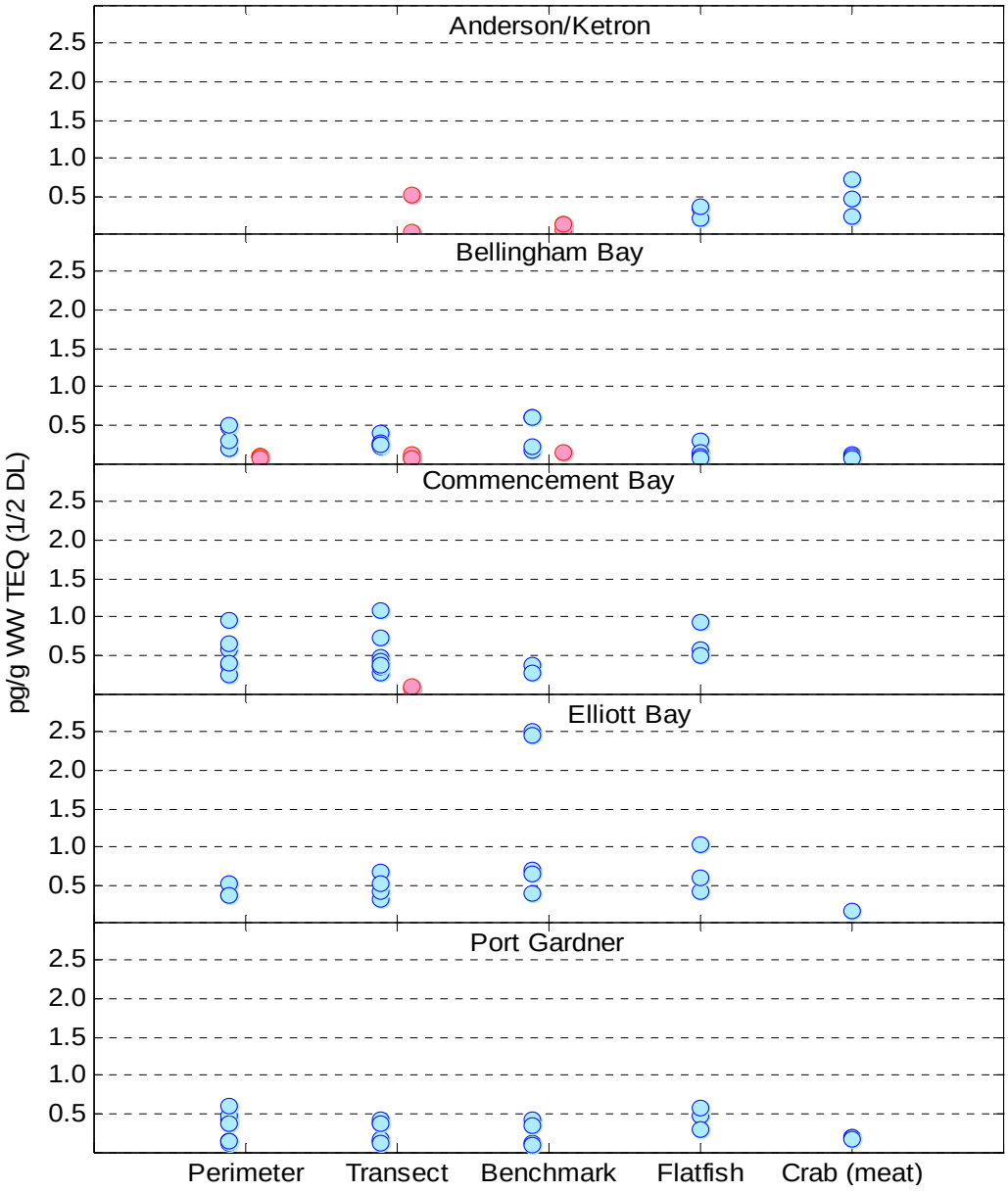
3.2 Tissue

The number of bivalve and polychaete samples collected are summarized by disposal site and station type in Table 3–2. Tissue samples collected from the bottom trawls are summarized in Table 3–3. All tissue concentrations, with the exception of the Dungeness crab hepatopancreas, are plotted by disposal area and location in Figure 3–2.

Tissue concentrations are low. Many of the tissue concentrations are close to the TEQ values derived from method detection limits (MDL). Using the tissue MDL in the TEQ calculation results in an average of 0.12 pg/g TEQ (calculated using MDLs, not ½ MDL). Twenty one tissue samples are less than or equal to this concentration. Fifty six samples are within a factor of three of the detection limit TEQ (Figure 3–2).

Few differences in tissue concentration were present between disposal sites. Concentrations were highest at Elliott Bay, averaging 0.76 ± 0.70 pg/g ww TEQ. Two benchmark samples, EBB01-Glycerid and EBB02-Glycerid, had the highest tissue concentrations, 2.51 pg/g and 2.45 pg/g TEQ, respectively. Both of these samples were collected close to shore and the mouth of the Duwamish River.

Bellingham Bay had the lowest average tissue concentrations, partly because of the greater number of low concentration bivalves collected there.



Note: At the perimeter, transect, and benchmark stations, polychaetes are represented by blue points, and bivalves are represented by red points.

Figure 3-2. Tissue Dioxin/Furan Concentrations in pg/g ww TEQ at the Five DMMP Dredged Material Disposal Sites

Table 3-2. Bivalve and Polychaete Tissue Samples Collected for Analysis of Dioxin/Furan Contamination at DMMP Dredged Material Disposal Sites

		Perimeter	Transect	Benchmark
Compsomyax	Anderson/Ketron		1	2
	Bellingham Bay	3	2	
	Commencement Bay		2	
	Elliott Bay			
	Port Gardner			
Macoma	Anderson/Ketron			1
	Bellingham Bay	1	1	1
	Commencement Bay			
	Elliott Bay			
	Port Gardner			
Yoldia	Anderson/Ketron		1	
	Bellingham Bay			
	Commencement Bay			
	Elliott Bay			
	Port Gardner			
Capitellidae	Anderson/Ketron			
	Bellingham Bay	3	3	2
	Commencement Bay			
	Elliott Bay			
	Port Gardner			
Glyceridae	Anderson/Ketron			
	Bellingham Bay	1		1
	Commencement Bay	2	3	2
	Elliott Bay	2	2	4
	Port Gardner			
Maldanidae	Anderson/Ketron			
	Bellingham Bay			
	Commencement Bay	2	2	
	Elliott Bay	2	1	
	Port Gardner			
Nephtys	Anderson/Ketron			
	Bellingham Bay			
	Commencement Bay			
	Elliott Bay			
	Port Gardner	4	3	2
Spionidae	Anderson/Ketron			
	Bellingham Bay		2	1
	Commencement Bay			
	Elliott Bay			
	Port Gardner			
Travisia	Anderson/Ketron			
	Bellingham Bay			
	Commencement Bay	2	2	
	Elliott Bay			1
	Port Gardner	4	3	2

Table 3-3. Trawl Tissue Samples Collected for Analysis of Dioxin/Furan Contamination at DMMP Dredged Material Disposal Sites

	English Sole	Starry Flounder	Dungeness Crab Meat	Dungeness Crab Hepatopancreas
Anderson/Ketron	3		3	3
Bellingham Bay	1	3	3	3
Commencement Bay	3			
Elliott Bay	3		1	1
Port Gardner	3		3	3

At locations where both bivalves (red points) and polychaetes (blue points) were collected, dioxin/furan concentrations were nearly a factor of three greater in the polychaetes (Figure 3–2). Crab tissue concentrations were also lower than the polychaetes. In addition, crab tissue concentrations were lower than the fish TEQ at all sites except Anderson/Ketron.

Though not visible on Figure 3–2, there are differences in TEQ between the various genera and families of polychaetes. For example, nine co-located samples of genera *nephtys* and *travisia* were collected from Port Gardner. The average dioxin/furan TEQ for the *nephtys* samples is 0.13 ± 0.02 pg/g, and the average for the *travisia* is 0.42 ± 0.08 pg/g.

In contrast, the four *travisia* samples from Commencement Bay averaged 0.85 ± 0.19 pg/g TEQ. Given the narrow range and low dioxin/furan concentrations found in tissues at the five disposal sites, differences between species at each site are as great as the differences between sites.

Dungeness crab hepatopancreas tissue is not included on Figure 3–2 due to the high concentrations measured. Both meat and hepatopancreas tissue results are presented in Table 3–4. Concentrations in meat range from 0.07 to 0.73 pg/g TEQ, whereas hepatopancreas concentrations range from 1.67 to 14.92 pg/g TEQ. The large difference in concentration is due to the higher lipid content of the hepatopancreas, which averages 9.8 percent. After lipid normalization, meat and hepatopancreas tissue have similar concentrations (Table 3–4).

Table 3-4. Concentrations of Meat and Hepatopancreas Tissue from Dungeness Crabs

	Meat			Hepatopancreas		
	Lipid%	**pg/g ww**	**mg/g Lipid**	**Lipid%**	**pg/g ww**	mg/g Lipid
AK-REP-1	0.51	0.73	0.143	9.69	14.92	**0.154**
AK-REP-2	0.36	0.47	0.131	8.94	11.52	**0.129**
AK-REP-3	0.37	0.25	0.068	10.40	14.05	**0.135**
EB-REP-1	0.069	0.17	0.253	18.9	5.55	**0.029**
PG-REP-1	0.44	0.18	0.041	6.08	1.67	**0.027**
PG-REP-2	0.4	0.19	0.048	10.9	2.77	**0.025**
PG-REP-3	0.57	0.16	0.028	8.35	1.68	**0.020**
BB-REP-1	0.21	0.11	0.055	6.21	3.34	**0.054**
BB-REP-2	0.23	0.09	0.041	9.76	2.78	**0.028**
BB-REP-3	**0.2**	**0.07**	**0.035**	**9.08**	**1.73**	**0.019**

4.0 DISCUSSION

This section describes the congener profiles of the surface sediment to further explore the relationship between samples. In addition, biota sediment accumulation factors (BSAF) are calculated for the tissue samples to determine the uptake of dioxin/furan congeners by species and sampling location.

4.1 Sediment Partitioning

Dioxin/furan congeners partition between the sediment water interface, binding more strongly to sediments with higher percentages of TOC. Figure 4–1 shows the relationship between dioxin/furan TEQ and sediment TOC for each of the disposal sites.

Most of the sites show a positive correlation with TOC. The strongest of these correlations is for Port Gardner ($r^2 = 0.659$), followed by Anderson/Ketron ($r^2 = 0.377$) and Commencement Bay ($r^2 = 0.195$). Though the sample size is limited to five, the Carr Inlet reference stations have an r^2 of 0.981. Correlations are much weaker for Bellingham and Elliott Bays. Bellingham Bay has an r^2 of 0.061 between TEQ and TOC, while Elliott Bay has an r^2 of 0.029.

From Section 3.1, Elliott and Bellingham Bays have the highest average dioxin/furan TEQs. Commencement Bay, Port Gardner, and Anderson/Ketron have lower average TEQ concentrations, and the Carr Inlet reference site has the lowest TEQ.

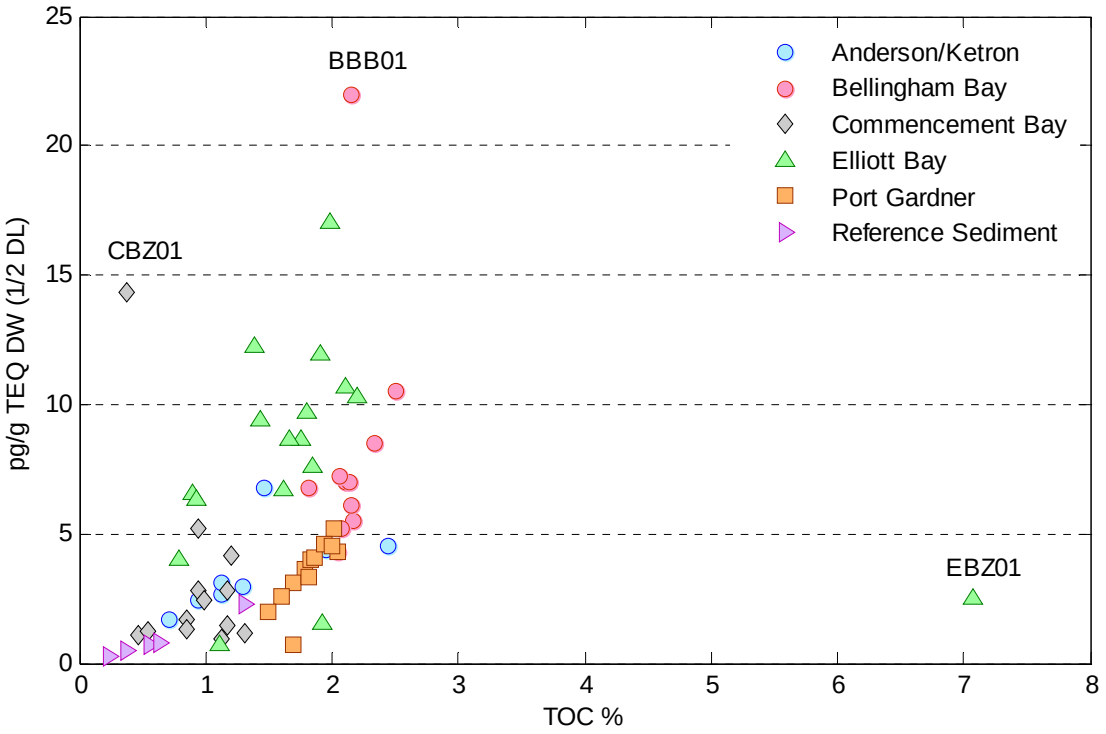
4.2 Dioxin/Furan Congener Profiles

The dioxin/furan congener profile (i.e., fingerprint) is an informative method for evaluating the relative combination of the different congeners measured in a given matrix. To calculate the profiles, the concentration of each individual congener (not adjusted to TEQ) was divided by the sum of the total dioxin/furan concentration in a given sample. In the case of non-detects, concentrations were estimated at one-half the detection limit. Samples with more than seven undetected congeners were excluded from congener profiling.

4.2.1 Sediment Profiles

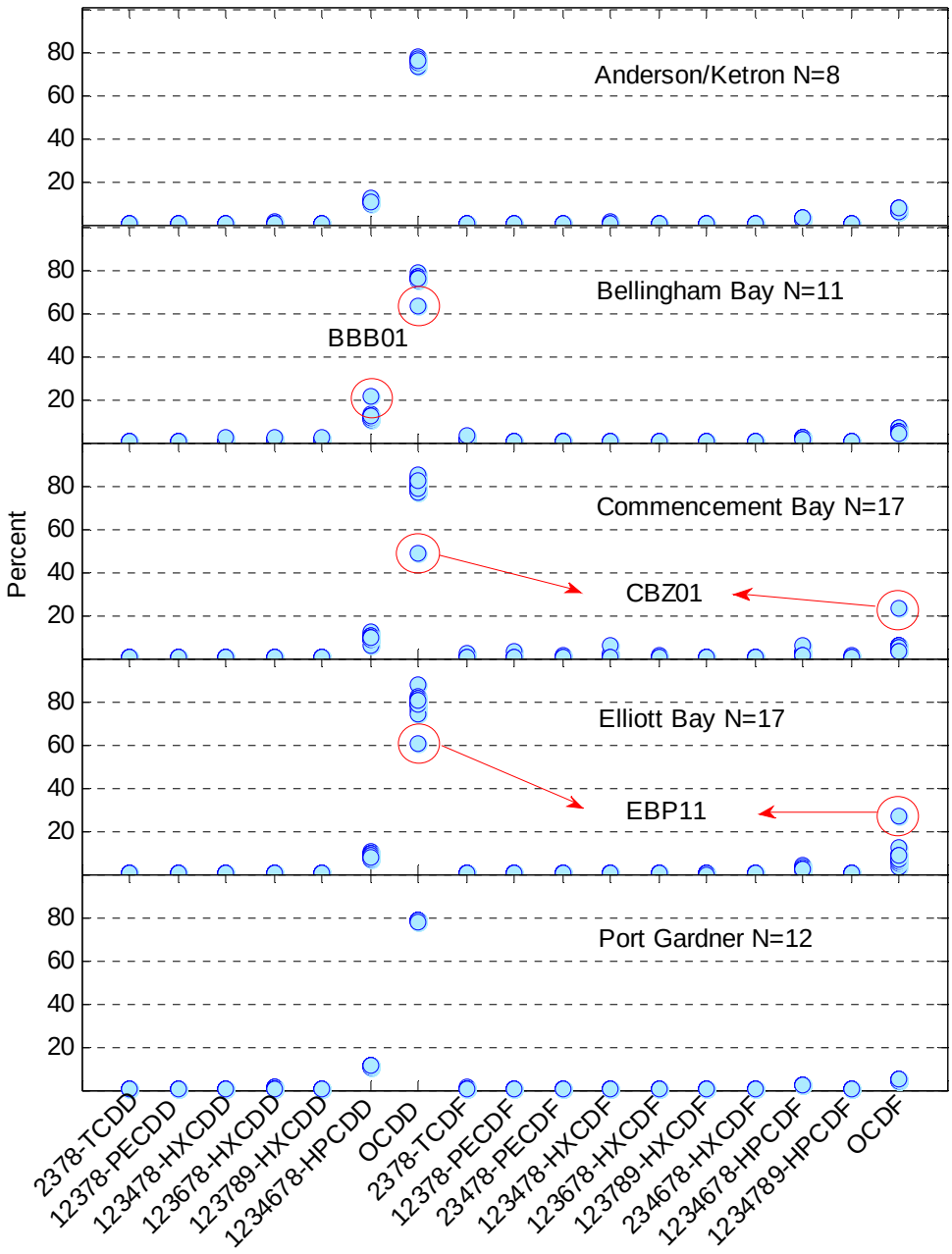
The profiles in Figure 4–2 illustrate the relative amount of each dioxin/furan congener observed in the sample. The majority of samples had a similar profile, regardless of site. In all cases, OCDD was the dominant congener, with an average relative abundance ranging from 75 to 79 percent. 1,2,3,4,6,7,8-HPCDD was the next most abundant congener, with averages ranging from 9 to 12 percent. OCDF and 1,2,3,4,6,7,8-HPCDF made up the remainder of the total.

There were samples that did not match the average congener profile (Figure 4–2). EBP11 and CBZ01 had a higher percentage of OCDF and a lower percentage of OCDD than most samples. BBB01 had less OCDF than most samples, and a higher percentage of 1,2,3,4,6,7,8-HPCDD. Two of the outliers in Figure 4–2 were also outliers in the TEQ versus TOC correlation (Figure 4–1). CBZO1 and BBB01 had dioxin/furan concentrations that were higher than might be expected based upon the amount of TOC in the sediment in these samples. It is unclear whether these stations represent a unique source dioxin/furan contamination, or if analytical variability responsible.



Note: Outliers are labeled.

Figure 4-1. Dioxin/Furan TEQ Versus Percent TOC.



Note: Points represent individual samples.

Figure 4-2. Dioxin/Furan Congener Profiles for the Five Disposal Sites

4.2.2 Tissue Profiles

Congener profiles were also calculated for the tissue samples. Samples from within each organism group (species, genus, or family) were averaged by disposal site. As with the sediment, all samples with more than seven undetected congeners were excluded from congener profiling. Because of the low dioxin/furan concentrations in the tissue samples, congener profiles were not calculated for many samples.

Figure 4–3 shows the congener profiles of the Port Gardner sediment compared to the average profiles of *nephtys* and *travisia* polychaetes, English sole, and Dungeness crab meat and hepatopancreas tissue (congener profiles for the other sites are in Appendix A). The congener profiles differ between matrices. Polychaetes have a profile similar to that of the sediment, but with a reduced relative amount of OCDD. English sole and Dungeness crab have congener profiles that are different than the sediment.

Sediment at Port Gardner averages 78.4 percent OCDD, while the triplicate English sole samples averaged 42.6 percent OCDD. The sole and crab had higher relative amounts of 2,3,7,8-TCDF and other lesser chlorinated congeners. There was little difference between the profiles for Dungeness crab meat and hepatopancreas tissue.

The other disposal sites showed similar trends: polychaetes and bivalves had congener profiles that were comparable to the sediment, while English sole and Dungeness crabs had a lower abundance of OCDD and a greater abundance of the lesser chlorinated congeners. Differential uptake of the dioxin/furan congeners may be responsible for the differences in the congener profiles.

4.3 Biota Sediment Accumulation Factors

Biota sediment accumulation factors were calculated for all tissue samples to better understand this uptake of dioxin/furan contamination from the sediment. 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).

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

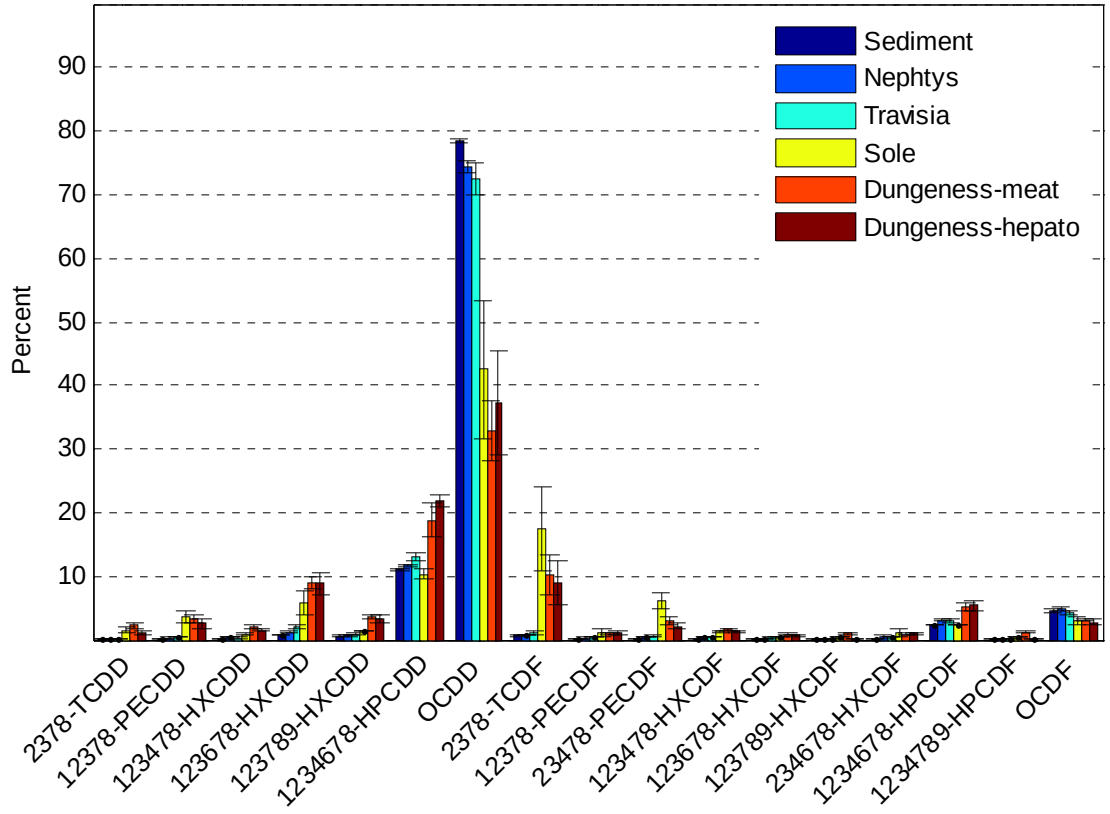
C_t is the tissue concentration (pg/g ww), f_l is the fraction by weight lipid concentration, C_s is the sediment concentration (pg/g dw), and f_{oc} is the fraction of organic carbon (TOC) in the sediment (USEPA 2000).

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).

BSAF values were calculated using the average sediment congener and TOC concentrations at each site. Undetected congeners were not used in the calculation. The final BSAF values were averaged by organism group (Appendix A).

Larger BSAF values indicate greater uptake of dioxin/furan contamination. *Travisia* polychaetes consistently had the highest BSAF, while *Compsomyax* bivalves had the lowest values. The concentrations reported in Section 3 are a direct reflection of these values. *Travisia* had some of the highest tissue concentrations of dioxin/furan, while the bivalves typically had the lowest concentrations.

As evidenced by the congener profiles, BSAF values also differ by congener. For the Dungeness crab at Anderson/Ketron, BSAF are lowest for the octa and hepta chlorinated dioxin/furan congeners, and highest for 1,2,3,7,8-PECDD and the tetra chlorinated dioxin/furan congeners.



Note: Error bars are the standard deviations.

Figure 4-3. Congener Profiles for Sediment, Tissue, and Trawl Samples at Port Gardner

5.0 SUMMARY

Dioxin/furan concentrations within the disposal sites ranged from a high of 21.97 pg/g TEQ at BBB01 to a low of 0.71 pg/g TEQ at EBZ01, with lower concentrations measured at the reference stations. Bellingham Bay had the highest average concentrations and had a gradient of decreasing concentrations moving away from shore, while Commencement Bay had the lowest concentration. While the difference between the highest and lowest sediment concentrations was over 20 pg/g TEQ, the difference between the highest and lowest tissue concentrations was only 2.5 pg/g TEQ. In general, tissue concentrations were similar between sites, although differences in concentrations did occur between species. The crab hepatopancreas concentrations were higher than other tissues, ranging up to 14.92 pg/g TEQ. However, once these concentrations were lipid normalized they were comparable to dioxin/furan levels in crab meat.

The congener profiles of the sediment samples were similar in most cases with OCDD being the dominant congener, followed by 1,2,3,4,6,7,8-HPCDD, OCDF and 1,2,3,4,6,7,8-HPCDF. Congener profiles were also calculated for the tissue samples. Polychaetes had profiles that were similar to the sediment, while the flatfish and Dungeness crabs had congener profiles that showed an increased abundance of the lesser chlorinated congeners relative to the sediment. Lastly, BSAF values were calculated for the tissue to show the update of dioxin/furan congeners by biota. *Travisia* polychaetes had the highest BSAF values. BSAF values differed between congeners for the crabs. The octa and hepta chlorinated congeners had the lowest BSAF values. The low accumulation of these congeners matched their low relative abundance in the congener profiles.

6.0 REFERENCES

PSDDA. 1988a. Management plans technical appendix – Phase I (Central Puget Sound). Puget Sound Dredged Disposal Analysis reports series. Cooperatively published by (in alphabetical order) U.S. Army Corps of Engineers, Seattle District; U.S. Environmental Protection Agency, Region 10; Washington State Department of Ecology; and Washington State Department of Natural Resources.

PSDDA. 1988b. Final environmental impact statement – unconfined open-water disposal sites for dredged material, Phase I (Central Puget Sound). Puget Sound Dredged Disposal Analysis Reports Series. Cooperatively published by (in alphabetical order) U.S. Army Corps of Engineers, Seattle District; U.S. Environmental Protection Agency, Region 10; Washington State Department of Ecology; and Washington State Department of Natural Resources.

PSDDA. 1988c. Evaluation procedures technical appendix – Phase I (Central Puget Sound). Puget Sound Dredged Disposal Analysis reports series. Cooperatively published by (in alphabetical order) U.S. Army Corps of Engineers, Seattle District; U.S. Environmental Protection Agency, Region 10; Washington State Department of Ecology; and Washington State Department of Natural Resources.

PSDDA. 1988d. Disposal site selection technical appendix – Phase I (Central Puget Sound). Puget Sound Dredged Disposal Analysis reports series. Cooperatively published by (in alphabetical order) U.S. Army Corps of Engineers, Seattle District; U.S. Environmental Protection Agency, Region 10; Washington State Department of Ecology; and Washington State Department of Natural Resources.

PSDDA. 1989a. Management Plan Report – Unconfined Open Water Disposal of Dredged Material, Phase II (North and South Puget Sound). Puget Sound Dredged Disposal Analysis reports series. Cooperatively published by (in alphabetical order) U.S. Army Corps of Engineers, Seattle District; U.S. Environmental Protection Agency, Region 10; Washington State Department of Ecology; and Washington State Department of Natural Resources. September 1989.

PSDDA. 1989b. Final Environmental Impact Statement – Unconfined Open-water Disposal for Dredged Material, Phase II (North and South Puget Sound). Puget Sound Dredged Disposal Analysis reports series. Cooperatively published by (in alphabetical order) U.S. Army Corps of Engineers, Seattle District; U.S. Environmental Protection Agency, Region 10; Washington State Department of Ecology; and Washington State Department of Natural Resources. September 1989.

PSEP. 1986. Puget Sound Estuary Program. Recommended protocols for measuring selected environmental variables in Puget Sound. Final Report. Prepared for the U.S. Environmental Protection Agency Region 10, Office of Puget Sound, and the U.S. Army Corps of Engineers. Tetra Tech, Bellevue, WA.

PSEP. 1987. Puget Sound Estuary Program. Recommended protocols for sampling and analyzing subtidal benthic macroinvertebrate assemblages in Puget Sound. Prepared for the U.S. Environmental Protection Agency Region 10, Office of Puget Sound, and the U.S. Army Corps of Engineers. Tetra Tech, Inc., Bellevue, WA.

PSEP. 1997a. Puget Sound Estuary Program. Recommended protocols for measuring metals in Puget Sound marine water, sediment and tissue samples. Prepared for the U.S. Environmental Protection Agency Region 10, Office of Puget Sound, and the U.S. Army Corps of Engineers. PTI Environmental Services, Inc., Bellevue, WA.

PSEP. 1997b. Puget Sound Estuary Program. Recommended guidelines for measuring organic compounds in Puget Sound water, sediment and tissue samples. Prepared for the U.S. Environmental Protection Agency Region 10, Office of Puget Sound, and the U.S. Army Corps of Engineers. PTI Environmental Services, Inc., Bellevue, WA.

PSEP. 1997c. Puget Sound Estuary Program. Recommended guidelines for sampling marine sediment, water column, and tissue in Puget Sound. Prepared for the U.S. Environmental Protection Agency, Region 10.

SAIC. 2005. Contaminant investigation at the Elliott Bay PSDDA site, Seattle, Washington—Draft. December 5, 2005. Prepared for Washington State Department of Natural Resources, Olympia, WA. Submitted by Science Applications International Corporation, Bothell, WA.

SAIC. 2006. Quality assurance and sampling and analysis plan. 2006 full monitoring at the Port Gardner non-dispersive unconfined open-water dredged material disposal site. June 16, 2006. Submitted to Washington State Department of Natural Resources, Olympia, WA. Submitted by Science Applications International Corporation, Bothell, WA.

SAIC. 2007. 2007 DMMP quality assurance and sampling and analysis plan. Draft. June 20, 2007. Submitted to Washington State Department of Natural Resources, Olympia, WA. Submitted by Science Applications International Corporation, Bothell, WA.

SAIC. 2008. 2007 Full Monitoring at the Commencement Bay Non-Dispersive Unconfined Open-Water Dredged Material Disposal Site. April 2, 2008. Prepared for the Washington State Department of Natural Resources, Olympia, WA. Prepared by Science Applications International Corporation, Bothell, WA.

Van den Berg, M., L.S. Birnbaum, 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.E. Peterson. 2006. The 2005 World Health Organization reevaluation of human and mammalian toxic equivalency factors for dioxins and dioxin-like compounds. *Toxicological Sciences* 93(2): 223-241.

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.